AFML-TR-73-114

## ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

O. L. Deel, P. E. Ruff and H. Mindlin

Battelle Columbus Laboratories

#### TECHNICAL REPORT AFML-TR-73-114

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| Mechanical Properties<br>Fatigue Properties<br>Creep Properties<br>Chemical Composition<br>Physical Properties<br>Aluminum Alloys<br>Stainless Steal<br>Titanium Alloys<br>X-2048<br>21-6-9<br>7050<br>Ti-8Mo-8V-2Fe-3A1<br>Ti-6A1-22r-28n-2Mo-20 |  |             |         |       |  |  |
| T1-0A1-24r-25n-2M0-20<br>T1-6A1-6V-25n  |  |             |         |       |  |  |
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#### FOREWORD

This report was prepared by Battelle's Columbus Laboratories, Columbus, Ohio, under Contract F33615-72-C-1280. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth (AFML/MXE), technical manager.

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This final report covers work conducted from April, 1972, to April, 1973. This report was submitted by the authors on April 30, 1973.

This technical report has been reviewed and is approved.

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A. Olevitch Chief, Materials Engineering Branch Materials Support Division Air Force Materials Laboratory

#### ABSTRACT

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The major objectives of this research program were to evaluate newly developed materials of interest to the Air Force for potential structural airframe usage, and to provide "data sheet" type presentations of engineering data for these materials. The effort covered in this report has concentrated on X2048-T351 plate, 7050-T73651 plate, 21-6-9 annealed sheet, Ti-8Mo-8V-2Fe-3Al STA sheet, Ti-6A1-2Zr-2Sn-2Mo-2Cr STA plate, and Ti-6A1-6V-2Sn STA isothermal die forgings.

The properties investigated include tension, compression, shear, bend, impact, fracture toughness, fatigue, creep and stress-rupture, and stress corrosion at selected temperatures.

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|                                       | Page       |
|---------------------------------------|------------|
|                                       | 1          |
|                                       |            |
| $X \ge 048 - T351$ Aluminum Allov     | . 2        |
| Material Description                  | 2          |
| Processing and Heat Treating          | , 2        |
| Test Results                          | . 2        |
| 7050-T73651 Aluminum Alloy            | . 19       |
| Material Description                  | , 19       |
| Processing and Heat Treating          | . 19       |
| Test Results                          | . 19       |
| 21 6-9 Stainless Steel Allov          | 36         |
| Matarial Description                  | 36         |
| Processing and Heat Treating          | 36         |
| Test Results                          | . 36       |
|                                       | 50         |
| 71-AMO-6V-2FE-JAL ALLCY               | , )4       |
|                                       | , J2<br>50 |
| Test Regults                          | . 52       |
|                                       |            |
| T1-6A1-2Zr-2Sn-2Mo-2Cr Alloy          | . 68       |
| Material Description                  | , 68       |
| Processing and Heat Treating          | . 68       |
| Test Results                          | , 68       |
| Ti-6A1-6V-2Sn Isothermal Die Forgings | , 85       |
| Material Description                  | . 85       |
| Processing and Heat Treating          | . 85       |
| Test Results                          | . 85       |
| DISCUSSION OF PROGRAM RESULTS         | . 98       |
| CONCLUSIONS                           | . 98       |

## APPENDIX I

| EXPERIMENTAL PROCEDURE  | •   | •   | ٠  | • | • | • | • | • |   | • | •  | • | • | • | • | • | • | • | • | • | • | • | • | 101 |
|-------------------------|-----|-----|----|---|---|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|---|---|-----|
| Mechanical Properties . |     |     |    |   |   |   |   |   |   |   |    |   |   |   |   |   |   |   | • |   |   |   |   | 102 |
| Specimen Identification | •   |     |    |   | • | • | ÷ |   | ٠ | • |    | • |   | • |   | • | • |   | • |   |   |   |   | 103 |
| Test Description        |     |     |    |   |   | • |   |   |   | • | ۰. |   |   |   |   | • | • |   |   |   |   | , |   | 104 |
| Tension                 |     | •   |    |   |   |   | • |   | • | ٠ |    |   | • | • | • |   |   |   |   | • |   | • |   | 104 |
| Compression             |     |     |    |   | • |   |   |   |   | ÷ |    | • |   |   |   |   |   |   |   |   |   |   |   | 105 |
| Shear                   |     |     |    |   |   |   |   |   |   | • |    |   |   |   |   |   |   |   |   |   |   |   | • | 105 |
| Bend                    |     |     |    |   |   |   |   |   |   |   |    |   |   |   | • |   |   |   |   |   |   |   | • | 105 |
| Creep and Stress R      | upl | tui | re |   |   |   |   |   | • | • |    |   |   |   |   |   | • |   | • | • |   |   |   | 105 |

Preceding page blank

· V



## TABLE OF CONTENTS (Continued)

## APPENDIX I (Continued)

| Stress Corresion  |    |   |   |   |   |   |   |    |   |   |   |    |   |   |   |   |    |   |   |    |   |   |   |   |   |   | 1.06 |  |
|-------------------|----|---|---|---|---|---|---|----|---|---|---|----|---|---|---|---|----|---|---|----|---|---|---|---|---|---|------|--|
| Thomas Evenuedan  | •  | • | • | • | • | • | • | '  | • | • | • | •  | • | • | • | • | •  | • | • | •  | • | • | • | • | • | • | 107  |  |
| inermal Expansion | ٠  | ٠ | ٠ | ٠ | • | • | ٠ | •  | ٠ | ٠ | ٠ | •  | • | ٠ | ٠ | ٠ | ٠  | ٠ | ٠ | •  | ٠ | ٠ | ٠ | • | ٠ | ٠ | 107  |  |
| Fatigue           |    |   |   |   |   |   |   |    |   |   |   |    |   |   |   |   |    |   | • |    |   | • |   |   |   |   | 107  |  |
| Fracture Toughnes | ġ. |   |   | • |   | • |   | ۰. |   | • |   | •. | • | • | • | • |    | • |   | 4- |   |   | ÷ | • |   | • | 108  |  |
|                   |    |   |   |   |   |   |   |    |   |   | • |    | • |   |   |   | 11 |   | ÷ |    |   |   |   |   | ' |   |      |  |

## APPENDIX II

Page

109

113

SPECIMEN DRAWINGS

APPENDIX III

DATA SHEETS

vi

## LIST OF TABLES

é

ŝ,

4

į,

З,

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÷

٠,

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1

÷

| ÷                                     |          |   | Page |        |
|---------------------------------------|----------|---|------|--------|
| Table                                 | I        | Tension Test Results for X2048-T851 Aluminum Plate  | ່ 5  |        |
|                                       | II       | Compression Test Results for X2048-T851 Aluminum Plate  | б    | •      |
|                                       | TII      | Shear Test Results for X2048-T851 Aluminum Plate at<br>Room Temperature                                     | 7    |        |
|                                       | IV       | Charpy V-Notch Test Results for X2048-T851 Aluminum Plate.  | 7    |        |
| •<br>•                                | <b>V</b> | Results of Slow-Bend Type Fracture Toughness Tests for X2048-T851 Aluminum Plate                            | 8    |        |
| · · · · · · · · · · · · · · · · · · · | VI       | Axial Load Fatigue Test Results for X2048-T851 Aluminum Plate (Unnotched, $R = 0.1$ ) (Longitudinal)        | 9    |        |
|                                       | VII      | Axial Load Fatigue Results for X2O48-T851 Aluminum Plate (Notched, $K_t = 3.0$ , $R = 0.1$ ) (Longitudinal) | 10   | •      |
|                                       | VIII     | Summary Data on Creep and Rupture Properties for X2048-<br>T851 Aluminum Plate (Longitudinal)               | 11   |        |
|                                       | IX       | Tension Test Results for 7050-T73651 Aluminum Alloy Plate.  | 22   |        |
|                                       | x        | Compression Test Results for 7050-T73651 Aluminum<br>Alloy Plate  | 23   | · .    |
|                                       | XI       | Shear Tert Results for 7050-T73651 Aluminum Alloy Plate<br>at Room Temperature                              | 24   | •<br>• |
|                                       | XII      | Impact Test Results for 7050-T73651 Aluminum Alloy<br>Plate at Room Temperature                             | 24   | х      |
| -                                     | XIII     | Results of Slow-Bend Type Fracture Toughness Tests for 7050-T73651 Aluminum Alloy Plate                     | 25   | ·      |
|                                       | XIV      | Axial Load Fatigue Test Results for Unnotched 7050-T73651<br>Aluminum Plate (Transverse)                    | 26   |        |
|                                       | xv       | Axial Load Fatigue Test Results for Notched (K = 3.0)<br>7050-T73651 Aluminum Plate (Transverse)            | 27   | <br>   |
|                                       | XVI      | Summary Data on Creep and Rupture Properties for 7050<br>Aluminum Plate (Transverse)                        | 28   | · .    |
| : *                                   | XVII     | Tensile Tost Results for Annealed 21-6-9 Stainless<br>Steel Sheet   | 39   |        |
|                                       | XVIII    | Compression Test Results for Annealed 21-6-9 Stainless<br>Steel Sheet                                       | 40   |        |
|                                       |          |   |      |        |

LIST OF TABLES (Continued)

DOCUMENT PROVIDED BY THE ABBOTT AEROSPACE TECHNICAL LIBRARY ABBOTTAEROSPACE.COM

| ·           | •       |   | Pag  | <u>e.</u>                             |
|-------------|---------|---|------|---------------------------------------|
| Table       | XIX     | Shear Test Rogults for Annealed 21-6-9 Stainless<br>Steel Sheet at Room Temperature   | , 41 |                                       |
|             | XX      | Axial Load Fatigue Test Results for Unnotched 21-6-9<br>Annealed Stainless Steel Sheet (Transverse)                               | 42   | <u>!</u>                              |
|             | XXI     | Axial Load Fatigue Test Results for Notched (K = 3.0)<br>21-6-9 Annealed Stainless Steel Sheet (Transverse)                       | . 43 | ł                                     |
| Γ.          | XXII    | Summary Data on Creep and Rupture Properties for 21-6-9<br>Stainless Steel Sheet (Transverse) ,                                   | . 44 | · · · · · · · · · · · · · · · · · · · |
|             | XXIII   | Tensile Test Results for Solution-Troated and Aged<br>Ti-BMe+8V-2Fe-3A1 Alloy Sheet   | . 55 | •<br>;<br>••.                         |
| -<br>-<br>- | XXIV    | Compression Test Results for Solution-Treated and<br>Aged Ti-8Mo-8V-2Fe-3Al Alloy Sheet   | . 56 | ) ·                                   |
|             | . XXV . | Shear Test Results for Solution-Treated and Aged Ti-8Mo-<br>8V-2Fe-3Al Alloy Sheet at Room Tempurature                            | . 57 | <br><br>1                             |
| -           | XXVI    | Axial Load Fatigue Test Results for Unnotched, Solution-<br>Treated and Aged Ti-8Mo-8V-2Fe-3A1 Alloy Sheet<br>(Transverse)        | ەر   | b                                     |
|             | XXVII   | Axial Load Fatigue Test Results for Notched (K, = 3.0)<br>Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Alloy<br>Sheet (Transverse) | . 59 | ,                                     |
|             | XXVIII  | Summary Data on Creep and Rupture Properties for Ti-8Mo-<br>8V-2Fe-3A1 Alloy Sheet (Transverse)                                   | . 60 | )                                     |
| · · ·       | XXIX    | Tensile Tqst Results for Solution-Treated and Aged<br>Ti-6A1-27r-25n-2Mo-2Cr Alloy Plate ,  | . 71 | i                                     |
| · · ·       | XXX     | Compression Test Results for Solution-Tropted and Aged Ti-6A1-2Zr-2Sn-2Mo-2Cr Alloy Plate   | . 72 | 2                                     |
| •••         | XXX I   | Shear Test Results for Solution-Treated and Aged Ti-6Al-<br>2Zr-2Sn-2Mo-2Cr Alloy Plate at Room Temperature                       | . 73 | J                                     |
|             | XXXII   | Impact Test Results for Solution-Troated and Aged TL-6A1-<br>2Zr-2Sn-2Mu-2Cr Alloy Plate at Room Temperature                      | . 73 | 3                                     |
|             | XXX III | Results of Slow-Bend Type Fracture Toughness Tosts on Solution-Treated and Aged T1+5A1+22r+2Sn 2Mo+2Cr Plate .                    | . 74 |                                       |
|             | XXX IV  | Axial Load Fatigue Test Results for Unnotched Solution-<br>Treated and Aged Ti-6A1-2Sn-2Mo-2Gr Alloy Plate<br>(Transverse)        | . 75 | 5                                     |

LIST OF TABLES (Continued)

ECHNICAL LIBRARY

ABBOTTAEROSPACE.COM

Page Table XXXV Axial Load Fatigue Test Results for Notched  $(K_{-} = 3.0)$ Solution-Treated and Aged Ti-6A1-2Zr-2Sn-2Mo-2Cr 76 XXXVI Summary Data on Creep and Rupture Properties for Solution-Treated and Aged Ti-6A1-2Zr-2SnO2Mo-2Cr Alloy Plate 7 XXXV11 Tension Test Results for Solution-Treated and Aged 87 Ti-6Al-6V-2Sn Isothermal Die Forging (Transverse) XXXVIII Compression Test Results for Solution-Treated and Aged T1-6A1-6V-2Sn Isothermal Die Forgings (Transverse) . . . 88 XXXIX Shear Test Results at Room Temperature for Solution-Treated and Aged Ti-6A1-6V-2Sn Isothermal Die Forgings . . 89 ХL Impact Test Results for Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings . . . . . 89 XLI Axial Load Fatigue Test Results for Unnotched Solution-Treated and Aged Ti-bA1-6V-2Sn Isothermal Die Forgings . . 90 XLII Axial Load Fatigue Test Results for Notched  $(K_t = 3.0)$ Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings . 91 . . . . . . . . . . XLIII Summary Data on Creep and Rupture Properties for Solution-Treated and Age J Ti-6A1-6V-2Sn Isothermal Die Forgings 92

#### LIST OF ILLUSTRATIONS

THIS DOCUMENT PROVIDED BY THE ABBOTT AEROSPACE TECHNICAL LIBRARY ABBOTTAEROSPACE.COM

|        |    |   | TAKE |
|--------|----|---|------|
| Figure | 1. | Specimens Layout for X2048-T851 Plate   | 3    |
|        | 2  | Typical Tensile Stress-Strain Curves at Temperature for X2048-T851 Plate (Longitudinal)                             | 12   |
|        | 3  | Typical Tensile Stress-Strain Curves at Temperature for X2048-T851 Plate (Transverse)                               | 13   |
|        | 4  | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for X2048-T851 Plate (Longitudinal)  | 14   |
|        | 5  | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for X2048-T851 Plate (Transverse)    | 15   |
|        | 6  | Effect of Temperature on the Tensile Properties of X2048-T851<br>Plate  | 16   |
|        | 7  | Effect of Temperature on the Compressive Properties of X2048-T851 Plate   | 16   |
|        | 8  | Axial Load Fatigue Behavior of Unnotched X2048-T951 Plate (Longitudinal)  | 17   |
|        | 9  | Axial Load Fatigue Behavior of Notched (K = 3.0) X2048-T851<br>Plate (Longitudinal)                                 | 17   |
|        | 10 | Stress-Rupture Curves for X2048-1851 Plate (Longitudinal)   | 18   |
|        | 11 | Specimen Layout for 7050-T73651 Plate   | 20   |
|        | 12 | Typical Tensile Stress-Strain Curves at Temperatule for 7050-773651 Plate (Longitudinal)                            | 29   |
|        | 13 | Typical Tensile Stress-Strain Curves at Temperature for 7050-T73651 Plate (Transverse)                              | 30   |
|        | 14 | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for 7050-T73651 Plate (Longitudinal) | 31   |
|        | 15 | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for 7050-T73651 Plate (Transverse)   | 32   |
|        | 16 | Effect of Temperature on the Tensile Properties of 7050-T73651 Plate  | 33   |
|        | 17 | Effect of Temperature on the Compressive Properties of 7050-T73631 Plate  | 33   |
|        |    |   |      |

х

Page

# THIS DOCUMENT PROVIDED BY THE ABBOTT AEROSPACE TECHNICAL LIBRARY ABBOTTAEROSPACE.COM LIST OF ILLUSTRATIONS (Continued)

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1.15 ÷.

<u>،</u> ۱.

|           | · • |  | <u>Page</u> |
|-----------|-----|--|-------------|
| Figure    | 18  | Axial Load Fatigue Behavior of Unnotched 7050-T73651<br>Plate (Transverse)   | 3/;         |
|           | 19  | Axial Load Fatigue Behavior of Notched (K = 3.0)<br>7050-T73651 Plate (Transverse)   | 34          |
|           | 20  | Stress-Rupture and Plastic Deformation Curves for 7050-T73651<br>Plate (Transverse)  | 35          |
| · · · · · | 21  | Specimen Layout for 21-6-9 Annealed Sheet  | 37          |
|           | 22  | Typical Tensile Stress-Strain Curves at Temperature for 21-6-9 Annealed Sheet (Longitudinal)   | 45          |
|           | 23  | Typical Tensile Stress-Strain Curves at Temperature for 21-6-9 Annealed Sheet (Transverse)   | 46          |
|           | 24  | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for 21-6-9 Annealed Sheet (Longitudinal)                                | 47          |
|           | 25  | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for 21-6-9 Annealed Sheet (Transverse)                                  | 48          |
|           | 26  | Effect of Temperature on the Tonsile Properties of 21-6-9<br>Annealed Sheet  | 49          |
|           | 27  | Effect of Temperature on the Compressive Properties of 21-6-9 Annealed Sheet   | 49          |
| •         | 28  | Axial Load Fatigue Behavior of Unnotched 21-6-9<br>Annealed Sheet (Transverse)   | 50          |
| ı         | 29  | Axial Load Fatigue Behavior of Notched (K = 3.0) 21-6-9<br>Annealed Sheet (Transverse)   | 50          |
| ·<br>·    | 30  | Stress-Rupture and Plastic Deformation Curves for 21-6-9<br>Annealed Sheet (Transverse)  | 51          |
| .•        | 31  | Specimen Layout for Ti-8Mo-BV-2Fe-3Al Sheet  | 53          |
|           | 32  | Typical Tensile Stress-Strain Curves at Temperature for Solution<br>Streated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Longitudinal)                           | 61          |
|           | 33  | Typical Tensile Stress-Strain Curves at Temperature for Solution<br>Troated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Tranverse)                               | - 62        |
|           | 34  | Typical Compressive Stress-Strain and Tangent-Modulus Curves<br>at Temperature for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al<br>Sheet (Longitudinal) | 63          |

THIS DOCUMENT PROVIDED BY THE ABBOTT AEROSPACE TECHNICAL LIBRARY ABBOTTAEROSPACE.COM LIST\_OF\_ILLUSTRATIONS (Continued)

Page

| Figure | 35  | Typical Compressive Stress-Strain and Tangent-Modulus<br>Curves at Temperature for Solution-Treated and Aged<br>Ti-8Mo-8V-2Fe-3Al Sheet (Transverse) | 64         |
|--------|-----|--|------------|
|        | 36  | Effect of Temperature on the Tensile Properties of Solution Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet   | 65         |
|        | 37  | Effect of Temperature on the Compressive Properties of Solution Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet   | 65         |
|        | 38  | Axial Load Fatigue Behavior of Unnotched Solution-Treated<br>and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)   | 66         |
|        | 39  | Axial Load Fatigue Behavior of Notched (K = 3.0) Solution<br>Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)                                   | 6 <b>6</b> |
|        | 40  | Stress-Rupture and Plastic Deformation Curves for Solution<br>Treated and Aged Ti-8Mo-3V-2Fe-3Al Sheet (Transverse)                                  | 67         |
|        | 41  | Specimen Layout for T1-6A1-2Zr-2Sn-2Mo-2Cr Plate   | 69         |
|        | 42  | Typical Tensile Stress-Strain Curves at Temperature for Solution<br>Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Longitudinal) .                   | 78         |
|        | 43  | Typical Tensile Stress-Strain Curves at Temperatures for<br>Solution Treated and Aged Ti-6A1-2Zr-2Sn-2Mo-2Cr<br>Plate (Transverse)                   | 7 <b>9</b> |
|        | 44  | Typical Compressive Stress-Strain and Tangent-Modulus<br>Curves for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr<br>Plate (Longitudinal)         | 80         |
|        | 45. | Typical Compressive Stress-Strain and Tangent-Modulus<br>Curves for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr<br>Plate (Transversc)           | 81         |
|        | 46  | Effect of Temperature on the Tensile Properties of<br>Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate   | 82         |
|        | 47  | Effect of Temperature on the Compressive Properties of Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo+2Cr Plate  | 82         |
|        | 48  | Axial Load Fatigue Behavior of Unnotched Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse)   | 83         |
|        | 49  | Axial Load Fatigue Behavior of Notched (K = 3.0) Solution<br>Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse)                              | 83         |

ć

# LIST OF ILLUSTRATIONS

ал 19

ï

4

9 1

) | $G_{i}^{i} \rightarrow$ 

|        |            |  | · · · · |
|--------|------------|--|---------|
| •      | ••         |  | Page    |
| Figure | 50         | Stress-Rupture and Plastic Deformation Curves for Solution<br>Treated and Aged Ti-6A1-22r-2Sn-2Mo-2Cr Plate (Transverse)               | 84      |
|        | 51         | Typical Tensile Stress-Strain Curves for Solution Treated<br>and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings                            | 93      |
|        | 52         | Typical Compressive Stress-Strain and Tangent Modulus Curves<br>for Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal<br>Die Forgings | 94      |
|        | 53         | Effect of Temperature on the Tensile Properties of Solution<br>Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings                  | 95      |
| •••    | 54         | Effect of Temperature on the Compressive Properties of Solution<br>Treated and Aged T1-6A1-6V-2Sn Isothermal Die Forgings              | 95      |
|        | 55         | Axial Load Fatigue Behavior of Unnotched Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings (Transverse)                  | 96      |
|        | 56         | Axial Load Fatigue Behavior of Notched (K = 3.0) Solution<br>Treated and Aged Ti-6Al-6V-25n Isothermal Die Forgings<br>(Transverse)    | 96      |
|        | 57         | Stress Rupture and Plastic Deformation Curves for Solution<br>Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings                   | 97      |
|        | 58         | Tensile Ultimate Strength as a Function of Temperature   | 99      |
|        | 59         | Tensile Yield Strength as a Function of Temperature  | 100     |
|        | 60         | Sheet and Thin-Plate Tensile Specimen  | 110     |
|        | 61         | Round Tensile Specimen   | 110     |
|        | 62         | Sheet Compression Specimen   | 110     |
|        | 63         | Round Compression Specimen   | 110     |
|        | 64         | Sheet Creep- and Stress-Rupture Specimen   | 110     |
| ;      | 65         | Round Creap- and Stress-Rupture Specimen   | 110     |
| •      | 6 <b>6</b> | Sheet Shear Test Specimen  | 111     |
|        | 67         | Pin Shear Specimen   | 111     |
|        | 6 <b>8</b> | Unnotched Sheet Fatigue Specimen   | 111     |
|        | 69         | Notched Sheet Fatigue Specimum   | 111     |
|        |            |  |         |

. . .

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ziii

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#### LIST OF ILLUSTRATIONS (Continued)

١

.

÷

|        |     |                                       | Page |
|--------|-----|---------------------------------------|------|
| Figure | 70  | Unnotched Round Fatigue Specimen      | 111  |
|        | 71  | Notched Round Fatigue Specimen        | 111  |
|        | 72  | Sheet Fracture Toughness Specimen     | 112  |
|        | 73  | Slow Bend Fracture Toughness Specimen | 112  |
|        | 74  | Stress-Corrosion Specimen             | 112  |
|        | 75  | Thermal-Expansion Specimen            | 112  |
|        | .76 | Sheet Bend Specimen                   | 112  |
|        | 77  | Notched Impact Specimen               | .112 |

#### **INTRODUCTION**

The selection of materials to most effectively satisfy new environmental requirements and increased design load requirements for advanced Air Force weapons systems is of vital importance. A major difficulty that design engineers encounter, particularly for newly developed materials, materials processing, and product forms, is a lack of sufficient engineering data to effectively evaluate the relative potential of these developments for a particular application.

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In recognition of this need, the Air Force has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for newly developed materials. The materials included in these evaluation programs were carefully selected to insure that they were either available or could become quickly available on request and that they would represent potentially attractive alloy projections for weapons system usage. The results of these programs have been published in five technical reports, AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, AFML-TR-71-249, and AFML-TR-72-196, Volumes I and JI.

This technical report is a result of the continuing effort to relieve the above situation and to stimulate interest in the use of newly developed alloys, or new processing techniques for older alloys, for advanced structures.

The materials evaluated under this program are as follows

- (1) X2048-T851 Plate
- (2) 7050-T73651 Plate
- (3) 21-6-9 Annealed Sheet
- (4) T1-8Mo-8V-2Fe-3A1 STA Sheet
- (5) T1-6A1-2Zr-2Sn-2Mo-2Cr STA Plate
- (6) Ti-6A1-6V-2Sn STA Isothermal Die Forgings .

The temper or heat-treat conditions selected for evaluation are described in each alloy section.

The program approach was, as on previous contracts, to search the published literature and to contact metal producers and aerospace companies for any pertinent data. If very little pertinent information was available, a complete material evaluation was conducted. On this program a complete evaluation was conducted for each material. Upon completion of each evaluation, a "data sheet" was issued to make the information immediately available to potential users rather than defer publication to the end of the contract term and this summary technical report. These data sheets are reproduced as Appendix III of this report.

Detailed information concerning the properties of interest, test techniques, and specimen types are contained in Appendices I and II of this report. X2048-T851 Aluminum Alloy

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#### Material Description

Alloy X2048-T851 is a recent development of the Reynolds Metals Company. The development aim was a thick section alloy with high toughness and stability at moderate temperatures. The goal was to achieve the strength, fatigue resistance, corrosion resistance, and thermal stability of 2024-T851 or 2124-T851 and the toughness of 2219.

The material used for this evaluation was 3-inch place produced within the following composition limits

| Copper       | 2.8 to 3.8   |
|--------------|--------------|
| Manganese    | 0.20 to 0.60 |
| Magnesium    | 1.2 to 1.8   |
| Zinc         | 0.25 max     |
| Titanium     | 0.10 max     |
| Silicon      | 0.15 max     |
| Iron         | 0.20 max     |
| Others total | 0.15 max     |
| Aluminum     | Balance      |

#### Processing and Heat Treating

Specimens were cut from the plate as shown in Figure 1 and were tested in the as-received -T851 temper.

#### Test Regults

<u>Tension</u>. Test results for longitudinal and transverse specimens at .com temperature, 250 F, 350 F, and 500 F are given in Table I. Short-transverse test results at room temperature only are also given in Table I. Stress-strain curves at temperature are shown in Figures 2 and 3. Effect-of-temperature curves are presented in Figure 6.

<u>Compression</u>. Results of tests in both the longitudinal and transverse directions at room temperature, 250 F, 350 F, and 500 F are given in Table II. Stress-strain and tangent-modulus curves at temperature are shown in Figures 4 and 5. Effect-of-temperature curves are presented in Figure 7.

Shear. Results of room temperature pin shear tests in both the longitudinal and transverse directions are given in Table III.

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| 989  |       |      | <b>.</b> | 97         | 9  |     |    | 3              |    | 3        |     |        |    |       |
| 686  |       |      |          | 54         | 9  |     |    |                |    |          |     |        |    | !     |
| 128  |       |      |          | 28         | 9  |     |    |                |    |          |     |        |    |       |
| 615  |       | _    |          | 60         | 5  |     |    |                |    |          |     |        | _  |       |
| 119  |       |      |          | •          | 9  |     |    |                |    |          | 3   | 1 H    |    |       |
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| Hg   |       |      |          | 15         | •  |     |    | 11.1.2         | -  | \$113    | 9   |        | ľ  |       |
| 69   |       |      |          | 01         | •  |     |    | 619            |    | 111      | ~   | 20     |    | 1     |
| 46   |       | -    |          |            | •  |     |    | 1              |    | 2        | 2   | 82     |    |       |
| 69   |       | _    |          |            |    |     |    | 617            |    | 912      | 2   |        |    | 1     |
| 59   | ···   |      | _        |            | ╏  |     |    | 512            |    |          | 21  | 2      |    |       |
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| 675<br>775        | 818<br>818        | 212 212 | 20.02  |  |
| ETS<br>275<br>775 | 876<br>876<br>876 | 212 212 | 210 21 |  |

SPECIMEN LAYOUT FOR X2048-T851 PLATE FIGURE 1. 5

Impact. Charpy V-motch test results for longitudinal and transverse specimens are given in Table IV.

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<u>Fracture Toughness</u>. Results of slow-bend type tests in both the longitudinal (L-T) and transverse (T-L) directions are given in Table V. The specimens were 1.00-inch thick by 2.00-inches wide with a span of 8 inches. The candidate K<sub>0</sub> values shown in Table V are considered valid K<sub>Ic</sub> values by existing ASTM criteria. (Higher K<sub>Ic</sub> values may be achieved with larger specimens. Reference J. G. Kaufman, "Notes for E-24.01 Meeting", held at Battelle's Columbus Laboratories on October 4, 1972.)

