



DECLASSIFIED

NAVAL RESEARCH LABORATORY REPORT

17 July 1944

THIRD PARTIAL REPORT ON
THE THERMAL BEHAVIOR AND MECHANICAL PROPERTIES
OF IRON-MANGANESE AND
IRON-MANGANESE-NICKEL ALLOYS

BY

I. R. KRAMER
S. L. TOLEMAN
W. T. HASWELL

Report M-2328

FR-2328

DECLASSIFIED by NRL Contract
Declassification Team
Date: 17 AUG 2016
Reviewer's name(s): H. Do, P. HANNA

Declassification authority: NAVY DECLASS
GUIDE, 11 DEC 2012, PGS 6-7, PARA 3(2)

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by
UNLIMITED only.

DECLASSIFIED NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

27 July 1944

DECLASSIFIED NRL Report No. M-2328

Navy Department

Third Partial Report on

The Thermal Behavior and Mechanical Properties
of Iron-Manganese and Iron-Manganese-Nickel AlloysNAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text 12 Tables 12 Plates 12

Authorization: BuShips ltr JJ46-7/L5(350) of 30 June 1942.

Date of Tests: February 1943 - June 1944

Prepared by: I. R. Kramer, Metallurgist
S. L. Toleman, Associate Metallurgist
W. T. Haswell, Jr., Contract Employee

Reviewed by: F. M. Walters, Jr., Superintendent
Division of Physical Metallurgy

Approved by: A. H. Van Keuren, Rear Admiral, USN
Director

Distribution: BuShips (10)
BuOrd (5)

bd

DECLASSIFIED

DECLASSIFIED

Page

Abstract	
Introduction	
Statement of Problem	1
Known Facts and Theoretical Considerations	1
Narrative of Original Work Done at this Laboratory	1
Methods	3
Data Obtained and Discussion	3
Conclusions	5
Recommendations	10
References	11
	12

Table

Chemical Compositions	1
Effect of Austenitizing Temperature on the Transformation Temperature and Percentage of Retained Austenite	2
Austenitized at Indicated Temperature for 2 Hours, Furnace Cooled According to Curve A, Plate 3, Tempered at 650°C (1200°F) for 2 Hours and Water Quenched	3
Effect of Tempering Temperatures on the Formation of Austenite	4
Effect of Double Tempering on Charpy V-Notch Impact	5
Effect of Tempering Time and Rate of Cooling From Tempering Temperature on Charpy Impact of Alloy MVK	6
Effect of Double Tempering on Temper Brittleness	7
Effect of Tempering Time on Impact Resistance of Alloy MVK	8
Hardness Data of Alloys Containing Titanium, Vanadium, Chromium and Molybdenum	9
Mechanical Properties	10
Coupon Fracture Study	11
High Velocity Shock Test	12

Plate

Iron-Manganese Constitutional Diagram	1
Iron-Manganese Equilibrium Diagram	2
Cooling Curves	3
Typical Examples of Brittle Coupon Fractures	4
Typical Examples of Ductile Coupon Fractures	5
Finger Specimen for High Velocity Impact Test	6
Effect of Tempering on Austenite Formation	7
Typical Dilatation Curve for Iron-Manganese Alloys	8
Continuous Cool Transformation Curves	9
Continuous Cool Transformation Curves	10
Comparison of Results of Finger Tests of Fe-Mn-Ni Alloys with STS Deck Armor	11
Effect of Temperature on Impact Resistance	12

DECLASSIFIED

ABSTRACT

Alloys which contain 3-4 per cent Mn, 1-1 $\frac{1}{4}$ per cent Ni, $\frac{1}{4}$ per cent Mo, have excellent ductility. When heat treated to simulate the cooling conditions at the center of an air cooled 18 inch plate, the alloys gave fibrous fracture in both the coupon and high velocity shock tests, which indicate that these alloys may have useful ballistic properties in heavy sections. A low temperature impact study of an alloy MDS showed that it was ductile down to temperatures of -90°C (-130°F).

The mechanical properties are superior to those required for heavy forgings under Navy Specifications 49S2 for Class An steel.



1. The investigation of iron-manganese alloys was authorized by the Bureau of Ships letter JJ46-7/L5(350) of 30 June 1942.

STATEMENT OF PROBLEM

2. Attention in this report is directed towards the study of a new class of alloy steels that hitherto has been unexplored. These alloys contain, in the main, four per cent manganese or manganese plus nickel equivalent to four per cent manganese.

3. The composition of these alloys is such that the gamma to alpha transformation temperature is unaffected by the rate of cooling, making it possible to normalize a large forging or casting to a martensitic structure throughout its cross-section.

4. The work covered by this report includes a rather detailed study of the behavior of iron-manganese and iron-manganese-nickel alloys under various conditions of heat treatment by the use of x-ray and dilatometric techniques. The coupon fracture and high velocity shock tests were used as a means for evaluating the ductility in large sections.

KNOWN FACTS AND THEORETICAL CONSIDERATIONS

5. The effect of manganese on the allotropic transformation of iron (Plate 1) is to stabilize the face-centered cubic phase, gamma. The temperature at which the body centered phase, alpha, transforms to gamma is lowered by increasing amounts of manganese. Not only is the alpha to gamma transformation lowered by manganese but the reverse transformation, that of gamma to alpha, is lowered still more so that a wide difference between the transformation temperatures on heating and cooling (thermal hysteresis) exists.

6. Although the thermal hysteresis is due to an extremely slow rate of transformation, the rate is so slow, particularly below 400°C (750°F), that for all practical purposes the thermal hysteresis is real. For example, on cooling, a six and one half per cent manganese, carbon free alloy begins to transform at 400°C regardless of whether it is quenched or very slowly cooled.

7. The equilibrium diagram (Plate 2) was determined by Troiano and McGuire (1) by holding small slivers or filings at temperature for an extremely long time, for example, 545 days at 400°C and 700 days at 300°C. Their diagram shows that binary alloys containing over 3 per cent manganese slowly transform to produce two phases, alpha and gamma, when held at temperatures

above 400°C. The gamma phase upon cooling may transform at a low temperature to produce an alpha phase rich in manganese.

8. Previous work (2) at this Laboratory on iron base alloys demonstrated that many of the iron-manganese alloys are ductile after air cooling and tempering. Additions to a 4 per cent manganese alloy of molybdenum and other elements that form stable carbides permits the carbon content to be raised to 0.1 per cent without adversely affecting the ductility even though the alloys were furnace cooled before tempering (3).

9. It is now generally recognized that the best combination of strength and ductility is found in a steel which has been tempered after having been quenched completely to martensite. However, this condition cannot always be attained, for, as the section size of an object increases the cooling rate in the interior decreases. Furthermore, when heavy sections are quenched such as armor plate thicker than 3 inches, there is danger of cracking if the center of the plate is allowed to cool below 900°F. Since a time quench procedure is used to avoid cracking, the interior of the plate is never martensitic. Heavy forgings are generally annealed to avoid stresses or cracks, thereby sacrificing a large percentage of strength and ductility.

10. In the development of armor in a laboratory there are certain inherent obstacles which are difficult to overcome, for at present there are no completely satisfactory small scale methods of testing a steel to predict its large scale ballistic behavior. There is, however, a method generally used in armor making plants for judging the quality of armor by the appearance of the fracture of a notched test bar broken by bending. The fractured surfaces are classified as crystalline, woody, fibrous, laminated, etc. At best, this test is only qualitative and is used to reject those plates which exhibit obvious defects; a satisfactory fracture does not guarantee that a plate will pass the ballistic test. Extensive use has been made of a "coupon fracture" test to study the effect of alloying elements on the behavior of the iron-manganese alloys and to eliminate alloys that gave crystalline fractures.

11. One of the main advantages of the coupon fracture test is that it gives some idea of the "size effect". The term "size effect" is used to denote the loss in ductility that occurs when the section size of test specimens is increased. It is possible for a steel to have very high ductility when tested in small sizes, such as the Charpy impact specimen, and yet be brittle when tested as a 1½ inch bar. NRL Report No. 20, 20 May 1943 discusses size effect in some detail.

12. Charpy V-notch impact specimens have been used with varying degrees of success to study the effect of various alloying elements and heat treatments on the ductility of iron-manganese alloys. Although the test may be insensitive to some causes of brittleness because of the small test area fractured, it does aid in eliminating the more brittle alloys.

13. Realizing the need for a quantitative laboratory test that would assimilate actual ballistic conditions, the Ballistic Section, Division of Mechanics and Electricity at the Naval Research Laboratory, has proposed a high velocity shock test (finger test). This test uses as a criterion of ductility the velocity necessary to just shoot off a notched finger from a test bar. The details of this test are given in Paragraph 22. Although the test does not duplicate the actual conditions of a large scale ballistic test, it does embrace some of the most important features, namely, resistance to shock and to crack propagation. It is believed that proper exploitation of this test in conjunction with Charpy impact tests will be fruitful in studying the behavior of iron-manganese alloys as armor.

