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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD REPORT No. 581

on

Cooperative Creep Testing Programme

by

D. Coutsouradis and D. K. Faurschou

NORTH ATLANTIC TREATY ORGANIZATION

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North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development
COOPERATIVE CREEP TESTING PROGRAMME
D.Coutsouradis and D.K.Faurschou
Published March 1971
114 pages, including tables and figs.

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This Report has been sponsored by the Structures and Materials Panel of AGARD.

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

COOPERATIVE CREEP TESTING PROGRAMME

by

D.Coutsouradis* and D.K.Faurschou†

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FOREWORD

Creep testing at elevated temperatures is an expensive and time-consuming business. Nevertheless, creep tests are frequently duplicated, there appears to be little confidence in creep data obtained from other laboratories. This lack of confidence is due in part to the extreme variability of the creep properties, which exceeds that of the other mechanical properties of the materials most commonly used. However, differing laboratory techniques and specifications give rise to uncertainties as to the amount of scatter that should be attributed solely to the variability of the material properties.

The AGARD Working Group on High-Temperature Material Testing was established in 1966 with the aim of improving the specifications and raising the standard of determination of the mechanical properties of materials at high temperatures in the NATO countries. This report describes the results accomplished.

The interest and devoted work of the members of the Working Group are gratefully acknowledged. On behalf of the Group I offer sincerest thanks to the coordinator, Mr Coutsouradis, and the statistical advisor, Mr Faurschou (the authors of this report) for their efforts. The report is based on results obtained from 18 laboratories in seven countries, whose kind cooperation is greatly appreciated.

Frithiof Niordson
Chairman
High Temperature Testing Working Group,
AGARD Structures and Materials Panel.

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LIST OF THE PARTICIPATING LABORATORIES

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ACKNOWLEDGEMENTS

The completion of the programme was made possible by the cooperation and encouragement of Panel members of the Structures and Materials Panel and of members of the High Temperature Testing Working Group.

The contribution of Henry Wiggin and Co. Ltd, Hereford, UK, for donating and pretesting the Nimonic-105 bars and the fruitful discussions with Dr A.Duce, are thankfully acknowledged.

Mr J.Collin, Chief Engineer, F.N., made arrangements for the cutting of the test blanks in the workshops of Fabrique Nationale d'Armes de Guerre (Herstal, Belgium).

One of the authors (D.C.) wishes to express his appreciation to Messrs Stoumont and Erniquin of the CNRM Computer Center for their able assistance in computer programming and operation. The other (D.K.F.) is indebted to G.C.Cameron, Computer Science Division, Department of Energy Mines and Resources.

Finally, the initiation and completion of this programme would have not been possible without the cooperativeness of the participating laboratories.

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COOPERATIVE CREEP TESTING PROGRAMME

D.Coutsouradis and D.K.Faurschou

1. INTRODUCTION

The results of creep and creep rupture measurements are subject to seemingly wide scatter. The major contributing factors have generally been qualitatively related to inhomogeneity of commercial materials and to inherent or inadequately controlled testing techniques and instrumentation. The latter sources of variability may be lessened by improved design of equipment and by improved specifications.

The problem is of primary importance to metallurgists involved in the development of new materials, and also, to design engineers. Time and again creep laboratories are getting involved in interlaboratory evaluations of data either on the basis of private initiatives or within the framework of national or international cooperative programmes. Generally a representative material is chosen, the sampling of which is carried out either systematically or randomly depending on whether the number of participating laboratories is small or large. Comprehensive studies have been, apparently, limited to alloys with a useful operating temperature limit of about 700°C. During the preliminary discussions of the Working Group on High Temperature Testing of the Structures and Materials Panel of AGARD, it appeared that the implementation of a programme involving testing conditions currently encountered in superalloy technology, would be desirable.

Tests of the type considered are currently performed in a large number of laboratories using more or less well established national or international specifications. In addition producers as well as users of superalloys have developed a variety of specific acceptance tests through which various materials can be evaluated. However, lack of a quantitative assessment of interlaboratory and intralaboratory variability hampers, the efficient development, evaluation and utilisation of materials.

The sheer enumeration of the various sources of variabilities in creep testing is impressive: between and within materials, heats, ingots, bars, locations and laboratories, as well as between testing variables, etc. A comprehensive and quantitative programme taking into account all the possible variability sources would require a formidable amount of materials and testing time.

A more rational approach is required. The primary requirement is to generate some quantitative data and to stimulate interest in a succession of studies to identify and quantify significant sources of variability. This AGARD programme has been authorized with this primary requirement in mind. More precisely, the following considerations were taken into account:

(i) In a cooperative programme it is desirable to have many participants to lessen the commitment at each laboratory, provided of course that the test results from each laboratory are additive.

(ii) The participation of a large number of laboratories is also necessary because the primary objective was to evaluate interlaboratory variability.

(iii) In order to obtain the most satisfactory conclusions it is necessary to establish the programme on the basis of experimental design principles and to subject the data to a quantitative evaluation.

(iv) It might have been desirable to have the test programme represent ranges of stress and temperature sufficiently large to make possible the determination of parametric constants. However this would have extended the programme considerably and, hence, a single test temperature was considered.

(v) A better understanding of stress rupture variability is useful in the design of any effective programme to evaluate parametric techniques.

(vi) An additional desirable feature of a cooperative programme is the incidental calibration of a standard lot of material which could be subsequently used for the assessment of the techniques of other laboratories or for the design of an additional programme aiming at the evaluation of other variables. Unfortunately a large supply of suitable material was not available when the programme was undertaken. The calibrated "reserve" of material available for further testing is therefore limited.

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In summary, the objectives of the programme may be outlined as follows:

(a) the comparison of creep and stress rupture data from different laboratories
(b) the determination or estimation of relevant standard deviations
(c) the evaluation of the adequacy of current specifications and testing techniques
(d) the identification of possible significant sources of variability for further investigation
(e) the establishment of a standard lot of material for use within laboratories in NATO countries
(f) the determination for the material used of statistically significant creep data.

The programme outlined in Section 3 is considered as the minimum one able to yield the information pertaining to the basic requirements.

Test conditions and the description of the material are given in the following sections. In the Appendices more details will be found on the recommended procedures and property evaluation of the material.

2. MATERIAL

The test material used is the nickel base alloy Nimonic-105. It was kindly made available for the purpose of the programme by Henry Wiggin and Co., Hereford, UK. It was carefully selected to ensure acceptable homogeneity. It was delivered in the fully heat treated condition in the form of five bars, each 3 m (10 ft) long and with a rectangular section of 1.1/8 x 5/8 in. (28 x 16 mm). Appendix I reproduces relevant data on the production and processing of the material, as communicated by the producer.

Appendix I also reproduces the results of tests carried out by the producer in order to assess the homogeneity of the material. The tests carried out on blanks taken from both ends of the five bars, included:

(a) hardness
(b) tensile tests at 900°C (1652°F)
(c) creep rupture tests at 900°C (1652°F) under a stress of 10.4 ton.f/in^2 and at 950°C (1742°F) under a stress of 7 ton.f/in^2.

Appendix II gives an evaluation of the homogeneity of the material. The 900°C tensile properties (0.2% yield strength and ultimate tensile strength) reveal no variation from bar to bar or from different ends within a bar. Analysis of the rupture data at both 900°C and 950°C revealed a significant variability between bars; however the variability was only significant for the 950°C data and the combined 900° plus 950°C data.

The test material was marked systematically and cut to blanks 100 mm long. Each blank was subsequently cut lengthwise into two blanks. All pieces were numbered in order to identify the bar number and the location within a bar. In this way 58 blanks were obtained per bar i.e. a total of 290 blanks. The identification of each blank comprises:

– a first number corresponding to the bars (1 to 5)
– a second number corresponding to the position within a bar. This number has values from 2 to 32, number 2 corresponding to the leading edge of the extruded bar which, in turn, corresponds to the bottom of the extruded ingot.
– a letter G or D, which differentiates the two blanks obtained by cutting longitudinally each 100 mm long piece.

The blanks were randomised and then randomly distributed to the participant laboratories. The individual test blanks were allocated to the different tests also in a random manner.

3. DESIGN OF THE PROGRAMME AND TESTING

Two factorial designs here in designated Models "A" and "C" were developed as appropriate to the purposes of the programme. Eighteen laboratories from several NATO countries (Belgium, Netherlands, Germany, France, UK, Italy and USA) participated in this programme. Eleven of these laboratories conducted the Model "C" testing programme. The features of the programme design were as follows:

(i) in each of these models log "stress" ($\log \sigma$), replicates and laboratories are considered to be fixed independent factors (controlled variables)

(ii) the fact that these are fixed rather than random factor implies that extrapolation to predict behaviour in other laboratories or replicates of other suppliers of material is not strictly possible

(iii) the dependent factor (response variable) is log stress variability time ($\log t$) although it may also be a measure of creep rate or strain.

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The independent factor of log "stress" has been set at five levels which are equally spaced on a log scale. The five levels of log "stress" and the nominal stress rupture times, based on data provided by the producer and in the AGARD Material Properties Handbook, Vol.4 are shown in Table I. Starting with σ_5, successively determined increments of load in Table I of about 18 percent were added to set $\sigma_4, \sigma_3, \sigma_2$, and σ_1 at suitable intervals on a log scale.

It is important to have the "stress" levels at unit log intervals to facilitate the analysis of variance and to calculate confidence intervals for the relationships between log t and log "stress".

Table II shows the testing required by Models "A" and "C". The stress for each test is indicated by two subscript numbers. The first denotes the stress level, the second denotes the replicate.

Factorial designs provide for testing the significance of all interactions, if there is appropriate replication. If the interactions are not significant, as is probable in the proposed program, the interaction mean squares may be pooled by themselves or with a residual mean square to form a residual "variance" which may be used in "variance" ratio for F tests of the significance of main factors and to calculate confidence intervals which contain the true laboratory means.

It was known that some variability exists from bar-to-bar and end-to-end in the Nimonic 105 supplied for this programme. It was considered to be most realistic, on a long-range basis, to randomize completely all of the test coupons.

Details of the proposed designs and analysis of variance for Models "A" and "C" are given in Tables III and IV respectively. It is worth noting that in factorial designs all of the data are analysed together and every test contributes to the effect of each of the independent factors and the residual (uncontrolled factors).

It was expected that interlaboratory variability would be significant. The differences between laboratories were shown by use of the Duncan multiple range test[1] for means and by calculation of individual confidence limits to contain each of the true means.

For each of these tests, the determination of the following data were requested:

- total deformation on loading
- time to total deformation values of respectively, 0.1, 0.2, 0.5, 1 and 2%
- time to rupture
- elongation and reduction of area at rupture.

The recommendations proposed for carrying out these tests are given in Appendix III. These recommendations are based on those of International Standard Organization (ISO/R.204-1961 and ISO/R.206-1961). As seen from Appendix III some of the recommendations considered in this programme were stated more precisely.

In the absence of ISO or specific recommendations resort to national specifications was advised.

In summary, the whole test programme was designed to evaluate test results which were representative of material variability of one batch of material and of routine good practice in the participating laboratories. It would have been possible to minimize variability by machining all specimens at one facility, providing precalibrated thermocouples from a common supply, or monitoring the precision and accuracy of instrumentation for measuring and controlling temperatures. However this would not have been consistent with the intent of the programme and would really have limited the practical usefulness of the data in some important respects.

4. EXPERIMENTAL RESULTS

The results generated within the framework of this programme are reproduced in Appendix IV.

In Table IV.1, the results are listed separately for each replicate and each load. In these tables the different columns give the informations listed in Table V. Laboratories are indicated in an anonymous way by numbers.

In Table IV.2, the results are listed per data produced i.e. total deformation on loading, time to 0.1% total deformation, etc.

Finally in Table IV.3 the results are listed per laboratory. Relevant remarks reported in the individual laboratory reports regarding the test results listed in the Tables are commented also in Appendix IV.

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5: STATISTICAL EVALUATION OF RUPTURE TIME

Option "C" involving 10 tests per laboratory was completed by eleven laboratories. Option "A" involving 4 tests was completed by eighteen laboratories. The discussion here will deal mainly with the interlaboratory variability and the examination of the causes responsible for the observed variabilities.

5.1 Effect of Macroinhomogeneity

The stress rupture data might have been affected by a systematic effect of macroinhomogeneity of the experimental material: that is between bars or between positions in the bars. In order to make the comparisons it was necessary to transform the data to a common stress. This transformation was made possible by the determination of a stress-time relationship.

5.1.1 Log σ – log t Relationship

The regression relationship was determined using all available results (138 data). It was postulated that the following relation was valid:

$$\log t = A + B \log \sigma + C(\log \sigma)^2 \tag{1}$$

The analysis of the data resulted in the following relation

$$\log t = 2.85247427 + 4.25218077 \log \sigma - 3.92866945 (\log \sigma)^2 \ . \tag{2}$$

Table VI reproduces for the different stresses used in the programme the calculated rupture times and also the calculated ranges corresponding to ±2S and to ±3S (residual log standard deviation S = 0.0640706, 15%).

In view of the fact that the S limits were calculated from log t values, the ±2S limits expressed in hours are at the constant ratio of 1.8 whereas the ratio of the 3σ limits is of 2.4.

The outliers identified with the criterion of ±2S are listed to Table VII. None of the results fell outside of ±3S range. Figure 1 reproduces the log t – log σ relation with the corresponding 2S limits.

5.1.2 Data Transformation

All experimental data were transformed to the common stress of 10.5 kg mm² by means of the following relation

$$t_{10.5a} = t_{10.5c} \frac{t\sigma}{t\sigma_c} \tag{3}$$

where

$t_{10.5a}$ = value of rupture time adjusted to a stress of 10.5 kg/mm²

$t_{10.5c}$ = value of rupture time for a stress of 10.5 kg/mm² calculated from Equation (2)

$t\sigma$ = actual rupture time for a stress of σ kg/mm²

$t\sigma_c$ = rupture time for a stress of σ kg/mm² calculated from Equation (2).

Examination of the transformed data showed that they have an acceptable normal distribution (Fig.2).

5.1.3 Effect of Bars and of Position Within a Bar

The adjusted data were grouped in five groups corresponding respectively to the five bars used in this programme. Pertinent data on the five groups are given in Table VIII. The adjusted rupture times were similarly grouped into five groups according to their position within a bar. The groups were 1-6, 7-12, 13-18, 19-24 and higher than 24. The results are summarised in Table IX. The analysis of variance is reproduced in Table X, and shows that the between bars variability is highly significant whereas the between position variability is not significant.

Duncan's test applied to means of bars shows that they are grouped as follows:

Bar	Mean
5	3.1448
1	3.1133
2	3.1108
4	3.0799
3	3.0539

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Figure 3 shows schematically the variation of mean rupture time as a function of the number of bars and location within a bar. Figure 3 also indicates the origin of the outlying values (Table VII). It is remarkable that most of the outliers (high or low) originated from position 2-13, i.e. from the leading edge of the bars.

5.1.4 Adjustment of log Rupture Time Data for Bar Variability

The previous analysis showed that between bars variability was significant and this may affect the interlaboratory variability.

In order to correct for this variability all values corresponding to bar 5 were adjusted by subtracting 0.0468 and all values corresponding to bar 3 were adjusted by adding 0.0441. These amounts were shown to be necessary in order to eliminate the significance of the between bar variability.

Tables XI and XII summarise the adjusted data according, respectively, to bars and positions. The analysis of variance for between bars and between position variability is shown in Table XIII. With the adjusted data both the between bars and between position variability are not significant.

Figure 3 shows the evolution of mean log rupture times adjusted for bar variability as a function of bar number and position.

5.2 Interlaboratory Variability for Time to Rupture

The analysis of the log rupture time was made:

- on the basis of the data adjusted to a common stress,
- on the basis of the same data adjusted for bar variability as indicated in the previous section.

The analysis of the log as reported rupture times on the basis of the programme design is reproduced in Appendix VI.

In Table XIV the results of the 18 Option "A" laboratories are ranked in the order of decreasing mean log rupture time according to the two methods indicated above. The corresponding analysis of variance is shown in Table XV. The brackets in Table XIV indicated the statistically homogeneous groups of laboratories (95% confidence level) revealed by Duncan's test.

The data of Table XV indicate that the variabilities due to replicates and stresses are not significant. The residual mean square in this Table represents intralaboratory variability, macroinhomogeneity and interactions. The adjustment of data for bar variability results in a lower value for the residual mean square and thus to a more sensitive Duncan's test. The results of the latter shown in Table XIV, indicate a larger number of homogeneous groups in the case of the data adjusted for bar variability.

Similarly, in Table XVI the results of the 11 option "C" laboratories are ranked in the order of decreasing mean log rupture time. The corresponding analysis of variance is reproduced in Table XVII. In this case also the adjustment of data for bar variability results in a lower mean square and in a more sensitive Duncan's test. The ranking of the laboratories, option "A" or option "C" undergoes slight modifications by considering the data adjusted for bar variability. Generally the change in ranking does not exceed 2 positions. An exception is provided by laboratories 11 and 15 having used, more than two blanks from bars 5 or 3, respectively, without compensation.

The comparison of Tables XIV and XVI shows that the rank of the 11 option "C" laboratories is modified when they are considered as option "A" laboratories. However, laboratories that belong to the same group in option "C", they also belong to the same group in option "A".

6. STATISTICAL EVALUATION OF OTHER DATA

In this section, the different data generated are analysed without adjusting them to a common stress or for macroinhomogeneity. In the examples given here below only the main sources of variability are considered i.e. Labs and Stresses. Preliminary examinations have actually shown that the effect of replicates and interactions were not significant. More complete analysis is given in Appendix VI.

6.1 Total Deformation on Loading

The examination of the data shown in Table VI.2 (Appendix IV, page IV-5), reveals the presence of wide scatter. In view of the considerations given in Section 7.5 on strain measurement the amount of data that meet the basic requirements for adequate strain measurement is quite limited.

The wide scatter in the data is reflected also in the times to specified total deformation as shown in the following sections.

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6.2 Time to 0.5% Total Deformation

6.2.1 Log t (0.5%) – Log σ Relationship

The following $\log t\,(0.5\%) - \log \sigma$ relationship was established by regression analysis:

$$\log t\,(0.5\%) = 5.154097 - 2.447134\,(\log \sigma)^2 \,. \tag{4}$$

The residual log standard deviation was

$$S = 0.287424\,(93\%) \,.$$

Tables XVIII and XIX reproduce the calculated times to 0.5% total deformation and the identified outliers outside the ±2S limits, respectively.

Figure 4 reproduces graphically the $\log t\,(0.5\%) - \log \sigma$ relation. The range (±2S) within which most of the data are included is very large, relatively to the previously shown log rupture time – $\log \sigma$ relation (Fig.1).

6.2.2 Analysis of Variance for 17 Option "A" Laboratories

The analysis of variance in Table XX shows that interlaboratory variability is significant. It is assumed that the effect of replicates and interactions is not significant. In Table XXI the laboratories are ranked in the order of decreasing mean $\log t\,(0.5\%)$. Duncan's test reveals one statistically homogeneous group that comprises all laboratories except labs 16, 8 and 19.

6.3 Time to 1% Total Deformation

6.3.1 Log t (1%) – Log σ Relationship

The regression analysis showed that the following relation was significantly valid:

$$\log t\,(1\%) = 5.221785 - 2.317995\,(\log \sigma)^2 \,. \tag{5}$$

The residual log standard deviation was

$$S = 0.167091\,(46\%) \,.$$

Table XXII reproduces the times calculated from the above relation and also the ±2S limits. Table XXIII indicates the outliers identified outside the ±2S limits. In Figure 7, the calculated times to rupture and to different total deformation are compared.

6.3.2 Analysis of Variance for 17 Option "A" Laboratories

Table XXIV reproduces the results of the analysis of variance for 17 option "A" laboratories. The interlaboratory variability is shown to be significant. In Table XXV the laboratories are ranked in the decreasing order of mean $\log t\,(1\%)$. Duncan's test reveals the presence of several overlapping statistically homogeneous groups.

6.4 Time to 2% Total Deformation

6.4.1 Log t (2%) – Log σ Relationship

The regression analysis for the log time to 2% total deformation was made, assuming the same basic relationship as far time to rupture. The analysis gave rise to the following relation

$$\log t\,(2\%) = 2.353456 + 3.360188 \log \sigma - 3.697968\,(\log \sigma)^2 \,. \tag{6}$$

The residual log standard deviation was

$$S = 0.0983384\,(25\%) \,.$$

Table XXVI reproduces the times calculated from the above relation and also the ±2S limits. Table XXVII indicates the outliers identified outside the ±2S limits.

Figure 6 reproduces the graphical representation of $\log t\,(2\%) - \log \sigma$ relation and the ±2S limits. In Figure 7, the curves for time to rupture and time to 2% total deformation are compared.

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6.4.2 Analysis of Variance for 17 Option "A" Laboratories

Table XXVIII shows that the interlaboratory variability is significant. The laboratories ranking in Table XXIX represents several statistically homogeneous groups revealed by Duncan's test.

6.5 Comparison of Intralaboratory Variances

Intralaboratory variances corresponding to the different data discussed in the previous sections are compared in Table XXX. The variances considered include also the variance due to the material. For time to rupture the variance calculated from data adjusted for bar to bar variability are also given.

The standard deviation of time to rupture has a standard deviation of 0.0550 or 13.5%.

The standard deviation of time to 2% total deformation is slightly higher (14.5%) whereas the standard deviations of times to 1% and 0.5% increase rapidly (respectively 19.5 and 34%). Time to 0.2% and 0.1% total deformation were not analysed because of the limited amount of data available. Previous examination of these data showed that their standard deviation exceeded 100%.

For comparison purposes, Table XXXI reproduces the standard deviations calculated from total variances on the basis of the regression analysis. The trend of these "total" standard deviations is similar to the intralaboratory ones. The latter data reflect in addition to intralaboratory and macroinhomogeneity variability also the interlaboratory one.

7. EXPERIMENTAL TECHNIQUES

Considering the design of the programme with the randomised distribution of the test samples, the significant interlaboratory differences could be, to a large extent, accounted for by the single and combined effect of test variables. It is thus necessary to review these in detail. Appendix V reproduces in extenso the description of the experimental techniques as given in the individual laboratory reports. Five tables summarise the techniques per group of properties referring respectively to the specimen geometry, loading, heating, temperature measurement and strain measurement. These tables summarise also the recommendations used for carrying out the tests.

7.1 Specimen

As shown in Table XXXII and Figure 8 most of the laboratories used specimens in agreement with those recommended i.e. a gauge diameter not less than 4 mm and a gauge length equal to $5.65\sqrt{So}$ (5D).

The noticeable exceptions are the following: Laboratory 1 used a subsize specimen and Laboratory 2 a special hollow one. In all other cases the gauge diameter ranged from 5 to 9.1 mm the most frequent size being in the range 5 to 6.5 mm. The gauge length was generally in agreement with the specified values except for Laboratory 11 which for some tests, used specimens with a higher length to diameter ratio. Referring to Table XIV – B, the extreme ranking of these laboratories may be observed. However, the rank of Laboratory 5 which used a high L/D ratio does not reveal any significant trend.

Specimen machining is often suspected as a source for variability in stress rupture data. In this programme, many laboratories attempted to prepare their specimens with a surface finish as good as possible and free from cold working. It is difficult to assess the extent of cold working in surface layers. The surface finish was measured by many laboratories and the values reported range from 0.12 to 0.55 μ-RMS. In Table XXXVII the ranks of the mean for different laboratories are compared to the surface finish measured (in μ RMS).

The results regarding specimen geometry or machining are too limited to infer significant trends. This parameter might however deserve further systematic investigation at individual laboratories under carefully controlled conditions to minimise the residual variance.

7.2 Loading

On the basis of relation (1) the effect of a stress variation on the stress rupture time may be approximately expressed as follows:

$$d \ln t = \frac{d\sigma}{\sigma} (B + 2C \ln \sigma) . \qquad (7)$$

It should be emphasised that the above relation is not valid appreciably outside the range of stresses considered for its establishment. Taking into account the values of relation (2) Equation (7) may be written

$$d \log t = \frac{d\sigma}{\sigma} (1.83 - 3.41 \log \sigma) . \qquad (8)$$

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The application of relation (5) with load errors of 0.5 or 1% results in corrections of rupture times that cannot explain to any appreciable degree the interlaboratory differences observed. For the stresses considered in this programme, a stress variation of 0.5% results in a variation of rupture time of about 3% (Table XXXVIII). In fact control of load in all laboratories was reported to be better than 0.5%.

The quantitative measurement of axiality is generally expressed as the difference in percent of strain readings of two extensometers placed at right angles on a specimen at RT or at the test temperature. In one case also the tangent of the angle representing the deviation from perfect axiality was measured. In Table 33 the different systems used to ensure self alignment are summarised. An additional feature regarding axiality is also the length of the loading system. Relevant data were not reported.

The loading procedure was in all cases shock free through various systems (mechanical, hydraulic, springs). Loading was either continuous or incremental. The latter was used in connection with intermediate readings of strain: reported total loading times range from 0.5 to 17 minutes. As regards time to rupture, the present programme did not reveal any effect of incremental loading. For example the rupture times determined by Laboratory 5 that used a particularly low load rate (1 kg/mm^2/min), have not been significantly affected by this procedure. The possible effect of loading rate on time to a specified creep or total deformation could be revealed by testing under controlled continuous.

Finally some of the laboratories have used an automatic beam levelling device. The possible effect of such devices on creep data cannot be ascertained. Laboratory 10 used as indicated in Appendix IV, both types of machines in carrying out the 10 option "C" tests. An analysis[2] of the two groups of data, showed that in the conditions of the present programme, automatic beam levelling did not accelerate the creep rupture process. This finding should not be generalised to other materials with large ductility.

7.3 Heating

The use of three-zone furnaces appears to be a general one in this programme. According to the specifications, furnaces of any type may be used provided that they are able to meet the requirements on heating and soaking time and the temperature control.

For temperature control, the systems used varied widely. For this purpose the sensing device is either a thermocouple, or a platinum resistance or a dilatable rod. The controlling devices varied also among laboratories. A detailed description of the overall system has not been given in most of the individual laboratory reports. It is certainly of major importance to know the stability and reliability of such systems over long periods of time in order to assess for their effectiveness.

Except for Laboratory 1, which used a vacuum atmosphere, all other laboratories did their testing in air. It may be argued that the results of Laboratory 1 might have been affected by the use of a vacuum atmosphere. It has been in fact reported[3] that the creep strength of a Ni-Cr alloy was higher in vacuum than in air for low temperatures and high strain rates whereas the opposite occurred at high temperatures and low strain rates.

Heating and soaking times were recommended to be 1 to 2 hours and 4 to 5 hours respectively. This procedure was followed by most of the laboratories. However, for creep laboratories operating in one shift the procedure allows little time for strain measurement at the beginning of the tests. Thus some laboratories prefer soaking overnight. The high rank of Laboratory 10 (Table XVI) which used for some of its tests long heating and soaking times may not be significant. Here again, testing at individual laboratories under controlled conditions may reveal the possible effect of this parameter.

7.4 Temperature

Table XXXV shows that the recommended values for temperature control have been obtained, at least nominally, by most of the laboratories. In this table the variation of temperature with time and along the gauge length refer to indicated temperatures. The accuracy values derive from the calibration of the thermocouples used, by comparison to a standard thermocouple. The sensitivity values refer to the final temperature measuring equipment which generally is a precision potentiometer. Except for a few cases, accuracy values for the whole systems used in temperature measurement were not explicitly given. Laboratory 17 reported that the accuracy of the thermocouple was ±0.5°F whereas that of the whole system was ±2°F. Evidently only values relating to the whole system are significant in the effective control of temperature.

Temperature control is generally identified as the major factor affecting stress rupture data. It is useful to establish whether or not interlaboratory differences in this programme can be accounted for by temperature. The effect of a temperature variation on stress rupture time of Nimonic-105 may be estimated, by the following relation[4] on the basis of a Larson-Miller parameter:

$$\Delta(\log t) = \frac{20 + \log t}{T} \Delta T \ . \qquad (9)$$

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Relation (9) shows that the error on $\log t$ decreases as the temperature increases and that it increases as the time to rupture increases. Table XXXIX reproduces some specific data which show that for temperature errors ranging from 2 to 5°C, the error in rupture life varies respectively from about 10% to 25%.

If temperature were the sole testing factor out of control for an ideally homogeneous material the rupture lives would be roughly accounted for by temperature deviations of more than ±5°C. In fact, under normal conditions the total error in temperature measurement may well reach that level.

Assuming that the permissible error in indicated temperature is of ±2°C, the instrumental errors excluding drift may be decomposed as follows[5]: ±1°C thermal gradient error, ±1°C for calibration and ±1°C for instrument error. These partial errors added to the permissible error give rise to a total possible error of ±5°C.

Another important factor which should be considered is the drift of the thermocouples during testing. In the present programme the thermocouples used were various types of noble metal thermocouples and Chromel-Alumel.

For the times and temperatures involved in this programme it has been reported[6,7] that Chromel-Alumel thermocouples are subject to a significant positive drift. For example, at 1000°C a positive drift of 0.4 mv (~10°C) was observed after 120 hours of exposure. Under similar conditions the drift of noble metal thermocouples is negligible. At lower temperatures, Cr-Al is reported to be subject to a negative drift. More recently an evaluation of Chromel-Alumel thermocouple drift at 900°C was carried out[8]. The results shown in Figure 9 show appreciable drift, positive or negative occurring often even after 100 hours of exposure. From Table XXXV it appears that laboratories 8, 16, 17 and 20 used Chromel-Alumel couples and Laboratory 1 used such a couple as sensing device for the temperature controller. Table XIV shows on the other hand, that the means obtained from these laboratories are located on the high side. Although care was taken by these laboratories to make corrections during testing it appears that the above mentioned association of long rupture times to the use of Chromel-Alumel thermocouples is not a mere coincidence. Furthermore the analysis of variance carried out on all option "A" laboratories except the above mentioned five laboratories indicates no significant interlaboratory variability.

7.5 Strain Measurement

The specifications recommended the reporting of total deformation as a function of time. Total deformation comprises the elastic and plastic deformation on loading and the creep deformation. In view of the possible difficulties of dissociating the plastic deformation on loading from the elastic strain the total deformation data were preferred. The presentation of the results as requested would then allow the evaluation of the results expressed as total strain or as creep strain.

The elastic deformation on loading may be assessed by calculations based on the dynamic modulus of Nimonic-105 alloy at 900°C which is reported to be of 15,820 kg/mm^2. The elastic strain for the various stresses considered in the programme are given in Table XL.

Table XXXVI summarises the techniques used for strain measurement and Figure 8 shows the specimens used. Strain was measured by various means: mechanical (dial gauges) optical (mirrors) or electrical (transformer or capacitance transducers).

To obtain adequate data on total deformation at the time of loading it is necessary to use a device with an accuracy of better than 10^{-3} percent in view of the fact that the nominal (elastic) deformation on loading ranged, depending on the load, from 0.066 to 0.128 percent. In the original specifications, it was recommended that strain be measured with an accuracy of not less than 0.1% of the gauge length up to 5% strain. In fact such an accuracy is only sufficient for strains above 1%. However, many laboratories used extensometers with an accuracy of 10^{-3} percent or better, indicating that this requirement had been recognised.

The measurement of total deformation as opposed to that of plastic deformation, was considered by some laboratories as a difficult operation. However many laboratories gave consistent measurements of total deformation. A good criterion for the overall accuracy of the strain measuring device is provided by the measurement of the total deformation on loading, at room as well as at the test temperature, which can be estimated from the elastic properties of the material. In this respect, incremental loading appears to be preferable in view of the possibility of assessing both the elastic and plastic deformation on loading. Such a procedure tends to increase the loading time but there is no evidence that this might have some influence on the creep curve. Figure 10 shows typical loading curves derived from data produced at Laboratory 10. Figure 11 reproduces a typical total deformation versus time curve, determined in this programme.

The lack of adequate control in strain measurement resulted in large intralaboratory variability of total deformation on loading and times to 0.5, 1 and 2% total deformation as commented in paragraph 6.

Regarding total deformation on loading, only few laboratories (Laboratories 6, 9, 10, 14 and 20) gave values approaching the nominal ones (Table XL) to ±30%. Only two laboratories (Laboratories 10 and 20) gave total deformation values to within ±20% of the nominal ones, although many laboratories used extensometers with adequate sensitivity.

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Under these conditions the evaluation of time to small total deformation (i.e. 0.1 and 0.2%) is meaningless. As shown previously the intralaboratory variability for times to larger total deformations, 0.5, 1 and 2%, decreases with time in view of the fact that the effect of initial error becomes less and less pronounced.

