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WAR METALLURGY DIVISION

Final Report

on

IMPROVEMENT IN GUN STEEL INGOT PRACTICE (OD-34-3): PART II - PLANT EXPERIMENTS

by

[illegible], J. W. SPRETNAK, AND C. F. SAWYER
CARNEGIE INSTITUTE OF TECHNOLOGY

OSRD No. 5438

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August 13, 1945

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August 13, 1945

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Final Report on "Improvement in Gun Steel Ingot Practice (OD-34-3): Part II - Plant Experiments"

The attached final report submitted by R. F. Mehl, Technical Representative on NDRC Research Project NRC-39, has been approved by representatives of the War Metallurgy Committee in charge of the work.

The first section of this report presents a comparison between the bore quality of experimental seamless gun tubes made from ingots cast in a standard 20" x 23" ingot mold and those cast in the same mold with a carbon insert in the bottom. The second section compares the quality of the steel in basic open hearth ingots cast by direct pouring through a 2" nozzle and by basket pouring through 1½" and 1-3/4" nozzles.

I recommend acceptance as a satisfactory final report on a phase of the work under Contract OEMsr-755 with the Carnegie Institute of Technology.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division

Enclosure

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PREFACE

This report is pertinent to the problems designated by the War Department Liaison Officer with NDRC as OD-34-3, and to the project designated by the War Metallurgy Division as NDRC Research Project NRC-39.

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FINAL REPORT

OF

RESEARCH PROJECT NRC-39 (OEMsr-755)
IMPROVEMENT IN GUN STEEL INGOT PRACTICE

PART II - PLANT EXPERIMENTS

June 15, 1945

From: Metals Research Laboratory
Carnegie Institute of Technology

Report Prepared by: R. F. Mehl
J. W. Spretnak
C. F. Sawyer

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ABSTRACT

The first section of the report summarizes the comparison between the bore quality of experimental 40 mm seamless gun tubes made from ingots cast in a standard 20" x 23" ingot mold and in the same mold with a carbon insert in the bottom. The work was done on basic electric gun steel, although it was originally planned for the basic open hearth practice. In the latter practice the rejections of seamless gun tubes for bore defects from the bottoms of ingots was twice the combined rejections for tubes from the middles and tops of ingots. Previous work by NRC-39 has indicated that the high rejections of the bottom tubes was not primarily due to non-metallic inclusions but rather to the inherent weakness of the structure of this part of the ingot. This weakness was thought to be associated with the "cone of the solidification" formed by solidification from the mold walls and from the bottom of the mold. The object of the carbon insert was to restrict this cone in the portion of the ingot which is normally cropped off.

The use of the carbon insert was successful in greatly restricting the cone of solidification. However, because of the absence of internal laps in tubes made from this heat of basic electric steel, no comparison was obtained on the hot working characteristics of these two types of ingots. On the basis of the distribution of small non-metallic inclusions, the special ingots were superior in the bottom and next to bottom cuts, while the standard ingots were superior in the third cut from the bottom (eight cuts per standard ingot and seven per special ingot). Thus it appeared that the use of the carbon insert brought about a redistribution of non-metallics in the bottom half of the ingot. The top half of the ingot was unchanged in this respect by the carbon insert.

Further work on the use of insulating inserts in ingots for seamless gun tubes with the basic electric practice of Producer B does not appear to be warranted. However, in the event of a return to the former basic open hearth practice the insulated bottom ingot mold is probably a step in the right direction because of the changes in ingot structure as observed in this experiment.

The second section of the report summarizes a comparison of steel quality in basic open hearth ingots for 75 mm M-3 gun tubes cast by direct pouring through a 2" nozzle and by basket pouring through 1 1/2" and 1 3/4" nozzles. A 1 1/2" nozzle in basket pouring is too small for casting a large open hearth heat. The change from direct to basket pouring did not significantly change the macro quality, micro cleanliness, transverse ductility, or bore quality (bore defects).

SECTION A - PLANT INGOT EXPERIMENT

1. Introduction

This is a final report on the plant experiments which were conducted as part of the program of NDRC Research Project NRC-39. This project was carried out under the general supervision of the War Metallurgy Committee and under the immediate supervision of Jerome Strauss, Research Supervisor for Gun Steel Research, War Metallurgy Committee.

Previous studies by NRC-39 have demonstrated the inferior performance of bottom thirds of ingots in the production of seamless gun tubes(1). The tubes processed from ingot bottoms contributed more than two thirds of the total rejections for bore defects. NRC-80 has demonstrated the high frequency of occurrence of quench cracking in the 75 mm seamless gun tubes processed from the bottom thirds of ingots(2).

There are other examples of inferior performance of ingot bottoms in processing or in performance in which the material is subjected to complex stresses. Thus it appears that ingot bottoms are inherently less able to withstand imposed stresses than are the other parts of the ingot. Studies have indicated that this inherent weakness appears to be related initially to the primary crystal structure of the ingot. Decreasing cleanliness of the steel seems to accentuate this weakness, probably because of the location of non-metallics in planes of weakness in the primary structure. Processing of the solidified ingot also seems to affect the quality of the bottom thirds of ingots for seamless gun tubes(3).

The primary structure of ingots cast into a closed bottom cast iron mold is a result of solidification from the walls and from the bottom of the ingot. The result of this directional heat abstraction is a directionality in the growth and therefore the properties of the steel, evidenced by columnar crystals and by less perfect alignment for some distance beyond the columnar zone. The directionality from the bottom of the mold is accentuated by the undercooling at this position, due mainly to the fact that the air gap is least

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(1) Final Report, "Improvement in Gun Steel Ingot Practices (OD-34-3): Part I - Statistical and Laboratory Studies", OSRD No. 4122, Serial No. M-343, issued as of August 28, 1944.

(2) Progress Report "Prevention of Cracking in Gun Tubes (OD-34-3)", OSRD No. 4567, Serial No. M-406, issued as of January 13, 1945.

(3) Final Report "Control of Basic Open Hearth Melting Practice for the Manufacture of Wrought Gun Tubes (OD-34-3)", OSRD No. 4497, Serial No. M-420, issued as of December 19, 1944

effective at this position. The inherent weakness of ingot bottoms appears to be due to the intersection of the directional growth from the bottom and from the walls of the mold, forming the "cone of solidification" observed in ingot sections.

From these considerations it was decided to cast several experimental ingots in molds with carbon inserts in the bottom, which were to be processed into seamless gun tubes. The inserts were to decrease the rate of heat abstraction through the bottom of the mold, thereby decreasing columnar or directional crystallization from the bottom of the mold. It was thought that in this manner the inherent weakness of the bottom could be restricted within the bottom crop.

2. The Original Plans

Arrangements were made with Producer G to cast ingots in molds with carbon inserts using basic open hearth gun steel. Several types of ingots were included in the program. The special ingots (from molds with carbon inserts) were to be processed into seamless gun tubes along with the balance of the heat. Comparison of the ingots was to be made in terms of macro etch tests, mechanical properties, and bore inspection of the gun tubes.

