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Division of Physical Metallurgy  
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Summary Report on the Application  
of the Thermit Process to Production  
of Carbon and Alloy Steel Castings  
for Naval Service

by

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### ABSTRACT

The following improvements have been made in the thermit steel casting process: For casting purposes, a special grade of thermit has been developed which is less violent in its reaction than the welding thermit mixture previously employed. A mounting fixture has been developed which simplifies the operation of the process and makes it more widely applicable. It has also been demonstrated that the thermit class B steels have tensile strength, ductility, fatigue and impact strength, and weldability equal to furnace-melted steels.

It has been found that steels of alloy compositions ranging from carbon-molybdenum steel to 18 percent chromium- 8 percent nickel steel can be readily produced by addition of the appropriate alloying metals to base steel compositions, made from the casting thermit and plain thermit mixture. The alloy steels so produced show normal mechanical properties. They also show structural stability when employed under conditions of elevated temperature and stress. It is indicated that these steels will make satisfactory materials for emergency repair service.

### AUTHORIZATION

1. This work was authorized by Bureau of Ships letters QP/Castings (692-334) of 22 February 1944 and 12 March 1945.

### STATEMENT OF PROBLEM

2. The objects of this work were (1) to improve the thermit steel casting practice as described in NRL Report M-2336 of 28 July 1944 and to test further the products of this practice for serviceability, (2) to determine the practicability of producing alloy steels for castings by application of the thermit process. If the fact were established that the thermit process could be used to produce such alloy steels, work was then to be carried out to determine the most satisfactory procedures for making these alloy steels under field conditions.

### KNOWN FACTS BEARING ON THE PROBLEM.

3. The welding applications of the thermit process have been well established by approximately forty years of use in this country and Europe.<sup>(1)</sup> In an article in the British Journal "Engineering" of 22 July, 1938, a process is described which was developed by Thermoloy's Ltd., for making stainless steel for castings and ingots by the thermit reaction.<sup>(2)</sup> The manufacture of a small heat of 18 percent chromium - 8 percent nickel stainless steel is described with references to "secret powders" and "special reagents".

4. Previous work on this project, initiated in March 1944 and described in NRL Report M-2336 of 28 July 1944, provided a background for the present work.<sup>(3)</sup> Instruction Book No. A856A covering "Recommended Procedures for Making Steel Castings by the Thermit Process Under Field Conditions" was issued by the Naval Research Laboratory in April 1945 and describes the thermit steel casting techniques as developed at that time.<sup>(4)</sup>

### THEORETICAL CONSIDERATIONS

5. The thermit reaction proceeds according to well known principles. A discussion of the theoretical considerations underlying the application of the process is presented in NRL Report M-2336. One of the most obvious characteristics of the thermit steel-making process is the tremendous amount of superheat acquired by the steel in the course of its production.

Although the temperatures developed vary to a certain extent with the size of the heat, the tapping temperatures for 100 pound melts of steels produced from the casting grade of thermit are in the neighborhood of 3800°F, those from the welding thermit about 4200°F, and those from the plain thermit mixture are in the neighborhood of 4500°F. Since these large amounts of superheat above the usual pouring temperatures for cast steel (approximately 2900°F) are obtained, it was believed that the thermit steel could be alloyed to a considerable extent without danger of chilling the metal below a satisfactory pouring temperature. This high superheat presented an additional problem in the matter of molding sand. It was found by the previous tests that the synthetic molding sand mixture developed at this Laboratory produced castings with good surfaces at pouring temperatures as high as 3500°F for castings of medium section thickness.

#### NARRATIVE OF ORIGINAL WORK DONE AT THIS LABORATORY

6. Further studies were made on the techniques of thermit casting and on the properties of the thermit class B steel, as described below:

(a). Tests were carried out to determine the reaction characteristics and foundry handling qualities of grades of casting thermit developed by the commercial suppliers. These casting thermit mixtures have been found to be a satisfactory material for general service in producing class B steel. Included in the studies on these materials were observations of reaction characteristics, and the slag condition as well as measurements of the fluidity and physical properties and the determination of the chemical compositions of the steels produced.

(b). To facilitate the making of thermit steel heats aboard ship and at advanced bases, a fixture was designed to support the thermit reaction crucible and the steel ladle as well as to provide a receptacle for the large volume of slag produced in the reaction.

(c). An improved refractory lining material for the thermit reaction crucible was developed. This material has fewer undesirable characteristics than the magnesia-tar refractory originally employed for this purpose.

(d). Notched bar impact tests were carried out at various temperatures on several samples of class B steel produced from casting thermit mixtures.

(e). Fatigue tests were carried out on the class B thermit steels to ascertain if the high residual aluminum content would be detrimental to the endurance limit of the material.

(f). Weldability tests of the thermit class B steel were made in cooperation with the Welding Section and a recommended welding procedure for this steel was developed.

7. Studies were made on methods of producing alloy steels and on the properties of these alloy steels, as described below:

(a). Production of alloy steels;- methods of adding the alloying metals to the base steel were developed and the alloy recoveries from such additions were studied.

(b). The foundry characteristics of these steels were studied and observations of their fluidity and handling qualities were made.

(c). The mechanical properties of the thermit alloy steels were studied by tensile testing of the steels in various conditions of heat treatment.

(d). Micrographic examinations of the thermit alloy steels were carried out to determine if the materials had normal microstructures for their composition.

(e). Studies were made to determine the susceptibility of some of the thermit alloy steels to graphitization when maintained at conditions of elevated temperature and stress for prolonged periods of time.

#### PREPARATION OF MATERIALS

8. The thermit mixtures for these tests were obtained from commercial suppliers. The suppliers maintained control over the particle sizes of the constituent materials. The thermit mixtures available to provide the base steels for these tests were as follows:

Plain Thermit - essentially aluminum and magnetic oxide of iron.

Welding Thermit - Plain Thermit plus 15 percent of mild steel punchings, and one percent of ferromanganese.

Casting Thermit - Plain Thermit plus 30 percent of mild steel punchings, and one percent of ferromanganese.

The approximate average compositions of the steels produced by the above thermit mixtures are shown in Table 1.

9. Thermit Mixtures - Three types of base thermit mixture are available, as described in paragraph 8. These are commercial compositions and are available from two industrial suppliers, Metal and Thermit Corporation of New York, N. Y., and Unexcelled Manufacturing Company of Cambridge, Mass. The alloying materials were standard foundry alloys and required no preparation, except crushing to a convenient size in some cases. It was found that when the alloying metals were in the form of lumps of approximately 1/4 inch to 1/2 inch diameter that the recoveries of the alloys were at a maximum. The alloying materials used were:

Ferrosilicon	(Si = 50%)
Ferromolybdenum	(Mo = 62%)
Ferrochromium, low carbon	(Cr = 71%)
Ferromanganese, high carbon	(Mn = 80%)
Electrolytic nickel	(Ni = 99+%)
Electrolytic copper	(Cu = 99+%)
Ferrotitanium	(Ti = 42%)

#### DESCRIPTION OF EXPERIMENTS

##### General thermit casting practice

10. Development of the casting thermit mixture - Although the preliminary tests, which were described in NRL Report No. M-2336, demonstrated that the welding grade of thermit could be used to produce good quality steel for castings, it was believed that a thermit mixture having a slower, less violent reaction and a greater percentage yield of steel would be more desirable. The Metal and Thermit Corporation carried out experiments at their laboratory and developed a thermit mixture design-

nated as "Thermicast N-1". This material was tested and found to be "too cold"- i.e.,- the temperature developed was so low that the alumina slag was quite viscous and did not drain from the reaction crucible to leave the crucible in satisfactory condition for the next heat. Further work by the Metal and Thermit Corporation resulted in the development of "Thermicast N-2", a thermit mixture designed to produce steel for castings. This mixture composition closely approximates a plain thermit mixture to which 30% of mild steel punchings have been added. Also, the particles of aluminum and iron oxide are somewhat coarser resulting in a slower and less violent reaction than that which is usually associated with the plain thermit mixture. A similar casting thermit mixture, designated "Exocast", was obtained from the Unexcelled Manufacturing Company.

11. The compositions, fluidity and mechanical properties obtained in the production of several typical heats of steel made from "Thermicast N-2", are shown in Tables 2 and 3. The properties of steel made from this composition were found to be well above the specification-requirements for class B steel.

12. Development of fixture for making thermit steel heats. This apparatus was developed at NRL to facilitate the making of thermit steel heats aboard repair ships and at advanced bases. The fixture provides a support for the thermit reaction crucible, the steel ladle and also a catch basin for the slag produced in the thermit reaction. Important considerations in the development of such a fixture were that it should occupy a minimum of space, have a minimum weight, and require the least possible height consistent with safe operation. The space and height limitations were imposed on the apparatus so it could be fitted into the confined spaces and low overhead aboard ship.

13. In its final form, the thermit mounting fixture was designed to be collapsible for ready stowage and transportation and also to contain no loose parts which could be lost in handling. The final design of the apparatus is shown in Plates Nos. 1 - 4. This model weighs 300 pounds and occupies a space of approximately 36 inches x 46 inches x 6 inches when folded. When set up, the fixture requires a space of 36 inches x 36 inches x 60 inches (including the space required by the 8-N thermit reaction crucible). When used with the 8-N reaction

crucible and an extension ring this apparatus can be used to produce thermit heats of 400 pounds of steel. Without the extension ring, the 8-N reaction crucible has a normal capacity of approximately 250 pounds.

14. Improvement of refractory lining material. Although the magnesia-tar refractory supplied by the Metal and Thermit Corporation was satisfactory for the early work on the development of the thermit process, it became apparent that this material had certain disadvantageous characteristics, particularly its friability, its carbonaceous material content which would promote carbon pickup by the steel, and the inconvenience of its application in the lining and baking of reaction crucibles. Tests were carried out using various refractory mixtures and a composition which is essentially magnesium oxide, bonded with sodium silicate, was found to produce the most satisfactory results. The composition of this mixture is as follows:

Periclase	40%
Monoclase (finely ground periclase)	60%
Water glass (commercial sodium silicate solution)	) Sufficient to Bind
Water	

This material, which is similar to the composition used for lining steel ladles at the NRL foundry, has several features which make it more practicable than the magnesia-tar composition. In addition to obviating the features of carbon "pick-up" and friability of the magnesia-tar mixture, it requires no pre-heating before ramming and can be baked at 400°F rather than 800°F as required by the magnesia-tar mixture. Moreover, the objectionable tar fumes are eliminated and there is little danger of burning such a lining while baking it out as is encountered in the tar-bearing material. The new lining material has the further advantage that its components are rather generally available in foundries, while the magnesia-tar mixture is a proprietary material manufactured exclusively by the Metal and Thermit Corporation.

15. The observations of about 40 heats have indicated that the increased mechanical durability of the periclase-monoclase refractory supplies longer service life compared to the magnesia-tar mixture.

16. Notched Bar Impact Tests. Notched bar impact tests were carried out with specimens from five heats of Class B steel made from the casting grade of thermit. Additions of ferrosilicon were made to the ladle in two of the casting thermit heats, to increase the tensile and yield strength of the steel. The increased silicon content resulted in a lowered impact strength but did produce a marked increase in the yield and tensile strengths of the metal. The impact tests were conducted at room temperature (76°F) and at -40°F and indicated that the impact strength of the thermit steel is approximately equal to that usually found in Class B steel. (No Navy specification is available regarding the impact strength properties of this material). The results of the impact tests of the Class B steel are presented in Table 4.

17. Fatigue Tests. These tests were conducted to determine if the high residual aluminum content of the Class B thermit steel made from the casting thermit mixture would have a detrimental influence upon the endurance limit of the material. These tests were carried out using the R. R. Moore rotating-beam fatigue machine, with the standard 0.300 inch gage diameter specimens. The tests were conducted on specimens in the "as-cast" and in the annealed condition and the results obtained show that the thermit steel possesses normal fatigue strength in both conditions. The endurance ratio (endurance ratio is the ratio of the endurance limit to the ultimate tensile strength) in the "as-cast" condition was found to be 0.42 and in the annealed condition was found to be 0.45, based upon tensile strengths of 68,100 psi and 68,750 psi in these respective conditions. The results of these tests are depicted in Plate No. 5. The endurance limit for the as-cast steel was 28,500 psi and for the annealed steel was 31,000 psi.

18. Welding of Thermit Steel. Since it was anticipated that thermit steel castings might be used in welded assemblies and might also require repair-welding, it was considered advisable to study the weldability characteristics of the Class B steel. These tests were carried out with the cooperation of the Welding Section at NRL and were based upon the standard nick-bend test developed by that group. To provide plate specimens for conducting these tests, castings were made in the form of plates 12 inches by 6 inches by one inch. These plates were poured with

steel made from the casting thermit mixture, using the standard practice developed for this thermit mixture. The results of the weldability tests are listed in Table No. 5, and demonstrate that the thermit steel possesses satisfactory weldability characteristics. These data represent the results of tests on 3/4 inch thick plates, machined from the plates cast to one-inch thickness. As a nick-bend angle of greater than 35° for 3/4 inch plates is indicative of satisfactory weldability, the thermit steel is considered to show good weldability characteristics. A recommended welding practice was developed by the Welding Section. This practice is described in paragraph 19 of Instruction Book A856A.