7.6 Association of Mean Log Rupture Time and Testing Techniques

To summarise the previous considerations, Table XLI reproduces the rank of mean log rupture time for the 18 option "A" laboratories and the corresponding rank for the laboratories that have completed the option "C" tests. The peculiarities identified in testing procedures are mentioned aside the corresponding laboratory number.

Examination of the data summarised in Table XLI calls for the following remarks:

- the use of Chromel-Alumel thermocouple accounts probably for the high mean Log Rupture Times obtained by Laboratories 8, 1, 17, 20 and 16
- the low rank of Laboratory 2 is probably due to the use of specimen with a special design. The low ranks of Laboratories 11 and 9 appear associated with, respectively, large thermal gradient and low accuracy in thermocouple calibration
- parameters such as gauge length to diameter ratio, loading rate, heating and soaking time and beam levelling device have not apparently a clear effect.

8. VARIABILITY ASSOCIATED WITH CREEP RUPTURE TESTS

8.1 General Considerations

As mentioned in the introduction there are numerous sources accounting for the variability in creep rupture testing. For the purpose of clarity, they may be traced back to two major sources: the material itself and the testing techniques.

The variabilities related to a given material include those between melts, ingots, bars (or shapes in general), locations, etc. They are due to technological aspects such as nature of raw materials, melting methods, primary and secondary fabrication techniques, heat treatments, etc. Such sources of variability depend on the state of the art in the fields considered and are often in constant evolution. Superalloys have achieved a fairly high degree of feasibility and reliability because of progress made during the last twenty years through the development of vacuum melting techniques, the introduction of vacuum arc remelting and electroflux remelting facilities, the use of better controlled primary fabrication equipment, the evolution of secondary fabrication procedures such as precision forging or precision casting, etc. Fabrication methods which were considered a few years ago as giving rise to material with inconsistent properties are fairly well controlled to day. The quantitative assessment of these variabilities is useful in principle but requires considerable work. Furthermore the usefulness of such evaluation is reduced by the fact that a nominal material may in fact be produced and processed, depending on the final usage, for a wide range of properties, range which may exceed that expected from the variability sources outlined here above.

A classification of variability sources relating to test techniques comprises mainly temperature measurement and control, load applications and control, specimen design and machining, and extensometer design and control.

In view of the dependence of creep rupture data on temperature, this parameter accounts for the largest part in creep rupture data scatter. It should be appreciated that a variation of 5°C results in a variation of rupture time of about 25%, for a material obeying Larson-Miller's parametric relationship. Temperature control involves in turn a number of other parameters: furnace design, control device for furnace temperature, thermocouples nature attachment, calibration and drift, temperature measuring instruments.

Load errors of the magnitude permissible in present day specifications, result in time to rupture errors far smaller than those due to temperature variations. Axiality of load application and loading rates and techniques, may have also an effect which however has not been quantitatively estimated.

Test pieces design and preparation are definitely an identified source of variability. The quantitative assessment of this parameter becomes however unnecessary since for comparison purpose, this parameter may be held constant at least in intralaboratory work.

Within the scope of the AGARD cooperative programme it is useful to give an estimate of the variability due to testing techniques which in turn accounts to a large extent for the observed intra and interlaboratory variabilities. The estimates of these variabilities are given in the next section.

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8.2 Estimates of Variability Sources for Rupture Time

From the data generated in this programme and their analysis it is possible, with some conjecture, to estimate several variances pertaining to the scope of the programme. While the quantitative accuracy of these estimates may be gross, it is a useful exercise to help identify where significant improvement may be achieved. At the very least, it indicates the uncertainty of the contribution from some of these sources of variance.

8.2.1 Interlaboratory Variance ($S^2_{interlab.}$)

Considering the programme design (Tables III and IV) estimates of $S^2_{interlab.}$ are calculated from the analysis of variance Tables XV and XVII. These estimates are listed in Table XLII. The estimate from Table XV are about 0.00122 (S = 0.0350, 83%) and is inflated due to the effect of testing techniques. The estimate from Table XVII, $S^2_{interlab.} \simeq 0.00045$ (S = 0.0021, 4.9%), are representative of interlaboratory variance where testing conditions are more homogeneous.

8.2.2 Residual Variance ($S^2_{residual} = S^2_{intralab.} + S^2_{material}$)

The residual variance is assumed to be the sum of intralaboratory variance ($S^2_{intralab.}$) and material variance ($S^2_{material}$). Estimates of the residual variance are provided by the data in Tables XV.A and XVII.A. These estimates are of about 0.0033 ($S_{residual} \simeq 0.0575$, 14%) and are listed in Table XLIII.

8.2.3 Intralaboratory Variance ($S^2_{intralab.}$)

A low estimate of this variance is provided by the data regarding the preliminary evaluation of Nimonic-105 bars (Table VI, Appendix II, page II-5). This estimate is based on 13 d.f. and corresponds to one laboratory.

A more realistic estimate, although somewhat inflated is given in Tables XV.B and XVII.B relating to data adjusted for bar to bar variability. These different estimates are given in Table XLIV.

8.2.4 Material Variance ($S^2_{material}$)

The material variance is obtained by subtracting the intralaboratory variance from the residual variance. Depending on the value selected for the intralaboratory variance two estimates are obtained as shown in Table XLV.

8.2.5 Heat to Heat Variance (S^2_{Heat})

The present programme does not allow to estimate the heat to heat variance. From the producers experience it may be estimated to be within the range 0.0056–0.0067, taking into account the intralaboratory and material variance. The heat to heat log standard deviation is thus of 0.075–0.082 (19–21%).

8.2.6 Total Variance

If the heat to heat variance is not taken into consideration the total variance of individual stress rupture tests is estimated as the sum = $S^2_{total} = S^2_{intralab.} + S^2_{interlab.} + S^2_{material}$.

The contribution to the total variance of each individual source is as follows:

$S^2_{intralab.}$	0.0023, S = 0.0480,	11.5%
$S^2_{interlab.}$	0.0012, S = 0.0347,	8.3%
$S^2_{material}$	0.0010, S = 0.0316,	7.5%
S^2_{total}	0.0045, S = 0.0612,	17%

In considering the magnitude of these standard deviations it is sobering to reflect on the errors in rupture time induced by errors in load measurement and, particularly, temperature control. On the other hand it is confirmed that the heat to heat variance exceeds the total variance as calculated above and which is due to test techniques and within heats variability.

Regarding temperature it may be argued that the evolution in furnace and temperature control technology provides little hope for improved accuracy in temperature measurement even under the best possible operating conditions. It is possible however, with the progressing computerisation of creep laboratories, to increase considerably the frequency of readings and to process the data with the purpose of correcting the rupture times, provided that reliable calibration of the thermocouples is available.

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9. EVALUATION OF TEST TECHNIQUES AND SPECIFICATIONS

The AGARD Cooperative Creep Testing Programme was not designed to reveal the effect of specific test variables. Such effects can only be detected by means of experiments within individual laboratories where it is possible to maintain all but one test variable at the same level. The background available from the programme and the remaining material may serve the purpose of efficiently determining the effect of test parameters, by carrying out at individual laboratories in parallel the Model "A" or Model "C" tests, the pairs of tests differing in the parameter studied.

The general information on test techniques accumulated in this programme shows that the following parameters deserve further study:

- test-piece design
- thermocouple nature in temperature measurement
- heating and soaking time
- loading rate
- beam levelling device
- axiality.

Experimental work in this respect has been initiated.

Specifications on creep and creep rupture testing should be clarified in two important respects: temperature and strain measurement.

The present programme showed that, in spite of pertinent general recommendations, temperature control remains a serious source of variability. This situation may be only discontinued by providing recommendations on pyrometric practice including the choice of specific thermocouples of reliable stability.

The efficiency of recommendations regarding strain measurement appears questionable. In this respect it seems essential to check the performance of the extensometric device not only before loading but also during loading by, necessarily, recording the strain load curve.

10. SUMMARY AND CONCLUSIONS

The AGARD Cooperative Creep Testing Programme was statistically designed and was carried out with the collaboration of eighteen laboratories from various NATO countries. The design of the programme permitted the quantitative estimation of intralaboratory and interlaboratory variances. The analysis of the data gave evidence for the effect of specific test parameters and for the necessity to improve specifications particularly regarding temperature and strain measurement. The information derived from the programme allows to use efficiently the remaining of Nimonic-105 bars either as a limited bank of "calibrated" material or for use at individual laboratories for the assessment of specific test parameters. Finally, the results of the programme provide the quantitative information necessary to the design and conducting of other interlaboratory exercises.

REFERENCES

1. Duncan, D.B. — *Multiple Range and Multiple F Tests*. Biometrics, Vol.11, 1955, pp.1-42.

2. Voorhees, H.R. — Private Communication.

3. Shahinian, P., Achter, M. — Trans. ASM, Vol.56, 1959, p.244.

4. Dunsby, J.A. — *On the Furnace Requirements for the Mechanical Testing of Materials at Elevated Temperature*. NRC, Report No.6073, Ottawa, November 1960.

5. Few, I.G. — *Testing Experience on Aeroengine Materials*. In *Temperature Measurement and Control in Creep Testing*. NEL Report No.362, September 1968, p.73.

6. – — *Temperature Measurement and Control in Creep Testing*. NEL Report No.362, September 1968.

7. Bennett, R.L., Rainey, T.R., Jr. — *Drift Studies on Chromel-P-Alumel Thermocouples in Helium Atmospheres*, C.Herzfeld (editor). In *Temperature, Its Measurement and Control in Science and Industry*. Vol.III, Part II, Rheinhold, New York, 1962, p.289.

8. Caubo, M., Mathonet, J. — CNRM unpublished data.

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TABLE I

"Stress" Levels and Estimated Rupture Times

"Stress" Level Code	*Arbitrary Specified Stress (log scale)*		*Estimated Stress Rupture (Hours)*
	psi.f.	kg.f/mm²	
σ_1	28.87	20.3	35
σ_2	24.467	17.2	100
σ_3	20.768	14.6	240
σ_4	17.639	12.4	500
σ_5	14.936	10.5	1000

TABLE II

Testing Required by Models "A" and "C"

Replicate	*Model "A"*	*Model "C"*
1		σ_{11} (20.3)
	σ_{21} (17.2)	σ_{21} (17.2)
	–	σ_{31} (14.6)
	–	σ_{41} (12.4)
	σ_{51} (10.5)	σ_{51} (10.5)
2	–	σ_{12} (20.3)
	σ_{22} (17.2)	σ_{22} (17.2)
	–	σ_{32} (14.6)
	–	σ_{42} (12.4)
	σ_{52} (10.5)	σ_{52} (10.5)
Total	4 tests 2200 Hrs (nominal)	10 tests 3750 Hrs (nominal)

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TABLE III

Design and Analysis of Model "A"

This is a factorial with two separate randomised replicates. One replicate should be done before the other is started if one test machine is used for all tests. If two machines are used, the machines and replicates should be paired.

$$X_{ijkm} = \mu + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{ik} + \epsilon m_{(ijk)}$$

where

X_{ijkm} experimental result or response of the $ijkm^{th}$ test

μ true mean of all test results

A_i laboratory effect (fixed, qualitative variable i = 1 – 18)

B_j "stress" level effect (fixed quantitative, independent variable) (j = 1,2 for two stress levels) (the stress levels are σ_2 and σ_5 of Table II)

C_k replication effect (k = 1,2 for 2 replicates) (the difference between two replicates of ij = 36 tests each)

AB_{ij} interaction effect of laboratories and stress levels (probably not significant)

AC_{ik} interaction effect of laboratories and replicates (probably not significant)

BC_{jk} interaction effect of "stress" level and replicates (probably not significant)

m number of tests per unit cell (m = 1)

$\epsilon m_{(ijk)}$ random residual effect, which includes effects due to intralaboratory variables and material inhomogeneity.

Source of Variation	d.f.	*Expected Mean Square**	*F Statistic and* (d.f.)
A_i	i – 1 = 17	$\sigma_0^2 + 4\sigma_A^2$ ... (1)	$\frac{\text{EMS 1}}{\text{EMS 7}}$ (18,18)
B_j	j – 1 = 1	$\sigma_0^2 + 36\sigma_B^2$ ... (2)	$\frac{\text{EMS 2}}{\text{EMS 7}}$ (1,18)
AB_{ij}	(i – 1) (j – 1) = 17	$\sigma_0^2 + 2\sigma_{AB}^2$ ... (3)	$\frac{\text{EMS 3}}{\text{EMS 7}}$ (18,18)
C_k	k – 1 = 1	$\sigma_0^2 + 36\sigma_C^2$ ... (4)	$\frac{\text{EMS 4}}{\text{EMS 7}}$ (1,18)
AC_{ik}	(i – 1) (k – 1) = 17	$\sigma_0^2 + 2\sigma_{AC}^2$ ... (5)	$\frac{\text{EMS 5}}{\text{EMS 7}}$ (18,18)
BC_{jk}	(j – 1) (k – 1) = 1	$\sigma_0^2 + 18\sigma_{BC}^2$ ... (6)	$\frac{\text{EMS 6}}{\text{EMS 7}}$ (1,18)
$\epsilon m_{(ijk)}$	(i – 1) (j – 1) (k – 1) = 17	σ_0^2 ... (7)	
Total	(ijkm – 1) = 71		

* Apart from the residual, the variances shown are of the "fixed" type e.g.

$$\sigma_A^2 = \frac{\sum_i A_i^2}{a - 1}.$$

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TABLE IV

Design and Analysis of Model "C"

The experimental pattern and analysis of this programme are analogous to those of Model "A" in Table III. However there are five "stress" levels instead of two.

$$X_{ijkm} = \mu + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{jk} + \epsilon m_{(ijk)}$$

where

A_i laboratory effect (i = number of laboratories, 11)

B_j "stress" level effect (j = 5)

C_k replication effect (ij tests per replicate)

m number of tests per unit cell = 1

Source of Variation	d.f.	*Expected Mean Square**	*F Statistic and* (d.f.)
A_i	$i - 1 = 10$	$\sigma_0^2 + jk\sigma_A^2$ ... (1)	$\frac{EMS\ 1}{EMS\ 7}$ $(i-1),(i-1),$ $(j-1),(k-1)$
B_j	$j - 1 = 4$	$\sigma_0^2 + ik\sigma_B^2$ ... (2)	$\frac{EMS\ 2}{EMS\ 7}$ $(j-1),(i-1);$ $(j-1),(k-1)$
AB_{ij}	$(i-1)(j-1) = 40$	$\sigma_0^2 + k\sigma_{AB}^2$ ... (3)	$\frac{EMS\ 3}{EMS\ 7}$ $(i-1),(j-1),(i-1),$ $(j-1),(k-1)$
C_k	$(k-1) = 1$	$\sigma_0^2 = ij\sigma_C^2$ ... (4)	$\frac{EMS\ 4}{EMS\ 7}$ $(k-1),(i-1),$ $(j-1),(k-1)$
AC_{ik}	$(i-1)(k-1) = 10$	$\sigma_0^2 + j\sigma_{AC}^2$ ... (5)	$\frac{EMS\ 5}{EMS\ 7}$ $(j-1),(k-1),(i-1),$ $(j-1),(k-1)$
BC_{jk}	$(j-1)(k-1) = 4$	$\sigma_0^2 + i\sigma_{BC}^2$ ... (6)	$\frac{EMS\ 6}{EMS\ 7}$ $(j-1),(k-1),(i-1),$ $(j-1),(k-1)$
$m_{(ijk)}$	$(i-1)(j-1)(k-1) = 40$	σ_0^2 ... (7)	
Total	$ijkm - 1 = 109$		

* σ_A^2, σ_B^2, σ_{AB}^2, σ_C^2, σ_{AC}^2, and $\sigma\sigma_{BC}^2$ are "fixed" variances.

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TABLE V

Information Coded in Computer Tables

Rep.	Replicate number, 1 or 2
Load	The stress in kg/mm^2
Nom.	The nominal rupture time in hours
Labo.	The laboratory code number (1 to 20)
Blank	The blank identification number
Total	Total deformation in percent on loading at time zero
0.1	Time in hours to reach a total deformation of 0.1%
0.2	Time in hours to reach a total deformation of 0.2%
0.5	Time in hours to reach a total deformation of 0.5%
1.0	Time in hours to reach a total deformation to 1%
2.0	Time in hours to reach a total deformation to 2%
Rupt.	Time in hours to reach rupture
Elong.	Elongation at rupture in percent
R.A.	Reduction of area at rupture in percent.

TABLE VI

Calculated Rupture Times and Limits

Stress	*Number of Tests*	*Calculated Rupture times, hours*	2S *limits*	3S *limits*
20.3	22	48.5	36.6–65.6	31.1–75.4
17.2	36	128.0	95.4–172	82.3–199.6
14.6	22	303.0	225–406	194–471
12.4	22	643.0	479–864	413–1001
10.5	36	1250.0	929–1670	801–1942

TABLE VII

Outliers

(a) Outside 2σ range

Lab.	*Replicate*	*Blank*	*Stress*	*Rupture life*	2S *range*
9	1	3.11 G	20.1	36	36.6–65.6
16	1	5.9 D	12.4	927	479–864
3	1	3.13 G	10.5	844	929–1670
11	2	3.8 D	20.3	34.4	36.6–65.6
19	2	2.2 D	20.3	68	36.6–65.6
4	2	5.1 G	17.2	174	95.4–172
16	2	1.26 G	10.5	1768	929–1670

(b) Outside 3σ range

None

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TABLE VIII

Between Bar Group of Data

	Number of Bars				
	1	2	3	4	5
Number of data	27	24	28	34	24
Average st. deviation	3.1133 0.05962	3.1108 0.05372	3.0539 0.05978	3.0779 0.03634	3.1448 0.05959

TABLE IX

Between Positions Group of Data

	Position				
	1–6	7–12	13–18	19–24	>24
Number of data	27	23	28	28	31
Average st. deviation	3.1173 0.07054	3.0819 0.07899	3.0867 0.05015	3.1003 0.04558	3.1011 0.05724

TABLE X

Analysis of Variance for Between Bars and Between Positions Variability on the Basis of Data Adjusted to a Common Stress

Source	*Sum of Squares*	d.f.	*Mean Sq.*	F
Between bars	0.1285811	4	0.0321453	11.47
Between positions	0.0200529	4	0.00501323	1.79
Residual	0.3586015	128	0.0028016	
Total	0.5072355	136		

$F99\ (4,128) \simeq 3.48$
$F95\ (4,128) \simeq 2.45$

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TABLE XI

Data Relating to the Different Bars on the Basis of Data Adjusted to a Common Stress and for Bar Variability

Bar no.	*Number of Tests*	*Mean*
1	27	3.1133
2	24	3.1108
5	24	3.0980
3	29	3.0938
4	34	3.0799

TABLE XII

Data Relating to the Different Positions on the Basis of Data Adjusted to a Common Stress and for Bar Variability

Position	*Number of Tests*	*Mean*
1–6	27	3.1118
>24	31	3.1022
19–24	28	3.0997
13–18	28	3.0927
7–12	24	3.0807

TABLE XIII

Analysis of Variance for Between Bars and Between Positions Variability on the Basis of Data Adjusted to a Common Stress and for Between Bar Variability

Source	*Sum of Squares*	d.f.	*Mean Squares*	F
Between bars	0.02192783	4	0.005481958	1.86
Between positions	0.01370048	4	0.003425121	1.16
Residual	0.37904069	129	0.002938300	
Total	0.41466900	137		

$F95\ (4,129) \simeq 2.45$

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TABLE XIV

Mean Log Rupture Times Adjusted to a Common Stress for 18 Option "A" Laboratories (4 Tests per Laboratory)

(A) Data not Adjusted for Bar Variability

Rank	*Laboratory*	*Mean*
1	17	3.1736
2	8	3.1715
3	20	3.1440
4	16	3.1307
5	1	3.1294
6	4	3.1376
7	12	3.1210
8	14	3.1150
9	10	3.1124
10	13	3.0980
11	19	3.0810
12	11	3.0721
13	6	3.0708
14	5	3.0487
15	3	3.0455
16	2	3.0436
17	15	3.0381
18	9	3.0375

(B) Data Adjusted for Bar Variability

Laboratory	*Mean*
8	3.1709
1	3.1515
17	3.1503
20	3.1434
16	3.1300
12	3.1210
4	3.1149
10	3.1124
13	3.1091
14	3.1033
6	3.0819
19	3.0810
15	3.0602
5	3.0598
3	3.0556
9	3.0485
11	3.0370
2	3.0320

Brackets identify homogeneous groups (Duncan's test, 95%).

TABLE XV

Analysis of Variance for 18 Option "A" Laboratories on the Basis of Data Adjusted to a Common Stress

(A) Data not Adjusted for Bar Variability

Source	*Sum of Squares*	d.f.	*Mean Square*	F
Labs	0.13707970	17	0.008063512	2.51
Replicates	0.00200550	1	0.00200550	–
Stresses	0.00006831	1	0.00006831	–
Residual	0.16704454	52	0.00321231	F99 (17,52) 2.35
Total	0.30619805	71		

(B) Data Adjusted for Bar Variability

Source	*Sum of Squares*	d.f.	*Mean Square*	F
Labs	0.12358420	17	0.00726965	3.047
Replicates	0.00004900	1	0.00004900	–
Stresses	0.00016148	1	0.00016148	–
Residual	0.12405999	52	0.00238676	–
Total	0.24785467	71		F99 (17,52) 2.35

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TABLE XVI

Mean Log Rupture Times Adjusted to a Common Stress for 11 Option "C" Laboratories (10 Tests per Laboratory)

(A) Data not Adjusted for Bar Variability

Rank	*Laboratory*	*Means*
1	10	3.1326
2	16	3.1165
3	12	3.1150
4	19	3.1135
5	4	3.1058
6	14	3.1050
7	13	3.0810
8	11	3.0781
9	15	3.0750
10	3	3.0560
11	9	3.0458

(B) Data Adjusted for Bar Variability

Laboratory	*Means*
10	3.1326
16	3.1203
19	3.1180
12	3.1144
4	3.1050
13	3.0942
14	3.0909
15	3.0835
3	3.0645
9	3.0588
11	3.0544

Brackets identify statistically homogeneous groups (Duncan's test, 95%).

TABLE XVII

Analysis of Variance for 11 Option "C" Laboratories on the Basis of Data Adjusted to a Common Stress

(A) Data not Adjusted for Bar Variability

Source	*Sum of Squares*	d.f.	*Mean Square*	F
Labs	0.07616583	10	0.00761658	2.26
Replicates	0.00029579	1	0.00029579	–
Stresses	0.00456997	4	0.00114249	–
Residual	0.31655980	94	0.00336765	
Total	0.39759139	109		F99 (10,94) ≃ 2.50 F95 (10,94) ≃ 1.95

(B) Data Adjusted for Bar Variability

Source	*Sum of Squares*	d.f.	*Mean Square*	F
Labs	0.07093753	10	0.00709375	3.13
Replicate	0.00019140	1	0.00019140	–
Stresses	0.00396867	4	0.00099216	–
Residual	0.21292164	94	0.00226512	–
Total	0.28801924	109		F99 (10,94) ≃ 2.50

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TABLE XVIII

Calculated Time to 0.5% Total Deformation and ±2S Limits

Stress kg/mm²	*Calculated Time (0.5%) Hrs*	±2S *limits*
20.3	9.3	4.8–18.0
17.2	26.2	13.6–51.0
14.6	68.6	35.5–132.0
12.4	169.0	88.0–326
10.5	400.0	207–772

TABLE XIX

Outliers of Time to 0.5% Total Deformation

Laboratory	*Replicate*	*Blank*	*Stress*	*Time (0.5%) Hrs*	±2S *limits*
19	1	1.21 b	17.2	5.5	13.6–51.0
19	1	1.30 D	12.4	0.6	88–326
19	2	2.2 D	20.3	1.9	4.8–18.0
19	2	2.7 D	12.4	35.0	88–326

TABLE XX

Analysis of Variance. Time to 0.5% Total Deformation.
17 Option "A" Laboratories

Source	*Sum of Squares*	d.f.	*Mean Squares*	F
Labs	1.72471856	16	0.10779491	6.82
Stresses	23.96481934	1	23.96481934	1520.0
Residual*	0.78991608	50	0.01579832	F99 (16,50) 2.4
Total	26.47945398	67		

* comprises the effects of replicates, interactions, macro inhomogeneity and intralaboratory variability.

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TABLE XXI

Time to 0.5% Total Deformation.
Ranking of 17 Options "A" Laboratories

Rank	*Laboratory*	*Means*
1	16	2.2609
2	18	2.1891
3	17	2.1640
4	10	2.1502
5	13	2.1482
6	14	2.1137
7	15	2.0388
8	6	2.0284
9	2	2.0108
10	4	2.0061
11	20	1.9840
12	11	1.9650
13	5	1.9458
14	12	1.9328
15	3	1.8996
16	9	1.8776
17	19	1.5413

Brackets identify statistically homogeneous groups (Duncan's test, 95%).

TABLE XXII

Calculated Time to 1% Total Deformation and ±2S Limits

Stress kg/mm²	*Calculated Time (1%) Hrs*	±2S *limits*
20.3	18.2	10.6–31
17.2	48.2	28.2–82.0
14.6	120.0	70–205
12.4	282.0	165–482
10.5	632.0	369–1080

TABLE XXIII

Outliers of Time to 1% Total Deformation

Laboratory	*Replicate*	*Blank*	*Stress*	*Time (1%) Hrs*	±2S *Range Hrs*
16	1	5.9 D	12.4	650	165–482
19	1	1.21 G	17.2	22	28.2–82.0
19	1	1.30 D	12.4	12	165–482
19	2	3.23 D	14.6	280	70–205

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TABLE XXIV

**Analysis of Variance. Log Time to 1% Total Deformation.
17 Option "A" Laboratories**

Source	*Sum of Squares*	d.f.	*Mean Square*	F
Labs	0.51255064	16	0.03203444	4.85
Stresses	20.90387397	1	20.90387397	$F_{99}(16,50) \simeq 2.4$
Residual	0.33041746	50	0.006608249	
Total	21.74684207	67		

TABLE XXV

**Time to 1% Total Deformation.
Ranking of 17 Option "A" Laboratories**

Rank	*Laboratory*	*Means*
1	16	2.0497
2	17	2.3614
3	8	2.3605
4	10	2.3235
5	14	2.3121
6	13	2.0387
7	4	2.2713
8	6	2.2669
9	20	2.2494
10	15	2.2296
11	2	2.2200
12	3	2.2182
13	11	2.1822
14	5	2.1762
15	12	2.1716
16	9	2.1408
17	19	2.0652

TABLE XXVI

Calculated Time to 2% Total Deformation and ±2S Limits

Stress kg/mm²	*Calculated Time (2%) Hrs*	±2S *limits*
20.3	26.6	17–42
17.2	72.5	46–114
14.6	179.0	114–281
12.4	404.0	257–634
10.5	849.0	541–1333

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TABLE XXVII

Outliers of Time to 2% Total Deformation

Laboratory	*Replicate*	*Blank*	*Stress*	*Time (2%) Hrs*	±2S *Range Hrs*
11	2	3.8 D	20.3	14.6	17–42
16	1	5.9 D	12.4	730	257–634
16	2	1.26 G	10.5	1400	541–1333
19	1	1.30 D	12.4	110	257–634
19	2	3.23 D	14.6	310	114–281

TABLE XXVIII

Analysis of Variance. Time to 2% Total Deformation.
17 Option "A" Laboratories

Source	*Sum of Squares*	d.f.	*Mean Square*	F
Labs	0.25237296	16	0.01577331	4.38
Stresses	19.54961684	1	19.54961684	$F99(1,50) \simeq 2.4$
Residual	0.17915270	50	0.003583054	
Total	19.98114250	67		

TABLE XXIX

Time to 2% Total Deformation.
Ranking of 17 Option "A" Laboratories

Rank	*Laboratory*	*Means*
1	16	2.5008
2	17	2.4936
3	8	2.4825
4	10	2.4529
5	14	2.4496
6	4	2.4397
7	13	2.4310
8	20	2.4186
9	6	2.4094
10	3	2.3760
11	2	2.3727
12	15	2.3686
13	12	2.3332
14	19	2.3291
15	5	2.3280
16	11	2.3228
17	9	2.3208

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TABLE XXX

Comparison of Intralaboratory Variance and Standard Deviations

Property	*Variance*	d.f.	*Log Stand. Deviation*	*Stand. Dev. %*	*Data from*
Log time to 0.5% total def.	0.01579832	50	0.1270	34	Table XX
Log time to 1% total def.	0.006608	50	0.0813	19.5	Table XXIV
Log time to 2% total def.	0.003583	50	0.0599	14.5	Table XXVIII
Log time to rupture	0.003212	52	0.0550	13.5	Table XV
Log time to rupture*	0.002386	52	0.0488	12.0	Table XV

* On the basis of Data adjusted for bar to bar variability.

TABLE XXXI

Comparison of Standard Deviations, Calculated from Regression Analysis

Property	*Log Stand. Deviation*	*Stand. Dev. %*	*Calculated from*
Log time to 0.5% total def.	0.287424	93	Relation (4)
Log time to 1% total def.	0.167091	46	Relation (5)
Log time to 2% total def.	0.0983384	25	Relation (6)
Log time to rupture	0.0640706	15	Relation (2)

TABLE XXXII

Specimen

Laboratory Code No.	*Size*		*Surface Finish*
	ϕ,	*G.L.*	
1	3.4 mm	16 mm	NR
2	Do = 8,93 mm Di = 4 mm	$5.65\sqrt{So}$	600 grit paper
3	5 mm	25 mm	5–18μ inch RMS (0.13–0.46μ RMS)
4	NR		NR
5	5 mm	36 mm, $L = 8.14\sqrt{So}$	Ground
8	6	30 mm	Ground
9	7.5 mm	37.5 mm	0.20μ
10	8 mm	40 mm	0.16μ CLA (0.20μ RMS)
11	9.1 or 6.4 mm	50.8 mm	NR
12	6.4 mm	38.1 mm	0.2–0.44μ CLA (0.25–0.55μ RMS)
13	6.4 mm	34.3 mm	Ground
14	6.4 mm	32 mm	Ground
15	6.4 mm	32 mm	Turn, 8μ (CLA)
16	6.35 mm	31.75 mm	16μ inch RMS (0.41μ)
17	6.35 mm	31.75 mm	4.7μ inch RMS (0.12μ)
20	5 mm	25 mm	0.12μ CLA (0.15μ RMS)
SPEC.	>4 mm	$5.65\sqrt{So}$	grinding; last two passes less than 0.05 mm deep

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TABLE XXXIII

Loading

Laboratory Code No.	*System*	*Axiality*	*Procedure*	*Accuracy*	*Levelling Device*
1	10 : 1; 500 kgs	NR	screw device	0.2%, ±0.025 kg	NR
2	10 : 1, 2,500 kgs	pin univ. joint	screw device	0.5%	manual
3	10 : 1	pin, tang : 10^{-3}	manual	0.3%	manual
4	NR	NR	NR	NR	NR
5	20 : 1	ball bearings	1 kg/mm²/min	±0.05%	NR
8	1200 kgs double lever	Crossed knife-edges	NR	NR	manual
9	20 : 1; 2,000 kgs	Ball-plate	manual incremental	better than ±1%	
10	20 : 1 sliding, 2,000 kgs	NR	increments of 50 or 100 kgs	±0.4% maximum	Automatic, manual
11	10 : 1 sliding	pin-joints	shock free (5 min)	specifications	
12	sliding, 5,000 kgs	knife edge	increments 50 kgs (1, 5 min)	±1 kg	NR
13	5.6 : 1; 1 ton	Ball and plate		specifications	
14	5.6 : 1; 3000 kgs	Ball-plate	increments of 1.6 or 3, 2 kg/mm²	±0.5%	
15	double lever, 40 : 1, 5 T	knife-edge < 3%	increments	±0.5%	
16	20 : 1	specific	mechanic	±0.5 kg	
17	cantilever beam	< 15%	increments (2 min)	±0.5%	
19	10 : 1	NR	NR	NR	NR
20	10 : 1, 2,000	knife edge	mechanical (0.5 min)	+0.25–0.50%	Automatic
SPEC.	–	–	shock free	±1%	–

TABLE XXXIV

Heating

Laboratory Code No.	*Furnace*	*Atmosphere*	*Heating Time Hrs*	*Soaking Time Hrs*
1	3 zones, Cr-Al for control	vac	3	4
2	3 zones, Dilatable rod	Air	1–2	4–5
3	3 zones, Pt resist.	Air	0.4–0.6	4–6
4	NR	Air	NR	NR
5	4 zones	Air	< 2 hrs (500°C/H)	5
8	3 zones, dilatable rod	Air	3	2
9	3 zones	Air	0.5	3
10	3 zones	Air	2–10	2–26
11	Center Therm. for control	Air	1–2	4–5
12	Single zone	Air	1–2	3–4
13	3 zones, Pt resist. sat. reactor	Air	1–2	2–3
14	3 zones, Pt resist. sat. reactor	Air	1–2	4–5
15	3 zones, Pt resist. Thyristor controller	Air	3–3.5	2–3
16	Single zone with control, recording potentiometer	Air	1.75	3
17	3 zones	Air	1.5	4
19	3 zones, constant RT and voltage	Air	NR	NR
20	3 zones, constant RT and voltage	Air	1–1.5	5
SPEC.	–	–	1–2	4–5

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TABLE XXXV

Temperature Measurement

Laboratory Code No.	*System*	*Accuracy*	*Sensitivity*	*Variation in Time*	*Variation along G.L.*
1	2 Pt-Pt 10 Rh; Pot. + DC galvano	±0.5°C		897–904	2°C
2	3 Pt-Pt Rh; Pot.	±0.5°C	0.1°C	900.5–903	3°C
3	3 Pt-Pt 10 Rh; dig. voltmeter	±1°C	0.5°C	+2°C–1°C	+2°C–1°C
4	NR	NR	NR	899–907	2°C
5	2 Pt-Pt 10 Rh	±0.5°C	NR	±3°C	2°C
8	NiCr	NR	0.2°C	±2°C	2°C
9	3 Pt-Pt 10 Rh	±0.5% (4.5°C)	0.1°C	±1.5°C	±1.5°C
10	3 Pt-Pt 10 Rh	NR	NR	896–904	2°C
11	2 Pt-Pt 10 Rh; Pot.	NR	NR	±3°C	4°C
12	3 Pt-Pt 13 Rh	−0.14°C at 1063°C +0.5°C at 660°C	0.08°C		
13	Pt-Pt 13 Rh	±1°C	±0.2°C	±2°C	2°C
14	3 Pt-Pt 10 Rh	calib.	±0.2°C	±3°C	3°C
15	3 Pt-Pt 13 Rh	±1°C max.		±1.5°C	2°C
16	3 Cr-Al	±0.25% (2.25°C)		±0.55°C	1.6°C
17	3 Cr-Al, Prec. Pot.	Therm. ±0.3°C System:±1.1°C	(0.25°C)	2°C	1°C
20	3 Cr-Al spot welded + 1 Pt-Pt 10 Rh	Cr-Al: ±0.31°C Pt-Pt Rh: ±0.885°C	Cr-Al 0.25	899–902	2°C max.
SPEC.	–	±0.6°C	0.5°C	±2°C	3°C max.