Estime. Axial-load test results for longitudinal specimens at a ratio of R = 0.1 are given in Tables VI and VII. These tests were conducted for both unnotched and notched ( $K_{\rm L} = 3.0$ ) specimens at room temperature, 250 F, and 350 F. S-N curves are presented in Figures 8 and 9.

<u>Creep and Stress-Rupture</u>. Results of tests on longitudinal specimens at 250 F, 350 F, and 500 F are given in Table VIII. Log-stress versus log-time curves are presented in Figure 10.

<u>Stress Corrosion</u>. Specimens were tested as described in the experimental procedure section of this report. No cracks or failures occurred in the 1000-hour test duration.

<u>Thermal Expansion</u>. The coefficient of thermal expansion for this alloy was determined to be  $12.9 \times 10^{-6}$  in./in./F for 68 F to 350 F.

Density. The density of this material is 0.0994 lb./in.<sup>3</sup>.

| <br>                |          |                                   |  | ABBOTTAEROSPACE.C                     | ЭМ                               |                                |
|---------------------|----------|-----------------------------------|--|---------------------------------------|----------------------------------|--------------------------------|
|                     | TABLE    | I. TENSION                        | TEST RESULTS FOR                             | X2048-T851 ALUN                       | IINUM PLATE                      |                                |
| Specimen<br>Number  | Str      | Ultimate<br>Tenzile<br>ength, ksi | 0.2 Percent<br>Offset Yield<br>Strength, ksi | Elongation<br>in 2 Inches,<br>percent | Raduction<br>in Area,<br>percent | Tensile<br>Modulus,<br>10" psi |
|                     | -        | Long                              | itudinal at Room                             | Temperature                           |                                  |                                |
| 1L-1                |          | 66.2                              | 60.5   | 8.0                                   | 15.7                             | 10.2                           |
| 1L-2                |          | 66.2                              | 60.3   | 8.5                                   | 15.8                             | 10.3                           |
| 1L=3                | A        | 66,4                              | <u>60.4</u>                                  | 8.5                                   | $\frac{15.5}{15.7}$              | $\frac{10.2}{10.2}$            |
|                     | Average  | 00.5<br>Trø                       | 00.4<br>Inaverse at Room 1                   | emneraturo                            | 13.7                             | 10.2                           |
| 17-1                |          | <u></u> :<br>69.4                 | 62.4   | -8.0                                  | 12.5                             | 10.8                           |
| 1T-2                |          | 66.4                              | 60.0   | 7.0                                   | 12.2                             | 10.5                           |
| 1T-3                |          | 66.3                              | 60.2   | <u>6,5</u>                            | 10.3                             | 10.3                           |
|                     | Average  | 67,4                              | 60.9   | 7,2                                   | 11.7                             | 10.5                           |
|                     |          | Short                             | Transverse at Roc                            | m lemperature                         |                                  |                                |
| 1ST-1<br>1ST-2      |          | 67.6<br>67.4                      | 59.6   | 7.0                                   | 11.4                             | 11.1                           |
| 1ST-3               | •        | 66,4                              | 58.2   | 6.0                                   | 9.0                              | 11.1                           |
|                     | Average  | 67.1                              | 58.9   | 6.3                                   | 9.4                              | 11.1                           |
|                     |          |                                   | Longitudinal at                              | 250 F                                 |                                  |                                |
| 11-4                |          | 59.8                              | 56.5   | 13.5                                  | 33.9                             | 9.5                            |
| 1L=5                |          | 60.5<br>60 1                      | 57.0   | 12.5                                  | 28.4                             | 9.9                            |
| 1 <b>L-0</b>        | Average  | 60.1                              | 56.8   | 12.7                                  | 31.6                             | 9.9                            |
|                     |          |                                   | Transverse at                                | <u>250 F</u>                          |                                  |                                |
| 1T-4                |          | 60.4                              | 56.5   | 11.5                                  | 26.3                             | 10.0                           |
| 1T-5                |          | 59.7                              | 56.0   | 13.5                                  | 29.3                             | 10.0                           |
| II-0                | Average  | <u>29.8</u><br>60.0               | <u>20.3</u><br>56.3                          | $\frac{13.0}{12.7}$                   | 27.0                             | 9.8                            |
|                     | •        |                                   | Longitudinal at                              | : 350 F                               |                                  |                                |
| 1L-7                |          | 51.6                              | 49.4   | 13.5                                  | 38.8                             | 9.3                            |
| 1L-8                |          | 51.4                              | 49.1   | 14.5                                  | 38.1                             | 9.3                            |
| 1L <b>-9</b>        | <b>A</b> | $\frac{51,1}{51,1}$               | 48.8   | $\frac{14.5}{14.2}$                   | $\frac{35.0}{37.3}$              | 9.4                            |
|                     | Average  | 51.4                              | 4714<br>Transverse at                        | 14.2<br>350 F                         | د./د                             | 7.3                            |
| 1                   |          | 50 B                              | <u>/0</u> 7                                  |                                       | 26 1                             | 0 1                            |
| 11-7<br>1T-8        |          | 50.5                              | 40.7   | 16.5                                  | 33.5                             | 9.3                            |
| 1T-9                |          | 49.3                              | 48.2   | 16.0                                  | 33.9                             | 9.1                            |
|                     | Average  | 50.3                              | 48.8   | 16.5                                  | 34.2                             | 9.3                            |
|                     |          |                                   | Longitudinal at                              | <u>500 F</u>                          |                                  |                                |
| 1L-10               |          | 34.5                              | 32.1   | 10.0                                  | 27.2                             | 8.6                            |
| 1L=12               |          | 33.7                              | 31.3   | 10.0                                  | 21.5                             | 7.9                            |
|                     | Average  | 34.0                              | 31.7   | 9.5                                   | 23.4                             | 8.3                            |
|                     |          |                                   | Transverse at                                | 500 F                                 |                                  |                                |
| 1 <b>T-</b> 10      |          | 32.3                              | 30.5   | 10.0                                  | 14.7                             | 7.5                            |
| 1T-11               |          | 35.0<br>32.8                      | 33.2<br>31 0                                 | 7.5                                   | 15.1                             | 8.0<br>7 K                     |
|                     |          | 33.4                              | 31.6   | 8.2                                   | 15.0                             | 7.7                            |
| المر المنطق مع عن ا |          | والمرد الخديد سوينقا              | متاذاته وعنشوه موجا بي معرف                  | فالانتهاب كالبواء فالإعادي وزاراه     | ويحتج بالتي المتكلية أطلابه      |                                |

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# TABLE II. COMPRESSION TEST RESULTS FOR X 2048-T851 ALUMINUM PLATE

| Specimen<br>Number      | 0<br>Of<br>Sti | .2 Percent<br>føet Yield<br>rength, køi | Compression<br>Modulus,<br>10 <sup>3</sup> psi                                    |
|-------------------------|----------------|---|---|
|                         | Longitudin     | al at Room Temperature                  |   |
| 2L-1<br>2L-2<br>2L-3    | Average        | 62.0<br>59.0<br>61.6<br>60.9            | $   \begin{array}{r}     11.4 \\     11.1 \\     11.5 \\     11.3   \end{array} $ |
|                         | Transverse     | at Room Temperature                     |   |
| 2T-1<br>2T-2<br>2T-3    | Average        | 60.6<br>61.2<br>60.0<br>60.6            | $   \begin{array}{r}     10.9 \\     11.1 \\     11.4 \\     11.1   \end{array} $ |
|                         | Long           | itudinal at 250 F                       | -   |
| 2L-4<br>2L-5<br>2L-6    | Åverege        | 56.2<br>56.8<br>57.0<br>56.7            | 10.1<br>10.3<br>10.3<br>10.2  |
|                         | Tra            | nsverse at 250 F                        |   |
| 2T-4<br>2T-5<br>2T-6    | Average        | 56.8<br>56.8<br>54.4<br>56.0            | 10.3<br>10.3<br>10.2<br>10.3  |
|                         | Long           | itudinal at 350 F                       |   |
| 2L-7<br>2L-8<br>2'9     | Average        | 51.7<br>48.8<br>51.3<br>50.6            | 9.8<br>9.4<br><u>9.6</u><br>9.6   |
|                         | Tra            | nsverse at 350 F                        |   |
| 2T-7<br>2T-8<br>2T-9    | Average        | 52.0<br>50.3<br>50.9<br>51.1            | 9.9<br>9.7<br>9.6<br>9.7  |
|                         | Long           | itudinal at 500 F                       |   |
| 2L-10<br>2L-11<br>2L-12 | Average        | 35.0<br>35.3<br><u>35.3</u><br>35.2     | 9.6<br>9.0<br>9.7<br>5.4  |
|                         | Tra            | nsverse at 500 F                        |   |
| 2T-10<br>2T-11<br>2T-12 | Averace        | 33.1<br>32.5<br><u>33.1</u><br>32.9     | 9.7<br>9.9<br>9.7<br>9.7  |

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| TABLE | III. | SHEAK IN | ST RES | ULTS FOR | X2048-T851  |
|-------|------|----------|--------|----------|-------------|
|       |      | ALUMINUM | PLATE  | AT ROOM  | TEMPERATURE |
|       |      |          |        |          |             |

| Specimen<br>Number |              | Ultimate Shear<br>Strength, ksi |
|--------------------|--------------|---------------------------------|
|                    | Longitudinal |                                 |
| 4L-1               |              | 39.3                            |
| 4L-2               |              | 39.0                            |
| 413                |              | 39.8                            |
| 4L-4               |              | 39.3                            |
|                    | Avorage.     | 39,3                            |
| •                  | Transverse   |                                 |
|                    |              | 39.5                            |
| 4T-2               |              | 40.1                            |
| 4T-3               |              | 38.8                            |
| 4T-4               |              | 38.5                            |
|                    | Average      | 39.2                            |

#### TABLE IV. CHARPY V-NOTCH TEST RESULTS FOR X2048-T851 ALUMINUM FLATE

• .

| Specimen<br>Number  | ······································ | Energy,<br>ft./1bs.                                   |
|---|--|---|
|   | Longitudinal                           |   |
| 10-1L<br>10-2L<br>10-3L<br>10-4L<br>10-5L<br>10-6L<br>10-7L | Ave <b>rag</b> e                       | 7.0<br>9.0<br>5.0<br>9.0<br>10.0<br><u>6.5</u><br>8.9 |
|   | Transverse                             |   |
| 10-1T<br>10-2T<br>10-3T<br>10-4T<br>10-5T<br>10-6T          | Average                                | 4.0<br>5.0<br>4.0<br>5.0<br>5.0<br>4.5                |

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#### TABLE V. RESULTS OF SLOW-BEND TYPE FRACTURE TOUCHNESS TESTS FOR X2048-T851 ALUMINUM PLATE

| Specimen<br>Number |     | W,<br>inches | a,<br>inches | T,<br>inches | P,<br>Abs    | Span,<br>Inches | { ( <sup>1</sup> / <sub>W</sub> ) | K <sub>Q</sub> (a) |
|--------------------|-----|--------------|--------------|--------------|--------------|-----------------|-----------------------------------|--------------------|
| •                  |     |              |              | Transverse   | <u>(T-L)</u> |                 | · ·                               |                    |
| 6-1T               | 1   | 2.00         | 0.903        | 1.00         | 4,500        | 8.0             | .2.294                            | 29, 20,            |
| 6-2T               | ••  | · 2,00.;     | 0.936        | 1.00         | 4,100        | 8.0             | 2.410                             | 27.95              |
| 6-3T               |     | 2.00         | 0,946        | 1,00         | 4,350        | <b>B</b> .0     | 2.448                             | 30,12              |
| 6-4T               | • • | 2,00         | 0,942        | 1,00         | 4,300        | 8.0             | 2.433                             | 29, 59             |
| 6-5T               |     | 2.00         | 0.911        | 1,00         | 4,350        | 8.0             | 2.321                             | 28.56              |
| 6-6T               |     | 2.00         | 0.916        | 1.00         | 4,425        | 9.0             | 2,339                             | 29.27              |
|                    |     |              |              |              | Ť í          |                 | Average                           | 29.12              |
|                    |     |              | L            | ongitudinal  | (L-7)        |                 |                                   |                    |
| 6-1L               |     | 2.00         | 0.876        | 1,00         | 4,925        | 8.0             | 2,205                             | 30.72              |
| 6-2L               | •   | 2.00         | 0.903        | 1,00         | 4,950        | 8.0             | 2.294                             | 32.12              |
| 6-3L               |     | 2.00         | 0.918        | 1.00         | 4,900        | 8.0             | 2.346                             | 32.52              |
| 6-41               |     | 2.00         | 0,947        | 1.00         | 5.075        | 8.0             | 2.452                             | 35.19              |
| 6-5L               |     | 2.00         | 0.880        | 1.00         | 4.880        | 8.0             | 2.218                             | 30.61              |
| 6.6L               |     | 2.00         | 0.920        | 1.00         | 4.950        | 8.0             | 2.353                             | 32.94              |
| • •                |     | -,           |              |              | ,            |                 | Average                           | 32,35              |

(a) These candidate K<sub>Q</sub> values do meet existing ASTM size and crack length criteria and are considered valid K<sub>IC</sub> numbers.

TABLE

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#### VI. AXIAL LOAD FATIGUE TEST RESULTS FOR X2048-T851 ALUMINUM PLATE (UNNOTCHED, R = 0.1) (LONGITUDINAL)

|  | • .  |   |
|--|--|---|
| Specimen<br>Number   | Maximum<br>Stress, ksi   | Lifetime,<br>cycles   |
|  | Room Temperature   | · · · ·   |
| 5-2<br>5-3<br>5-1<br>5-4<br>5-8<br>5-5<br>5-7<br>5-7<br>5-6<br>5-9           | 60.0<br>55.0<br>50.0<br>45.0<br>42.5<br>40.0<br>37.5<br>35.0<br>35.0<br>35.0 | 9,500<br>21,300<br>30,200<br>70,600<br>2,581,900<br>50,400<br>53,300<br>3,858,400<br>11,340,800(a)                |
|  | <u>250 F</u>   |   |
| 5-10<br>5-11<br>5-12<br>5-13<br>5-15<br>5-14<br>5-16<br>5-17<br>5-18<br>5-19 | 60.0<br>55.0<br>50.9<br>45.0<br>42.5<br>40.0<br>37.5<br>35.0<br>30.0<br>25.0 | 8,400<br>17,400<br>42,200<br>124,100<br>223,900<br>109,300<br>2,384,200<br>204,300<br>238,300(b)<br>11,538,190(a) |
|  | <u>350 F</u>   |   |
| 5-20<br>5-24<br>5-22<br>5-25<br>5-21<br>5-26<br>5-23<br>5-27<br>5-28         | 60.0<br>50.0<br>45.0<br>42.5<br>40.0<br>27.5<br>35.0<br>30.0<br>25.0         | 100<br>28,100<br>33,700<br>97,800<br>177,990<br>212,300<br>2,851,600<br>236,800<br>14,461,900                     |

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(a) Did not fail.

(b) Failed at Radius.

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### TABLE VII. AXIAL LOAD FATIGUE RESULTS FOR x2048-T851ALUMINUM PLATE (NOICHED, K = 3.0, R = 0.1) (LONGITUDINAL)

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|                        |                  | -                         |
|------------------------|------------------|---------------------------|
| Specimen               | Max Inum         | Lifetime,                 |
| Number                 | Strese, ksi      | cycles                    |
|                        | Room Temperature |                           |
| its <b>5-31</b>        | 40.0             | 7,500                     |
| 5-32                   | 30,0             | 21,600                    |
| 1 5-54 · · · · · · · · | 25.0             | 44,700                    |
| 5-36                   | 22.5             | 107,400                   |
| 5-33                   | 20.0             | 247,500                   |
| 5-35                   | 17.5             | 2,646,500                 |
| 5-37                   | 15.0             | 14,621,000 <sup>(a)</sup> |
|                        | <u>250 F</u>     | •                         |
| S-44                   | 40.0             | 6,400                     |
| 5-45                   | 30.0             | 26,600                    |
| 5-47                   | 25.0             |                           |
| 5-46                   | 20.0             | 91,800                    |
| 5-49                   | 17.5             | 1,061,800                 |
| 5-50                   | 15.0             | 8,524,200                 |
| 5-51                   | 12.5             | 11,392,300 <sup>(A)</sup> |
| 1                      | <u>350 F</u>     |                           |
| 5-38                   | 40.0             | 6,100                     |
| 5-39                   | 30.0             | 15,400                    |
| 5-41                   | 25.0             | 43,800                    |
| 5-40                   | 20.0             | 128,400                   |
| 5-42                   | 17.5             | 243,600                   |
| 5-43                   | 15.0             | 509,000                   |
| 5-52                   | 12.5             | 4,744,700, 、              |
| 5-53                   | 10.0             | 13,384,100 <sup>(a)</sup> |
|                        |                  |                           |

(a) Did not fail.

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|                                      | тні     | s.Do | сù        | ME    | NT       | PROV                 | IDEC        | B        | Y TH                                    | IE .       | Авв                  | от | TA    | ERO      | SP          | AD                     | ΞE   |
|--------------------------------------|---------|------|-----------|-------|----------|----------------------|-------------|----------|---|------------|----------------------|----|-------|----------|-------------|------------------------|------|
| Creep kate,                          | percent | T    | 0 037     |       | 0.0004   | T /0000.0            |             | 0.055    | 0.0023 D                                | BB         | 0.00028              | AE |       | 6.002 dd | 0.00032     | 0.00008                |      |
| of Area,                             | percent | 22 4 |           | 4°07  | ł        | ł                    | 41.1        | 10.1     | 0.6                                     | <b>```</b> | 1                    |    | 27.0  | 54.5     | ł           | 1                      |      |
| in 2 in.,                            | percent | 0    | •         | 4.    | (1.315   | 0.770                | 12.6        | о<br>У   | ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ |            | <sup>)</sup> 0.655   |    | 8.2   | 14.1     | 0.397       | 0.255                  |      |
| Time,                                | hours   | c    |           | 11.8  | 1363.2%  | 1325.410             | 0.02        | *        | 222                                     |            | 1033.1 <sup>(b</sup> |    | 6.7   | 416.6    | 527.3(0     | 984 . 5 <sup>( b</sup> |      |
| Strain,                              | percent |      | - NT/ - 7 | 0.674 | 0.507    | 0.574                | 2.655       | 142 0    | 140.0                                   | 102.0      | . 0.274              |    | 0.274 | 0.141    | 0.118       | 0-056                  |      |
| Hours to Indicated treep betweeting, | 2.0     |      | ]         | 36    | ł        | ł                    | ł           | 00       | 276                                     | C7C        | 1                    |    | 5.4   | 352      | ł           | 1                      |      |
|                                      | 1.0     |      | ł         | Ц     | (B) 0061 | 1                    | ١           | ,<br>,   | L L                                     | C/7        | 3165 <sup>(a)</sup>  |    | 3.5   | 277      | 1           | ł                      |      |
|                                      | 0.5     |      | 1         | 3.1   | 1150     | 5650 <sup>(a)</sup>  | I           |          | n ç                                     | 180        | 1475 <sup>(a)</sup>  |    | 1.6   | 160      | 1200 (3)    |                        | }    |
|                                      | 0.2     |      | ł         | 0.50  | 8        | 1375                 |             | ,<br>  • | 1.0                                     | 62         | 410                  |    | 0.6   | \$       | 310         |                        | non  |
|                                      | 0.1     |      | 1         | 0.15  | 10       | 60                   |             | ;<br>  4 | 0.17                                    | 11         | 125                  |    | 0.2   | 12       | 105         |                        | 007  |
| Temper-<br>ature.                    | ц.      |      | 250       | =     | :        | =                    | 036         | 000      | : :                                     | :          | :                    |    | 500   | 005      | 3 =         | :                      | ;    |
| Stress.                              | ksi     |      | 60        | 50    | 46       | 64                   | c<br>L      | Ŋ,       | 42                                      | 35         | 25                   | 1  | 20    | 01       | v<br>v<br>v |                        | 4.7  |
| Cnerimen                             | Number  |      | 3-3       | 3-4   | ۲.<br>۲. | 5 80<br>5 80<br>5 80 | 6<br>7<br>6 | 3-10     | 3-12                                    | 9-6        | 3-2                  | )  | 3-7   |          | 4 v<br>5 c  |                        | 3-11 |

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(a) Estimate.

(b) Test discontinued.

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FIGURE 2. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR X2048-T851 PLATE (LONGITUDINAL)

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FIGURE 3. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR X2048-T051 PLATE (TRANSVERSE)

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FIGURE 4. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR X2048-T851 PLATE (LONGITUDINAL)

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FIGURE 6. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF X2048-T851 PLATE



FIGURE 7. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF X2048-T851 PLATE

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FIGURE 9. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K = 3.0) X2048-T851 PLATE (LONGITUDINAL)



#### 7050-173651 Aluminum Alloy

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#### Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used in this evaluation was 1-inch plate from Heat S-416420 produced within the following composition limits

| 2.0 to 2.8 |
|------------|
| 0.15 max   |
| 0.12 max   |
| 0.10 max   |
| 1.9 to 2,6 |
| 5.7 to 6.7 |
| 0.04 max   |
| 0.06 max   |
| Balance .  |
|            |

#### Processing and Heat Treating

The specimen layout is shown in Figure 11. Specimens were tested in the as-received -T73651 temper.

#### Test Results

<u>Tension</u>. Tast results for both longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table IX. Typical stress-strain curves at temperature are presented in Figures 12 and 13. Effectof-temperature curves are shown in Figure 16.

<u>Compression</u>. Test results for longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table X. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 14 and 15. Effect-of-temperature curves are shown in Figure 17.


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Shear. Results of pin-type shear tests for longitudinal and transverse specimens at room temperature are given in Table XI.

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Impact. Charpy V-notch test results for longitudinal and transverse specimens at room temperature are presented in Table XII.

Fracture Toughness. Results of slow-bend type tests in both the longitudinal (L-T) and transverse (T-L) directions are given in Table XIII. The candidate  $K_0$  values shown in the Table are considered valid  $K_{Ic}$  values by existing ASTM criteria.

Fatigue. Axial load fatigue test results at a stress ratio of R = 0.1are given in Tables XIV and XV for unnotched and notched transverse specimens. These tests were conducted at room temperature, 250 F, and 350 F. S-N curves are presented in Figures 18 and 19.

<u>Creep and Stress-Rupture</u>. Tests were conducted at 250 F, 350 F, and 500 F on transverse specimens. Tabular test results are given in Table XVI. Log-stress versus log-time curves are presented in Figure 20.

Stress Corrosion. Tests were performed as described in the experimental procodures section of this report. No failures or cracks occurred in the 1000 hour test duration.

<u>Thermal Expansion</u>. The coefficient of thermal expansion for this alloy is  $12.8 \times 10^{-8}$  in./in./F from 68 F to 212 F.

Density. The density of this material is 0.102 lb./in.<sup>3</sup>.

# TARLE IX. TENSION TEST RESULTS FOR 7050-T73651 ALUMINUM ALLOY PLATE

| Specimen<br>Number | Ul<br>T<br>St | ltimate<br>ensile<br>rength,<br>ksi | 0,2 Percent<br>Offset Yield<br>Strength,<br>ksi | Elongation<br>in 2 Luchos,<br>percent | Reduction<br>in Area,<br>percent | Tensile<br>Modulus,<br>10 <sup>5</sup> psi |
|--------------------|---------------|-------------------------------------|---|---------------------------------------|----------------------------------|--|
| •                  |               | Ŀ                                   | ongitudinal at Roo                              | om Temperature                        |                                  |  |
| 1L-1               |               | 82.1                                | 73.4  | 12.0                                  | 30.8                             | 10.3                                       |
| 1L-2               |               | 82.9                                | 74.0  | 12.0                                  | 30.0                             | 10,4                                       |
| 1L-3               | Average       | 82.8                                | 73.9<br>73.8                                    | $\frac{11.5}{11.8}$                   | <u>29.9</u><br>30.2              | $\frac{10.1}{10.3}$                        |
|                    |               |                                     | Transverse at Room                              | m Temperaturo                         | andara tana                      |  |
| 1T-1               |               | 81.4                                | 72.4  | 10.0                                  | 23,3                             | 10.6                                       |
| 17-2               | ·             | 81.4                                | 72.7  | 10,5                                  | 25.2                             | 10,5                                       |
| 1T-3               |               | 81.7                                | 72.6  | 11,0                                  | 24.9                             | 10.4                                       |
|                    | Average       | 81.5                                | 72.5  | 10.5                                  | 24.5                             | 10.5                                       |
|                    |               |                                     | Longitudinal                                    | at 250 F                              | • -                              |  |
| 1L-4               | ·             | 65.1                                | 65.0  | 15.5                                  | 47.6                             | 9.3  |
| 1L-5               |               | 64.8                                | 64.8  | 15.5                                  | 48.2                             | .9.4                                       |
| 1 <b>L-6</b>       | Average       | 65.2<br>65.0                        | <u>65.2</u><br>64.9                             | <u>15.5</u><br>15.5                   | 48.5<br>48.1                     | 9.5  |
|                    | -             |                                     | Transverse                                      | at 250 F                              |                                  |  |
| 1T-4               |               | 64.4                                | 63.8  | 13.5                                  | 39,1                             | 9.3  |
| 1T-5               |               | 64.6                                | 64.2  | 13.5                                  | 40.3                             | 10.1                                       |
| 17-6               | Average       | <u>64.5</u><br>64.5                 | $\frac{64.2}{64.1}$                             | $\frac{13.0}{13.3}$                   | $\frac{36.8}{38.3}$              | <u>9.7</u><br>9.7                          |
|                    |               |                                     | Longitudinal                                    | at 350 F                              |                                  |  |
| 1L-7               |               | 52.7                                | 52.3  | 17.0                                  | 58.8                             | 8.8  |
| 1L-8               |               | 54.6                                | 54.4  | 16.5                                  | 57.2                             | 8.4  |
| 1L-9               |               | 54.0                                | 54.0  | 17.0                                  | 58.3                             | 8.9  |
|                    | Average       | 53.7                                | 53.5  | 16.8                                  | 58,1                             | 8.7  |
| ·                  |               |                                     | Transverse                                      | at 350 F                              |                                  |  |
| 1T-7               |               | 53.0                                | 52.8  | 14.5                                  | 48.8                             | 3.9  |
| 1 <b>T</b> -8      |               | 50.2                                | 52.8  | 15.0                                  | 47.5                             | 8.1  |
| 1 <b>T-9</b>       | Average       | 54.3                                | <u>54.3</u><br>53.3                             | $\frac{14.5}{14.7}$                   | 47.8                             | <u>9.1</u><br>8.7                          |
|                    | ·· · : : ·    |                                     | Longitudinal                                    | at 500 F                              |                                  |  |
| 1L-10              |               | 21.6                                | 21.2  | 25.0                                  | 80.3                             | 8.4  |
| 1L-11              |               | 22.2                                | 21.8  | 22.0                                  | 79.8                             | 8.1  |
| 1L-12              |               | 19.9                                | 19.7  | 24.5                                  | 83.0                             | 8.7  |
| ••                 | Average       | 21.2                                | 20.9  | 23.8<br>at 500 4                      | 81.0                             | 8.4  |
|                    |               | •• •                                | ITANSVETSE                                      |                                       |                                  |  |
| 11-10              |               | 19.9                                | 19.7  | 23.0                                  | 80.8                             | 8,5  |
| 1T-11              |               | 23,5                                | 23.5  | 22.5                                  | 13,4                             | 8.0  |
| 1T=12              | A             | 19.4                                | 19.4  | 23.U<br>ठेठा ह                        | 303,2                            | <u>0.8</u>                                 |
|                    | AVETAge       | 20.9                                | 20.8  | 23.5                                  | 13.0                             | 0./  |