Unfortunately before the experimental ingots could be poured, an order was issued to the effect that future gun steels were to be made in the basic electric furnace. Accordingly, new plans had to be formulated for the experiment. Although it was not known how basic electric steel would perform in seamless gun tube production, it was felt that this study would be equally instructive for electric steel as it would be for open hearth steel.

3. The Experiment

At the time, Producer B was melting basic electric gun steel for the production of 40 mm seamless gun tubes. Arrangements were next made with this producer to cast several special ingots to be processed into gun tubes with the balance of the heat. The comparison between the regular and special ingots was to be made on the same basis as previously discussed. The ingot used for this gun size was cast in a 20" x 23" x 71 1/2" rectangular plugged-bottom cast iron mold. Figure 1 is a sketch of this ingot mold.

The inserts for the experimental molds were machined from blocks of carbon so as to fit snugly in the bottom of the mold. Carbon was selected in preference to a refractory in order to eliminate the possibility of providing a source of exogenous non-metallic inclusions. The insert proper was three inches thick; calculations indicated that no additional insulating effect would be obtained with greater thickness. The inserts had a projection which extended into the plug hole of the mold. It was thought that this projection would be of aid in preventing the insert from rising in the mold. The thermal conductivity of this material was purported to be approximately 5 BTU/Hr./sq. ft./°F/ft. at room temperature. A photograph of one of the inserts is included in Figure 2.

This method of placing carbon inserts in ingot molds is not recommended for regular plant practice, since it is too cumbersome and costly. The procedure was adopted simply for its expediency in carrying out this experiment. A simple and effective method of obtaining the same effect is the use of open bottom molds with a stool containing a refractory brick insert, as described in a previous report(1) in which Producer M's ingot practice was discussed.

(a) Pouring of the Special Heat

Basic electric heat X63566 was poured into twelve regular 20" x 23" molds and nine molds with carbon inserts. Ingots Nos. 1-4 and 14-21 were standard ingots and Nos. 5-13 were the special ingots. Special ingot No. 13

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(1) Progress Report, "Improvement in Gun Steel Ingot Practices (OD-34-3)", OSRD No. 3347, Serial No. M-209, issued as of February 29, 1944.

was slow cooled by burying in ashes for sectioning and examination of the etched section.

The ladle chemistry was the following:

C	Mn	P	S	Ni	Cr	Mo	Va
0.35	0.75	0.015	0.014	2.44	1.05	0.46	0.11

Other data on the heat were the following:

Tapping temperature	3010°F
Hold in ladle	11 minutes
Pouring temperature	2845°F
Total pouring time	38 minutes
Nozzle size	1 3/4 inches
Holding time before moving ingots	2 hours

(b) Carbon Checks on the Ingots

The carbon content of the ingots was checked for the top and bottom position. The chemical specification called for a carbon range of 0.30 - 0.35%. The results of the carbon checks are listed in Table I.

It is evident that there was an average carbon increase of approximately 0.05% in the special ingots. This carbon increase was rather well distributed throughout the ingot. Examination of the carbon inserts after use indicated that at least 1 1/2 inches of thickness of the insert had spalled off, probably explaining the unusually high and uniform carbon pickup in these special ingots. Although this carbon pickup was undesirable, it was felt that if the special ingots did show an advantage over the standard, then the evidence would be stronger because of this increase in carbon.

(c) Processing of the Ingots

Shortly before Heat 203566 was made, all production of [illegible] gun tubes was discontinued. This action necessitated a change in the procedure for this special heat since it was planned to process the entire heat into 40 mm seamless gun tubes.

It was next decided to process this heat into billets to be used in the production of 37 mm forged and bored gun tubes. This order called for 7 1/2" square billets in multiples of 550#. The minimum yield strength and transverse reduction of area specified was 120,000 psi y.s. and 35% R.T.

The ingots were rolled into 7 1/2" square billets 12' 1/2" long. Two such billets were obtained from each ingot, each of which produced four 550# multiples. Thus there were four 550# multiples from the top half and four from the bottom half of each ingot, with the exception of the special ingots which produced only three bottom multiples because of the use of carbon inserts.

(d) <u>Preliminary Transverse Tensile Tests</u>

In all, bottom sections of four different ingots were tested, two special and two standard ingots, also one top test from each type ingot. After forging all tests from 7 1/2" square to 6" round, one inch and eighteen inch slices were cut, heat treated, and tested. The results are tabulated in Table II.

The results appear to be erratic from ingot to ingot and the standard ingots appear to have some advantage in RAT. The results indicate that this heat had inherent low ductility as a heat characteristic.

(e) <u>Examination of Split Ingot</u>

Special ingot No. 13 was buried in ashes for slow cooling, sectioned longitudinally, machined and etched for examination. Figure 3 is a photograph of the etched section.

The section shows the elimination of the inverted V type segregation at the bottom of the ingot and almost complete suppression of columnar crystallization from the bottom of the ingot with an almost complete restriction of the "cone of solidification". The insert thus had obtained the desired effect.

There was a center line region of porosity starting from about one quarter of the ingot height from the bottom. This porosity was much finer than the typical "herringbone" porosity found in other ingots examined by NRC 39 and consisted of several rather fine lines. No evidence of this porosity was discernable on etch tests from the 7 1/2" square billets, apparently having been welded up by the hot rolling.

(f) Processing of Square Billets into Seamless Tubes

Since the problem of rejections for bore defects was severe in the seamless gun tubes and not in the forged tubes, it was believed that the value of this experiment would be lost if the heat were to be processed into forgings. Accordingly, steps were taken to secure a portion of the heat which would give a good comparison between the two types of ingots, for processing into 40 mm seamless tubes. The piercing was to be done as a special job by Producer A, since seamless gun tube production had been suspended. The tubes were then to be studied for etch quality and for bore quality by means of an ID step down test, examining and noting any bore defects observed through the borescope.

The bottom 7 1/2" square x 12' billet (four 550# multiples) was obtained from standard ingots Nos. 2, 4, 14, 15, 16, and 18 and from special ingots (three 550# multiples) Nos. 5, 6, 8, 10, 11 and 12. In addition the top billet (four multiples) was obtained from special ingots Nos. 5, 6, 8, 10, 11 and 12 as a check on possible deterioration of quality in the top half of the ingots as a result of the use of carbon inserts. Each 550# multiple was sufficient to make a 40 mm experimental seamless tube. A total of 62 such multiples was selected for the special study.

The twelve foot billets were swage forged by Producer B from 7 1/2" square to 6 1/4" round. The rounds were shipped to Producer A where the billets were cut up into the multiples and hot pierced into tubing 4 3/4" OD and 1 1/4" ID as in the regular 40 mm practice. No upsetting was done on the tubes as they were not intended to be made into gun tubes. After this operation there remained 55 tubes, seven being lost because of insufficient length of some of the original billets.

(g) <u>Heat Treatment of Tubes</u>

The tubes were next shipped to Producer F for heat treatment in order to establish a machinability comparable to that of the regular seamless tubes. This was done in order to prevent surface marks on the bore surface due to the action of a poorer machining steel.