TABLE XXXVI

Strain Measurement

Laboratory Code No.	*System*	*Accuracy*	*Sensitivity*
1	–	–	–
2	Axial quartz rod and tube; dial gauge	2.10^{-3} pct	0.5μ
3	Extensom. Diff. transformer	20μ	1μ
4	NR	NR	NR
5	Mechanical extensometer	NR	$\pm10^{-3}$%
8	Ridge extensometer, mirrors, dial gauge	0.1μ, 3.3×10^{-3} pct.	0.1μ, 3.3×10^{-3} pct.
9	Pin-ridge Ext., dial gauge	0.1% up to 5% total strain	10μ
10	Ridge Ext., dial gauge	NR	10μ
11	Ridge groove. Ext. mirrors	NR	0.3×10^{-3} pct (0.15μ)
12	Ridge Ext.; mirrors	NR	11×10^{-4} pct (0.40μ)
13	Ridge Ext.; dial gauge	NR	2.5μ
14	Ridge Ext.; transducer	1μ, 3×10^{-3} pct	4×10^{-4} pct (0.13μ)
15	Ridge Ext.; capacitance transducer	60μ inch (1.5μ)	–
16	Knife Ext. LVDT	±0.05% up to 10% total strain (16μ)	–
17	Collar Ext.; modified Martens.	NR	5×10^{-6} (0.5μ)
20	Ridge Ext.; VDT	1μ	4×10^{-3} pct; 1μ
SPEC.		0.1% up to 5% total strain	

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TABLE XXXVII

Rank of Means and Surface Finish

Option "C"		*Option "A"*	
Labs No.	*RMS*	*Labs No.*	*RMS*
10	0.20	17	0.12
12	0.25–0.55	20	0.15
3	0.13–0.46	12	0.25–0.55
9	0.20	10	0.20
		3	0.13–0.46
		9	0.20

TABLE XXXVIII

Effect of Stress Variation on Stress Rupture Time of Nimonic-105 at 900°C

		$\frac{\Delta\sigma}{\sigma} = 0.005$		$\frac{\Delta\sigma}{\sigma} = 0.01$	
σ	*Calculated Rupture Time*	*%*	*Range*	*%*	*Range*
20.3	48.5	3.1	47.0–50.0	6.2	45.6–51.5
17.2	128.0	2.8	125–131	5.5	21–135
14.6	303.0	2.5	296–311	5.0	288–318
12.4	643.0	2.2	629–657	4.5	616–672
10.5	1250.0	1.9	226–1275	3.9	1203–1298

TABLE XXXIX

Effect of Temperature Variations on Rupture Life of Nimonic-105 at 900°C

σ	*Calculated Rupture Time*	*Rupture Time Errors and Range for Different Values of* ΔT							
		$\Delta T = 2$		$\Delta T = 3$		$\Delta T = 4$		$\Delta T = 5$	
		%	*Range*	*%*	*Range*	*%*	*Range*	*%*	*Range*
20.3	48.5	8.9	44.6–52.7	13.6	42.7–55.0	18.5	41–57.5	23.7	39.3–60.0
17.2	128.0	9.0	117–139	13.9	112–146	19.0	108–152	24.2	103–159
14.6	303.0	9.2	275–328	14.2	263–343	19.3	257–358	24.7	242–374
12.4	643.0	9.3	587–702	14.4	562–734	19.6	537–766	25.1	514–803
10.5	1250.0	9.5	1140–1370	14.6	1090–1430	19.8	1040–1500	25.5	995–1570

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TABLE XL

Calculated Elastic Strain of Nimonic-105 at 900°C

Stress (kg/mm²)	*Elastic Strain %*
20.3	0.128
17.2	0.109
14.6	0.092
12.4	0.078
10.5	0.066

TABLE XLI

Rank of Mean Log Rupture Time (Option "A") and Corresponding Peculiarities in Testing Techniques

Rank Option "A"	*Labs.*	*Remarks*	*Rank Option "C"*
1	8	Ni-Ni Cr thermocouples	–
2	1	Cr-Al for control, subsize specimen vacuum	–
3	17	Cr-Al	–
4	20	Cr-Al	–
5	16	Cr-Al	2
6	12	Overload corrected	4
7	4		5
8	10	Long heating and soaking Time, Automatic beam levelling (partly)	1
9	13		6
10	14		7
11	6		–
12	19		3
13	15		8
14	5	G.L. = $8.14\sqrt{So}$; low loading rate	–
15	3	Short heating time	9
16	9	Short heating time, Low accuracy of therm. calibration	10
17	11	G.L. = 5.6 or 8 x D; one test overhead corrected; large gradient	11
18	2	Special specimen, overheat corrected	–

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TABLE XLII

Estimates of Interlaboratory Variance

Data from Table	d.f.	$S^2_{interlab.}$	*Standard Deviation*	%
15A	17	0.001213	0.0348	8.3
15B	17	0.001221	0.0350	8.3
17A	10	0.00042489	0.00206	4.8
17B	10	0.00048286	0.00220	5.0

TABLE XLIII

Estimates of Residual Variance

Data from Table	d.f.	$S^2_{residual}$	S	%
15A	52	0.00321231	0.0566	14.0
17A	94	0.00336765	0.0581	14.2

TABLE XLIV

Estimates of Intralaboratory Variance

Data from Table	d.f.	$S^2_{interlab.}$	S	%
VI, App.II	13	0.00120	0.0347	8.3
15B	52	0.00238676	0.0487	11.8
17B	94	0.00226512	0.0476	11.2

TABLE XLV

Estimates of Material Variance

$S^2_{material} = 0.0033 - 0.0012 = 0.0021, \quad S = 0.0418, \quad 11.1\%$

$S^2_{material} = 0.0033 - 0.0023 = 0.0010, \quad S = 0.0316, \quad 7.5\%$

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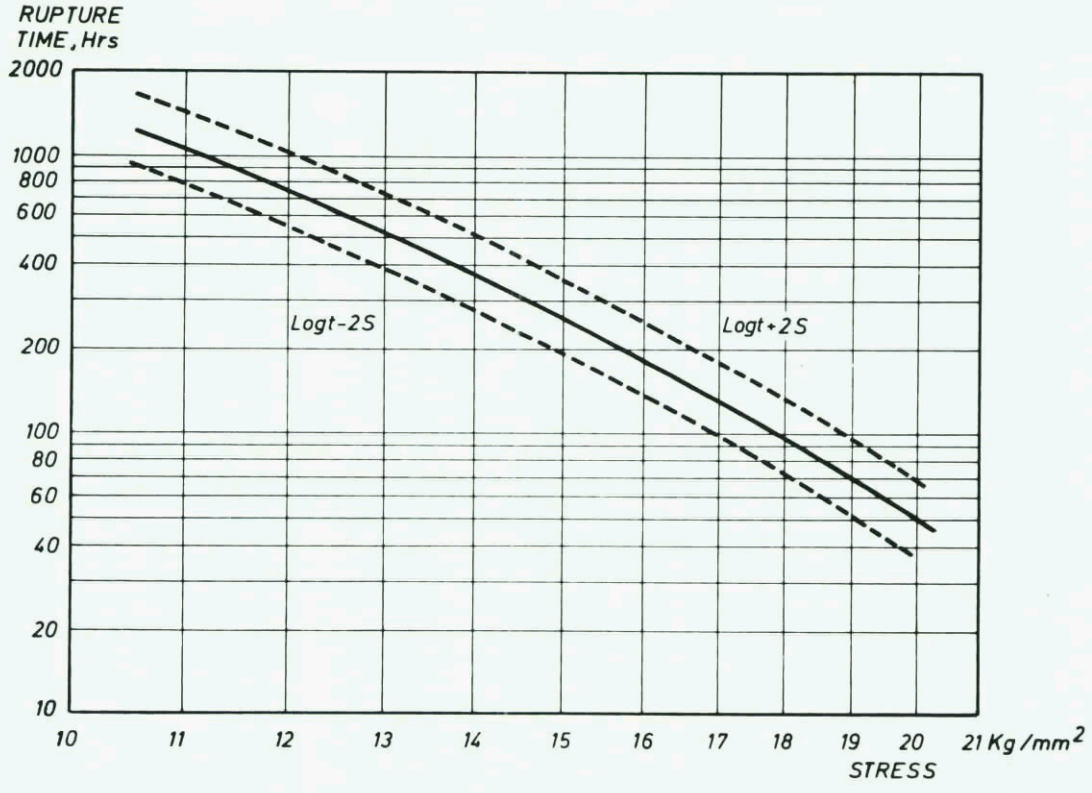

Fig.1 Log rupture time – $\log \sigma$ relationship with the corresponding $\pm 2S$ limits (S = 0.06407, 15%)

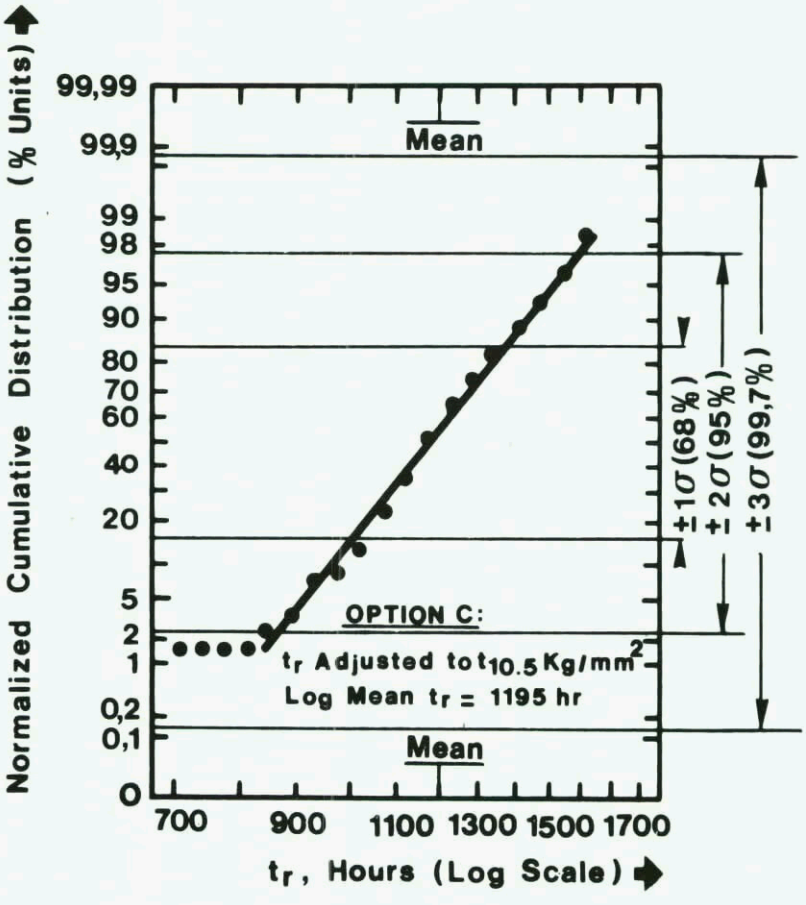

Fig.2 Cumulative distribution curve showing that log stress rupture times have an acceptable gaussian distribution. The stress rupture results represent the five fixed experimental "stress" levels. However, the results were, where necessary, adjusted to the σ_5 level of stress

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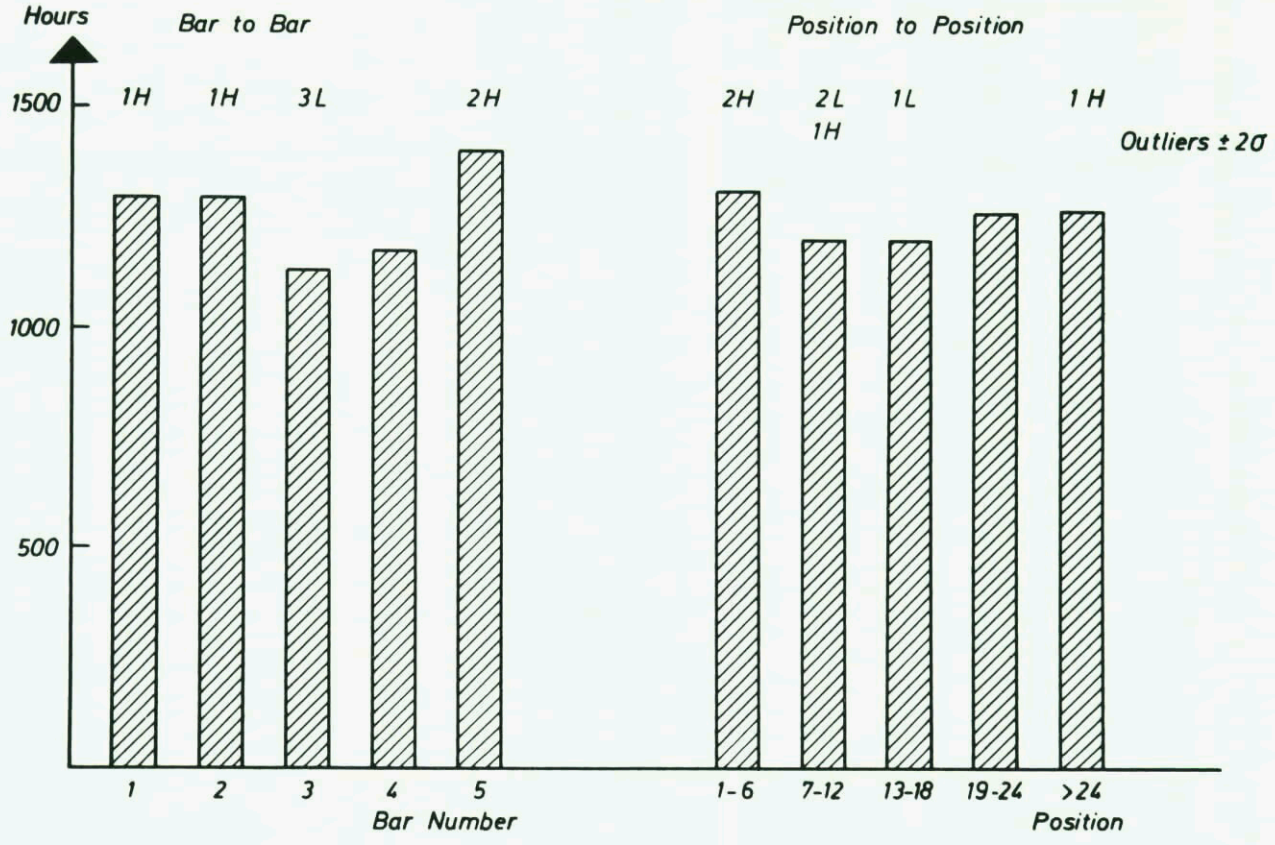

Fig.3(a) (a) Effect of bars or position on mean rupture times adjusted to a common stress (10.5 Kgrf/mm^2). Between bar variability is significant whereas between position variability is not.

(b) Mean rupture time for different bars and positions on the basis of data adjusted for bar variability.

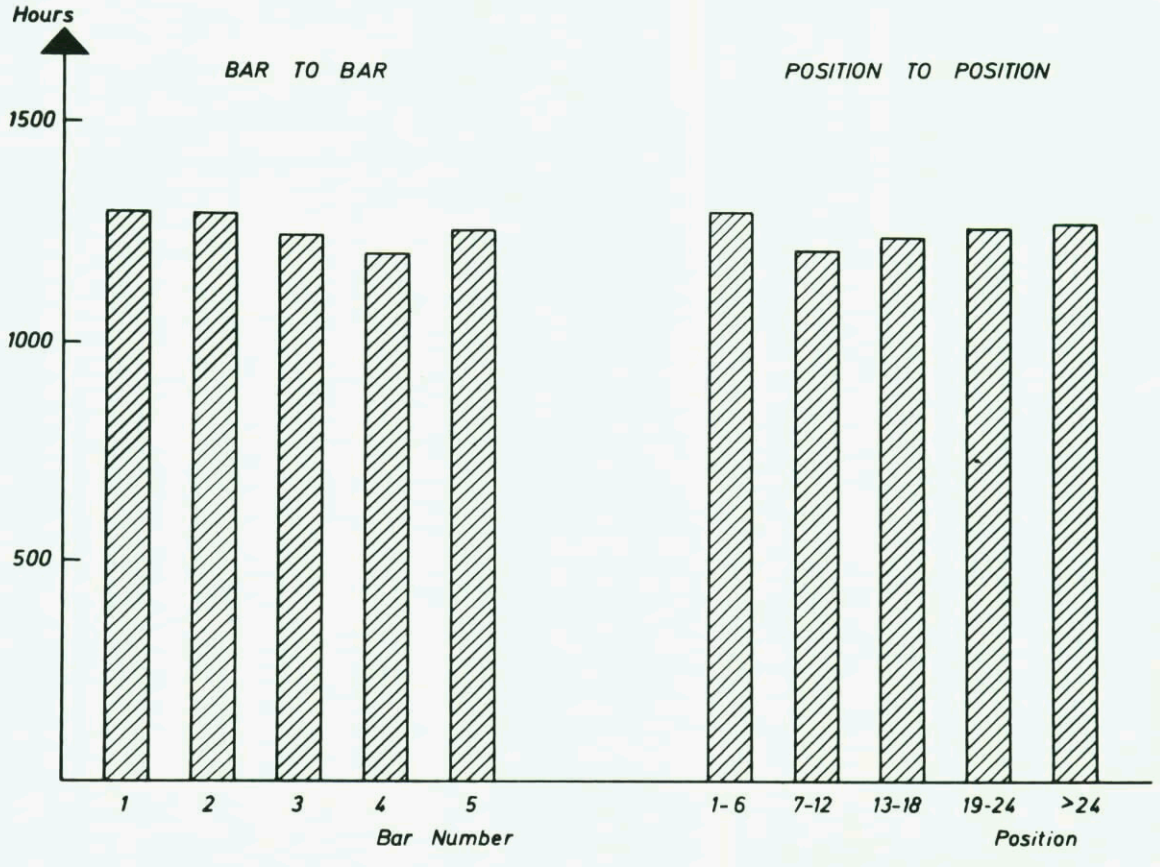

Figure 3(b)

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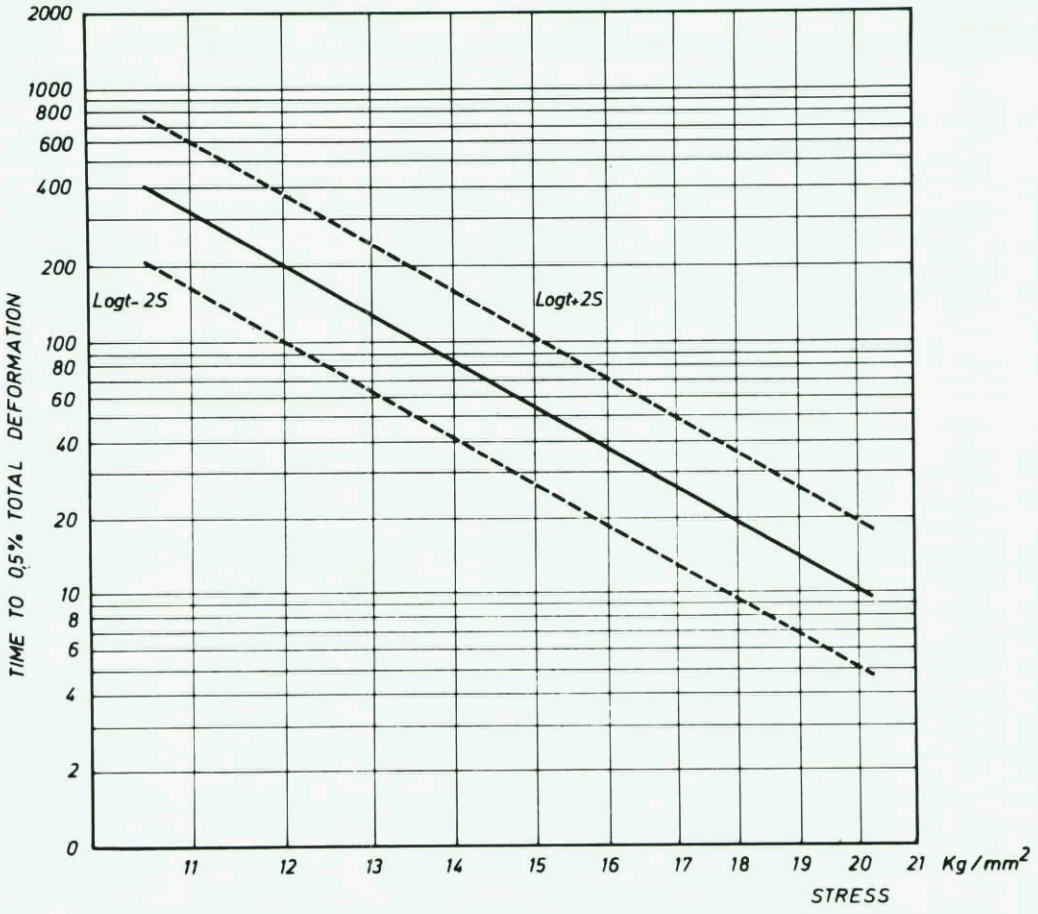

Fig.4 Log time to 0.5% total deformation as a function of $\log \sigma$ and the corresponding $\pm 2S$ limits ($S = 0.2874$, 93%)

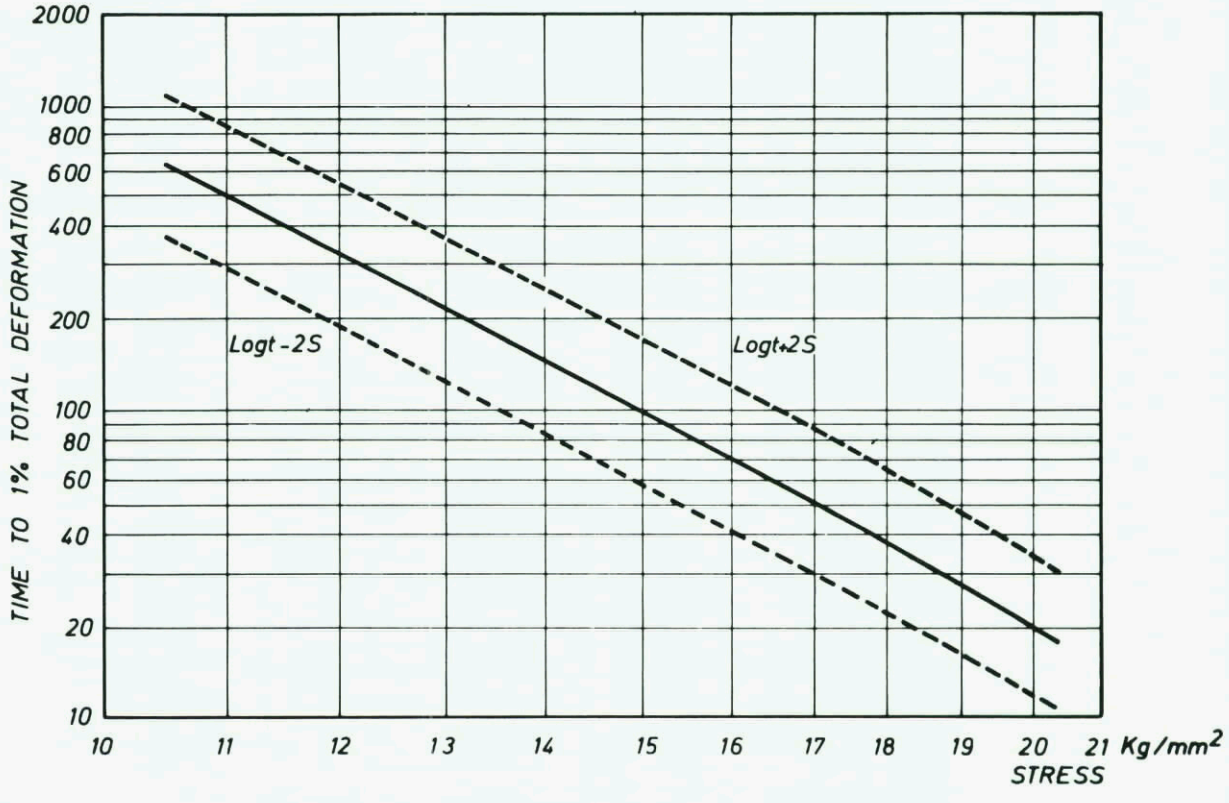

Fig.5 Log time to 1% total deformation as a function of $\log \sigma$ and the corresponding $\pm 2S$ limits ($S = 0.167091$, 46%)

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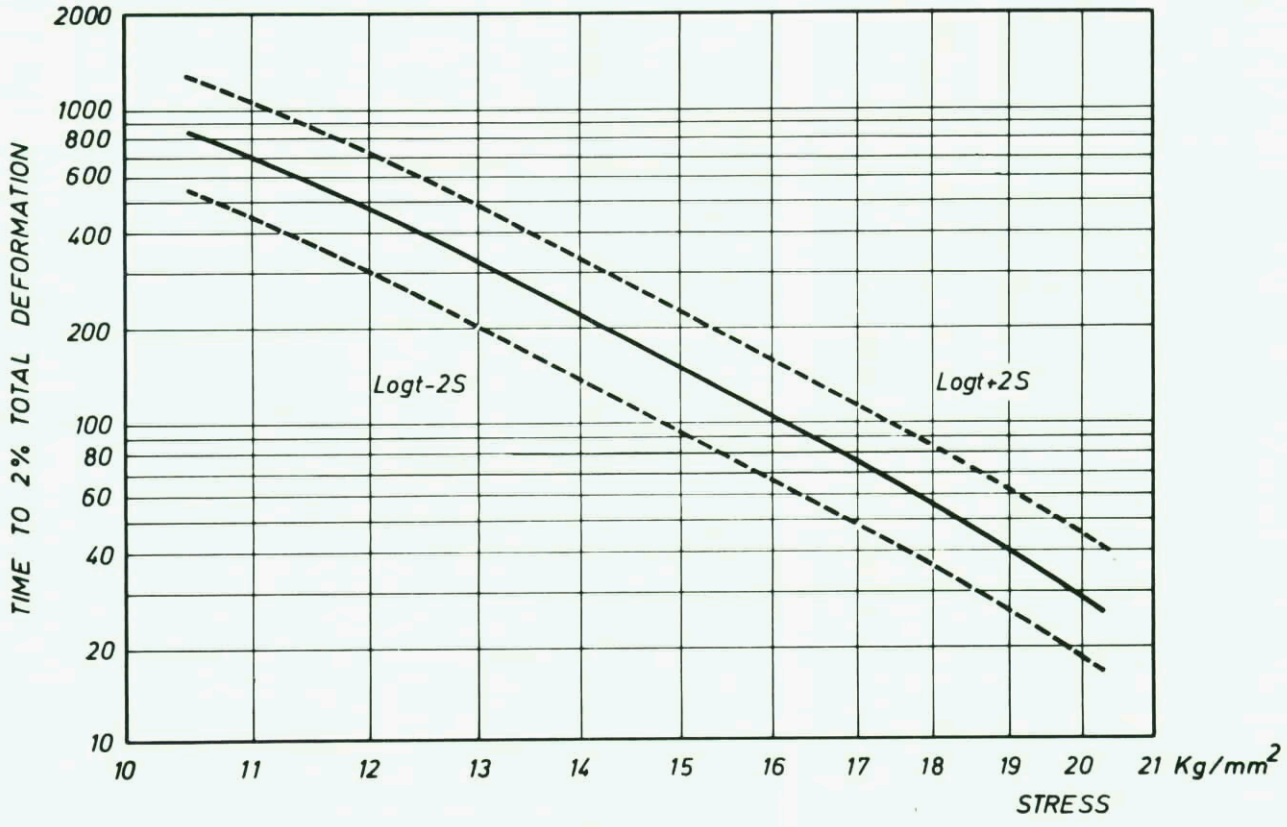

Fig.6 Log time to 2% total deformation as a function of $\log \sigma$ and the corresponding $\pm 2S$ limits ($S = 0.098338$, 25%)

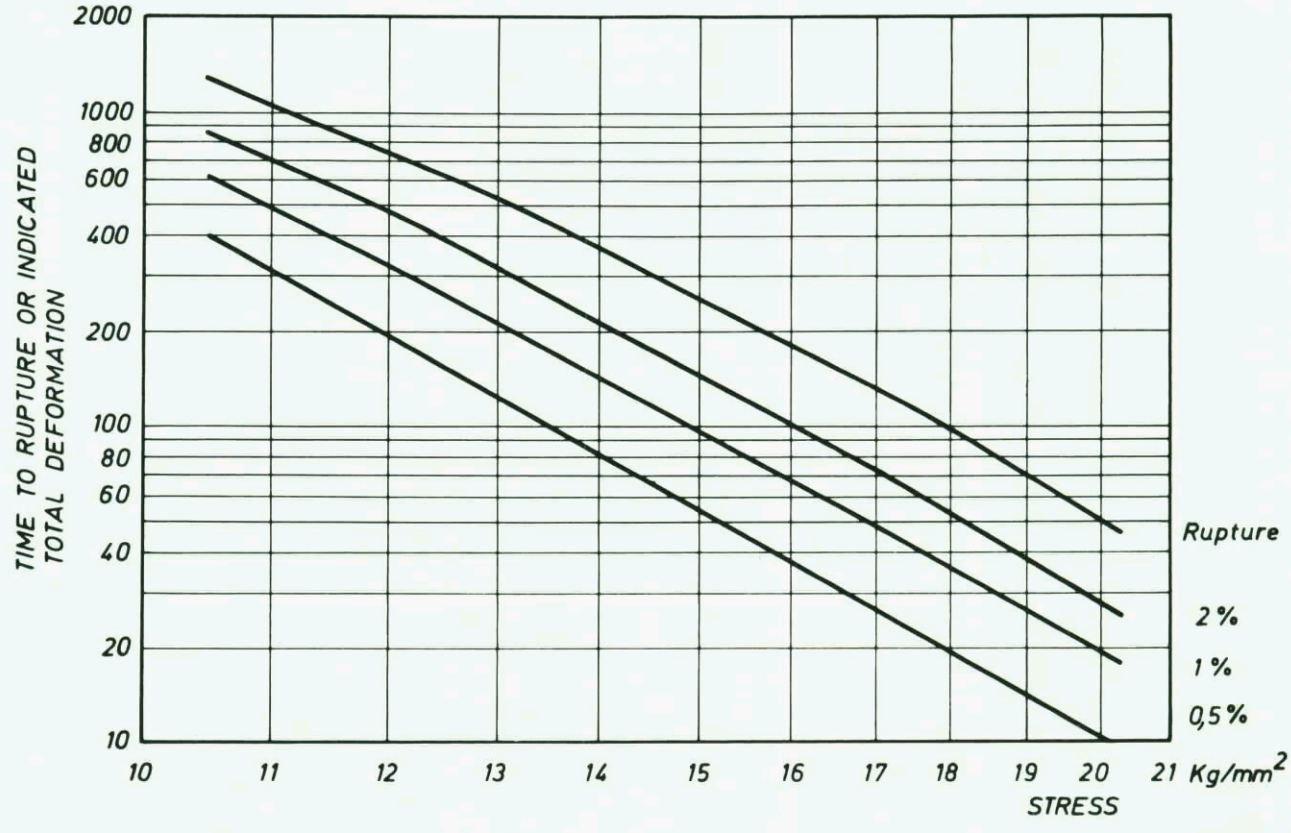

Fig.7 Log time to rupture, and to 2%, 1% and 0.5% total deformation as a function of $\log \sigma$