#### TABLE X. COMPRESSION TEST RESULTS FOR 7050-173611 ALUMINUM ALLOY PLATE

| Specimen<br>Number | 0<br>0f<br>Su1 | .2 Percent<br>fsot Yield<br>rength, ksi | Compressive<br>Nodulus,<br>10 <sup>4</sup> psi |
|--------------------|----------------|---|--|
|                    | Longitudin     | al at Room Temper                       | ature  |
| 2L-1               |                | 73.1                                    | 10.8   |
| 2L-2               |                | 73.3                                    | 10,8   |
| 2L-3               | Average        | $\frac{72.7}{73.0}$                     | $\frac{10.8}{10.8}$                            |
|                    | Transverse     | at Room Tempora                         | turo   |
| 2T-1               |                | 75 4                                    | 11.2   |
| 2T-2               |                | 75.2                                    | 10.9   |
| 2T-3               | 1              | 75.2                                    | 11.0   |
|                    | Average        | 75.3                                    | 11.0   |
|                    | Long           | itudinal at 250 F                       |  |
| 2L-4               |                | 64.4                                    | 9.5  |
| 2L-5               | 19 (Fr. 19)    | 64.8                                    | 9.6  |
| 2L-6               |                | <u>63.7</u>                             | 9,4  |
|                    | Average        | 64.3                                    | <b>9</b> , 5                                   |
|                    | Trai           | nsverse at 250 F                        |  |
| 2T-4               |                | 66.4                                    | 10.0   |
| 2T <b>-5</b>       |                | 66.1                                    | 9.9  |
| 21-6               |                | 65.7                                    | 10,1   |
|                    | Average        | 66,1                                    | 10.0   |
|                    | Long           | itudinal at 350 F                       | •  |
| 2L-7               |                | . 54.2                                  | 9.0  |
| 2L-8               |                | 54.7                                    | 9.C  |
| 26-9               | Aurana         | 52.1                                    | 9,1  |
|                    | Average        |   | 2,1  |
|                    | Tra            | neverse at 350 F                        |  |
| 2T-7               |                | 54.8                                    | 9.4  |
| 2T-8               |                | 54.8                                    | 9.6  |
| 21-9               | Average        | 55.1                                    | 9.3  |
|                    | Lone           | ftudinal at 500 F                       |  |
|                    | Long           |   | O 6  |
| 21-10              |                | 20.1<br>91 9                            | 0.J<br>7 Q                                     |
| 2L-12              |                | 21.3                                    | 7.8  |
|                    | Average        | 20.9                                    | 8.1  |
|                    | Tra            | nsverse at 500 F                        |  |
| 2T <b>-10</b>      |                | 22.6                                    | 8.2  |
| 2T-11              |                | 21.0                                    | 7,9  |
| 21-12              |                | 22.5                                    | 8.0  |
|                    | Average        | 22.0                                    | 8.0  |

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## TABLE XI. SHEAR TEST RESULTS FOR 7050-T73651 ALUMINUM ALLOY PLATE AT ROOM TEMPERATURE

| Specimen<br>Number           |              | Ultimate Shear<br>Strength, ksi                    |
|------------------------------|--------------|--|
| -                            | Longitudinal |  |
| 4L-1<br>4L-2<br>4L-3<br>4I4  | Ave          | 46.8<br>46.5<br>50.2<br><u>51.3</u><br>rage ' 48.7 |
|                              | Transverse   |  |
| 4T-1<br>4T-2<br>4T-3<br>4T-4 | Ave          | 47.5<br>41.9<br>48.2<br>4 <u>3.3</u><br>47.9       |

## TABLE XII. IMPACT TEST RESULTS FOR 7050-T73651 ALUMINUM ALLOY PLATE AT ROOM TEMPERATURE

in.

| Specimen<br>Number |       |         |         | Energy,<br>ft. 1bs, |
|--------------------|-------|---------|---------|---------------------|
|                    | Longi | cudinal |         |                     |
| 10L-1              |       |         | . '     | 26.5                |
| 10L-2              |       |         | 1       | 44.0                |
| 10L-3              |       |         |         | 29.0                |
| 10L-4              |       |         | :<br>•  | 57.0                |
| 10L-5              |       | • •     | ,       | 22.0                |
| 19L-6              |       |         | •       | 30.0                |
|                    |       |         | Average | 34.7                |
|                    | Trar  | sverse  | ,       | •                   |
| 10T-1              | -     |         | X       | 6.0                 |
| 10T-2              |       |         | 1.1     | 6.0                 |
| 10T-3              |       |         |         | 5.5                 |
| 10T-4              |       |         | · .     | 6.0                 |
| 10 <b>T</b> -5     |       |         |         | 5.5                 |
| 10T-6              | . 1 . |         |         | 5.0                 |
|                    |       |         | Average | 5.7                 |

| Specimen<br>Number    | w,<br>inches | a,<br>inches | T,<br>inches | P,<br>1bs.   | Span,<br>inches | $f(\frac{a}{w})$ | K <sub>Q</sub> (a) |
|-----------------------|--------------|--------------|--------------|--------------|-----------------|------------------|--------------------|
|                       |              | L            | ongitudinal  | (L-T)        |                 |                  |                    |
| 6-1L                  | 2.00         | 1.00         | 1.00         | 5,000        | 8.0             | 2.664            | 37,68              |
| 6 - 2L                | 2.00         | 0,990        | 1.00         | 5,100        | 8.0             | 2.622            | 37,83              |
| :6 <b>-3L</b>         | 2.00         | 0.992        | 1.00         | 4,950        | 8.0             | 2.622            | 36.35              |
| 6-4L                  | 2.00         | 1.01         | 1.00         | 5,100        | 8.0             | 2.708            | 39.07              |
| 6-5L                  | 2.00         | 1.00         | 1.00         | 5,000        | 8.0             | 2.664            | 37.68              |
| 6-6L                  | 2.00         | 0.964        | 1.00         | 5,190        | 8.0             | 2,508            | 36.90              |
| · · ·                 |              | ·            |              |              |                 | Average          | 37.68              |
|                       |              |              | (Transverse  | (T-L)        |                 |                  |                    |
| 6-1T                  | 2.00         | 0,963        | 1.00         | 5.200        | 8.0             | 2.510            | 36.90              |
| 6-2T                  | 2.00         | 0.963        | 1.00         | 5,200        | 8.0             | 2.510            | 36.90              |
| 6-3T                  | 2.00         | 1.00         | 1.00         | 5,000        | 8.0             | 2,663            | 37.70              |
| ··· 6.4T              | 2.00         | 0.997        | 1.00         | 4,900        | 8.0             | 2,652            | 36.75              |
| 6-5T                  | 2.00         | 0.990        | 1.00         | 4,900        | 8.0             | 2,623            | 36.30              |
| 6-6T                  | 2.00         | 0.978        | 1.00         | 5,200        | 8.0             | 2,573            | 37.80              |
| n<br>Nagata<br>Nagata |              |              | 14           | <sup>.</sup> |                 | Ave rage         | 36.99              |

# TABLE XIII.RESULTS OF SLOW-BEND TYPE FRACTURE TOUGHNESSTESTS FOR 7050-T73651ALUMINUM ALLOY PLATE

(a) These candidate K values do meet existing ASTM size and crack length criteria and are considered valid K Ic numbers.

| Specimen<br>Number | Maximum<br>Streas, kai | Lifetime,<br>cycles       |
|--------------------|------------------------|---------------------------|
|                    | Room Temperature       |                           |
| 5-7                | 60.0                   | 11,580                    |
| 5-6                | 50.0                   | 46,700                    |
| 5-5                | 46.0                   | 55.420                    |
| 5-1                | 40.0                   | 84,500                    |
| 5-3                | 37.5                   | 296,600                   |
| 5-2                | 35.0                   | 4,527,400                 |
| 5-4                | 30.0                   | 12,500,000 (a)            |
|                    | <u>250 F</u>           |                           |
| 5-16               | 60.0                   | 9,390                     |
| 5-14               | 50.0                   | 21,680                    |
| 5-13               | 45.0                   | 29,390                    |
| 5-9                | 40.0                   | 77,100                    |
| 5-10               | 37.5                   | 133,200                   |
| 5-11               | 35.0                   | 99,900                    |
| 5-25               | 32.5                   | <b>1,086,4</b> 00         |
| 5-8                | 30,0                   | 363,800                   |
| 5-15               | 25.0                   | 443,400                   |
| 5-22               | 20.0                   | 10,151,300 <sup>(</sup>   |
|                    | <u>350 F</u>           | · · · ·                   |
| 5-17               | 60.0                   | 220                       |
| 5-19               | 50.0                   | 26,350                    |
| 5-20               | 45.0                   | <b>60,4</b> 60            |
| 5-18               | 40.0                   | <b>83,69</b> 0            |
| 5-21               | 35.0                   | <b>88,99</b> 0            |
| 5-23               | 30.0                   | 401,600                   |
| 5-24               | 25.0                   | 10,604,650 <sup>(a)</sup> |

# TABLE XIV.AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED7050-T73651ALUMINUM PLATE (TRANSVERSE)

(a) Did not fail.

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TABLE XV. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K<sub>E</sub>=3.0) 7050-T73651 ALUMINUM PLATE (TRANSVERSE)

| Specimen<br>Number | Maxii um<br>Stress, ksi | Lifetime,<br>cycles       |
|--------------------|-------------------------|---------------------------|
|                    | Room Temperature        |                           |
| 5-32               | 37.5                    | 11,500                    |
| 5-31               | 35.0                    | 15,600                    |
| 5-33               | 32.5                    | 14,800                    |
| 5-34               | 30.0                    | 21,900                    |
| 5-36               | 27.5                    | 25,400                    |
| 5-35               | 25.0                    | 42,200                    |
| 5-37               | 20.0                    | 70,800                    |
| 5-38               | 15.0                    | 363,800                   |
| 5-39               | 10.0                    | 10,480,000 <sup>(a)</sup> |
|                    | <u>250 F</u>            |                           |
| 5-40               | 37.5                    | 7,200                     |
| 5-41               | 35.0                    | 13,000                    |
| 5-42               | 32.5                    | 14,400                    |
| 5-43               | 30.0                    | 17,100                    |
| 5-44               | 25.0                    | 36,900                    |
| 5-46               | 20.0                    | 127,300                   |
| 5 - 45             | 15.0                    | 293,600                   |
| 5-47               | 10.0                    | 10,000,480 <sup>(a)</sup> |
|                    | <u>350 F</u>            |                           |
| 5-48               | 37.5                    | 3,670                     |
| 5-49               | 35.0                    | 8,190                     |
| 5-50               | 32.5                    | 43,510                    |
| 5-51               | 30.0                    | 42,450                    |
| 5-52               | 25.0                    | 87,300                    |
| 5-53               | 20.0                    | 89,950                    |
| 5-54               | 15.0                    | 521,300                   |
| 5 - 55             | 10.0                    | 12,237,900 <sup>(a)</sup> |

(a) Did not fail.

TABLE XVI. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 7050 ALIMINUM PLATE (TRAUSVERSE)

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| , and a second se | 0<br>0<br>0<br>0 | Temper- | Hours | to Indica           | ted Creep<br>arcent | De format            | ion         | Initia]<br>Strain | Rupture<br>Time        | Elongation<br>in 2<br>Faches | Reduction<br>of Area | Minimum<br>Creep<br>Rare |
|---|------------------|---------|-------|---------------------|---------------------|----------------------|-------------|-------------------|------------------------|------------------------------|----------------------|--------------------------|
| Number  | ksi.             | arare,  | 0.1   | 0.2                 | 0.5                 | 1.0                  | 2.0         | percent.          | hours                  | parcent                      | percent              | percent                  |
| 3-10  | 60               | 250     | 0.04  | 0.07                | 0.18                | 0.38                 | 0.85        | 0.803             | 3.9                    | 13.2                         | 43.2                 | I.35                     |
| 3-1   | 50               | 250     | 30    | 70                  | 195                 | 305,2,               | <i>±</i> 15 | 0.553             | 472.5                  | 9.9                          | 46.1                 | 0.0125                   |
| 3-11  | 5 <del>1</del>   | 250     | 15    | 110,                | 605 , , ,           | 600 <sup>( g )</sup> | ł           | 0.504             | 576.1.5                | 0.993                        | 1                    | 0.00053                  |
| 3-13  | 35               | 250     | 425   | 2700 <sup>(a)</sup> | 8700 <sup>(a)</sup> | ł                    | :           | 0.315             | 1007.3                 | Q.432                        | 1                    | 0-00005 H                |
| 3-4   | 45               | 350     | 0.02  | 0.03                | 0.07                | 0.13                 | 0.22        | 0.603             | 0.4                    | 16.7                         | \$0.5                |                          |
| 2 3-10<br>2 3-10  | 32               | 350     | 1.5   | 3.8                 | 6.9                 | 10                   | !           | 0.405             | 13.0                   | .t.<br>.t                    | 62.5                 |                          |
| 3-2   | сі<br>С          | 350     | 11    | 64                  | 103                 | 133                  | 145         | 0.306             | 1.55.1                 |                              | 70.4                 | 0.003 %                  |
| 3-8   | 20               | 359     | 35    | 30                  | 305                 | 420                  | 065         | 0.315             | 502.7 /F               | 21.2                         | 75.9                 | 0.001 10                 |
| 3-12  | 12               | 350     | 675   | 1600 <sup>(a)</sup> | 4800 <sup>(a)</sup> | ł                    | ;           | 0.156             | 1028.9                 | 0.317                        | ł                    | C.000095                 |
| 3 <b>-</b> 5  | 12               | 500     | 10'0  | 0.02                | 0.06                | 0.1                  | 0.19        | 0.303             | <b>0.</b> 4            | 25.0                         | 89.5                 | IB<br>ERO<br>0.01        |
| 3-7   | 6                | 500     | e     | 8.5                 | 14.3                | 23.6                 | 29.5        | 0.155             | 37.7                   | · · · 5                      | 87.6                 | R P 780 0                |
| 3-3   | 7                | 500     | 9     | 15                  | 40                  | 70                   | 101         | C.121             | 139.9                  | 30°                          | 91.2                 | A 110.0                  |
| 3-14  | Ś                | 500     | 10    | 40                  | 220                 | 525,2                | 2:5         | 0.102             | 1126.9 <sub>/b</sub> ) | 36.5                         | 91.0                 | R 100 0                  |
| 3-9   | 4                | 500     | 25    | 320                 | 910                 | 1550'a'              | ł           | 0.645             | 1148.0                 | C.720                        | 1                    | Y 15000.0                |
|   |                  |         |       |                     |                     |                      |             |                   |                        |                              |                      |                          |

(a) Estimated.

(b) Test discontinued.

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FIGURE 12. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (LONGITUDINAL)

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FICURE 13. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (TRANSVERSE)

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FIGURE 14. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (LONGITUDINAL)

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FIGURE 15. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (TRANSVERSE)

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FIGURE 16. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T73651 PLATE



FIGURE 17. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T73651 PLATE







FIGURE 19. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K = 3.0) 7050-T73651 PLATE (TRANSVERSE)



#### 21-6-9 Stainless Steel Alloy

#### Material Description

Alloy 21-6-9 is a recent development of the Armco Steel Corporation. It is an austenitic stainless steel, combining high yield strength with good corrosion resistance. The room temperature yield strength of 21-6-9 is superior to Types 304, 321, and 347. It has good elevated temperature properties and retains high strength and toughness at subzero temperatures.

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Armco 21-6-9 stainless steel is available in standard finishes in annealed or high tensile temper sheet and strip as well as in bar, wire, forging billets, and plate.

The materials used in this evaluation was an 0.072-inch thick sheet produced within the following composition limits

| Carbon     | 0.08 max      |
|------------|---------------|
| Manganese  | 8.00 - 10.00  |
| Phosphorus | 0.060 max     |
| Sulfur     | 0.030 max     |
| Silicon    | 1.00 max      |
| Chromium   | 19.00 - 21.50 |
| Nickel     | 5.50 - 7.50   |
| Nitrogen   | 0.15 - 0.40   |
| Iron       | Balance       |

#### Processing and Heat Treating

The specimen layout is shown in Figure 21. The alloy was evaluated in the as-received annealed condition.

#### Test Results

Tension. Results of tests on longitudinal and transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XVII. Typical stress-strain curves at temperature are presented in Figures 22 and 23. Effectof-temperature curves are shown in Figure 26.

<u>Compression</u>. Test results for longitudinal and transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XVIII. Typical





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FIGURE 21. SPECTOEN LAYOUT FOR 21-6-9 ANDEALED SHEET

compressive stress-strain and tangent-modulus curves at temperature are presented in Figures 24 and 25. Effect-of-temperature curves are presented in Figure 17.

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Shear. Results of sheet-shear type tests for longitudinal and transverse specimens at room temperature are given in Table XIX.

Bend. The minimum bend radius for this material was 1T.

Fracture Toughness. Tests were conducted on transverse (T-L) specimens of full-sheet thickness  $(0.072 \text{-inch}) \times 18$  inches x 3C inches with an EDM flaw in the center. The net section yield stress at fracture was greater than the tensile yield strength of the material; therefore, the K values obtained are considered invalid.

<u>Fatigue</u>. Axial-1 ad test results for transverse specimens at a stress ratio of R = 0.1 are given in Tables XX and XXI. These tests were performed on both unnotched and notched specimens at room temperature, 400 F, and 700 F. S-N curves are presented in Figures 28 and 29.

<u>Creep and Scress Rupture</u>. Tests were conducted for transverse specimens at 400 F, 700 F, and 900 F. Tabular test results are given in Table XXII. Log-stress versus log-time curves are presented in Figure 30.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No cracks or fractures occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of expansion for this alloy is  $10.6 \times 10^{-8}$  in./in./F from 80 F to 1000 F.

Density. The density of this material is 0.283 lb./in.<sup>3</sup>.

#### TABLE XVII, TENSILE TEST RESULTS FOR ANNEALED 21-6-9 STAINLESS STEEL SHEET

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| Specimen<br>Number | Ulti<br>Str | mate Tensile<br>ength, ksi | 0.2 Percent<br>Offset Yield<br>Strength, ksi | Elongation<br>in 2 Inches,<br>percent | Tensile<br>Modulus,<br>10 <sup>6</sup> psi |
|--------------------|-------------|----------------------------|--|---------------------------------------|--|
|                    |             | Longitudin                 | al at Room Temperat                          | ure                                   |  |
| 1 <b>L-</b> 1      |             | 113.0                      | 64.3   | 54.0                                  | 26.7                                       |
| 1L-2               |             | 113.0                      | 65.0   | 54.5                                  | 26.6                                       |
| 1L-3               |             | 113.0                      | 65.1   | 56.5                                  | 26.4                                       |
|                    | Average     | 113.0                      | 64.8   | 55.0                                  | 26.6                                       |
|                    |             | Transvers                  | e at Room Temperatu                          | ire                                   |  |
| 1T-1               |             | 114.0                      | 65.3   | 50.0                                  | 28.6                                       |
| 1T-2               |             | 113,0                      | 66.3   | 50.0                                  | 28,2                                       |
| 1T-3               |             | 113,0                      | 66.0   | 50.0                                  | 28.4                                       |
|                    | Average     | 113,3                      | 65.7   | 50.0                                  | 28.4                                       |
|                    |             | Long                       | itudinal at 400 F                            |                                       |  |
| 1L-4               |             | 88.4                       | 42.3   | 44.0                                  | 21.2                                       |
| 1L-5               |             | 87,6                       | 42.6   | 43.0                                  | 21.8                                       |
| 1L-6               |             | 98.4                       | 42.6   | 43.5                                  | 20.2                                       |
|                    | Average     | 88.1                       | 42.5   | 43.5                                  | $\frac{1}{21.1}$                           |
|                    | 2           | Tra                        | nsverse at 400 F                             |                                       |  |
| 1T-4               | 1 1         | 88.4                       | 42.7   | 42.0                                  | 19.9                                       |
| 1T-5               |             | 88.4                       | 42.5   | 42.0                                  | 20.5                                       |
| 1T-6               |             | 88.4                       | 43.0   | 42.0                                  | 19.3                                       |
|                    | Average     | 88.4                       | 42.7   | 42.0                                  | 19.9                                       |
|                    |             | Long                       | itudinal at 700 F                            |                                       |  |
| 1L-7               |             | 84.2                       | 35.9   | 46.0                                  | 24.8                                       |
| 1L-S               |             | 83.5                       | 35.9   | 45.5                                  | 18.3                                       |
| 1L-9               |             | 83.5                       | 35.9   | 45,5                                  | 22.0                                       |
|                    | Average     | 83.7                       | 35.9   | 45.7                                  | 21.7                                       |
|                    |             | Tre                        | insverse at 700 F                            |                                       |  |
| 1 <b>T-</b> 7      |             | 82.8                       | 35.8   | 41.5                                  | 19.4                                       |
| 11-8               |             | 83,4                       | 35.9   | 42.0                                  | 18.4                                       |
| 1 <b>T</b> -9      |             | 83,5                       | 36.0   | 42.0                                  | 17.4                                       |
|                    | Average     | 83.2                       | 35.9   | 41.8                                  | 18,4                                       |
|                    |             | Long                       | itudinal at 900 F                            |                                       |  |
| 1L-10              |             | 76.0                       | 33.0   | 43.0                                  | 20.4                                       |
| 1L-11              |             | 76.6                       | 33.2   | 43.0                                  | 16.9                                       |
| 1L-12              |             | 75.7                       | 32.9   | 43.0                                  | 20.2                                       |
|                    | Average     | 76.1                       | 33.0   | 43.0                                  | 19.2                                       |
|                    |             | Tre                        | insverse at 900 F                            |                                       |  |
| 1T-10              |             | 76.4                       | 33.3   | 41.5                                  | 15.9                                       |
| 1T-11              |             | 76.6                       | 33.3   | 41,0                                  | 17.6                                       |
| 1 <b>T-</b> 12     |             | 76.6                       | 33.0   | 41.5                                  | 15.4                                       |
|                    | Average     | 76.5                       | 33.2   | 41.3                                  | 16.3                                       |

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| TABLE XVIII. | COMPRESSION TEST | RESULTS FOR | ANNEALED |
|--------------|------------------|-------------|----------|
|              | 21-6-9 STAINLESS | STEEL SHEET |          |

| Specimen<br>Number                           | 0<br>0<br>5 נ | ),2 Percent<br>ffset Yield<br>rength, ksi  | Compression<br>Modulus,<br>10'psi   |
|--|---------------|--|-------------------------------------|
|  | Longitudin    | al at Room Temper                          | sture                               |
| 2L-1<br>2L-2<br>2L-3                         | Average       | 67.2<br>67.2<br><u>67.2</u><br><u>67.2</u> | 29.3<br>28.6<br>27.8<br>28.5        |
|  | Transvers     | e at Room Tempera                          | ture                                |
| 2 <b>T-1</b><br>2 <b>T-2</b><br>2 <b>T-3</b> | Average       | 66.3<br>66.5<br>66.8<br>66.5               | 29.1<br>29.0<br>29.0<br>29.0        |
|  | Long          | itudinal at 400 F                          |                                     |
| 2L-4<br>2L-5<br>2L-6                         | Average       | 44.4<br>45.6<br>45.4<br>45.1               | 26.2<br>27.4<br>26.6<br>26.7        |
|  | Tre           | insverse at 400 F                          |                                     |
| 2T-4<br>2T-5<br>2T-6                         | Average       | 47.0<br>46.7<br>45.3<br>46.3               | 29.3<br>29.0<br>28.0<br>28.8        |
|  | Long          | itudinal at 700 F                          | -                                   |
| 2L=7<br>2L=8<br>2L=9                         | Average       | 40.2<br>39.9<br>4 <u>1.4</u><br>40.5       | 25.8<br>25.3<br><u>26.4</u><br>25.8 |
|  | Tre           | insverse at 700 F                          |                                     |
| 2T-7<br>2T-8<br>2T-9                         | Average       | 38.3<br>37.2<br><u>38.3</u><br>37.9        | 27.7<br>25.5<br><u>26.4</u><br>26.5 |
|  | Long          | gitudinal at 900 H                         |                                     |
| 2L-10<br>2L-11<br>2L-12                      | Average       | 25.3<br>34.8<br>33.8<br>34.7               | 25.8<br>26.1<br>24 <u>1</u><br>25.3 |
|  | Tra           | ansverse at 900 F                          |                                     |
| 2T-10<br>2T-11<br>2T-12                      | Average       | 34.0<br>34.1<br>34.1<br>34.1               | 26,1<br>25,8<br>25,2<br>25,7        |

# TABLE XIX.SHEAR TEST RESULTS FOR ANNEALED21-6-9STAINLESS STEEL SHEETAT ROOM TEMPERATURE

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| Specimen<br>Number | Ultimato Shea<br>Strength, ka |
|--------------------|-------------------------------|
| Lor                | gitudinal                     |
| 4L-1               | 101.0                         |
| 4L-2               | 102.0                         |
| 4L-3               | 103.0                         |
| 4L-4               | 103.0                         |
|                    | Average 102.3                 |
| <u>T1</u>          | ansverse                      |
| 4T-1               | 102.0                         |
| 4T-2               | 102.0                         |
| 4T-3               | 104.0                         |
| 4T-4               | 103.0                         |
|                    | Average 102.8                 |

 TABLE XX.
 AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED 21-6-9

 ANNEALED STAINLESS STEEL SHEET (TRANSVERSE)

| Specimen<br>Number |          | Maximum<br>Stress, ksi | Lifetime,<br>cycles       |
|--------------------|----------|------------------------|---------------------------|
|                    |          | Room Temperature       |                           |
| 5-5                |          | 105.0                  | 3,500                     |
| 5-4                |          | 100.0                  | 43,500                    |
| 5-3                |          | 95.0                   | 83,500                    |
| 5-2                |          | 90.0                   | 153,300                   |
| 5-1                |          | 85.0                   | 294,600                   |
| 5-6                |          | 80.0                   | 344,900                   |
| 5-7                |          | 75.0                   | 206,000                   |
| 5-8                |          | 65.0                   | 10,000,000                |
|                    |          | <u>400 F</u>           |                           |
| 5-9                | -        | 100.0                  | (b)                       |
| 5-14               |          | 90.0                   | 200                       |
| 5-10               |          | 90.0                   | 500                       |
| 5-16               |          | 87.5                   | 122,700                   |
| 5-13               |          | 85.0                   | 63,600                    |
| 5-17               |          | 82.5                   | 153,300                   |
| 5-12               |          | 80.0                   | 110,500                   |
| 5-18               |          | 77.5                   | 258,400                   |
| 5-15               |          | 75.0                   | 10,167,000 <sup>(</sup>   |
| •                  |          | <u>700 F</u>           |                           |
| 5-19               |          | 85.0                   | (b)                       |
| 5-21               | . · ·    | 80.0                   | 600                       |
| 5-20               | · · · ·  | 75.0                   | 3,399,200                 |
| 5-24               |          | 72.5                   | 4,821,600                 |
| 5-22               |          | 70.0                   | 140,400                   |
| 5+25               | с.<br>19 | 70.0                   | 4,842,000                 |
|                    | .}       | 65.0                   | 10,029,000 <sup>(a)</sup> |

(a) Did not fail.

(b) Failed on first cycle.

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| TABLE XXI | AXIAL LOAD FAT | TIGUE TEST RESULTS | FOR NOTCHED $(K_{+}=3,0)$ |
|-----------|----------------|--------------------|---------------------------|
|           | 21-6-9 ANNEALI | ED STAINLESS STEEL | SHEET (TRANSVERSE)        |

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| Specimen<br>Number | Maximum<br>Stress, ksi | Lifetime,<br>cycles      |
|--------------------|------------------------|--------------------------|
|                    | Room Temperature       |                          |
| 5-11               | 75.0                   | 12,240                   |
| 5-4                | 70.0                   | 38,380                   |
| 5-5                | 65.0                   | 74,510                   |
| 5-3                | 60.0                   | 97,190                   |
| 5-14               | 55.0                   | 186,620                  |
| 5-6                | 50,0                   | 1,757,000                |
| 5-30               | 40.0                   | 10,744,400 <sup>(±</sup> |
| - 1                | <u>400 F</u>           |                          |
| 5-13               | 75.0                   | 10,300                   |
| 5-31               | 70.0                   | 11,200                   |
| 5-22               | 65.0                   | 14,000                   |
| 5-21               | 55.0                   | 26,900                   |
| 5-20               | 45.0                   | 84,400                   |
| 5-32               | 40.0                   | 204,600                  |
| 5-17               | 35.0                   | 10,589,500 <sup>(a</sup> |
|                    | 700 F                  |                          |
| 5-29               | 75.0                   | 3,300                    |
| 5-28               | 65.0                   | 11,400                   |
| 5-24               | 55.0                   | 27,200                   |
| 5-19               | 50.0                   | 116,300                  |
| 5-26               | 45.0                   | 144', 200                |
| 5-18               | 40.0                   | 143,700                  |
| 5-24               | 35.0                   | 10,519,200 (*            |

(a) Did not fail.