The heat treatment consisted of normalizing from 1700°F, water quenching from 1525°F, and tempering at 1150°F. The range desired on yield strength was 100,000-130,000 psi and on Brinell hardness from 241-309.

After heat treatment, a macro etch disc was cut from each tube and the tubes were cut to a length of 100 inches. Brinell hardness readings were taken on each etch disc; the average hardness was 319 with a range of 293-341. A limited number of tensile tests were taken on the tubes with the following results:

Tube No.	Y. S.	T. S.
2B2	135000	152500
4B	137000	157000
5B1	143000	158000
12B	130500	145000
15B3	139000	157500

The tubes were numbered according to ingot number, billet (top A, bottom B), and multiple number. The designation of tubes from an ingot from top to bottom of the ingot would be, for example for ingot No. 2, the following:

2A, 2A1, 2A2, 2A3, 2B, 2B1, 2B2, 2B3. It is evident that the Brinell hardness and yield strength values were somewhat above the desired range. No ductility figures were available from the tensile tests.

The tubes in 100 inch lengths were then shipped to Watervliet Arsenal for machining required in the ID stop down tests.

4. Results

(a) Macro Etch Tests on Heat Treated Tubes

Etch tests made on discs cut from each of the 55 heat treated tubes were examined mainly for evidence of wall breaks in the vicinity of the bore surface.

The etch tests were uniformly good. A few of the tubes showed suggestions of small wall breaks at the bore. They were the following:

Tube No.	Ingot Type	Remarks
4B	Standard	Several small wall breaks out to about 3/8" from bore
4B1	Standard	Suggestion of few small wall breaks within 1/8" of bore
10B	Special	Suggestion of two small wall breaks
11B1	Special	Suggestion of one small wall break 1/8" from bore

The remainder of the tests showed satisfactory etches and no indications of ID wall breaks.

In most cases there was some doubt if the marks observed were actually wall breaks. Because of this doubt and the uniformly good tests, no advantage could be claimed by one ingot type over the other on this basis.

(b) The I.D. Step Down Tests

The main objective of this study was to compare the seamless tubes made from the standard and special ingots on the basis of occurrence of bore defects in the machined bores of the finished gun tubes. Because of the termination of the seamless gun tube program, it became necessary to improvise a procedure which would accomplish the same comparison.

It was decided to machine the bores initially to a diameter of 1.574 inches, which corresponds to the diameter of the tops of the lands in a 40 mm tube. The tubes were bored and ream finished for examination. No rifling or O.D. machining was done on the tubes; a smooth bore was examined in every case. The bores were then carefully examined by means of a borescope and any bore defects were noted and rated as to their severity.

This procedure was repeated for a diameter of 1.619 inches, which corresponds to the diameter of the grooves in a 40 mm tube. The bore surfaces were again examined for defects.

The results of the first bore examination are presented graphically in Figure 4. The ingots which contributed tubes for this study and the multiples of these ingots are here represented. The 55 tubes examined have in the proper positional blocks, rating numbers based on the defects observed. The number is the total of the defects present with their weighting as judged from a classification chart.(1) For example, in a particular tube having three Class I defects and one Class II defect, its index number would be 5. No account was taken as to the position of occurrence along the length of the tube. Those tubes having a rating of zero had no visible bore defect.

The ratings are summarized as follows:

Position	Ingot Type	Average Rating
All Bottom Tubes	Standard	4.0
All Bottom Tubes	Special	5.1
All Top Tubes	Special	3.2

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(1) Revised Progress Report, "Improvement in Gun Steel Ingot Practice (OD-34-3): Classification of Bore Defects in Seamless Gun Tubes," OSRD No. 5052, Serial No. M-336, revised March 20, 1944

defects in the machined bores of the finished gun tubes. Because of the termination of the seamless gun tube program, it became necessary to improvise a procedure which would accomplish the same comparison.

It was decided to machine the bores initially to a diameter of 1.574 inches, which corresponds to the diameter of the tops of the lands in a 40 mm tube. The tubes were bored and ream finished for examination. No rifling or O.D. machining was done on the tubes; a smooth bore was examined in every case. The bores were then carefully examined by means boroscope and any bore defects were noted and rated as to their seve .

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The ratings are summarized as follows:

Position	Ingot Type	Average Rating
All Bottom Tubes	Standard	4.0
All Bottom Tubes	Special	5.1
All Top Tubes	Special	3.2

---

(1) Revised Progress Report, "Improvement in Gun Steel Ingot Practice (OD-34-3); Classification of Bore Defects in Seamless Gun Tubes," OSRD No. 5052, Serial No. M-136, revised March 20, 1944

Position	Ingot Type	Average Rating
Extreme Bottom Tubes	Standard	5.0
" " "	Special	3.2
Next to Bottom Tubes	Standard	4.8
" " " "	Special	3.3
Third from Bottom Tubes	Standard	2.5
" " " "	Special	8.5

On the overall averages for the bottom tubes the standard ingot showed an advantage of one index number. The average of all the top tubes from the special ingots was about one index number lower than that for the standard tubes. This indicated that the use of carbon inserts did not bring about a deterioration of bore quality of tubes made from the top half of these ingots.

Considering the tubes by multiples of the ingot, the extreme bottom tubes showed an advantage of 1.8 index numbers for the special ingots. The tubes from the next to bottom multiples also showed an advantage of 1.5 index numbers for the special ingots. However in tubes made from the third multiples from the extreme bottoms indicated a definite advantage for the standard ingot of 6.0 index numbers. It will be noted that tube 125 had a rating of 17 which accounted for one index number in the average. This tube was checked independently by two observers.

The defects noted in these tubes were all small spots with but a few being judged severe enough to be judged as Class II. They appeared to be due in general to non-metallic inclusions, either exogenous or resulting from the deoxidation process in steelmaking. There was no evidence in any of the tubes of internal laps which were the cause of rejection of many of the seamless tubes as was indicated by the almost complete absence of wall breaks in the etch tests. This indicated that the heat had good hot working characteristics, and by the same token this eliminated the possibility of a comparison of the hot working characteristics of the bottoms of the two types of ingots, which was the primary objective of the experiment. Thus the comparison between the regular and special ingots resolved itself on a basis of defects mainly due to non-metallic inclusions.

The results of the second inspection at a diameter corresponding to the grooves in a 40 mm tube are presented graphically in Figure 5. The results are summarized as follows:

Position	Ingot Type	Average Rating
All Bottom Tubes	Standard	1.25
All Bottom Tubes	Special	1.70
All Top Tubes	Special	0.56
Extreme Bottom Tubes	Standard	1.60
" " "	Special	0.20
Next to Bottom Tubes	Standard	1.33
" " " "	Special	2.50
Third from Bottom Tubes	Standard	1.15
" " " "	Special	2.16

It is immediately evident that the overall frequency of bore defects was considerably less in the second inspection as compared to the first. The average ratings were in general several numbers lower than in the first tabulation for the diameter corresponding to the tops of the lands.

The overall average for the bottom tubes again showed a slight advantage of 0.45 of an index number for the standard ingot. The average index for the tubes from the tops of special ingots was definitely less than that for the bottoms of both ingot types, indicating again that the use of carbon inserts did not bring about a deterioration of bore quality in the tubes from the top half of the ingots.