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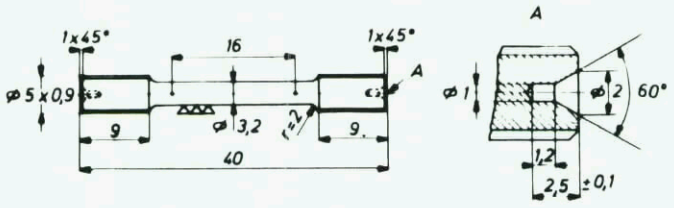
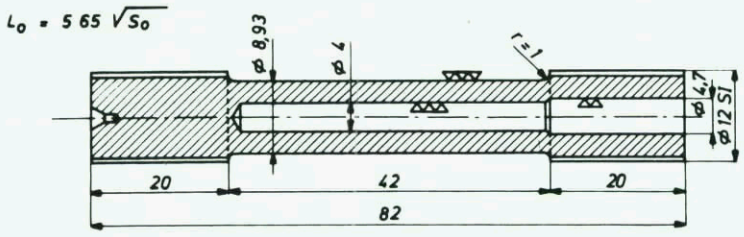
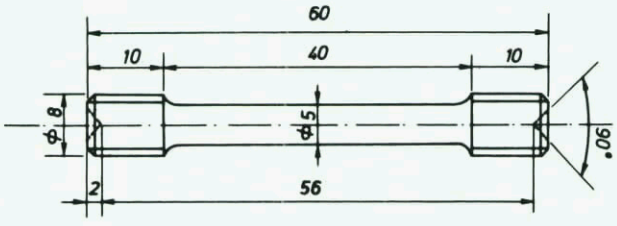
Lab. 1



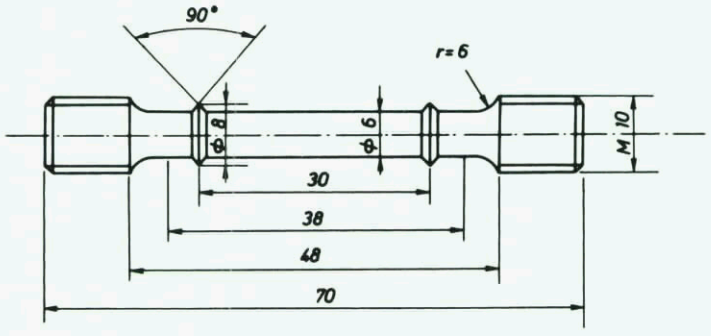
Lab. 2



Lab 5



Lab 8



Lab. 9

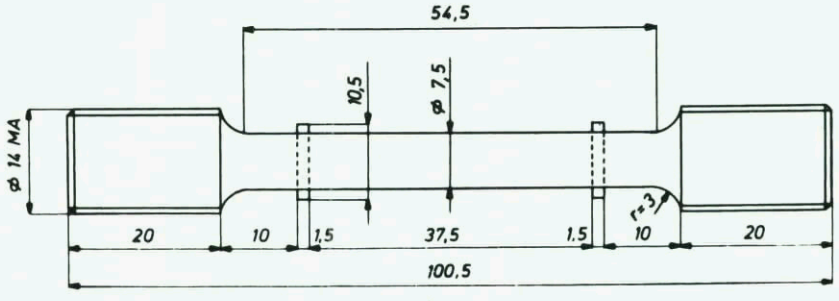


Fig.8(a) Test specimen geometry

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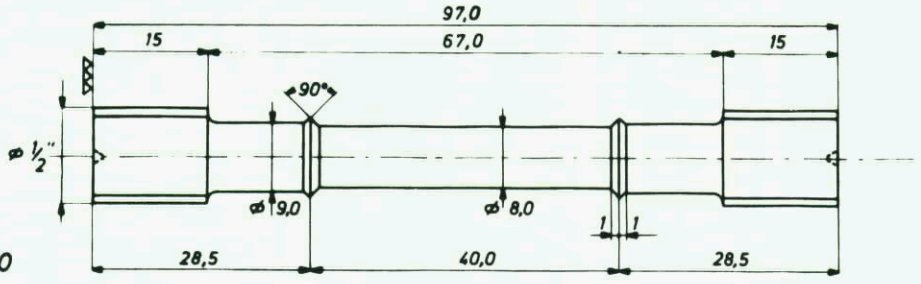
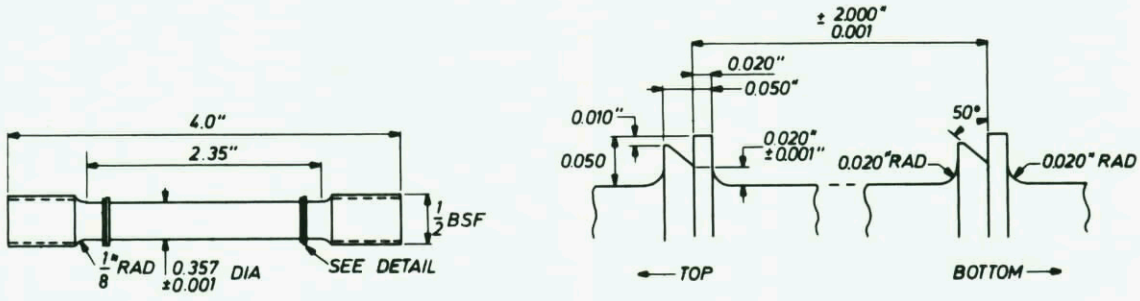
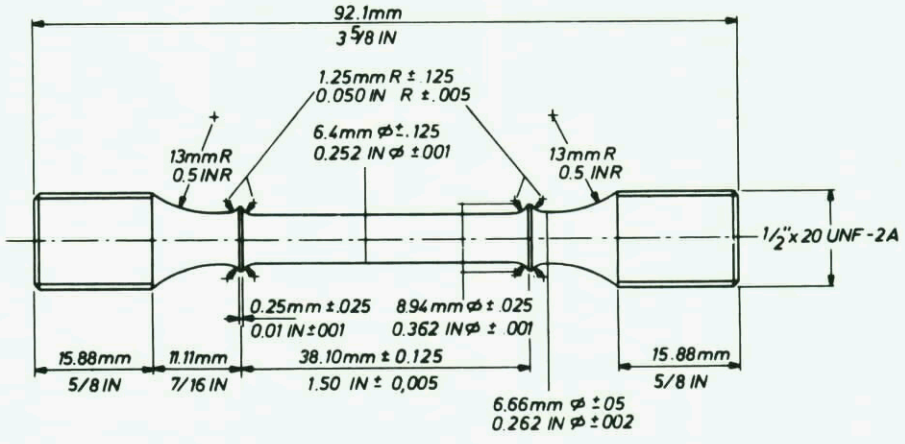
Lab. 10



Lab .11



Lab . 12



Lab 13

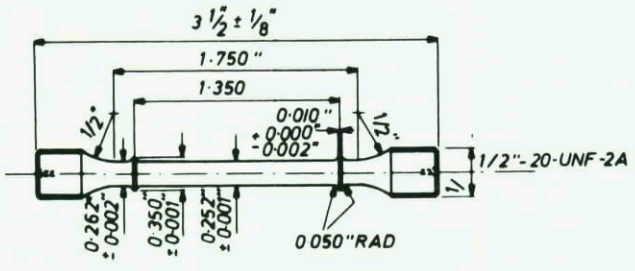


Figure 8(b)

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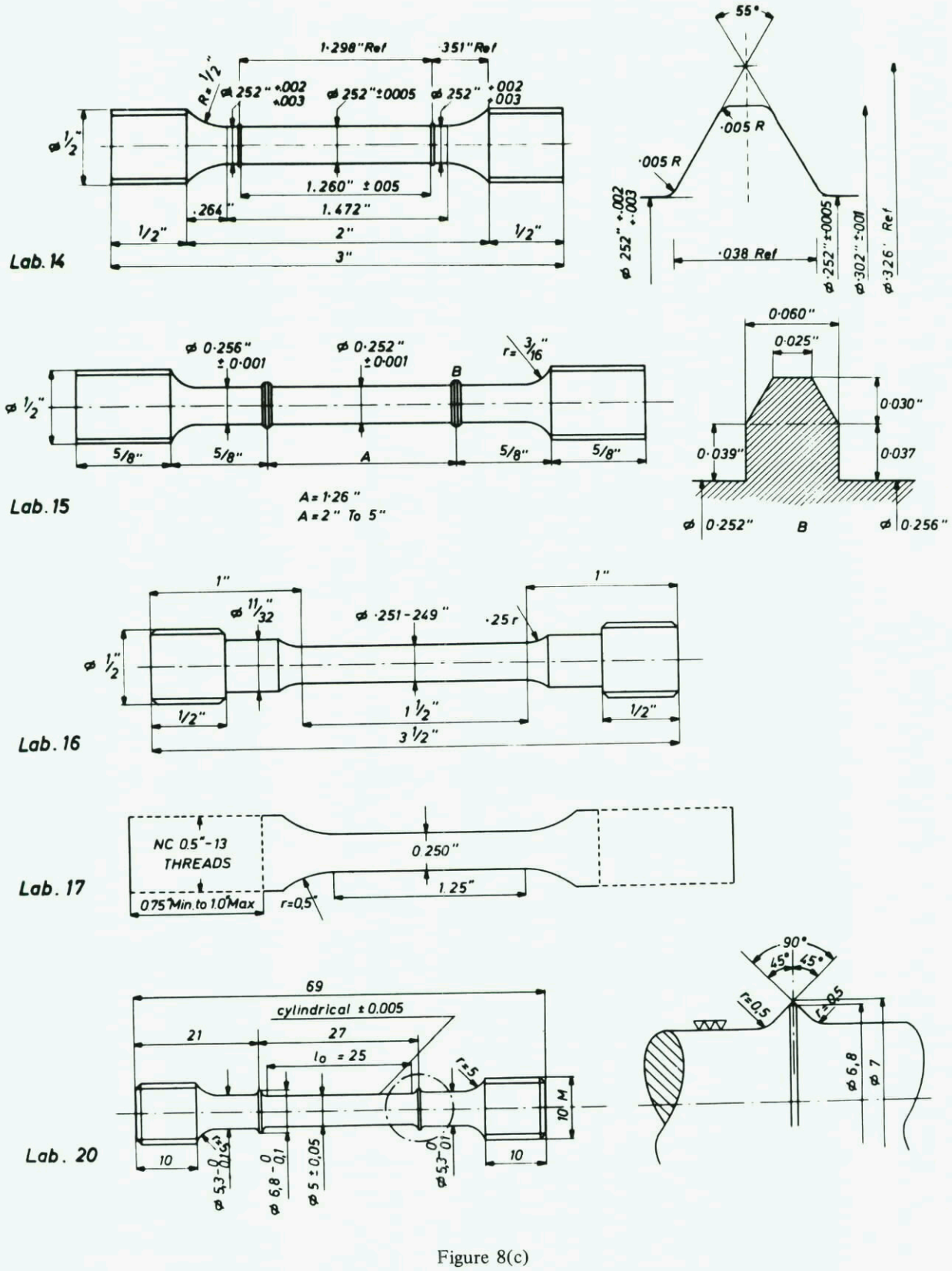

Figure 8(c)

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Number	ϕ mm	Producer	Isolation	Contact
1	0.51	A	Quartz	No
2	0.30	B	"	No
3	0.30	A	Glass on glass	No
4	0.30	A	Glass fiber	No
1M	0.51	A	Quartz	Yes
2M	0.30	B	"	Yes
3M	0.30	A	Glass on glass	Yes
4M	0.30	A	Glass fiber	Yes

Ligature with fiberfrax wire

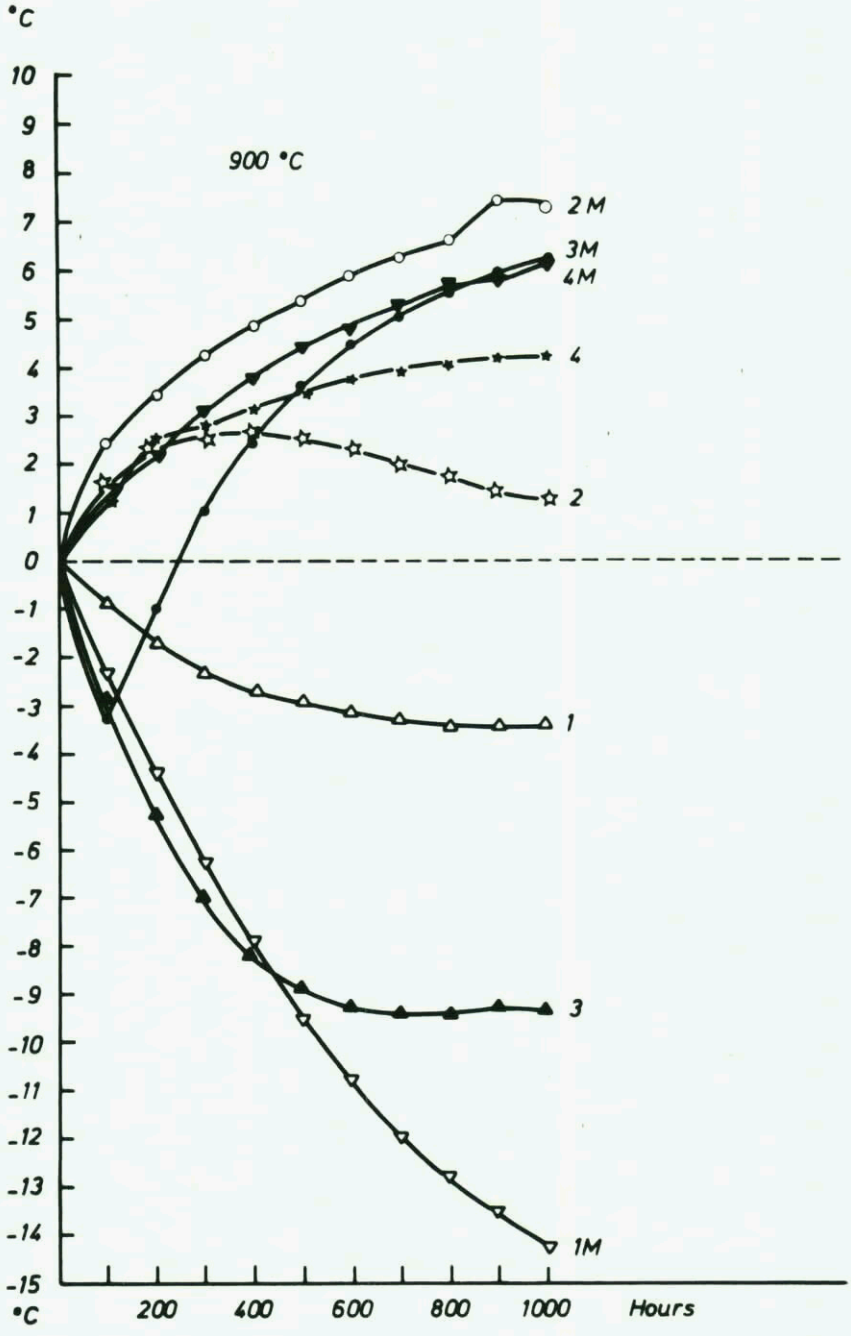

Fig.9 Drift of Chromel Alumel thermocouples exposed at 900°C (Ref.8)

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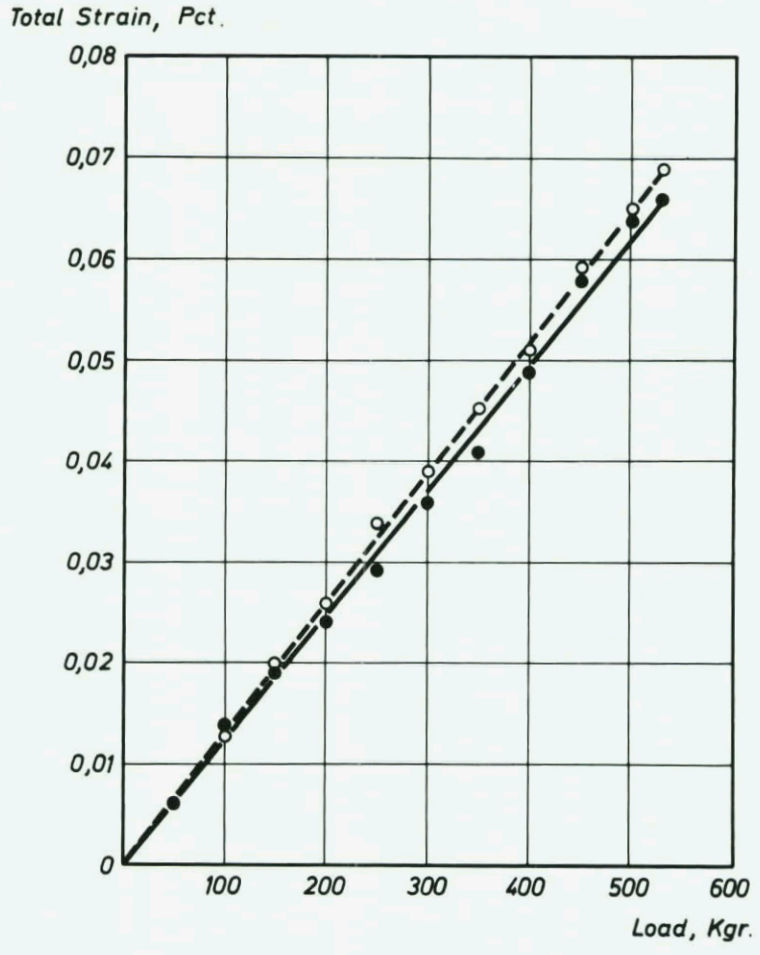

Fig.10(a) Strain versus load during incremental loading (Laboratory 10, Data)

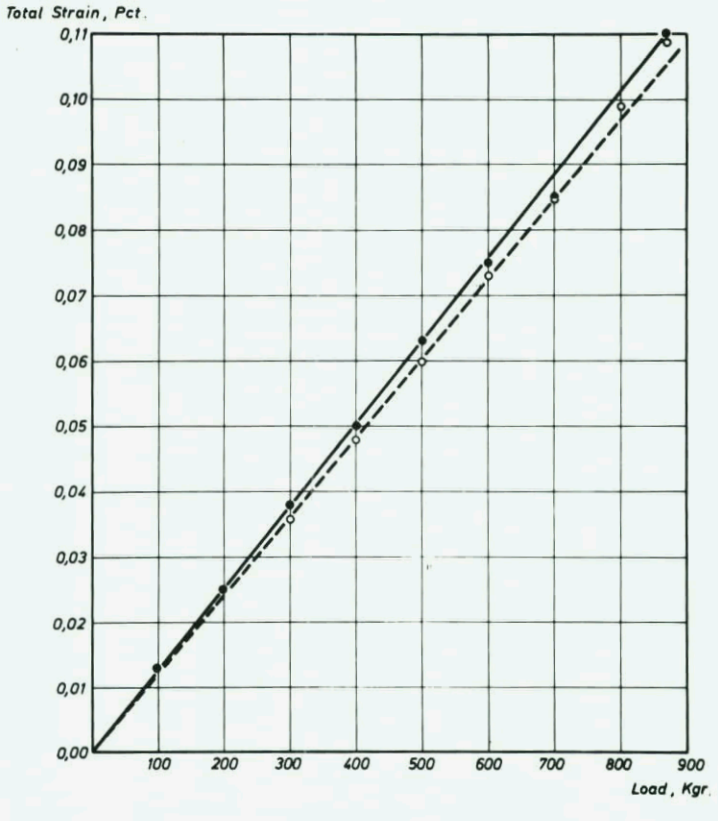

Figure 10(b)

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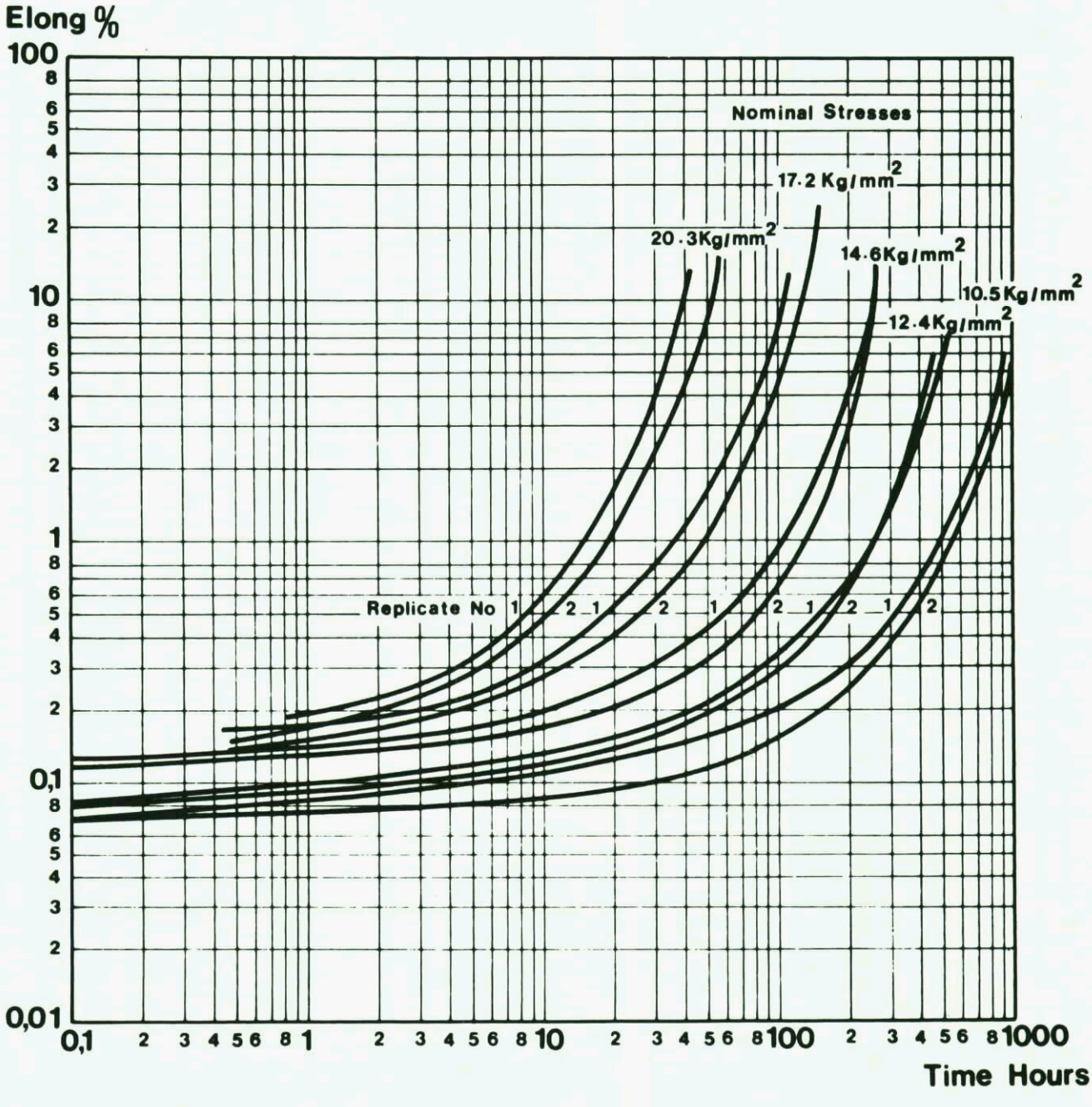

Fig.11 Typical total deformation versus time curves (Laboratory 12)

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APPENDIX I

FABRICATION HISTORY AND EVALUATION OF NIMONIC ALLOY 105 BARS

by

Henry Wiggin & Co. Ltd

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FABRICATION HISTORY AND EVALUATION OF NIMONIC ALLOY 105 BARS

Henry Wiggin & Co. Ltd

For the Agard co-operative creep testing programme, five bars of rectangular section (1.1/8 x 5/8 in.) and 1.10 in. long have been selected. The material was processed as follows:

1. A heat (Cast. No.TAD.706) of approximately 3,000 lbs was made from virgin raw materials by air melting in a high frequency furnace and cast into a large number of ingots by the Durville process.

2. Five ingots were selected and extruded into bars of rectangular section.

3. These bars were then cold rolled approximately 8% to the final dimensions (1.1/8 x 5/8 in.).

4. A length of 120 in. was cut from the leading end of each extrusion and so identified. The leading end corresponds to the beginning of the extrusion which in turn comes from the bottom of the ingot.

5. All the bars were heat treated as a batch together, the treatment given being: 4 h. 1150°C, AC + 16 h. 1050°C, AC + 16 h. 850°C, AC.

6. The bars were then examined for flaws by ultrasonic testing.

7. The chemical analysis by weight of the heat (cast number TAD.706) is as follows:

   C : 0.15%, Si : >0.15%, Cu : 0.01%, Fe : 0.15%, Mn : 0.03, Pb : 0.0011%, Cr : 14.45, Co : 20.0%, Mo : 4.85%, Ti : 1.21%, Al : 4.60%, Zr : 0.10%, B : 0.0045%, Ag : >0.001%.

   The homogeneity of this material has been assessed by taking blanks from each end of the 5 bars (total of 10 blanks), and the following tests made:

   I. hardness traverse along the blank (transverse and longitudinal)
   II. tensile test at 900°C
   III. creep rupture test at 900°C and 10.4 ton.f/in²
   IV. creep rupture test at 950°C and 7 ton.f/in².

The results of these determinations are given in Tables I to V.

TABLE I

Results of a Transverse Hardness Survey (HV 30)

C	x		x		x		x	D		
A	x	x	x	x	x	x	x	B		
E	x		x		x		x	F		

	1E	2E	3E	4E	5E	1L	2L	3L	4L	5L
A	375	427	422	449	454	415	432	422	454	441
	393	418	422	436	457	427	444	422	439	441
	406	427	418	434	449	422	422	420	449	436
	409	400	422	436	444	418	411	439	444	434
	404	418	420	446	444	441	419	449	444	439
	411	434	420	441	444	429	425	439	441	446
B	385	432	429	449	457		422		465	
C	377	418	422	446	436	434	439	445	457	436
	411	432	418	432	429	415	413	429	457	429
	420	429	425	434	432	413	406	422	444	432
D	491	439	434	451	446	429	449	432	457	446
E	365	436	432	454	454	427	429	446	446	454
	377	404	420	422	434	441	429	441	454	434
	363	400	420	439	449	418	422	422	441	449
F	385	439	422	454	462	409	427	422	454	462

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TABLE II

Results of a Longitudinal Hardness Survey (HV 30)

A | x x x x x x x x x x x x | B

1E	2E	3E	4E	5E	IL	2L	3L	4L	5L
377	362	358	370	362	358	344	364	375	360
362	360	357	360	362	366	358	366	375	355
348	355	366	371	355	358	358	366	381	366
355	351	362	370	360	360	360	370	341	358
366	348	360	358	353	364	366	368	360	351
357	341	362	358	370	362	366	362	351	344
366	353	370	362	357	371	371	371	366	339
348	364	360	366	358	360	366	362	351	346
355	357	368	366	379	366	364	362	348	341
355	360	364	371	373	368	358	362	357	353
351	368	313	310	366	368	364	358	371	362
355	364	364	364	375	366	368	368	371	351
	358	362	371			366	366	366	348

TABLE III

Results of Tensile Tests at 900°C

Testing Machine: Avery
Extensometer: Mayes
Test piece: ϕ – 0.25 in., gauge length: 1.25 in.

	Stress ton.f/in²					
Test Piece	0.1% P.S.	0.2% P.S.	0.5% P.S.	T.S.	*% Elong.*	*Red. of Area %*
1E	25.7	27.2	28.8	35.3	39.2	48
1L	24.7	26.5	27.8	34.9	30.4	48
2E	25.5	26.5	28.3	35.1	35.0	49
2L	26.8	ND	ND	35.3	36.8	48
3E	25.3	26.8	28.2	36.0	39.2	45
3L	26.8	27.9	28.8	35.4	43.2	48
4E	27.4	28.7	29.8	34.7	39.2	49
4L	25.1	26.7	27.7	35.9	37.6	45
5E	27.0	28.3	29.6	35.1	32.0	45
5L	26.9	28.5	29.9	35.2	41.6	48

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TABLE IV

Results of Creep Rupture Tests at 900°C and 10.4 ton.f/in²

Test Piece	*Life to Rupture*	*Elongation of Rupture %*
1E	158	21.0
1L	158	25.5
2E	176	23.8
2L	169	22.1
3E	150	22.3
3L	147	28.1
4E	130	21.6
4L	162	15.4
5E	163	21.1
5L	202	23.8

TABLE V

Results of Creep Rupture Tests at 950°C and 7 ton.f/in²

Test Piece	*Life to Rupture*	*Elongation of Rupture %*
1E	87	19.9
1L	113	27.2
2E	93	ND
2L	119	23.1
3E	82	18.3
3L	92	16.1
4E	67	202
4L	76	24.1
5E	89	302
5L	104	23.8

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APPENDIX II

EVALUATION OF THE HOMOGENEITY OF THE NIMONIC-105 BARS

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EVALUATION OF THE HOMOGENEITY OF THE NIMONIC-105 BARS

(a) *Tensile Tests Data*

The tensile tests data (0.2% YS and UTS) are reproduced in Table I, in a way convenient to analysis of variance calculations. The results are expressed in kg.f/mm².

TABLE I

Tensile Properties of Nimonic-105 Bars at 900°C

0.2 YS (kg.f/mm²)

	1	2	3	4	5	*Average*	*Total*
E	42.8	41.7	42.2	45.2	44.6	43.3	216.5
L	41.7	ND	43.9	42.0	44.9	42.8	214.2
Total	84.5	83.4	86.1	87.2	89.5		
Av.	42.2	41.7	43.0	43.6	44.7	43.1	430.7

UTS (kg.f/mm²)

	1	2	3	4	5	*Average*	*Total*
E	55.6	55.3	56.7	54.6	55.3	55.5	277.5
L	55.0	55.6	55.7	56.5	55.4	55.6	278.2
Total	110.6	110.9	112.4	111.1	110.7		
Av.	55.3	55.4	56.2	55.6	55.3	55.6	55.7

The analysis of variance is shown in Table II.

TABLE II

Analysis of Variance of Data in Table I

0.2% YS

Source	S.S.	D.F.	M.S.	F
Ends	0.52	1	0.52	–
Bars	11.30	4	4.50	2.7/F99 (4,4)
Residual	6.70	4	1.67	= 16.0
Total	18.52	9		

UTS

Source	S.S.	D.F.	M.S.
Ends	0.04	1	0.04
Bars	1.06	4	0.26
Residual	2.50	4	0.62
Total	3.60	9	

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Examination of the above data shows that the variability due to different positions is always smaller than the residual one. This is also valid for the between bars variability except for the 0.2% YS. Even in the latter case the difference is not significant at the 99% level.

In summary, the 900°C tensile properties show, obviously, no variation either from bar to bar or from different ends within a bar.

(b) *Creep Rupture Data*

The creep rupture data are reproduced in Table III.

TABLE III

Creep Rupture Data

Life (hours) 900°C, 10.4 ton.f/in²

	1	2	3	4	5	*Average*	*Total*
E	158	176	150	130	163	155.4	777.0
L	158	169	147	162	202	167.6	838.0
Total	316	345	297	292	365		
Av.	158	177.5	148.5	146.0	182.5	161.5	1616.0

Life (hours) 950°C, 7 ton.f/in²

	1	2	3	4	5	*Average*	*Total*
E	87	93	82	67	89	83.6	418.0
L	113	119	92	76	104	100.8	504.0
Total	200	212	174	143	193		
Av.	100	106	87	71.5	96.5	92.2	922.0

The analysis of variance was carried out in three different ways: by considering the results separately (Table IV), by considering the results together (Table V) and by considering all the results expressed in logarithms (Table VI).