TABLE XXII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 21-6-9 STAINLESS STEEL SHEET (TRANSVERSE)

| Specimen | Stress, | Temper-<br>ature, |      | Hours to Ind          | licated Cree<br>percent | ep Deformati         | on,           | Initial<br>Strain. | Rupture<br>Time.       | Elongation<br>In 2 Inches. | Creep<br>Rate |
|----------|---------|-------------------|------|-----------------------|-------------------------|----------------------|---------------|--------------------|------------------------|----------------------------|---------------|
| Number   | ksi     | ы                 | 0.1  | 0.2                   | 0.5                     | 1.0                  | 2.0           | percent            | hours                  | percent                    | percent       |
| 3-1      | 88      | 500               | 1    | :                     | :                       | :                    | :             | ;                  | On Loading             | 41.3                       |               |
| 3-4      | 83      | 500               | 0.01 | 0.20                  | 0.45                    | 19                   | $1,500^{(a)}$ | 26.68              | 841.4 (b) <sup>o</sup> | 28.4                       | 0.0005        |
| 3-7      | 70      | 500               | 0.10 | 0.35                  | 5.0                     | 85, _,               |               | 13.220             | 169.9 <sup>(1)</sup>   | 14.42                      |               |
| 3-9      | 40      | 500               | 5.0  | 70, 2)                | 1,455                   | 4,800 <sup>(a)</sup> | ł             | 0.826              | 650.1 <sup>(D)</sup>   | 1.355                      | 0.0001        |
| 3-12     | 35      | 500               | :    | 3,000 <sup>( d)</sup> | ł                       |                      | •             | 0.229              | 715.1 <sup>( D)</sup>  | 0.251                      | 3F            |
| ر<br>د   | 70      | 50                |      |                       |                         |                      |               |                    |                        |                            | 1 F           |
| 7-0      |         | 8                 | 1    | ;                     | :                       | :                    | •             |                    | On LOADING             | 43.1                       | <b>V</b>      |
| 3-S      | 80      | 700               | :    | :                     | 1                       | ;                    | ;             | 28.24              | 813.4/2                | 31.1                       | 0.00007       |
| 3-8      | 50      | 200               | ;    | 0.05                  | 0.3                     | 7.0                  | :             | 4.920              | 309.7 <sup>(b)</sup>   | 5.990                      | 0.00002       |
| 51-C 4   | 40      | 700               | :    | 0.10                  | 10,                     | >1,000               | :             | 1.452              | 498.6 <sup>(D)</sup>   | 2.050                      |               |
| 3-14     | 35      | 700               | 0.20 | 0*0                   | 5,000 <sup>(3)</sup>    | . :                  | ;             | 0.314              | 120.7(5)               | 1.051                      | L<br>звс      |
| 3-11     | 30      | 700               | :    | 10,000 <sup>(a)</sup> | :                       | :                    | :             | 0.180              | 268.5 <sup>( D)</sup>  | 0.218                      | L<br>DTTA     |
| 3-3      | 76.5    | <b>006</b>        | :    | :                     | :                       |                      | :             | :                  | On Loading             | 42.2                       |               |
| 3-10     | 70      | 006               | ;    | ;                     | ;                       | :                    | ł             | 20.852             | 438.9                  | 27.6                       | R<br>SP       |
| 3-6      | 65      | <b>006</b>        | :    | ;                     | 1                       | •                    | :             | 10.8               | 753.7,                 | 20.9                       | 0.0006 >      |
| 3-17     | 35      | 006               | ;    | 0.10                  | >1,000                  | ;                    | :             | 1.260              | 480.0                  | 1.475                      | E.C           |
| 3-16     | 30      | 006               | ł    | $5,000^{(a)}$         | :                       | 1                    | :             | 0.198              | 738.5                  | 0.222                      |               |
| 3-13     | 22      | 900               | :    | 1                     | ł                       | :                    | :             | 0.162              | 289.4                  | 0.167                      | и-<br>•       |

(a) Estimate.

(b) Test discontinued.

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FIGURE 22. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET (LONGITUDINAL)

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FIGURE 23. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET (TRANSVERSE)



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CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET FIGURE 25. (TRANSVERSE)





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FIGURE 27. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 21-6-9 ANNEALED SHEET



FIGURE 29. AXIAL LOAD FATIGUE BEHAVIOR OF NGTCHED ( $R_{g} = 3.0$ ) 21-6-9 ANNEALET SHEET (TRANSVERSE)



FIGURE 30. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 21-6-9 ANNEALED SHEET (TRANSVERSE)

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#### T1-8Mo-8V-2Fe-3A1 Alloy

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#### Material Description

The 8Mo-8V-2Fe-3Al beta titanium alloy is a recent development of TIMET. The alloy was selected for full-scale evaluation after confirming (by TIMET) that it could be malted by the conventional consumable electrode vacuum arc process. It shows producibility and property characteristics that make it suitable for a variety of airframe applications. A variety of heat treatments are available to allow the designer to take advantage of its individual properties or its generally good overall properties.

The material used in this evaluation was an 0.040-inch-thick sheet from TIMET Heat K-5055 with the following composition

| Molybdenum | 8.0     |
|------------|---------|
| Vandaium   | 8.2     |
| Iron       | 2.0     |
| Aluminum   | 3.0     |
| Oxygen     | 0.14    |
| Nitrogen   | 0.011   |
| Titanium   | Balance |

#### Processing and Heat Treating

The specimen layout is shown in Figure 31. The material was received in the solution-treated condition. Specimens were aged at 900 F for 6 hours. This condition is called the high strength, fully-aged condition.

#### Test Results

Tension. Test results for longitudinal and transverse specimens at room temperature, 400 F, 600 F, and 800 F are given in Table XXIII. Stressstrain curves at temperature are presented in Figures 32 and 33. Effect-oftemperature curves are shown in Figure 36.

<u>Compression</u>. Test results for longitudinal and transverse specimens at room temperature, 400 F, 660 F, and 800 F are given in Table XXIV. Typical stress-strain and tangent moudlus curves at temperature are presented in Figures 34 and 35. Effect-of-temperature curves are presented in Figure 37.



|       |   |         | 53    | •  |   |   |   | 525   |   |   |   | 5   | 3  |  |   |   | 51   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|-------|---|---------|-------|--|---|---|---|---|---|---|---|---|--|--|---|---|--|--|---|---|--|--|--|-----------|--|--|---|--|--|-----|--|--|
|       |   |         | 53    |  |   |   |   | 526   |   |   |   | 5 - B   | 4  |  |   |   | 52   |  |   |   |  |  | ·  |           |  |  |   |  |  |     |  |  |
|       |   |         | 53    | 0  |   |   |   | 527   |   |   |   | 5   | 5  |  |   |   | 53   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         | 54    | 0.   |   |   |   | 528   |   |   |   | 5   | 6  |  |   |   | 54   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         | 54    |  |   |   |   | 529   |   | Folig   |   | 5   | 7  |  | <b>.</b>  |   | 55   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   | <b></b> | 54    | 2  |   |   |   | 530   |   | 60 1  | •<br>••••••••••••••   | - 5   |  |  |   |   | 56   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         | 34    | 3  |   |   |   | 531   |   |   |   |   | 9  |  |   |   | 57   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         | 54    | 4  |   |   |   | 532   |   | 532   | 32  |   |  | - 5  | 20  |   |  | -  | 58  |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         | 34    | \$   |   |   |   | 53.5  |   |   |   | 5   | 21   |  |   |   | 59   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       | 546   |         |       |  | 534   |   |   |   |   | 22  |   |   |  | 510  |   |   |  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
| 547   |   |         |       |  | 535   |   | •   | <b>-</b>  |   | 23  |   |   |  | - 511  |   |   |  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         | - 194 | 8  | <b>.</b>  |   | <del></del>   | 536   |   | <b></b>   |   | 13.   | 24   |  |   |   | 512  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         |       |  |   |   |   |   | •   |   |   | 11  |  |  |   |   | E  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         |       |  |   | 1 1   |   |   |   |   |   |   |  |  | 3   |   |  |  |   | -   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         |       |  |   |   |   |   |   |   |   |   | •  |  |   |   | N  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   | Ē       |       |  |   |   |   |   |   |   |   |   |  |  |   |   |  |  |   |   |  |  |  | d Tensila |  |  | ā |  |  | 121 |  |  |
|       |   |         |       |  |   |   |   |   |   |   |   | i i   |  |  |   |   | Ŧ  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       | -   |         |       |  |   |   |   |   |   | •   |   |   |  |  |   |   |  |  | -   |   |  |  |  |           |  |  |   |  |  |     |  |  |
| iu.   | 11.2  | IL 3    | 11,4  | iL5  | 11.6  | 11.7  | 11.8  | IL9   | 1110  | IL II   | 1112  | <b>z</b>  |  |  |   |   | <b>ن</b> ي<br>   |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       |   |         |       |  |   |   |   |   |   |   |   | 1112  |  |  |   |   | 176  |  |   |   |  | -  |  |           |  |  |   |  |  |     |  |  |
| ្រទ្រ |   |         |       |  | ۲   | ****  |   |   | 1   |   |   | <b>T</b>  |  | 217  |   | 271   |  |  |   |   | £  | _  |  |           |  |  |   |  |  |     |  |  |
| y.    |   |         |       |  | 54  |   |   |   |   |   |   | -   |  | 218  |   | 272   |  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
| 1     |   |         |       |  |   |   |   |   | 1 a   |   |   | -   |  | 219  | Comp  | 273   | 12 T   | 2  | 212   | 31  | 21   | <u>j</u>   | 5  |           |  |  |   |  |  |     |  |  |
|       |   |         |       |  | <u>u</u>  |   |   |   | 13  | 4 T   |   | -   |  | 2110   |   | 214   |  |  |   | i   | P.   | i  | 1  |           |  |  |   |  |  |     |  |  |
| X     |   |         |       |  | ¥.  | Creep   | 1   |   | 12  |   |   | 411   | 412  | 2111   |   | 275   |  |  |   | ~ .   | ~  | N  | N  |           |  |  |   |  |  |     |  |  |
| 3     |   |         |       |  | 5   | 15 T  |   |   | Ī   |   |   |   | ž  | 2112   |   | 216   |  | 5  | ٦,  | 5   | 5  | Ξ  | Ň  |           |  |  |   |  |  |     |  |  |
| ¥     |   |         |       |  | *   |   |   |   | 1   |   |   |   |  |  |   |   |  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
| y.    |   |         |       |  | u   |   |   |   | -   |   |   |   |  | İ  |   |   |  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
| ٹ ا   |   |         |       |  |   |   |   |   | _   |   |   | 413   | 414  |  |   |   |  |  |   |   |  |  |  |           |  |  |   |  |  |     |  |  |
|       | 2 Sol 10 | ILI IL2 |       | 53       53       53       53       53       53       54 <td>537       538       539       539       540       341       542       543       344       345       546       347       548       111       112       112       111       112       111       112       111       112       111       112       111       112       112       113       114       115       115       115       111       112   <!--</td--><td>937           338           539           539           540           542           543           544           545           546           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           549           549           540           541           542           543           544           545           546           547           548           548           549           549           549           549           549           549           549           549           549</td><td>537       538       539       540       541       542       543       544       345       544       345       544       345       546       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       549       10       10       10       10       10       10       10       10       10       10       11       10       11       11       11       11       11       11       11       11       12       12       13       14       11       12       12       13</td><td>53*       538       539       540       541       542       543       544       545       546       547       548       11       12</td><td>537     525       538     524       539     527       540     528       541     529       542     530       543     531       544     532       545     533       546     534       547     535       548     535       549     536       549     536       549     536       549     536       549     535       548     535       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     547       549     548       549     548       549     548       549     548       549     548       549     548       549     548       549     548       549     548</td><td>937     925       938     526       939     527       940     328       941     529       942     330       943     331       944     532       945     933       945     933       945     933       944     532       945     933       946     934       947     935       948     934       949     936       949     946       949     946       949     946</td><td>537     525       538     526       539     527       540     528       541     529       542     530       544     532       345     533       546     534       547     535       546     534       547     535       548     536       549     536       540     536       540     536       541     116       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       112     112       113     112       114     112       115     11       12     12       13     14       14     15       15     12       15     12  </td><td>537     525       338     526       539     527       540     528       541     529       543     530       544     532       544     532       544     532       544     532       544     532       544     532       544     532       544     532       546     534       547     535       548     536       10     10       110     10       111     10       &lt;</td><td>337     325     A1       338     326     31       340     328     31       341     329     Folique       342     330     60 T       343     331     31       344     332     50       345     333     35       344     332     50       345     333     35       344     332     50       345     333     5       346     336     50       347     335     5       346     336     50       347     335     5       348     336     50       347     355     5       348     336     50       349     336     50       340     336     50       347     355     5       348     336     50       349     336     50       340     336     50       341     14     14       342     34     35       347     356     50       348     336     50       349     34     14       340     14       340     14</td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td>537         525         613           538         526         514           539         527         515           540         528         516           541         529         Foligue         517           542         530         60 T         516           543         531         533         520           544         532         520         545           544         533         521         546           544         533         521         520           544         533         522         520           544         533         521         523           546         535         523         524           547         535         523         524           548         536         524         524           549         546         536         524           549         546         546         536         524           549         546         547         548         548           549         546         547         548         524           549         7         548         7         7&lt;</td><td>937     925     513       938     526     514       939     527     513       940     528     516       941     529     Foligue       942     530     60 T       943     532     520       944     532     520       945     533     521       946     534     522       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       949     148     149       949     149     1419       949     149     1419       949     149     1419       949     149     141       949     141     1412       949     157     147<td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block"> \begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block"> \begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td></td></td> | 537       538       539       539       540       341       542       543       344       345       546       347       548       111       112       112       111       112       111       112       111       112       111       112       111       112       112       113       114       115       115       115       111       112 </td <td>937           338           539           539           540           542           543           544           545           546           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           549           549           540           541           542           543           544           545           546           547           548           548           549           549           549           549           549           549           549           549           549</td> <td>537       538       539       540       541       542       543       544       345       544       345       544       345       546       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       549       10       10       10       10       10       10       10       10       10       10       11       10       11       11       11       11       11       11       11       11       12       12       13       14       11       12       12       13</td> <td>53*       538       539       540       541       542       543       544       545       546       547       548       11       12</td> <td>537     525       538     524       539     527       540     528       541     529       542     530       543     531       544     532       545     533       546     534       547     535       548     535       549     536       549     536       549     536       549     536       549     535       548     535       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     547       549     548       549     548       549     548       549     548       549     548       549     548       549     548       549     548       549     548</td> <td>937     925       938     526       939     527       940     328       941     529       942     330       943     331       944     532       945     933       945     933       945     933       944     532       945     933       946     934       947     935       948     934       949     936       949     946       949     946       949     946</td> <td>537     525       538     526       539     527       540     528       541     529       542     530       544     532       345     533       546     534       547     535       546     534       547     535       548     536       549     536       540     536       540     536       541     116       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       11     112       112     112       113     112       114     112       115     11       12     12       13     14       14     15       15     12       15     12  </td> <td>537     525       338     526       539     527       540     528       541     529       543     530       544     532       544     532       544     532       544     532       544     532       544     532       544     532       544     532       546     534       547     535       548     536       10     10       110     10       111     10       &lt;</td> <td>337     325     A1       338     326     31       340     328     31       341     329     Folique       342     330     60 T       343     331     31       344     332     50       345     333     35       344     332     50       345     333     35       344     332     50       345     333     5       346     336     50       347     335     5       346     336     50       347     335     5       348     336     50       347     355     5       348     336     50       349     336     50       340     336     50       347     355     5       348     336     50       349     336     50       340     336     50       341     14     14       342     34     35       347     356     50       348     336     50       349     34     14       340     14       340     14</td> <td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td>537         525         613           538         526         514           539         527         515           540         528         516           541         529         Foligue         517           542         530         60 T         516           543         531         533         520           544         532         520         545           544         533         521         546           544         533         521         520           544         533         522         520           544         533         521         523           546         535         523         524           547         535         523         524           548         536         524         524           549         546         536         524           549         546         546         536         524           549         546         547         548         548           549         546         547         548         524           549         7         548         7         7&lt;</td> <td>937     925     513       938     526     514       939     527     513       940     528     516       941     529     Foligue       942     530     60 T       943     532     520       944     532     520       945     533     521       946     534     522       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       949     148     149       949     149     1419       949     149     1419       949     149     1419       949     149     141       949     141     1412       949     157     147<td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block"> \begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block"> \begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td><td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td></td> | 937           338           539           539           540           542           543           544           545           546           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           547           548           549           549           540           541           542           543           544           545           546           547           548           548           549           549           549           549           549           549           549           549           549 | 537       538       539       540       541       542       543       544       345       544       345       544       345       546       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       547       548       549       10       10       10       10       10       10       10       10       10       10       11       10       11       11       11       11       11       11       11       11       12       12       13       14       11       12       12       13 | 53*       538       539       540       541       542       543       544       545       546       547       548       11       12 | 537     525       538     524       539     527       540     528       541     529       542     530       543     531       544     532       545     533       546     534       547     535       548     535       549     536       549     536       549     536       549     536       549     535       548     535       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     536       549     547       549     548       549     548       549     548       549     548       549     548       549     548       549     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  112       115     11       12     12       13     14       14     15       15     12       15     12 | 537     525       338     526       539     527       540     528       541     529       543     530       544     532       544     532       544     532       544     532       544     532       544     532       544     532       544     532       546     534       547     535       548     536       10     10       110     10       111     10       < | 337     325     A1       338     326     31       340     328     31       341     329     Folique       342     330     60 T       343     331     31       344     332     50       345     333     35       344     332     50       345     333     35       344     332     50       345     333     5       346     336     50       347     335     5       346     336     50       347     335     5       348     336     50       347     355     5       348     336     50       349     336     50       340     336     50       347     355     5       348     336     50       349     336     50       340     336     50       341     14     14       342     34     35       347     356     50       348     336     50       349     34     14       340     14       340     14 | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ | 537         525         613           538         526         514           539         527         515           540         528         516           541         529         Foligue         517           542         530         60 T         516           543         531         533         520           544         532         520         545           544         533         521         546           544         533         521         520           544         533         522         520           544         533         521         523           546         535         523         524           547         535         523         524           548         536         524         524           549         546         536         524           549         546         546         536         524           549         546         547         548         548           549         546         547         548         524           549         7         548         7         7< | 937     925     513       938     526     514       939     527     513       940     528     516       941     529     Foligue       942     530     60 T       943     532     520       944     532     520       945     533     521       946     534     522       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       947     535     523       948     536     524       949     148     149       949     149     1419       949     149     1419       949     149     1419       949     149     141       949     141     1412       949     157     147 <td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td><math display="block"> \begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td><math display="block"> \begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> <td><math display="block">\begin{array}{c c c c c c c c c c c c c c c c c c c </math></td> | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ | $ \begin{array}{c c c c c c c c c c c c c c c c c c c $ | $ \begin{array}{c c c c c c c c c c c c c c c c c c c $ | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ | $\begin{array}{c c c c c c c c c c c c c c c c c c c $ |           |  |  |   |  |  |     |  |  |

FIGURE 31. SPECI. + LAYOUT FOR TI-8MC-8V-2Fe-3A1 SHEET

Shear. Test results for longitudinal and transverse specimens at room temperature are given in Table XXV.

Fracture Toughness. Specir is were full-sheet thickness (0.040-inch) by 18 inches wide by 36 inches long with an EDM flaw in the center. The average  $K_0$  obtained from four transverse (T-L) specimens was 50 ksi  $\sqrt{10}$ . By existing ASTM criteria, this is considered a valid  $K_c$  value.

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<u>Fatigue</u>. Axial load tests were conducted on transverse specimens, both unnotched and notched, at a stress ratio of R = 0.1. Test temperatures were room temperature, 400 F, and 600 F. Tabular test results are given in Tables XXVI and XXVII. S-N curves are presented in Figures 38 and 39.

Creep and Strezs-Rupture. Tests were performed at 550 F, 700 F, and 900 F. Tabular test results are given in Table XXVIII. Log-stress versus log-time curves are presented in Figure 40.

Stress-Corrosion. Tests were performed as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is  $5.0 \times 10^{-5}$  in./in./F from 68 F to 800 F.

Density. The density of this alloy is 0.175 lb./in.<sup>3</sup>.



# TABLE XXIII. TENSILE TEST RESULTS FOR SOLUTION-TREATED AND AGED T1-8M0-8V-2Fc-3A1 ALLOY SHEET

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| SpecImen<br>Number | Ulti<br>St | 0.2 Percent Elongation<br>Ultimate Tensile Offset Yield in 2 Inches,<br>Strength, ksi Strength, ksi percent |                     |          |             |     |
|--------------------|------------|---|---------------------|----------|-------------|-----|
|                    |            | Longitudi   | nal at Room Tempera | ture     |             |     |
| 1L-1               |            | 160.0   | 143.0               | 12.0     | 13.6        |     |
| 1 <b>L-</b> 2      |            | 162.0   | 147.0               | 12.0     | 13.6        |     |
| 1L-3               |            | 159.0   | 144.0               | 11.0     | 13.7        |     |
|                    | Average    | 160.3   | 144.7               | 11.7     | 13.6        |     |
|                    |            | Transveri   | se at Room Temperat | ure      |             | 2   |
| 1T-1               |            | 176.0   | 160.0               | 9,0      | 15.4        | -   |
| 1T-2               | .*         | 175.0   | 157.0               | . 10,0   | 14.9        |     |
| 1T+3               |            | 173.0   | <u>157.0</u>        | 9.5      | 14.5        |     |
|                    | Average    | 174.7   | 158.0               | 9,5      | 14,9        |     |
|                    |            | Lon   | gitudinal at 400 F  |          |             |     |
| 1L-4               | -          | 148.0   | 123,0               | 9,5      | 13.2        |     |
| 1L-5               |            | 149.0   | 124.0               | 9,0      | 13.5        | •   |
| 1Ľ-6               |            | 149.0   | 123.0               | 8.5      | <u>13.2</u> |     |
| · · ·              | Average    | 148.7   | 123.3               | 9.0      | 12.3        |     |
|                    |            | Tr  | ansverse at 400 F   | ; ;<br>; |             | •   |
| 1T-4               |            | 153,0   | 135.0               | 7.0      | 14.4        |     |
| 1 <b>T-</b> 5      |            | 158,0   | 133,0               | 6.5      | 13.8        |     |
| 1T-6               |            | 155.0   | 132.0               | 7.0      | 14.1        |     |
|                    | Average    | 155.3   | 133.3               | 6.8      | 14.1        |     |
|                    |            | Lon   | gitudinal at 600 F  |          |             | • • |
| 1L-7               |            | 144.0   | 116.0               | 7,5      | 12.3        |     |
| 1 <b>J8</b>        |            | 147.0   | 118,0               | 7.5      | 12.4        |     |
| 1L-9               |            | 147.0   | 119,0               | 7.0      | 12.5        | ·   |
|                    | Average    | 146.3   | 117.7               | 7.3      | 12.4        |     |
|                    |            | Tr  | ansverse at 600 F   |          |             |     |
| 1 <b>T-</b> 7      |            | 152.0   | 123.0               | 6.0      | 13.2        |     |
| 1 <b>T</b> -8      |            | 153.0   | 124.0               | 6.5      | 13.5        |     |
| 1T-9               |            | 152.0   | 125.0               | 7.0      | 13.0        |     |
|                    | Average    | 152.3   | 124.0               | 6.7      | 13.2        |     |
|                    |            | Lon   | gitudinal at 800 F  |          |             |     |
| 1L-10              |            | 139.0   | 102.0               | 21.0     | 12.1        |     |
| 11:-11             |            | 140.9   | 110.0               | 19.0     | 11.8        |     |
| 1L-12              |            | 134.0   | 105.0               | 16.0     | 11.4        |     |
|                    | Average    | 137.7   | 105,7               | 18,7     | 11.8        |     |
|                    |            | Tr  | ansverse at 500 F   |          |             |     |
| 1 <b>T-1</b> 9     |            | 139.0   | 112.0               | 16.5     | 12.3        |     |
| 1 <b>T-</b> 11     |            | 146.0   | 118.0               | 16.0     | 12.4        |     |
| 1 <b>T-1</b> 2     |            | 138.0   | 108.0               | - 16.0   | 12,2        |     |
|                    | Average    | 141 0   | 1127                | 16-2     | 17-2        |     |