#### Production and Properties of Alloy Steels.

19. The production of alloy steels for castings by application of the thermit process is a rather straightforward procedure and consists essentially in adding the appropriate alloys to plain carbon steel made from one of the three base thermit mixtures described in Paragraph 8. The compositions of the steels produced by these thermit mixtures are presented in Table 1. The selection of the base thermit composition would be based upon two considerations; first, which thermit mixture was available at the activity and second, the amount of alloying material to be added to the base thermit steel. From the first consideration, it is apparent that the development of procedures should be based upon the use of the casting thermit composition wherever feasible since this is the standard material recommended for supply at installations where thermit casting operations are carried out. Since the different thermit mixtures vary considerably as to the temperature developed in their reaction and, hence in the amount of superheat of the steels produced, the higher alloy steels would necessarily be produced from the plain thermit or the welding thermit mixtures. The lower alloy steels could be made from the casting thermit. One of the objectives of this investigation was to establish the limits of alloy addition which could be made to each grade of thermit mixture.

20. A third important consideration was the question of whether the alloy additions should be made to the ladle or the reaction crucible. The factors governing this selection are those of safety, efficiency of recovery, the mixing of the alloy into the base metal and the effect upon the temperature and fluidity of the steel.

21. Carbon-Molybdenum Steel. Five heats of carbon-molybdenum steel were made. This composition consists essentially of plain carbon steel (Navy Class B) to which has been added 0.5% of molybdenum to improve its elevated temperature properties. The casting thermit provides a satisfactory base for the production of this steel since the alloy addition is small. The alloy additions to these heats were made by the following methods: (a) The molybdenum was added as ferromolybdenum (62.8% Mo) to the ladle. After the completion of the thermit reaction, the molten steel in the reaction crucible was tapped on the ferromolybdenum. (b) The molybdenum, as ferromolybdenum, was added to the reaction crucible with the charge of casting thermit.

22. Both of these procedures were found to be satisfactory for the production of carbon-molybdenum steel. For these steels, the molybdenum recoveries ranged from 88 percent to 91 percent and averaged about 90 percent. The chemical compositions obtained in these heats are listed in Table 6A.

23. The casting qualities of the carbon-molybdenum steel, as determined by the fluidity test (using the standard NRL fluidity spiral) are similar to those obtained with the plain carbon steel and are quite satisfactory. The fluidity data are also listed in Table 6A.

24. Tensile tests were conducted to determine the mechanical properties of the carbon-molybdenum steel. The results of these tests (Table 7A) demonstrate that the steel considerably surpasses the requirements of Navy Department Specification 46S33 of 1 September 1939. Average tensile test properties for the thermit carbon-molybdenum steel, in the normalized and tempered condition are as follows:

Yield Strength	50,000 psi
Ultimate Tensile Strength	77,000 psi
Elongation in 2 inches	28%
Reduction of area	53%

The microstructure of this steel which is depicted in Plates Nos. 6 - 9, does not show any abnormal characteristics.

25. Chromium-Molybdenum Steel. Six heats of chromium-

molybdenum steel were made in these tests. The casting thermite was used to provide the base steel for these heats. The steels contained approximately 0.5 percent of molybdenum and chromium in amounts ranging from 0.98 percent to 7.28 percent. Low-carbon ferrochromium (71.33 percent Cr) was used as the source of the chromium and ferromolybdenum as the source of the molybdenum. It was found that the chromium recovery tended to be rather poor when the ferrochromium was added to the reaction crucible and that the chromium should be added to the ladle, whenever practicable. The chromium recoveries ranged from 58 percent to 98 percent. The chemical compositions obtained and the fluidity values found in these chromium-molybdenum steels are listed in Tables 6A and 6B. On the basis of the experience gained in the making of a few heats of this steel, the probable alloy recovery could be estimated and compositions reasonably close to those desired could be produced. The handling characteristics of these steels are comparable to those usually found in furnace-melted steels and the desired fluidity can be obtained by pouring at the proper temperature. The steel possesses sufficient superheat for most foundry requirements. If high fluidity values are required, it is necessary to pour the heat without delay.

26. The mechanical properties of the chromium-molybdenum steel, as measured by the tensile test were found to be approximately the same as those obtained in furnace-melted steels. Comparison data for the furnace-melted chromium-molybdenum steels were obtained from the "Steel Castings Handbook". The tensile test data from these tests are summarized in Table 7A, together with the tensile test properties listed in the "Steel Castings Handbook" for comparable furnace-melted steels. The photomicrographs of these steels (Plates Nos. 10 - 13) indicate normal microstructures for the compositions.

27. Chromium Steel. Two heats of steel containing only chromium, with alloy contents of 3.80 percent and 9.39 percent, were made as part of this test. The heat with the lower chromium content was made by addition of the alloy as low carbon-ferrochromium to the ladle. In one heat in which it was desired to produce a steel containing ten percent chromium, additions of ferrochromium were made to the reaction crucible as well as to the ladle to derive the maximum benefit from the superheat of the thermite steel. The casting grade of thermite was used as the

base for all the chromium steels. In Table 6B is given a summary of the chemical compositions, fluidity values and alloy-recoveries obtained. The chromium recoveries ranged from 63 percent to 67 percent.

28. The mechanical properties obtained from the chromium steels are summarized in Tables 7A and 7B. The values for these properties are comparable with those obtained from similar steels produced by conventional melting practices. The values for this comparison were obtained from the "Steel Castings Handbook".

29. Chromium-Nickel (18-8) Steel. From the information gained in the production of heat A13 (10 percent chromium steel) it was indicated that the approximate limit for alloy additions to the casting thermit is 20 percent of the weight of the steel produced. Therefore, in making a much higher alloy steel, such as the 18 percent chromium - 8 percent nickel corrosion-resisting steel, it was obvious that a thermit mixture producing much more highly superheated steel would be needed. Plain thermit (aluminum and iron-oxide) was selected as the logical material for making the base steel of this heat.

30. The following distribution of the alloying elements was employed: The nickel was charged as the pure metal, in the form of shot, to the reaction crucible. The chromium, as low-carbon ferrochromium, was distributed between the reaction crucible and the ladle. Ferromanganese, ferrosilicon and ferrotitanium were also charged to the ladle. The reaction proceeded somewhat slower than those normally encountered in thermit-steel making and the metal tapped was colder than usual for thermit steel but no difficulty was encountered in making and pouring the heat.

31. The chemical composition of this corrosion-resisting steel is shown in Table 6B, and conforms quite closely to the requirements of Navy Department Specification 46S276 of 1 September 1945, covering corrosion-resisting steel castings. The tensile test properties which are shown in Table 7B, are considerably above those required by that specification. The microstructure of this steel is shown in Plates Nos. 14 - 17, and does not seem to be identical with that found in steel of similar composition as produced in the electric furnace. There

are indications of what may be the delta constituent in the austenitic matrix. The tentative identification of the constituent is supported by the fact that the steel is slightly magnetic.

32. Miscellaneous compositions. Several heats of alloy steels of various compositions were made in order to obtain information concerning as many types of steel as possible.

33. One heat of high-manganese (Hadfield's) steel was made as part of this test. To provide the high superheat necessary for the melting and solution of the large quantity of alloying metal, welding thermit was used as the base thermit mixture. A steel containing 10 to 14 percent of manganese and 1.25% of carbon was desired in this heat. High-carbon ferromanganese was added to the ladle and provided the required manganese and carbon. A manganese recovery of 75 percent and a carbon recovery of 85 percent were obtained. The composition and fluidity obtained are shown in Table 6B. The tensile properties found in this heat are very nearly the same as those found in furnace-melted steel of similar composition. The microstructure of this steel is shown in Plates Nos. 18 and 19 and is the austenitic structure normal for the type. The strain lines, indicated in the austenite grains, are the result of the cold-work involved in cutting the specimen.

34. Five heats of the precipitation-hardening copper steel (Cu = approximately 1.5 percent) were made. The composition was considered to be of possible application for repair service in view of its high strength and yield ratio characteristics compared to Class B steel. Two of these heats were of approximately one pound in size and were made to determine if the addition of copper to the highly superheated thermit steel would be a safe practice. Since those preliminary heats indicated no violent reaction between the copper (as copper metal turnings and shot) and the steel, three full size heats were made. Since the casting grade of thermit was used as the base composition, the carbon content of the steel (0.26 percent) was higher than the 0.10 - 0.15 percent recommended for this composition and the yield and tensile strengths are somewhat higher than usual while the ductility (as measured by elongation and reduction of area) is lower than usual. The chemical compositions, alloy recoveries and fluidity values for these steels are shown in Table 6C. The

tensile properties and hardness values are shown in Table 8B and the microstructure is shown in Plates Nos. 20 and 21. The properties and structure of the steel are normal for the composition.

35. One heat of nickel-chromium steel similar in composition to SAE 3335 steel was made as part of the program but no tests were made of the mechanical properties of the steel due to loss of the specimens.

36. Graphitization Tests. Recent metallurgical and engineering literature has contained numerous references to graphitization of certain types of carbon and carbon-molybdenum steel when employed under service conditions of elevated temperature and stress. These service conditions are encountered in high-pressure steam lines. The graphitization has been reported to take place in the region of welded joints. (Items 5 and 6 of the bibliography present a discussion of this phenomenon). Several metallurgists have expressed the opinion that the susceptibility of steel to graphitization under such conditions is a function of the amount of metallic aluminum remaining in the steel after deoxidation. Metallic aluminum contents of the order of 0.05 to 0.10% have been reported as sufficient to make the steel susceptible to graphitization in the region of welded joints when it is employed at elevated temperatures and pressures for 5,000 to 10,000 hours. In general, this graphitization has been reported to take place along an isothermal plane on the thermal gradient from the weld. Heating of the steel to this temperature in the process of welding is believed to make it susceptible to later graphitization in service. (The temperature to which the steel is heated to make it susceptible to graphitization is a matter of debate). The graphitization has been reported to take place in two patterns in which the graphite appears as dispersed particles or as more or less continuous chains. The chain pattern is considered to be the more dangerous form since it causes a more continuous plane of weakness through the steel.

37. Since the thermit steel may contain as much as 1.5 percent of residual metallic aluminum, which amount is many times that reported to be sufficient to render carbon or carbon molybdenum steel susceptible to graphitization after welding, it was considered desirable to investigate the susceptibility of these steels to graphitization before recommending their use

in such elevated temperature applications as valves and fittings for high pressure steam-lines. Two sets of tests were conducted for this purpose. The first group of tests was carried out to provide a quick check to learn if there was any immediate danger in the use of these thermit steels under the service conditions described. These tests were carried out under conditions in which no stress was applied to the specimens. In the second set of tests, stresses as well as elevated temperatures were employed as test conditions. These tests are described below in more detail.

38. Unstressed Tests. The specimens for these tests were obtained from the test coupons cast for heats A2, A7M and A14. The compositions of these heats are shown in Table 7. The blanks were heat-treated by normalizing (1700°F, three hours, air cool) and tempering (1250°F, three hours, air cool) and were machined to form cylinders 3/4 inch in diameter by 5 inches long. A bead of 25 percent chromium- 20 percent nickel weld metal was laid longitudinally on each specimen. The nature of the weld metal is comparatively unimportant in this test since the essential function of the welding operation is to provide a zone of metal which has been heated to the temperature at which graphitization takes place. Plates Nos. 22 and 23 show the welding of these specimens. The welding conditions were as follows: reversed polarity; speed of travel = 6 inches per minute; 75 amperes; 26 volts. Plate No. 24 shows a typical welded specimen. After welding the test pieces were placed in a muffle furnace and maintained at 1000 degrees F. (This temperature is considerably higher than the maximum temperature at which these steels would be expected to be used in service but was selected because it should provide an accelerated graphitization if this phenomenon were to take place). Specimens from each heat were withdrawn from the furnace after exposure for 100, 200, 400, 800 and 1600 hours respectively and examined to ascertain if graphitization had taken place. The specimens for the examination consisted of two slices, cut transversely through the weld, from each piece. These slices were prepared for study with a metallurgical microscope and were examined at various magnifications as high as 1000 diameters to determine if any graphite had formed. In some cases, inclusions were found which exhibited a form and color similar to that of the microstructural constituent presented as graphite in the literature by the various authors in the field. The use of polarized light provided a means of identifying such structures as inclusions. No

indications of graphite were found in any of the unstressed specimens which were subjected to the test conditions. Photomicrographs of the weld areas and weld-affected base metal of specimens subjected to the 1600 hour test are shown in Plates No. 25 - 27.

39. Stressed Graphitization Tests. These tests were conducted to determine if the thermit alloy steels would graphitize under conditions of stress at elevated temperature. The materials selected for these tests were carbon-molybdenum and chromium-molybdenum steel from heats A18, A19 and A20. The specimens were machined to cylinders, 5/8 inch in diameter by 4 1/4 inches long and a bead of 25 percent chromium- 20 percent nickel weld metal was laid circumferentially around each piece. Since the purpose of the welding operation was not to provide weld metal but to heat the adjacent metal to the temperature at which graphitization is reported to take place, the nature of the weld metal is unimportant. Once the welding had provided the proper thermal gradient in the base metal, it had served its purpose. Since the presence of the weld would be expected to cause the development of a more complicated stress pattern when the specimen was put under tension for the test, the weld metal was machined to the level of the base metal.