TABLE IV

Analysis of Variance of Stress Rupture Time Data

900°C/10.4 ton.f/in²

Source of Variation	S.S.	D.F.	M.S.	F
Ends	372	1	372	1.6: F99 (1,4) = 21.20
Bars	1967	4	492	2.12: F99 (4,4) = 16.0
Residual	930	4	232	
Total	3269	9		

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TABLE IV (continued)

950°C/7 ton.f/in²

Source of Variation	S.S.	D.F.	M.S.	F
Ends	740	1	740	21.1: F99 (1,4) = 21.2
Bars	1451	4	363	10.4: F99 (4,4) = 16.0
Residual	139	4	35	F95 (1,4) = 7.71
Total	2380	9		F95 (4,4) = 6.39

TABLE V

Analysis of Variance of Stress Rupture Time Data

Source of Variation	D.F.	S.S.	M.S.	F
Bars	4	2.915.30	728.825	5.91: F99 (4,13) = 5.21
Ends	1	1.080.45	1080.45	8.76: F99 (1,13) = 9.07
Test conditions	1	24.012.45	24.012.45	194.8
Residual*	13	1.602.35	123.26	
Total	19	29.610.55		

Residual standard deviation (13 df) = 11.1 hours.

* The residual sources of variation are intralaboratory variation, micro inhomogeneity of Nimonic-105 and interactions.

TABLE VI

Analysis of Variance of Log Stress Rupture Time Data

Source of Variation	D.F.	S.S.	M.S.	F
Bars	4	0.040110	0.0100275	8.34: F99 (4,13) = 5.21
Ends	1	0.013265	0.013265	11.03: F99 (1,13) = 9.07
Test conditions	1	0.314458	0.314458	261
Residual	13	0.015633	0.00120254	
Total	19	0.383466		

Residual standard deviation (13 df) = 0.0346778.

The analysis in Table IV shows that the between bar or between ends variation of the 900°C rupture time is not significant at the 99% or 95% level of significance. The 950°C rupture time is not affected by these variable at the 99% level but it is affected at the 95% level of significance.

Considering all the results together, increases the sensitivity of the analysis. The F test becomes still more sensitive when the log of the stress rupture time is analysed. Tables V and VI shows that there is a significant difference between bars and between ends. The difference is mainly revealed by the 950°C rupture tests.

The data in Table VI allow, also the calculation of the components of variance from the "fixed" expected mean squares used in the F test. Components of variance calculation are usually only of interest in random models. In fixed models there are no real components of variance; however, if the F test is statistically significant the treatment mean squares of the significant fixed factors are mathematically equivalent to variances.

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$$X_{ijk} = \mu + A_i + B_j + C_k + \text{Residual}$$

where A_i = effect of bars (5 fixed levels)

B_j = effect of ends (2 fixed levels)

C_k = temperature and "stress" of test (2 fixed levels)

Residual = random effect of intralaboratory variables, short-range material variability and interaction effects.

$$\text{EMS} \quad A_i \text{ is analogous to } \sigma_e^2 + 4\sigma_A^2$$

$$\text{EMS} \quad B_j \text{ is analogous to } \sigma_e^2 + 10\sigma_B^2$$

$$\text{EMS} \quad C_k \text{ is analogous to } \sigma_e^2 + 10\sigma_C^2$$

where σ_e^2 = residual variance

$\sigma_A^2 = \dfrac{\Sigma_i A_i^2}{a - 1}$ = "variance" due to bars

$\sigma_B^2 = \dfrac{\Sigma_i B_j^2}{b - 1}$ = "variance" due to ends

$\sigma_C^2 = \dfrac{\Sigma_k C_k^2}{k - 1}$ = "variance" due to conditions.

Equating the M.S. of Table VI to the "EMS" values:

$$\sigma_A^2 = \frac{0.01002750 - 0.00120254}{4} = 0.00030063$$

$\sigma_A = 0.01733868$ (4.1%)

$$\sigma_B^2 = \frac{0.01326500 - 0.00120254}{10} = 0.00012025$$

$\sigma_B = 0.010966$ (2.6%)

$\sigma_e^2 = 0.00120254$

$\sigma_e = 0.03468$ (8.3%) .

The variance due to intralaboratory variability and macroinhomogeneity effects (between bars and between ends) is:

$$\sigma_e^2 + \sigma_A^2 + \sigma_B^2 = 0.00162342 .$$

The corresponding standard deviation is equal to 0.0403 (9.8%).

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APPENDIX III

RECOMMENDED PROCEDURES

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RECOMMENDED PROCEDURES

PRELIMINARY REMARKS

The purpose of the recommendations given here is not to compete with or to supersede existing specifications in the field. Most of the latter, however, are intended for a wide range of materials and test conditions and consequently are more or less general in some respects. On the other hand, in view of the purpose of the cooperative programme it is necessary to control, as closely as possible the testing variables among laboratories. The recommendations given here-in aim at this objective and it is requested that they be followed as closely as possible.

Although it is preferable to use the same machine for all tests, at least the machines used should be of the same type and of equivalent performance.

1. TEST-PIECE DIMENSIONS

The test specimens will have a circular section. The initial section So and the gauge length Lo will satisfy the relationship:

$$Lo = 5.65\sqrt{So}$$

In other words the gauge length will be equal to 5 (five) times the initial diameter Do. The latter will not be less than 4 mm (0.157 in.).

The grip ends will be of any form suitable to the machine used.

2. TEST-PIECE PREPARATION

The test pieces will be machined according to any method suitable to aged Nimonic-105 alloy bar. Final machining of the gauge length will be carried out, over a depth of 0.5 mm, preferably, by grinding. An assessment of the surface finish obtained, will be obtained by adequate measurement of the surface roughness. Before testing the test piece will be inspected for any physical flaws.

3. LOADING EQUIPMENT

The loading equipment should be capable of applying without shock, the required load with an accuracy of not less than ±1%.

4. STRAIN MEASUREMENT

For the measurement of strain an extensometer will be used. The extensometers will preferably be attached to the gauge length of the specimen. The equipment shall be capable of measuring the extension of the specimen to an accuracy of not less than ±0.1% of the gauge length up to at least 5% total strain.

5. HEATING APPARATUS

The heating apparatus shall be capable to comply with the requirements in Sections 6 and 7.

6. HEATING TO TEMPERATURE AND SOAKING AT TEMPERATURE

Heating to temperature will be carried out by introducing the specimen in the hot furnace. Heating time up to the soaking temperature (900°C – 7°C) will be comprised between 1 and 2 hours. A soaking time of 4 to 5 hours will be allowed to reach the prescribed temperature and the requested temperature gradient along the gauge length.

7. TEMPERATURE MEASUREMENT AND CONTROL

Temperature shall be measured with a sensitivity of ±0.5°C. The indicated temperature at any point within the gauge length of the test piece shall not vary by more than ±2°C. The temperature along the gauge length of the specimen should not vary by more than 2°C at any period during the test.

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The accuracy of the temperature measurement should be within ±0.5°C. This goal will be achieved by careful calibration of the thermocouples and by adequate use and control of the measuring system. In view of the fact that temperature is responsible for a large part of the scatter encountered in creep and creep rupture data it is strongly recommended to maintain a good temperature control throughout the test.

8. REPORTS

The report shall include the following:

1. identification of test pieces with respect to the original test blanks;
2. drawing of the test-pieces used; description of the machining procedure; the result of the surface roughness measurement;
3. description of the test equipment:
   - type of machine and characteristics
   - gripping method and axiality
   - method of loading and strain measurement
   - accuracy for measuring load and strain
   - methods of heating, temperature measurement and temperature control;
4. heating time and soaking time before loading;
5. test temperature variation along the gauge length and during the duration of the test;
6. the test results:
   - rupture time rounded to the nearest hour
   - total deformation versus time, date presented in tabular and graphical forms currently used by each laboratory
   - to facilitate comparison of the different data the following presentation is also requested on common diagrams and tables:
     (i) log total deformation (in per cent of the gauge length) as a function of log time.
     (ii) total deformation data versus time reproduced in suitable Tables. Unless deformation and/or temperature are recorded continuously it is necessary to report, in these tables, a sufficient number of measurements.
   - elongation and reduction of area values at rupture.

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APPENDIX IV

COMPUTER TABLES LISTING THE DATA GENERATED

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TABLE I

Results Listed per Replicate and Stress Conditions

LISTING GENERAL — MISE A JOUR DU 01.10.70

REP	LOAD	NOM	LABO	BLANK	TOTAL	0.1	0.2	0.5	1.0	2.0	RUPT	ELONG	RA
1	20.3	35.	3	4 3 G	0.0120	2.0	4.6	11.0	18.0	25.0	44.	23.0	32.4
1	20.3	35.	4	5 5 G		-	-	7.5	18.0	28.0	56.	27.0	38.0
1	20.3	35.	9	3 11 G	0.1470	-	0.2	5.5	14.0	21.0	36.	22.4	31.2
1	20.3	35.	10	1 7 D	0.1320	-	1.2	11.0	20.0	30.0	61.	25.0	32.0
1	20.3	35.	11	4 5 D	0.1460	-	0.5	7.4	15.0	24.0	46.	13.0	32.0
1	20.3	35.	12	3 15 D	0.1397	-	1.1	8.0	15.0	23.0	47.	13.0	25.0
1	20.3	35.	13	2 5 G	0.1190	-	4.8	14.0	23.0	32.0	56.	20.7	32.0
1	20.3	35.	14	4 8 G	0.1520	-	0.6	8.0	18.0	26.0	45.	26.0	33.0
1	20.3	35.	15	5 29 D		-	1.4	9.7	20.0	30.0	58.	24.0	32.0
1	20.3	35.	16	1 10 G		0.1	2.0	10.0	18.0	25.0	46.	17.0	25.0
1	20.3	35.	19	1 22 D	0.1250	-	0.5	4.8	14.0	30.0	51.	16.3	32.0
1	17.2	100.	1	1 3 G							133.	6.5	17.9
1	17.2	100.	2	2 9 G	0.0775	-	8.0	28.2	46.5	65.0	109.	21.0	26.2
1	17.2	100.	3	5 28 D	0.1300	-	2.4	36.0	67.0	90.0	136.	19.0	26.8
1	17.2	100.	4	5 5 D							166.	19.0	32.0
1	17.2	100.	5	4 27 D	0.1750	-	1.2	22.0	41.0	61.0	118.	22.2	30.7
1	17.2	100.	6	3 21 D	0.1250	-	3.7	33.5	63.5	92.0	139.	18.0	28.0
1	17.2	100.	8	5 1 D	0.1818	-	0.5	30.0	53.0	78.0	166.	21.0	
1	17.2	100.	9	1 18 D	0.1330	-	1.0	19.0	36.0	56.0	109.	24.8	31.2
1	17.2	100.	10	4 23 G	0.1090	-	9.0	42.0	70.0	95.0	145.	18.0	25.0
1	17.2	100.	11	5 22 G	0.1070	-	-	19.5	38.0	58.0	112.	19.0	26.0
1	17.2	100.	12	3 22 D	0.1463	-	2.6	18.0	36.0	57.0	124.	13.0	28.0
1	17.2	100.	13	1 28 G	0.0990	0.1	13.0	42.0	62.0	80.0	132.	20.7	29.0
1	17.2	100.	14	5 27 D	0.1140	-	4.6	36.0	65.0	95.0	152.	18.0	27.0
1	17.2	100.	15	3 15 G		-	6.5	33.0	57.0	80.0	118.	16.0	25.0
1	17.2	100.	16	4 2 G		1.6	13.0	40.0	60.0	80.0	135.	28.7	29.0
1	17.2	100.	17	1 5 D	0.1460	-	5.0	44.0	72.0	100.0	164.	22.5	27.0
1	17.2	100.	19	1 21 G	0.2500	-	-	5.5	22.0	50.0	113.	13.0	26.0
1	17.2	100.	20	2 29 D	0.1142	-	5.9	31.5	52.5	75.8	139.	16.7	25.3
1	14.6	240.	3	3 28 G	0.2000	-	-	60.0	115.0	162.0	231.	17.0	17.5
1	14.6	240.	4	1 24 G		-	-	72.0	116.0	174.0	302.	19.0	29.0
1	14.6	240.	9	3 17 G	0.1000	-	16.0	60.0	105.0	160.0	260.	15.2	23.5
1	14.6	240.	10	1 13 D	0.0950	0.0	31.0	105.0	166.0	225.0	354.	18.0	26.0
1	14.6	240.	11	5 24 G	0.0480	5.8	45.0	97.0	142.0	190.0	300.	14.0	22.0
1	14.6	240.	12	2 31 G	0.1149	-	10.0	59.0	107.0	157.0	304.	13.0	26.0
1	14.6	240.	13	3 25 G	0.0889	8.0	35.0	90.0	140.0	185.0	292.	20.0	20.0
1	14.6	240.	14	2 9 D	0.1120	-	21.0	100.0	150.0	210.0	333.	18.0	22.0
1	14.6	240.	15	4 26 G		0.1	12.5	60.5	112.0	165.0	266.	18.0	26.0
1	14.6	240.	16	3 20 D		14.0	50.0	110.0	160.0	200.0	309.	18.0	20.0
1	14.6	240.	19	4 2 D	0.0250	22.0	46.0	90.0	140.0	180.0	303.	17.5	28.0
1	12.4	500.	3	2 20 D	0.0820	40.0	98.0	190.0	290.0	420.0	618.	4.0	16.5
1	12.4	500.	4	2 17 D		-	-	223.0	333.0	434.0	683.	15.0	24.0
1	12.4	500.	9	2 7 G	0.0930	0.5	17.0	130.0	340.0	480.0	706.	16.0	15.3
1	12.4	500.	10	2 29 G	0.0750	6.0	67.0	193.0	310.0	430.0	680.	13.0	23.0
1	12.4	500.	11	2 5 D	0.1700	-	7.0	142.0	268.0	390.0	715.	17.0	22.0
1	12.4	500.	12	1 26 D	0.0825	0.7	43.0	150.0	260.0	360.0	631.	8.0	20.0
1	12.4	500.	13	4 27 G	0.0481	60.0	120.0	210.0	300.0	385.0	580.	13.4	20.0
1	12.4	500.	14	4 14 D	0.0760	3.0	90.0	220.0	320.0	420.0	585.	13.0	15.0
1	12.4	500.	15	4 24 G		2.7	23.0	150.0	235.0	295.0	611.	12.0	15.0
1	12.4	500.	16	5 9 D		-	500.0	580.0	650.0	730.0	927.	11.0	11.0
1	12.4	500.	19	1 30 D	0.2500	-	-	0.6	12.0	110.0	710.	12.2	28.0
1	10.5	1000.	1	3 28 D							1601.	10.5	20.4
1	10.5	1000.	2	4 18 D	0.0700	8.0	155.0	490.0	720.0	1000.0	1149.	14.0	9.0
1	10.5	1000.	3	3 12 G	0.1190	-	4.6	105.0	350.0	580.0	844.	12.0	11.6
1	10.5	1000.	4	3 8 G							963.	11.0	19.0
1	10.5	1000.	5	1 25 D	0.1250	-	90.0	345.0	550.0	750.0	1117.	9.2	14.0
1	10.5	1000.	6	4 10 D	0.0610	3.5	187.0	382.0	585.0	775.0	1134.	10.2	15.0
1	10.5	1000.	8	1 2 G	0.0626	330.0	530.0	800.0	1000.0	1250.0	1668.	11.1	
1	10.5	1000.	9	4 21 G	0.0800	1.0	85.0	300.0	520.0	780.0	1159.	11.2	14.0
1	10.5	1000.	10	1 29 D	0.0690	90.0	290.0	550.0	750.0	1000.0	1386.	12.0	18.0
1	10.5	1000.	11	5 7 G	0.0550	24.0	190.0	440.0	650.0	850.0	1220.	12.0	11.0
1	10.5	1000.	12	1 22 G	0.0660	3.2	192.0	320.0	500.0	690.0	1226.	10.7	12.0
1	10.5	1000.	13	2 21 D	0.0629	50.0	240.0	480.0	700.0	950.0	1419.	13.3	14.0
1	10.5	1000.	14	4 5 G	0.0870	2.2	120.0	420.0	650.0	850.0	1179.	14.0	19.0
1	10.5	1000.	15	1 6 G		16.0	150.0	390.0	575.0	800.0	1165.	10.0	15.0
1	10.5	1000.	16	5 23 G		600.0	800.0	960.0	1100.0	1200.0	1237.	11.0	11.0
1	10.5	1000.	17	5 22 D	0.0736	7.0	200.0	540.0	760.0	1000.0	1382.	10.0	10.5
1	10.5	1000.	19	4 16 D							1262.	5.8	12.0
1	10.5	1000.	20	5 18 D	0.0726	2.5	35.0	325.0	663.3	992.5	1610.	11.0	14.6

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TABLE I (continued)

LISTING GENERAL — MISE A JOUR DU 01.10.70

REP	LOAD	NOM	LABO	BLANK	TOTAL	0.1	0.2	0.5	1.0	2.0	RUPT	ELONG	RA
2	20.3	35.	3	4 15 D	0.1960	-	2.0	33.0	37.0	40.0	46.	10.0	29.8
2	20.3	35.	4	1 15 G		-	-	6.0	15.0	25.0	48.	24.0	35.0
2	20.3	35.	9	3 5 D	0.1530	-	0.5	5.5	13.5	22.0	38.	26.6	27.1
2	20.3	35.	10	1 4 G	0.1280	-	2.0	11.5	21.0	30.0	54.	23.0	32.0
2	20.3	35.	11	3 8 D	0.1240	-	0.5	4.8	8.4	12.3	29.	15.0	33.0
2	20.3	35.	12	5 2 G	0.1271	-	2.0	10.0	19.0	28.0	58.	16.0	32.0
2	20.3	35.	13	4 30 G	0.1220	-	2.0	8.8	15.5	23.0	43.	22.2	32.0
2	20.3	35.	14	5 21 D	0.1300	-	1.9	10.0	19.0	28.0	53.	22.1	28.0
2	20.3	35.	15	2 18 D		-	1.2	10.5	20.0	30.0	58.	29.0	34.0
2	20.3	35.	16	3 9 D		0.1	4.0	12.0	19.0	26.0	45.	19.0	25.0
2	20.3	35.	19	2 2 D	0.1250	-	0.3	1.9	8.5	28.0	68.	30.3	34.0
2	17.2	100.	1	3 27 G							136.	26.0	29.0
2	17.2	100.	2	2 2 G	0.1110	-	4.0	20.0	36.0	53.0	106.	16.5	26.0
2	17.2	100.	3	3 4 G	0.1540	-	1.4	25.0	49.0	72.0	113.	24.0	28.0
2	17.2	100.	4	5 1 G		-	-	30.0	62.0	94.0	174.	29.0	37.0
2	17.2	100.	5	2 14 G	0.1200	-	5.6	25.0	45.0	66.0	126.	25.1	29.5
2	17.2	100.	6	2 16 G	0.1440	-	2.0	30.5	57.0	80.0	117.	19.8	30.0
2	17.2	100.	8	3 26 D	0.1439	-	4.0	34.0	55.0	78.0	121.	15.7	
2	17.2	100.	9	2 22 G	0.1200	-	2.5	17.5	34.0	55.0	106.	26.9	29.4
2	17.2	100.	10	4 28 G	0.1100	-	10.0	32.0	50.0	70.0	117.	16.0	29.0
2	17.2	100.	11	2 28 G	0.0740	0.3	7.4	19.2	35.0	49.0	117.	14.0	28.0
2	17.2	100.	12	5 8 D	0.1166	-	3.6	26.0	50.0	75.0	159.	22.0	30.0
2	17.2	100.	13	3 13 G	0.0963	0.1	10.5	36.0	55.0	75.0	111.	15.9	27.0
2	17.2	100.	14	4 22 G	0.1020	-	11.0	46.0	70.0	95.0	145.	15.0	24.0
2	17.2	100.	15	4 13 D		-	5.8	28.5	46.0	63.0	101.	20.0	28.0
2	17.2	100.	16	3 14 D		-	3.0	30.0	55.0	75.0	119.	15.0	23.0
2	17.2	100.	17	5 15 D	0.1190	-	3.0	36.0	63.0	93.0	158.	21.5	27.0
2	17.2	100.	19	4 12 D	0.5000	-	-	-	36.0	80.0	135.	20.5	32.0
2	17.2	100.	20	3 19 D	0.1160	-	3.5	24.5	45.5	69.7	119.	15.3	25.8
2	14.6	240.	3	2 6 D	0.1200	-	4.8	37.0	90.0	170.0	337.	15.6	21.3
2	14.6	240.	4	3 17 D		-	-	91.0	140.0	188.0	296.	19.0	27.0
2	14.6	240.	9	5 4 G	0.1000	-	17.0	70.0	120.0	130.0	301.	16.3	27.1
2	14.6	240.	10	4 17 D	0.0940	0.1	33.0	108.0	163.0	220.0	324.	17.0	21.0
2	14.6	240.	11	5 29 G	0.0880	0.1	20.0	61.0	98.0	142.0	263.	11.0	26.0
2	14.6	240.	12	4 15 G	0.1045	-	17.0	81.0	130.0	178.0	309.	13.0	22.0
2	14.6	240.	13	3 5 G	0.0815	3.0	40.0	105.0	148.0	190.0	275.	15.6	24.0
2	14.6	240.	14	4 3 D	0.1170	-	16.0	85.0	145.0	190.0	295.	20.0	27.0
2	14.6	240.	15	3 21 G		0.2	27.0	83.0	135.0	190.0	290.	20.0	25.0
2	14.6	240.	16	4 7 G		1.0	40.0	100.0	150.0	190.0	287.	14.0	20.0
2	14.6	240.	19	3 23 D	0.0500	21.0	90.0	210.0	280.0	310.0	325.	16.7	23.0
2	12.4	500.	3	1 15 D	0.1340	-	42.0	150.0	250.0	355.0	576.	19.0	16.0
2	12.4	500.	4	3 10 D		-	-	163.0	266.0	353.0	507.	15.0	23.0
2	12.4	500.	9	2 30 G	0.0930	0.2	48.0	185.0	300.0	420.0	632.	13.9	17.4
2	12.4	500.	10	4 25 D	0.0750	1.0	58.0	215.0	350.0	480.0	688.	17.0	20.0
2	12.4	500.	11	5 21 G	0.0400	85.0	190.0	370.0	460.0	570.0	800.	11.0	17.0
2	12.4	500.	12	2 24 D	0.0825	1.6	52.0	154.0	260.0	355.0	673.	10.0	24.0
2	12.4	500.	13	4 30 D	0.0481	100.0	140.0	210.0	280.0	370.0	548.	12.7	20.0
2	12.4	500.	14	5 23 D	0.0750	2.0	60.0	230.0	330.0	450.0	666.	14.0	18.0
2	12.4	500.	15	1 6 D		1.0	36.0	165.0	275.0	385.0	586.	19.0	20.0
2	12.4	500.	16	2 27 G		-	160.0	210.0	250.0	300.0	605.	18.0	16.0
2	12.4	500.	19	2 7 D	0.1250	-	1.8	35.0	145.0	270.0	627.	13.2	21.0
2	10.5	1000.	1	1 25 G							1199.	8.5	12.7
2	10.5	1000.	2	5 18 G	0.0660	26.0	170.0	400.0	630.0	900.0	1187.		12.0
2	10.5	1000.	3	4 10 G	0.0910	20.0	160.0	420.0	650.0	850.0	1236.	7.0	15.4
2	10.5	1000.	4	4 19 D		-	-	343.0	563.0	806.0	1224.	14.0	17.0
2	10.5	1000.	5	3 19 G	0.0840	2.5	110.0	320.0	500.0	680.0	994.	12.1	13.5
2	10.5	1000.	6	4 6 D	0.0800	1.0	105.0	333.0	552.0	762.0	1098.	10.7	17.0
2	10.5	1000.	8	1 29 G	0.0634	220.0	400.0	700.0	950.0	1120.0	1528.	14.8	
2	10.5	1000.	9	3 18 G	0.0730	1.0	85.0	325.0	575.0	800.0	1112.	10.1	16.0
2	10.5	1000.	10	4 16 G	0.0660	29.0	260.0	540.0	750.0	975.0	1262.	8.0	11.0
2	10.5	1000.	11	5 9 G	0.0500	108.0	203.0	440.0	620.0	810.0	1281.	11.0	13.0
2	10.5	1000.	12	4 26 D	0.0660	24.0	144.0	360.0	540.0	730.0	1330.	12.0	11.0
2	10.5	1000.	13	4 14 G	0.0592	160.0	300.0	540.0	720.0	930.0	1251.	10.4	13.0
2	10.5	1000.	14	1 16 D	0.0750	24.0	190.0	410.0	600.0	820.0	1170.	10.0	15.0
2	10.5	1000.	15	3 7 G		15.0	200.0	390.0	550.0	740.0	1079.	13.0	16.0
2	10.5	1000.	16	1 26 G		400.0	650.0	960.0	1200.0	1400.0	1768.	9.0	9.0
2	10.5	1000.	17	1 23 D	0.0760	0.3	150.0	530.0	810.0	1015.0	1457.	7.0	11.0
2	10.5	1000.	19	1 12 D	0.1500	-	0.8	220.0	480.0	720.0	1155.	13.0	17.0
2	10.5	1000.	20	2 8 D	0.0739	2.8	59.7	344.5	628.0	902.0	1492.	10.0	14.5

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TABLE II

Results Listed per Data

LISTING PAR DEFORMATION — MISE A JOUR DU 01.10.70

Data	Lab.	REPLICATE 1 20.3	17.2	14.6	12.4	10.5	REPLICATE 2 20.3	17.2	14.6	12.4	10.5
TOT	2		0.0775			0.0700		0.1110			0.0660
TOT	3	0.0120	0.1300	0.2000	0.0820	0.1190	0.1960	0.1540	0.1200	0.1340	0.0910
TOT	5		0.1750			0.1250		0.1200			0.0840
TOT	6		0.1250			0.0610		0.1440			0.0800
TOT	8		0.1818			0.0626		0.1439			0.0634
TOT	9	0.1470	0.1330	0.1000	0.0930	0.0800	0.1530	0.1200	0.1000	0.0930	0.0730
TOT	10	0.1320	0.1090	0.0950	0.0750	0.0690	0.1280	0.1100	0.0940	0.0750	0.0660
TOT	11	0.1460	0.1070	0.0480	0.1700	0.0550	0.1240	0.0740	0.0880	0.0400	0.0500
TOT	12	0.1397	0.1463	0.1149	0.0825	0.0660	0.1271	0.1166	0.1045	0.0825	0.0660
TOT	13	0.1190	0.0990	0.0889	0.0481	0.0629	0.1220	0.0963	0.0815	0.0481	0.0592
TOT	14	0.1520	0.1140	0.1120	0.0760	0.0870	0.1300	0.1020	0.1170	0.0750	0.0750
TOT	17		0.1460			0.0736		0.1190			0.0760
TOT	19	0.1250	0.2500	0.0250	0.2500		0.1250	0.5000	0.0500	0.1250	0.1500
TOT	20		0.1142			0.0726		0.1160			0.0739
0.1	2		-			8.0		-			26.0
0.1	3	2.0	-	-	40.0	-	-	-	-	-	20.0
0.1	4	-		-	-		-	-	-	-	-
0.1	5		-			-		-			2.5
0.1	6		-			3.5		-			1.0
0.1	8		-			330.0		-			220.0
0.1	9	-	-	-	0.5	1.0	-	-	-	0.2	1.0
0.1	10	-	-	0.0	6.0	90.0	-	-	0.1	1.0	29.0
0.1	11	-	-	5.8	-	24.0	-	0.3	0.1	85.0	108.0
0.1	12	-	-	-	0.7	3.2	-	-	-	1.6	24.0
0.1	13	-	0.1	8.0	60.0	50.0	-	0.1	3.0	100.0	160.0
0.1	14	-	-	-	3.0	2.2	-	-	-	2.0	24.0
0.1	15	-	-	0.1	2.7	16.0	-	-	0.2	1.0	15.0
0.1	16	0.1	1.6	14.0	-	600.0	0.1	-	1.0	-	400.0
0.1	17		-			7.0		-			0.3
0.1	19	-	-	22.0	-		-	-	21.0	-	-
0.1	20		-			2.5		-			2.8
0.2	2		8.0			155.0		4.0			170.0
0.2	3	4.6	2.4	-	98.0	4.6	2.0	1.4	4.8	42.0	160.0
0.2	4	-		-	-		-	-	-	-	-
0.2	5		1.2			90.0		5.6			110.0
0.2	6		3.7			187.0		2.0			105.0
0.2	8		0.5			530.0		4.0			400.0
0.2	9	0.2	1.0	16.0	17.0	85.0	0.5	2.5	17.0	48.0	85.0
0.2	10	1.2	9.0	31.0	67.0	290.0	2.0	10.0	33.0	58.0	260.0
0.2	11	0.5	-	45.0	7.0	190.0	0.5	7.4	20.0	190.0	203.0
0.2	12	1.1	2.6	10.0	43.0	192.0	2.0	3.6	17.0	52.0	144.0
0.2	13	4.8	13.0	35.0	120.0	240.0	2.0	10.5	40.0	140.0	300.0
0.2	14	0.6	4.6	21.0	90.0	120.0	1.9	11.0	16.0	60.0	190.0
0.2	15	1.4	6.5	12.5	23.0	150.0	1.2	5.8	27.0	36.0	200.0
0.2	16	2.0	13.0	50.0	500.0	800.0	4.0	3.0	40.0	160.0	650.0
0.2	17		5.0			200.0		3.0			150.0
0.2	19	0.5	-	46.0	-		0.3	-	90.0	1.8	0.8
0.2	20		5.9			35.0		3.5			59.7
0.5	2		28.2			490.0		20.0			400.0
0.5	3	11.0	36.0	60.0	190.0	105.0	33.0	25.0	37.0	150.0	420.0
0.5	4	7.5		72.0	223.0		6.0	30.0	91.0	163.0	343.0
0.5	5		22.0			345.0		25.0			320.0
0.5	6		33.5			332.0		30.5			333.0
0.5	8		30.0			800.0		34.0			700.0
0.5	9	5.5	19.0	60.0	130.0	300.0	5.5	17.5	70.0	185.0	325.0
0.5	10	11.0	42.0	105.0	193.0	550.0	11.5	32.0	108.0	215.0	540.0
0.5	11	7.4	19.5	97.0	142.0	440.0	4.8	19.2	61.0	370.0	440.0
0.5	12	8.0	18.0	59.0	150.0	320.0	10.0	26.0	81.0	154.0	360.0
0.5	13	14.0	42.0	90.0	210.0	480.0	8.8	36.0	105.0	210.0	540.0
0.5	14	8.0	36.0	100.0	220.0	420.0	10.0	46.0	85.0	230.0	410.0
0.5	15	9.7	33.0	60.5	150.0	390.0	10.5	28.5	83.0	165.0	390.0
0.5	16	10.0	40.0	110.0	580.0	960.0	12.0	30.0	100.0	210.0	960.0
0.5	17		44.0			540.0		36.0			530.0
0.5	19	4.8	5.5	90.0	0.6		1.9	-	210.0	35.0	220.0
0.5	20		31.5			325.0		24.5			344.5

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TABLE II (continued)