17 51 - 1

| Longitudinal at Room Temperature           21-1         177.0         15.9           213         179.0         16.0           Average         177.7         15.9           213         179.0         16.0           Average         177.7         15.9           213         199.0         16.8           271         190.0         16.8           272         193.0         17.1           Average         151.7         16.9           Longitudinal at 400 F         16.8           214         138.0         14.4           215         164.0         15.9           216         142.0         14.7           Average         163.0         16.1           215         164.0         15.9           216         163.0         16.2           Average         163.7         16.1           215         164.0         15.9           216         163.0         16.2           Average         163.7         16.1           215         164.0         15.9           217         141.0         14.5           218         137.0  | pecimen<br>Number                                     | 0,2 Perc<br>Offset Yi<br>Strength, | ent<br>leld<br>ksi | Compression<br>Modulus,<br>10 <sup>4</sup> psi |   |      |
|--|---|------------------------------------|--------------------|--|---|------|
| 21-1       177.0       15.9         21-2       177.0       15.8         213       179.0       16.0         Avorage       177.7       15.9         Transverse at Room Temperature       16.8         27-1       190.0       16.8         27-2       192.0       16.8         27-3       193.0       17.1         Average       191.7       16.9         Longitudinal at 400 F       14.4         21-5       164.0       15.9         21-6       142.0       14.7         Average       140.7       14.5         21-5       164.0       15.9         21-6       163.0       16.1         21-7       164.0       15.9         21-8       137.0       13.9         21-9       163.0       16.2         Average       165.7       16.1         Longitudinal at 600 F       14.2         21-7       141.0       14.5         21-8       137.0       13.9         21-9       138.0       14.1         Average       138.7       14.2         Transverse at 600 F       14.9         21-8 <td></td> <td>Longitudinal at R</td> <td>oom Temperatu</td> <td>re</td>  |   | Longitudinal at R                  | oom Temperatu      | re   |   |      |
| 212       177.0       15.8         213       179.0       16.0         Average       177.7       15.9         Transverse at Room Temperature       16.8         271       190.0       16.8         272       192.0       16.8         272       192.0       16.8         272       193.0       17.1         Average       191.7       16.9         Longitudinal at 400 F       14.4         215       164.0       14.7         216       142.0       14.7         Average       163.0       16.1         215       164.0       15.9         216       163.0       16.1         215       164.0       15.9         216       163.0       16.1         217       164.0       14.5         219       138.0       14.1         Average       138.7       14.2         Transverse at 600 F       14.2         217       152.0       14.9         219       138.0       14.1         Average       151.7       14.2         Transverse at 600 F       12.7  | 2L-1  | 177.0                              |                    | 1.5.9  |   |      |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$  | 2L-2  | 177.0                              | •                  | 15.8   |   |      |
| Average $177.7$ $15.9$ Transverse at Room Temperature         2T-1       190.0       16.8         2T-2       192.0       16.8         2T-3       193.0       17.1         Average       191.7       16.9         Longitudinal at 400 F       16.9         2L-4       138.0       14.4         2L-5       164.0       15.9         2L-6       142.0       14.7         Average       140.7       14.5         2L-6       142.0       14.7         Average       164.0       16.1         2L-7       140.7       14.5         2T-4       164.0       16.1         2T-5       164.0       16.1         2T-5       164.0       16.1         2T-6       163.0       16.2         Average       163.0       16.2         Average       137.0       13.9         2L-7       141.0       14.5         2L-8       137.0       13.9         2L-9       138.0       14.1         Average       151.7       14.2         Transverse at 600 F       14.7         Average  | 21,-3   | 179.0                              |                    | $\frac{16.0}{16.0}$                            |   |      |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$  |   | Average 1//./                      |                    | 12.4   |   |      |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$  |   | Transverse at Ro                   | om Temperatur      | 8  |   |      |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$  | 2T-1  | 190.0                              |                    | 16.8   |   |      |
| 21-3       193.0       17.1         Average 193.0         17.1         Average 193.0         17.1         Average 193.0         17.1         Longitudinal at 400 F         21-4         142.0         142.0         142.0         142.0         144.0         15.9         144.0         164.0         164.0         165.7         165.7         165.0         163.0         164.0         16.1         Longitudinal at 600 F         21-7         152.0         14.9         144.0         14.9         152.0         14.9         14.9         149.0         144.9         2"-7         152.0         14.9 </td <td>2T=2</td> <td>192.0</td> <td></td> <td>16,8</td>   | 2T=2  | 192.0                              |                    | 16,8   |   |      |
| Longitudinal at 400 F         2L-4       138.0       14.4         2L-5       164.0       15.9         2L-6       142.0       14.7         Avurage       140.7       14.5         Transverse at 400 F         2T-4       164.0       16.1         2T-5       164.0       16.1         2T-5       163.0       16.2         Average       165.7       16.1         Longitudinal at 600 F         2L-7       141.0       14.5         2L-7       141.0       14.5         2L-7       141.0       14.5         2L-8       137.0       13.9         2L-9       138.0       14.1         Average       138.7       14.2         Transverse at 600 F       14.9         2T-7       152.0       14.9         2T-8       154.0       14.9         2T-9       149.0       14.7         Average       151.7       14.8         Longitudinal at 800 F       12.7         2L-10       134.0       12.7         12.11       136.0       12.5         2L-12       134.0       12.7 <td>41-3</td> <td>Average 193,0</td> <td></td> <td>16.9</td>  | 41-3  | Average 193,0                      |                    | 16.9   |   |      |
| Image constraint at row t           21-4         138.0         14.4           21-5         164.0         15.9           21-6         142.0         14.7           Avurage         140.7         14.5           Transverse at 400 F           21-6         164.0         16.1           Transverse at 400 F           21-5         164.0         15.9           21-5         164.0         16.1           21-5         164.0         15.9           21-6         163.0         16.2           Average         165.7         16.1           Iongitudinal at 600 F         21-7         141.0           21-9         138.0         14.1           Average         138.7         14.2           Transverse at 600 F         21-7         14.2           21-9         138.0         14.1           Average         151.7         14.9           21-7         152.0         14.9           21-7         154.0         14.9           21-7         154.0         14.7           Average         151.7         14.8           Longitudinal at 800 F         12.7   |   | Longituding                        | 1 at 400 F         |  |   |      |
| 2L-5       164.0       15.9         2L-6       142.0       14.7         Avurage       140.7       14.5         Transverse at 400 F         2T-4       164.0       16.1         2T-5       164.0       16.1         2T-5       164.0       15.9         2T-4       164.0       16.1         2T-5       163.0       16.2         Average       165.77       16.1         Longitudinal at 600 F         2L-7       141.0       14.5         Longitudinal at 600 F         2L-7       141.0       14.5         Longitudinal at 600 F         2L-7       141.0       14.5         Longitudinal at 600 F         2L-9       138.0       14.1         Average 138.7       14.9         2T-8       154.0       14.9         2T-9       149.0       14.7         Average       151.7       14.8         Longitudinal at 800 F         2L-10       134.0       12.7         2L-12       134.0       12.9         Average       134.7       12.7  | 21  | 110 0                              |                    | 14 4   |   |      |
| 2L-6 $142:0$ $14.7$ Avurage 140.7         142:0         142:0         142:0         142:0         142:0         142:0         142:0         142:0         142:0         142:0         142:0         142:0         15:0         16:1         Longitudinal at 600 F         2L-7         138:0         14:1         Average 138:7         14:1         Average 151:7         14:1         14:0         14:0         14:0         14:0         14:0         14:0         14:0         14:0         14:0         14:0         14:0         12:0         13:1:0         13:2:0  | 215   | 150.0                              |                    | 14,4   |   |      |
| Avurage $140.7$ $14.5$ $17ansverse at 400 F$ $16.1$ $2T-4$ $164.0$ $16.1$ $2T-5$ $164.0$ $15.9$ $2T-6$ $163.0$ $16.2$ Average $163.0$ $16.2$ Average $163.7$ $16.1$ Longitudinal at 600 F $16.1$ 2L-7 $141.0$ $14.5$ 2L-8 $137.0$ $13.9$ 2L-9 $138.0$ $14.1$ Average $138.7$ $14.2$ Transverse at 600 F $14.9$ 2T-7 $152.0$ $14.9$ ZT-8 $154.0$ $14.9$ ZT-9 $149.0$ $14.7$ Average $151.7$ $14.8$ Longitudinal at 800 F $12.7$ ZL-10 $134.0$ $12.7$ Average $134.7$ $12.7$ Transverse at 800 F $12.7$ ZT-10 $140.0$ $13.5$ ZT-11 $139.0$ $13.7$ $13.7$ $13.7$ $13.5$   | 2L_6  | 142.0                              |                    | 14.7   |   |      |
| $\frac{\text{Transverse at 400 F}}{2T-4}$ $\frac{164.0}{15.9}$ $\frac{16.1}{2T-5}$ $\frac{163.0}{16.2}$ $\frac{16.2}{163.7}$ $\frac{16.1}{16.1}$ $\frac{100 \text{ gitudinal at 600 F}}{163.7}$ $\frac{2L-7}{141.0}$ $\frac{14.5}{2L-9}$ $\frac{138.0}{138.0}$ $\frac{14.1}{14.2}$ $\frac{14.2}{14.2}$ $\frac{138.0}{14.2}$ $\frac{14.9}{14.2}$  | Avurage 140.7                      | •                  | 14.5   |   |      |
| 27-4       164.0       16.1         27-5       163.0       15.9         27-6       163.0       16.2         Average 163.7         Longitudinal at 600 F         21-7       141.0       14.5         21-7       141.0       14.5         21-9       138.0       14.1         Average 138.7       14.2         Transverse at 600 F         21-9       138.0         14.9         Average 138.7       14.2         Transverse at 600 F         21-9         149.0         14.9         27-6         149.0         14.9         21-9         149.0         14.9         21-10         134.0         12.7         134.0         12.9         Average 134.7         134.0         12.9         Average 134.7         139.0   | -   | Transverse                         | at 400 F           |  |   |      |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | 2 <b>T-</b> 4   | 164.0                              |                    | 16,1   |   |      |
| 2T-6       163.0       16.2         Average       163.7       16.1         Longitudinal at 600 F         2L-7       141.0       14.5         2L-7       141.0       14.5         2L-7       141.0       14.5         2L-7       141.0       14.5         2L-9       138.0       14.1         Average       152.0       14.9         2T-7       152.0       14.9         Average       151.7       14.8         Longitudinal at 800 F         2L-10       134.0       12.7         Average       134.7       12.7         Average       134.7       12.7         Transverse at 800 F         2T-10       140.0       13.5         Average       134.7       13.5         T-10 <th 1<="" colspan="2" td=""><td>21-5</td><td>164.0</td><td>)</td><td>15.9</td></th>   | <td>21-5</td> <td>164.0</td> <td>)</td> <td>15.9</td> |                                    | 21-5               | 164.0  | ) | 15.9 |
| Longitudinal at 600 F         2L-7       141.0       14.5         2L-9       138.0       14.1         Average       138.7       14.2         Transverse at 600 F       27-7       152.0       14.9         2T-7       152.0       14.9         2T-8       154.0       14.9         2T-9       149.0       14.7         Average       151.7       14.8         Longitudinal at 800 F       12.7         2L-10       134.0       12.7         2L-11       136.0       12.7         2L-12       134.0       12.7         Average       134.7       12.7         ZT-11       136.0       12.7         2L-12       134.0       12.7         ZT-11       136.0       12.7         ZT-12       134.0       12.7         ZT-10       140.0       13.5         ZT-10       140.0       13.5         ZT-11       139.0       13.7         ZT-12       137.0       13.5   | 2T <b>-6</b>  | 103.0                              | -                  | 16.2<br>16.1                                   |   |      |
| 2L-7       141.0       14.5         2L-9       137.0       13.9         2L-9       138.0       14.1         Average 138.7       14.2         Transverse at 600 F         2T-7       152.0       14.9         Transverse at 600 F         2T-7       152.0       14.9         Transverse at 600 F         2T-7       152.0       14.9         T-8       154.0       14.9         T-8       154.0       14.9         T-9       149.0       14.7         Average 151.7       14.8         Longitudinal at 800 F         2L-10       134.0       12.7         Average 134.7       12.5         ZI-12       134.0       12.9         Average 134.7       12.7         Transverse at 800 F         2T-10       140.0       13.5         139.0       13.7         137.0       13.5  |   | Longitudina                        | 1 at 600 F         | ~~, *  |   |      |
| 2L-9       137.0       13.9         2L-9       138.0       14.1         Average 138.7         Transverse at 600 F         2T-7       152.0       14.9         2T-7       152.0       14.9         2T-7       152.0       14.9         2T-7       152.0       14.9         2T-8       154.0       14.9         2T-9       149.0       14.7         Average 151.7       14.8         Longitudinal at 800 F         2L-10       134.0       12.7         2L-11       136.0       12.7         2L-12       134.0       12.9         Average 134.7         Transverse at 800 F         2T-10       140.0         137.0         137.0         137.0  | 217   | 141.0                              | ,                  | 14.5   |   |      |
| 2L-9 $138.0$ $14.1$ Average 138.7         Transverse at 600 F         2T-7       152.0       14.9         2T-7       152.0       14.9         2T-7       152.0       14.9         2T-8       154.0       14.9         2T-9       149.0       14.7         Average 151.7       14.8         Longitudinal at 800 F         2L-10       134.0       12.7         Transverse at 800 F         2T-10       140.0       13.5         Transverse at 800 F         2T-10       140.0       13.5         T-10       134.7       12.7         Transverse at 800 F       2         139.0       13.7         137.0       13.5  | 2L-9  | 137.0                              | )                  | 13.9   |   |      |
| Average $\overline{138.7}$ $\overline{14.2}$ Transverse at 600 F2T-7152.014.92T-8154.014.92T-9149.014.7Average151.714.8Longitudinal at 800 F2L-10134.012.72L-10134.012.52L-11136.C12.52L-12134.012.7Average134.712.7Transverse at 800 F2T-10140.C13.52T-11139.013.72T-12137.013.5  | 2L-9  | 138.0                              | <u>)</u>           | 14.1   |   |      |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$  |   | Average 138.7                      | Г                  | 14.2   |   |      |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   |   | Transverse                         | at 600 F           |  |   |      |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | 2T-7  | 152.0                              | )                  | 14.9   |   |      |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$  | 2T-8  | 154.0                              | )                  | 14.9   |   |      |
| Longitudinal at 800 F           2L-10         134.0         12.7           2L-11         136.0         12.5           2L-12         134.0         12.9           Average         134.7         12.7           Transverse at 800 F         12.7           2T-10         140.0         13.5           2T-11         139.0         13.7           2T-12         137.0         13.5  | 2T-9  | Average 149.0                      | )<br>F             | $\frac{14.7}{12.8}$                            |   |      |
| Longitudinal at 800 F           2L-10         134.0         12.7           2L-11         136.0         12.5           2L-12         134.0         12.9           Average 134.7         12.7           Transverse at 800 F           2T-10         140.0         13.5           2T-11         139.0         13.7         13.7           2T-12         137.0         13.5         12.7   |   | nvetage 131./                      |                    | 14.0   |   |      |
| 2L-10       134.0       12.7         2L-11       136.0       12.5         2L-12       134.0       12.9         Average 134.7         Transverse at 800 F         2T-10       140.0         139.0         137.0         137.0         137.0   |   | Longirudina                        | L AC DUU P         | •••  |   |      |
| ZL-11         130.0         12.3           2L-12         134.0         12.9           Average         134.7         12.7           Transverse at 800 F         12.7           2T-10         140.0         13.5           2T-11         139.0         13.7           2T-12         137.0         13.5   | 2L-10   | 134.0                              | ,<br>,             | 12./   |   |      |
| Average         134.7         12.7           Transverse at 800 F         13.5           2T-10         140.0         13.5           2T-11         139.0         13.7           2T-12         137.0         13.5   | 2L=12   | 136.0                              | )                  | 12.9   |   |      |
| Transverse at 800 F           2T-10         140.0         13.5           2T-11         139.0         13.7           2T-12         137.0         13.5   |   | Average 134.7                      | r                  | 12.7   |   |      |
| 2T-10     140.0     13.5       2T-11     139.0     13.7       21-12     137.0     13.5   |   | Transverse                         | at 800 F           |  |   |      |
| 2T-11     139.0     13.7       2T-12     137.0     13.5       137.0     13.5   | 2 <b>T-1</b> 0  | 140.0                              |                    | 13.5   |   |      |
| 2T-12 137.0 13.5   | 2T-11   | 139.0                              | )                  | 13.7   |   |      |
|  | 27=12   | 137.0                              | 5                  | 13.5   |   |      |

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TABLE XXV. SHEAR TEST RESULTS FOR SOLUTION-TREATED AND AGED T1-8Mo-8V-2Fe-3A1 ALLOY SHEE1 AT ROOM TEMPERATURE

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| Specimen<br>Number |              | Ultimate Shear<br>Strength, ksi |
|--------------------|--------------|---------------------------------|
|                    | Longitudinal | •                               |
| 4L-1               |              | 92.9                            |
| 4L-2               |              | 102.0                           |
| 4 <b>L-3</b>       |              | 102.0                           |
| 4L-4               |              | 100,5                           |
|                    | Average      | 100.5                           |
|                    | Transverse   |                                 |
| 4 <b>T</b> -1      |              | 103.0                           |
| 4 <b>T</b> -2      |              | 106.0                           |
| 4 <b>T-</b> 3      |              | 109,0                           |
| 4 <b>T</b> -4      |              | 109,0                           |
|                    | Average      | 106.8                           |

#### TABLE XXVI. AXIAL LOAD FATIGUE TEST RESULTS FOR UN-NOTWHED, SOLUTION-TREATED AND AGED TI-8MO-SV-2Fe-3A1 ALLOY SHEET (TRANSVERSE)

| Specimen<br>Number | Maximum<br>Stress, ksi | Lifetime,<br>cycles    |
|--------------------|------------------------|------------------------|
|                    | Room Temperature       | 2                      |
| 5-2                | 110.0                  | 8,200                  |
| 5-1                | 100.0                  | 16,800                 |
| 5-3                | 90.0                   | 24,000                 |
| 5-4                | 80.0                   | 34,800                 |
| 5-5                | 70.0                   | 61,400                 |
| 5-25               | 70.0                   | 324,000                |
| 5-6                | 65.0                   | 11,153,000             |
| 5-7                | 60.0                   | 11,053,400             |
|                    | 400 F                  |                        |
| 5-11               | 110.0                  | 12,100                 |
| 5-12               | 100.0                  | 13,500                 |
| 5-13               | 90.0                   | 22,400                 |
| 5-15               | 85.0                   | 40,600                 |
| 5-14               | 80.0                   | 33,900                 |
| 5-16               | 75.0                   | 36,500                 |
| 5-9                | 70.0                   | 290,000 <sup>(C)</sup> |
| 5-10               | 70.0                   | 10,940,500             |
| 5-8                | 60.0                   | 10,245,100(8)          |
|                    | <u>700 F</u>           |                        |
| 5-17               | 110.0                  | 4,010                  |
| 5 <b>-18</b>       | 100.0                  | 4,870                  |
| 5-19               | 90.0                   | 7,650                  |
| 5-20               | 80.0                   | 12,500                 |
| 5-21               | 70.0                   | 100,380,               |
| 5-22               | 60.0                   | 10,352,900             |

(a) Failed in grip.

(b) Did not fail.

(c) Failed at thermocouple.

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# TABLE XXVII. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K=3.0) SOLUTION-TREATED AND AGED TI-8M0 8V-2Fe-3A1 ALLOY SHEET (TRANSVERSE)

| Specimen<br>Number                       | Maximum<br>Stress, ksi | Lifetime,<br>cycles                    |
|--|------------------------|--|
| en en en en en en en en en en en en en e | Room Temperature       | ананананананананананананананананананан |
| 5-31                                     | 80.0                   | 3,700                                  |
| 5-32                                     | 70.0                   | 4,300                                  |
| 5-35                                     | 60.0                   | 6,600                                  |
| 5-33                                     | 50.0                   | 12,500                                 |
| 5-36                                     | 40.0                   | 17,000                                 |
| 5-34                                     | 30.0                   | 911,500                                |
| 5-37                                     | 20.0                   | 10,001,300 <sup>(a)</sup>              |
|  | <u>400 F</u>           |  |
| 5-39                                     | 80.0                   | 4,700                                  |
| 5-40                                     | 70.0                   | 5,500                                  |
| 5-41                                     | 60.0                   | 6,700                                  |
| 5-42                                     | 50.0                   | 11.400                                 |
| 5-43                                     | 40.0                   | 21,100                                 |
| 5-44                                     | 30.0                   | 10.329.900                             |
| 5-38                                     | 20.0                   | 10,001,700 (2)                         |
|  | <u>700 F</u>           |  |
| 5-45                                     | 80.0                   | 2,900                                  |
| 5-46                                     | 70.0                   | 3,200                                  |
| 5-47                                     | 60.0                   | 5,100                                  |
| 5-48                                     | 50.0                   | 8,200                                  |
| 5-49                                     | 40.0                   | 26,500                                 |
| 5-50                                     | 30.0                   | 33,400                                 |
| 5-51                                     | 25.0                   | 16,537,900 <sup>(a)</sup>              |

(a) Did not fail.

TABLE XXVIII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR TI-8M0-8V-2Fe-3A1 ALLOY SHEET (TRANSVERSE)

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|      | Tempar | Hourse | to India  | and pose               |                     |                    |                    |                              |                           |                       |
|------|--------|--------|-----------|------------------------|---------------------|--------------------|--------------------|------------------------------|---------------------------|-----------------------|
| ess, | ature, | STRON  | רח זוומזו | percent                | ep uerorn           | la t l on,         | Initial<br>Straín. | Rupture<br>Time              | Elongation<br>in 2 Inches | Minimum<br>Creen Pare |
| si   | Ľ.     | 0.1    | 0.2       | 0.5                    | 1.0                 | 2.0                | percent            | hours                        | percent                   | percent               |
| 56   | 200    | 1      |           |                        | Г.<br>Э             |                    |                    |                              |                           |                       |
| 50   | 200    | 1      |           | 1  <br>1  <br>1  <br>2 | 9<br>1 1            | 1                  | 1                  | Ur, Loading                  |                           | 1                     |
| 40   | 700    | 0.05   | 0.20      | 1.3                    | 4.2                 | 13                 | 1 187              | U.L<br>162 3                 | 0.0<br>0                  |                       |
| 00   | 700    | 1.6    | 4         | 11                     | 23                  | 75                 | 0 751              | 080 7                        | 1 - C                     | 0.047                 |
| 60   | 700    | 4      | 80        | 27.                    | 95.                 | 500 <sup>(a)</sup> | 107 0              | (q) * (p) *                  | 1.1                       | C700.0                |
| 30   | 200    | 20     | 55        | 450 <sup>(a)</sup>     | 2000 <sup>(a)</sup> |                    | 0.082              | 313.3 <sup>(b)</sup>         | 0.529                     | 0.00036               |
| 75   | 006    | 8      | 0.1       | 0.3                    | 0.65                | 1.7                | 0 545              | 8 ]                          | 1 1                       | - L                   |
| 50   | 006    | 0.05   | 0.15      | 0.6                    | 2.0                 | 6.7                | 0.264              | 59.4                         | 50.2                      | 0.22                  |
| 25   | 006    | 0.50   | 2.5       | 10                     | 40,04               | 155                | 0.135              | 1406.2.                      | 57.3                      | 0,008                 |
| 12   | 006    | 4.3    | 20        | 153                    | 450 <sup>(a)</sup>  |                    | 0,109              | 172.8 <sup>(b)</sup>         | 0.647                     | 0.0018                |
| 55   | 550    | 1      | :         | 1                      | 1                   | :                  | 1                  | On Loading                   | . C                       |                       |
| 45   | 550    | 0.3    | 2.8       | 30                     | 105,                | $1200^{(a)}$       | 2.538              | $\frac{1104}{1104} 6^{(b)5}$ | 4.50                      | 0 0003                |
| 10   | 550    | 8.0    | 26        | 98                     | 3500 <sup>(a)</sup> | 1                  | 0.968              | 173.9(b)                     | 1 682                     |                       |
| 70   | 550    | 30     | 103       | 360 <sup>(a)</sup>     | 1                   | <br>1              | 0.422              | $234.6^{(b)}$                | 0.780                     | 1                     |

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(a) Estimate.

(b) Test discontinued.

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TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED T1..8Mo-8V-2Fe-3A1 SHEET (LONGITUDINAL)

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FIGURE 33. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND ACED T1-8No-8V-2Fe-3A1 SHEET (TRANSVERSE)



FIGURE 34. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED T1-8M0-8V-2Fe-3A1 SHEET (LONGITUDINAL)





FIGURE 35. TYPICAL COMPRESSIVE STRESS-STRATE AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR SOLUTION-TREACED AND AGED TI-EMG-8V-2FG-JA1 SHEET (TRANSVERSE)

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FIGURE 36. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION-TREATED AND AGED T1-SMO-8V-2Fg-3A1 SHEET



FIGURE 37. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION-TREATED AND AGED TI-8MO-8V-200-3A4 SHEET



FIGURE 38. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION-TREATED AND AGED T1-8Mo-8V-2Fe-3A1 SHEET (TRANSVERSE)



FIGURE 39. ANIAL LOAD (ATAGUE SUBAVIOR OF SOTCHED (F. - (.0) SOUTION-FREATED AND ACCD T(-896-59-200- COSTOP) (FLARSYERS))



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#### Ti-6A1-2Zr-2Sn-2Mo-2Cr Alloy

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#### Material Description

This alloy is a recent development of RMI Company. It is an alpha-beta type alloy designed for deep hardenability. Preliminary information shows the material to have low density, high modulus, high toughness, and good producibility. Strength retention to 200 F is good.

The material used for this evaluation was a 1 1/2-inch-thick plate from RMI ingot number 890180.

#### Processing and Heat Treating

The specimen layout is shown in Figure 41. The material was received in the solution treated (1740 F, 1 hour, AC) condition and specimens were aged at 1000 F for 8 hours.

#### Test Results

Tension. Results of tests in both the longitudinal and transverse directions at room temperature, 400 F, 600 F, and 800 F are given in Table XXIX. Typical stress-strain curves at temperature are shown in Figures 42 and 43. Effectof-temperature curves are presented in Figure 46.

Compression. Results of tests in both the longitudinal and transverse directions at room temperature, 400 F, 600 F, and 800 F are given in Table XXX. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 44 and 45. Effect-of-temperature curves are shown in Figure 47.

Shear. Results of pin shear tests at room temperature for longitudinal and transverse specimens are given in Table XXXI.

Impact. Results of Charpy V-notch tests at room temperature in both the longitudinal and transverse directions are given in Table XXXII.

Fracture Toughness. Results of slow-bend type tests in both the longitudinal (L-T) and transverse (T-L) directions are given in Table XXXIII. Even though the candidate  $K_Q$  values do not meet the rigorous a, T, < 2.5  $(\frac{K_Q}{TYS})^2$  criteria they are above  $2.2(\frac{K_Q}{TYS})^2$  and should be considered good indicative  $K_{Ic}$  values.



| 3 | 33 | ន        | 16 |  |
|---|----|----------|----|--|
| 2 |    | <u>چ</u> | 66 |  |

Fatigue. Axial load failigue tests were conducted at room temperature, 400 F, and 500 F for unnotched and notched transverse specimens at a stress ratio of R = 0.1. Results are given in tabular form in Tables XXXIV and XXXV. S-N curves are presented in Figures 48 and 49.

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<u>Creep and Stress Rupture</u>. Tests were conducted on transverse specimens at 400 F, 600 F, and 800 F. Tabular test results are given in Table XXXVI. Log-stress versus log-time curves are presented in Figure 50.

Stress Corrosion. Specimens were tested as described in the experimental procedures section of this report. No fractures or cracks occurred in the 1000-hour test duration.

<u>Thermal Expansion</u>. The thermal expansion coefficient for this alloy is  $5.1 \times 10^{-6}$  in./in./F for 70 to 800 F.

Density. The density value is 0.162 lb./in.<sup>3</sup>.



## TABLE XXIX, TENSILE TEST RESULTS FOR SOLUTION-TREATED AND AGED T1-6A1-2Zr-2Sn-2Mo-2Cr ALLOY PLATE

| Specime<br>Number       | l<br>n Tens | Jltimate<br>sile Strength,<br>ksi       | 0.2 Percent<br>Offset Yield<br>Strength, ksi | Elongation<br>in 1-inch,<br>percent | Reduction<br>in Area,<br>p <b>er</b> cent | 'Tensile<br>Modulus,<br>10 <sup>d</sup> psi   |
|-------------------------|-------------|---|--|-------------------------------------|---|---|
|                         |             | Longi                                   | tudinal at Room Te                           | mperature                           |   |   |
| 1L-1<br>1L-2<br>1L-3    | Average     | 169.0<br>168.0<br><u>168.0</u><br>168.3 | 155.0<br>156.0<br><u>156.0</u><br>155.6      | 18.0<br>18.0<br><u>18.0</u><br>18.0 | 25.0<br>24.8<br><u>24.6</u><br>24.8       | 17.9<br>17.9<br><u>17.8</u><br>17.9   |
|                         |             | Trans                                   | sverse at Room Tem                           | perature                            |   |   |
| 1T-1<br>1T-2<br>1T-3    | Average     | 168.0<br>169.0<br><u>169.0</u><br>168.7 | 157.0<br>156.0<br><u>157.0</u><br>156.6      | 18.0<br>17.5<br><u>17.5</u><br>17.7 | 24.0<br>27.3<br><u>27.4</u><br>26.2       | 17.5<br>17.7<br><u>18.3</u><br>17.8   |
|                         |             |   | Longitudinal at 4                            | 00 F                                |   |   |
| 1L-4<br>1L-5<br>1L-6    | Average     | 144.0<br>147.0<br><u>145.0</u><br>145.3 | 111.0<br>120.0<br><u>117.0</u><br>116.0      | 17.5<br>20.5<br><u>20.5</u><br>19.5 | 29.8<br>34.6<br><u>35.3</u><br>33.2       | 15.4<br>17.0<br><u>15.2</u><br>15.9   |
|                         |             |   | Transverse at 4                              | 00 F                                |   |   |
| 1T-4<br>1T-5<br>1T-6    | Average     | 145.0<br>147.0<br><u>146.0</u><br>146.0 | 120.0<br>120.0<br><u>119.0</u><br>119.7      | 19.0<br>20.0<br><u>20.0</u><br>19.7 | 34.5<br>33.5<br><u>33.0</u><br>33.7       | 15.9<br>16.1<br><u>16.7</u><br>16.2   |
|                         |             |   | Longitudinal at 60                           | <u>00 F</u>                         |   |   |
| 1L-7<br>1L-8<br>1L-9    | Average     | 138.0<br>139.0<br><u>140.0</u><br>139.0 | 107.0<br>107.0<br><u>107.0</u><br>107.0      | 18.5<br>20.0<br><u>17.0</u><br>18.5 | 34.5<br>36.0<br><u>34.2</u><br>34.9       | 14.8<br>16.2<br><u>15.8</u><br>15.6   |
|                         |             |   | Transverse at 600                            | <u>DF</u>                           |   |   |
| 1T-7<br>1T-8<br>1T-9    | Average     | 139.0<br>140.0<br><u>140.0</u><br>139.7 | 108.0<br>109.0<br><u>109.0</u><br>108.7      | 18.5<br>18.0<br><u>18.0</u><br>18.2 | 30.4<br>35.0<br><u>34.6</u><br>33.3       | 16.0<br>16.0<br><u>16.0</u><br>16.0   |
|                         |             |   | Longitudinal at 80                           | <u>00 F</u>                         |   |   |
| 1L-10<br>1L-11<br>1L-12 | Average     | 131.0<br>132.0<br><u>133.0</u><br>132.0 | 99.5<br>102.0<br><u>102.0</u><br>101.2       | 22.0<br>22.0<br><u>20.0</u><br>21.3 | 41.3<br>44.0<br><u>40.9</u><br>42.1       | 13.8<br>14.5<br><u>14.9</u><br>14.4   |
|                         |             |   | Transverse at 800                            | <u>) F</u>                          |   |   |
| 1T-10<br>1T-11<br>1T-12 | Average     | 133.0<br>131.0<br><u>132.0</u><br>132.0 | 106.0<br>102.0<br><u>104.0</u><br>104.0      | 21.0<br>21.0<br><u>21.0</u><br>21.0 | 44.7<br>37.4<br><u>42.0</u><br>41.4       | $   \begin{array}{r}     13.9 \\     14.4 \\     \underline{15.5} \\     14.6   \end{array} $ |



## TABLE XXX. COMPRESSION TEST RESULTS FOR SOLUTION-TREATED AND AGED Ti-6A1-2Zr-2Sn-2MO-2Cr ALLOY PLATE

| Specimen<br>Number      | C<br>S     | 0.2 Percent<br>ffset Yield<br>trength, ksi       | Compressive<br>Modulus,<br>10 <sup>4</sup> psi   |
|-------------------------|------------|--|--|
|                         | Longitudi  | nal at Room Temperat                             | ure  |
| 2L-1<br>2L-2<br>2L-3    | Average    | 16 <b>8</b> .0<br>170.0<br><u>171.0</u><br>169.7 | 17.8<br>18.5<br><u>18.0</u><br>18.1  |
| · .                     | Transver   | se at Room Temperatu                             | re   |
| 2T-1<br>2T-2<br>2T-3    | Average    | 172.0<br>174.0<br><u>174.0</u><br>173.3          | 18.3<br>18.5<br><u>18.6</u><br>18.5  |
|                         | Lon        | gitudinal at 400 F                               |  |
| 2L-4<br>2L-5<br>2L-6    | Average    | 132.0<br>125.0<br><u>128.0</u><br>128.3          | 16.5<br>17.2<br><u>16.5</u><br>16.7  |
|                         | Tra        | ansverse at 400 F                                |  |
| 2T-4<br>2T-5<br>2T-6    | Average    | 130.0<br>130.0<br><u>128.0</u><br>129.3          | $   \begin{array}{r}     16.3 \\     16.5 \\     \underline{16.2} \\     16.3 \\   \end{array} $ |
|                         | Long       | gitudinal at 600 F                               |  |
| 2L-7<br>2L-8<br>2L-9    | Average    | 113.0<br>113.0<br><u>111.0</u><br>112.3          | 15.7<br>16.4<br><u>15.4</u><br>15.8  |
|                         | Tra        | ansverse at 600 F                                |  |
| 2T-7<br>2T-8<br>2T-9    | Average    | 114.0<br>116.0<br><u>115.0</u><br>115.0          | 15.9<br>15.6<br><u>15.9</u><br>15.8  |
|                         | Long       | <u>gitudinal at 800 F</u>                        |  |
| 2L-10<br>2L-11<br>2L-12 | Average    | 107.0<br>105.0<br><u>105.0</u><br>105.7          | $     14.4 \\     14.7 \\     14.7 \\     14.6     $   |
|                         | <u>Tra</u> | insverse at 800 F                                |  |
| 2T-10<br>2T-11<br>2T-12 | Average    | 106.0<br>106.0<br><u>107.0</u><br>106.3          | $   \begin{array}{r}     14.7 \\     14.7 \\     \underline{14.4} \\     14.6   \end{array} $    |

TABLE XXXI.SHEAR TEST RESULTS FOR SOLUTION-TREATED<br/>AND AGED TI-6A1-2Zr-2Sn-2Mo-2Cr ALLOY<br/>PLATE AT ROOM TEMPERATURE

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S (\* 23)

| Specimen<br>Number |              | Ultimate Shear<br>Strength, ksi |
|--------------------|--------------|---------------------------------|
|                    | Longitudinal |                                 |
| 4L-1               |              | 103.0                           |
| 4L-2               |              | 114.0                           |
| 4L-3               |              | 107.0                           |
| 4L-4               |              | 109.0                           |
|                    | Average      | 108.3                           |
|                    | Transverse   |                                 |
| 4 <b>T-1</b>       |              | 108.0                           |
| 4T-2               |              | 109.0                           |
| <b>4T-</b> 3       |              | 109.0                           |
| 4 <b>T</b> -4      |              | 106.0                           |
|                    | Average      | 168.0                           |

TABLE XXXII.IMPACT TEST RESULTS FOR SOLUTION-TREATEDAND AGED Ti-6A1-2Zr-2Sn-2Mo-2Cr ALLOYPLATE AT ROOM TEMPERATURE

| Specimen<br>Number |              | Energy,<br>ft./1bs. |
|--------------------|--------------|---------------------|
|                    | Longitudinal |                     |
| 10L-1              |              | 14.0                |
| 10L-2              |              | 13.0                |
| 10L-3              |              | 13.0                |
| 10L-4              |              | 15.0                |
| 1015               |              | 15.0                |
| 10L-6              |              | 13.0                |
|                    | Average      | 13.9                |
|                    | Transverse   |                     |
| 10T-1              |              | 16.0                |
| 10T-2              |              | 15.0                |
| 10T-3              |              | 16.5                |
| 10T-4              |              | 17.0                |
| 10T-5              |              | 16.0                |
| 10T-6              |              | 17.0                |
|                    | Average      | 16.3                |

| TABLE XXXIII. | RESULTS OF SLOW-BEI | ND TYPE | FRACTURE  | TOUGHNESS   | TESTS ON   |   |
|---------------|---------------------|---------|-----------|-------------|------------|---|
|               | SOLUTION-TREATED AN | ND AGED | Ti-6A1-22 | 2r=2Sn=2Mo- | -2Cr PLATE | Ξ |

| Specimen<br>Number           | w,<br>inches                     | a,<br>inches                     | T,<br>inches                     | P,<br>1bs.                       | Span,<br>inches          | f( <mark>a</mark> )          | K <sub>Q</sub> <sup>(a)</sup> |
|------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------|------------------------------|-------------------------------|
|                              |                                  | Loi                              | ngicudinal                       | <u>(L-T)</u>                     |                          |                              |                               |
| 6L-1<br>6L-2<br>6L-3<br>6L-4 | 1.500<br>1.500<br>1.500<br>1.500 | 0.746<br>0.783<br>0.723<br>0.763 | 0.750<br>0.750<br>0.750<br>0.750 | 7,600<br>7,200<br>7,950<br>7,350 | 6.0<br>6.0<br>6.0<br>6.0 | 2.64<br>2.86<br>2.52<br>2.74 | 87.4<br>89.8<br>87.1<br>87.7  |
|                              |                                  | T                                | cansverse ('                     | <u>T-L)</u>                      |                          |                              |                               |
| 6T-1<br>6T-2<br>6T-3         | 1.500<br>1.500<br>1.500          | 0.770<br>0.777<br>0.770          | 0.750<br>0.750<br>0.750          | 7,650<br>7,550<br>8,025          | 6.0<br>6.0<br>6.0        | 2.78<br>2.82<br>2.78         | <b>92.7</b><br>92.9<br>97.2   |

(a) Candidate K<sub>Q</sub> values are invalid as K<sub>Q</sub> values since they do not meet the rigorous standard of a, T, < 2.5  $(\frac{K_Q}{TYS})^2$ . However, they do exceed a 2.2  $(\frac{K_Q}{TYS})^2$  and as such should be considered marginally valid.