40. To provide the tensile stress during the elevated temperature test, the ends of the specimen bars were threaded and the bars were placed in a fixture such as is shown in Plate No. 28. Plate No. 28 also shows typical castings used to provide material for the fixtures. The specimens then acted as bolts. Hexagonal nuts were screwed on each end of the specimens and the nuts were tightened against the resistance of the fixture, to introduce tensile stresses in the specimens. The ends had previously been ground flat and parallel and chromium-plated. The specimens were stressed to approximately one-half the yield strength of the material. From previous tests, the yield strength of the thermit carbon-molybdenum steel had been found to be about 50,000 psi and that of the thermit chromium-molybdenum steel to be about 65,000 psi. By assuming that the value of Young's modulus is 30,000,000 psi for the thermit steel, the stress on the bolt could be computed from the extension of the bolt as the nuts were tightened. The nuts were turned tightly on the specimens until the extension in the length

of the specimens, as measured with micrometer calipers indicated that the desired stress had been developed. A summary of the stress-extension data is presented in Table No. 8. The initial stresses employed were many times higher than those which are encountered in service applications but these higher stresses were used to provide an accelerated graphitization tendency and also to compensate for the anticipated relaxation of the steel under the elevated temperature test conditions. The fixtures and the nuts were also made of thermit steel of composition similar to that of the specimens to eliminate stress effects due to the differential expansion which might take place if the bolt specimens and the fixtures were made of different steels. After the nuts had been tightened on the specimens to provide the desired stresses, the entire assemblies of bolts and fixtures were placed in a muffle furnace and slowly brought to the test-temperature of 1000°F. The tests were conducted for 150, 300, 450 and 600 hours respectively. At the end of each of these times, the power was shut off and the fixtures allowed to furnace-cool to room temperature. When the furnace had cooled, the fixtures were removed. One bolt-specimen was removed from each fixture and its length was measured in the stressed and unstressed conditions to determine the amount of stress remaining in the specimen. After the specimen had been removed from the fixture, it was replaced by a mild steel bolt and nut drawn sufficiently tight to hold the fixture together. The fixtures were then replaced in the furnace and the temperature slowly raised to 1000°F to resume the test.

41. To provide a specimen for microscopic examination, a semi-cylindrical sample was cut from the bolt as shown in Plate No. 29. This sample was prepared for metallographic examination and searched for the presence of graphite as in the unstressed tests. No indications of graphite were found in any of the stressed specimens under the limited conditions of the tests. Plates Nos. 30 - 32, show photomicrographs of the weld areas of the specimens which were subjected to the test for 600 hours.

42. It is realized that these graphitization tests were rather crude but, nevertheless, it is believed that they did serve the purpose of providing a reasonably quick and practical indication of the graphitizing characteristics of these thermit alloy steels. From the limited data obtained, it is indicated

that the thermit alloy steels should be comparatively free from graphitization failures if used for emergency elevated temperature service for limited periods of time. If these steels are to be used at such elevated temperatures for extended periods, further studies should be made to study the long-time microstructural stability under operating conditions.

GENERAL DISCUSSION OF THE APPLICATION OF THE THERMIT PROCESS TO THE PRODUCTION OF STEEL FOR CASTINGS.

43. The thermit process is simple and straightforward in operation. It provides a practical means for producing carbon and alloy steels of a wide range of compositions. These steels are suitable for use in making castings for emergency service in that they possess satisfactory foundry characteristics such as fluidity and sufficient superheat to allow a reasonable handling time before the molds are poured. The molding requirements are comparatively simple in that a synthetic sand, such as that developed at the Naval Research Laboratory, is satisfactory for producing clean, sound castings. The mechanical properties of the thermit steels, as measured by the tensile, notched-bar impact and fatigue tests, show that these steels are generally of a quality such as to meet standard specifications for their composition. While no long-time service data have been received from operating units of the fleet or field units, the mechanical properties found in laboratory tests indicate that the thermit steels should render satisfactory service in machine and structural castings. The results of weldability tests indicate that thermit steel castings (at least in the Class B composition) may be satisfactorily welded for repair or fabrication purposes.

44. The limits of alloy additions to carbon thermit steels for making alloy steel castings have been found to be as follows: The casting thermit will take alloy additions to 20 percent of the weight of the steel produced. The welding thermit will take alloy additions to 35 percent and the plain thermit will take alloy additions to 55 percent of the weight of the steel produced in the reaction crucible in heats of about 50 pound size. These limits represent the total weight of additions which can be made to the reaction crucible as well as to the ladle. As the alloy additions approach these limits, the temperature of the metal in the ladle is reduced to levels below those convenient for pouring and skimming. However, if the size of the alloy steel heat were increased, a smaller percentage of the superheat of

the metal would be lost to the reaction crucible and the ladle and, consequently, it is expected that greater alloy additions could be made to the larger heats.

45. It is believed that some question may arise with regard to the hazards attendant to the use of the thermit process as a steel-making method. In this connection, it may be stated that over 100 heats of thermit steel were made at NRL and that no injury to personnel was sustained in any of these heats. If all materials and equipment are maintained dry and free from contamination with organic materials or volatile metals, it is believed that the thermit process should be no more hazardous than any other steel-making process.

46. The economic aspects of the thermit process as a means for producing steel for castings should be mentioned. At present market prices for the thermit casting mixture, the cost of the plain carbon thermit steel in the ladle is approximately \$0.25 per pound compared to the figure of approximately \$0.02 per pound usually assigned by production foundries to this item. However, the price set by a production foundry is based upon the use of an open-hearth, converter or electric furnace, costing several thousand dollars and used for the melting of millions of pounds of steel. The reaction crucible and mounting fixture employed in the thermit process cost only a few hundred dollars. Therefore, the economic efficiency of the thermit steel-making process compared to conventional steel-making processes is determined by the probable demand for steel castings at the activity. If the probable demand for steel will be on the order of 10,000 pounds, the thermit process in making steel at \$0.25 per pound will have an economic advantage over a conventional melting unit such as a high frequency induction electric furnace. The cost of such a furnace is approximately \$15,000. If this amount must be amortized for the production of 10,000 pounds of steel, there exists an equipment charge of \$1.50 per pound of steel. Moreover, the operation of an electric furnace requires a source of large quantities of electric power and the services of a highly-skilled melter. The thermit process requires no electric power for its operation and an intelligent steel foundry molder can be trained to carry out the process by an instruction period of one week. From this discussion, it should be apparent that the thermit process is an economically

efficient method for producing steel for castings at activities having a comparatively small demand for such castings. It is also economically efficient as a stand-by method for activities having conventional steel-melting equipment, since it may be used in the event of an electric power failure or other emergency.

## CONCLUSIONS

47. Thermit mixtures of various grades can be used to produce a wide variety of carbon and alloy steels for castings.

48. The properties of these steels are such that they should be satisfactory for most naval requirements, at least for emergency service.

49. The equipment required for the operation of the thermit process is comparatively simple and can be largely improvised. No source of electrical or mechanical power is required. Personnel can be readily trained in the application of the process.

## RECOMMENDATIONS

50. It is recommended that thermit steel-making materials and equipment be made available at such activities where emergency steel castings may be required and that Naval foundry personnel be trained to carry out the process for operational and instructional purposes.

51. It is recommended that the experimental data on operating procedure and the properties of the thermit steel be made available to industry for commercial exploitation. This should help to provide the Navy with sources of supply of thermit materials when they are required.

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2. Anonymous, "The Thermoleys Process for the Manufacture of Steel Castings", Engineering, July 22 1938, pp. 110-111, Vol. 146, No. 3784.
3. Naval Research Laboratory Report No. M-2336, "Report on the Thermit Process for the Production of Steel for Castings", July 28, 1944.
4. Naval Research Laboratory Instruction Book No. A856A of April, 1945, "Recommended Procedures for Making Steel Castings by the Thermit Process under Field Conditions".
5. "Graphitization of Low-Carbon and Low-Carbon-Molybdenum Steels" (Discussion) The Welding Journal, June 1945, Vol. 24, No. 6, pp. 350S-359S.
6. "Carbide Instability of Carbon-Molybdenum Steel Piping", R. W. Emerson. Presented at the Annual Meeting of The American Society of Mechanical Engineers, Nov. 29 - Dec 3, 1944.

Table 1

Typical Compositions of the Steels Produced by the Reaction  
of the Plain Thermit, Welding Thermit and  
Casting Thermit Mixtures

<u>Element</u>	<u>Plain Thermit</u>	<u>Welding Thermit</u>	<u>Casting Thermit</u>
Carbon	0.10 percent	0.22 percent	0.26 percent
Manganese	0.10	0.79	0.70
Silicon	0.10	0.18	0.30
Acid Soluble Aluminum	0.10 - 1.00	0.15 - 1.00	0.15 - 1.50
Chromium	0.05	0.05	0.05
Molybdenum	0.05	0.05	0.05
Copper	0.13	0.13	0.13
Nickel	0.09	0.09	0.09
Phosphorus	0.02	0.02	0.02
Sulfur	0.02	0.02	0.02

Table 2

Chemical Compositions and Fluidity Data of Typical Class B Steel  
Heats Made From Casting Thermit Mixtures

Heat No.	Wt. of Steel Made, lbs.	Composition-Percent				Pouring Temp., °F	Fluidity, Inches	Remarks
		C	Mn	Si	Al			
M 48	45	0.24	0.82	0.30	1.16	3050	18	
M 50	75	0.26	0.70	0.30	0.85	3420	37.5	
M 51	50	0.26	0.72	0.21	0.85	3520	40.5	
M 52	125	0.28	0.74	0.99	1.10	3250	30.0	FeSi added to determine effect on physical properties
M 53	175	0.25	0.75	0.81	1.10	3260	29.5	"
F 1	100	0.28	0.66	0.12	0.87	3250	-	Used for fatigue tests
Navy Dept Spec; 49Slj, Class B Steel Castings, requirements*		0.30 max.	0.60 max.	0.50 max.	-			

\*This specification provides that "for each reduction of 0.01 percent carbon below the maximum of 0.30 percent, an increase of 0.025 percent manganese above 0.60 maximum will be permitted but in no case shall the manganese exceed 0.85 percent".

Table 3

Tensile Test Properties of Typical Class B Steel  
Heats Made From Casting Thermit Mixtures

Heat No.	Heat Treatment	Yield Str. p.s.i.**	Ult. Tens. Str. psi	Elongation in 2 in. Percent	Reduction of Area Percent
M 48	(1700°F-2.5 hrs.)	40,150	73,000	33.3	52.5
M 50	Air Cool	38,500	73,100	30.7	47.8
M 51	(1200°F- 2 hrs.)	41,000	74,000	32.2	50.3
M 52	Air Cool	47,500	84,650	26.8	40.0
M 53		44,150	82,350	25.3	40.0
F 1	As Cast	Not Indicated	68,100	24.3	31.3
F 1	1700 F.-2 hrs. Furn. Cool	33,800	68,750	31.7	46.5
*		30,000	60,000	24.0	35.0

\* Requirements of Navy Department Specification 49Slj of February 1, 1939 for Class B steel castings.

\*\* Yield strength determined by "drop of the beam" method.

Table 4

Notched Bar Impact Test Properties of Steels  
Made From Casting Thermit Mixtures

Heat No.	Heat Treatment	Testing Temperature °F.	Mean Value for Energy Absorbed-ft. lbs.
M 50	As Cast	76	24.0
M 51	As Cast	76	25.5
M 52*	As Cast	76	5.5
M 53*	As Cast	76	6.5
M 48	1700°F - 2 hrs. Furnace Cool	76	22.0
M 48	" " " "	-40	5.0
M 48	1700°F - 2 hrs. AirCool 1200°F - 2 hrs. AirCool	76	27.0
M 48	" " " "	-40	9.0
M 50	" " " "	76	24.5
M 51	" " " "	76	39.0
M 52*	" " " "	76	12.0
M 53*	" " " "	76	12.5

All tests were conducted using Charpy V-notch specimens.

\*Heats M52 and M53 contained added silicon.

Table 5

Nick-Bend Weldability Test Data on Steels Made  
From Casting Thermit Mixture

<u>Prior to Welding</u>	<u>Heat Treatment Post Welding</u>	<u>Nick-Bend Performance Angle at maximum load</u>
As cast	Stress Relieved	49°
Annealed (plate specimen)		58°
Annealed	As Welded	34°
Annealed	Stress Relieved	57°
Normalized & tempered	(Plate specimen)	57°
Normalized & tempered	Stress Relieved	60°
Normalized	Stress Relieved	61°

Heat No.	Normal Composition	Weight of Steel (lbs)	Method of Alloy Addition	Chemical Composition Percent										Alloy Recoveries Percent					Pouring Temp. °F	Fluidity Inches	Remarks
				C	Mn	Si	Al	Cr	Ni	Mo	Cu	S	P	Si	Cr	Ni	Mo	Cu			
A1	C Mo (Cr 0.25%) (Mn 0.5%)	50	Ladle	0.24	0.64	0.08	0.98	-	-	0.45	0.16	-	-	-	-	90	-	3020	17		
A2	C Mo (Cr 0.25%) (Mn 0.5%)	50	Reaction Crucible	0.28	0.64	0.10	1.18	-	-	0.53	0.16	-	-	-	-	88	-	3200	-		
A18	C Mo (Cr 0.25%) (Mn 0.5%)	200	Ladle	0.21	0.65	0.16	0.16	0.05	-	0.51	-	0.018	0.018	-	-	92	-	3150	-		
A19	C Mo (Cr 0.25%) (Mn 0.5%)	275	Ladle	0.20	0.55	0.20	0.20	0.05	-	0.50	-	0.017	0.018	-	-	90	-	3100	-		
A22	C Mo (Cr 0.25%) (Mn 0.5%)	125	Ladle	0.26	0.66	0.10	0.84	0.04	0.05	0.51	-	0.013	0.020	-	-	91	-	3200	-		
A7M	CrMo (Cr 4%) (Mn 2.5-0.5%)	125	FeCr to reaction crucible FeMo to Ladle	0.27	0.76	0.11	1.34	3.45	-	0.41	0.11	-	-	-	58	-	68	-	3160	14.5	Made by splitting A7, one half used for straight Cr steel and remainder for Cr-Mo steel. Fe Mo stirred into metal in ladle.
A10	CrMo (Cr 4%) (Mn 0.5%)	75	Ladle	0.27	0.62	0.07	0.90	3.60	-	0.41	-	-	-	-	60	-	68	-	3200	20	
A12	CrMo (Cr 7%) (Mn 0.5%)	75	Ladle	0.23	0.61	0.09	0.69	7.28	-	0.52	-	-	-	-	81	-	87	-	3100	10.5	
A14	CrMo (Cr 1%) (Mn 0.5%)	50	Ladle	0.25	0.73	0.15	1.01	0.98	-	0.71	-	0.010	0.017	-	98	-	95	-	3150	-	Made for unstressed graphitisation tests.