NARRATIVE OF ORIGINAL WORK DONE AT THIS LABORATORY

14. Alloys of iron-manganese and iron-manganese-nickel with varying additions of molybdenum, chromium, vanadium and titanium were prepared and their mechanical properties determined.

15. The mechanical properties were studied after cooling slowly from the austenitizing temperature. The cooling rates used (Plate 3) approximate those for the center of a 6 inch plate and an 18 inch plate cooled in air. Hereafter the cooling rates of the 6 inch plate and 18 inch plate will be referred to as furnace cool A and B, respectively.

16. A rather detailed study of the behavior of iron-manganese and iron-manganese-nickel alloys was made using x-ray and dilatometric techniques. The dilatometer was used to determine the effect of austenitizing temperatures and the effect of various rates of cooling on the gamma to alpha transformation temperature. Both x-ray and dilation techniques were used to study the alpha to gamma transformation that occurs during tempering.

METHODS

17. The alloys were prepared from SAE 1015 stock and electrolytic manganese; to various heats were added electrolytic nickel, scrap molybdenum wire, ferro-chromium, ferro-titanium, ferro-vanadium and ferro-silicon. The heats were finally deoxidized with 1 pound of aluminum per ton. The alloys were melted in 100 and 300 pound high frequency induction furnaces with magnesia crucibles and poured into cast iron ingot molds.

DECLASSIFIED

18. The ingots were homogenized at 1250°C (2300°F) for 4 hours and forged into suitable stock for testing. The alloys forge very well and since the austenite decomposition temperature is low, the forging range is correspondingly long. In fact, these alloys may be forged from 1250°C (2300°F) to as low as 800°C (1500°F) before difficulty is encountered.

19. The heat treatments employed for the forged specimens generally consisted of austenitizing for 2 to 4 hours at 1650°F and cooling according to curve A or B of Plate 3.

20. The tensile specimens were 0.505 inches in diameter with two inch gage lengths and the impact specimens were V-notch Charpy. The yield strengths were taken at 0.2 per cent offset from the stress-strain curves drawn by a Peters recorder. Duplicate specimens were used for each test.

21. The coupon fracture test bars were prepared by forging a 40 pound ingot into bars $12'' \times 2\frac{1}{2}'' \times 1\frac{1}{2}''$. The bars were heat treated and sawed to a depth of approximately $1/2$ inch. The coupon was then broken by bending as a simple beam in a manner such that the bottom of the notch was in tension. The type of fracture was judged by at least three observers. Typical examples of crystalline and fibrous fractures are shown in Plates 4 and 5 respectively.

22. The high velocity shock test (finger test) consists of the determination of the velocity necessary to just shoot off a finger of a test specimen. The test pieces, which may be of various designs, are best described by Plate 6. The piece is generally made by sawing $1/4$ inch wide slots from the edge of a $1\ 5/16''$ plate to a distance of $2\frac{1}{2}$ inches. The distance between fingers is not critical but it must be sufficiently wide to allow for deformation of the finger when it is shot. The bottom of the saw cut slots are carefully machined to a radius of $1/8$ inch and a notch is machined across the face of each finger. After preliminary trials, it was found that a $1/8$ inch radius notch at a depth of $1/3$ of the thickness of the plate gave good results. The specimens were tested with .50 cal. ball M1 bullets shot base foremost. The distance from the notch on the face to the point of impact was $1\frac{1}{2}$ inches. The velocity of the projectile was measured by a ballistic pendulum.

23. The high velocity shock tests were made on forged iron-manganese alloys and on STS that was known to have passed the ballistic tests.

24. The x-ray diffraction studies were made with a Seeman-Bolin 6-inch focusing camera using chromium radiation at 35 kilovolts for 18 milliampere hours. Solid samples ground to a radius of 3 inches were used. The x-ray measurements were made by the X-Ray Section of the Division of Physical Metallurgy.

25. The dilatometric studies were carried out in a quartz tube dilatometer using cylindrical specimens 1 inch long by 1/2 inch in diameter. An Amos dial capable of being read to 0.00002 inches was used to measure the expansion and a potentiometer was used for temperature measurements.

DATA OBTAINED AND DISCUSSION

26. The composition of the alloys as determined by chemical analysis is given in Table 1. Since the heats were made from SAE stock, phosphorus and sulphur determinations were not made; however, from past experience it may be assumed that the phosphorus is approximately 0.02 per cent and the sulphur 0.03 per cent.

27. At the beginning of this study, it was decided that the effect of austenitizing temperatures should be further investigated for it was found that although the previously used austenitizing temperature of 845°C (1550°F) was 50°C (90°F) above the completion of the alpha to gamma transformation temperature, undissolved carbides were present in the microstructure. If the austenitizing temperature were raised and more of the carbides were dissolved, a change of the gamma to alpha transformation temperature and in mechanical properties would be expected. That this is apparently correct is shown by the results of the dilation work on alloy MVK, where repeated heatings to 840, 870, 900 and 955°C (1545, 1600, 1650 and 1750°F) and holding for one hour at each temperature before cooling lowered the gamma to alpha transformation temperature. The amount of retained austenite was also decreased (Table 2). The per cent austenite was estimated from the distance that the dilatometer curve failed to close divided by the total change of length on transforming from gamma to alpha.

28. A fifth run was made at a lower austenitizing temperature to determine the effect of the increased homogenization that must have occurred during the previous thermal cycles. When the specimen was reheated to 870°C (1600°F) the transformation temperature remained about the same as after the previous 955°C (1750°F) treatment. Although the amount of retained austenite was increased, a lower percentage than that after the first 870°C (1600°F) treatment was observed. This latter treatment shows that both the transformation temperature and the amount of retained austenite are affected by the austenitizing temperature and degree of homogenization.

29. The effect of austenitizing temperature on the resistance to impact was studied for alloy MVK, furnace cooled (A) (Plate 3). Increasing the temperature from 800°C (1475°F) to 870°C (1600°F) increased the Charpy value from 31 to 100 ft. lbs. Further increases in temperature up to 930°C (1705°F) produced no change but the impact resistance dropped when the austenitizing temperature reached 955°C (1750°F).

7. The microstructure after furnace cooling showed numerous undissolved carbides when cooled from temperatures below 870°C. Although carbides were still evident after the 500°C treatment they were much fewer.

8. To obtain a better insight into the behavior of these iron-manganese-molybdenum alloys on tempering several alloys with varying manganese, molybdenum and carbon contents were selected and investigated by x-ray diffraction. The results show that more austenite is retained after furnace cooling than after oil quenching from the austenitizing temperature and, as in the case of alloy MVK, less austenite is retained after furnace cooling from 900°C (1650°F) than from 840°C (1550°F). After tempering at 500°C (930°F) there was a definite decrease in the austenite present; however, there was still a moderately strong gamma line in the diffraction pattern of a furnace cooled (A) alloy MTL (5 per cent Mn). The stability of the austenite of alloy MTL is probably associated with its high manganese content. Tempering at 600°C (1100°F) caused the austenite content to increase and in some alloys caused a broadening of the alpha lines. Retempering the specimens at 600°C (1100°F) did not change the intensity or width of the diffraction lines. When the alloys were tempered at 650°C (1200°F) the austenite increased and the alpha diffraction lines broadened. Retempering at 650°C (1200°F) generally resulted in sharpening of the alpha lines and a decrease in the per cent austenite.

9. The results of the x-ray study clearly reveal that the alpha to gamma transformation occurs at temperatures above 600°C (1100°F). The austenite that is formed on tempering will, upon cooling, transform back to alpha. The temperature of this latter transformation seems to depend upon the composition of the austenite which is determined by the composition of the alloy, the tempering time and temperature.

10. The effect of the rate of cooling from 650°C of alloy MVK is shown in Table 6. That the austenite formed during tempering is retained by a quench from the tempering temperature is shown by the strong gamma lines of specimens 12 and 26 and the sharpness of the alpha lines. When the alloy was slowly cooled as in specimens 15 and 17, the austenite decreased and the alpha line broadened. The broadening of the alpha lines indicates that the transformation occurred at low temperatures with little or no diffusion. The long tempering treatment of specimens 17 and 26 seems to accentuate the conditions necessary for transformation of the austenite to alpha as shown by the very faint gamma line of specimen 17. The Charpy impact values are shown to be in agreement with the x-ray diffraction patterns; those heat treatments that produced broad alpha lines gave low impact resistance. Retained austenite appears to improve impact resistance.

34. Additional information on the behavior of these alloys was obtained by a dilatometric study of alloy MVK. When dilation specimens were held at 550, 600, 650, 675 and 700°C (1022, 1112, 1200, 1250 and 1300°F) a partial transformation from alpha to gamma occurred when the temperature exceeded 600°C (1100°F). The amount of austenite that formed increased with tempering temperature and was practically completed in about 5 hours. Plate 7 shows the decrease in length that occurred after holding for 6.5 hours at 650°C (1200°F). The per cent austenite formed at the various tempering temperatures is given in Table 4. The austenite was estimated by dividing the change in length that occurred on tempering by the change in length to form 100 per cent austenite. A typical dilation curve obtained by heating and cooling at a rate of 20°C per minute is shown in Plate 8.