#### TABLE XXXIV. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED SOLUTION-TREATED AND AGED T1-6A1-2Sn-2M0-2Cr ALLOY PLATE (TRANSVERSE)

| Specimen<br>Number | Maximum<br>Stress, ksi | Lifetime,<br>cycles       |
|--------------------|------------------------|---------------------------|
|                    | Room Temperature       |                           |
| 5-6                | 160.0                  | 7,600                     |
| 5-5                | 150.0                  | 23,300                    |
| 5-4                | 140.0                  | 189,600                   |
| 5-3                | 130.0                  | 208,900                   |
| 5-2                | 120.0                  | 302,400                   |
| 5-7                | 115.0                  | 424,400                   |
| 5-8                | 110.0                  | 1,087,800                 |
| 5-9                | 105.0                  | 818,800                   |
| 5-10               | 100.0                  | 1,767,200                 |
| 5-1                | 90.0                   | 1,616,800                 |
| 5-11               | 80.0                   | 5,855,600                 |
| 5-27               | 70.0                   | 13,625,400 <sup>(a)</sup> |
|                    | <u>400 F</u>           |                           |
| 5-12               | 150.0                  | 7,100                     |
| 5-13               | 140.0                  | 12,000                    |
| 5-14               | 130.0                  | 21,400                    |
| 5-15               | 120.0                  | 178,500                   |
| 5-16               | 110.0                  | 369,000                   |
| 5-17               | 100.0                  | 829,500                   |
| 5-18               | 90.0                   | 2,142,600                 |
| 5-19               | 80.0                   | 3,059,600                 |
| 5-24               | 70.0                   | 10,144,000 <sup>(a)</sup> |
|                    | <u>600 F</u>           |                           |
| 5-28               | 140.0                  | (b)                       |
| 5-29               | 130.0                  | 9,000                     |
| 5-20               | 120.0                  | 16,700                    |
| 5-21               | 110.0                  | 458,800                   |
| 5-22               | 100.0                  | 1,341,600                 |
| 5-23               | 90.0                   | 2,653,700                 |
| 5-25               | 80.0                   | 4,227,400                 |
| 5-26               | 70.0                   | 10,305,400 <sup>(a)</sup> |

(a) Did not fail.

(b) Failed on loading.

TABLE XXXV. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K<sub>t</sub>=3.0) SOLUTION-TREATED AND AGED T1-6A1-2Zr-2Sn-2Mo-2Cr ALLOY PLATE (TRANSVERSE)

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| •                                     | Specimen<br>Numb <b>e</b> r | Maximum<br>Stress, ksi | Lifetîme,<br>cycles                    |                |
|---------------------------------------|-----------------------------|------------------------|--|----------------|
| e e e e e e e e e e e e e e e e e e e |                             | Room Temperature       | ······································ |                |
|                                       | 5-31                        | 120.0                  | 1,590                                  |                |
|                                       | 5-32                        | 100.0                  | 5,780                                  | • • • •<br>•   |
|                                       | 5-33                        | 90.0                   | 7,700                                  |                |
|                                       | 5-34                        | 80.0                   | 11,100                                 | •              |
| 1                                     | 5-38                        | 75.0                   | 24,800                                 |                |
|                                       | 5-35                        | 70.0                   | 133,400                                |                |
|                                       | 5-36                        | 60.0                   | 400,250                                |                |
| ·                                     | 5-37                        | 50.0                   | 813,600                                |                |
|                                       | 5-41                        | 45.0                   | 1,135,800                              |                |
|                                       | 5-40                        | 40.0                   | 10,624,900 <sup>(a)</sup>              |                |
|                                       |                             | <u>400 F</u>           |  |                |
|                                       | 5-46                        | 75.0                   | 9,500                                  |                |
|                                       | 5~47                        | 70.0                   | 27,600                                 |                |
|                                       | 5-48                        | 65.0                   | 39,900                                 | • <sup>1</sup> |
|                                       | 5-49                        | 60.0                   | 67,000                                 |                |
|                                       | 5~50                        | 55.0                   | 124,000                                |                |
|                                       | 5-51                        | 50.0                   | 1,846,000                              |                |
|                                       | 5~53                        | 40.0                   | 1,568,200                              |                |
|                                       | 5-54                        | 30.0                   | 16,000,000 <sup>(a)</sup>              |                |
|                                       | · .                         | <u>600 F</u>           |  |                |
|                                       | 5-39                        | 80.0                   | 2,530                                  |                |
|                                       | 5-40                        | 70.0                   | 9,100                                  |                |
|                                       | 5-42                        | 60.0                   | 25,480                                 |                |
|                                       | 5-45                        | 55.0                   | 361,150                                |                |
|                                       | 5-43                        | 50.0                   | 366,120                                |                |
|                                       | 5-53                        | 40.0                   | 1,417,600                              |                |
|                                       | 5 - 55                      | 30.0                   | 14,718,600 <sup>(a)</sup>              |                |

(a) Did not fuil.

SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR SOLUTION-TREATED AND AGED Ti-6A1-2Zr-2Sn-2Mo-2Cr ALLOY PLATE (TRANSVERSE) TABLE XXXVI.

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| Specimen            | Stress. | Temper-<br>ature. | Hours to            | Indicate            | d Creep lent        | Deformati           | •uo             | Initial<br>Sțrain, | Rupture<br>Time,      | Elongation<br>in 2 Inches, | Reduction<br>of Area, | Minimum<br>Creep Rate, |
|---------------------|---------|-------------------|---------------------|---------------------|---------------------|---------------------|-----------------|--------------------|-----------------------|----------------------------|-----------------------|------------------------|
| Number              | ksi     | ۲.<br>۲.          | 0.1                 | 0.2                 | 0.5                 | 1.0                 | 2:0             | percent            | hours                 | percent                    | percent               | percent                |
|                     | 676     | 007               |                     |                     |                     |                     |                 |                    | On Loading            | 13 E                       | 47.7                  | !                      |
| ר ה<br>איר<br>ג     | 142     | 400               |                     | 0.03                | 0.7                 | : :                 |                 | 3.725              | 353.7(b) <sup>b</sup> | 4.302                      |                       | 0.00005                |
| 3-6                 | 120     | 400               | 0.10                | 550                 |                     | ł                   | . <b>I</b><br>1 | 1.180              | 574.5 <sup>(b)</sup>  | 1.400                      | -                     | 0.00004                |
| 3_)                 | 133     | 600               | :                   | ł                   | 1                   | !                   | :               | 1                  | On Loading            | 1                          | <b>1</b><br>1         | ł                      |
| <br>                | 128     | 600               | 0.05                | 10                  | 4000 <sup>(a)</sup> | 1                   | ł               | 2.980              | 643.9(b)              | 3.280                      | 8                     | 0.000055               |
| 0 <b>1-</b> 0<br>77 | 120     | 600               | 3.5                 | 100                 | ł                   | 1                   | I<br>I          | 1.940              | 382.3(0)              | 2.168                      | 1                     | ;                      |
| 3-7                 | 110     | 600               | 1350 <sup>(a)</sup> | 1                   | 1                   | L<br>L              | ł               | 1.260              | 365.7 (")             | 1.332                      |                       |                        |
| 3-11                | 130     | 800               | ł                   | :                   | ł                   | 1                   | ł               | ł                  | On Loading            | 13.6                       | 48.3                  | ;                      |
| 3-9                 | 120     | 800               | 0.1                 | 0.3                 | 1.5                 | 6.2                 | 21              | 2,408              | 504.9, 1              | 11.2                       | 21.5                  | !                      |
| 3 -8                | 100     | 800               | 9                   | 10                  | 175                 | 2200 <sup>(a)</sup> | !               | 0.992              | 504.4 <sup>(D)</sup>  | 1.731                      | :                     | 0.0004                 |
| 3-1                 | 50      | 800               | 320                 | 2200 <sup>(a)</sup> | 7500 <sup>(a)</sup> | 1                   | ;               | 0.456              | 841.0 <sup>(U)</sup>  | 0.584                      | 4                     | 0.000056               |

(a) Estimate.

(b) Test discontinued.

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FIGURE 42. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED TI-6A1-2Zr-2Sn-2Mo-2Cr PLATE (LONGITUDINAL)

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FIGURE 43. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURES FOR SOLUTION-TREATED AND AGED T1-6A1-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

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FIGURE 44. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR SOLUTION-TREATED AND AGED T1-6A1-2Zr-2Sn-2Mo-2Cr PLATE (LONGITUDINAL)



FIGURE 45. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR SOLUTION-TREATED AND AGED TI-6A1-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSION)

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FIGURE 46. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION-TREATED AND AGED Ti-6A1-2Zr-2Sn-2Mo-2Cr PLATE



FIGURE 47. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION-TREATED AND AGED Ti-6A1-2Zr-2Sn-2Mo-2Cr PLATE



FIGURE 48. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION-TREATED AND ACED T1-6A1-22r-2Sn-2Mo-2Cr PLATE (TRANSVERSE)



FIGURE 49. AN TAL LOAD FATICUE BEHAVIOR OF NOTCHED ( $K_{t} = 3.0$ ) SOLUTION-TREATED AND AGED TI-6Al-22r-2Sn-2Mo-2Cr PLATE (TRANSUERSE)



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#### Ti-6Al NV-23n Isothermal Die Forgings

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#### Material Description

This is a heat-treatable alpha-beta type alloy similar in many respects to Ti-6Al-4V, but containing increased content of beta-stabilizing elements which provide higher strength potential.

The material used for this evaluation was made by IIT Research Institute under Air Force Contract F33615-67-C-1722. It consisted of structural shapes and nose wheels that were isothermally creep (slow speed) forged from flat preforms machined from conventionally forged Ti-6A1-6V-2Sn alloy billets.

#### Processing and Heat Treating

The material was received with no heat treatment after forging. Specimens were solution treated at 1650 F for 1/2 hour, water quenched, and aged at 1050 F for 4 hours and air cooled as suggested by IIT Research Institute. Other heat treatments designed for lower UTS and higher toughness should be considered for other applications.

Since the material was of complex shapes, it was necessary to cut specimens from various positions and no specimen layout drawing is shown.

#### Test Results

Tension. Test results for transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XXXVII. Typical stress-strain curves at temperature are presented in Figure 51. Effect of temperature curves are shown in Figure 53.

<u>Compression</u>. Results of tests on transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XXXVIII. Typical stress-strain and tangent-modulus curves at temperature are shown in Figure 52. Effect of temperature curves are shown in Figure 54.

Shear. Pin shear test results at room temperature for longitudinal and transverse specimens are given in Table XXXIX.

Impact. Test results for longitudinal and transverse specimens at room temperature are given in Table XL.

Fracture Toughness. Slow-bend tests were attempted, but the material thickness was not sufficient to obtain large specimens. The candidate  $K_0$  values did not meet ASTM criteria and are not reported. Results of tests on compact tension specimens at AFML are reported in the data sheet in Appendix III.

Fatigue. Axial load tests were conducted at room temperature, 400 F, and 700 F for both unnotched and notched transverse specimens at a stress ratio of R = 0.1. Tabular test results are given in Tables XLI and XLII. S-N curves are presented in Figures 55 and 56.

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Creep and Stress Rupture. Test results for transverse specimens at 700 F and 900 F are given in Table XLIII. Tests were attempted at 400 F and 550 F, but no appreciable creep occurred. Log-stress versus log-time curves are presented in Figure 57.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

<u>Thermal Expansion</u>. The coefficient of thermal expansion for this alloy is  $5.3 \times 10^{-6}$  in /in./F from 70 F to 900 F.

Density. The density value for this alloy is 0.164 lb./in.<sup>3</sup>.

#### TABLE XXXVII. TENSION TEST RESULTS FOR SOLUTION-TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGING (TRANSVERSE)

| Specimen<br>Number | Sti    | Ultimate<br>Tensile<br>rength, ksi | 0.2 Percent<br>Offset Yicld<br>Strength, ksi | Elongation,<br>in 1 Inch,<br>percent | Tensile<br>Modulus,<br>10 <sup>6</sup> psi |
|--------------------|--------|------------------------------------|--|--------------------------------------|--|
|                    |        |                                    | Room Temperature                             | · · ·                                | _  |
| 5                  |        | 203.3                              | 194.1  | 3.0                                  | 14,9                                       |
|                    |        | 199,6                              | 188.6  | 7.0                                  | 16.0                                       |
| 13                 |        | 204.5                              | 196.1  | 4.0                                  | 17.0                                       |
| A                  | verage | 202.5                              | 192.9  | 4.7                                  | 16.0                                       |
|                    |        |                                    | <u>400 F</u>                                 |                                      |  |
| 7                  |        | 171.6                              | 154.8  | 7.0                                  | 15.4                                       |
| 8                  |        | 174.0                              | 152.0  | 9.0                                  | 14.1                                       |
| 9                  |        | 165.5                              | 152.7  | 7.0                                  | 14.7                                       |
| A                  | verage | 170.4                              | 153.2  | 7.7                                  | 14.7                                       |
|                    |        |                                    | 700 F  |                                      |  |
| 10                 |        | 154.7                              | 134.4  | 12.0                                 | 13.0                                       |
| 11                 |        | 155.7                              | 132.8  | 8.0                                  | 13.3                                       |
| 12                 |        | 164.8                              | 128.2  | 5.0                                  | 13.0                                       |
| A                  | verage | 158.4                              | 131.8  | 8.3                                  | 13.1                                       |
|                    |        |                                    | 900_F  |                                      |  |
| 15                 |        | 137.4                              | 82.4   | 23.0                                 | 11.5                                       |
| 16                 |        | 143.6                              | 87.5   | 20.0                                 | 12.4                                       |
| 17                 |        | 119.7                              | 70 <b>.9</b>                                 | 23.0                                 | 12.4                                       |
| A                  | verage | 133.6                              | 80.3   | 22.0                                 | 12.1                                       |

.

| Specimen<br>Number      | 0.2 P<br>Yiel    | ercent Offset<br>d Strength,<br>ksi | Compre  | ssion Modulus,<br>10° psi |
|-------------------------|------------------|-------------------------------------|---------|---------------------------|
|                         |                  | Room Temperature                    |         |                           |
| 2T-1<br>2T-2<br>2T-3    |                  | 202.6<br>200.1<br>195.2             |         | 18.0<br>18.5<br>17.6      |
|                         | Average          | 199.3                               | Average | 18.0                      |
|                         |                  | 400 F                               |         |                           |
| 2T-4<br>2T-5<br>2T-6    |                  | 170.6<br>172.2<br>180.0             |         | 16.6<br>16.0<br>15.7      |
|                         | Average          | 174.3                               | Average | 16.1                      |
|                         |                  | 700 F                               |         |                           |
| 2T-7<br>2T-8<br>2T-9    |                  | 156.6<br>150.0<br>152.3             |         | 12.0<br>13.6<br>14.0      |
|                         | Average          | 152.9                               | Average | 13.2                      |
|                         |                  | 900 F                               |         |                           |
| 2T-10<br>2T-11<br>2T-12 |                  | 101.2<br>110.0<br>112.0             |         | 12.0<br>12.2<br>11.6      |
|                         | Ave <b>rag</b> e | 107./                               | Average | 11.9                      |

## TABLE XXXVIII.COMPRESSION TEST RESULTS FOR SOLUTION-TREATED AND AGEDT1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)



#### TABLE XXXIX. SHEAR TEST RESULTS AT ROOM TEMPERATURE FOR SOLUTION-TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS

| Specimen<br>Number |              | U1<br>St | timate Shear<br>rength, kai |
|--------------------|--------------|----------|-----------------------------|
|                    | Longitudinal |          |                             |
| 4L-1               |              |          | 131.0                       |
| 4L - 2             |              |          | 132.0                       |
| 4L-3               |              |          | 131.7                       |
| 4L-4               |              |          | 131.6                       |
|                    | Αν           | erage    | 131.6                       |
|                    | Transverse   |          |                             |
| 4 <b>T</b> -1      |              |          | 130.0                       |
| 4T-2               |              |          | 130.0                       |
| 4 <b>T</b> -3      |              |          | 130.1                       |
| 4T-4               |              |          | 130.0                       |
|                    |              |          |                             |
|                    | Av           | erage    | 130,0                       |

### TABLE XL. IMPACT TEST RESULTS FOR SOLUTION-TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS

| Specimen<br>Number               |             | Energy,<br>ft. 1 <b>bs</b> . |
|----------------------------------|-------------|------------------------------|
| <u>L</u>                         | ongitudinal |                              |
| 10L-1<br>10L-2<br>10L-3<br>10L-4 |             | 12.0<br>11.0<br>11.0<br>11.7 |
|                                  | Average     | 11.7                         |
|                                  | Transverse  |                              |
| 10T-1<br>10T-2<br>10T-3<br>10T-4 |             | 8.5<br>9.0<br>8.0<br>8.5     |
|                                  | Average     | 8.5                          |

->



## TABLE XLI.AXIAL LOAD FATIGUE TEST RESULTS FOR<br/>UNNOTCHED SOLUTION-TREATED AND AGED<br/>T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS

| Specimen<br>Number | Maximum<br>Stress, ksi | Lifetime,<br>cycles       |
|--------------------|------------------------|---------------------------|
|                    | Room Temperature       |                           |
| 5-1                | 100.0                  | 4,700                     |
| 5-2                | 100.0                  | 15,300                    |
| 5-3                | 90.0                   | 15,500                    |
| 5-4                | 80.0                   | 15,300                    |
| 5-6                | 70.0                   | 19,900                    |
| 5-5                | 60.0                   | 25,800                    |
| 5-7                | 50.0                   | 35,990                    |
| 5-17               | 40.0                   | 12,679,200 <sup>(a)</sup> |
|                    | 400 F                  |                           |
| 5-8                | 80.0                   | 15,900                    |
| 5-9                | 70.0                   | 19,900                    |
| 5-10               | 60.0                   | 100,400                   |
| 5-11               | 50.0                   | 3 <b>0,70</b> 0           |
| 5-18               | 40.0                   | <b>100,</b> 700           |
| 5-19               | 30.0                   | 10,452,600 <sup>(a)</sup> |
|                    | <u>700 F</u>           |                           |
| 5-12               | 80.0                   | 18,000                    |
| 5-13               | 70.0                   | 30,200                    |
| 5-14               | 60.0                   | 27,500                    |
| 5-15               | 60.0                   | 38,900                    |
| 5-16               | 50.0                   | 3,161,100 <sup>(b)</sup>  |
| 5-20               | 40.0                   | 11,436,800 <sup>(a)</sup> |
|                    |                        |                           |

(a) Did not fail.

(b) Grip failure.

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# TABLE XLII.AXIAL LOAD FATIGUE TEST RESULTS FOR<br/>NOTCHED (K, = 3.0) SOLUTION-TREATED<br/>AND AGED TI-6A1-6V-2Sn ISOTHERMAL DIE<br/>FORGING S

| Specimen<br>Number | Maximum<br>Stress, ksi | Lifetime,<br>cycles       |
|--------------------|------------------------|---------------------------|
|                    | Room Temperature       |                           |
| 5-35               | 70.0                   | 3,900                     |
| 5-31               | 60.0                   | 16,200                    |
| 5-32               | <b>50.</b> 0           | 26,300                    |
| 5-33               | 40.0                   | 244,000                   |
| 5-34               | 30.0                   | 8,134,400                 |
| 5-21               | 25.0                   | 10,189,800 <sup>(a)</sup> |
|                    | 400 F                  |                           |
| 5-37               | 70.0                   | 9,400                     |
| 5-38               | <b>60.</b> 0           | 18,200                    |
| 5-40               | 55.0                   | 26,600                    |
| 5-39               | 50.0                   | 662,200                   |
| 5-41               | 45.0                   | 61,200                    |
| 5-36               | 40.0                   | 4,784,900                 |
| 5-20               | 35.0                   | 10,160,400 <sup>(a)</sup> |
|                    | 700 F                  |                           |
| 5-42               | 65.0                   | 6,100                     |
| 5-43               | 60.0                   | 7,800                     |
| 5-44               | 55.0                   | 19,700                    |
| 5-45               | 50.0                   | 56,400                    |
| 5-46               | 45.0                   | 120,700                   |
| 5=47               | 40.0                   | 86,.00                    |
| 5-48               | 35.0                   | 1,110,500                 |
| 5=49               | 30.0                   | 14,219,800 <sup>(a)</sup> |

(a) Did not fail.
|                         |                                    |   | L LIBR                                   | ARY                   |
|-------------------------|------------------------------------|---|--|-----------------------|
|                         | Minimum<br>Creep Rate,<br>percent  | 1.5<br>0.13<br>0.0050<br>0.000350                                 | 0.31<br>0.020<br>                        |                       |
|                         | Reduction<br>of Area,<br>percent   | 24.8<br>32.6<br>45.3<br>  | 73.2<br>81.0<br>                         |                       |
| ION-TREATED<br>ERSE)    | Flongation<br>in 2 ln.,<br>percent | 8.9<br>13.8<br>6.96<br>0.465                                      | 33.9<br>48.5<br>C.469<br>0.377           | · · · ·               |
| ES FOR SOLUT            | Rupture<br>Tíme,<br>hours          | Om Loading<br>2.6<br>59.8(h)<br>1007.8(b)<br>122.8(b)<br>935.5(b) | 27.6<br>624.3(b)<br>119.8(b)<br>937.5(b) |                       |
| PROPERTEI               | Initial<br>Strain,<br>percent      | 4.133<br>1.680<br>0.781<br>0.242<br>0.073                         | 0.446<br>0.350<br>0.138<br>0.173         |                       |
| D RU PTURE<br>SCTHERMAL | mation,<br>2.0                     | 0.70<br>11.0<br>180   | 5.2<br>77<br>                            |                       |
| REEP AN                 | befor                              | 0.25<br>2.5<br>47   | 2.0<br>28<br>                            |                       |
| DATA ON CI<br>Ti-6A1-61 | ated Creel<br>ercent<br>0.5        | 0.07<br>0.8<br>0.8<br>1000(a)<br>7500(a)                          | 0.7<br>6.0<br>5.000(a)                   |                       |
| SUMMARY I               | to Indica<br>0.2                   |   | 0.15<br>1.0<br>25<br>125                 |                       |
| XLITT.                  | Hours<br>0.1                       |   | 0.07<br>0.30<br>5.5<br>100               |                       |
| TABLE                   | Temper-<br>ature,<br>F             | 700<br>700<br>700<br>700<br>700                                   | 900<br>900<br>900                        | pene                  |
|                         | Stress,<br>ksi                     | 153.3<br>145<br>145<br>135<br>110<br>50<br>25                     | 30<br>30<br>3                            | disconti              |
|                         | Specimen<br>Number                 |   | 3-2<br>3-7<br>3-10<br>3-11               | (a) Estír<br>(b) Test |

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FIGURE 51. TYPICAL TENSILE STRESS-STRAIN CURVES FOR SOLUTION TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS

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FIGURE 52. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR SOLUTION TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS

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FIGURE 53. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS



FIGURE 54. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS



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FIGURE 55. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION-TREATED AND ACED T1-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)



FIGURE 56. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ( $K_{L} = 3.0$ ) SOLUTION-TREATED AND AGED Ti-6A1-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)



### DISCUSSION OF PROGRAM RESULTS

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The tendency in an evaluation program of this type is to compare the materials property information obtained with similar data on materials already in use. Whether such a comparison should be the deciding factor for interest in a newer alloy is open to question. Many criteria, such as forming characteristics, weldability, oxidation resistance, etc., can be of particular importance so that strength properties may become secondary. However, since first comparisons are usually made on the basis of mechanical strength (tensile ultimate and tensile yield), the data generated on this program are compared to information for similar alloys. Figures 58 and 59 are effect-of-temperature curves concerned with these properties.

### CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed materials. During the contract term, the following materials were evaluated

- (1) X2048-T851 Plate
- (2) 7050-I73651 Plate
- (3) 21-6-9 Annealed Sheet
- (4) Ti-8Mo-8V-2Fe-3A1 (STA) Sheet
- (5) Ti-6Al-2Zr-2Sn-2Mo-2Cr (STA) Plate
- (6) Ti-6A1-6V-2Sn STA Isothermal Die Forgings.

A data sheet was issued for each material. As a summary, each of the data sheets is reproduced in Appendix III.





TENSILE VIELD STRENGTH AS A FUNCTION OF TEMPERATURE

FIGURE 59.

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Tensile Yield Strength, ksi

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### APPENDIX I

### EXPERIMENTAL PROCEDURE

### APPENDIX I

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### EXPERIMENTAL PROCEDURE

### Mechanical Properties

The various mechanical properties of interest for each of the materials are as follows:

(1) Tension

- (a) Tensile ultimate strength, TUS
- (b) Tensile yield strength, TYS
- (c) Elongation, e,
- (d) Reduction in area, RA
- (e) Modulus of elasticity, E.
- (2) Compression
  - (a) Compressive yield strength, CYS
  - (b) Modulus of elasticity, E.
- (3) Creep and stress-rupture
  - (a) Stress for 0.2 or 0.5 percent deformation in 100 hours and 1000 hours
  - (b) Stress for rupture in 100 hours and 1000 hours.
- (4) Shear
  - (a) Shear ultimate strength, SUS
- (5) Axial fatigue\*
  - (a) Unnotched, R = 0.1, lifetime:  $10^3$  through  $10^7$  cycles

<sup>\* &</sup>quot;R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is,  $R = S_{min}/S_{max}$ . "K<sub>t</sub>" represents the Neuber-Peterson theoretical stress concentration factor.