TABLE 6A  
CHEMICAL COMPOSITIONS, ALLOY RECOVERIES, AND FLUIDITY CHARACTERISTICS OF THERMIT ALLOY STEELS

Heat No.	Normal Composition	Weight of Steel (lbs)	Method of Alloy Addition	Chemical Composition Percent										Alloy Recoveries Percent					Pouring Temp. °F	Fluidity Inches	Remarks
				C	Mn	Si	Al	Cr	Ni	Mo	Cu	S	P	Si	Cr	Ni	Mo	Cu			
A17	Cr-Mo (Cr=5%) (Mo=0.5%)	175	Ladle	0.21	0.58	0.16	0.34	6.48	-	0.52	-	0.016	0.016	-	87	-	89	-	3150	-	For stressed graphitization tests
A20	Cr-Mo (Cr=5%) (Mo=0.5%)	50	Ladle	0.25	0.63	0.11	1.25	6.09	-	0.43	-	0.022	0.019	-	82	-	77.5	-	3150	-	For stressed graphitization tests
A70	Cr (Cr=1%)	125	Reaction Crucible	0.26	0.75	0.11	1.35	3.80	-	0.01	0.10	-	-	-	63	-	-	-	3280	28	Made by splitting A7 into 2 parts A7C and A7M
A13	Cr (Cr=10%)	50	Ladle and Reaction Crucible	0.32	0.72	0.14	1.08	9.39	-	0.05	0.10	-	-	-	67	-	-	-	2960	8	
A21	18-8 Corrosion-Resisting (Cr=18%) (Ni=8%)	70	FeCr to reaction crucible & ladle Ni to reaction crucible FeSi, FeMn, FeTi to ladle	0.10	0.56	1.28	0.67	17.8	8.19	-	0.056	0.020	0.017	-	70	84	98	FeMn =80 FeTi =10	3080	20	
A11	Hadfield's Steel (C=1.25) (Mn=13.5%)	50	Ladle High-carbon FeMn to Supply C and Mn	1.21	10.08	0.56	0.11	0.02	-	0.01	-	-	-	-	Mn=75 C=85	-	-	-	2700	8	Welding thermit used as base mixture

TABLE 6B  
CHEMICAL COMPOSITIONS, ALLOY RECOVERIES, AND FLUIDITY CHARACTERISTICS OF THERMIT ALLOY STEELS

Heat No.	Normal Composition	Weight of Steel (lbs)	Method of Alloy Addition	Chemical Composition Percent										Alloy Recoveries Percent					Pouring Temp. °F	Fluidity Inches	Remarks
				C	Mn	Si	Al	Cr	Ni	Mo	Cu	S	P	Si	Cr	Ni	Mo	Cu			
A5	Cu (precipitation-hardening) (Cu=1.35%)	75	Reaction Crucible	0.27	0.61	0.12	0.86	-	-	0.01	1.37	-	-	-	-	-	-	83	3100	32-3/4	
A6	Cu (Precipitation-hardening) (Cu=1.35%) (Mn=1%) (Si=1%)	75	Reaction Crucible	0.26	0.87	0.75	1.41	-	-	0.01	1.63	-	-	58	65	-	-	94	3200	25	
A9	Cu (Precipitation-hardening) (Cu=1.35%)	75	Ladle	0.28	0.65	0.11	0.91	-	-	0.01	1.37	-	-	-	-	-	-	91	3150	26	
A8	NiCr- (SAE 3335 Type) (Ni=3.5%) (Cr=1.5%)	75	FeCr to Reaction Crucible Ni to ladle	0.29	0.67	0.21	0.49	1.10	3.47	0.02	-	-	-	-	63	93	-	-	3080	30	No tensile tests on this heat due to loss of specimens

TABLE 6C  
CHEMICAL COMPOSITIONS, ALLOY RECOVERIES, AND FLUIDITY CHARACTERISTICS OF THERMIT ALLOY STEELS

Heat No.	Nominal Composition	Heat Treatment	Tensile Test				Hardness Test		Tensile Test Properties of Similar Alloy Steel Made by Furnace-Melting Processes					Source of Comparison Data
			Yield Str. psi	Ult. Tens. Str. psi	Elong. in 2 in. Percent	Reduction of Area Percent	A <sub>s</sub> Meas.	BHN Equiv.	Yield Str. psi	Ult. Tens. Str. psi	Elong. in 2 in. Percent	Reduction of Area Percent	Heat Treatment	
A1	C-Mn (C=0.25%) (Mn=0.5%)	1725°F-3 hrs AC 1250°F-3 hrs AC	55,000	77,250	29.0	55.5	-	-	35,000	65,000	20.0	30.0	Annealed	Navy Department Spec. 46833, 9/1/39
A1	C-Mn (C=0.25%) (Mn=0.5%)	Normalized and tempered as above, then 1650°F-3 hrs WQ 1250°F-3 hrs AC	51,250	75,650	30.3	53.3	R <sub>pm</sub> 88.5	177	65,950	94,200	26.0	59.9	1650°F,WQ 1200°F,AC	Steel Castings Handbook
A2	C-Mn (C=0.25%) (Mn=0.5%)	1725°F-3 hrs FC	49,900	79,500	27.5	53.0	-	-	See A-1					
A10	Cr-Mn (Cr=4%) (Mn=0.5%)	1780°F-3 hrs AC 1250°F-3 hrs AC	80,000	106,250	20.3	54.6	E <sub>g</sub> 98.0	220	80,800	111,000	20.5	48.2	1700°F-AC 1200°F-AC	Steel Castings Handbook
A12	Cr-Mn (Cr=7%) (Mn=0.5%)	1780°F-3 hrs AC 1250°F-3 hrs AC	82,400	110,000	18.5	41.4	-	-	77,350	106,500	18.0	45.2	1700°F-AC 1200°F-AC	Steel Castings Handbook
A14	Cr-Mn (Cr=1%) (Mn=0.5%)	1725°F-3 hrs AC 1250°F-3 hrs AC	Not Indicated	101,250	15.8	38.3	R <sub>pm</sub> 98.0	220	80,000	100,000	26.0	40.0	1650°F-AC 1200°F-AC	Steel Castings Handbook
A7C	Cr (Cr=4%)	1725°F-3 hrs AC 1250°F-3 hrs AC	63,750	101,500	20.8	54.4	R <sub>pm</sub> 98.0	220	75,000	103,500	19.0	44.0	1800°F-AC 1400°F-FC	Steel Castings Handbook
A7C	Cr (Cr=4%)	Normalized and tempered as above, then 1650°F-3 hrs WQ 1250°F-3 hrs AC	66,250	75,750	28.8	61.4	R <sub>pm</sub> 88.0	174	Not Available for Similar Composition					

AC - Air cooled  
FC - Furnace cooled  
WQ - Water Quench

AC - Air cooled  
FC - Furnace cooled  
WQ - Water quench

TABLE 7A  
PHYSICAL PROPERTIES OF THERMIT ALLOY STEELS TOGETHER WITH THE PHYSICAL PROPERTIES  
REPORTED FOR SIMILAR ALLOY STEELS PRODUCED BY FURNACE MELTING PROCESSES

Heat No.	Nominal Composition	Heat Treatment	Tensile Test				Hardness Test		Tensile Test Properties of Similar Alloy Steel Made by Furnace-Melting Processes					Source of Comparison Data	Remarks
			Yield Str. psi	Ult. Tens. Str. psi	Elong. in 2 in. Percent	Reduction of Area Percent	As Meas.	BHN Equiv.	Yield Str. psi	Ult. Tens. Str. psi	Elong. in 2 in. Percent	Reduction of Area Percent	Heat Treatment		
A13	Cr (Cr=10%)	1600°F-4 hrs FC 1780°F-3 hrs AC 1250°F-3 hrs AC	66,750	94,500	21.8	48.2	R <sub>pm</sub> 96.0	212	73,000	117,000	18.0	35.0	1800°F-AC* 1200°F-AC	Steel Castings Handbook	*Contains 13.87% Cr
A21	18% Cr- 8% Ni Corrosion Resisting	As Cast	37,150	76,250	30.8	33.5	R <sub>pm</sub> 79.0	143					Not Available		
A21	18% Cr- 8% Ni Corrosion Resisting	2000°F-2.5 hrs WQ	34,900	82,150	57.2	50.2	R <sub>pm</sub> 88.0	174	28,000	70,000	35.0	40.0	1950°F-WQ		Navy Dept. Spec. 46527b of sept. 1, 1945
A11	Hadfield's Mn=10%	1925°F-3 hrs WQ	53,500	96,750	23.8	26.1	R <sub>C</sub> = 19.0	220	42,900	118,000	44.1	39.0	1900°F-WQ	Cast Metals Handbook	
A 5	Cu (Cu=1.5%)	1725°F-3 hrs AC 930°F-3 hrs AC	78,700	106,000	19.2	32.5	-	-	79,500	106,500	24.0	48.4	1650°F-AC 930°F-AC	Steel Castings Handbook	
A6	Cu (Cu=1.5%) (Mn=1%) (Si=1%)	1725°F-3 hrs AC 930°F-3 hrs AC	88,350	120,900	17.5	32.9	R <sub>C</sub> = 24.0	248	70,500	90,500	27.7	49.5	1750°F-AC 840°F-AC	Steel Castings Handbook	
A9	Cu (Cu=1.5%)	1725°F-3 hrs AC 930°F-3 hrs AC	66,250	95,400	20.4	35.4	-	-	79,500	106,500	24.0	48.4	1650°F-AC 930°F-AC	Steel Castings Handbook	

AC - Air cooled  
FC - Furnace cooled  
WQ - Water quench

TABLE 7B  
PHYSICAL PROPERTIES OF THERMIT ALLOY STEELS TOGETHER WITH THE PHYSICAL PROPERTIES  
REPORTED FOR SIMILAR ALLOY STEELS PRODUCED BY FURNACE MELTING PROCESSES

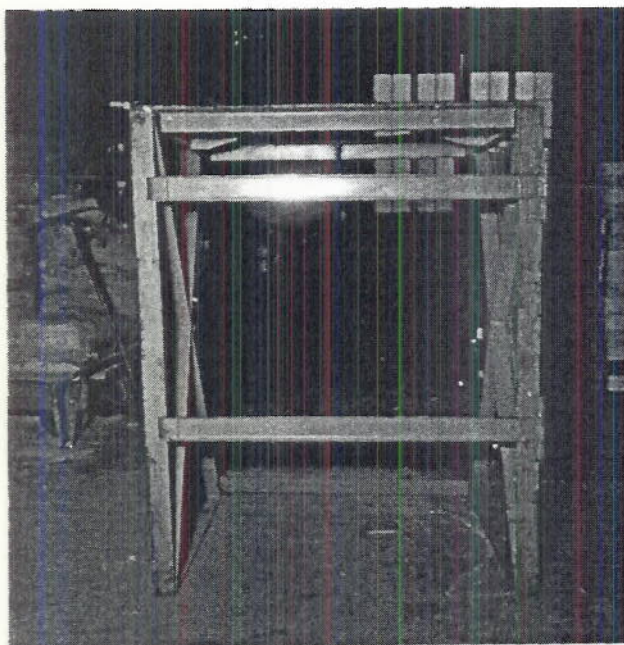
Table 8

Stress Values for Thermit Alloy Steel Specimens Used for Stressed  
Graphitization Tests

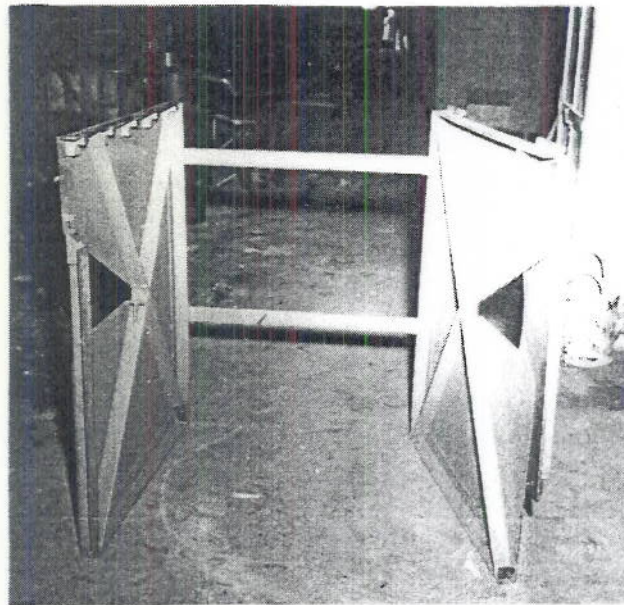
Comp- osition	'Num- ber	Initial Unstr. Length-Inches.	Initial Str. Length-Ins.	'Equivalent' Stress-psi	Time at Temp-hrs.	'Final Str.' Length-In.	'Final Unstr.' Length-Ins.	'Equiv.' Final Str.
CrMo	'18-1'	4.2553	4.2596	32,500	150	4.2530	4.2500	21,300
CrMo	'18-2'	4.2505	4.2548	32,500	300	4.2850	4.2820	21,300
CrMo	'18-3'	4.2555	4.2598	32,500	450	4.2590	4.2563	19,000
CrMo	'18-4'	4.2600	4.2643	32,500	600	4.2530	4.2508	15,000
C Mo	'19-1'	4.2580	4.2615	25,000	150	4.2505	4.2470	24,800
C Mo	'19-2'	4.2485	4.2520	25,000	300	4.2516	4.2492	17,000
C Mo	'19-3'	4.2480	4.2515	25,000	450	4.2612	4.2590	15,500
C Mo	'19-4'	4.2600	4.2635	25,000	600	4.2645	4.2630	10,500
C Mo	'20-1'	4.2630	4.2665	25,000	150	4.2570	4.2540	24,000
C Mo	'20-2'	4.2535	4.2570	25,000	300	4.2554	4.2532	15,500
C Mo	'20-3'	4.2520	4.2555	25,000	450	4.2661	4.2643	13,000
C Mo	'20-4'	4.2485	4.2520	25,000	600	4.2630	4.2615	10,500

The first two figures of the specimen number indicate the heat from which the specimens were made—e.g., specimen No. 18-1 is from A18, specimen No. 19-4 is from heat A19; specimen No. 20-2 is from heat A-20. See table 6 for the chemical compositions of these heats.