35. Austenite which formed at 650°C (1200°F) or above, when slowly cooled transformed to alpha at about 100-130°C. This decomposition of the austenite to form a low temperature transformation product decreased the ductility of the alloy and accounted for the broadening of the alpha diffraction lines.

36. This low temperature transformation product may be softened by a second tempering. Using alloy MVK, it was found that during this second tempering at 650°C there was also a partial transformation from alpha to gamma, but it was much slower and less complete than in the first tempering. Upon cooling, this austenite did not transform to alpha.

37. The effect of double tempering Charpy V-notch impact specimens of alloy MVK is shown in Table 5. Specimens which were tempered for 2 hours at 650°C (1200°F), or 675°C (1250°F) and then retempered for 2 hours at 600°C (1200°F) to 675°C (1250°F) have impact values of 100 foot-pounds.

38. Since the x-ray, impact and dilatometric studies demonstrated that the austenite formed on tempering at 650°C (1200°F) transforms on slow cooling to a hard and brittle structure, it was concluded that the impact resistance after slow cooling from the tempering temperature could be improved by double tempering. The impact resistance of alloy MVK, after an initial 650°C (1200°F) temper, Table 7, was markedly improved by a second tempering treatment even though the specimen was furnace cooled (A) after the final treatment. However, high temperature initial or low temperature secondary tempering treatments generally resulted in little or no improvement. The impact resistance of alloy MVK progressively decreases after tempering in excess of 8 hours (Table 8).

39. Those alloys (MEB, MDZ, MDS - Table 7) in which part of the manganese was replaced by nickel were not as susceptible to embrittlement upon furnace cooling (A) after tempering as

those alloys without nickel. The susceptibility is dependant upon the carbon content. The impact value of alloy MEB (3.68 Mn, 1.16 Ni, 0.28 Mo, 0.26 C) dropped from 87 ft.lbs. to 51 ft.lbs. after furnace cooling from 600°C (1100°F); however, the impact strength fully recovered after a second tempering treatment at 600°C (1100°F). The impact strength of alloys MDS (2.75 Mn, 2.24 Ni, 0.61 Mo, 0.08 C) and MDZ (3.40 Mn, 0.72 Ni, 0.31 Mo, 0.15 C) was not lowered by furnace cooling after tempering.

40. Transformation characteristics of the iron-manganese alloys were studied by observing the changes in dilation of specimens cooled at different rates. In the usual steels the transformation of austenite is dependant upon the rate of cooling; the transformation temperature is lowered with increasing rates of cooling until the martensite point is reached. However, in these iron-manganese alloys such is not the case, for the transformation temperature remains constant for any practical rate of cooling. The behavior of alloy MDS (Mn 2.75, Ni 2.24, Mo 0.61, C 0.08) and that of alloy MEP (Mn 3.31, Ni 1.55, Mo 0.29, Cr 0.36, C 0.16) are typical examples (Plates 9 and 10). In all cases, even when cooled at rates comparable to the center of a 12 inch plate cooled in air (curve F, Plate 9) the alloys transformed only at one temperature; there was no evidence of any higher temperature transformation products.

41. The effect of various combinations of titanium and vanadium with molybdenum and chromium on the hardness after furnace cooling (A) and tempering is shown in Table 9. A titanium content in excess of 0.2 per cent causes a marked lowering of the hardness after furnace cooling. This decrease in hardness is also accompanied by an increase of the gamma to alpha transformation temperature. However, titanium with less than 0.2 per cent in combination with molybdenum or chromium gave hardnesses after furnace cooling commensurate with those expected from the carbon content. Vanadium, while quite influential in suppressing high temperature transformation products, decreases the ability of the alloy to temper to hardnesses generally applicable for naval ballistic purposes.

42. Table 10 shows some typical tensile and impact data for alloys containing varying percentages of molybdenum, chromium, vanadium, columbium, nickel, titanium and carbon. These alloys were furnace cooled (A) from 1650°F and tempered at temperatures 600°C (1100°F) to 675°C (1250°F). In general, the alloys containing molybdenum are more ductile than any of the alloys containing other stable carbide forming elements. It is of importance to note that those alloys containing nickel and molybdenum have the highest ductility of any of the alloys studied thus far. The products of tensile strength and per cent elongation for alloys MDO, MCT and MDV are about 33,000,000 which are about 10 per cent higher than that obtained for

DECLASSIFIED

quenched and tempered SAE steels. In addition to the high per cent elongation and reduction of area, the impact values are exceptionally good.

43. The alloys containing chromium, columbium or vanadium without molybdenum have tensile strength - per cent elongation products which are generally lower than those for quenched and tempered SAE steels. The addition of titanium in combination with chromium or molybdenum does not effect any increase in ductility.

44. Although chromium does not aid in increasing the ductility, it does raise the yield-tensile strength ratio. Alloy MDO (Mo .28, Cr .28) has a yield-tensile ratio of 0.91 while the alloy without chromium MCT (Mo .50) has a yield-tensile ratio of 0.72. The effect of chromium in raising the yield ratio is also shown by the alloys that contain chromium without molybdenum.

45. That the ductility as measured by per cent elongation, reduction of area or Charpy V-notch impact is not a measure of ductility in heavy sections may be readily seen in Table 11. Some of the alloys have excellent Charpy V-notch impact values but when $1\frac{1}{2}$ inch coupon bend specimens were broken they failed in a very brittle manner. It is very important to note that those alloys containing over 0.75 per cent nickel with molybdenum, or molybdenum and chromium gave excellent coupon fractures upon tempering either after air cooling or furnace cooling (B) from the austenitizing temperature (1650°C).

46. Other alloying elements such as titanium, vanadium and chromium, either with or without nickel and in the absence of molybdenum, gave brittle fractures in the $1\frac{1}{2}$ inch coupon test. Those alloys (MDA, MDB, MDC) containing molybdenum without nickel gave fibrous fractures but it is believed that the fibrous fracture was due to the low hardness, since alloys of similar compositions MBV, MBW, MCC, MCE were brittle at hardnesses of 250 Brinell. One alloy, MED, containing 3.00 per cent Mn, 1.70 per cent Ni, 0.25 per cent Mo, 0.11 per cent C gave an excellent fibrous fracture when tested as a 3-inch coupon specimen.

47. The behavior of some of the alloys under the high velocity shock test (finger test) is given in Table 12. A comparison of the limit velocities with those of $1\frac{1}{2}$ inch STS deck armor at the same hardness is given graphically in Plate 11. The results show that on the basis of this test, the iron-manganese-nickel alloy samples have as good resistance to shock as the samples of STS armor.

48. Although an exact interpretation of this shock test in terms of actual large scale ballistic performance is not possible at this time, certain features of the test are worthy of consideration. The high velocity impact more closely

assimilates actual ballistic testing than the coupon fracture test. Furthermore, it is possible to evaluate steels on a numerical basis rather than on a visual basis while still retaining the opportunity for a visual examination. Some evidence of the sensitivity of the test is indicated by the behavior of alloy MEC. This alloy in the coupon fracture test gave a ductile fibrous fracture which did not differ from other alloys; however, when the finger test was applied, the fracture was crystalline and the limit velocity was 2620 ft/sec. - (140 ft/sec. lower than STS at the same hardness).

49. The effect of temperature on the impact resistance of an iron-manganese-nickel alloy (MDS) is shown in Plate 12. The impact value is 120 ft.lbs. at room temperature, and increases to 130 ft.lbs. at 100°C (212°F). On cooling, the impact strength gradually decreases to 100 ft.lbs. at -90°C (-130°F) and then drops sharply to 40 ft.lbs. For comparison, a temperature impact curve is given for 1½ inch STS deck armor. This steel begins to lose impact resistance rapidly at -70°C (-94°F).

CONCLUSIONS

50. The transformation temperatures from gamma to alpha of iron base alloys containing about the equivalent of 4 per cent manganese with 0.25 molybdenum, 0.25 per cent C are unaffected by the rate of cooling, even after cooling at a rate equivalent to that of the center of an 18 inch plate cooled in air. The equivalent manganese is defined as the manganese content plus one-half of the nickel content.

51. Alloys in which nickel is used to replace part of the manganese have mechanical properties which are superior to those of the alloys without nickel. Excellent fibrous fractures on thick sections and good resistance to high velocity shock have been obtained. The limit velocity of the shock test compared favorably with those obtained for STS armor.