LISTING PAR DEFORMATION — MISE A JOUR DU 01.10.70

		REPLICATE 1					REPLICATE 2				
Data	Lab	20.3	17.2	14.6	12.4	10.5	20.3	17.2	14.6	12.4	10.5
1.0	2		46.5			720.0		36.0			630.0
1.0	3	18.0	67.0	115.0	290.0	350.0	37.0	49.0	90.0	250.0	650.0
1.0	4	18.0		116.0	333.0		15.0	62.0	140.0	266.0	563.0
1.0	5		41.0			550.0		45.0			500.0
1.0	6		63.5			585.0		57.0			552.0
1.0	8		53.0			1000.0		55.0			950.0
1.0	9	14.0	36.0	105.0	340.0	520.0	13.5	34.0	120.0	300.0	575.0
1.0	10	20.0	70.0	166.0	310.0	750.0	21.0	50.0	163.0	350.0	750.0
1.0	11	15.0	38.0	142.0	268.0	650.0	8.4	35.0	98.0	460.0	620.0
1.0	12	15.0	36.0	107.0	260.0	500.0	19.0	50.0	130.0	260.0	540.0
1.0	13	23.0	62.0	140.0	300.0	700.0	15.5	55.0	148.0	280.0	720.0
1.0	14	18.0	65.0	150.0	320.0	650.0	19.0	70.0	145.0	330.0	600.0
1.0	15	20.0	57.0	112.0	235.0	575.0	20.0	46.0	135.0	275.0	550.0
1.0	16	18.0	60.0	160.0	650.0	1100.0	19.0	55.0	150.0	250.0	1200.0
1.0	17		72.0			760.0		63.0			810.0
1.0	19	14.0	22.0	140.0	12.0		8.5	36.0	280.0	145.0	480.0
1.0	20		52.5			663.3		45.5			628.0
2.0	2		65.0			1000.0		53.0			900.0
2.0	3	25.0	90.0	162.0	420.0	580.0	40.0	72.0	170.0	355.0	850.0
2.0	4	28.0		174.0	434.0		25.0	94.0	188.0	353.0	806.0
2.0	5		61.0			750.0		66.0			680.0
2.0	6		92.0			775.0		80.0			762.0
2.0	8		78.0			1250.0		78.0			1120.0
2.0	9	21.0	56.0	160.0	480.0	780.0	22.0	55.0	130.0	420.0	800.0
2.0	10	30.0	95.0	225.0	430.0	1000.0	30.0	70.0	220.0	480.0	975.0
2.0	11	24.0	58.0	190.0	390.0	850.0	12.3	49.0	142.0	570.0	810.0
2.0	12	23.0	57.0	157.0	360.0	690.0	28.0	75.0	178.0	355.0	730.0
2.0	13	32.0	80.0	185.0	385.0	950.0	23.0	75.0	190.0	370.0	930.0
2.0	14	26.0	95.0	210.0	420.0	850.0	28.0	95.0	190.0	450.0	820.0
2.0	15	30.0	80.0	165.0	295.0	800.0	30.0	63.0	190.0	385.0	740.0
2.0	16	25.0	80.0	200.0	730.0	1200.0	26.0	75.0	190.0	300.0	1400.0
2.0	17		100.0			1000.0		93.0			1015.0
2.0	19	30.0	50.0	180.0	110.0		28.0	80.0	310.0	270.0	720.0
2.0	20		75.8			992.5		69.7			902.0
RUPT	1		133.0			1601.0		136.0			1199.0
RUPT	2		109.0			1149.0		106.0			1187.0
RUPT	3	44.0	136.0	231.0	618.0	844.0	46.0	113.0	337.0	576.0	1236.0
RUPT	4	56.0	166.0	302.0	683.0	963.0	48.0	174.0	296.0	507.0	1224.0
RUPT	5		118.0			1117.0		126.0			994.0
RUPT	6		139.0			1134.0		117.0			1098.0
RUPT	8		166.0			1668.0		121.0			1528.0
RUPT	9	36.0	109.0	260.0	706.0	1159.0	38.0	106.0	301.0	632.0	1112.0
RUPT	10	61.0	145.0	354.0	680.0	1386.0	54.0	117.0	324.0	688.0	1262.0
RUPT	11	46.0	112.0	300.0	715.0	1220.0	29.0	117.0	263.0	800.0	1281.0
RUPT	12	47.0	124.0	304.0	631.0	1226.0	58.0	159.0	309.0	673.0	1330.0
RUPT	13	56.0	132.0	292.0	580.0	1419.0	43.0	111.0	275.0	548.0	1251.0
RUPT	14	45.0	152.0	333.0	585.0	1179.0	53.0	145.0	295.0	666.0	1170.0
RUPT	15	58.0	118.0	266.0	611.0	1165.0	58.0	101.0	290.0	586.0	1079.0
RUPT	16	46.0	135.0	309.0	927.0	1237.0	45.0	119.0	287.0	605.0	1768.0
RUPT	17		164.0			1382.0		158.0			1457.0
RUPT	19	51.0	113.0	303.0	710.0	1262.0	68.0	135.0	325.0	627.0	1155.0
RUPT	20		139.0			1610.0		119.0			1492.0
ELON	1		6.5			10.5		26.0			8.5
ELON	2		21.0			14.0		16.5			
ELON	3	23.0	19.0	17.0	4.0	12.0	10.0	24.0	15.6	19.0	7.0
ELON	4	27.0	19.0	19.0	15.0	11.0	24.0	29.0	19.0	15.0	14.0
ELON	5		22.2			9.2		25.1			12.1
ELON	6		18.0			10.2		19.8			10.7
ELON	8		21.0			11.1		15.7			14.8
ELON	9	22.4	24.8	15.2	16.0	11.2	26.6	26.9	16.3	13.9	10.1
ELON	10	25.0	18.0	18.0	13.0	12.-	23.0	16.0	17.0	17.0	8.0
ELON	11	13.0	19.0	14.0	17.0	12.0	15.0	14.0	11.0	11.0	11.0
ELON	12	13.0	13.0	13.0	8.0	10.7	16.0	22.0	13.0	10.0	12.0
ELON	13	20.7	20.7	20.0	13.4	13.3	22.2	15.9	15.6	12.7	10.4
ELON	14	26.0	18.0	18.0	13.0	14.0	22.1	15.0	20.0	14.0	10.0

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TABLE II (continued)

LISTING PAR DEFORMATION — MISE A JOUR DU 01.10.70

		REPLICATE 1					REPLICATE 2				
Data	Lab	20.3	17.2	14.6	12.4	10.5	20.3	17.2	14.6	12.4	10.5
ELON	15	24.0	16.0	18.0	12.0	10.0	29.0	20.0	20.0	19.0	13.0
ELON	16	17.0	28.7	18.0	11.0	11.0	19.0	15.0	14.0	18.0	9.0
ELON	17		22.5			10.0		21.5			7.0
ELON	19	16.3	13.0	17.5	12.2	5.8	30.3	20.5	16.7	13.2	13.0
ELON	20		16.7			11.0		15.3			10.0
RA	1		17.9			20.4		29.0			12.7
RA	2		26.2			9.0		26.0			12.0
RA	3	32.4	26.8	17.5	16.5	11.6	29.8	28.0	21.3	16.0	15.4
RA	4	38.0	32.0	29.0	24.0	19.0	35.0	37.0	27.0	23.0	17.0
RA	5		30.7			14.0		29.5			13.5
RA	6		28.0			15.0		30.0			17.0
RA	9	31.2	31.2	23.5	15.3	14.0	27.1	29.4	27.1	17.4	16.0
RA	10	32.0	25.0	26.0	23.0	18.0	32.0	29.0	21.0	20.0	11.0
RA	11	32.0	26.0	22.0	22.0	11.0	33.0	28.0	26.0	17.0	13.0
RA	12	25.0	28.0	26.0	20.0	12.0	32.0	30.0	22.0	24.0	11.0
RA	13	32.0	29.0	20.0	20.0	14.0	32.0	27.0	24.0	20.0	13.0
RA	14	33.0	27.0	22.0	15.0	19.0	28.0	24.0	27.0	18.0	15.0
RA	15	32.0	25.0	26.0	15.0	15.0	34.0	28.0	25.0	20.0	16.0
RA	16	25.0	29.0	20.0	11.0	11.0	25.0	23.0	20.0	16.0	9.0
RA	17		27.0			10.5		27.0			11.0
RA	19	32.0	26.0	28.0	28.0	12.0	34.0	32.0	23.0	21.0	17.0
RA	20		25.3			14.6		25.8			14.5

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TABLE III

Results Listed per Laboratory

LISTING PAR LABORATOIRE — MISE A JOUR DU 01.10.70

LABO	REP	LOAD	NOM	BLANK	TOTAL	0.1	0.2	0.5	1.0	2.0	RUPT	ELONG	RA
1	1	17.2	100.	1 3 G							133.	6.5	17.9
1	1	10.5	1000.	3 28 D							1601.	10.5	20.4
1	2	17.2	100.	3 27 G							136.	26.0	29.0
1	2	10.5	1000.	1 25 G							1199.	8.5	12.7
2	1	17.2	100.	2 9 G	0.0775	-	8.0	28.2	46.5	65.0	109.	21.0	26.2
2	1	10.5	1000.	4 18 D	0.0700	8.0	155.0	490.0	720.0	1000.0	1149.	14.0	9.0
2	2	17.2	100.	2 2 G	0.1110	-	4.0	20.0	36.0	53.0	106.	16.5	26.0
2	2	10.5	1000.	5 18 G	0.0660	26.0	170.0	400.0	630.0	900.0	1187.		12.0
3	1	20.3	35.	4 3 G	0.0120	2.0	4.6	11.0	18.0	25.0	44.	23.0	32.4
3	1	17.2	100.	5 28 D	0.1300	-	2.4	36.0	67.0	90.0	136.	19.0	26.8
3	1	14.6	240.	3 28 G	0.2000	-	-	60.0	115.0	162.0	231.	17.0	17.5
3	1	12.4	500.	2 20 D	0.0820	40.0	98.0	190.0	290.0	420.0	618.	4.0	16.5
3	1	10.5	1000.	3 12 G	0.1190	-	4.6	105.0	350.0	580.0	844.	12.0	11.6
3	2	20.3	35.	4 15 D	0.1960	-	2.0	33.0	37.0	40.0	46.	10.0	29.8
3	2	17.2	100.	3 4 G	0.1540	-	1.4	25.0	49.0	72.0	113.	24.0	28.0
3	2	14.6	240.	2 6 D	0.1200	-	4.8	37.0	90.0	170.0	337.	15.6	21.3
3	2	12.4	500.	1 15 D	0.1340	-	42.0	150.0	250.0	355.0	576.	19.0	16.0
3	2	10.5	1000.	4 10 G	0.0910	20.0	160.0	420.0	650.0	850.0	1236.	7.0	15.4
4	1	20.3	35.	5 5 G		-	-	7.5	18.0	28.0	56.	27.0	38.0
4	1	17.2	100.	5 5 D							166.	19.0	32.0
4	1	14.6	240.	1 24 G		-	-	72.0	116.0	174.0	302.	19.0	29.0
4	1	12.4	500.	2 17 D		-	-	223.0	333.0	434.0	683.	15.0	24.0
4	1	10.5	1000.	3 8 G							963.	11.0	19.0
4	2	20.3	35.	1 15 G		-	-	6.0	15.0	25.0	48.	24.0	35.0
4	2	17.2	100.	5 1 G		-	-	30.0	62.0	94.0	174.	29.0	37.0
4	2	14.6	240.	3 17 D		-	-	91.0	140.0	188.0	296.	19.0	27.0
4	2	12.4	500.	3 10 D		-	-	163.0	266.0	353.0	507.	15.0	23.0
4	2	10.5	1000.	4 19 D		-	-	343.0	563.0	806.0	1224.	14.0	17.0
5	1	17.2	100.	4 27 D	0.1750	-	1.2	22.0	41.0	61.0	118.	22.2	30.7
5	1	10.5	1000.	1 25 D	0.1250	-	90.0	345.0	550.0	750.0	1117.	9.2	14.0
5	2	17.2	100.	2 14 G	0.1200	-	5.6	25.0	45.0	66.0	126.	25.1	29.5
5	2	10.5	1000.	3 19 G	0.0840	2.5	110.0	320.0	500.0	680.0	994.	12.1	13.5
6	1	17.2	100.	3 21 D	0.1250	-	3.7	33.5	63.5	92.0	139.	18.0	28.0
6	1	10.5	1000.	4 10 D	0.0610	3.5	187.0	382.0	585.0	775.0	1134.	10.2	15.0
6	2	17.2	100.	2 16 G	0.1440	-	2.0	30.5	57.0	80.0	117.	19.8	30.0
6	2	10.5	1000.	4 6 D	0.0800	1.0	105.0	333.0	552.0	762.0	1098.	10.7	17.0
8	1	17.2	100.	5 1 D	0.1818	-	0.5	30.0	53.0	78.0	166.	21.0	
8	1	10.5	1000.	1 2 G	0.0626	330.0	530.0	800.0	1000.0	1250.0	1668.	11.1	
8	2	17.2	100.	3 26 D	0.1439	-	4.0	34.0	55.0	78.0	121.	15.7	
8	2	10.5	1000.	1 29 G	0.0634	220.0	400.0	700.0	950.0	1120.0	1528.	14.8	
9	1	20.3	35.	3 11 G	0.1470	-	0.2	5.5	14.0	21.0	36.	22.4	31.2
9	1	17.2	100.	1 18 D	0.1330	-	1.0	19.0	36.0	56.0	109.	24.8	31.2
9	1	14.6	240.	3 17 G	0.1000	-	16.0	60.0	105.0	160.0	260.	15.2	23.5
9	1	12.4	500.	2 7 G	0.0930	0.5	17.0	130.0	340.0	480.0	706.	16.0	15.3
9	1	10.5	1000.	4 21 G	0.0800	1.0	85.0	300.0	520.0	780.0	1159.	11.2	14.0
9	2	20.3	35.	3 5 D	0.1530	-	0.5	5.5	13.5	22.0	38.	26.6	27.1
9	2	17.2	100.	2 22 G	0.1200	-	2.5	17.5	34.0	55.0	106.	26.9	29.4
9	2	14.6	240.	5 4 G	0.1000	-	17.0	70.0	120.0	130.0	301.	16.3	27.1
9	2	12.4	500.	2 30 G	0.0930	0.2	48.0	185.0	300.0	420.0	632.	13.9	17.4
9	2	10.5	1000.	3 18 G	0.0730	1.0	85.0	325.0	575.0	800.0	1112.	10.1	16.0

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TABLE III (continued)

LISTING PAR LABORATOIRE — MISE A JOUR DU 01.10.70

LABO	REP	LOAD	NOM	BLANK	TOTAL	0.1	0.2	0.5	1.0	2.0	RUPT	ELONG	RA
10	1	20.3	35.	1 7 D	0.1320	-	1.2	11.0	20.0	30.0	61.	25.0	32.0
10	1	17.2	100.	4 23 G	0.1090	-	9.0	42.0	70.0	95.0	145.	18.0	25.0
10	1	14.6	240.	1 13 D	0.0950	0.0	31.0	105.0	166.0	225.0	354.	18.0	26.0
10	1	12.4	500.	2 29 G	0.0750	6.0	67.0	193.0	310.0	430.0	680.	13.0	23.0
10	1	10.5	1000.	1 29 D	0.0690	90.0	290.0	550.0	750.0	1000.0	1386.	12.0	18.0
10	2	20.3	35.	1 4 G	0.1280	-	2.0	11.5	21.0	30.0	54.	23.0	32.0
10	2	17.2	100.	4 28 G	0.1100	-	10.0	32.0	50.0	70.0	117.	16.0	29.0
10	2	14.6	240.	4 17 D	0.0940	0.1	33.0	108.0	163.0	220.0	324.	17.0	21.0
10	2	12.4	500.	4 25 D	0.0750	1.0	58.0	215.0	350.0	480.0	688.	17.0	20.0
10	2	10.5	1000.	4 16 G	0.0660	29.0	260.0	540.0	750.0	975.0	1262.	8.0	11.0
11	1	20.3	35.	4 5 D	0.1460	-	0.5	7.4	15.0	24.0	46.	13.0	32.0
11	1	17.2	100.	5 22 G	0.1070	-	-	19.5	38.0	58.0	112.	19.0	26.0
11	1	14.6	240.	5 24 G	0.0480	5.8	45.0	97.0	142.0	190.0	300.	14.0	22.0
11	1	12.4	500.	2 5 D	0.1700	-	7.0	142.0	268.0	390.0	715.	17.0	22.0
11	1	10.5	1000.	5 7 G	0.0550	24.0	190.0	440.0	650.0	850.0	1220.	12.0	11.0
11	2	20.3	35.	38D	0.1240	-	0.6	5.7	10.0	14.6	34.3	15.0	33.0 *
11	2	17.2	100.	2 28 G	0.0740	0.3	7.4	19.2	35.0	49.0	117.	14.0	28.0
11	2	14.6	240.	5 29 G	0.0880	0.1	20.0	61.0	98.0	142.0	263.	11.0	26.0
11	2	12.4	500.	5 21 G	0.0400	85.0	190.0	370.0	460.0	570.0	800.	11.0	17.0
11	2	10.5	1000.	5 9 G	0.0500	108.0	203.0	440.0	620.0	810.0	1281.	11.0	13.0
12	1	20.3	35.	3 15 D	0.1397	-	1.1	8.0	15.0	23.0	47.	13.0	25.0
12	1	17.2	100.	3 22 D	0.1463	-	2.6	18.0	36.0	57.0	124.	13.0	28.0
12	1	14.6	240.	2 31 G	0.1149	-	10.0	59.0	107.0	157.0	304.	13.0	26.0
12	1	12.4	500.	1 26 D	0.0825	0.7	43.0	150.0	260.0	360.0	631.	8.0	20.0
12	1	10.5	1000.	1 22 G	0.0660	3.2	192.0	320.0	500.0	690.0	1226.	10.7	12.0
12	2	20.3	35.	5 2 G	0.1271	-	2.0	10.0	19.0	28.0	58.	16.0	32.0
12	2	17.2	100.	5 8 D	0.1166	-	3.6	20.0	50.0	75.0	159.	22.0	30.0
12	2	14.6	240.	4 15 G	0.1045	-	17.0	81.0	130.0	178.0	309.	13.0	22.0
12	2	12.4	500.	2 24 D	0.0825	1.6	52.0	154.0	260.0	355.0	673.	10.0	24.0
12	2	10.5	1000.	4 26 D	0.0660	24.0	144.0	360.0	540.0	730.0	1330.	12.0	11.0
13	1	20.3	35.	2 5 G	0.1190	-	4.8	14.0	23.0	32.0	56.	20.7	32.0
13	1	17.2	100.	1 28 G	0.0990	0.1	13.0	42.0	62.0	80.0	132.	20.7	29.0
13	1	14.6	240.	3 25 G	0.0889	8.0	35.0	90.0	140.0	185.0	292.	20.0	20.0
13	1	12.4	500.	4 27 G	0.0481	60.0	120.0	210.0	300.0	385.0	580.	13.4	20.0
13	1	10.5	1000.	2 21 D	0.0629	50.0	240.0	480.0	700.0	950.0	1419.	13.3	14.0
13	2	20.3	35.	4 30 G	0.1220	-	2.0	8.8	15.5	23.0	43.	22.2	32.0
13	2	17.2	100.	3 13 G	0.0963	0.1	10.5	36.0	55.0	75.0	111.	15.9	27.0
13	2	14.6	240.	3 5 G	0.0815	3.0	40.0	105.0	148.0	190.0	275.	15.6	24.0
13	2	12.4	500.	4 30 D	0.0481	100.0	140.0	210.0	280.0	370.0	548.	12.7	20.0
13	2	10.5	1000.	4 14 G	0.0592	160.0	300.0	540.0	720.0	930.0	1251.	10.4	13.0
14	1	20.3	35.	4 8 G	0.1520	-	0.6	8.0	18.0	26.0	45.	26.0	33.0
14	1	17.2	100.	5 27 D	0.1140	-	4.6	36.0	65.0	95.0	152.	18.0	27.0
14	1	14.6	240.	2 9 D	0.1120	-	21.0	100.0	150.0	210.0	333.	18.0	22.0
14	1	12.4	500.	4 14 D	0.0760	3.0	90.0	220.0	320.0	420.0	585.	13.0	15.0
14	1	10.5	1000.	4 5 G	0.0870	2.2	120.0	420.0	650.0	850.0	1179.	14.0	19.0
14	2	20.3	35.	5 21 D	0.1300	-	1.9	10.0	19.0	28.0	53.	22.1	28.0
14	2	17.2	100.	4 22 G	0.1020	-	11.0	46.0	70.0	95.0	145.	15.0	24.0
14	2	14.6	240.	4 3 D	0.1170	-	16.0	85.0	145.0	190.0	295.	20.0	27.0
14	2	12.4	500.	5 23 D	0.0750	2.0	60.0	230.0	330.0	450.0	666.	14.0	18.0
14	2	10.5	1000.	1 16 D	0.0750	24.0	190.0	410.0	600.0	820.0	1170.	10.0	15.0
15	1	20.3	35.	5 29 D		-	1.4	9.7	20.0	30.0	58.	24.0	32.0
15	1	17.2	100.	3 15 G		-	6.5	33.0	57.0	80.0	118.	16.0	25.0
15	1	14.6	240.	4 26 G		0.1	12.5	60.5	112.0	165.0	266.	18.0	26.0
15	1	12.4	500.	4 24 G		2.7	23.0	150.0	235.0	295.0	611.	12.0	15.0
15	1	10.5	1000.	1 6 G		16.0	150.0	390.0	575.0	800.0	1165.	10.0	15.0
15	2	20.3	35.	2 18 D		-	1.2	10.5	20.0	30.0	58.	29.0	34.0
15	2	17.2	100.	4 13 D		-	5.8	28.5	46.0	63.0	101.	20.0	28.0
15	2	14.6	240.	3 21 G		0.2	27.0	83.0	135.0	190.0	290.	20.0	25.0
15	2	12.4	500.	1 6 D		1.0	36.0	165.0	275.0	385.0	586.	19.0	20.0
15	2	10.5	1000.	3 7 G		15.0	200.0	390.0	550.0	740.0	1079.	13.0	16.0

(*) Corrections for a temperature increase of 4°C.

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TABLE III (continued)

LISTING PAR LABORATOIRE — MISE A JOUR DU 01.10.70

LABO	REP	LOAD	NOM	BLANK	TOTAL	0.1	0.2	0.5	1.0	2.0	RUPT	ELONG	RA
16	1	20.3	35.	1 10 G		0.1	2.0	10.0	18.0	25.0	46.	17.0	25.0
	1	17.2	100.	4 2 G		1.6	13.0	40.0	60.0	80.0	135.	28.7	29.0
16	1	14.6	240.	3 20 D		14.0	50.0	110.0	160.0	200.0	309.	18.0	20.0
16	1	12.4	500.	5 9 D		-	500.0	580.0	650.0	730.0	927.	11.0	11.0
16	1	10.5	1000.	5 23 G		600.0	800.0	960.0	1100.0	1200.0	1237.	11.0	11.0
16	2	20.3	35.	3 9 D		0.1	4.0	12.0	19.0	26.0	45.	19.0	25.0
16	2	17.2	100.	3 14 D		-	3.0	30.0	55.0	75.0	119.	15.0	23.0
16	2	14.6	240.	4 7 G		1.0	40.0	100.0	150.0	190.0	287.	14.0	20.0
16	2	12.4	500.	2 27 G		-	160.0	210.0	250.0	300.0	605.	18.0	16.0
16	2	10.5	1000.	1 26 G		400.0	650.0	960.0	1200.0	1400.0	1768.	9.0	9.0
17	1	17.2	100.	1 5 D	0.1460	-	5.0	44.0	72.0	100.0	164.	22.5	27.0
17	1	10.5	1000.	5 22 D	0.0736	7.0	200.0	540.0	760.0	1000.0	1382.	10.0	10.5
17	2	17.2	100.	5 15 D	0.1190	-	3.0	36.0	63.0	93.0	158.	21.5	27.0
17	2	10.5	1000.	1 23 D	0.0760	0.3	150.0	530.0	810.0	1015.0	1457.	7.0	11.0
19	1	20.3	35.	1 22 D	0.1250	-	0.5	4.8	14.0	30.0	51.	16.3	32.0
19	1	17.2	100.	1 21 G	0.2500	-	-	5.5	22.0	50.0	113.	13.0	26.0
19	1	14.6	240.	4 2 D	0.0250	22.0	46.0	90.0	140.0	180.0	303.	17.5	28.0
19	1	12.4	500.	1 30 D	0.2500	-	-	0.6	12.0	110.0	710.	12.2	28.0
19	1	10.5	1000.	4 16 D							1262.	5.8	12.0
19	2	20.3	35.	2 2 D	0.1250	-	0.3	1.9	8.5	28.0	68.	30.3	34.0
19	2	17.2	100.	4 12 D	0.5000	-	-	-	36.0	80.0	135.	20.5	32.0
19	2	14.6	240.	3 23 D	0.0500	21.0	90.0	210.0	280.0	310.0	325.	16.7	23.0
19	2	12.4	500.	2 7 D	0.1250	-	1.8	35.0	145.0	270.0	627.	13.2	21.0
19	2	10.5	1000.	1 12 D	0.1500	-	0.8	220.0	480.0	720.0	1155.	13.0	17.0
20	1	17.2	100.	2 29 D	0.1142	-	5.9	31.5	52.5	75.8	139.	16.7	25.3
20	1	10.5	1000.	5 18 D	0.0726	2.5	35.0	325.0	663.3	992.5	1610.	11.0	14.6
20	2	17.2	100.	3 19 D	0.1160	-	3.5	24.5	45.5	69.7	119.	15.3	25.8
20	2	10.5	1000.	2 8 D	0.0739	2.8	59.7	344.5	628.0	902.0	1492.	10.0	14.5

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COMMENTS ON RESULTS LISTED IN TABLES I TO III

Lab.1 No strain measurements were made. The use of subsize specimens enabled this laboratory to carry out three tests per blank. The complete set of data are reproduced here below:

Blank No.	*Repl.*	*Load*	*Time R.*	*Elongation*	R.A.
1.3 G	1	17.2	133	6.5	17.9
			91	7.2	16.7
			111	7.5	17.0
3.28 D	1	10.5	1601	10.5	20.4
			1869	16.0	23.0
			1558	9.5	15.8
3.27 G	2	17.2	136	26.0	29.0
			134	13.5	27.6
			107	19.0	25.0
1.25 G	2	10.5	1199	8.5	12.7
			1146	11.0	13.7
			973	4.5	20.0

Only the underlined values have been retained in the computer tables.

Lab.2 The results for this laboratory were corrected for a systematic temperature error. The uncorrected values are given here below:

Rep.	*Load*	*Blank*	*Total*	0.1	0.2	0.5	0.10	2.0	*Rupt.*	*Elong.*	R.A.
1	17.2	2.9 G	0.0775	0.1	8	28.2	46.5	65.0	102	21.0	26.2
1	10.5	4.18 G	0.0700	8.1	140	380.0	550.0	750.0	1046	14.0	9.0
2	17.2	2.2 G	0.1110	–	3.4	36.0	53.0	53.0	93	16.5	26.0
2	10.5	5.18 G	0.0660	23.0	160.0	370.0	560.0	780.0	1059	–	12.0

Lab.4 Time to specified total deformation were computed from data relating to plastic deformation and are thus subject to errors. Total deformation on loading was not measured.

Lab.8 Two blanks were used to carry out replicate 1 test under a load of 10.5 kg/mm^2. Blank 5.7.D resulted in an abnormally high rupture life (2,538 hours). This result was not considered in the tables.

Lab.10 The tests with stresses of 20.3, 14.6 and 12.4 kg/mm^2 were carried out on a machine with automatic beam levelling device.

Lab.11 The two tests under a load of 20.3 kg/mm^2 were carried out on specimens with a gauge diameter of 6.4 mm. Similarly one test under a load of 12.4 and one under a load of 14.6 kg/mm^2 were done with the smaller diameter specimen. All other tests were carried out with specimens the gauge diameter of which was of 9.1 mm. In all cases the gauge length was of 50.8 mm.

The short life of specimen 3.8 D (29 hours) tested under a load of 20.3 kg/mm^2 was attributed to a higher average temperature during testing, estimated at 904°C. The results were thus corrected for a temperature increase as indicated in Table III, page 62.

Lab.12 As mentioned in the text, the results of this laboratory were obtained with a systematic overload of 0.44 kg/mm^2. In the tables listed by the computer only the rupture times were corrected for this overload. The uncorrected rupture times were as follows:

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Rep.	*Blank No.*	*Nom. Stress*	*Act. Stress*	*Rupture life*	*Corrected Rupture Life*
1	3.15.D	20.3	20.74	43	47
1	3.22.D	17.2	17.64	110	124
1	2.31.G	14.6	15.04	265	304
1	1.26.G	12.4	12.84	534	631
1	1.22.G	10.5	10.94	994	1226
2	52.G	20.3	20.74	554	58
2	58.D	17.2	17.64	145	159
2	415.G	14.6	15.04	262	309
2	224.D	12.4	12.84	576	673
2	426.D	10.5	10.94	1098	1330

The correction was made by use of the relation:

$$\log t = -4.78089 \log \sigma + 7.99592 .$$

The above relation was derived by the regression analysis of the results from 5 labs having completed model "C" programme.

Lab.13 The first test on Blank No. 1.8 G (Replicate 1, stress: 14.6 kg/mm^2) gave rise to an abnormally low life (105 hours) because of temperature control fault. The final test of Blank No.3.25 G, gave the values indicated in the table.

Lab.15 Total deformation on loading has not been reported.

Lab.16 Total deformation on loading was not reported. Deformation data refer to creep strain (total deformation minus the elastic + plastic deformation on loading).

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APPENDIX V

EXPERIMENTAL TECHNIQUES AS DESCRIBED IN THE INDIVIDUAL LABORATORY REPORTS

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EXPERIMENTAL TECHNIQUES AS DESCRIBED IN THE INDIVIDUAL LABORATORY REPORTS

LABORATORY 1

Four home made machines were used. A screw device allows to apply the load without shock. The description of the equipment and information on test load and temperature will be found in the table below. The test specifications follow as close as possible the recommended procedures.

TABLE I

Experimental Procedure Characteristics

1. Description of the test equipment
   - vertical creep apparatus with a maximum load of 500 kg
   - horizontal lever ($\pm 1°$ on the horizontal position) with a lever ratio of 10/1
   - test load accuracy $< \pm 0.025$ kg
   - no strain recorder
   - atmosphere : vacuum : 10^{-3} mm Torr
   - 3 heating zones furnace controlled by 1 thermocouple (Cr-Alumel)
   - temperature measurement on the sample: 2 thermocouples (Pt-Rh 10 Rh)
   - temperature measurement unit

   Type K-3 universal potentiometer No. 7553–5, and DC galvanometer No. 2430.

2. Heating time: 3 hours
   soaking time: 4 hours.

3. Maximum sample temperature variation
   - on thermocouple one: 896°C and 903°C
   - on thermocouple two: 898°C and 905°C
   - between the two thermocouples: 2°C.

LABORATORY 2

The creep machines used for the tests has a maximum capacity of 2000 kgf with a lever ratio of 15 : 1. The accuracy of load measurement was better than 0.5%. This accuracy is regularly checked by calibration.

Loading and subsequently the horizontal levelling was accomplished by means of a screw device at the lower part of the stressing bars.

The furnace had three zones each of which was fitted with a potentiometer. Temperature control was carried out by means of a dilatable rod.

Temperature was measured by means of three Pt-Pt 10 Rh thermocouples attached respectively to the bottom, centre and top of the gauge length. The thermocouples originated from a batch calibrated against a secondary reference thermocouple.

Electromotive forces were measured with a potentiometer, the sensitivity of which was 0.005 mV. The gauge length of the specimen used is equal to $5.65\sqrt{So}$. The specimen is hollow and the strain measurement, under load, is performed by means of coaxial quartz rod and tube resting at the respective gauge length ends. Strain measurement was made by means of a dial gauge reading 1 micron. The accuracy of strain measurement was 2.10^{-5}.

The test pieces were lathe machined with carbide tools and polished with 600 emery paper (4/0).

Dye penetrant inspection was made in order to check for the absence of cracks at the outer surface of the specimens.

The test pieces were introduced in the hot furnace and brought to a temperature of 893°C in 1 hr 30 min. Homogenization of temperature at 900°C required 4 hr 30 min.

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Loading was performed manually and time was measured from the moment where the full load was applied.

Examination of the test conditions after the test were completed showed that a systematic error was made in temperature measurement. Actually, reference was made to standard EMF tables for Pt-Pt 10 Rh thermocouples instead of to the calibration tables. This resulted in a systematic error of 1.5°C overheat. The results were corrected for this systematic error and also for those observed during the individual tests.

LABORATORY 3

In the home-made machines used, load is transmitted by means of a lever with an amplification of 10 times ($\pm 3.10^{-3}$). Load was made up of calibrated weights. These were applied manually and freedom from shock was ensured by means of a spring.

Axiality was ensured by a self-aligning joint system; the distance between joints was of 94 cm. The deviation of the alignment direction from the vertical line did not exceed 10^{-3} (tangent of the angle).

The furnaces were equipped with three independent zones. Control of the thermal gradient was achieved by controlling the voltage applied to each zone. Temperature control was made by means of a platinum resistance and a continuous saturable core system.

Strain measurement was performed in two ways:

(a) the signal from a differential transformer system attached to the extensometer the legs of which were attached to the ends of the gauge length, was fed to an X–Y recorder (X: elongation, Y: time).

Accuracy	±0.020 mm
Sensitivity	for elongation of
1μ	0 – 100μ
5μ	100 – 500μ
10μ	0.5 – 1 mm
20μ	1 – 10 mm.

(b) for the purpose of rapid control, the displacement of the lever extremity was recorded on a drum recorder.

Accuracy	±0.050 mm (referring to the specimen)
Sensitivity	0.020 mm (referring to the specimen).

Temperature was measured by means of 3 Pt-Pt 10 Rh thermocouples attached to the gauge length (bottom, middle, top) and feeding a digital voltmeter

Accuracy	±1°C
Sensitivity	0.5°C.