Considering the results by ingot multiples, the extreme bottom guns showed an advantage of 1.40 index numbers for the inserted ingots. Only one defect was observed in the five bottom guns examined from the special ingots. In the tubes from multiples next to the bottom an advantage of 1.27 index numbers is indicated for the standard ingots. In the tubes from multiples third from the bottom an advantage of 1.0 index number is noted for the standard ingots.

The bore quality generally was excellent. The defects were again small spots due mainly to non-metallic inclusions. The first evidence of internal laps occurred in tube 10B, which had these laps along a four inch length of the tube. This is the only evidence of laps found in the entire study.

The use of the carbon insert apparently has brought about a redistribution of non-metallics in the bottom half of the ingot in addition to altering the crystal structure as discussed earlier in the report. The bottom tubes (2/7 of total height of special ingots) were improved in terms of non-metallics, but the tubes from the third multiples from the bottom were inferior in the special ingots as compared to the standard ingots. This redistribution of non-metallics did not manifest itself in the upper half of the ingot. The absence of internal laps in these tubes indicated that both ingot types had satisfactory hot working characteristics.

The general high quality of the bore surfaces as observed in these studies indicated that basic electric steel melted and processed into rounds with practices as used by Producer B should produce very satisfactory material for the manufacture of seamless gun tubes. This conclusion is substantiated by the record of this steel in the production of 40 mm seamless tubes. Producer B steel was used in the last 25 heats for 40 mm tubes in the seamless program. The overall average rejections for all causes amounted to a remarkably low figure of 0.9%, compared to approximately 15% for basic open hearth steel.

Because of the uniformly good performance of this grade of basic electric steel, it appears doubtful if the use of insulated bottom ingot molds would be warranted in this practice. The performance of basic open hearth ingots in seamless gun tube production demonstrated that the losses of gun tubes from the bottom of ingots was twice the losses of tubes from the middle and top of the ingots. As was previously indicated, these high losses appeared to be associated with the "cone of solidification" which results from directional solidification from the side walls and the bottom of the mold. The present experiment demonstrated that the cone was brought into the section of the ingot that was cropped off by the use of carbon inserts. Although further experimentation on basic electric steel does not appear to be in order, it does seem to be the right step in the event that the previous basic open hearth practice is installed in the production of seamless gun tubes. Other factors may have affected the performance of the open hearth steel such as the different type of ingot mold used (21" round vs 20" x 23" rectangular) and possibly differences in practice in reducing the ingots to rounds for piercing.

5. Conclusions

1. The use of the carbon insert in ingot molds employed in the production of 40 mm seamless gun tubes did bring about the desired decrease in rate of heat abstraction through the bottom of the ingot as evidenced by the almost complete elimination of the columnar growth from the bottom and the absence of the "cone of solidification".

2. Rolled rounds from regular ingots had somewhat higher transverse ductility at a given yield strength. This is not believed to be significant.

3. The etch tests on the heat treated tubes were uniformly good. Suggestions of wall breaks were found only in two tubes from standard ingots and in two tubes from special ingots, but probably none would have been rejected for this reason.

4. The small defects observed in the ID step down tests were mainly the result of non-metallic inclusions. The comparison between the two types of ingots thus was based on distribution of non-metallics rather than on the hot working characteristics, as only one isolated case of internal laps was observed. The rejections at the machiners for these small non-metallic inclusions has been insignificant.

5. The use of the insert improved the bottom two tubes from the ingot, but the tubes third from the bottom from the standard ingots were definitely superior, indicating that a redistribution of non-metallics in the ingot was brought about by the use of the carbon inserts.

6. The carbon inserts did not adversely affect the quality of the tubes made from the top half of the ingot.

7. Basic electric steel made and processed by the practice such as followed by Producer B should furnish very satisfactory material for the production of seamless gun tubes.

SECTION B - PRODUCER C POURING EXPERIMENT

1. Introduction

Heat No. 128366 of basic open hearth Cr-Ni-Mo steel for 75 mm M-3 seamless gun tube application was melted by Producer C to study the effects of nozzle size and of a change from direct to basket pouring on the micro and macro quality, and on transverse ductility of the product so produced.

The following data were obtained by the personnel of Producer C and were made available to NRC-39 through their cooperation.

2. Steel Making

Heat 128866 was melted by Producer C in a basic open hearth furnace. The steel was of the SAE 4335 grade with the following composition: C-0.34, Mn-0.83, P-0.024, S-0.015, Si-0.30, Cr-0.85, Ni-1.87, Mo-0.33.

The full addition of silicon was made in the ladle added as calcium-silicon, amounting to approximately 8 lbs. per ton; 150 lbs. of aluminum, or 1.1 lbs. per ton were also added to the ladle as stick aluminum during tap. The tapping temperature was 3010°F. The cast Jominy hardenability was the following:

Distance	1/16"	1/4"	1/2"	3/4"	1"	1-1/4"	1-1/2"	1-3/4"	2"
Rc	52	52	51	51	51	50	49	49	48

3. Pouring Practice

The ladle was equipped with a 2" nozzle and the basket was equipped with 1 1/2" and 1 3/4" nozzles. The steel was poured in 22" x 25" x 71" ingot molds. Four 75 mm M-3 tubes were obtained from each ingot. The following tabulation shows the ingot number, the nozzle sizes, and teeming time when basket or direct pouring was used.

Ingot No.	Ladle Nozzle Size	Basket Nozzle Size	Teeming Time Minutes
1	2"	1 1/2"	3'
2	2"	1 3/4"	1'
3	2"	1 1/2"	2'
4	2"	1 3/4"	1' 30"
5	2"	1 1/2"	2' 30"
6	2"	1 3/4"	1' 10"

At this time, the ladle stream checked 2900°F and the basket stream 2850°F.

Ingot No.	Ladle Nozzle Size	Basket Nozzle Size	Teeming Time Minutes
7	2"	1 1/2"	2'50"
8	2"	1 3/4"	1'15"
9	2"	1 1/2"	3'
10	2"	1 3/4"	1'15"
11	2"	1 1/2"	3'40"
12	2"	1 3/4"	1'
13	2"	1 1/2"	2'30"

Ingots No. 14 through 30 were poured directly from the ladle because of excessively long holding time in pouring the first 13 ingots through the basket with small nozzles. The total teeming time was 1 hour and 4 minutes.

It was concluded that the 1 1/2" nozzle for basket pouring is definitely too small for casting a large open hearth heat.

4. Effect of Change from Direct to Basket Pouring on Transverse Ductility

Tensile test results are tabulated in Table III for the basket poured ingots, and in Table IV for the ingots poured directly from the ladle. Four guns were obtained per ingot, designated as B, B1, B2 and B3 with the B cut corresponding to the bottom of the ingot. The specification called for a minimum yield strength of 110,000 psi and a minimum transverse reduction of area (RAT) of 35%.