52. The ductility of the iron-manganese alloys, even after slow cooling and tempering, is superior to that of quenched and tempered SAE steels when measured by per cent elongation, reduction of area and Charpy V-notch impact. When a comparison is made between the physical properties of the iron-manganese-nickel alloys and those required by Navy Specifications 49S2 (INT) the superiority is at once apparent. The iron-manganese-nickel alloys have twice the yield strength for the equivalent ductility of the Navy steel class "An" as shown by the following data:

	Alloy MDO	An	Ratio $\frac{MDO}{An}$
Tensile Strength, psi	119,300	80,000	1.5
Yield Strength, psi	92,000	45,000	2
Per Cent Elongation	25.5	25.0	1
Reduction of Area (%)	62.0	45.0	1.4

DECLASSIFIED

53. The iron-manganese-nickel alloys with less than 0.15 per cent carbon are not susceptible to embrittlement upon furnace cooling after tempering as measured by Charpy V-notch impact. Those alloys without nickel and 0.25 per cent C are embrittled on slow cooling after tempering; however, the ductility is fully recovered by a second tempering treatment.

54. An alloy MDS (Fe-Mn-Ni) gave exceedingly good Charpy impact resistance down to -90°C (-130°F). The critical impact temperature for this alloy was -90°C (-130°F) as compared to -70°C (-94°F) for $1\frac{1}{2}$ inch STS deck armor.

55. Although no quantitative forging tests have been made, these iron-manganese alloys were found to forge very easily and have an unusually long forging range (2300°F to 1500°F), which is particularly advantageous for deep drawing or the shaping of complicated sections.

56. Although no full scale tests have been made on the iron-manganese-nickel alloys, the physical properties such as high velocity shock and coupon fracture test indicate that these alloys may have good ballistic properties.

RECOMMENDATIONS

57. It is recommended that an alloy of the following composition be tested for heavy forgings: Mn 3.3, Ni 1.5, Mo .25, Cr .25, C .15, Si .25 per cent.

58. A list of possible uses is suggested.

- (a) Heavy forgings
- (b) Crank shafts
- (c) Main line shafts
- (d) Gears (Large)
- (e) Gun barrels
- (f) Turret tops
- (g) Turret rings
- (h) Heavy armor (over $1\frac{1}{2}$ inches thick)

DECLASSIFIED

REFERENCES

1. Troiano and McGuire, "A Study of Iron-Rich Iron-Manganese Alloys. T.A.S.M., Vol. 31, June 1943. P. 340.
2. NRL Report M-1785 (Confidential) Partial Report on the Mechanical and Ballistic Properties of Fe-Mn Alloys dated 9-26-41.
3. NRL Report M-2020 (Confidential) Second Partial Report on Mechanical and Ballistic Properties on Low Carbon Fe-Mn Alloys dated 2-43.

CONFIDENTIAL

DECLASSIFIED

DECLASSIFIED

TABLE I CHEMICAL COMPOSITIONS

	<u>C</u>	<u>Si</u>	<u>Mn</u>	<u>Ni</u>	<u>Mo</u>	<u>Cr</u>		
MBR	0.14	0.01	3.25		0.22		V	0.05
MBS	0.14	0.16	3.92		0.19		Ti	0.04
MBT	0.15	0.19	3.36				V	0.06
MBU	0.10*	0.20*	4.00*				Ti	0.10*
MBV	0.15	0.03	4.16		0.04			
MBW	0.15	0.27	3.87		0.29		B	0.003*
MCC	0.16	0.14	3.38		0.99			
MCD	0.20	0.26	3.42		0.03			
MCE	0.25	0.10	3.04		1.02			
MCG	0.21	0.17	2.97				V	0.06
MCH	0.21	0.18	2.97				V	0.06
MCK	0.22	0.16	2.94				V	0.06
MCL	0.15	0.14	2.81	1.97	0.52			
MCM	0.22	0.25	3.33				Ti	0.015
MCN	0.19	0.13	3.27				Ti	0.01
MCO	0.21	0.07	1.88	3.78	0.53			
MCP	0.17	0.09	2.00	3.86	0.54			
MCR	0.23	0.06	1.56	3.68	0.47			
MCS	0.15	0.27	3.54					
MCT	0.22	0.13	2.73	1.93	0.50		Ti	0.04
MDA	0.22	0.03	3.68		0.16			
MDB	0.18	0.03	3.43		0.29			
MDC	0.16	0.03	3.57		0.43			
MDE	0.18	0.03	2.83	2.20			Ti	0.03
MDG	0.17	0.06	2.97	2.23			Ti	0.055
MDH	0.18	0.03	2.78	2.22				
MDK	0.18	0.07	2.79	2.25		0.29		
MDL	0.17	0.06	2.84	2.25		0.48		
MDM	0.18	0.06	2.77	2.26		0.73		
MDN	0.15	0.03	2.77	2.27	0.28	0.18		
MDO	0.19	0.03	2.72	2.24	0.28	0.28		
MDP	0.19	0.02	2.60	2.27	0.28	0.40		
MDR	0.10	0.03	2.65	2.23	1.01			
MDS	0.08	0.05	2.75	2.24	0.61			
MDT	0.10	0.05	2.84	2.46	0.26			
MDU	0.20*	0.20*	2.81*	1.88*	1.00*			
MDV	0.17	0.03	2.85	2.35	0.28			
MDX	0.17	0.13	3.17	1.13	0.26			
MDW	0.18	0.04	2.97	2.37	0.16			
MDZ	0.15	0.13	3.40	0.72	0.31			
MEA	0.26	0.17	3.25	1.68	0.30			
MEB	0.26	0.17	3.68	1.16	0.28			
MEC	0.26	0.14	3.64	0.83	0.30			
MED	0.11	0.16	3.00	1.70	0.25			
MEP	0.16	0.13	3.31	1.55	0.29	0.36		
MEQ	0.18	0.11	3.42	1.51	0.24	0.24		

DECLASSIFIED

DECLASSIFIED

	<u>C</u>	<u>Si</u>	<u>Mn</u>	<u>Ni</u>	<u>Mo</u>	<u>Cr</u>		
MTL	0.09	0.14	5.39		1.02			
MVK	0.11	0.13	3.66		0.89	0.16		
MXR	0.13	0.06	3.79		0.47			
MXS	0.13	0.04	3.96			0.50		
MXT	0.13	0.04	3.94			0.70		
MXU	0.11	0.03	3.80			0.96		
MXV	0.10	0.10	3.50		0.72			
MXW	0.11	0.16	3.93					
MXZ	0.11	0.03	3.77				Cb	0.26
MYM	0.12	0.20*	4.28		0.75*		V	0.31
							Ti	0.32
MYN	0.12	0.20*	4.28		0.75*		Ti	0.30*
MYO	0.12	0.20	4.28		0.75*		Ti	0.40*
MYP	0.13	0.20*	4.28		0.75*		Ti	0.55
MYR	0.13	0.20*	4.13		0.50*		Ti	0.28
MYS	0.13	0.20*	4.13		0.50*		Ti	0.30*
MYT	0.13	0.20*	4.13		0.50*		Ti	0.40*
MYU	0.13	0.20*	4.13		0.50*		Ti	0.50*
MYV	0.12	0.20*	4.21				Ti	0.53
MYW	0.12	0.20*	4.21				Ti	0.40*
MYX	0.13	0.20*	4.21				Ti	0.77
MYY	0.13	0.20*	4.21				Ti	0.60*
MZA	0.10*	0.20*	4.00*		0.75*		V	0.091
MZB	0.10*	0.20*	4.00*		0.75*		V	0.10*
MZC	0.10*	0.20*	4.00*		0.75*		V	0.15*
MZD	0.10	0.10	4.25		0.80		B	0.003*
MZE	0.10	0.17	4.60			0.79	Ti	0.11
MZG	0.10	0.16	4.56			0.81	Ti	0.086
MZH	0.09	0.17	4.63			0.83	Ti	0.11
MZJ	0.09	0.03	4.40			1.41	Ti	0.04
MZK	0.10	0.14	4.36			1.46	Ti	0.075
MZL	0.11	0.15	4.35			1.41	Ti	0.094
MZM	0.11	0.17	4.52		1.05		Ti	0.113
MZN	0.09	0.12	4.60		1.06		Ti	0.12
MZO	0.09	0.13	4.50		0.70		Ti	0.10
MZP	0.08	0.13	4.50		0.64		Ti	0.10

* Nominal content.

DECLASSIFIED

DECLASSIFIED

TABLE 2 EFFECT OF AUSTENITIZING TEMPERATURE ON THE TRANSFORMATION TEMPERATURE AND PERCENTAGE OF RETAINED AUSTENITE

ALLOY MVK

Run	Austenitizing Temperature		Start	End	Start	End	Retained Austenite Per Cent
	$^{\circ}\text{C}$	$^{\circ}\text{F}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	
1	840	1545	714	829	410	372	22
2	870	1600	714	834	396	336	19
3	900	1650	714	833	383	323	15
4	955	1750	714	822	384	314	13
5	870	1600	713	822	386	319	15

DECLASSIFIED

DECLASSIFIED

TABLE 3 EFFECT OF AUSTENITIZING TEMPERATURE ON CHARPY V-NOTCH IMPACT

Heat Treatment: Austenitized at Indicated Temperature for Two Hours, Furnace Cooled According to Curve A, Plate 3, Tempered at 650°C (1200°F) for Two Hours and Water Quenched.