LABORATORY 5

Specimen

The specimens were lathe machined with carbide tip tools to 0.5 mm from the final size. Linear speed was of 50 mm/sec, feed was of 0.1 mm per revolution and depth of cut was of 0.2 mm. Final machining was made by grinding at the linear speed of 27 m/sec with a silicon carbide wheel (grain 120).

The specimens had a diameter of 5 mm and a gauge length of 36 mm. The following relation was valid:

$$L = 8.14\sqrt{So}\ .$$

This type of specimen was quite different from those recommended. It was nevertheless used in order to provide data for possible comparison purpose.

Naked eye inspection of the specimen did not reveal the presence of any cracks or other defects. The diameter was controlled by means of a micrometer and the deviations were found inferior to 5 micron.

Surface roughness was measured by mechanical sens (Talysurf) and interferometry microscopy (Reichert).

The diagrams obtained with the Talysurf allow to determine the surface ondulation at average distance with reference to an ideal line followed by the sens tip: depending on the specimen the surface ondulations ranged between 1 and 2.5μ. The interferometric patterns allowed to estimate the short distance roughness which was found of the order of 0.5μ.

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Test Technique

All the tests were carried out with the same machine, fitted with a sliding furnace. The test pieces were screwed to the straining bars. Axiality was ensured by means to universal type joints. The machine was protected from sudden room temperature changes.

Load was applied with a lever (amplification 20 times). The weight of the pull rods was known to ±0.5 g.f. The cross section area of the specimen being about 20 mm^2, the accuracy of load measurement was better than ±0.05 pct for stresses higher than 10 kg/mm^2. The application of load was made at the rate of 1 $kg.f/mm^2/min$.

Strain was continuously recorded by means of the following device:

- the extensometer legs rested on conical seats machined at the ends of the specimen. The part of the extensometer exposed in the furnace was made in heat resisting alloy; the part exposed to room temperature was made in Invar.
- a double lever mechanical system with an amplification of 200 times.

The diagrams were read to the nearest 1/5 mm. With the specimens used the sensitivity of strain measurement was thus better than ±0.001%.

The tubular furnace was equipped with 4 zones. The two central zones could be independently adjusted by means of a potentiometer. In this way the thermal gradient of the furnace at 900°C was less than ±1°C over a length of 120 mm. The furnace was controlled with a dilatable rod. Temperature was measured with two calibrated Pt-Pt Rh thermocouples attached to the specimen's gauge length (about 1/4 and 3/4 of the gauge length), feeding a direct reading potentiometer. The accuracy of calibration allows to guarantee an accuracy for the indicated temperature values of better than ±0.5°C. The whole system consisting of the furnace and the measuring equipment allows to maintain a temperature of 900° ± 3°C over periods in excess of 1000 hours.

Procedure

The furnace being cold the specimen was attached to the pull rods and the extensometer was placed. The thermocouples were attached with asbestos rope. The extensometric system is checked and the furnace is placed around the specimen.

The furnace ends are closed with asbestos wool to avoid convection currents between the interior and the exterior of the furnace.

Heating was made at the rate of 500°C/hour. Thus heating time was less than 2 hours in agreement with the recommendation. Before loading, soaking for 5 hours was performed.

Strain measurements were started before the beginning of loading.

LABORATORY 8

Design of the Machine

The creep testing machine has been designed and built *intra-muros*. Figure A shows the scheme of design. The capacity of this machine is 1200 kpf. The threaded specimen A is jointed with the pulling rods T_1 and T_2 The load is applied by weights B by means of the rod B_1, helical spring F, knife edge joint V_2 at the end of one arm of the double-arm lever C-resting on the upper horizontal frame in a knife edge bearing – the knife edge joint V_1 and frame, the double crossed knife edge bearing X_1 and the pulling rod T_1. The lower pulling rod T_2 is also connected by means of a double crossed knife edges joint X_2 with a spindle type mechanism D and the hand operated handle E. This mechanism makes it possible to bring the lever C into the horizontal position again after any remarkable elongation of the specimen. Inherent weights are balanced with the movable jockey Z.

The specimen is stressed in the following way: the weights B are put at first onto the plate at the end of the pulling rod B_1, which is supported by the plate G and an axial ball bearing of the spindle Q, so that the helical spring F is free; then the weights are lowered by the spindle mechanism Q, the helical spring is elongated till the weights B are lifted off from G. Since the relation between the elongation of the helical spring F and the load is known, a pointer fixed to the rod B_1 indicates on the scale B_2 every load between zero and maximum so that during a perfectly shock-free loading the modulus of elasticity of the material of specimen can be measured by means of the extensometers S.

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Extensometers

The extensometer is a combination of Martens design (prisms and reflecting mirrors) for measuring of small elongations (accuracy 0.1μ) and dial gauges for measuring of larger elongations (accuracy 10μ). Always a pair of Martens-extensometers are fitted so that a bending free stressing of the specimen can be controlled, that should be realized by the crossed edge knifes joints X and X_2. Two long extensometer rods are attached to the ridges of the specimen; between both the Martens prisms is arranged at S; the relative movement between these two extensometer rods is indicated also by a dial gauge, the weight of which is counterbalanced as well as the weight of the extensometer rods; in this way no load into the ridges of the specimen influences the measurement of strain.

Furnace

The furnace I is normal with three heating zones as is shown in Figure B. A ceramic tube is covered by the heating wire coils. The furnace is suspended by two chains K, turned round on the discs L, balanced by weight M, and movable vertically.

The extensometers can be attached when the furnace is in the upper position; afterwards the furnace is lowered into the position shown in the Figure A. As the scheme of the temperature control device in Figure A shows the electric heating energy is delivered by the secondary coil of an adjustable transformer Tr_1 and adjusted by the resistors R_1, R_2, R_3. In parallel to the middle part of the heating coil the adjustable resistor R_3 is connected; the current in this by-pass is indicated by an amperemeter A. Additionally in order to realize an even temperature in the length of the specimen the distance between the windings of the heating coil is much smaller in zones 1 and 3 than in the middle zone 2. In order to balance the heat transported out of the furnace by the pulling rods T_1, T_2 these rods within the furnace have a number of radiator discs. The distribution of temperature in the gauge length has been measured by means of the Ni-Ni-Cr thermocouples spot welded to an austenitic alloy specimen. The deviation in the gauge length is about $\pm 1°C$. The temperature during creep testing has been measured with Ni-Ni-Cr thermocouples.

Temperature and Heating Rate Control

The heating rate is controlled by means of the transformer Tr_1. As soon as a temperature becomes a little bit smaller than the desired one, a controlling device begins to operate. Quite near the heating coil a thermal extension thermometer N is arranged; it consists of a quartz glass rod R within an austenitic alloy tube D; the difference between the thermal expansion of these two parts see Figure A, with the length c, corresponding to the length of furnace, is transmitted to a dial gauge M; on the shaft, that normally is carrying the pointer, now a reflecting mirror Sp is fixed.

As soon as the desired temperature has been measured by thermocouples in contact with the specimen, the position of the quartz glass rod E relative to the austenitic tube D is adjusted by means of a micrometer screw O so that just one end of the straight filament (length 20 mm) of the lamp B is projected to a germanium photodiode P in natural size. On the way of the light rays from the filament in the lamp B to the reflecting mirror the rays are ordered parallel by the lens L_1 and afterwards collected again onto the photodiode P by the lens L_2. By ordering of the light rays parallel a correct picture of the filament on the photodiode P is realized at all distances between the lamp B or the photodiode P and the reflecting mirror M.

The photodiode P is connected to a silicon rectifier G (voltage 8 volts), and amplifier V. When the picture of the filament begins to move onto the photodiode a direct current flows into the transistor amplifier and activates the relay Q that short circuits the resistor R_2. The heating energy is diminished, the temperature in the thermal expansion thermometer N is reduced, the picture of the filament disappears off the photodiode and the short circuit is interrupted. The sensitivity of the temperature control device is $0.2°C$, and the amplitude of temperature oscillation in the specimen $\pm 2°C$.

Measuring of Temperature

The control of heating rate and the adjustment of the desired temperature has been made by means of noble metal thermocouples Pt-Pt Pd (Pallaplat, 32/40 Heraeus, checked at the Gold point). The temperature has been recorded continuously with Ni-Ni-Cr thermocouples. These have been compared periodically with the noble metal thermocouples so that any drift of the Ni-Ni-Cr thermocouples could be eliminated.

The heating rate has been chosen so that the desired temperature in the specimen has been attained in three hours. The specimen is kept at constant desired temperature during two hours before the application of load.

LABORATORY 9

Test-Piece Preparation

The test pieces have been machined with a circular section. The initial section S_0 and the gauge length L_0 satisfy the following relationship:

$$L_0 = 5.65\sqrt{S_0}\,.$$

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Before testing, the test specimens have carefully been surface finished by machining with surface roughness = 0.20μ (cut off 0.25).

Loading Equipment

The tests have been conducted with an equipment having the power of 2000 kg lever amplifier, ratio 20/1, capable of applying the required load, axially, through spherical joints, without shocks, and with an accuracy superior to ±1%, as to the nominal stress value.

For the measurement of strain two precision extensometers have been used. The heating section was divided into three areas, which could separately be regulated. The furnaces were previously heated up to the soaking temperature near 900°C. At this point the complete set was introduced into the furnace. In this way it was possible to reach, in about 3 hours, the constant prescribed temperature along the gauge length with temperature gradients, as to the normal temperature, not superior to ±1.5°C.

The constance of the temperature has been checked with thermocouples Pt-Pt 10 Rh, being calibrated to an accuracy superior to ±0.5%. It must be pointed out, with reference to this, that the thermocouples placed on the superior and the inferior races of the specimen were assembled as a part of the set, whereas the central thermocouple was introduced through a hole in the external surface of the furnace.

The vibration of the temperature measured by the three thermocouples during each test, is graphically indicated together with the diagram strain-time for each test.

LABORATORY 10

Test Procedure

Test Specimens

Ten Nimonic-105 blanks were received. From these blanks ten test specimens were machined and were given the same markings as the original blanks.

The surface roughness of the gauge length of the specimens, were determined with the Talysurf M3.

Test Apparatus

The tests were carried out on two creep testing machines. Details of these machines with matching equipment are the following:

Specimen	4.23 LG, 1.29 LD, 4.28 LG and 4.66 LG	1.7 D, 1.3 D, 2.29 G, 1.4 G, 4.17 D and 4.25 D
Creep test machine	made *intra-muros*	commercial with automatic beam levelling facility
Type	single lever with a 150 kgf sliding weight and an end position lever ratio 20:1	single lever with a sliding weight up to a capacity of 25 kgf and a dead-weight with a lever ratio 20:1
Maximum capacity	3000 kgf	4000 kgf
Non-axiality of loading minimised	by ball bearings	by crossed pens
Furnace	"X" type with 3 zones	3 separate zones
Temperature adjustment	by "X" regulator	by constant voltage "X" regulator
Measurement of temperature	3 calibrated thermocouples Pt-Pt 10% Rh, secured to the gauge length of the specimen with asbestos cord and attached via compensating cable to a single pen Honeywell recorder (at 900°C on scale 5°C = 1.75 mm)	
Extensometer	"X" type with two clocks of 0.01 mm (readings in 0.001 mm) (enlargement 440)	"X" with two clocks of 0.01 mm (readings in 0.001 mm) (enlargement 200)
Relative accuracy load measurement	better than ±0.5%	better than ±5%
Absolute accuracy strain measurement	±0.03%	±0.03%
Accuracy temperature measurement	at 900°C: ±3°C	at 900°C: ±3°C

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Test Method

After mounting the specimen, thermocouples and extensometer in the creep machine and after heating and soaking the required load was applied in increments. The load increments and extensometer readings were measured. The heating – and soaking times are given in Table below.

For all tests the loading time was approximately 1.5 minutes. All tests were carried out in air and in a room with constant temperature.

Heating and Soaking Time

Specimen	*Heating Time Hours*	*Soaking Time Hours*
1.7 D	8	14
4.23 LG	3	2
1.13 D	4	17
2.29 G	3	26
1.29 LD	3	3
1.4 G	10	11
4.28 LG	3	5
4.17 D	10	15
4.25 D	10	13
4.16 LG	2	3

LABORATORY 11

Test Procedure

The specimen prepared for these experiments was of the form shown. The highest stress (20.3 kg/mm^2) could not be attained with the 9.1 mm diameter gauge length hence for these two tests the diameter in the gauge length was reduced to 6.4 mm. As a check on the effect of specimen diameter two other tests, one at 12.4 kg/mm^2 and one at 14.6 kg/mm^2 were also done with the smaller diameter specimen. Two grooves, 50.8 mm apart, were machined in the gauge length to hold the extensometer. These grooves were of the profile shown and were also used as gauge marks for measurement of elongation at fracture.

These tests were done in two creep machines (No.107 and 108) which are of the standard home design. These machines are of approximately 1000 kg maximum load capacity and the load is applied by means of a dead weight acting through a 10/1 lever system. The shackles include two sets of pin joints at right angles to one another, one above and one below the specimen, in order to ensure that bending loads are not applied to the test piece. The load was applied to the specimen without shock and loading took about 5 minutes.

The specimens were brought up to temperature over a period of 1–2 hours and the temperature stabilised over the next 4–5 hours. The temperature was controlled by means of an electronic proportionating controller using a Pt-Pt 10% Rh thermocouple sensor placed at the centre of the gauge length of test piece. The temperature was recorded continuously and was checked at regular intervals by means of a potentiometer and two Pt-Pt 10 Rh thermocouples attached at the top and bottom of the gauge length of the test piece. The temperature was controlled at 900°C and the check readings indicate that the temperature was generally within ±3°C of this value although occasional excursions outside these limits were recorded.

The strain was measured by means of an optical extensometer having knife edges fitting the grooves machined into the gauge length of the test piece. The roller system and scale distance used were arranged to give 0.3 x 10^{-3}% elongation on the specimen equal to 1 mm on the scale.

LABORATORY 12

Test Procedure

Test Pieces

The gauge length was machined to 0.75 mm oversize and reduced to size in one cut of 0.25 mm, one of 0.125 mm and subsequent cuts of 0.05 mm. The surface roughness of the specimens was between 0.2 and 0.44μ CLA. High grade high speed steel tools were used throughout with soluble oil coolant. The gauge diameter was measured by micrometer and the length "*l*" and elongation after fracture by dividers and a steel rule. A "Tensometer" gauge was used to measure reduction of area.

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Test Apparatus

All the tests were done on the same 5 tonf (≃ 5000 kgf) High Accuracy Creep Test Machine. In this machine the load is applied to the specimen by a poiseweight travelling along a graduated steelyard, which gives smooth shock-free loading. The load is transmitted to the test specimen through co-planar knife edged universal joints to minimise non-axiality of loading.

The graduations of the steelyard are in ≃ 10 kgf increments with a vernier scale reading to ≃ 1 kgf. Calibration of the machine after test showed that the applied load was in error by a constant 14.05 kgf. All stresses were therefore 0.44 kgf/mm² in excess of the nominal. Repeatability of loading was found to be ±1 kgf.

A roller type extensometer was attached to the two ridges on the specimen. Mirrors attached to the rollers were viewed through a telescope. The overall magnification of the system enabled the strain to be measured to within 11×10^{-4}%. The gauge constant was calculated from measurements of the optical system.

The specimen was heated in a single zone tube furnace, with the open ends of the tube insulated with kaolin wool. Heating time was 1–2 hours to 893°C and soaking time 3–4 hours at 900°C.

The temperature was regulated by a thermocouple precision temperature controller in conjunction with a thyristor power control unit.

Three Pt-Pt 13% Rh thermocouples for temperature measurement and one for temperature control were attached to the gauge length of the specimen by reinforced asbestos string. The temperature measurement thermocouples were attached via compensating cable and 45°C cold junction to a potentiometer. The sensitivity of this instrument is ±0.001 mV (≃0.08°C). Calibration of the batch material used to make the thermocouples showed that indicated temperature to be (−0.14°C) at 1063°C and +0.5°C at 660°C.

Test Method

After mounting the specimen in the testing machine, a test load was applied in increments of ≃100 kgs ≃ 15.5 kgf/mm² to check the axiality of the specimen. The load was removed and the furnace (cold) was lowered into position and insulated. After heating and soaking the required load was applied in increments of ≃50 kgf and extensometer readings taken. The loading time was approximately 1.1/2 minutes.

LABORATORY 13

Test-Piece Manufacture

Test pieces, as shown in Figure 1, were manufactured from the blanks in the following manner:

(a) cut to length, identity stamped and centred
(b) coupon turned to 0.410 in. (10.4 mm) dia.
(c) finish turned to 0.380 in. (9.7 mm) dia.
(d) gauge form and ridges turned
(e) each end thread ground
(f) from between the ridges and threaded ends groups to 0.262 in. (6.7 mm)
(g) gauge length between ridges finish ground to 0.252 in. (6.4 mm)
(h) degreased and inspected.

Creep Testing Procedure

Details of the creep testing machine, extensometer, furnace, temperature control and temperature measuring equipment used for the creep tests are given in Table below. All tests were carried out in a similar environment. Test pieces were heated to 900°C in 1–2 hours and soaked at temperature for 2–3 hours prior to the load being applied.

TABLE – Creep Test Equipment

1. *Machine*

Type: single overhead lever, balanced, ratio 5.6 : 1
Capacity: 0.1 ton to 1.0 ton
Calibration: national specifications
Shackles: self aligning, ball and plate, threaded connectors
Loading: calibrated weights as required.

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2. *Extensometer*

Comparator arms attached to ridges on the test piece. Deformation measured by dial gauges reading to 0.0001 in.

3. *Furnace*

2.1/2 in. (63.5 mm) bore

16 in. (406 mm) long

BRIGHTRAY alloy C windings, three zone.

4. *Temperature Control*

Platinum resistance thermometer sensing element with saturable reactor type proportional.

5. *Temperature Measurement*

Three platinum/platinum – 13% rhodium thermocouples attached to gauge length of test piece. Thermocouples calibrated at 950°C within ±1°C against a master couple certified by the Ministry of Technology.

Sensitivity: ±0.2°C

Temperature variation: ±2°C, temperature gradient 2°C.

LABORATORY 14

Test Pieces

Test pieces were machined from the blanks in the following sequence of operations:

(a) Centre end turn to 0.500 in. (12.7 mm) diameter

(b) Copy turn reduced section to 0.330 in. (8.4 mm) diameter

(c) Screw ends

(d) Plunge grind ridges and reduced section to size.

Creep Test Equipment

Table below gives details of the creep testing machine, extensometer, furnace, temperature control and temperature measuring equipment used for the creep tests reported. All tests were made in the same machine.

Heating and Soaking

Test pieces were heated to 900°C in 1–2 hours and soaked at temperature for 4–5 hours prior to the load being applied.

TABLE – Creep Test Equipment

1. *Machine* Designed and built by the Company

Type: Single overhead lever, balanced, ratio 5.6 : 1

Capacity: 3 kg – 3000 kg

Calibration: Better than ±0.5% verified by certified proving ring

Shackles: Self aligning, ball and plate, threaded connectors

Loading Calibrated weights as required.

2. *Extensometer* Designed and built by the Company

Comparator arms attached to ridges on the test piece. Deformation measured by transducer.

Sensitivity: 0.000005 in. (0.00013 mm)

Accuracy: 0.00004 in. (0.0010 mm) quoted by manufacturer.

3. *Furnace*

Bore: 57 mm, 254 mm long

Diameter outside casting 254 mm

Winding: three zone.

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4. *Temperature Control*

Platinum resistance thermometer sensing element with saturable reactor type proportional temperature controller.

5. *Temperature Measurement*

Three platinum/platinum – 10% rhodium thermocouples attached to gauge length of test piece. Thermocouples calibrated at 900°C against a certified master couple.

Sensitivity: ±0.2°C

Temperature variation: ±3°C max.

Temperature gradient: 3°C max.

LABORATORY 15

Machining

Test pieces were machined from the test blanks and precautions were taken to ensure that the identifying marks were transferred to the test pieces. The test pieces were machined by turning using high speed tools and soluble oil coolant. A turning technique was employed in which the depth of cut was progressively reduced, resulting in a final surface finish of better than 8μ (CLA).

Test Equipment

(i) All the tests were done using two 5 ton capacity creep testing machines. The load on the test piece was applied through co-planar knife edges by an overhead double lever system with a 40:1 ratio. The specimen was gripped in screwed holders attached to the universal co-planar knife edges, and the axiality of loading was better than 10% side to side variation of extensometer readings.

(ii) The test pieces were loaded by constant time incremental applications of calibrated weights and an extensometer reading was taken for each increment of load. The strain was measured by electronic transducers. The strain readings were automatically recorded in digital form at predetermined time intervals using an auto-scanning and print out system.

(iii) The creep machine was calibrated prior to starting the tests, using a calibrated proving ring. The accuracy was found to be better than ±0.5%. The electronic transducers and associated equipment were calibrated by the manufacturers and the error was not more than $\pm 6.0 \times 10^{-5}$ in. over the full range of the transducers.

(iv) The test specimens were heated in an electrical resistance three-zone furnace the temperature of which was controlled by a platinum resistance thermometer and a triple thyristor temperature controller. The temperature of the test specimens was measured by two Pt-Pt 13% Rh thermocouples attached to the specimens. The thermocouples were calibrated at 900°C prior to the tests and were accurate to better than ±1°C. The temperature gradient along the gauge length of the specimens was not more than 2°C during the life of the test, and the temperature variation during the life of the tests was not more than ±1.5°C.

Heating and Soaking

The specimens were heated at 900°C in the furnace over a period of 3 to 3.5 hours and were then allowed to soak to 900°C for 2 to 3 hours before being loaded.

LABORATORY 16

The specimens were machined to a surface roughness of 16 micro-inches.

A single zone furnace was used. With the use of an autotransformer the power input varied along the axis of the furnace in order to control thermal gradient.

Accuracy of load measurement as transmitted to the specimen was of ±~0.5 kg. Loading was accomplished with a continuously driven mechanical load weight elevator.

The accuracy of temperature measurement was of ±1/4%.

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LABORATORY 17

Specimens

Each blank was 100 mm long (3.94 in.) x 13 mm (1/2 in.) x 16 mm (5/8 in.). One specimen was machined from each blank with a gauge length of 32 mm (1.25 in.) x 6.35 mm (0.250 in.) in diameter.

The machining procedure included the following steps:

(i) drill centre holes

(ii) rough turn on centres to 0.500 in. diameter

(iii) cut threads

(iv) the gauge section was rough turned to within 0.5 mm (0.02 in.) of final diameter using a sharp tool, cutting speeds and depth of cut which resulted in a clean cut. The final finish was obtained with a sharp file followed by clean sharp abrasive paper grinding. No burnishing of the surface was allowed. The procedure used minimises cold working of the surface.

Profilometer Surface Roughness Measurement

	Root Mean Square		*Arithmetic*	
Specimen	*Range*	*Average*	*Range*	*Average*
5.15 LG	4.25–5.0	4.7	4.1–4.7	4.4
5.22 LD	4.25–4.75	4.5	4.25–4.50	4.4
5.15 LD	4.5–5.5	5.0	4.25–5.00	4.5
1.23 LD	4.25–5.00	4.6	4.0–5.1	4.6

Test Equipment

(a) The creep-rupture test units were home designed and made. One specimen per unit is tested. The load is applied with a cantilever beam. The load is transmitted through a set of knife edges, pin attachments to the lower and upper adapters, a universal joint, and a ball thrust bearing. The bearing and a keyed shaft allow the beam height to be adjusted without torque being applied to the specimen.

(b) The specimen was threaded to adapters which in turn were attached to extension rods through 3/4 in. – 10 threads. The axiality of these units as measured by a specimen with four resistance strain gauges at 90° show less than 15% variation between any two of the gauges.

(c) The specimen is brought to temperature and then loaded by attaching the beam and then applying the necessary weights at the end of the beam in increments. Strain measurements are made after each increment of load. The load for these tests was applied in approximately two minutes.

(d) Strain was measured by a modified Martens type extensometer. The extensometer extension rods were attached to collars threaded on the specimen shoulders ahead of the adapters. The reported strain was the average of reading taken on two sides of the specimen.

(e) The weight of the load was known to <0.01 pound. Calibration of the beams plus load with a calibrated ring gauge indicated that the accuracy of the stress on the specimen was known to $<0.5\%$.

(f) The sensitivity of the extensometer system for measuring strain was 15 millionths inch per inch for the 1.25 in. gauge length. Because the extensometer was attached to the shoulders of the specimen an effective gauge length to account for fillet and shoulder deformation was calculated. This was based on elastic properties for the strain during loading and on creep characteristics after the load was applied.

(g) A three zone adjustable height furnace made in-hours was used. Temperature was controlled by an automatic potentiometer type controller which varied the current between a value slightly less than that required to maintain temperatures and a high value slightly more than required to maintain temperature. The control thermocouple was located within the helix of resistance wire heating the furnace. It therefore heated and cooled more rapidly than the specimen, thereby keeping variation of specimen in temperature between cycles to 0.2°F.

(h) The specimen temperature was measured by 18-gauge chromel-alumel thermocouples. The temperatures were measured at the centre of the specimen and at both fillets. The couples were mechanically attached and were shielded from direct radiation. The couples were made from "Research Grade" matched spools of wire calibrated to within 0.5°F.

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Temperatures were measured periodically with a semi-precision potentiometer with a sensitivity of 0.01 millivolts. The potentiometer was checked and found accurate to <0.5°F before and after the tests.

Several attempts have been made to estimate the accuracy of the temperature measuring system with the result that all errors including instrument errors, etc. are <2°F.

An automatic temperature recorder was used during the tests to indicate temperatures between measurement with the potentiometer. Ambient temperatures were controlled with an "air-conditioning system" to <1°F. A "standby" diesel generator was available during the tests. However, no primary power interruptions required its use during the tests.

Heating and Soaking Time

The specimens were placed in the furnace and brought to 900°C (1652°F) in approximately 1.5 hours. Temperature distribution and control was adjusted in 4 hours and the specimen loaded.

LABORATORY 20

Preparation of Test Pieces

The four blanks, each measuring 100 x 16 x 13 mm^3, were machined by suitable turning operations. The test specimen used has a circular test section of 5 mm diameter and a gauge length equal to five times the diameter, viz. 25 mm. The annular ridges are used to attach the extension arms of extensometer. Rough-turning and finishing were done with cemented-carbide cutting tools of grade "K 10". Final machining of the gauge length was performed over a depth of 0.5 mm (5.5 mm to 5.0 mm diameter) in eight steps with a depth of each cut between 0.025 and 0.05 min. The feed was in this case 45μ/rotation, and the cutting speed 20 m/min. Soluble oil-emulsion was used as coolant and lubricant. Special attention was paid to always sharp cutting edges of the tools. During the final machining, the tools had to be ground therefore after each cut. The resulting surface roughness of the gauge length was determined by an electronic needle surface scanner. Although obtained by turning, the surface roughness corresponds more to a grinding operation. Usually the depth of the cold worked surface layer is greater for turning operations than for grinding. This cold working, if significant enough, must produce a fine grained recrystallised layer in the following creep test at 900°C. Metallographic examination of ruptured specimens showed no evidence for the presence of layers of the described type near the surface. So it may be accepted, that the cold working of the surface layer due to this turning operation had no remarkable effect on the structure. Optical inspection of the surface revealed no cracks or flaws in the gauge section on any of the specimens. Test diameters were measured with screw micrometer calipers, original gauge lengths with a high power magnifier equipped micrometer-screw extensometer with an accuracy in both cases of ±5 microns. The latter instrument also was used to determine the elongation at rupture, after removing from the creep testing machine. Before inserting into the machines, the specimens were equipped with chromel-alumel thermocouples by spot welding.

Loading Equipment

The testing machine used was a Stress Rupture Testing Machine with a maximum load of 2000 kgs and a single lever with a lever ratio of 10:1. The machine is equipped with an automatic beam levelling facility, weighing lever with sliding weight for applied loads from zero to ten kgf and a hydraulic shock absorber. Straining bars are connected on both sides to co-planar crossed knife edges to ensure a frictionless self-aligning. The length of the straining bars as well as the double universal knife edges contribute to the axiality of load. The weight pan may be lowered by a screw drive, and therefore in connection with the shock absorber the load on the test piece is applied without shock. Loading was done usually within a time of about half a minute.

The accuracy in load measurement was determined by calibrating with a certified proving ring. The error amounted at the minor test load used to +0.5%, at the major test load to +0.25%. Gripping was done by screwing the threaded heads (M 10 thread) of the specimen into the straining bars.

Heating Apparatus

The creep testing machines are equipped with counter-balanced three zone furnaces for electrical resistance heating, complete with temperature gradient controls. The maximum temperature is 1120°C. All tests were carried out in open air.

Heating to Temperature and Soaking Time

The counterbalanced furnace could be moved in the vertical direction, so that in its upper position the test piece with its thermocouples and the extensometer could easily be placed into the straining bars of the machine. When reaching the test temperature of 900°C, the furnace was pulled down over the specimen. In this way the test piece was introduced into the hot furnace. From this moment until the specimen reached the soaking

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temperature, an average time of about one to one and a half hours elapsed. Then corrections were made in order to improve the local temperature distribution.

The length of soaking time was determined by the time to reach a thermal equilibrium of the test chamber, so that no more thermal extension or contraction of any part of extensometer, specimen or pull rods could occur. This state was indicated by the extensometer recorder coming to rest. Heating time ranged from 1.0 to 1.6 hours whereas soaking time ranged from 4.33 to 5.5 hours.

Temperature Measurement and Control

For temperature measuring purpose three chromel-alumel thermocouples were attached to the specimen by spot welding. Two of them were located on opposite ends of the gauge length in the fillet radius between the ridges and the threaded head of the specimen, and one in the middle of the gauge length. Besides this arrangement an additional Pt-Pt 10 Rh thermocouple was installed in the middle of the gauge length by carefully tying its hot junction to the surface of the specimen with a thin nickel wire. Before its use the noble metal thermocouple first was annealed at recrystallisation temperature and then calibrated at 900°C against a standard Pt-Pt 10 Rh thermocouple in a special calibration furnace. There was no detectable deviation in emf between both thermocouples. The instrument used to measure the emf was a precision compensating potentiometer with a sensitivity of 0.001 mV (~±0.1°C). During the tests another measuring device was used for the Pt-Pt Rh-elements with an accuracy of 0.01 mV (~+0.885°C). The chromel-alumel couples were calibrated by use of a representative thermocouple, which was calibrated against the standard Pt-Pt Rh-couple. This calibration was done with a mean error of ±0.31°C. The sensitivity of the temperature measuring device during the tests in connection with the chromel-alumel couples was 0.01 mV (~+0.25°C). As it could be observed during the tests by comparison of Pt-Pt Rh and chromel-alumel couples, the latter showed a drift over longer periods of test, which had to be corrected. The temperature variations during the tests and along the gauge lengths always met the recommendations. Temperature control was performed by controlling the voltage supply to a constant value within ±0.7% and the room temperature within ±2°C. Setting of the voltage needed for test temperature was done with a variation transformer.

Strain Measurement

Specimen deformation was measured by a high magnification averaging extensometer fitted with variable differential transformers. The extension arms were attached to the annular ridges at the ends of the gauge length. The magnification is 1 : 500, and this corresponds to a strain measuring sensitivity of one micron or 4×10^{-3}% of the gauge length assuming, that a deflection of 1/2 millimeter on the registration strip of the recorder is detectable The extensometer was calibrated with a precision micrometer calibration device. It had a least scale reading of one micron. Besides this another independent calibration method was used by measuring the Youngs Modulus of the Nimonic specimens at room temperature in the creep testing machines with the extensometers in place. In this case the average error in measuring the elongation was +1.04 micron, and the average elastic modulus amounted to 20,670 ± 210 kg/mm^2. So the accuracy in strain measurement or reproducibility may be assumed to ±1 micron or $\pm 4 \times 10^{-3}$%. Deformations during creep tests were recorded continuously.