The overall average properties for the two types of ingots are as follows:

Basket Poured	Direct Poured
Y.S. - 113400	Y.S. - 114700
RAT - 47.3	RAT - 49.0

The change from direct to basket pouring did not significantly improve the steel quality with respect to transverse ductility. The difference between the RAT averages of 1.7% as given above is not significant and may be due entirely to sampling error.

5. Etch Quality

According to Producer C macro etch tests on the whole were exceptionally sound. The macroetch ratings on both the blooms and the bars were carefully analyzed by Producer C and it was found that there was no significant difference in macroetch quality between the direct poured and basket poured ingots. This analysis is illustrated graphically in Figure 6. In regard to microcleanliness, the producer reported that there was no apparent difference between the two pouring methods.

6. Bore Quality

Only three tubes from this heat were rejected for bore defects in the final inspection at the machiner. These tubes are listed below with their ingot position and reason for rejection.

Tube No.	Ingot Position	Defect
J717798	No. 8 - Top	Stringers on recoil (OD)
J718093	No. 12- Bottom	Porous metal 4'6"ME at 12:00
J718148	No. 18- Top	Porous metal 5'9"ME at 5:00

Ingots Nos. 3 and 12 were basket poured and Ingot No. 18 was direct poured. Because of the low number of rejections, no conclusions can be drawn as to the effect of the pouring methods on bore quality.

7. **Conclusions**

1. A 1 1/2" nozzle in basket pouring is too small for casting a large open hearth heat.
2. The change from direct to basket pouring did not significantly improve the steel quality with respect to transverse ductility.
3. No significant difference was noted in the macroetch quality of the two types of ingots.
4. No conclusions could be drawn on the comparative bore quality (bore defects) of tubes made from the two types of ingots.

TABLE I

Carbon Checks on Ingots of Heat 263566

Ingot No.	Top Check	Bottom Check	Ingot Type
1	--	0.330 - 0.338	Standard
2	0.350 - 0.354	0.314 - 0.328	"
3	0.348 - 0.350	0.334 - 0.340	"
4	0.342 - 0.346	0.334 - 0.340	"
5	0.392 - 0.398	0.374 - 0.376	Special
6	0.390 - 0.394	0.378 - 0.378	"
7	--	0.380 - 0.386	"
8	0.390 - 0.390	0.372 - 0.378	"
9	0.382 - 0.382	0.366 - 0.368	"
10	0.398 - 0.400	0.398 - 0.400	"
11	0.384 - 0.388	0.363 - 0.363	"
12	0.396 - 0.398	0.366 - 0.368	"
13	--	--	Buried
14	0.344 - 0.346	0.330 - 0.330	Standard
15	0.342 - 0.346	0.326 - 0.330	"
16	0.338 - 0.346	0.336 - 0.338	"
17	0.338 - 0.340	0.334 - 0.334	"
18	0.342 - 0.348	0.330 - 0.332	"
19	0.338 - 0.340	0.324 - 0.332	"
20	0.344 - 0.350	0.328 - 0.332	"
21	0.348 - 0.354	0.324 - 0.326	"

TABLE II

Results of Preliminary Transverse Tensile Tests on Heat E63566

Ingot No. and Type	BHN	0.2% Y.S.	T. S.	% RAT	% El.	Treatment
		A designates top and C bottom				
		6" rd x 1" slices				
C3-Standard	302	135000	149000	20.6	9.5	1625°F-W.Q.
" "	285	130000	142500	9.8	6.5	1550°F-W.Q.
C9-Insert	302	135000	148500	20.6	10.0	1175°F-draw
" "	302	135000	143000	13.4	7.5	1175°F-redraw
		C3 - C9 Retests				
C3-Standard	269	119500	135000	13.4	8.0	
" "	269	120000	134000	13.4	6.5	1625°F-W.Q.
C9-Standard	269	119500	134000	25.8	10.5	1550°F-W.Q.
" "	277	122500	137000	20.6	11.0	1200°F-draw
A11-Insert	285	127000	141000	27.5	14.0	1200°F-redraw
" "	285	126500	141500	37.3	14.0	
C11-Insert	277	126000	139500	17.1	11.0	
" "	285	123500	140500	11.6	8.0	
A17-Standard	277	125000	139000	43.4	16.0	
" "	277	124000	137500	43.4	16.0	
C17-Standard	277	122500	136000	30.9	14.0	
" "	277	122000	136000	18.8	12.0	
		Total Averages of All One Inch Slices				
Standard		124750	138625	24.2		
Insert		127500	141122	21.7		

TABLE II (Continued)

Ingot No. and Type	BHN	0.2% Y.S.	T. S.	% RA	% El.	Treatment
			6" Rounds by 18" Length Treated Solid			
C3-Standard	269	116000	132000	34.1	14.0	
" "	255	112500	127500	18.1	9.5	1625°F-W.Q.
C9-Insert	255	115000	127500	29.2	12.5	1550°F-W.Q.
" "	262	113500	129500	27.5	11.5	1150°F-draw
A11-Insert	311	127500	154500	40.4	13.0	1150°F-redraw
" "	311	122000	151000	41.9	14.5	
O11-Insert	302	126500	141500	20.6	10.0	
" "	302	128500	145000	20.6	10.0	
A17-Standard	302	127000	145500	44.9	14.5	
" "	302	127500	144500	45.3	16.0	
O17-Standard	311	139000	154000	37.3	13.5	
" "	302	132500	149000	35.7	12.0	
			Retests			
A11-Insert	311	136000	154500	37.3	12.5	
" "	311	134000	151000	35.7	12.0	1625°F-W.Q.
O11-Insert	302	131500	148500	20.6	11.5	1550°F-W.Q.
" "	302	129500	146000	22.4	12.0	1125°F-draw
A17-Standard	302	127000	145500	44.9	14.5	1125°F-redraw
" "	302	127500	144500	38.8	14.0	
O17-Standard	302	127000	145000	37.3	13.0	
" "	302	126500	144000	34.1	12.0	
			Total Averages of 6" Round x 18" Long Results			
Standard		126250	143150	37.2		
Inserts		126000	144200	29.6		

TABLE III

Test Results - Heat 128866

Basket Poured

Ingot	Cut	Y.S.	T.S.	R.A.	Fracture	Etch Quality Breech	 Muzzle	Pouring Practice
1	B3	114000	134000	45.7	1/2 C	--	--	Basket - 1 1/2"
		112000	132000	49.7	1/2 C	--	--	" "
1	B	110000	131000	44.4	Irreg.	--	--	" "
		110000	131000	47.7	1/2 C	--	--	" "
2	B1	113000	131000	48.1	1/2 C	Fair	Good	Basket - 1 3/4"
		115000	133000	48.9	1/2 C	small weld area near bore		" "
2	B2	110000	130000	49.7	1/2 C	Fair	Good	" "
		112000	130000	50.1	1/2 C	Incl. near bore		" "
2	B3	116000	133000	44.4	1/2 C	--	--	" "
		114000	131000	44.8	Irreg.	--	--	" "
3	B	112000	130000	46.5	1/2 C	Good	Good	Basket - 1 1/2"
		112000	130000	41.0	Irreg.	Good	Good	" "
3	B1	116000	132000	45.7	1/2 C	Good	Good	" "
		116000	132000	47.3	1/2 C	Good	Good	" "
3	B2	115000	130000	50.5	1/2 C	Good	Good	" "
		115000	132000	50.9	1/2 C	Good	Good	" "
3	B3	114000	131000	45.3	1/2 C	Good	Good	" "
		112000	132000	46.1	1/2 C	Good	Good	" "
4	B1	114000	134000	52.1	1/2 C	--	--	Basket - 1 3/4"
		116000	133000	47.3	F. C.	--	--	" "