ALLOY MVK

Austenitizing Temperature		Charpy V-Notch Impact	Hardness
°C	°F	ft.-lbs.	R _c
800	1472	31	--
815	1500	51	24
840	1545	47	--
870	1600	100	22
930	1706	104	22
955	1750	90	20

CONFIDENTIAL

DECLASSIFIED

DECLASSIFIED

TABLE 4 EFFECT OF TEMPERING TEMPERATURES ON THE FORMATION OF AUSTENITE

ALLOY MVK

Tempering Temperature		Per Cent Austenite Formed After 5 Hours	
°C	°F		
567	1050	0	
600	1112	4	
650	1200	16	
675	1250	24	
700	1292	35	

CONFIDENTIAL

DECLASSIFIED

DECLASSIFIED

TABLE 6 EFFECT OF TEMPERING TIME AND RATE OF COOLING FROM TEMPERING TEMPERATURE ON CHARPY IMPACT OF ALLOY MVK

Heat Treatment: 900°C (1650°F) for 2 hours, furnace cooled (A) and tempered as indicated

Specimen Number	Tempering Treatment 650°C (1200°F)	Charpy Impact ft.lbs.	X-Ray Diffraction
12	4 hours, W. Q.	123+	α sharp β moderately strong
15	4 hours, F. C.	25	α broad β medium
205	4 hours, A. C.	20	
17	16 hours, F. C.	25	α very broad β very faint
26	16 hours, W. Q.	52	α sharp β strong

CONFIDENTIAL

DECLASSIFIED

DECLASSIFIED

TABLE 7 EFFECT OF DOUBLE TEMPERING ON TEMPER BRITTLENESS

Heat Treatment:- 900°C (1650°F) 2 hours, furnace cooled (A)
furnace cooled after each tempering treatment.

Tempering Treatments	Held 3 hours Impact ft.lbs.	Hardness R _c	Held 5 hours Impact ft.lbs.
°C	<u>ALLOY MVK</u>		
650 W.Q.	123 plus	20	25**
650	25*	22	67
650 plus 650	69	22	67
650 plus 600	67	22	62
650 plus 550	42	22	40
675 plus 600	22	20	
650 plus 500	22	21	
600 plus 550	51	25	
	<u>ALLOY MEB</u>		
600 W.Q.	87	28	
600	51	28	
600 plus 600	85	28	
550	81	30	
	<u>ALLOY MDS</u>		
600 W.Q.	123	20	
600	123	20	
600 plus 600	136	20	
	<u>ALLOY MDZ</u>		
600 W.Q.	107	23	
600	102	22	

* Four hours
** Sixteen hours

CONFIDENTIAL

DECLASSIFIED

TABLE 8 EFFECT OF TEMPERING TIME ON IMPACT RESISTANCE OF ALLOY MVK

Heat Treatment: 900°C (1650°F) furnace cooled (A), tempered at 650°C (1200°F) for indicated time and water quenched.

Tempering Time (Hrs.)	Impact Resistance ft.-lbs.	Hardness R _c
2	104	21
4	123	20
8	93	20
16	52	20

DECLASSIFIED

TABLE 9 HARDNESS DATA OF ALLOYS CONTAINING TITANIUM,
VANADIUM, CHROMIUM AND MOLYBDENUM

Heat Treatment: Furnace cooled (A) from 900°C (1650°F) and
tempered for 2 hours at temperatures indicated

Alloy	Mn	Mo	Si	C	Ti	Furnace	600°C	650°C	675°C
						Cooled	1100°F	1200°F	1250°F
MYM	4.28	.75*	.20*	.12	.32	Rc	Rc	Rc	Rc
MYN	4.28	.75*	.20*	.12	.30*	32	26	25	26
MYO	4.28	.75*	.20*	.12	.40*	24			
MYP	4.28	.75*	.20*	.13	.50	15			
MYR	4.13	.50*	.20*	.13	.28	12			
MYS	4.13	.50*	.20*	.13	.30*	29	23	23	24
MYT	4.13	.50*	.20*	.13	.40*	29			
MYU	4.13	.50*	.20*	.13	.50*	26			
MYV	4.21		.20*	.12	.53	23			
MYW	4.21		.20*	.12	.40*	9			
MYX	4.21		.20*	.13	.77	9			
MYY	4.21		.20*	.13	.60*	10			
MZA	4.00*	.75*	.20*	.10*V	.091	39	32	30	31
MZB	4.00*	.75*	.20*	.10*V	.10*	40	36	33	32
MZC	4.00*	.75*	.20*	.10*V	.15*	39	37	34	30
		Cr	Si	C	Ti				
MZE	4.60	.79	.17	.10	.11	36	25	23	24
MZJ	4.40	1.41	.03	.09	.04	35	20	21	23
MZM	4.52	1.05	.17	.11	.12	36	29	27	27

* Nominal analysis

CONFIDENTIAL

DECLASSIFIED

TABLE 10 MECHANICAL PROPERTIES

Heat Treatment: 900°C (1650°F) 2 hours furnace cooled (A)

- A - Tempered 4 hours at 600°C (1112°F) water quenched
- B - Tempered 4 hours at 650°C (1200°F) water quenched
- C - Tempered 4 hours at 675°C (1250°F) water quenched
- D - Tempered 4 hours at 675°C (1250°F) furnace cooled (A)
retempered 650°C (1200°F) 2 hours, furnace cooled (A)
- E - Tempered 4 hours at 550°C (1020°F) and furnace cooled (A)
- F - Tempered 4 hours at 600°C (1112°F), furnace cooled (A)

Alloy	Treatment	Tensile Strength	(0.2 Per Cent) Yield Strength	% El	% RA	TS x % El x 10 ⁻⁶	Charpy V-Notch Impact ft.-lbs.
<u>MXR</u>	A	137,500		23.0	44.1	3.2	66
Mn 3.79	B	126,000		23.5	51.7	3.0	--
Mo .47	C	105,100		24.5	60.3	2.6	68
Si .06	D	115,500		33.5	57.3	3.9	55
C .13							
<u>MXS</u>	A	115,000		24.5	53.1	2.5	10
Mn 3.96	B	112,500		25.5	55.3	2.9	22
Cr .50	C	96,800		27.0	68.1	2.1	25
Si .04	D	116,200		28.0	46.3	3.3	3
C .13							
<u>MXT</u>	A	125,000		21.0	51.4	2.8	45
Mn 3.94	B	111,700		28.0	57.5	3.1	37
Cr .70	C	116,500		23.5	55.2	2.7	37
Si .04	D	122,200		26.5	42.0	3.3	3
C .13							
<u>MXU</u>	A	123,500		20.5	49.6	2.6	20
Mn 3.50	B	110,700		25.0	58.2	2.8	39
Cr 0.96	C	106,200		23.0	66.9	2.4	31
Si .03	D	125,700		22.5	48.3	2.8	4
C .11							
<u>MXV</u>	A	125,000		22.0	48.4	2.8	54
Mn 3.50	B	117,000		24.0	53.4	2.8	64
Mo .72	C	108,800		21.5	56.5	2.3	40
Si .10	D	114,000		30.0	53.4	3.4	6
C .10							
<u>MXW</u>	A	130,000		18.5	36.9	2.4	30
Mn 3.93	B	95,000		25.5	66.9	2.5	25
Cr .26	C	111,500		26.0	54.1	2.8	13
Si .16	D	115,200		28.5	46.3	3.3	20
C .11							