(b) Notched ( $K_t = 3.0$ ), R = 0.1, lifetime: 10<sup>3</sup> through 10<sup>7</sup> cycles.

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(6) Fracture toughness,  $K_{Ic}$  or  $K_{c}$ 

- (7) Stress corrusion
  - (a) 80 percent TYS for 1000 hours maximum, 3-1/2 percent NaCl solution.
- (8) Thermal expansion.
- (9) Bend
  - (a) Minimum radius.

(10) Impact

(a) Charpy V-notch.

(11) Density.

### Specimen Identification

A simple system of numbers and letters was used for specimen identification. Coding consisted of a number indicating the type of test and also indicating a comparable area on the sheet, plate, or forging. For certain test types, the number was followed by a letter signifying specimen orientation (L for longitudinal, T for transverse, ST for short transverse). The test types where the letter did not appear were creep, fatigue, and bend since, in these cases, only one specimen orientation was used. The next number in the coding specifies the location from which the specimen blank was taken from the original material configuration. Coding was as follows:

| Assigned<br>Number | Test Type                |
|--------------------|--------------------------|
| 1                  | Tension                  |
| 2                  | Compression              |
| 3                  | Creep and stress-rupture |
| 4                  | Shear                    |
| 5                  | Fat i gue                |
| 6                  | Fracture toughness       |



| Number_  | Test Type         |
|----------|-------------------|
| <b>7</b> | Stress corrosion  |
| 8        | Thermal expansion |
| 9        | Bend              |
| 10       | Impact            |
| 11       | Density           |

As an example, a specimen numbered 2-T5 is a compression specimen, transverse orientation, cut from Location 5. Also, a specimen numbered 5-12 is a fatigue specimen cut from Location 12.

### Test Description

### Tension

Procedures used for tension testing are those recommended in ASTM methods E8-68 and E21-66T as well as in Federal Test Method standard No. 151a (method 211.1). Six specimens (three longitudinal and three transverse) were tested at each temperature to determine ultimate tensile strength, 0.2 percent offset yield strength, elongstion, and reduction in area. The modulus of elasticity was obtained from load-strain curves plotted by an autographic recorder during each test.

All tensile tests were carried out in Baldwin Universal testing machines. These machines are calibrated at frequent intervals in accordance with ASTM method E4-64 to assure loading accuracy within 0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

Specimens tested at elevated temperatures were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within 5 F of the control temperature over a 2-inch gage length. Chromel-Alumel thermocouples attached to the specimen gage section were used to monitor temperatures. Each specimen was soaked at temperature at least 20 minutes before being tested.

An averaging-type linear differential transformer extensioneter was used to measure strain. For elevated temperature testing, the extensioneter was equipped with extensions to bring the transformer unit out of the furnace. The extensioneter conformed to ASTM E3-64T Classification B1 having a sensitivity of 0,0001 inch/inch. The strain rate in the elastic region was maintained at 0,005 inch/inch/minute. After yielding occurred, the head speed was increased to 0.1 inch/inch/minute until fracture.

Compression

Procedures for conducting compression tests are outlined in ASTM Method E9-67 along with temperature control provisions of E21-66T. All sheet and this plate tests were carried out in Baldwin Universal testing machines using a North American type compression fixture as shown in Reference 2. Specimen heating was accomplished by a forced-air furnace for temperatures up to 1000 F. Specimen temperature was maintained by means of a Wheelco pyrometer. Three Chromel-Alumel thermocouples attached to the fixture were used to monitor temperatures to within 3 F of the test temperature. For higher temperatures, wire-wound furnaces were used with controls as described in the tensile test section.

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The extensioneter used for the compression tests was quite similar to that used in the tonsile testing. The extension arms were fastened to the specimen at small notches spanning a 2-inch gage length. The output from the microformer was fed into a load-strain recorder to provide autographic load-strain curves. During testing the strain rate was adjusted to 0.005 inch/inch/minute.

For bar and forging material, cylindrical specimens similar to those described in ASTM E9.67 were used with appropriate temperature control and strain measurement as described above.

Six spaciments (three longitudinal and three transverse) were tested at each temperature.

### Shear

Single-shear sheet-type specimens were used for sheet and thin-plate material; for bar and forgings, a double-shear pin-type was used. Shear testing was performed at room temperature only. A minimum of six specimens (three longitudinal and three transverse) were used to determine ultimate shear strength.

### Bend

The procedures for conducting band tests are described in keport MAB-192-M. The specimens were placed in a rigid three-point loading fixture and bending tups of various sizes were used to determine the minimum bend radius at room temperature.

### Creep and Stress Rupture

Standard dead-weight type creep testing frames were used for the creep and stress-rupture tests. These machines are calibrated to operate well within the accuracy requirements of ASTM method E139-66T. Specimens similar to those used for tension tests were used for the creep and stress-rupture studies. A platinum strip "slide rule" extensometer is attached for measuring creep strain and three Chromel-Alumel thermocouples are attached to the gage section for temperature measurements. Extensometer measurements were made visually through windows in the furnace by means of a filar micrometer microscope in which the smallest division equals 0.00005 inch.

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The furnace was of conventional Chromel A wire-wound design with taps along the side to allow for correcting small temperature differences. Furnace temperature was maintained to within  $\pm 2$  F by Foxboro controllers in response to signals from the centrally located thermocouple. The temperature of a specimen under test was stabilized for at least 1/2 hour prior to loading.

For each temperature condition creep and stress-rupture data were obtained to 10C and 1000 hours using as many specimens as necessary to obtain precise information. The percent creep deformation obtained was dependent on the material under test. In most instances stress-time curves were defined for 0.2 and 0.5 percent elongation.

### Stress Corrosion

Seven specimens of each alloy were tested for susceptibility to stresscorrosion cracking by alternate immersion in 3-1/2 percent sodium chloride solution at room temperature.

Specimens were prepared for testing by degreasing with acetone. Where a surface film remained from heat treating, it was abraded off one side and the adjacent long edge of five of the specimens, and left intact on the other two.

Each specimen was placed in a four-point loading fixture and deflected to a stress corresponding to 80 percent of the tensile yield strength of the particular material. The specimen was electrically insulated from the fixture by means of glass or sapphire rods. Deflection for a given maximum fiber stress was calculated by the following expression:

$$y = \frac{\sigma(3l^2 - 4a^2)}{12dE}$$

where

y = deflection

- $\sigma$  = maximum fiber stress
- L = distance between outer load points
- a = distance between outer and inner load points
- d = specimen thickness
- E = modulus of specimen material.

Each stressed specimen was suspended on an alternate immersion unit. This unit alternately immersed specimens in the 3.5 percent sodium chloride solution for ten minutes and held them above the solution to dry for 50 minutes. Tests were continued to the first sign of cracking or for 1000 hours, whichever occurred first.

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Specimens were given frequent low-power microscopic examinations to detect cracks. At the first sign of cracking the specimen was removed. At the conclusion of the test, selected samples were sectioned and examined metallographically for any indication of cracking. Representative samples in which cracks were found were also given a metallographic examination to establish the type and extent of the cracks.

### Thermal Expansion

Linear-thermal-expansion measurements were performed in a recording dilatometer with specimens protected by a vacuum of about  $2 \times 10^{-5}$  mm of mercury. In this apparatus a sheet-type specimen is supported between two graphite structures inside a tantalum-tube heater element. On heating, the differential movement of the two structures caused by specimen expansion results in the displacement of the core of a linear-variable differential transformer. The output of the transformer is reported continuously as a function of specimen temperature. The entire assembly is enclosed in a vacuum chamber.

The furnace is controlled to heat at the desired rate, usually 5 F per minute. Errors associated with measurements in this apparatus are estimated not to exceed + 2 percent. This is based on calibration with materials of known thermal-expansion characteristics.

### Fatigue

Fatigue tests were conducted using MTS electrohydraulic-servocontrolled testing machines. The frequency of cycling of these machines is variable to beyond 2,000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain or load control. Under load control used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals. The calibration and alignment of each machine are checked periodically. In each case, the dynamic load-control accuracy is better than  $\pm 3$  percent of the test load.

For elevated temperature studies, an induction heating coil controlled by a Lepel Induction Heater was used. A thermocouple placed on the center of the specimen controlled temperature to + 5 degrees.

After machining and heat treating (when required), the edges of all sheet and plate specimens were polished according to Battelle-Columbus' standard practice prior to testing. The unnotched specimens were held against a rotating drum covered with emery paper and polished using a kerosene lubricant. Successively finer grits of emery paper were used, as required, to produce a surface of about 10 RMS. Unnotched round specimens were polished in the Battelle-Columbus polishing apparatus. This machine utilizes a rotating belt sander driven rectilinearly along the specimen test section while the specimen is being rotated. The belt speed and specimen speed are adjusted so that polishing marks on the specimen are in the longitudinal direction. The surface finish is about the same as that on the flat specimens. The notched flat specimens were held in a fixture and polished with a slurry of oil and alundum grit applied liberally to a rotating wire. Notched round specimens are polished in the same manner, except that the specimen is rotated.

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A shadowgraph optical comparator was used for measuring the test sections of all polished specimens and for inspection of the root radius in the case of the notched specimens.

The stress ratio for all specimens was R = 0.1. Stresses for notched  $(K_t = 3.0)$  and unnotched specimens were selected so that S-N curves were defined between  $10^3$  and  $10^7$  cycles using approximately 10 specimens for each set of fatigue conditions.

### Fracture Toughness

Two types of fracture toughness tests were used. For heavy section materials, the chevron-notched, slow bend test specimen of ASTM Method E-399-72 was selected. For thinner section sheet materials, center through-cracked tension panels were used as test specimens. All specimens were precracked in fatigue and subsequently fractured in a servocontrolled electrohydraulic testing system of appropriate load capacity.

The slow-bend type specimens were precracked and tested under 3-point loading. The pop-in load for materials susceptible to brittle fracture was determined from the load-compliance curve. When pop-in was not detectable, the curves were analyzed using the 5 percent secant offset method of the ASTM procedure.

The thin sheet center through-crack tension panels were initially sawcut and then precracked in constant amplitude fatigue loading. In order to maintain a flat fatigue crack and not plastically strain the uncracked section, the maximum stresses were adjusted to keep the applied stress-incensity factor less than one-third or one-quarter of that anticipated at fracture. This usually involved stepping down the stresses as the cracking proceeded. The crack was extended to approximately one-quarter of the panel width. Buckling guides were attached and a clip-type compliance gage was mounted in the central notch. The panels were fractured in a rising load test at a stress rate in the range

.002 E < S < .005 E ksi/min

which corresponds nominally to the gross strain rate of standard tensile testing.

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### APPENDIX II

### SPECIMEN DRAWINGS



FIGURE 60. SHEET AND THIN-PLATE TENSILE SPECIMEN

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FIGURE 61. ROUND TENSILE SPECIMEN



2 Surface must be free from nicks and scratches









FIGURE 64. SHEET CREEP - AND STRESS-RUPTURE SPECIMEN

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FIGURE 65. ROUND CREEP - AND STRESS-RUPTURE SPECIMEN

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.



Note taper in gage section



FIGURE 68. UNNOTCHED SHEET FATIGUE SPECIMEN



FIGURE 70. UNNOTCHED ROUND FATIGUE SPECIMEN











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### FIGURE 72. SHEET FRACTURE TOUGH-NESS SPECIMEN



FIGURE 74. STRESS-CORROSION SPECIMEN



FIGURE 75. THERMAL-EXPANSION SPECIMEN



FIGURE 76. SHEET BEND SPECIMEN



FIGURE 77. NOTCHED IMPACT SPECIHEN

APPENDIX III

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DATA SHEETS

X2068-T851 Aluminum Alley

### Material Description

Alloy X2048-T651 is a recent development of the Reymolds Metals Company. The development aim was a trick section alloy with high conginess and stability at modetate temperatures. The goal was to achieve the strength, fatigue resistance, corresion resistance, and thermal stability of 2004-T851 or 2:24-T851 and the trughness of 2219.

The material used for this evaluation was 3-inch plate produced within the fullowing composition limits:

| 2.6 to 3.8 | 0.20 to 0.60 | 1.2 to 1.5 | 1.25 max | 0.10     | 0.15 max | 0.70 | 0.15 max     | Balance . |
|------------|--------------|------------|----------|----------|----------|------|--------------|-----------|
| Соррег     | Hang and Se  | Magnesium  | ZAMC     | Titerium | Silicon  | lran | Others total | Aluminum  |

## Processing and Neat Treating

The specimens were tested in the as-received -1851 temper.

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X2068-T851 Aluainue Allov Data (a)

Thickness: 3-inch plate

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|   |          | Temperal       | ture. F         |                   |
|---|----------|----------------|-----------------|-------------------|
| Properties                                      | RI<br>KI | - 250          | 350             | 200               |
|   |          |                |                 |                   |
| Tension   |          |                |                 |                   |
| Tris (lone(redteal), ksi                        | 66.3     | 60.1           | 51.4            | 34.0              |
| TUS (transverse), isi                           | 67.4     | 60-0           | 50.3            | 33.4              |
| TUS (short transverse), ksi                     | 67.1     | J.             | <b>ن</b> ا<br>ا | <b>د</b> :        |
| TYS (lomeitudinal), ksi                         | -7-09    | 56.8           | 49.1            | 31.7              |
| TYS (transverse), ksi                           | 60.9     | 56.3           | 4.8.8           | 31.6              |
| IVS (short transverse), ksi                     | 58.9     | 5              | د               | TH<br>C           |
| e (longitudinal), percent in 2 in.              | 8.3      | 12.7           | 14.2            | 5.6               |
| e (transwerse), percent in 2 in.                | 7.2      | 12.7           | 16.5            | 2.8               |
| e (short transverse), percent (n 2 in.          | 6.3      |                | <u>ب</u>        |                   |
| KA (longitudian), percent                       | 15.7     | 31.6           | 57.3            | 23.4 M            |
| RA (transverse), percent                        | 11.7     | 27.7           | <b>JK</b> .2    | EN                |
| RA (short transverse), percent                  | 4.2      | <u>ت</u>       | -               | т<br>С            |
| E (lome(rudiael), 10 <sup>b</sup> psi           | 10.2     | 9.9            | 9.3             |                   |
| E (transverse) 10 psi                           | 10.5     | 9.6            | 9.3             | 1.1               |
| E (short transverse), 10 <sup>6</sup> psi       | 11.1     | ت              | а               | اما <i>ر</i><br>د |
|   |          |                |                 |                   |
| Compression                                     |          |                |                 | BY                |
| CVS (Josepheredina)) had                        | 60.9     | 56.7           | 50.6            | TH A A            |
| CYS (transverse), ksi                           | 60.6     | 56.0           | 51.1            | -<br>             |
| E (longitudinal). 10 <sup>6</sup> psi           | 11.3     | 10.2           | 9.6             |                   |
| E (cremswerse), 10 <sup>6</sup> p3i             | 11.1     | 10.3           | 9.7             |                   |
| (9)   |          |                |                 |                   |
| Wear .  |          |                |                 | RO                |
| SUS (loweitudinal), ksi                         | 39.3     | ()<br>()       |                 |                   |
| SUS (transverse), ksi                           | 39.2     | <u>ب</u>       | £               |                   |
| (P)   |          |                |                 |                   |
|   |          |                |                 | ₽A<br><b>?</b>    |
| V-motch Charpy, ft. 1b.                         |          |                |                 | CE<br>Y<br>JM     |
| (longicudical)                                  | \$ V     | <b>9</b> 2     | <u>،</u> ب      |                   |
|   | ;        | J              | •               | ,                 |
| Fracture Toughness (e)                          |          |                |                 |                   |
|   | 0 66     | -              |                 |                   |
| K <sub>1c</sub> , crack direction IL, hat . in. | 29.1     | <del>ر</del> , | د :             | <u>د ،</u>        |
| -   |          |                |                 |                   |

## X2048-T851 Aluminum Alloy (continued)

|   |  | Temperatur                                      | e. F                     |                 |    |
|---|--|---|--------------------------|-----------------|----|
| Properties  | RT   | 250   | 350                      | 200             |    |
| Awial Fatigue (longitudinal) (f)  |  |   |                          |                 |    |
| <b>Unnutched, R = 0.1</b>   |  |   |                          |                 |    |
| 10° cycles, ksi   | 63   | 63  | 63                       | 5               |    |
| 10 <sup>t</sup> cvcles, ksi   | 38   | 37  | 35                       | a               |    |
| 10° cycles, ksi   | 32   | 28  | 25                       | ъ <sup>г</sup>  |    |
| Notched, K, = 3.0. K = 0.1  |  |   | ÷                        |                 |    |
| lu <sup>n</sup> evelés, ksi   | 54   | 54  | 50                       | :1              |    |
| lo cvcles, ksi  | 22   | 21  | 61                       | <del>ت</del>    |    |
| lo cycles, ksi  | . 16   | 14  | 12                       | <u>.</u>        | ۰. |
| (reep_(long)tudinal)  |  | <br>  | ,4                       |                 |    |
|   | (c)  |   | :¶<br><br>               | 1.              |    |
| 0.2) plastic deformation, 100 Hr, Ksi   | AN<br>NA   | ŧ 3   | 61                       |                 |    |
| Stress-Rupture (largitudinal)   |  |   |                          |                 |    |
| Rupture, 104 hr, ksi  | NA   | 20  | 39                       | 13              |    |
| Rupture, 1000 hr. Asi   | NA.  | 41  | <b>7</b> 5               | <b>^</b> •<br>7 |    |
| Stress (orrosion (g)  | •  |   |                          |                 |    |
| 80: TVS, 1000 hr maximum  | no cracks  |   |                          |                 |    |
| Coefficient of Th <u>ermal Expansion</u>  | a  | •   |                          |                 |    |
|   |  |   |                          |                 |    |
| Dunsity   |  |   |                          |                 |    |
| .0994 lb/in <sup>3</sup>  |  |   |                          |                 |    |
| <ul> <li>(a) Values are average of triplicate tests<br/>contract unless otherwise indicated.</li> </ul> | <ul> <li>Aducted at</li> <li>Fatigue, creep</li> </ul> | Battelle unde<br>, and stress-<br>ater number o | r the subj<br>rupture va | eet<br>lues     |    |
|   | autes of a Ber   | >   |                          |                 |    |

Double-shear pin-type specimen; average of 4 tests in each direction. (4)

U. unavailable; NA, not applicable. ં

Values are average of 6 tests in each direction. Ð

- Values are average of 6 slow-bend type tests in each direction. Specimen size was 1.000-inch thick by 2.000 inches wide with a span of 8 inches. (Higher Ki values may be achieved with larger specimens. Reference J. G. Kaufman, "Notes for E-24.01 Meeting", held at Battelle's Columbus Laboratories on October 4. 1972. 3
- "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle: that is,  $R = S_{min}^{M/S} / S_{max}$ . "K<sub>k</sub>" represents the Neuber-Peterson theoretical stress concentration factor. 6
- Room-feaperature three-point bend test. Alternate immersion in 3-1/2% NaCl. (£)



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7050-173651 Aluminum Alloy

### Material it scription

Allow 7050 is an Al-Gn-We-Ku alloy developed by the Alcom Research Laboratories supported by the Xaval Air Systems command and the Air Force Paterials Laboratory. When heat treated and aged to the -T.3 temper, thick 3050 of and hand forgines of Nibits Strengths equal to or intereding these of 7079-16XX products or mich improved functors the grant to not intereding these of 7079-16XX products or mich improved functors the grant of the first statement of 7-73X strive alterium alloys in that interment is added and chunk monthemil are restricted in order to minize grant sensitivity.

The riterial used in this evaluation was fiinch plate from Heat S-w16420 produced within the following encloseftion limits:

| 2.0 co 2.8<br>0.15 max<br>0.12 max<br>0.12 max<br>0.10 max<br>1.9 to 2.6<br>1.9 to 2.6 | 0.04 max<br>0.06 max<br>Balance . |
|--|-----------------------------------|
| Copper<br>Iruc:<br>Salicon<br>Manzanuse<br>Manzanuse<br>Zinu:                          | Chr.vniue<br>Titanium<br>Aluminum |

### 11 Processing and Heat Treating

Spicimons were tested in the as-received +173651 temper.

# 2050-173651 Aluminum Alloy Data

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## Thickness: 1-inch plate

|   |       | Tesnerati     | ure. F   |              |             |
|---|-------|---------------|----------|--------------|-------------|
| Properties                                      | R     | 250           | 350      | 50<br>20     |             |
| lention   | ;     |               | •        |              |             |
| The (longenting) kei                            | 82.6  | 65-0          | 1.66     | 21.2         |             |
| TI'S (redoverse), that                          | 81.5  | 64.5          | \$3.5    | 20.9         |             |
| TYS (longirudinal), ksi                         | 73.E  | 5.79          | 53.5     | 20.9         |             |
| Tis (transverse), ksi                           | 72.5  | 1.10          | 53.3     | 20.8         |             |
| <pre>e (longitudinal), percent in 2 in.</pre>   | 11.7  | 2.41          | 16.8     | 9.5          |             |
| e (transverse), percent in 2 in.                | 10.5  | 13.3          | 14.7     | 23.5         |             |
| RA (longitudinal), percent                      | 30.2  | 48.1          | 58.1     | 31.0         |             |
| RA (rransverse), bergent                        | 24.5  | <u>18.</u> 7  | 47.8     | 19.8         |             |
| F (Inneitudinal), 10° psi                       | 10.3  | 9.4           | 8.7      | 8.4          | TH          |
| E (transverse), 10 psi                          | 11.5  | 5.7           | с.<br>а) | 6°.7         | -115        |
| Conpression                                     |       |               |          |              | ТЕ          |
| CYS (longitudinal), ksi                         | 73.0  | 6. ja         | 53.7     | 20.9         |             |
| CVS (transverse), ksi                           | 75.3  | 66.1          | 55.1     | 22-10        | ат н<br>С Н |
| E (longftudinal), 10° p≤i                       | 10.6  | 6.0           | 9.1      | 20           |             |
| c, (transverse). 10 psi                         | 11.0  | <b>10</b> .0  | 4.6      | 0.0          |             |
| Shear (b)                                       |       |               |          |              |             |
|   |       | (6)           |          | ;            | BY          |
| STS flong[tudinal], ksi<br>ere (erenerator) kei | 1.8.1 | یر د <u>.</u> | 22       | ا A<br>رد را | A           |
|   |       | •             |          | 88           | Ē           |
| Irpact (d)                                      |       |               |          | OTT          | АВЕ         |
| V-notch Charpy, ft. 1b.                         |       |               |          | AE           |             |
| (longitudinal)                                  | 34.7  | ::            |          | RD           | B           |
| (transverse)                                    |       | ,             | <b>.</b> | )SF          | AE<br>F     |
| Fracture Toughness                              |       |               |          | PAC          |             |
| Kic. L-T. kst in.                               | 5.7   | 1             | <br>د با | E.C          | R           |
| <sup>h</sup> lc, L-I, Ksi, in.                  |       | •             |          |              | Y           |
| Axial Farigue (reansverse)                      |       |               |          | Л            | E           |
| Ennotched, R = 0.1                              |       |               |          | :            |             |
| 10° cycles, kst                                 | ċ     | 00            | 2        | _ :          |             |
| 10 cvcles, kgi<br>10 loc bei                    | 77    | 20            | 1 2      | . u          |             |
| IC CACIES WEI                                   | ;     |               | -        |              |             |
| Notched, $K_c = 5.0$ , $k = 3.1$                | ;     |               | •        | :            |             |
| 10 <sup>7</sup> evelve, ksi<br>toi evelve kei   |       | : 91          | ; £      | سو د.        |             |
| In cycles, ksi                                  | 2     | 11            | e.       | <b>.</b>     |             |
|   |       |               |          | ,            |             |

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7050-173651 Alumin = Alloy inte (continued)

|   |             | Temperat | ure. F |     |
|---|-------------|----------|--------|-----|
| Properties                                  | I           | 550      | 350    | ŝ   |
| <u>Creep (transverse)</u>                   |             |          |        |     |
| 0.2% plastic deformation, 100 hr. ksi       | (c)<br>M(c) | 64       | 21     | ~   |
| 0.27. plastic deformation, 1000 hr, ksi     | <b>1:4</b>  | ŝ        | 13.5   | 3.5 |
| <u>Stress-Rupture (transverse)</u>          |             |          |        |     |
| Mupture, 100 hr, ksi                        | ž           | 23       | 26     | 7.5 |
| Rupture, 1000 hr, ksi                       | 1           | 47       | 17     | 4.5 |
| <u>Stress Corroston</u> (g)                 |             |          |        |     |
| 80% TYS, 1000 hr maximum                    | no cracks   |          |        |     |
| Coefficient of Thereal creansion            |             |          |        |     |
| 12.6 x 10 <sup></sup> 11/1n/F (68 to 212 F) |             |          |        |     |
| <u>Dens1cy</u>                              |             |          |        |     |
| C.102 1b/10 <sup>2</sup>                    |             |          |        |     |
|   |             |          |        |     |
|   |             |          |        |     |

(a) Using any inverse of triplicate tests conducted at Eattelle under the subject contract unless otherwise indicated. Fatigue, creep, and streasrepture values are from curves generated using the results of a greater number of tests.

118

(b) Druble-shear pin-type spectmen; average of 4 tests in each direction.

(c) // unavailable; A4, nut applicable.

(d) Average of 6 tests in each direction.

(e) Values are average of 6 slot-tend type tests in each direction. Specimen size was 1.000-much thick by 2.000 inches wide with a span of 8 inches. (f) "R" represents the algebraic ratio of viniaum stress to maximum stress in one cycle: that is,  $R=S_{min}/S_{max}$ . "K" (spresents the **Deuter-Peterson** theoreclical stress concentration factor.

1.) Ave-traperature three-point bead test. Alternate immersion in 3-1/22 MaCL.



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TESO-173651 ALCHING ALLON ALLON



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Unrotched Yigmswense R=GI

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ANTAL TOAD FATEGE BERAVIOR OF NOTCHED (K<sub>6</sub>=3.0) 2050-173551 ARIMINY FLATE (TRANSVERSE) FICTRY 4.

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Litetime, cycles

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ZI-u-9. Stainleys Stort Alloy

### Raterial Description

Alloy 21-6-9 is a recent Jevelopment of the Armaco Steel Corporation. It is an autivitie stainless steel, combining high yield strength with good correction resistance. The river traperature yield strength of 21-6-9 is superior or Types 136, 312, and 347. It has good elevated temperature properties and retains high strength art toughness at subzero temperatures.

Armoo 21-6-9 stainless steel is available in standard finishes in annealed of high tensife temper sheet and atrip as well as in bar, wire. forging billets, and plate. The material used in this evaluation was an U.072-inch thick sheet produced within the following composition limits:

| 0.08 max | <b>5.00 - 10.00</b> | 0.060 max  | 0.030 xxxx | 1.00 Dax | i9.00 - 21.50 | 5.50 - 7.50 | 0.15 - 0.40 | Ralance . |
|----------|---------------------|------------|------------|----------|---------------|-------------|-------------|-----------|
| Carbon   | Yangane se          | Phosphorus | Sulfur     | Silicon  | Chromium      | Xickel 34   | Natrogen    | Ison      |

## Privesing and that freating

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the allow was evaluated in the as-received annealed condition.