TABLE IV

Test Results - Heat 128866

Direct Poured

Ingot	Cut	Y.S.	T.S.	R.T	Fracture	Etch Quality Breech	Etch Quality Muzzle	Pouring Practice
15	B	110000	132000	39.3	Irreg.	--	--	Ladle Direct-2"
		114000	133000	41.0	Shear	--	--	" " "
15	B2	116000	134000	47.3	1/2 C	--	--	" " "
		117000	135000	52.1	1/2 C	--	--	" " "
15	B3	116000	134000	49.7	1/2 C	--	--	" " "
		116000	134000	50.9	1/2 C	--	--	" " "
16	B	116000	133000	49.3	1/2 C	Good	Good	" " "
		117000	134000	52.9	1/2 C	Good	Good	" " "
16	B1	116000	133000	45.7	Irreg.	Good	Good	" " "
		116000	134000	52.5	1/2 C	Good	Good	" " "
16	B2	116000	133000	50.1	1/2 C	Good	Good	" " "
		113000	133000	50.5	1/2 C	Good	Good	" " "
16	B3	116000	133000	46.1	Irreg.	Good	Good	" " "
		115000	133000	52.1	1/2 C	Good	Good	" " "
23	B1	111000	133000	44.4	Irreg.	--	--	" " "
		114000	132000	45.7	Irreg.	--	--	" " "
25	B3	115000	133000	48.9	Irreg.	--	--	" " "
		114000	131000	43.9	Irreg.	--	--	" " "
27	B3	116000	132000	48.9	Irreg.	--	--	" " "
		113000	131000	48.9	1/2 C	--	--	" " "
29	B	113000	131000	41.9	1/2 C	Good	Good	" " "
		113000	131000	50.9	Irreg.	Good	Good	" " "
29	B1	114000	132000	52.1	1/2 C	Good	Good	" " "
		117000	134000	48.1	1/2 C	Good	Good	" " "
29	B2	116000	132000	50.5	1/2 C	Good	Good	" " "
		116000	132000	52.9	1/2 C	Good	Good	" " "
29	B3	112000	132000	49.3	Irreg.	Good	Good	" " "
		115000	133000	52.0	1/2 C	Good	Good	" " "
30	B	116000	135000	51.3	1/2 C	--	--	" " "
		116000	134000	52.1	1/2 C	--	--	" " "
30	B3	111000	134000	52.1	1/2 C	--	--	" " "
		114000	134000	49.7	1/2 C	--	--	" " "

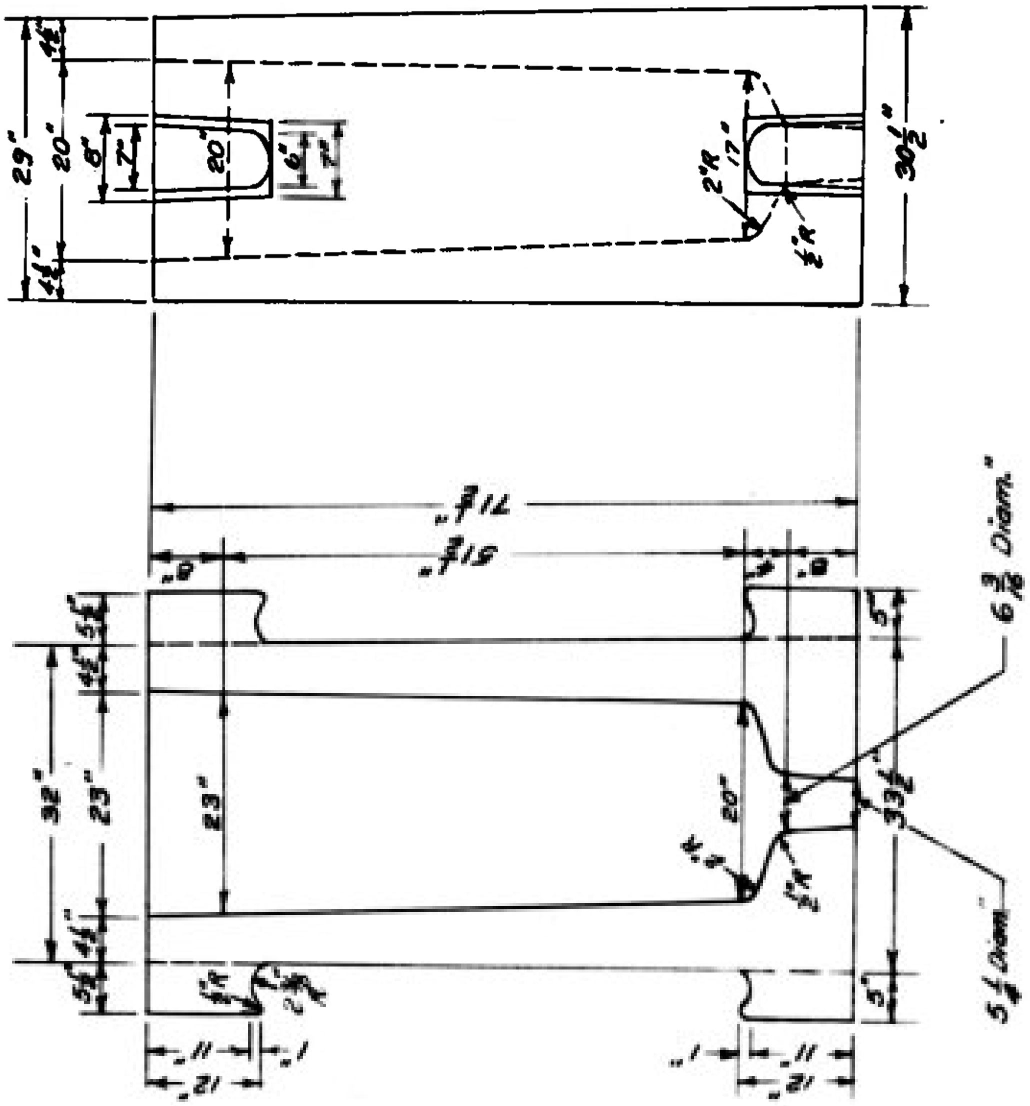

Fig. 1 - Producer B's 20" x 23" x 71 1/2" rectangular mold for gun steels.