CONFIDENTIAL

DECLASSIFIED

Alloy	Treatment	(0.2%) Tensile Strength	Yield Strength	% El	% RA	TS X $\frac{\%}{10^{-6}}$ El	Charpy V-notch Impact ft.-lbs.
<u>MXZ</u>	A	137,000		18.5	53.5	2.5	4
Mn 3.77	B	125,000		21.5	57.2	2.7	21
V .31	C	115,000		24.5	53.9	2.8	16
Si .03	D	131,700		21.0	55.7	2.3	5
C .11							
<u>MZD</u>	A	150,500	106,000	15.0	39.4	2.3	45
Mn 4.25	B	132,000	77,000	24.5	52.0	3.4	65
Mo 0.80	C	125,000	88,500	25.0	62.6	3.1	100
Si .10	D	139,000	71,500	26.4	48.4	3.7	77
C .10							
B .003 added							
<u>MZG</u>	A	155,300	87,700	16.0	41.5	2.5	23
Mn 4.56	B	131,000	72,250	27.5	55.5	3.6	43
Cr 0.81	C	119,500	81,000	27.0	60.7	3.2	--
Ti 0.086	D	144,500	58,500	24.0	48.8	3.5	41
Si .16							
C .10							
<u>MZH</u>	A	174,500	120,000	13.0	41.3	2.3	22
Mn 4.63	B	140,000	60,000	21.0	38.2	2.4	35
Cr 0.83	C	114,000	82,000	25.5	59.8	2.9	24
Ti 0.11	D	140,000	64,500	23.0	52.8	3.2	38
Si 0.17							
C 0.09							
<u>MZK</u>	A	160,500	94,500	18.0	45.8	2.6	24
Mn 4.36	B	127,300	74,300	24.0	56.0	3.0	42
Cr 1.46	C	122,500	82,300	23.5	58.2	3.1	15
Ti .075	D	140,500	61,500	20.0	44.9	2.8	38
Si .14							
C .10							
<u>MZM</u>	A	162,500	93,000	18.5	49.2	3.0	21
Mn 4.52	B	137,500	87,000	22.0	54.0	3.0	66
Mo 1.05	C	131,300	89,300	21.5	57.9	2.8	44
Ti .118	D	140,800	74,500	24.0	51.0	3.4	50
Si .17							
C .11							
<u>MZN</u>	A	161,500	101,500	14.0	45.8	2.3	22
Mn 4.60	B	138,300	92,000	21.0	43.7	2.8	77
Mo 1.06	C	135,500	93,000	21.0	55.7	2.7	50
Ti .12	D	140,000	78,000	24.0	49.5	3.4	45
Si .12							
C .09							

DECLASSIFIED

Table 10 (Continued)

Alloy	Treatment	Tensile Strength	(0.2 Per Cent) Yield Strength	% El	% RA	TS x 10 ⁻⁶ x 10 ⁻⁶ El	Charpy V-Notch Impact ft.-lbs.
MZO	A	151,500	94,000	15.0	51.5	2.2	29
Mn 4.50	B	127,000	80,500	22.0	50.3	2.8	26
Mo .79	C	119,500	88,500	22.5	58.0	2.6	26
Ti 0.10	D	134,500	67,000	27.0	56.8	3.6	21
Si .13							
C .09							
MZF	A	149,000	97,000	18.0	52.5	2.7	26
Mn 4.50	B	128,500	81,000	22.0	50.0	2.9	25
Mo .64	C	120,500	90,500	22.0	60.0	2.7	24
Ti .10	D	132,800	72,000	26.0	55.5	3.5	20
Si .13							
C .08							
MDO	E*	119,300	92,000	25.5	62.0	3.0	
Mn 2.72	F*	118,000	-----	27.5	62.7	3.3	96
Ni 2.24							
Mo .28							
Cr .28							
Si .03							
C .19							
MCT	E*	131,500	101,000	23.5	55.5	3.1	64
Mn 2.73	F*	126,000	90,000	26.5	58.0	3.3	
Ni 1.93							
Mo .50							
Si .13							
C .22							
MDV	E*	116,000	87,500	25.5	61.3	3.0	
Mn 2.85	F*	112,100	67,500	29.5	61.5	3.3	85
Ni 2.35							
Mo .28							
Si .03							
C .17							
MGL	A*	122,250	100,000	23.5	58.6	2.9	97
Mn 3.42	E*	127,500	104,500	23.3	57.6	3.0	105
Ni 1.51	F*	118,100	95,500	25.7	62.4	3.0	150
Mo .24							
Cr .24							
Si .11							
C .18							

* 900°C (1650°F) 2 hours furnace cooled (B)

TABLE 11 COUPON FRACTURE STUDY

Alloy	900°C (1650°F) Air Cooled; 600°C (1100°F) Oil Quenched			900°C (1650°F) Furnace Cooled; 600°C (1100°F) Oil Quenched			900°C (1650°F) Air Cooled; 600°C (1100°F) Furnace Cooled			900°C (1650°F) Furnace Cooled; 600°C (1100°F) Furnace Cooled		
	Fracture	Charpy Impact ft.lbs.	BHN	Fracture	Charpy Impact ft.lbs.	BHN	Fracture	Charpy Impact ft.lbs.	BHN	Fracture	Charpy Impact ft.lbs.	BHN
MBT	Cryst.	47	250				Cryst.	250		24		
MCH		--	264							24		
MCG		17	267									
MCK		16	263									
MBR		60	250				Cryst.	250				
MBU	"	102	248				Cryst.	250				
MCS	"	27	229							23		
MCM	"	8	266							11		
MCN	"	19	345							17		
MBS	"	92	260				Cryst.	250				
MBV	"	105	250				Cryst.	250				
MBW	"	73	250				Cryst.	250				
MCC	"	69	250									
MCD	"	20	241							22		
MCE	"	10	327							10		
MDA	Fibrous	58	204		75	200						
MDB	"	64	229	Cryst.	85	230						
MDC	"	63	222		78	220			Cryst.		220	
MDE	Cryst.	50	223		38	220						
MDG	"	55	223	Cryst.	33	226						
MDH	"	28	215	Cryst.	36	221						
MDK	"	--	231						Cryst.		237	
MDL	"	21	234	Cryst.	23	237						
MDM	"	4	224	Cryst.	18	224						
MDN	Fibrous	73	239	Fibrous	91	239						
MDO	"	100	229	Fibrous	96	242			Cryst.		249	
MDP	"	93	235		89							
MCO	"	50	298	Fibrous		256						
MCP	"	60	300	Fibrous		253						
MCR	"	54	313	Cryst.		253				16		
MDR	"	98	266	Fibrous	115	252						
MDS	"	111	218		122				Fibrous		229	
MDT	"	111	208		117				Cryst.		223	

DECLASSIFIED

DECLASSIFIED



Table 11 (Continued)

Alloy	900°C (1650°F) Air Cooled; 600°C (1100°F) Oil Quenched		900°C (1650°F) Furnace Cooled; 600°C (1100°F) Oil Quenched		900°C (1650°F) Air Cooled; 600°C (1100°F) Furnace Cooled		900°C (1650°F) Furnace Cooled; 600°C (1100°F) Furnace Cooled	
	Fracture	Charpy Impact ft.lbs.BHN	Fracture	Charpy Impact ft.lbs.BHN	Fracture	Charpy Impact ft.lbs.BHN	Fracture	Charpy Impact ft.lbs.BHN
MCL	Fibrous	286	Fibrous	266				
MCT	"	64 294					49	
MDU	"	93 215					Cryst.	220
MDV	"	97 230	Fibrous	85 240				
MDW	"	-- 234		82 240			Cryst.	241
MDX	"	90 228	Fibrous	99 232			75	230
MDZ	"	107 230	Cryst.	103 222			102	230
MEA	"	76 272	Fibrous	57 275			35	300
MEB	"	67 275	Fibrous	76 278			27	300
MEC	"	55 266	Fibrous	58 275			20	290
MED*	"	214						