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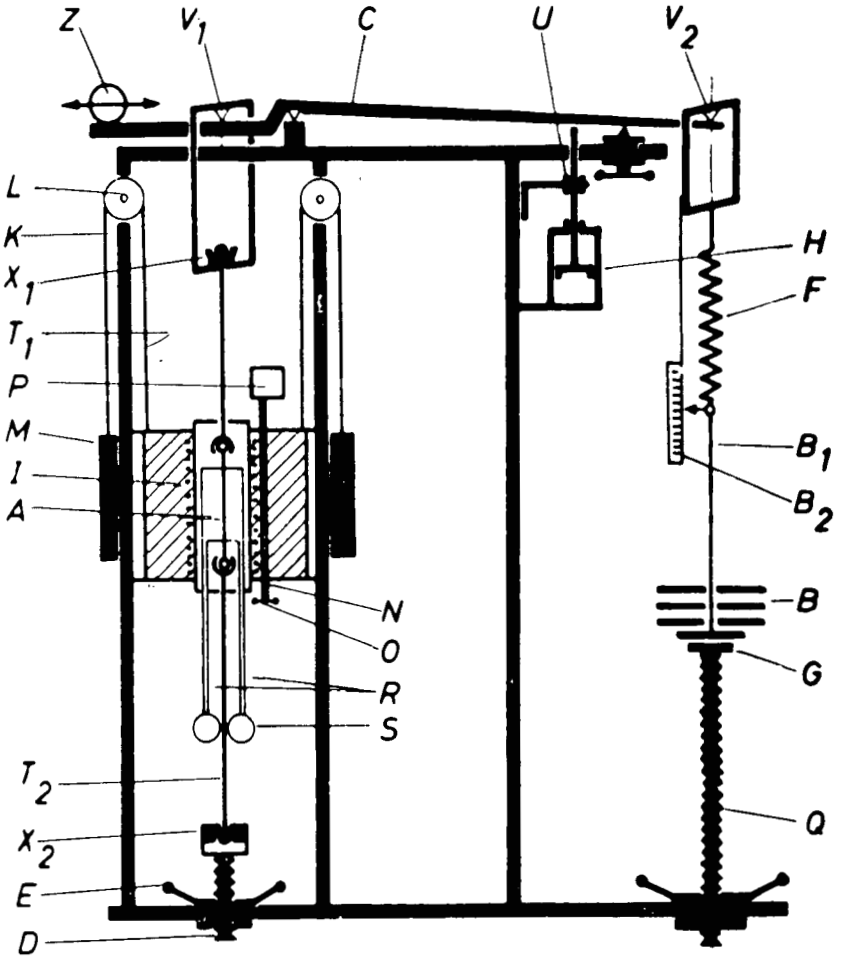

Figure V-A

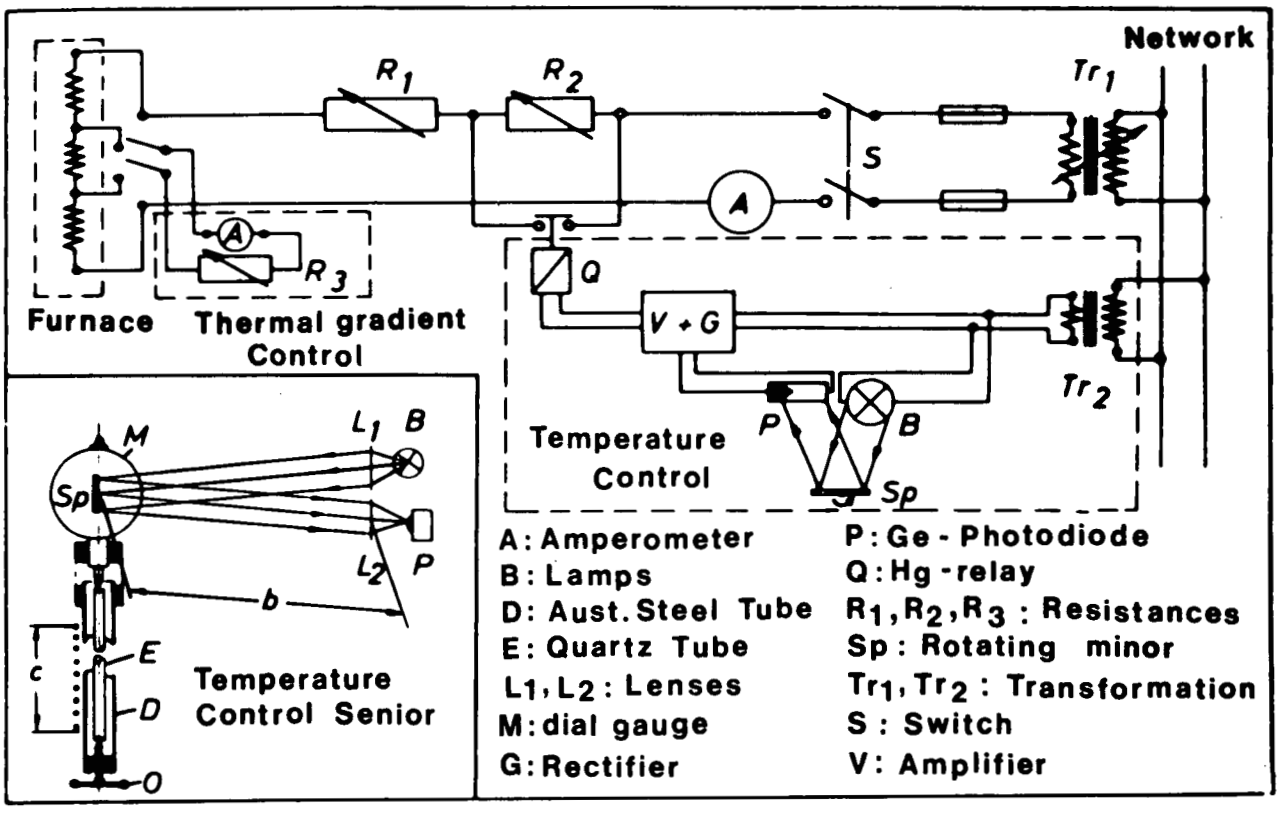

Figure V-B

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APPENDIX VI

STATISTICAL EVALUATION OF DATA ON THE BASIS OF THE PROGRAMME DESIGN

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STATISTICAL EVALUATION OF DATA ON THE BASIS OF THE PROGRAMME DESIGN

1. INTRODUCTION

As opposed to the main body of the report, Appendix VI reproduces the complete analysis of variance for all data on the basis of the statistical design. Although the complete analysis of data provides additional information, the main conclusions pertaining to the purposes of the cooperative programme are not substantially modified. The examination of the tables relative to the complete analysis of variance reveals the following features as to the significance of the various variability sources:

- The effect of replication is in all cases not significant
- The interaction between replicates and stresses or replicates and laboratories is not significant
- The interaction between stresses and laboratories approaches statistical significance, although the significance level is generally below 95%*.
- The values of residual variance derived from the complete analysis are generally smaller, with fewer degrees of freedom, than the residual variance calculated by pooling together the interactions.

2. LOG RUPTURE TIME

Table I reproduces the analysis of variance for 11 option "C" laboratories. The interlaboratory variability is significant.

In Table II the laboratory means are ranked in the decreasing order and the statistically homogeneous groups of laboratories revealed by Duncan's test are shown.

Tables III and IV show similar data for 18 option "A" laboratories. The interlaboratory variability is significant. Table V shows that 13 option "A" laboratories that have not used Cr-Al thermocouples give rise to a non-significant interlaboratory variability.

Tables VI to XI show the analysis of variance of rupture time data adjusted to a common stress and for bar variability. The analysis for the option "A" laboratories shows that interlaboratory variability is significant at the 95% level but not at the 99% one. The 13 laboratories that have not used Cr-Al form two groups of 12 laboratories each.

3. LOG TIME TO 2%, 1% AND 0.5% TOTAL DEFORMATION

Tables XII to XV summarise the results of analysis of variance of time to 2% total deformation option "C" and "A". The interlaboratory variability is highly significant and this is revealed by the large number of statistically homogeneous groups revealed by Duncan's test. In this case the interaction between laboratories and stresses becomes statistically significant.

The same conclusion can be drawn from the analysis of log time to 1% and 0.5% total deformation reproduced in Tables XVI–XIX and XX–XXIII respectively.

4. TOTAL DEFORMATION ON LOADING, ELONGATION AND REDUCTION OF AREA

As shown in Tables XXIV to XXVII, interlaboratory variability for total deformation on loading is significant due to the outlying position of laboratory 19.

Regarding elongation the interlaboratory variability of 11 option "C" laboratories is significant at the 95% level but not at the 99% one (Tables XXVIII–XXIX).

For the 18 option "A" laboratories interlaboratory variability for elongation is not significant (Table XXX).

The interlaboratory variability for reduction area of 11 option "C" laboratories is significant (Tables XXXI and XXXII). However the values of reduction of area of 18 option "A" laboratory are statistically homogeneous.

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* This is indicative of poor reproducibility of stress levels at different laboratories.

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5. RECAPITULATIVE TABLES

Table XXXIV reproduces the properties of Nimonic-105 determined in the present cooperative programme with the corresponding residual standard deviations.

Tables XXXV and XXXVI summarise respectively, the residual and interlaboratory variances for all the data determined in the cooperative programme.

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TABLE I

Log Rupture Time – 11 Option "C" Laboratories (Unadjusted Data)

CAS RUPLOG A VARIABLE TRAITEE 2

11 LABO RETENUS 3 4 9 10 11 12 13 14 15 16 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.43236

SOURCE OF VARIATION		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	-Labs	0.07648	10	0.00764	2.97666	2.08	2.80
T	-Stresses	27.01301	4	6.75325	2628.34510	2.61	3.83
LT	-Labs & Stresses	0.17330	40	0.00433	1.68623	1.69	
R	-Replicate	0.00033	1	0.00033	0.13063	-	
LR	-Labs x Repl.	0.03224	10	0.00322	1.25477	2.08	
TR	-Stress x Repl.	0.01108	4	0.00277	1.07849	2.61	
LTR	-Residual	0.10277	40	0.00256	1.00000	-	
TOTAL		27.40923	109				

TABLE II

Log Rupture Time – Ranking of 11 Option "C" Laboratories and Statistically Homogeneous Groups

Rank.	Lab.	Mean.
1	10	2.4719
2	16	2.4558
3	12	2.4543
4	19	2.4528
5	4	2.4451
6	14	2.4342
7	13	2.4203
8	11	2.4163
9	15	2.4143
10	3	2.3953
11	9	2.3851

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TABLE III

Log Rupture Time – 18 Option "A" Laboratories (Unadjusted Data)

CAS RUPLOG B VARIABLE TRAITEE 2

18 LABO RETENUS 1 2 3 4 5 6 8 9 10 11 12 13 14 15 16 17 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.60351

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	0.13708	17	0.00806	3.39273	2.28	3.28
T	17.52817	1	17.52817	7374.61275	4.45	
LT	0.08349	17	0.00491	2.06631	2.28	
R	0.00200	1	0.00200	0.84497	-	
LR	0.03941	17	0.00231	0.97555	-	
TR	0.00372	1	0.00372	1.56565	4.45	
LTR	0.04040	17	0.00237	1.00000	-	
TOTAL	17.83430	71				

TABLE IV

Log Rupture Time – Ranking of 18 Option "A" Laboratories and Statistically Homogeneous Groups

Rank	Lab	Mean
1	17	2.6793
2	8	2.6772
3	20	2.6497
4	16	2.6364
5	1	2.6351
6	4	2.6329
7	12	2.6267
8	14	2.6207
9	10	2.6180
10	13	2.6037
11	19	2.5867
12	14	2.5778
13	6	2.5765
14	5	2.5544
15	3	2.5512
16	2	2.5493
17	15	2.5438
18	9	2.5432.

TABLE V

Log Rupture Time – 13 Option "A" Laboratories (Unadjusted Data)

CAS RUPLOG C VARIABLE TRAITEE 2

13 LABO RETENUS 2 3 4 5 6 9 10 11 12 13 14 15 19

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.58349

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		F95	F99
L	0.05460	12	0.00455	2.27577	2.69	4.16
T	12.22145	1	12.22145	6112.24254	4.75	
LT	0.05771	12	0.00480	2.40551	2.69	
R	0.00017	1	0.00017	0.08781	-	
LR	0.02514	12	0.00209	1.04814	2.69	
TR	0.00140	1	0.00140	0.70210	-	
LTR	0.02399	12	0.00199	1.00000	-	
TOTAL	12.38449	51				

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TABLE VI

Log Rupture Time – Analysis of Variance 11 Option "C" Laboratories.
Data Adjusted to a Common Stress (10.5 kg/mm²)
and Corrected for Bar Variability

CAS RUPLOGAA VARIABLE TRAITEE 1

11 LABO RETENUS	3	4	9	10	11	12	13	14	15	16	19
5 TENSIONS RETENUES	1	2	3	4	5						
2 REPLICATES RETENUS	1	2									

GRAND MEAN 3.09426

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		F95	F99
L	0.07174	10	0.00717	3.64298	2.08	2.80
T	0.00399	4	0.00099	0.50761	-	
LT	0.10310	40	0.00257	1.30885	1.69	
R	0.00000	1	0.00000	0.00078	-	
LR	0.02156	10	0.00215	1.09511	2.08	
TR	0.01111	4	0.00277	1.41152	2.61	
LTR	0.07877	40	0.00196	1.00000	-	
TOTAL	0.29030	109				

TABLE VII

Log Rupture Time – Ranking of 11 Option "C" Laboratories
and Statistically Homogeneous Groups (Adjusted Data)

Rank	Lab	Mean
1	10	3.1326
2	16	3.1203
3	19	3.1180
4	12	3.1144
5	4	3.1050
6	13	3.0942
7	14	3.0909
8	15	3.0835
9	3	3.0645
10	9	3.0588
11	11	3.0544

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TABLE VIII

Log Rupture Time – Analysis of Variance 18 Option "A" Laboratories.
Data Adjusted to a Common Stress and for Bar to Bar Variability

CAS RUPLOGAB VARIABLE TRAITEE 1

18 LABO RETENUS 1 2 3 4 5 6 8 9 10 11 12 13 14 15 16 27 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 3.09799

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		F95	F99
L	0.12351	17	0.00726	2.92539	2.28	3.28
T	0.00016	1	0.00016	0.06706	-	
LT	0.04254	17	0.00250	1.00755	2.28	
R	0.00005	1	0.00005	0.02064	-	
LR	0.03728	17	0.00219	0.88310	-	
TR	0.00206	1	0.00206	0.83027	-	
LTR	0.04222	17	0.00248	1.00000	-	
TOTAL	0.24784	71				

TABLE IX

Log Rupture Time – Ranking of 18 Option "A" Laboratories
and Statistically Homogeneous Groups (Adjusted Data)

Rank	Lab	Mean
1	8	3.1709
2	1	3.1515
3	17	3.1503
4	20	3.1434
5	16	3.1300
6	12	3.1210
7	4	3.1149
8	10	3.1124
9	13	3.1091
10	14	3.1033
11	6	3.0819
12	19	3.0810
13	15	3.0602
14	5	3.0598
15	3	3.0556
16	9	3.0485
17	11	3.0370
18	2	3.0320

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TABLE X

Log Rupture Time – Analysis of Variance 13 Option "A" Laboratories.
Data Adjusted to a Common Stress and for Bar to Bar Variability

CAS RUPLOGAC VARIABLE TRAITEE 1

13 LABO RETENUS 2 3 4 5 6 9 10 11 12 13 14 15 19

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 3.07826

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		F95	F99
L	0.04712	12	0.00392	3.17950	2.69	4.16
T	0.00246	1	0.00246	1.99868	4.75	9.33
LT	0.03036	12	0.00253	2.04890	2.69	4.16
R	0.00004	1	0.00004	0.03700	-	-
LR	0.02297	12	0.00191	1.55006	2.69	4.16
TR	0.00091	1	0.00091	0.73985	-	-
LTR	0.01482	12	0.00123	1.00000	-	-
TOTAL	0.11871	51				

TABLE XI

Ranking of 13 Option "A" Laboratories (Adjusted Data)

Rank	Lab	Mean.
1	12	3.1210
2	4	3.1149
3	10	3.1124
4	13	3.1091
5	14	3.1033
6	6	3.0819
7	19	3.0810
8	15	3.0602
9.	5	3.0598
10	3	7.0556
11	9	3.0485
12	11	3.0370
13	2	3.0320

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TABLE XII

Log Time to 2% Total Deformation – 11 Option "C" Laboratories

CAS T2 A VARIABLE TRAITEE 3

11 LABO RETENUS 3 4 9 10 11 12 13 14 15 16 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.20982

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	0.22353	10	0.02235	3.61809	2.08	2.80
T	30.66805	4	7.66701	1240.99674	2.61	
LT	0.51106	40	0.01277	2.06805	1.69	2.11
R	0.00034	1	0.00034	0.05591	-	
LR	0.10349	10	0.01034	1.67523	2.08	
TR	0.00371	4	0.00092	0.15026	-	
LTR	0.24712	40	0.00617	1.00000	-	
TOTAL	31.75732	109				

TABLE XIII

Log Time to 2% Total Deformation – Ranking of 11 Option "C" Laboratories

Rank	Lab	Mean	
1	10	2.2775	
2	16	2.2736	709
3	14	2.2538	746
4	4	2.2303	769
5	13	2.2290	786
6	3	2.2117	799
7	15	2.1980	811
8	12	2.1694	818
9	11	2.1613	826
10	9	8.1570	831
11	19	2.1460	836

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TABLE XIV

Log Time to 2% Total Deformation – 17 Option "A" Laboratories

CAS T2 B VARIABLE TRAITEE 3

17 LABO RETENUS 2 3 4 5 6 8 9 10 11 12 13 14 15 16 17 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.40179

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	0.25240	16	0.01577	6.30753	2.36	3.41
T	19.49993	1	19.49993	7796.69551	-	8.53
LT	0.15005	16	0.00937	3.74986	-	3.41
R	0.00160	1	0.00160	0.64341	-	
LR	0.03599	16	0.00224	0.89939	-	
TR	0.00159	1	0.00159	0.63850	-	
LTR	0.04001	16	0.00250	1.00000	-	
TOTAL	19.98161	67				

TABLE XV

Log Time to 2% Total Deformation – Ranking of 17 Option "A" Laboratories

Rank	Lab	Mean
1	16	2.4097
2	17	2.3614
3	8	2.3605
4	10	2.3235
5	14	2.3121
6	13	2.3087
7	4	2.2713
8	6	2.2669
9	20	2.2494
10	15	2.2296
11	2	2.2200
12	3	2.2182
13	11	2.1812
14	15	2.1762
15	12	2.1716
16	9	2.1408
17	19	2.0652

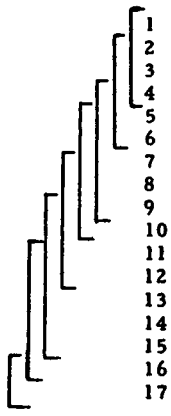

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TABLE XVI

Log Time to 1% Total Deformation – 11 Option "C" Laboratories

CAS T1 A VARIABLE TRAITEE 4

11 LABO RETENUS 3 4 9 10 11 12 13 14 15 16 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.04955

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	0.91190	10	0.09119	4.96794		2.80
T	32.67116	4	8.16779	444.96907		3.83
LT	1.44136	40	0.03603	1.96308	1.69	2.11
R	0.01122	1	0.01122	0.61166	-	
LR	0.22663	10	0.02266	1.23465	2.08	
TR	0.02850	4	0.00712	0.38821	-	
LTR	0.73423	40	0.01835	1.00000	-	
TOTAL	36.02504	109				

TABLE XVII

Log Time to 1% Total Deformation – Ranking of 11 Option "C" Laboratories

Rank	Lab	Mean
1	16	2.1763
2	10	2.1385
3	14	2.1143
4	13	2.1027
5	4	2.0674
6	3	2.0571
7	11	2.0146
8	12	2.0114
9	15	2.0030
10	9	1.9948
11	19	1.8170

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TABLE XVIII

Log Time to 1% Total Deformation – 17 Option "A" Laboratories

CAS T1 B VARIABLE TRAITEE 4

17 LABO RETENUS 2 3 4 5 6 8 9 10 11 12 13 14 15 16 17 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 2.25108

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F96
L	0.51255	16	0.03203	7.56980		3.41
T	20.90342	1	20.90342	4939.44618		8.53
LT	0.21458	16	0.01341	3.16911	2.36	3.41
R	0.00047	1	0.00047	0.11260	-	
LR	0.04344	16	0.00271	0.64158	-	
TR	0.00423	1	0.00423	1.00143	4.49	
LTR	0.06771	16	0.00423	1.00000	-	
TOTAL	21.74643	67				

TABLE XIX

Log Time to 1% Total Deformation – Ranking of 17 Option "A" Laboratories

Rank	Lab	Mean
1	16	2.4097
2	17	2.3614
3	8	2.3605
4	10	2.3535
5	14	2.3121
6	13	2.3087
7	4	2.2713
8	6	2.2669
9	20	2.2494
10	15	2.2296
11	2	2.2200
12	3	2.2182
13	11	2.1822
14	5	2.1762
15	12	2.1716
16	9	2.1408
17	19	2.0652

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TABLE XX

Log Time to 0.5% Total Deformation – 11 Option "C" Laboratories

CAS TOS A VARIABLE TRAITEE 5

11 LABO RETENUS 3 4 9 10 11 12 13 14 15 16 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 1.79606

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	3.86379	10	0.38637	8.26366		2.80
T	37.12992	4	9.28248	198.52825		3.83
LT	4.31583	40	0.10789	2.30761		2.11
R	0.05880	1	0.05880	1.25763	4.08	
LR	0.34089	10	0.03408	0.72908	-	
TR	0.11832	4	0.02958	0.63266	-	
LTR	1.87025	40	0.04675	1.00000	-	
TOTAL	47.69784	109				

TABLE XXI

Log Time to 0.5% Total Deformation – Ranking of 11 Option "C" Laboratories

Rank	Lab	Mean
1	16	2.0249
2	10	1.9375
3	13	1.9303
4	14	1.8991
5	15	1.8257
6	4	1.8054
7	11	1.7977
8	3	1?7959
9	12	1.7677
10	9	1.6995
11	19	1.2724

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TABLE XXII

Log Time to 0.5% Total Deformation – 17 Option "A" Laboratories

CAS TOS B VARIABLE TRAITEE 5

17 LABO RETENUS	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	19	20
2 TENSIONS RETENUES	1	4															
2 REPLICATES RETENUS	1	2															

GRAND MEAN 2.01514

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	1.72458	16	0.10778	10.87888		3.41
T	23.96508	1	23.96508	2418.79495		8.53
LT	0.52180	16	0.03261	3.29163	2.36	3.41
R	0.00010	1	0.00010	0.01078	-	
LR	0.09225	16	0.00576	0.58193	-	
TR	0.01728	1	0.01728	1.74456	4.49	
LTR	0.15852	16	0.00990	1.00000	-	
TOTAL	26.47964	67				

TABLE XXIII

Log Time to 0.5% Total Deformation – Ranking of 17 Option "A" Laboratories

Rank	Lab	Mean
1	16	2.2609
2	18	2.1891
3	17	2.1640
4	10	2.1502
5	13	2.1482
6	14	2.1137
7	15	2.0388
8	6	2.0284
9	2	2.0108
10	4	2.0061
11	20	1.9840
12	11	1.9650
13	5	1.9458
14	12	1.9328
15	3	1.8996
16	9	1.8776
17	19	1.5413

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TABLE XXIV

Total Deformation on Loading – 8 Option "C" Laboratories

CAS TOT A VARIABLE TRAITEE 8

8 LABO RETENUS 3 9 10 11 12 13 14 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 0.11057

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	0.05842	7	0.00834	3.93762	2.33	3.30
T	0.04686	4	0.01171	5.52657		4.02
LT	0.12244	28	0.00437	2.06291	1.84	2.39
R	0.00000	1	0.00000	0.00383	-	
LR	0.00729	7	0.00104	0.49146	-	
TR	0.00608	4	0.00152	0.71770	-	
LTR	0.05935	28	0.00211	1.00000	-	
TOTAL	0.30047	79				

TABLE XXV

Total Deformation on Loading – Ranking of 8 Option "C" Laboratories

Rank	Lab	Mean
1	19	0.1750
2	3	0.1238
3	9	0.1092
4	12	0.1046
5	14	0.1040
6	10	0.0953
7	11	0.0902
8	13	0.0825

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TABLE XXVI

Total Deformation on Loading – 14 Option "A" Laboratories

CAS TOT B VARIABLE TRAITEE B

14 LABO RETENUS 2 3 5 6 8 9 10 11 12 13 14 17 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 0.11003

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	0.11282	13	0.00867	6.63182		3.96
T	0.05205	1	0.05205	39.77742		4.07
LT	0.03368	13	0.00259	1.97972	2.60	
R	0.00002	1	0.00002	0.02054	-	
LR	0.01981	13	0.00152	1.16492	2.60	
TR	0.00070	1	0.00070	0.54143	-	
LTR	0.01701	13	0.00130	1.00000	-	
TOTAL	0.23613	55				

TABLE XXVII

Total Deformation on Loading – Ranking of 14 Option "A" Laboratories

Rank	Lab	Mean
1	19	0.2625
2	5	0.1260
3	3	0.1235
4	8	0.1129
5	17	0.1037
6	6	0.1025
7	9	0.1015
8	12	0.0987
9	14	0.0945
10	20	0.0942
11	10	0.0885
12	2	0.0811
13	13	0.0794
14	11	0.0715

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TABLE XXVIII

Elongation – 11 Option "C" Laboratories

CAS. ELON A VARIABLE TRAITEE 6

11 LABO RETENUS 3 4 9 10 11 12 13 14 15 16 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 16.32636

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	354.90054	10	35.49005	2.66202	2.08	2.80
T	1533.08490	4	383.27122	28.74825	2.61	
LT	476.23308	40	11.90582	0.89302	-	
R	9.36736	1	9.36736	0.70262	-	
LR	203.32163	10	20.33216	1.52506	2.08	
TR	40.38672	4	10.09668	0.75732	-	
LTR	533.27926	40	13.33198	1.00000	-	
TOTAL	3150.57352	109				

TABLE XXIX

Elongation – Ranking of 11 Option "C" Laboratories

Rank	Lab	Mean
1	4	19.2
2	9	18.3
3	15	18.1
4	14	17.0
5	10	16.7
6	13	16.5
7	16	16.1
8	19	15.8
9	3	15.1
10	11	13.7
11	12	13.1

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TABLE XXX

Elongation – 18 Option "A" Laboratories

CAS ELON B VARIABLE TRAITEE 6

18 LABO RETENUS 1 2 3 4 5 6 8 9 10 11 12 13 14 15 16 17 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 15.12361

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F90
L	178.21736	17	10.48337	0.77965	-	-
T	1264.20680	1	1264.20680	94.01928	4.45	
LT	203.64069	17	11.97886	0.89087	-	
R	3.87347	1	3.87347	0.28807	-	
LR	335.55402	17	19.73847	1.46795	2.28	
TR	9.03125	1	9.03125	0.67165	-	
LTR	228.58624	17	13.44624	1.00000	-	
TOTAL	2223.10984	71				

TABLE XXXI

Reduction of Area – 11 Option "C" Laboratories

CAS RA A VARIABLE TRAITEE 7

11 LABO RETENUS 3 4 9 10 11 12 13 14 15 16 19

5 TENSIONS RETENUES 1 2 3 4 5

2 REPLICATES RETENUS 1 2

GRAND MEAN 23.29545

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	502.59072	10	50.25907	6.48382		2.80
T	4145.34363	4	1036.33590	133.69559		3.83
LT	278.69836	40	6.96745	0.89885	-	
R	1.00227	1	1.00227	0.12930	-	
LR	36.27072	10	3.62707	0.46792	-	
TR	5.54363	4	1.38590	0.17879	-	
LTR	310.05835	40	7.75145	1.00000	-	
TOTAL	5279.50770	109				

TABLE XXXII

Reduction of Area – Ranking of 11 Option "C" Laboratories

Rank	Labs	Mean.
1	4	28.1
2	19	25.3
3	10	23.7
4	15	23.6
5	9	23.2
6	13	23.1
7	11	23.0
8	12	23.0
9	14	22.8
10	3	21.5
11	16	18.9

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TABLE XXXIII

Reduction of Area – 17 Option "A" Laboratories

CAS RA B VARIABLE TRAITEE 7

17 LABO RETENUS 1 2 3 4 5 6 9 10 11 12 13 14 15 16 17 19 20

2 TENSIONS RETENUES 1 4

2 REPLICATES RETENUS 1 2

GRAND MEAN 20.83823

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	F95	F99
L	238.07558	16	14.87972	1.76396	2.36	
T	3229.20529	1	3229.20529	382.81654		8.53
LT	139.94970	16	8.74685	1.03692	2.36	
R	4.05235	1	4.05235	0.48039	-	
LR	85.38264	16	5.33641	0.63262	-	
TR	12.02882	1	12.02882	1.42599	2.36	
LTR	134.96617	16	8.43538	1.00000	-	
TOTAL	3843.66058	67				

TABLE XXXIV

Effect of Stress on Creep Rupture Properties of Nimonic-105 and Corresponding Residual Standard Deviations*

Property	20.3	17.2	14.6	12.4	10.5	($S_{residual}$) log S or S	*From*
Time to 0.5% Total Deformation (Hrs)	9.3	26.2	68.6	169.0	400	0.2160 (64.5%)	Regression Analysis and Table XX
Time to 1% Total Deformation (Hrs)	18.2	48.2	120.0	282.0	632	0.1350 (36.5%)	Regression Analysis and Table XVI
Time to 2% Total Deformation (Hrs)	26.6	72.5	179.0	404.0	849	0.0785 (19.8%)	Regression Analysis and Table XII
Time to Rupture (Hrs)	48.5	128	303	643	1250	0.0506 (12.4%)	Regression Analysis and Table I
Total deformation on loading, pct.	0.1299	0.1476	0.0982	0.0968	0.0824	0.0459 (V = 41.5%)	Option "C", Table XXIV
(without Lab.19)	0.1306	0.1151	0.1068	0.0839	0.0728		
Elongation, pct.	21.1	19.4	16.6	13.5	10.9	3.65 (V = 22.4%)	Option "C", Table XXVIII
Reduction of Area, pct.	31.2	28.2	23.8	19.2	13.6	2.78 (V = 11.9%)	Option "C", Table XXXI

* Expressed in percent for Times to Rupture on Specified Total Deformation

$$S^2_{residual} = S^2_{intralab.} + S^2_{material}$$

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TABLE XXXV

Residual* Variances

Property	*OPTION "C"*					*OPTION "A"*				
	Log Variance	d.f.	Log S	*% Hrs*	*Table*	*Log Variance*	d.f.	Log S	*% Hrs*	*Table*
Time to Rupture	0.00256	40	0.0506	12.4	I	0.00237	17	0.487	11.9	III
Time to Rupture (Adjusted)	0.00196	40	0.04427	10.7	VI	0.00248	17	0.0498	12.2	VIII
Time to 2% Total Deformation	0.00617	40	0.0785	19.8	XII	0.00250	16	0.05	12.0	XIV
Time to 1% Total Deformation	0.01835	40	0.135	36.5	XVI	0.00423	16	0.065	16.2	XVIII
Time to 0.5% Total Deformation	0.04675	40	0.216	64.5	XX	0.00990	16	0.0995	25.8	XXII
	Variance	d.f.	*St. Dev.*	V%	*Table*	*Variance*	d.f.	*St. Dev.*	V%	*Table*
Total Deformation on Loading	0.00211	28	0.0459	41.5	XXIV	0.00130	13	0.03605	32.7	XXVI
Elongation	13.33198	40	3.651	22.4	XXVIII	13.4462	17	3.67	24.3	XXX
Reduction of Area	7.75145	40	2.78	11.9	XXXI	8.4354	16	2.90	13.9	XXXIII

* $S^2_{residual} = S^2_{intralab.} + S^2_{material}$

V: Coefficient of variation (standard deviation/grand mean).

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TABLE XXXVI

Interlaboratory Variances

Property	*OPTION "C"*					*OPTION "A"*				
	Log Variance	d.f.	Log S	%	*Table*	*Log Variance*	d.f.	Log S	%	*Table*
Time to Rupture	0.000508	10	0.02254	5.3	I	0.00142	17	0.0377	9.1	III
						0.00064	12	0.0253	6.0	V
Time to Rupture (Adjusted)	0.000521	10	0.02282	5.4	VI	0.00119	17	0.0345	8.3	VIII
						0.00067	12	0.0259	6.1	X
Time to 2% Total Deformation	0.001618	10	0.04022	9.7	XXII	0.00332	16	0.05762	14.2	XIV
Time to 1% Total Deformation	0.00728	10	0.0853	21.7	XVI	0.00695	16	0.0834	21.2	XVIII
Time to 0.5% Total Deformation	0.0339	10	0.184	52.8	XX	0.02447	16	0.1564	43.4	XXII
	Variance	d.f.	*St. Dev.*	V%	*Table*	*Variance*	d.f.	*St. Dev.*	V%	*Table*
Total Deformation on loading	0.000523	7	0.02287	21	XXIV	0.00184	13	0.0429	39	XXVI
Elongation	2.2158	10	1.49	9	XXVIII	0.	17		–	XXX
Reduction of Area	4.2507	10	2.06	9	XXXI	1.6111	16	1.27	6	XXXIII

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