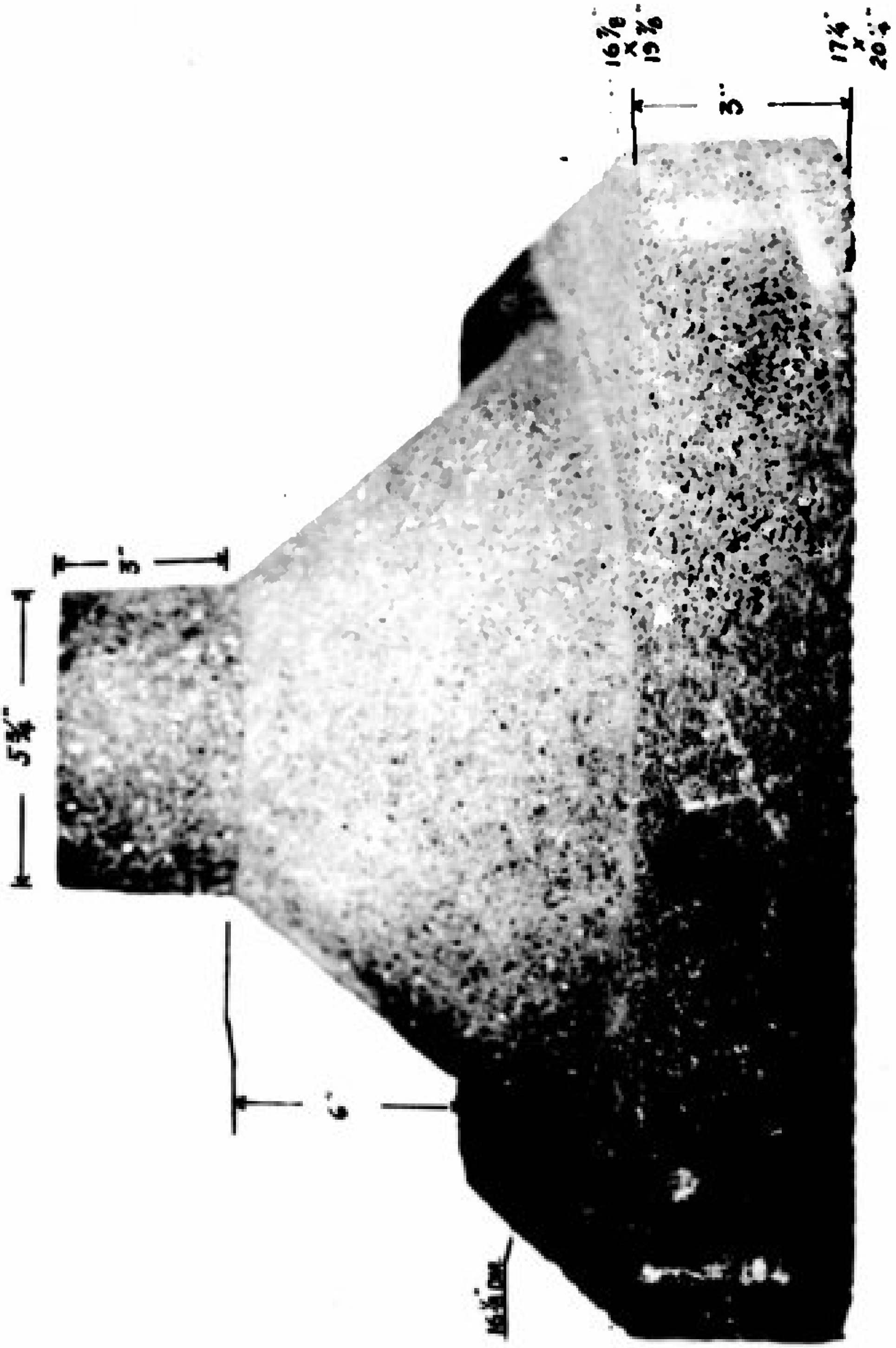

Fig. 2 - Side view of carbon insert.

Fig. 3 - 20" x 23" split ingot from carbon inserted mold. Macroetch.

Standard Ingots

	2	4	14	15	16	18
A						
A1						
A2						
A3						
B		1			0	3
B1	3	3	3	1	4	1
B2	4	6	3	3	6	7
B3	4	3	3	8		7

Special Ingots

	5	6	8	10	11	12
A			6	2	4	
A1	2	5	0	2	3	4
A2	2	6	6	2	2	4
A3	2	3				3
B	5	8	7	3	6	17
B1	4	4	4	3	4	1
B2	4	3	2	4		3

Fig. 4 - Bore quality indices for experimental 40 mm seamless tubes for bore diameter of 1.574 inches.

Standard Ingots

	2	4	14	15	16	18
A						
A1						
A2						
A3						
B		1			0	1
B1	0	1	1	2	3	0
B2	0	2	0	1	3	2
B3	1	0	4	3		0

Special Ingots

	5	6	8	10	11	12
A			0	0	0	
A1	0	1	0	1	0	1
A2	1	2	1	1	1	1
A3	0	0				0
B	1	0	1	5	1	5
B1	5	2	2	1	2	3
B2	0	0	0	1		0

Fig. 5 - Bore quality indices for experimental 40 mm seamless tubes for bore diameter of 1.619 inches.

MACRO ETCH RATINGS

Center

0 - None
1 - Trace of segregation
2 - Medium segregation
3 - Bad Segregation
4 - Trace of Pipe (doubtful
5 - Pipe
6 - Very bad pipe

General

0 - None
1 - Slight General porosity
2 - Few internal seams
3 - Many internal seams
4 - Definite ingot pattern
5 - Bad ingot pattern
6 - Very large pinholes spotty segregation

Sub-Surface

0 - None
1 - Few deep seated pinholes
2 - Few pinholes in outer 1/4"
3 - Many deep seated pinholes
4 - Medium pinholes in outer 1/4"
5 - Many pinholes in outer 1/4"
6 - Ribbon porosity