* 3-inch coupon bar

DECLASSIFIED

CONFIDENTIAL

DECLASSIFIED

DECLASSIFIED

TABLE 12 HIGH VELOCITY SHOCK TEST

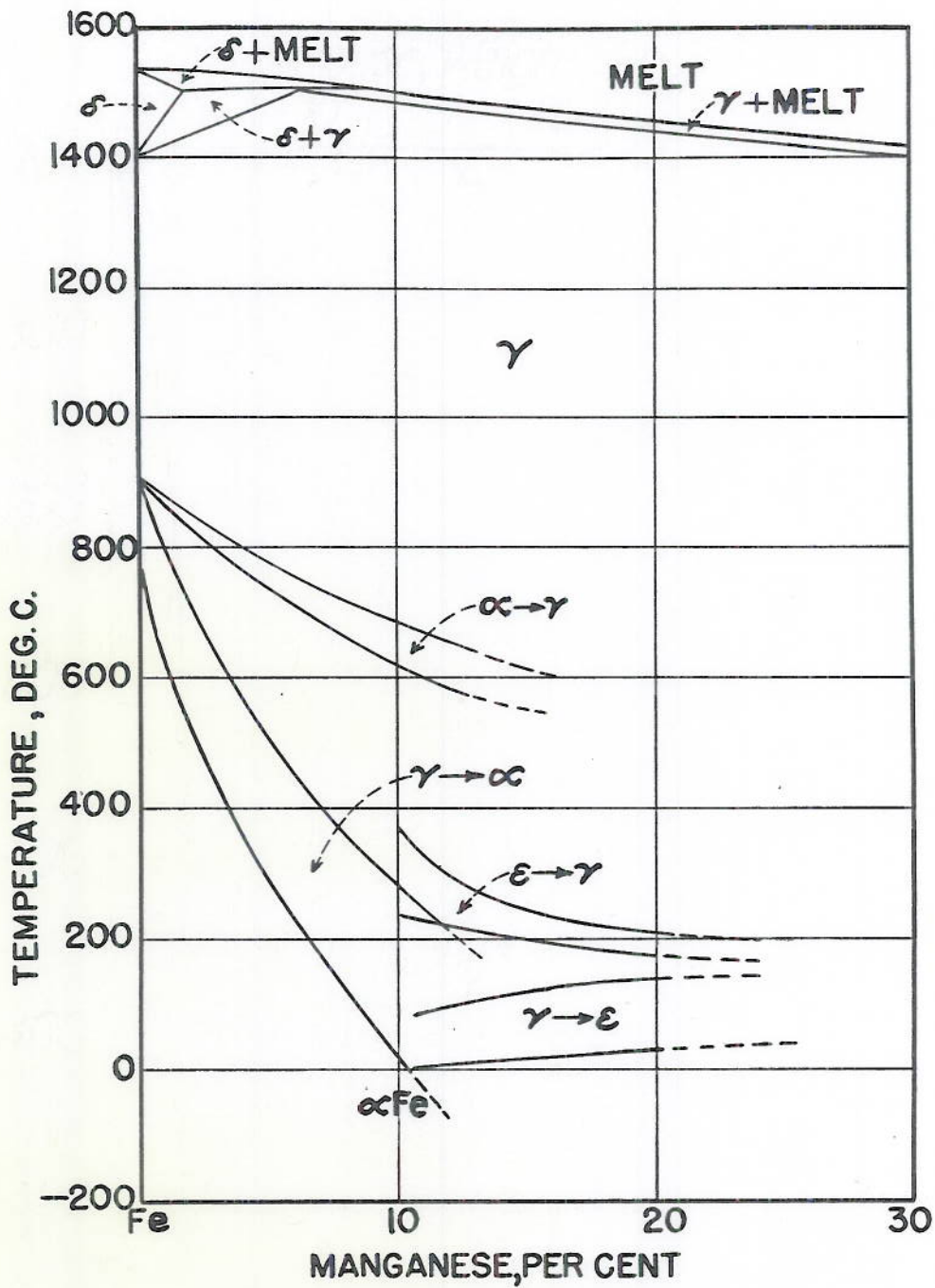
Heat Treatment: A - Air cooled from 900°C (1650°F).
 Tempered at 600°C (1112°F) oil quenched
 B - Furnace cooled (B) from 900°C (1650°F). Tempered at 600°C (1112°F). Oil quenched

Alloy	Composition				Heat Treatment	BHN	Limit Velocity ft./sec.	Fracture
	C	Mn	Mo	Ni				
MCO	.21	1.88	.53	3.78	A	298	2690	Fibrous
MCT	.22	2.71	.50	1.98	A	294	2660	Laminated, fibrous
MDV	.17	2.85	.28	2.35	A	230	2850	Fibrous
MDV					B	240	2850	Slightly grainy
MDS	.08	2.75	.61	2.24	A	218	2910	Slightly grainy
MDO	.19	2.72	.28	2.24	Cr .28 A	229	2880	Fibrous, woody
MDO					B	242	2830	Slightly grainy
MEC	.26	3.64	.30	.83	A	275	2620	Crystalline

~~CONFIDENTIAL~~

DECLASSIFIED

DECLASSIFIED

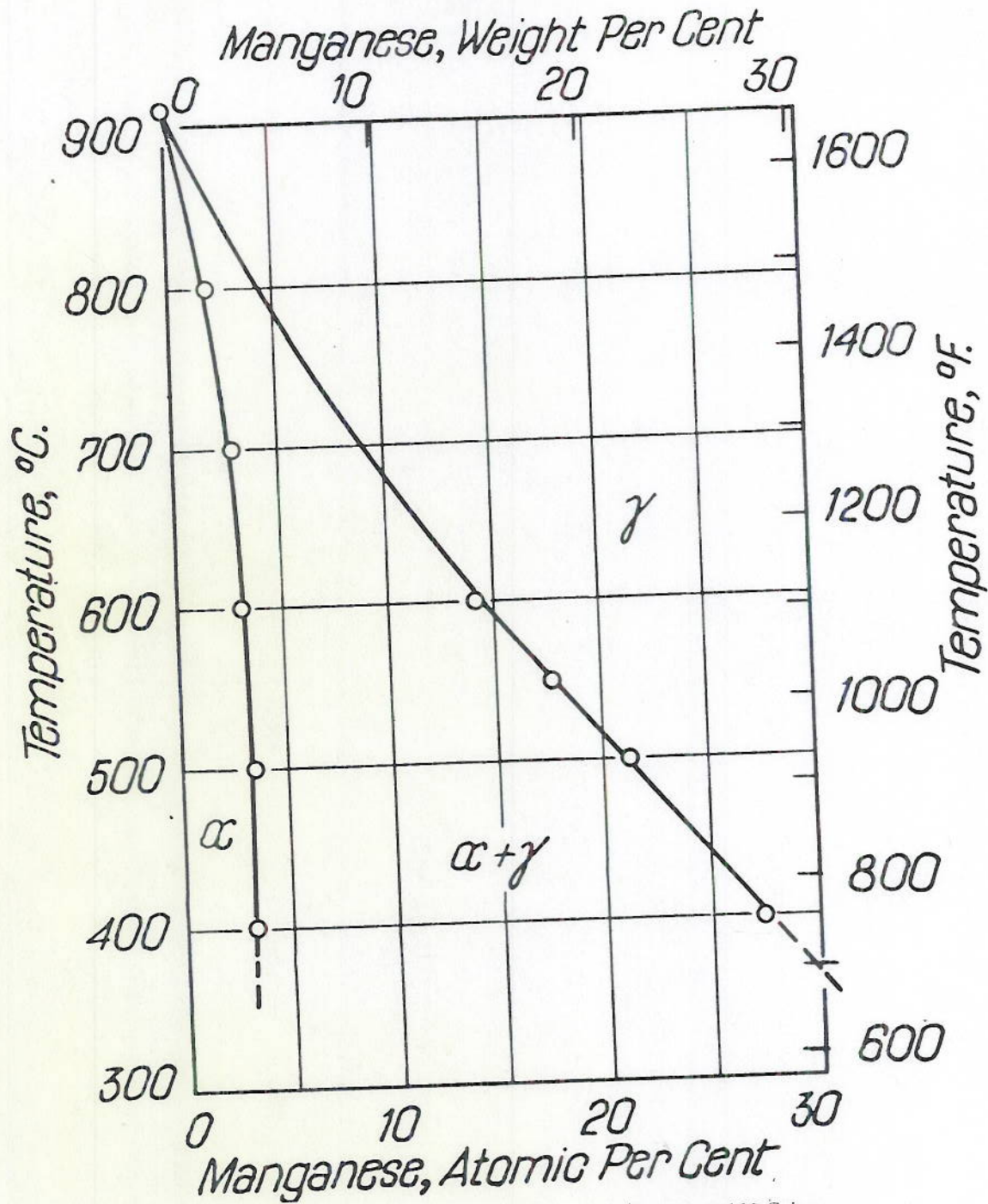


IRON-MANGANESE CONSTITUTIONAL DIAGRAM

DECLASSIFIED

CONFIDENTIAL

DECLASSIFIED



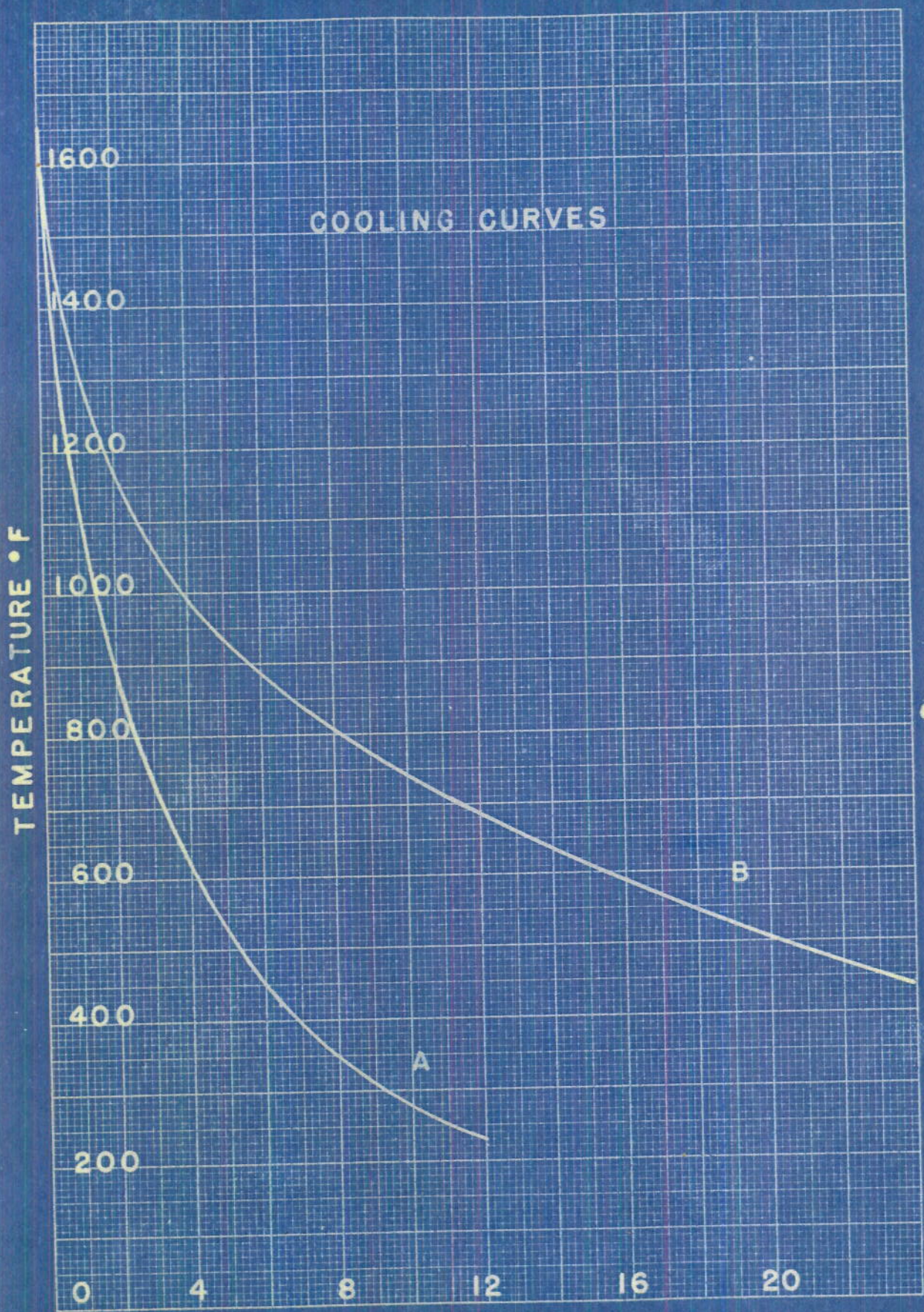
Trojano and McGuire..