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2<u>1-6-9 - 86, apply app. 56 col. 246.5</u>

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Condition: Annealed Thickness: 0.072-inch sheet 

|  |                 | Tenperate     | ۲, ۳<br>۲, |          |
|--|-----------------|---------------|------------|----------|
| croperties   |                 | 4.09          | 062        | 606      |
|  |                 |               |            |          |
|  |                 |               |            |          |
| TUS (lomeitudinal), ksi  | 113.0           | 88.1.         | 83.7       | 76.1     |
| TUS (transverse), Ast  | 113.3           | 2.44          | 83.2.      | 74.5     |
| The The Transitional State in the test   | 8. <del>1</del> | 12.5          | 35.9       | 33.0     |
| DS (rransverse), ksi   | 65.7            | 12.7          | 35.4       | 33.2     |
| e (lonvitudinal), percent in 2 in.   | 55.9            | 2.52          | 45.5       | E 6.64   |
| e (transverse), bercent in 2 in.   | 59.0            | 42.0          | 11.8       | 21.3 6   |
| E (longitudinal), 10 pst   | 26.6            | 1.12.         | 21.7       | 14-2 D   |
| E (transverse), 10 <sup>7</sup> psi  | 28.4            | 19.9          | 16.4       | •        |
| Compression  |                 |               |            |          |
| Constructional) kei  | 67.2            | 1.62.         | \$0.5      |          |
| Contractions and the second se | 5 99            | 5 - 4 S       | 9.75       |          |
| F (]ongination]) ]/ Det  | 28.5            | 26.7          | 25.8       | 254      |
| E (transverse), 10 psi   | C- 62           | 28.8          | 26.5       | 22       |
| Shear (b)  |                 |               |            |          |
| SUS (longitudinal), ksi<br>SUS (transverse), ksi :   | 102.3<br>102.8  | ្តិ<br>ភូមិទេ |            | E AB     |
| Bernd (d)  |                 |               |            |          |
| Minimum Radius   | 31              | ų             | ى          |          |
| Fracture Toughness   |                 |               |            |          |
| K., T-L, ksi, Ia.  | (e)             | 2,            | <b>ب</b>   | <b>R</b> |
| Arial Fatigue (transverse) (1)   |                 |               |            | Y<br>M   |
| $\frac{1}{2}$ introf chird, $\mathbf{R} = 0.1$   | -               | e             | Ğ          | -        |
| 10 <sup>°</sup> cycles, ksi  | ទីខ             | 5             | 10         |          |
| 10 cycles, ksi<br>10 cycles, ksi   | 2 2             | 12            | 8          | ÷        |
|  |                 |               |            |          |
|  |                 |               |            |          |

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21-6-9-Stainless Steel Data (continued)

|  |                           | Temperat | ture, F          |         |
|--|---------------------------|----------|------------------|---------|
| Properties   | 13                        | 400      | 700              | 905     |
| Autal Lacigue (transverse) (continued)   |                           |          |                  |         |
| Motched, K <sub>c</sub> = J.O. R = P.J<br>10 <sup>°</sup> tyclev, ksi          | G                         | - 52     | n                | -       |
| ld <sup>i</sup> cycles, ksi<br>10° cycles, ksi                                 | 9.<br>19                  | 38       | 38               |         |
| Creep (flansweise)   |                           |          |                  |         |
| 0.2% plastic deformation. 200 hr. ksi<br>0.2% plastic deformation. 200 hr. ksi | ка <sup>т</sup> с).<br>ХА | 34       | е н              | ű       |
| Stress Rupture (transverse   | 2                         |          |                  |         |
| Rupture, 100 hr. ks:<br>Kupture, 1030 hr. ksi                                  | NA<br>NA                  | 65<br>67 | <b>đ</b> 3<br>82 | 72<br>9 |
| Stress Corresion (5)   |                           |          |                  |         |
| do INS. 2000 hr maximum  | nu cracks                 |          |                  |         |
| <u>Contincient of Thermal Expansion</u>  |                           |          |                  |         |
| 10 5 5 10 10 10 10 10 10 10 10 10 10 10 10 10                                  |                           |          |                  |         |

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7.283 Ib. in

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(a) Values are average of replicate tests conducted at battelle under the subject contrast unless otherwise foldicated. Fatigue, croop, and stress-rapture calles are into convergenerated using the results of a greater Here's Contracted

Sheet-shear type speciment average of 4 tests in each direction. Ē

 unavailable: NA. not applicable. , c ,

Specimens tested from RI to and F. No cracks. ĝ

inches link vith an EDV flaw in the center. The net vection yield street was greater than the tensule vield strength of the material; therefore, the K values obtained are considered <u>not valid</u>. Transverse spectrens tere cull sheet thickness by 13 inches wide by 35 3

"R" represents the algebraic rate, of minimum stress to maximum stress in the order that is  $R \to S_{\rm min}^{-1} S_{\rm min}^{-1} = N_{\rm min}^{-1} R_{\rm min}^{-1}$  where the the theorem is the stress concontration factor. 11)

Romatempositure interviewit bene test. Alternate interview in 3-1/2 NaCL. 3



<u>له</u> FLUCKE 1. EFFECT OF TEXPERATURE ON THE LENSTRE PROPRITIES ANNEALED 21-6-9 STAINLESS STEEL SHEET



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FLOCKE 4. ANIAL LOAD FALTCH E BEMANION OF NITCHED (N. 3.0) AXVEALED 21-6-9 STAINLESS STEEL SHEET





11-640-8V-2FE-3A1 ALLCY

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### Material Arectiption

THE The BY0-BV-ZFE-MA beta titanies allow is a recent development of THET. The alloy was selected for full-scale evaluation after confirming (by THET) that it could be melted by the consentional consenable electrode vacuum arc process. It shows producibility and property characteristics that make it suitable for a variety of alfricase applications. A variety of heat treatments are available to allow the designet to take advantage of its individual propertises of its generally good overall properties. Its short aging times and low density make it particularly desirable for some applications.

The material used in this craimation was from TIMET Huat K+5055 and was analyzed as follows:

| د.<br>ف     | 2.0  | 0.14                 | Balance . |
|-------------|------|----------------------|-----------|
| to Lubdenar | Iron | 0. ygen<br>Bi trogen | Titanium  |

## Processing and Meat Ireating

123

The "laterial was received in the solution treated condition. **Speci**mens were aged at 900 F for 6 hours. This condition is called the high strength, fully-aged condition.

## T1-8%0-8V-2Fe-JAL AIL y Data

Condition: Solution treated and aged 900 F) Thickness: 0.040-inch sheet

| 2roperties                          | R:      | 007   | 600   | 88                           |
|-------------------------------------|---------|-------|-------|------------------------------|
| uci sue                             |         |       |       |                              |
| The (Lowlending) bei                | 160.3   | 148-7 | 145.0 | 1.761                        |
| T'S (transverse), kei               | 174.7   | E.231 | 152.3 | 0-121                        |
| TYS (longitudinai), ksi             | 144.7   | 123.3 | 117.7 | 105.7                        |
| TVS (transverse), ksi               | L58.1   | 133.4 | 124.0 | 111.7                        |
| e (longitudinal), percent in 2 in-  | 11.7    | 9.0   | 1.1   | 18.7                         |
| e (transverse), percent in 2 in.    | 9.5     | 6.B   | 6.7   | 16.2                         |
| E (longitudinal) IC pri             | 13.6    | 13.3  | 12.4  | 11.6                         |
| E (treasverse), 10 psi              | 14.9    | 1.1   | 11.2  | 12.3                         |
| carpt es s l'on                     |         |       |       |                              |
| -                                   |         |       |       |                              |
| CTS (longitudinal), ksi             | 1.11.   | 140.7 | 1.961 |                              |
| CYS (transverse), ksi               | 191.7   | 153.7 | 151.7 | 1.96.1                       |
| E_ (longitudinal), 10 psi           | 15.9    | 14.5  | 14.2  | 12.5                         |
| E (transverse), 10 psi              | 16.9    | 1.41  | 9.41  |                              |
| liear (b)                           |         |       |       |                              |
|                                     |         | (?).  | :     |                              |
| SUS (l'mgitudinal), ksi             |         | \     |       |                              |
| SUS (transverse), ksi               | q '۲' I |       |       |                              |
| racture Toughness (d)               |         |       |       | <b>L</b><br>380 <sup>-</sup> |
|                                     | :       | :     | :     | T T'                         |
| K <sub>c</sub> , T-L, ksi/In.       | Ţ       |       | J     | ÅE                           |
| wind Fatigue (Transverse)(e)        |         |       |       | B                            |
|                                     |         |       |       | R<br>SP4                     |
| libortica, m - 0.1<br>10 curlet ksi | 1.18    | 138   | 001   |                              |
| In review het                       | ł       | 7.5   | 61    | Ē.                           |
| 10 cycles, ksi                      | •       | C;    | 60    |                              |
| Yorched [ = ],] 2 = ],]             |         |       |       | м                            |
|                                     | 501     | 8     | 96    | :<br>                        |
| la cycles, isi                      | 30      | 5     | . 25  | ر.<br>ا                      |
|                                     | ÷       |       | 5     | r.                           |

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Lisbin-AV ([fs-04] Alloy Data (continued)

|  |              | le apera   | ture, F | 1           |
|--|--------------|------------|---------|-------------|
| Prosperties                            | 16           | 153        | 200     | <b>20</b> 5 |
| Creep (Transverse)                     |              |            |         |             |
| 0.25 plastic deformation. 100 hr. ksi  | 1            | 70         | 27      | ~           |
| 0.27 plastic deformation, 1000 hr. ksi | \$           | <b>U</b> 7 | 20      | •           |
| Stress Rupture (Transverse)            |              |            |         |             |
| Rusture 100 hr. ksi                    | I            | 149        | 1       | £3          |
| Rupture 1000 hr. ksi                   | ž            | 147        | 100     | 26          |
| Stress Girinston                       |              |            |         |             |
| 60 TVS, 1000 hr ruximur                | n.<br>cracks |            |         |             |
|  |              |            |         |             |

## Coefficient of Thermal Expansion

5.3 x 10 in./in./F (ET to 800 F)

### Density

.175 lo/in.

124

- (a) "alues are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicate!. Fatigue, creep, and stress-tupture values are from curves generated using the results of a preater number of rests.
- (b) Sheet-shear type spectreat average of a tests in each direction.
- (c) U. unavailable; NA. not applicable.
- (J) Transverse spectrens were fall since thickness by 18 inches wide by 26 inches long with an EDM ilaw in the center.
  - (e) "R" represents the algebraic ratio of riangum stress to maximum stress in one cycle; that is R =  $S_{ain}(S_{ain} k_c)$  represents the Neuber-Potenson theoretic cal stress concentration factor.
    - Kummerature three-point bend test. Alternate inversion in 3-1/2. Nacl.



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Ti-641-22r-25a-240-2Cr Allur

### Material Description

This alloy is a recont development of RVI Corpany. It is an alpha-beta type alloy designed for deep hardenavility. Freli-finary information shows the material to have low density, high modulus, high coughness, and good producibility. Stremgth retention to 800 F is good.

The material used for this evaluation was a 1 1/2-inch thick plate from RML ingot number 890180

| try:             |     |     |     |     |     |      |          |      |       |       |  |
|------------------|-----|-----|-----|-----|-----|------|----------|------|-------|-------|--|
| following chemis | 5.8 | 2.1 | 8.1 | 2.0 | 1.9 | 0.21 | 0.06     | 0.02 | 0.010 | 0.012 |  |
| which had the    | IF  | S.  | Zr  | ₽   | ა   | 51   | Fe<br>Fe | U    | ×"    | 6     |  |

Additional information on this alloy is uvailable on work performed by 2341 Company under Wright Field Air Force Contract F33615-72-6-1152.

### Processing and Heat Treating 126

The plate product evaluated was alpha beta proceesed to develop a retined microstructure. The plate was received in the solution-iterated condition (1740 F, 1 hour, Air Cosled) condition. Specireus were then aged at 1000 f for 8 hours. It should be noted that header sections require oil or water quench to effectively solution treat the preduct.

Ti-641-225-250-240-2CF ALLUY DATA<sup>(3)</sup>

Condition: solution treated and aged Thickness: 1 1/2 inch plate

|   |       | Tenterat    | ure F        |                |
|---|-------|-------------|--------------|----------------|
| Properties                                | КŢ    | <b>U</b> U7 | Cu9          | VC8            |
| Tenston                                   |       |             | <br> <br>  . |                |
| TUS (longitudinal), ksi                   | 168.3 | 145.3       | 139.0        | 132.0          |
| TI'S (transverse), ksi                    | 158.7 | 146.0       | 1.961        | 132.0          |
| TTS (longitudinal), ksi                   | 155.5 | 116.0       | 107.0        | 101.2          |
| TYS (transverse), ksi                     | 150.6 | 119.7       | 108.7        | 104.0          |
| e (longitudiral), percent in I in.        | Id.0  | 19.5        | 18.5         | 21.3           |
| e (transverse), percent in l in.          | 17.7  | 19.7        | 18.2         | 21.0           |
| RA (longicudinal). percent                | 24.8  | 23.20       | K. 9         | 42.1F          |
| Ra.(transverse), percent                  | 26.2  | 77.00       | 13.3         | 41.40          |
| E (long(tudiral), lo psi                  | 17.9  | 15.4        | 15.6         | 1              |
| E (transverse), 10° psi                   | 17.8  | 16.2        | 16.0         |                |
| Compression                               |       |             |              |                |
| CYS (loneitudinal) hei                    | 169.7 | 1 961       | 0 413        |                |
| CIS transverse) hsi                       | 171.1 | 1.941       |              | PR             |
| E. (lockitudinal), 10                     | 10.1  | 16.7        |              | •••            |
| Ec (transverse), lf psi                   | 18.5  | 16.3        | 15.8         |                |
|   |       |             |              | =D<br>  (      |
| Shear (B)                                 |       |             |              | BY             |
| SUS (longitudinal), hst                   | 108.3 | (c).'       | :.           |                |
| SUS (transverse), ksi                     | 176.0 | ı.          | ·<br>.1      | B              |
| (p)                                       |       |             |              |                |
| Control Character In                      |       |             |              |                |
| (loczitudinal)                            | 13 4  | 1:          | •            |                |
| (transverse)                              | 15.3  | , : .       | , <b>1</b>   | R              |
| (r.)                                      |       |             |              | AI<br>BF       |
| Fracture Toughness                        |       |             |              | R<br>R<br>P    |
| KIC. L-T. ksi in.                         | n5.0  | • ,         | :J           |                |
| K <sub>lc</sub> . T-L. ksi ´in.           | 93.0  | .,          | :.           | F              |
| Arial fatieue (transverse) <sup>(f)</sup> |       | •           |              | AC<br>2)<br>CO |
| Unnotched, R=0.1                          |       |             |              | E<br>M         |
| 10° cycles, ksi                           | 196   | 159         | 134          |                |
| 10 <sup>-</sup> cycles, ksi               | 135   | 6.1         | -11-         |                |
| 10° cycles, ksi                           | 75    | - 75        | 75           |                |
|   |       |             | •            |                |
|   |       |             |              | :              |
|   |       | 2           | 5            |                |
| 10 CYCLES, KSL<br>10 cucles bot           |       | ¢ :         | 50.          | -              |
|   | 4     | -           | -            |                |

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T1-6AJ-22r-25n-2No-2Cr ALLOY DATA (Continued)

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|  | i         | Temperat | are. F |     |
|--|-----------|----------|--------|-----|
| Properties   | LL .      | 004      | 009    | 008 |
| <u>Creep (transverse)</u><br>0.22 plactic deformation - 100 br hei               | 1         |          |        |     |
| 0.2% plastic deformation, 1000 hr., ksi  | 1         | 118      | 31     | 8   |
| <u>Stress-Aupture (transverse)</u><br>Rupture, 100 br., kat                      | I         | 142      | 2(1    | 122 |
| Rupture, 1000 hr., ksi   | 1         | 141      | 151    | 119 |
| <u>šttess Cortosion</u> (8)<br>Bui 175, 1000 hr. martean                         | Jo cracks |          |        |     |
| Coefficient of Thermal Expansion<br>5.1 x 10 <sup></sup> in./in./f (68 to 500 F) |           |          |        |     |

<u>Densicy</u> 0.165 lb./in.<sup>2</sup>

- contract unless utherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests. (a) Values are average of triplicate tests conducted at Mattelle under the subject
- Denible-shear pin-type specimen; average of 4 tests in each direction. 3

127

- univailable; MA, not applicable. 3
- (d) Values are awrage of 6 tests in each direction.
- ie) These values do monomet the rightous  $A_{1}T_{1} \leq 2.5$  ( $\frac{R_{0}}{175}$ ) criteria. However, they are over 2.2 ( $\frac{50}{10}$ ) and should be considered good indicative  $T_{1c}$  values. Thy
- "K" represents the algebraic ratio of minimu≕ stress to maximum stress in one cycle: that us. R = S<sub>ala</sub>/S<sub>aax</sub>. "K<sub>c</sub>" represents the Meuber-Peterson theoretical stress concentration factor. e
- Rowm-trupersture three-point bend test. Alrernate immersion in J-1/2. NaCL. 3

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EFFCL OF TEPPERATURE OF THE CONFRESSION PROPERTIES OF SOLATION THEARID ALD ACED TE-6A1-22r-23o-20c PLATE FIGTRE 2.


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128

HishMandson (sothermal Die Forgings

## Vaterial "escription

This is a heat-treatable alpha beta type alloy similar in many respects to Ti-6Al-4V, but containing increased content of beta stabilizing elements which provide higher strength potential. The material used for this evaluation was made by 117 Research Institute unter Air Force Contract F33615-67-C-1722. It consisted of structural shapes and move wheels that were isothermally creep (show speed) forged from flat preforms rachined from convertionally forced T1-6A1-6V-2Sn alloy billets.

## Processing and Heat Treating

The material was received with no hear treatment after forging. Specimens were solution treated at 1450 F for 1/2 hour, water quenched, and aged at 1050 F for 2 hours and air cooled. This treatment was as suggested by IIT Research Institute.

and the second of the Condition: Solution treated and aged Thickness: Use forging of varying thickness Ti-6A1-6V-2Sn Allov Data 5 

| TensionTIS (transverse), ksiTIS (transverse), ksiTIS (transverse), ksie (transverse), percent in 1 in.e (transverse), percent in 1 in.t.7E (transverse), por psic'vs (transverse), ksif (transverse), transverse), transverse)f (transverse), ksif (transverse), transverse), transverse)f (transverse), transverse), transverse)f (transverse), transverse), transverse)f (transverse), transverse), transverse)f (transverse), transverse), transverse), transverse)f (transverse), transverse), transverse), transverse)f (transverse), transverse), tran   | 202.5<br>192.9<br>4.7<br>16.0<br>199.3<br>199.3<br>13.0<br>13.0<br>13.0<br>13.0<br>13.0<br>13.0<br>11.1<br>130.0<br>1<br>11.1<br>130.0<br>1<br>11.1<br>130.0<br>1<br>130.0<br>1<br>130.0<br>1<br>130.0<br>1<br>130.0<br>1<br>13.2<br>13.2<br>13.2<br>13.2<br>13.2<br>13.2<br>13.2<br>13   | 158:24<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3<br>131:3 |
|--|---|--|
| TtS (transwerse), ksi<br>TtS (transwerse), ksi<br>e (transwerse), percent in 1 in.<br>e (transwerse), 10° psi<br>compression<br>Compression<br>Cyrs (transwerse), ksi<br>c'rs (transwerse), ksi<br>c'rs (transwerse), ksi<br>c'rs (transwerse), ksi<br>fc (transwerse), ksi<br>Sits (longtudinal), ksi<br>sits (transwerse), ksi<br>(130.0<br>Shear<br>(b)<br>Shear<br>(b)<br>Shear<br>(b)<br>Shear<br>(b)<br>Shear<br>(b)<br>Shear<br>(b)<br>Shear<br>(b)<br>Shear<br>(b)<br>Stearworse), ksi<br>(130.0<br>130.0<br>Stearworse), ksi<br>(130.0<br>Stearworse), ksi<br>(130.0<br>(130.0<br>Stearworse), ksi<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(130.0<br>(13   | 202.5<br>192.9<br>14.7<br>16.0<br>193.3<br>18.0<br>13.0<br>13.0<br>13.0<br>13.0<br>13.0<br>11.1<br>13.0<br>13.0   | 1595 2<br>1595 2<br>1313 8<br>1313 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1312 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 1<br>1313 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| TYS (transwerse), ksi<br>e (transwerse), lo <sup>7</sup> psi<br>f (transwerse), lo <sup>7</sup> psi<br>(transwerse), ksi<br>f <sup>6.0</sup><br>Compression<br>Compression<br>Compression<br>(transwerse), ksi<br>f <sup>13.0</sup><br>Sis (longtudinal), ksi<br>sis (longtudinal), ksi<br>sis (longtudinal), ksi<br>sis (longtudinal)<br>f <sup>11.7</sup><br>(transwerse), ksi<br>sis (longtudinal)<br>f <sup>11.7</sup><br>(transwerse)<br>f <sup>11.7</sup><br>(tr | 192.9 153.2<br>4.7<br>16.0 15.7<br>199.3 174.3<br>199.3 16.1<br>130.0 U <sup>(C)</sup><br>130.0 U <sup>(C)</sup>  | ت د در<br>1333 د د<br>1323 د د   |
| E (transverse), 10° psi<br>Compression<br>Compression<br>CYS (transverse), 10° psi<br>f (transverse), 10° psi<br>f (transverse), 10° psi<br>Stear(b)<br>Shear(b)<br>Shear(b)<br>SiS (long(tudinal), ksi<br>SiS (long(tudinal), ksi<br>SiS (long(tudinal), ksi<br>131.6<br>SiS (transverse), ksi<br>130.0<br>Int. 7<br>(transverse), ksi<br>f (long(tudinal))<br>f   | 16.0<br>17.1<br>199.3<br>117.4<br>113.0<br>111.6<br>111.7<br>111.7<br>111.7<br>111.7<br>111.7<br>111.7<br>111.7<br>111.7<br>111.7<br>111.7<br>111.6<br>111.7<br>111.7<br>111.6<br>111.6<br>111.7<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>111.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>11.6<br>1 | د د<br>1333<br>113   |
| Compression<br>CYS (transverse), ksi<br>f (transverse), 10° psi<br>Stear (b)<br>Stear (b)<br>Sty (long(tudinal), ksi<br>Sty (ransverse), ksi<br>Sty (transverse), ksi<br>(transverse), ksi<br>(transverse), ksi<br>fransverse)<br>(transverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse)<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransverse]<br>fransver   | 199.3<br>199.3<br>18.0<br>13.0<br>13.0<br>130.0<br>11.1<br>130.0<br>11.2<br>130.0<br>13.5<br>13.5<br>13.5<br>13.5<br>13.5<br>13.5<br>13.5<br>13.5   | د د<br>11:23<br>13:23  |
| CYS (transverse), ksi<br>f (transverse), l0 psi<br>Shear (b)<br>Stear (b)<br>Sts (longtudinal), ksi<br>SYS (longtudinal), ksi<br>SYS (ransverse), ksi<br>SYS (ransverse), ksi<br>130.0<br>Impsec (d)<br>Impsec (d)<br>Impsec (d)<br>Impsec (d)<br>Terature Toughness (e)<br>Fracture Toughness (e)<br>K[c, L-T, ksi 'In.<br>K[c, L-T, ksi 'In.<br>K[c, I-L, ksi 'In.<br>(inotched, R = 0.1<br>Impsec (c)<br>(inotched, R = 0.1<br>Impsec (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SYS (c)<br>SY   | 199.3<br>117.13<br>18.0<br>13.0<br>131.6<br>131.6<br>130.0<br>11.7<br>11.7<br>1.2<br>1.2<br>1.3<br>1.5<br>1.5<br>1.5<br>1.5<br>1.5<br>1.5<br>1.5<br>1.5<br>1.5<br>1.5   | در<br>11:35<br>12:2  |
| F. (transverse), 10 psi [13.0]<br>Shear (b)<br>Sis (long(tudinal), ksi [131.6]<br>Sis (ransverse), ksi [131.6]<br>Sis (transverse), ksi [130.0]<br>Impact (d)<br>Transverse), ksi [13.6]<br>(long(tudinal), ksi [13.6]<br>(long(tudinal)), ksi [13.6]<br>Fracture Toughness (e)<br>Ktc, L-T, ksi [10.7]<br>Ktc, L-T,   | 13.0 16.1<br>131.6<br>131.6<br>130.0<br>130.0<br>11.7<br>11.7<br>13.5<br>2.5  | ود رو  |
| Shear(b)StS (longitudinal), ksi131.6StS (transverse), ksi130.0StS (transverse), ksi130.0Impsec(d)Impsec(d)Impsec(d)Impsec(e)Impsec(f)StS (transverse)(f)StS (transverse)(f)  | 1.1.1.6<br>1.30.0<br>1.1.7<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני<br>ני  |  |
| <pre>StS (longtudinal), ksi<br/>StS (transverse), ksi<br/>Impace (d)<br/>Impace (d)<br/>V-notch Charpy, ft. 15s.<br/>(longtudinal)<br/>(longtudinal)<br/>(transverse)<br/>(transverse)<br/>(ingture Toughness(e)<br/>Fracture Toughness(e)<br/>Fracture Toughness(e)<br/>Fracture Toughness(e)<br/>ftc. L-T, kst in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.<br/>K[c. T-L, ksi in.] (I) (I) (I) (I) (I) (I) (I) (I) (I) (I)</pre>  | 1,11.6<br>130.0<br>1130.0<br>11.7<br>11.7<br>12.5<br>2.5<br>2.5   | 2 <b>1</b>   |
| SUS (transverse), ksi<br><u>Impace</u> (d)<br><u>Impace</u> (d)<br>V-notch Charpy, ft. 15s.<br>(longitudinal)<br>(transverse)<br><u>Fracture Toughness</u> (e)<br><u>Ktc. 1-1. ksi in</u> .<br><u>Ktc. 1-1. ksi in</u> .<br><u>in otched</u> , R = 0.1<br><u>in otched</u> , R = 0.1  | 130.0<br>ני ני<br>ני<br>ני<br>ני  |  |
| <pre>Impact (d) Impact (d) V-notch Charpy, ft. 15s. (longtudinal) (transverse) (transverse) Eracture Toughness (e) Ntc. L-T, kst in. Ntc. T-L, kst in. Ntc. T-L, kst in. Ntc. T-L, kst in. Ntc. T-L, kst in. Ntc. V-L, kst in. Ntc.</pre>  | ۱۲.۶<br>۱۳.۶<br>۱۳.۶  | <b></b>  |
| <pre>V-notch Charpy, ft. 1bs.<br/>(longitudinal)<br/>(transverse)<br/>(transverse)<br/>Eracture Toughness(e)<br/>%ic. L-T. kst in.<br/>%ic. L-T. kst in.<br/>%it. I-L. kst in.<br/>%ital Fatigue (transverse)<br/>(i)<br/>(nnotched, R = 0.1<br/>Inf verlag ks. 112</pre>  | 11.7<br>2.9<br>3.5<br>7   | <b>1</b>   |
| (ionșitudinai)<br>(transverse)<br><u>Fracture Toughness</u> (e)<br>N <sub>Tc</sub> . L-I. ksi in.<br>K[c. T-L. kai 'In.<br>Atial Fatiyue (transverse) <sup>(i)</sup><br>('motched, R = 0.1<br>In corlos kei  | 11.7<br>9.5<br>7  | <b>5</b> 5   |
| Fracture Toughness (e)<br>FLc. L-T. Kst in.<br>K[c. I-L. kst in.<br>K[c. I-L. kst in.<br>(i)<br>kial Fatigue (transverse)<br>(i)<br>(inotched, R. # 0.1<br>112   |   |  |
| <pre>kic, L-T, kst in.<br/>kic, T-L, kst in.<br/>kic, T-L, kst in.<br/>istal Fatigue (transverse)<sup>(t)</sup><br/>innotched, R = 0.1<br/>inf ovelae ksi</pre>  | 25.3  |  |
| k <mark>lč. I-L. ksi ln.</mark> 25.7<br><u>Avial Fatigue (transverse)</u> (1)<br>['unotched. R = 0.1<br>lf verlae is ei  |   |  |
| <pre>Axial Fat(yue (transverse) ' [unotched, R = 0.1 [unotched, R = 0.1 ]]]</pre>  | 26.7 :  | :,   |
| [nnotched, R = 0.1<br>10 <sup>2</sup> curvise kei  |   |  |
|  |   |  |
| 10 cvcles ksi 50   |   | 05   |
| 10 cycles, ksi   | 12 32   | 5  |
| <pre>%otched, K = 3.0, R = 0.1<br/>.*</pre>  | 76<br>76  | 16   |
| 10° cycles, ksi 13   | : C   |  |
| 10° cycles, ksi  | , 25 30   |  |
| Croop (transverse)   |   |  |
| 0.1 plastic deferration. 100 hr., kei 1. 2A <sup>(c)</sup>   | Y: (2, <sup>Y:1</sup>   | 19<br>20   |

A. 6 .

•

4 9

0.2 plastic deferration, 100 hr., ksi 0.2 plastic contration, 100 hr., 2si

T1-6A1-6V-2Ss Alloy Data (Centinued)

| ;   |         |          |             |           |
|---|---------|----------|-------------|-----------|
|   |         | Temperal | ture, F     |           |
| Properties  | RT      | 007      | 700         | 006       |
| Stros-Rupture (transwirse)                                |         |          |             |           |
| Ruptura, 100 hr., ksi                                     | ¥.      | 2        | 061         | U*<br>. 1 |
| Ruptvire, 1000 hr., k.i                                   | Ş.      | 2        | <b>11</b> 5 | 36        |
| <u>Stress Corrosion</u> (R)                               |         |          |             |           |
| 80 TVS, 1000 hr. maximum                                  | n racks |          |             |           |
| Coefficient of Thermal Expansion                          |         |          |             |           |
| 5.3+10 <sup>-6</sup> in.'in' <sup>1</sup> (68 ° to 900 F) |         |          |             |           |
| Density   |         |          |             |           |
| 0.164 lb./in.   |         |          |             |           |

- (a) Unloss are average of triplitate tests conducted at fattelle under the subject contract unliss otherwise indicated. Entitude, croop, ind stress-rupture values are from curves windared using the results of a frontly number of tests.
- ind the shear pintape spectron, average of 4 rests in each direction
- Foll comble-search practice spectrate average
   Foll C, underthablet XX, inteleptedee;
- (d) Average of 4 tests in tack derection.
- Revults of tests at AFML or compact tension specimens.
- (1) TWT spectrates the algebraic much of which matrices to maximum stress in one cycle that is,  $E=45, -10^{-10}$ . Topesants the Venber-Seterson theoretical stress contentwing fletwin
- (c) wor-torperature thras-point binliests. Altornate issues in 3-12 NaCL.



FIGRE 2. FFECT OF TRAFERATION ON THE COPAGETY, PROPERTIES OF SOLUTION TRAFERATION AND ACTD IN-GAL-NU-251 ISOTHREVAL DIE MADING 

ECHNICAL





131