In each case, the ends of the specimens were cleansed of scale after heat treatment and before measuring the length of the specimens. The removal of oxidized metal accounts for the decrease in length of some of the above specimens.



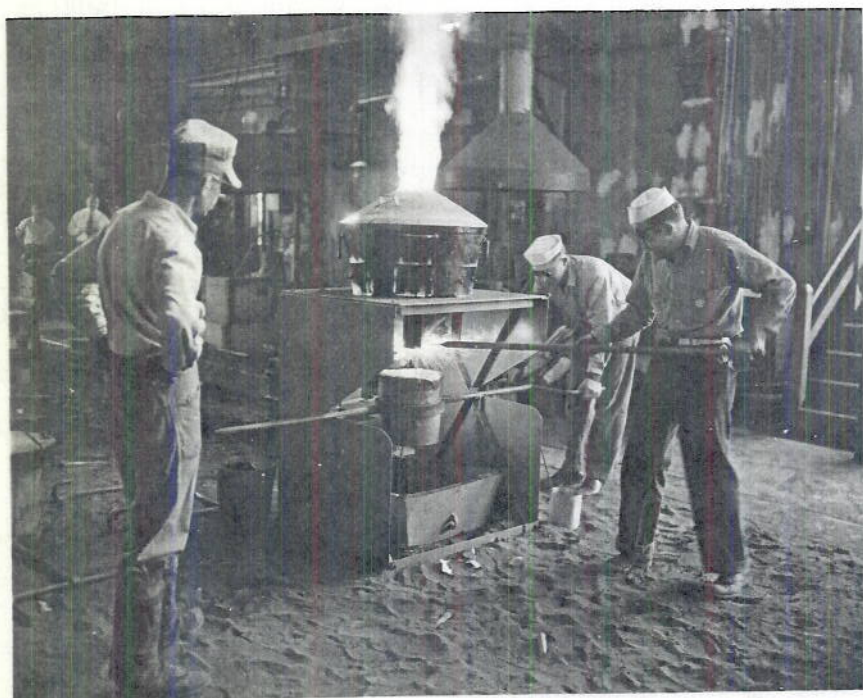
THERMIT MOUNTING FIXTURE  
REAR VIEW. SHOWING THE HINGED CONSTRUCTION



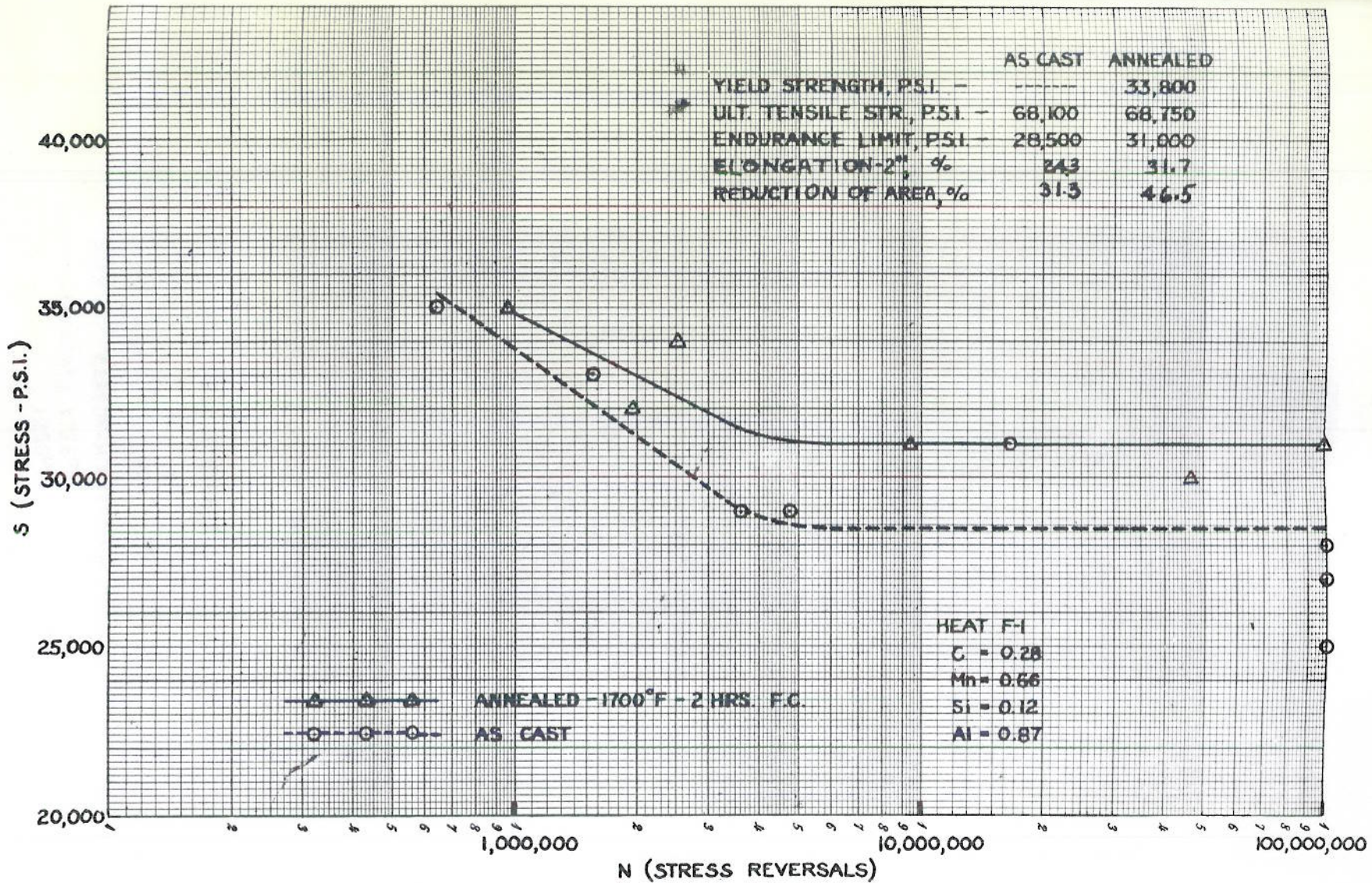
THERMIT MOUNTING FIXTURE  
FRONT VIEW, SHOWING THE TOP MEMBER FOLDED DOWN AND  
THE SIDE MEMBERS READY TO BE FOLDED INTO POSITION  
FOR PACKING THE FIXTURE FOR TRANSPORTATION.



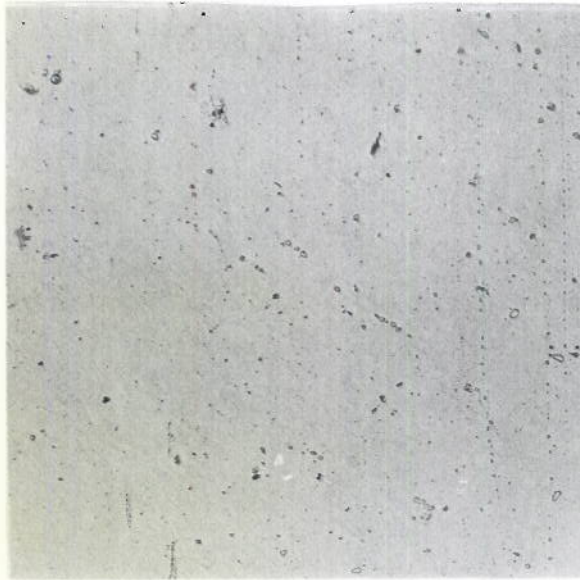
THERMIT MOUNTING FIXTURE  
FOLDED UP AND READY FOR TRANSPORTATION



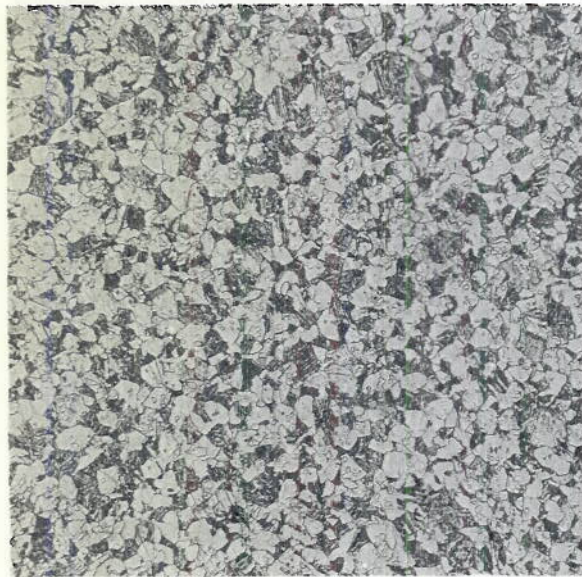
TAPPING A HEAT IN WHICH THE THERMIT MOUNTING FIXTURE HAS BEEN USED TO SUPPORT THE REACTION CRUCIBLE AND THE STEEL LADLE. THE SAND-LINED PAN UNDERNEATH THE LADLE IS USED AS A CATCH-BASIN FOR THE SLAG AFTER THE LADLE OF STEEL HAS BEEN WITHDRAWN FROM THE FIXTURE.



FATIGUE TESTS OF CLASS B STEEL MADE FROM CASTING THERMIT MIXTURE

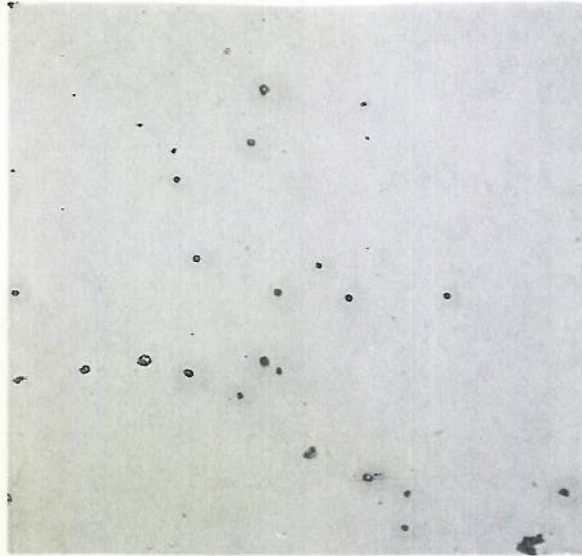


100 X UNETCHED

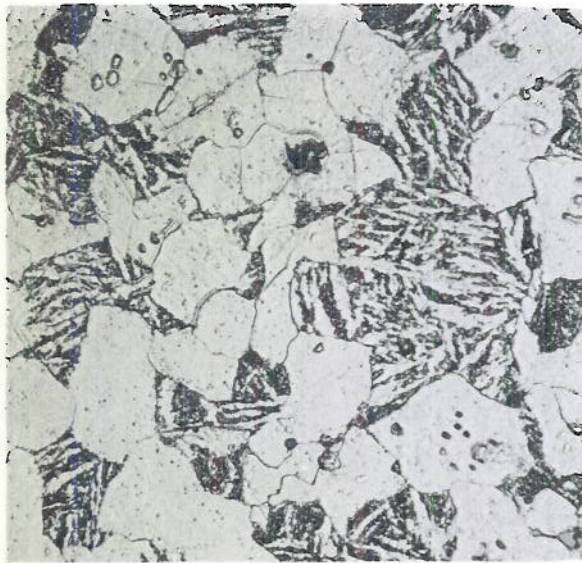


100 X ETCHED

HEAT A1, CARBON-MOLYBDENUM STEEL  
HEAT TREATMENT: 1725°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.