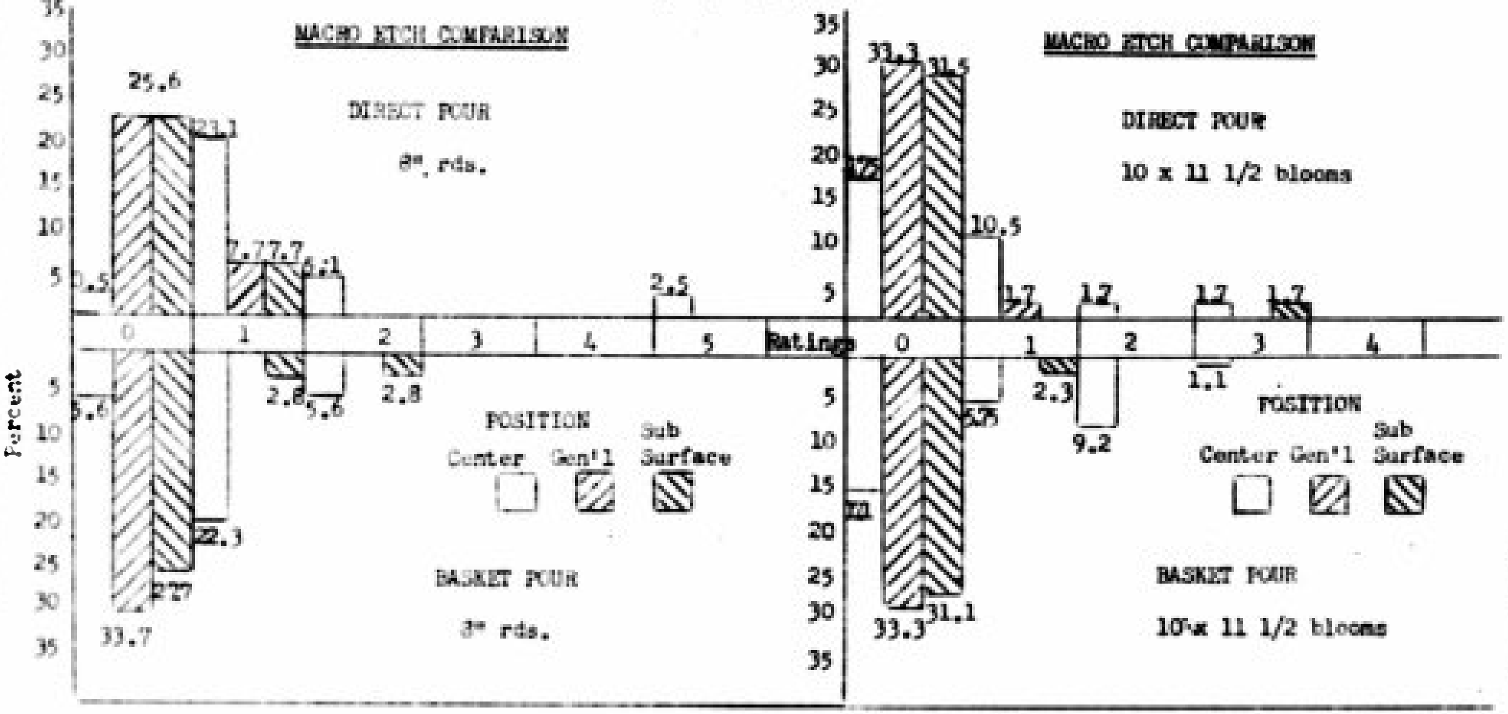

Fig. 6 - Comparison of macroetch quality for the two methods of pouring.

MACRO ETCH RATINGS

Center

0 - None
1 - Trace of segregation
2 - Medium segregation
3 - Bad Segregation
4 - Trace of Pipe (doubtful
5 - Pipe
6 - Very bad pipe

General

0 - None
1 - Slight General porosity
2 - Few internal seams
3 - Many internal seams
4 - Definite ingot pattern
5 - Bad ingot pattern
6 - Very large pinholes spotty segregation

Sub-Surface

0 - None
1 - Few deep seated pinholes
2 - Few pinholes in outer 1/4"
3 - Many deep seated pinholes
4 - Medium pinholes in outer 1/4"
5 - Many pinholes in outer 1/4"
6 - Ribbon porosity

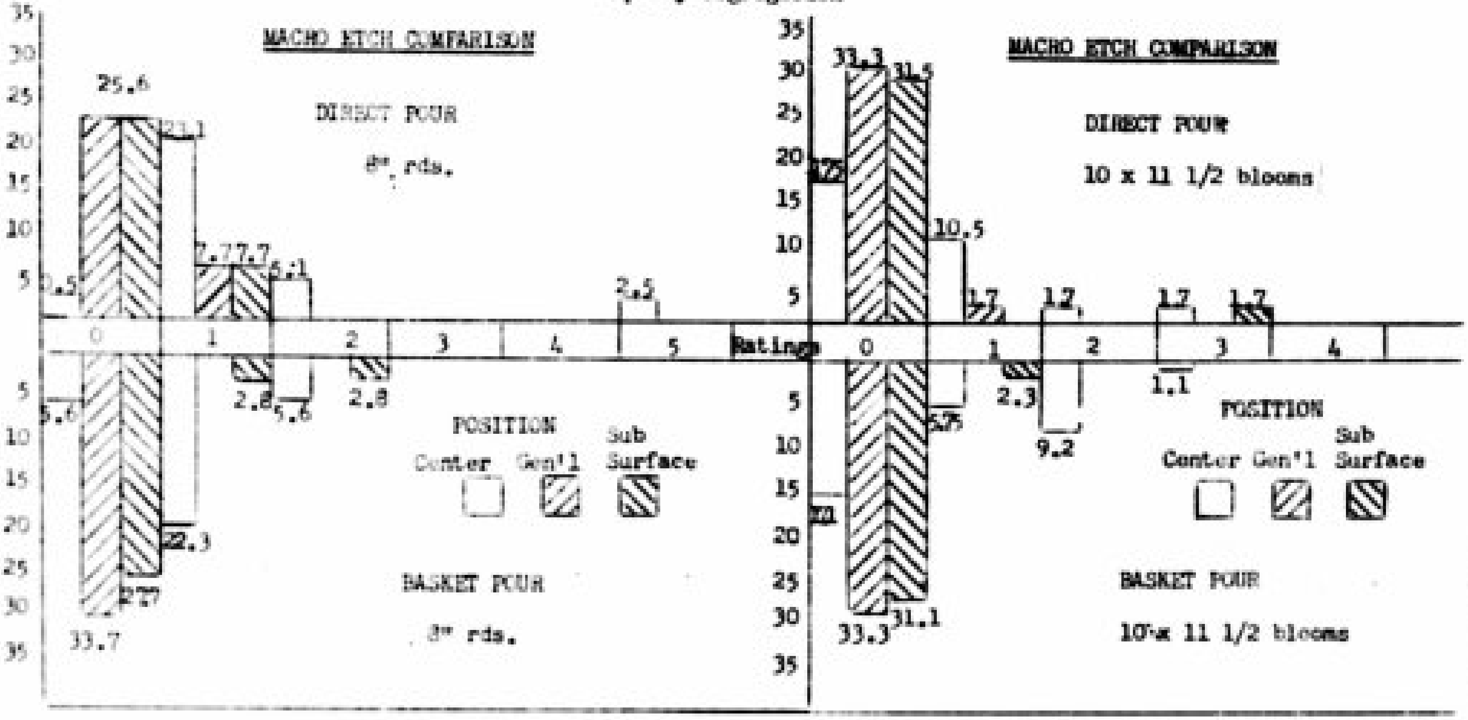

Fig. 6 - Comparison of macroetch quality for the two methods of pouring.

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TITLE: Improvement in Gun Steel Ingot Practice (OD-34-3): Part II - Plant Experiments

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ABSTRACT:

Bore quality of experimental 40 mm seamless gun tubes made from ingots cast in a standard 20 x 23" ingot mold and in the same mold with carbon inserts in the bottom are compared. Previous work indicated that high rejections of the bottom tubes was not primarily due to non-metallic inclusions but rather to the inherent weakness of structure of this part of the ingot, assumed to be associated with the cone of solidification formed by solidification from the mold walls and bottom of the mold. The object of the carbon insert was to restrict this cone in the portion of the ingot which is normally cropped off. The use of the carbon insert was successful in greatly restricting the cone of solidification, and brought about redistribution of non-metallics in the bottom half of the ingot. The top half of the ingot was unchanged in this respect.

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