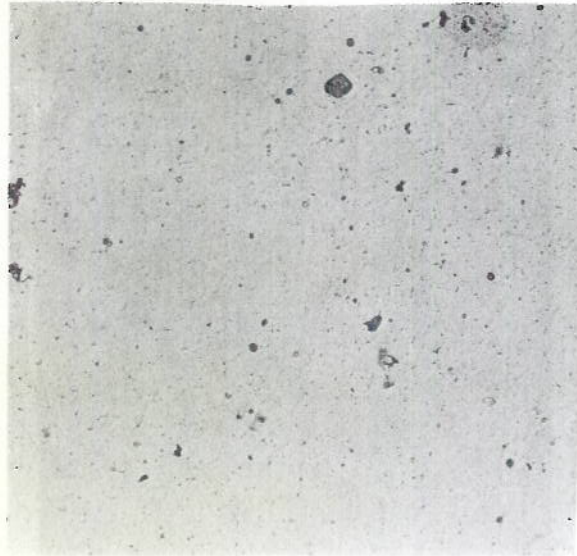


500 X UNETCHED

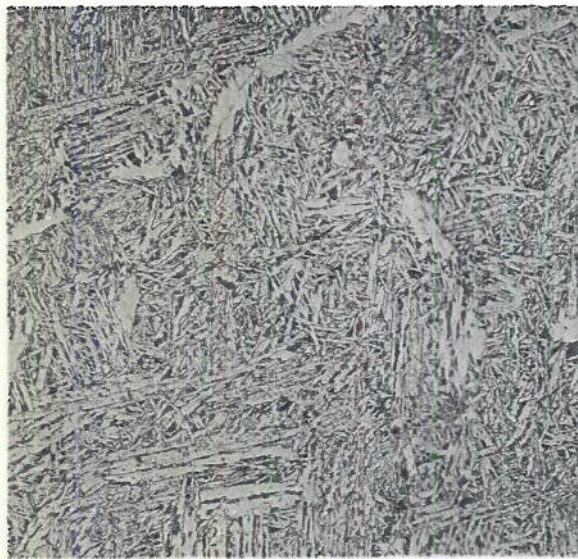


500 X ETCHED

HEAT A1, CARBON-MOLYBDENUM STEEL  
HEAT TREATMENT: 1725°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.



100 X UNETCHED

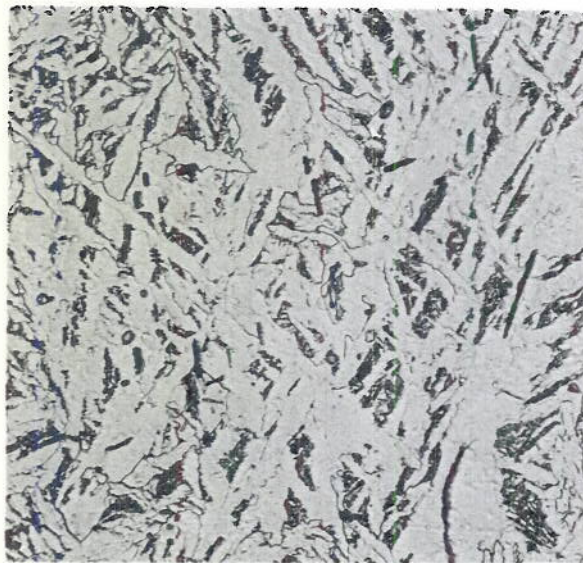


100 X ETCHED

HEAT A18, CARBON-MOLYBDENUM STEEL  
HEAT TREATMENT: 1725°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.

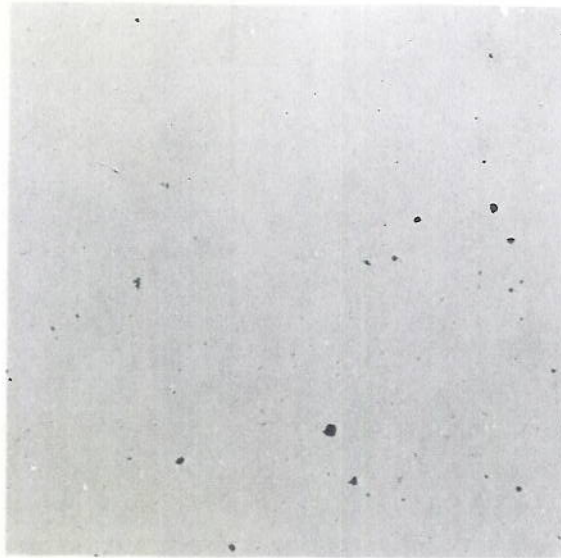


500 X UNETCHED



500 X ETCHED

HEAT A18, CARBON-MOLYBDENUM STEEL  
HEAT TREATMENT: 1725°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.

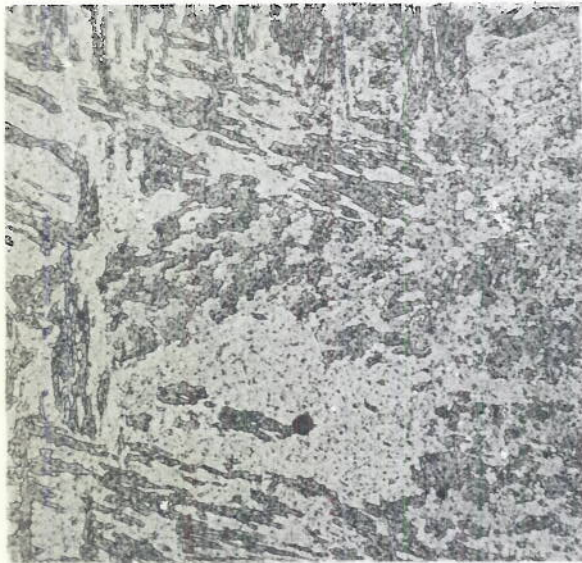


100 X UNETCHED



100 X ETCHED

HEAT A10, CHROMIUM MOLYBDENUM STEEL  
HEAT TREATMENT: 1780°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.

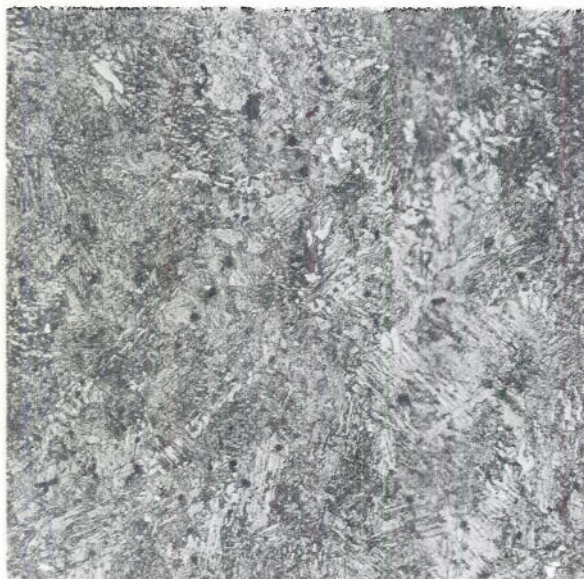


500 X ETCHED

HEAT A10 CHROMIUM-MOLYBDENUM STEEL  
HEAT TREATMENT: 1780°F - 3 HOURS, A.C.  
1250°F - 3 HOURS. A.C.



100 X UNETCHED

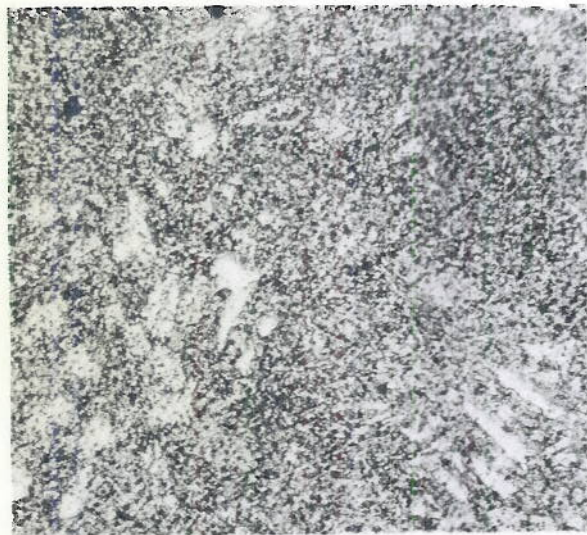


100 X ETCHED

HEAT A17, CHROMIUM-MOLYBDENUM STEEL  
HEAT TREATMENT: 1780°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.

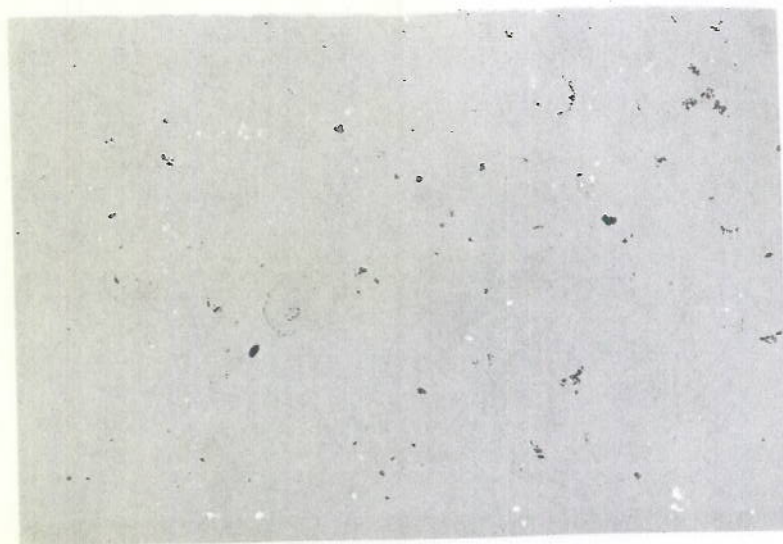


500 X UNETCHED

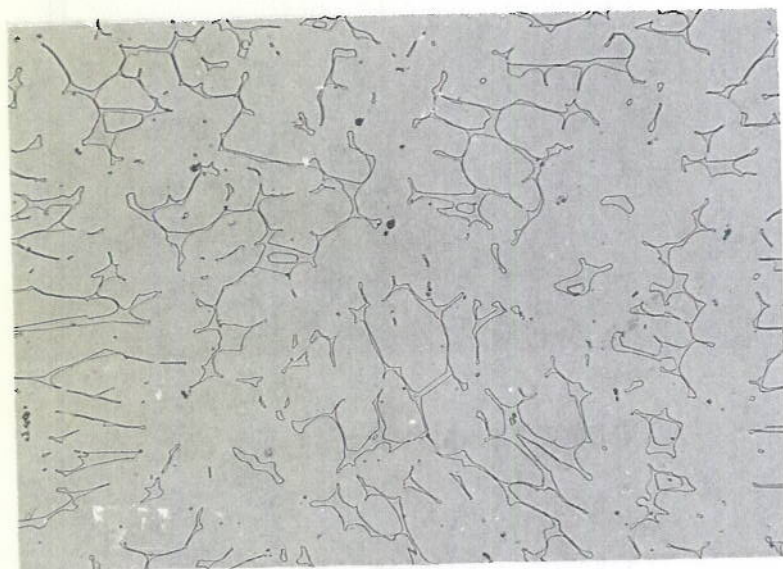


500 X ETCHED

HEAT A17, CHROMIUM-MOLYBDENUM STEEL  
HEAT TREATMENT: 1780°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.

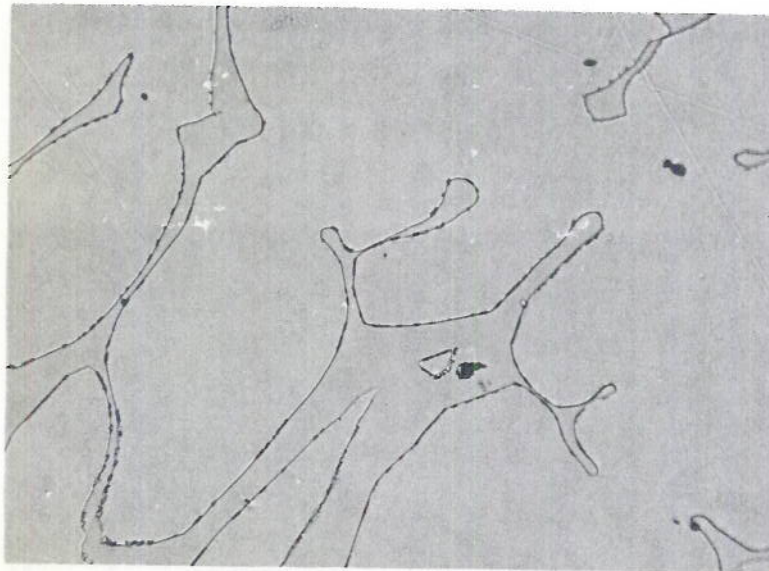


100 X UNETCHED



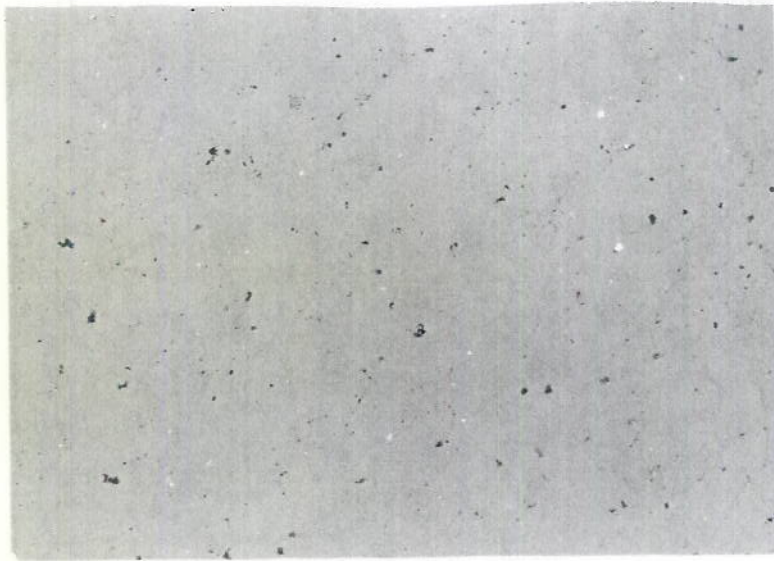
100 X ELECTROLYTICALLY ETCHED

HEAT A21, 18 PERCENT CHROMIUM - 8 PERCENT NICKEL  
CORROSION-RESISTING STEEL  
HEAT TREATMENT: AS CAST

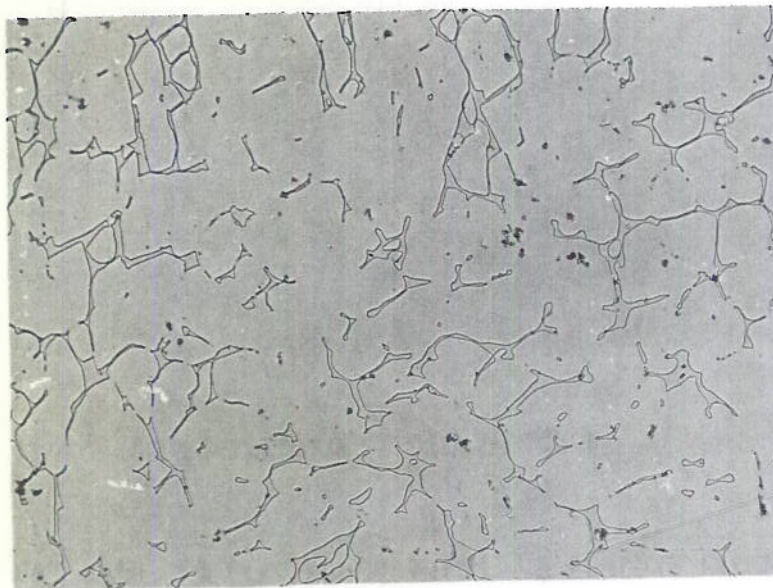


500 X ELECTROLYTICALLY ETCHED

HEAT A21, 18 PERCENT CHROMIUM - 8 PERCENT NICKEL  
CORROSION-RESISTING STEEL  
HEAT TREATMENT: AS CAST



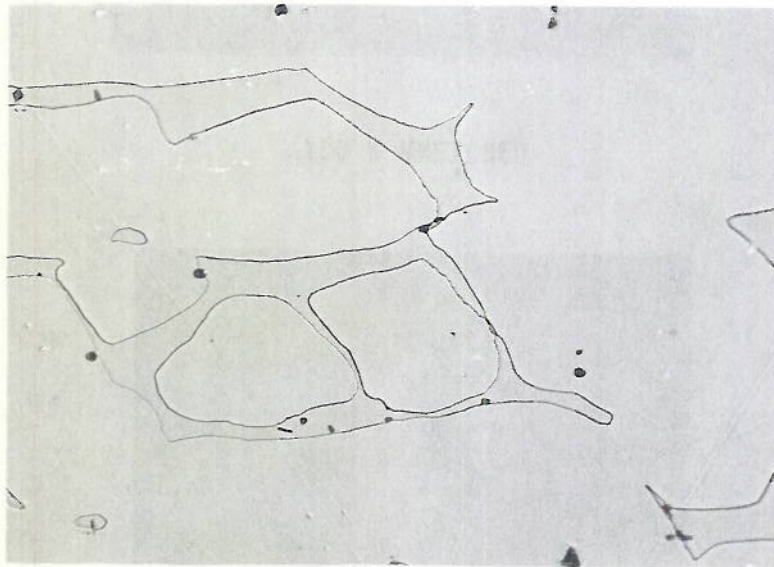
100 X UNETCHED



100 X ELECTROLYTICALLY ETCHED

HEAT A21, 18 PERCENT CHROMIUM - 8 PERCENT NICKEL  
CORROSION-RESISTING STEEL

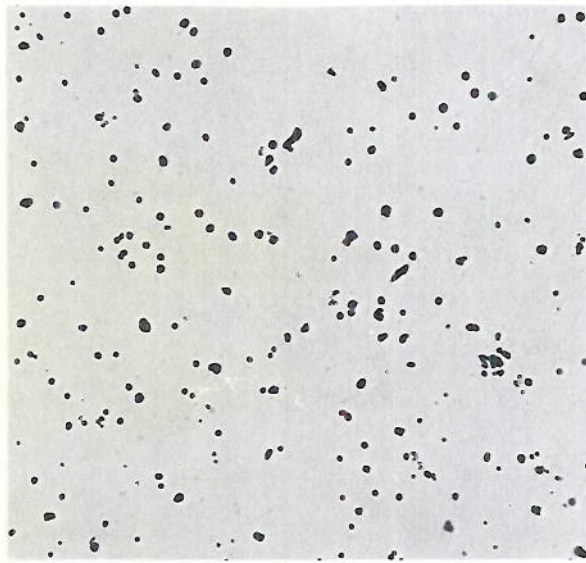
HEAT TREATMENT: 2000°F - 2.5 HOURS, WQ



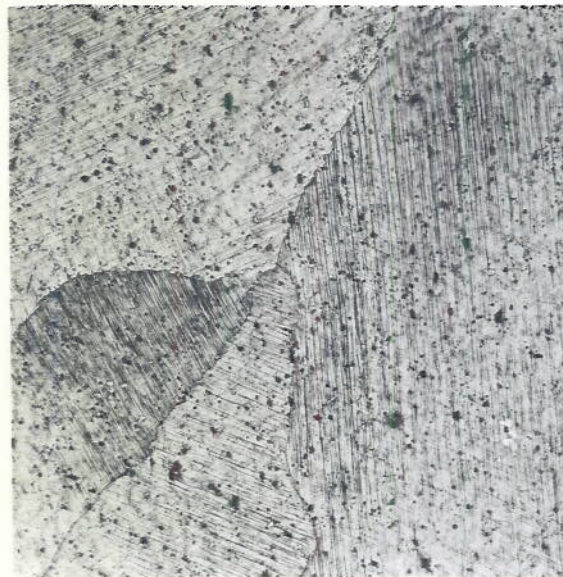
500 X ELECTROLYTICALLY ETCHED

HEAT A21H, 18 PERCENT CHROMIUM - 8 PERCENT NICKEL  
CORROSION-RESISTING STEEL

HEAT TREATMENT: 2000°F - 2.5 HOURS. W0



100 X UNETCHED

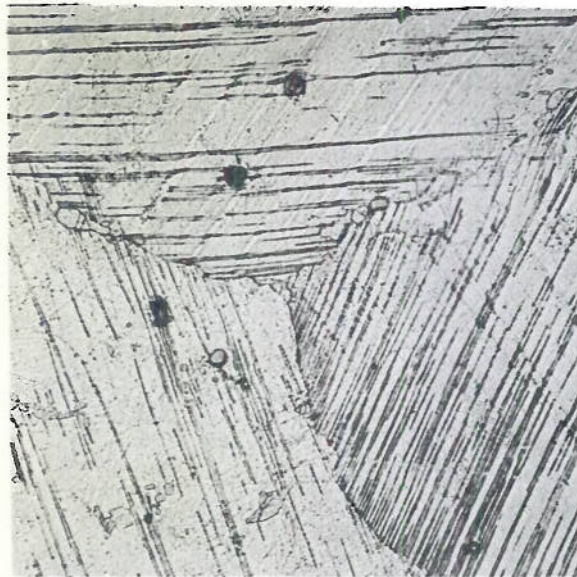


50 X ETCHED

HEAT A11, "HADFIELD'S" MANGANESE STEEL  
HEAT TREATMENT: 1925°F - 3 HOURS, WQ

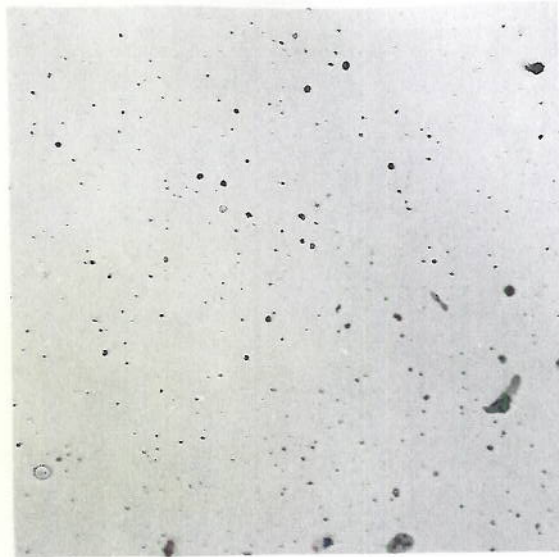


500 X UNETCHED



500 X ETCHED

HEAT A11, "HADFIELD'S" MANGANESE STEEL  
HEAT TREATMENT: 1925°F - 3 HOURS, WQ

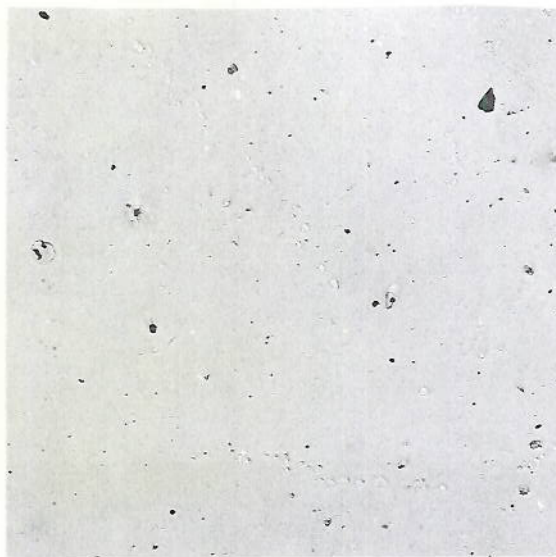


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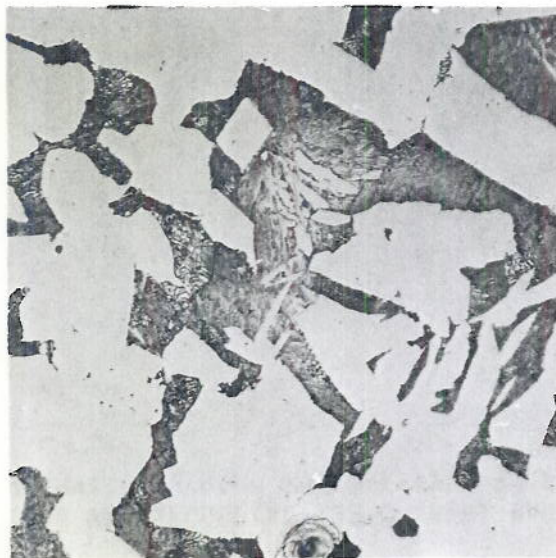


100 X ETCHED

HEAT A6, COPPER-MANGANESE-SILICON STEEL  
HEAT TREATMENT: 1725°F - 3 HOURS, A.C.  
930°F - 3 HOURS, A.C.



500 X UNETCHED

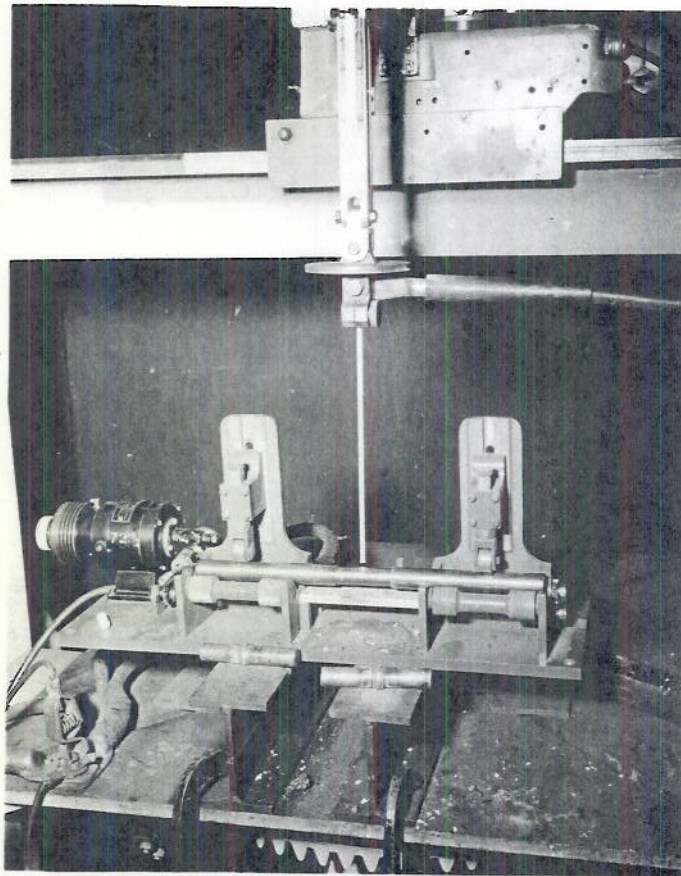


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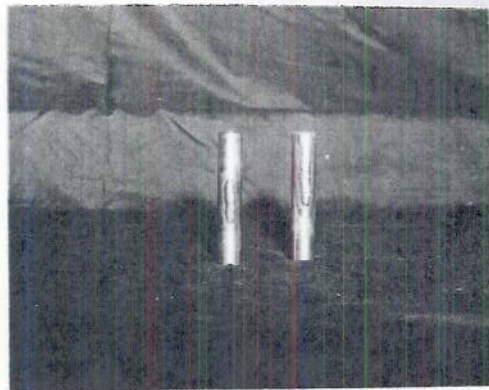
HEAT A6, COPPER-MANGANESE-SILICON STEEL  
HEAT TREATMENT: 1725°F - 3 HOURS, A.C.  
1250°F - 3 HOURS, A.C.



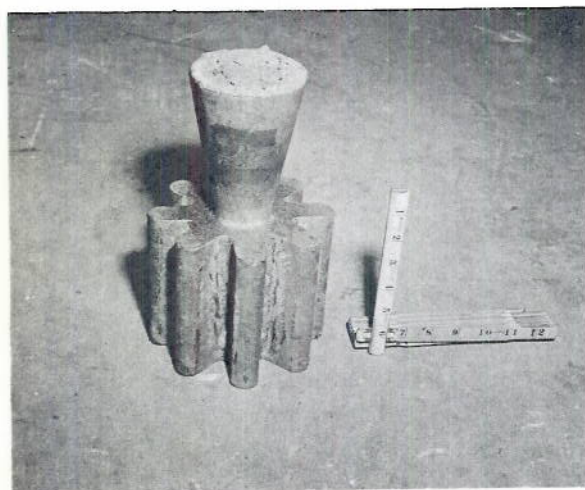
VIEW OF AUTOMATIC WELDING MACHINE AND INSTRUMENTS  
FOR MEASURING AND RECORDING THE CURRENT AND VOLTAGE.



WELDING THE GRAPHITIZATION TEST SPECIMENS.  
THE SAME EQUIPMENT AND WELDING CONDITIONS  
WERE USED FOR THE UNSTRESSED AND STRESSED  
GRAPHITIZATION TEST SPECIMENS.



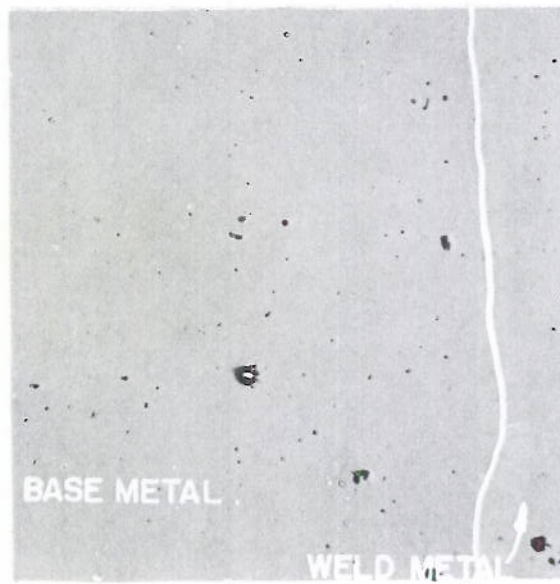
**UNSTRESSED GRAPHITIZATION SPECIMENS.**



**TEST COUPON USED TO PROVIDE BLANKS FOR SPECIMENS FOR THE TENSILE, FATIGUE, NOTCHED-BAR IMPACT AND GRAPHITIZATION TESTS.**



500 X UNETCHED

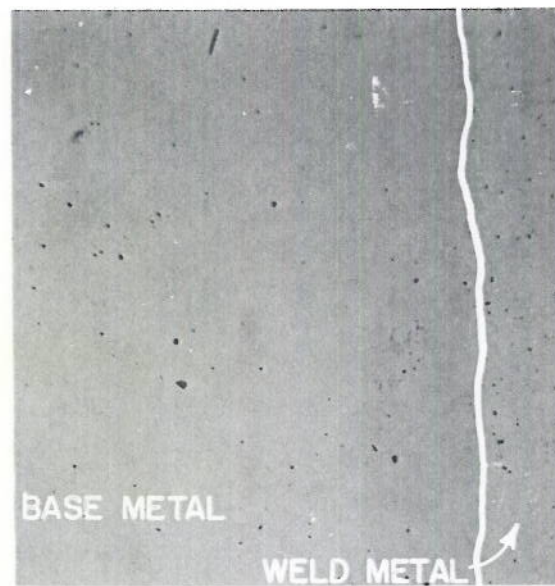


50 X UNETCHED

UNSTRESSED GRAPHITIZATION TESTS  
SPECIMEN FROM HEAT A2, CARBON-MOLYBDENUM STEEL  
AGED AT 1000°F FOR 1600 HOURS

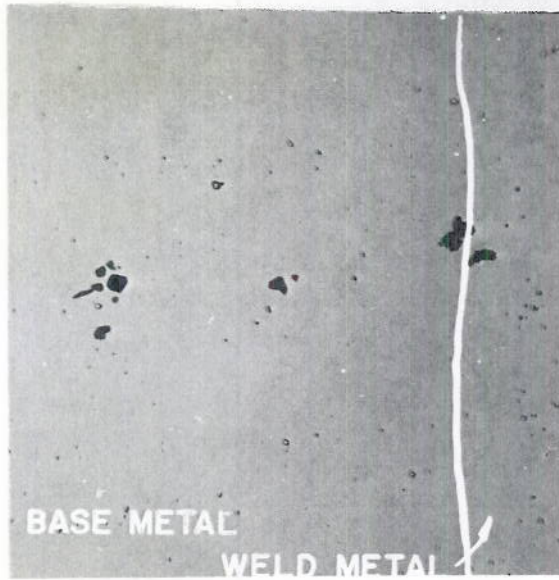


50 X UNETCHED



500 X UNETCHED

UNSTRESSED GRAPHITIZATION TESTS  
SPECIMEN FROM HEAT A7M, CHROMIUM-MOLYBDENUM STEEL  
AGED AT 1000°F FOR 1600 HOURS

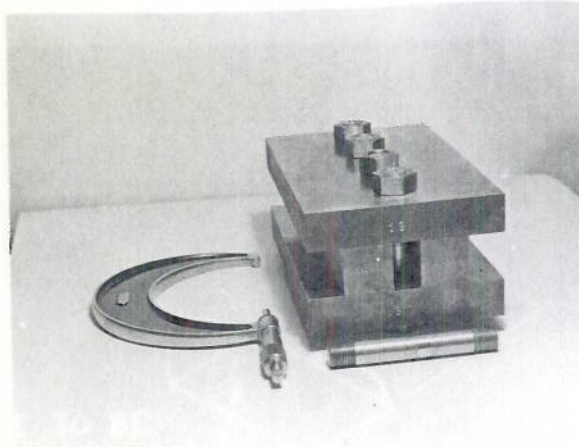


50 X UNETCHED



500 X UNETCHED

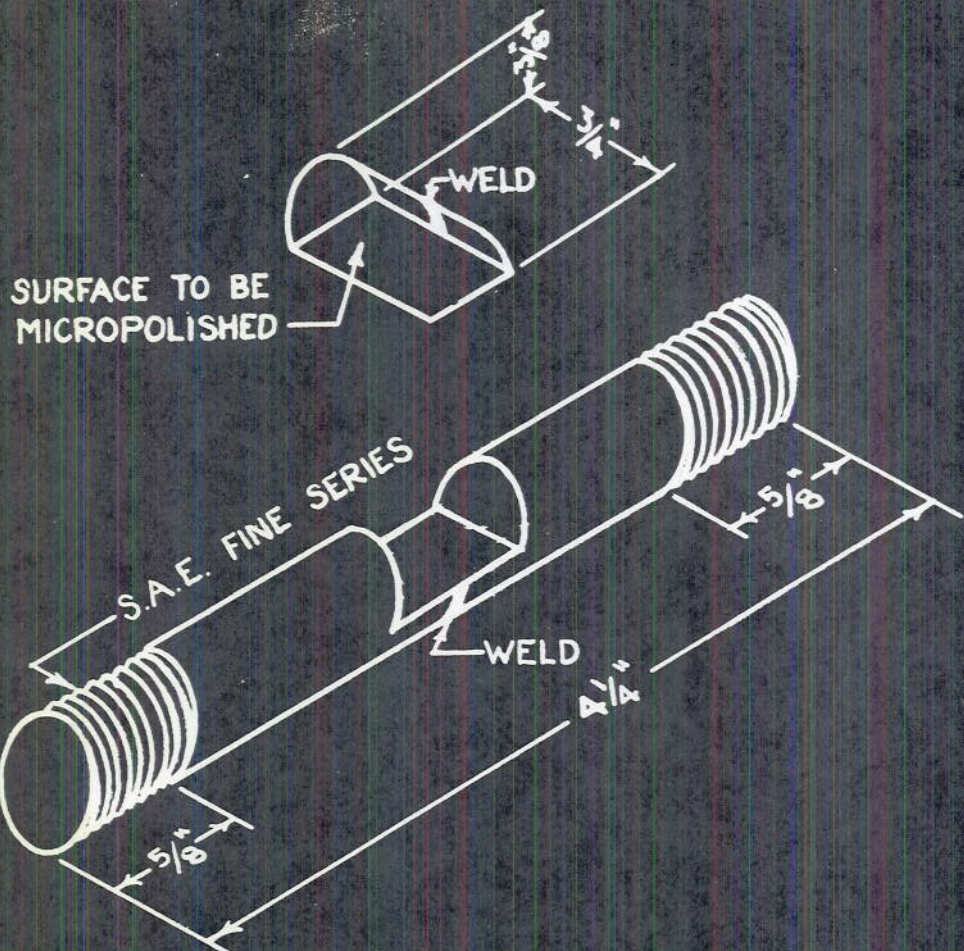
UNSTRESSED GRAPHITIZATION TESTS  
SPECIMEN FROM HEAT A14, CHROMIUM-MOLYBDENUM STEEL  
AGED AT 1000°F FOR 1600 HOURS



**VIEW OF STRESSED GRAPHITIZATION SPECIMENS IN  
FIXTURE, WITH AN EXTRA SPECIMEN AND THE  
MICROMETER CALIPHERS USED FOR THE EXTENSION  
MEASUREMENTS.**



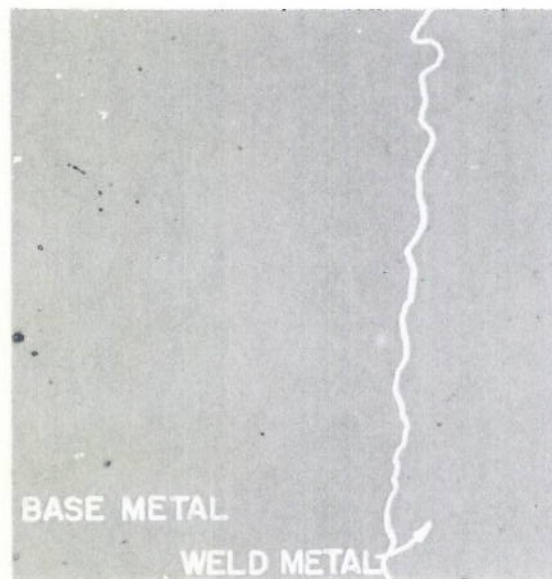
**TYPICAL CASTINGS USED TO PROVIDE MATERIAL FOR  
STRESSED GRAPHITIZATION TEST FIXTURES.**



**LOCATION OF METALLOGRAPHIC  
SAMPLE FOR STRESSED  
GRAPHITIZATION TEST**



50 X UNETCHED



500 X UNETCHED

STRESSED GRAPHITIZATION TESTS  
SPECIMEN FROM HEAT A18, CARBON-MOLYBDENUM STEEL  
AGED AT 1000°F FOR 600 HOURS

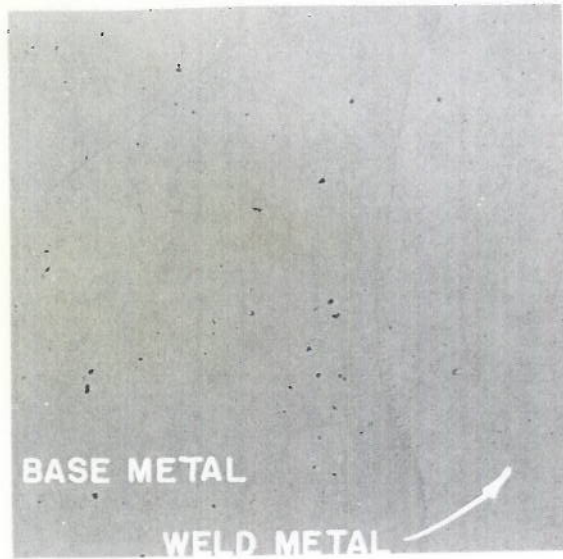


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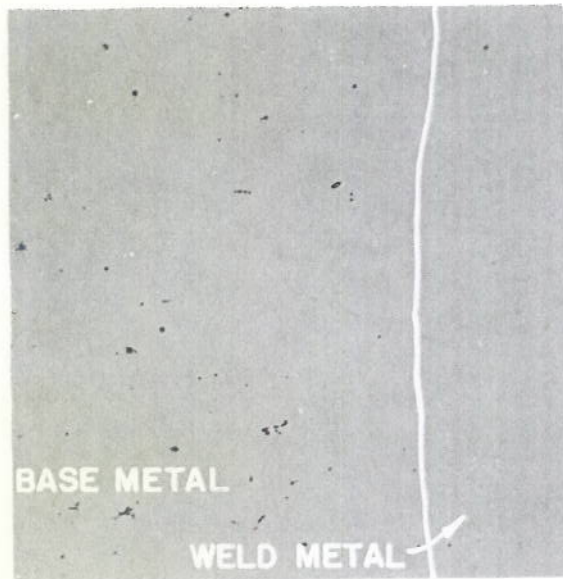


500 X UNETCHED

STRESSED GRAPHITIZATION TESTS  
SPECIMEN FROM HEAT A19, CARBON-MOLYBDENUM STEEL  
AGED AT 1000°F FOR 600 HOURS



50 X UNETCHED



500 X UNETCHED

STRESSED GRAPHITIZATION TESTS  
SPECIMEN FROM HEAT A20, CHROMIUM-MOLYBDENUM STEEL  
AGED AT 1000°F FOR 600 HOURS

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NavShpYd Portsmouth, Va.	(2)
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NGF	(2)
NTS Newport, R. I.	(1)
NAB San Diego, Calif.	(1)