DECLASSIFIED

PLATE 2

CONFIDENTIAL

UNCLASSIFIED



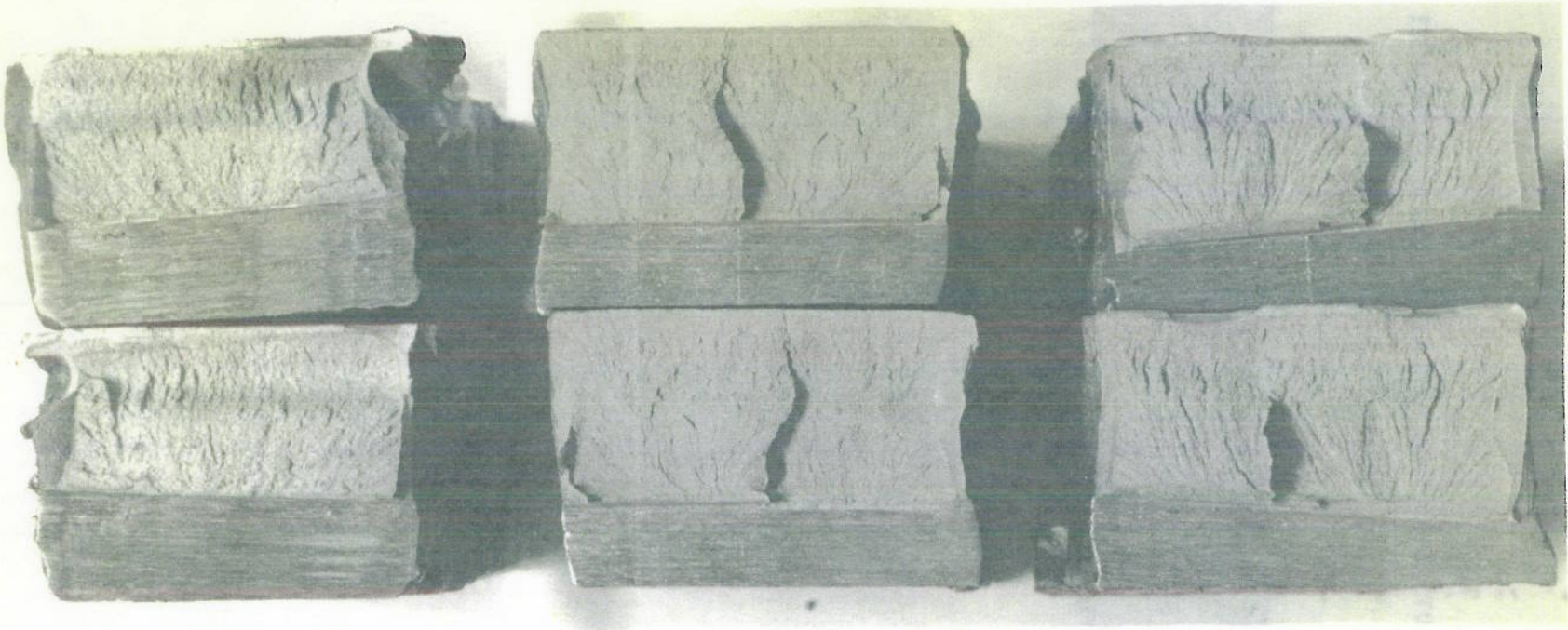
TIME-HRS

PLATE 3

UNCLASSIFIED

CONFIDENTIAL

TYPICAL EXAMPLES OF GRAINY FRACTURES



MAZ-1

MAZ-2

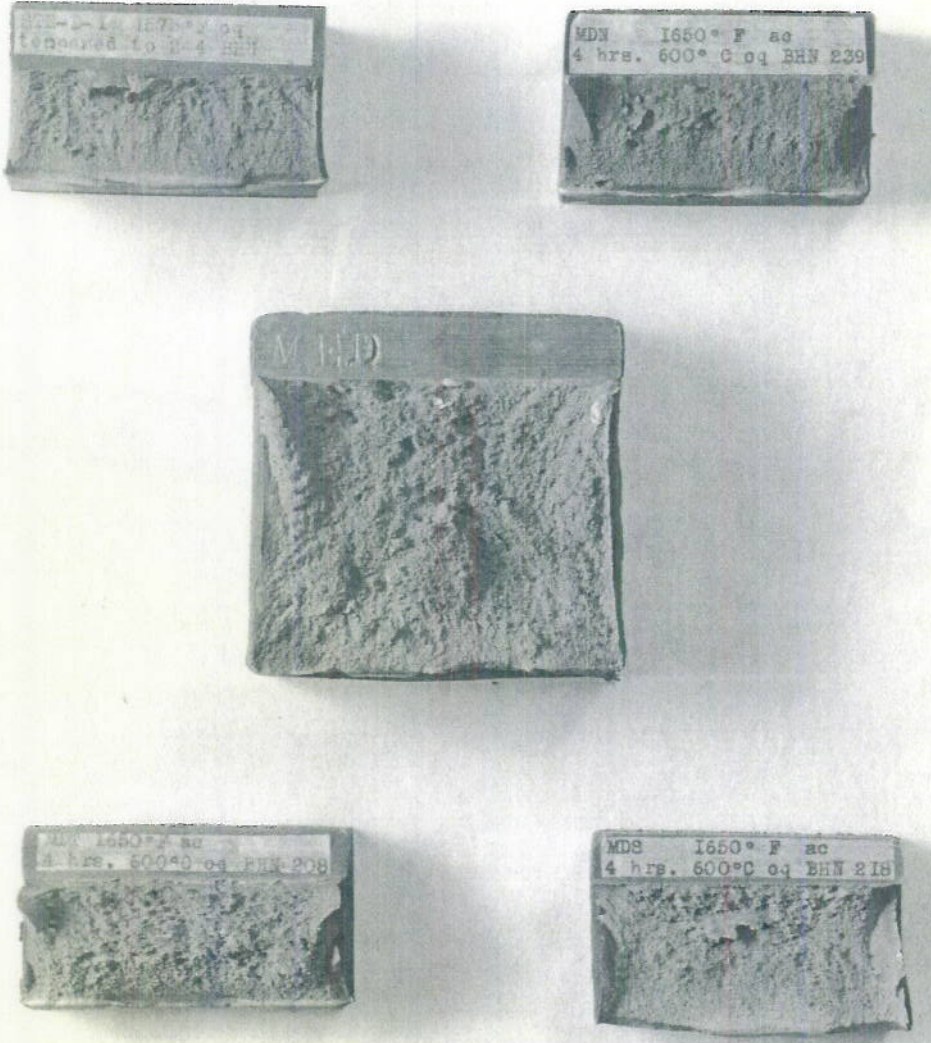
MAZ-3

DECLASSIFIED

DECLASSIFIED

DECLASSIFIED

TYPICAL EXAMPLES OF DUCTILE COUPON FRACTURES



DECLASSIFIED

FINGER SPECIMEN FOR HIGH VELOCITY IMPACT TEST



DECLASSIFIED

CONFIDENTIAL

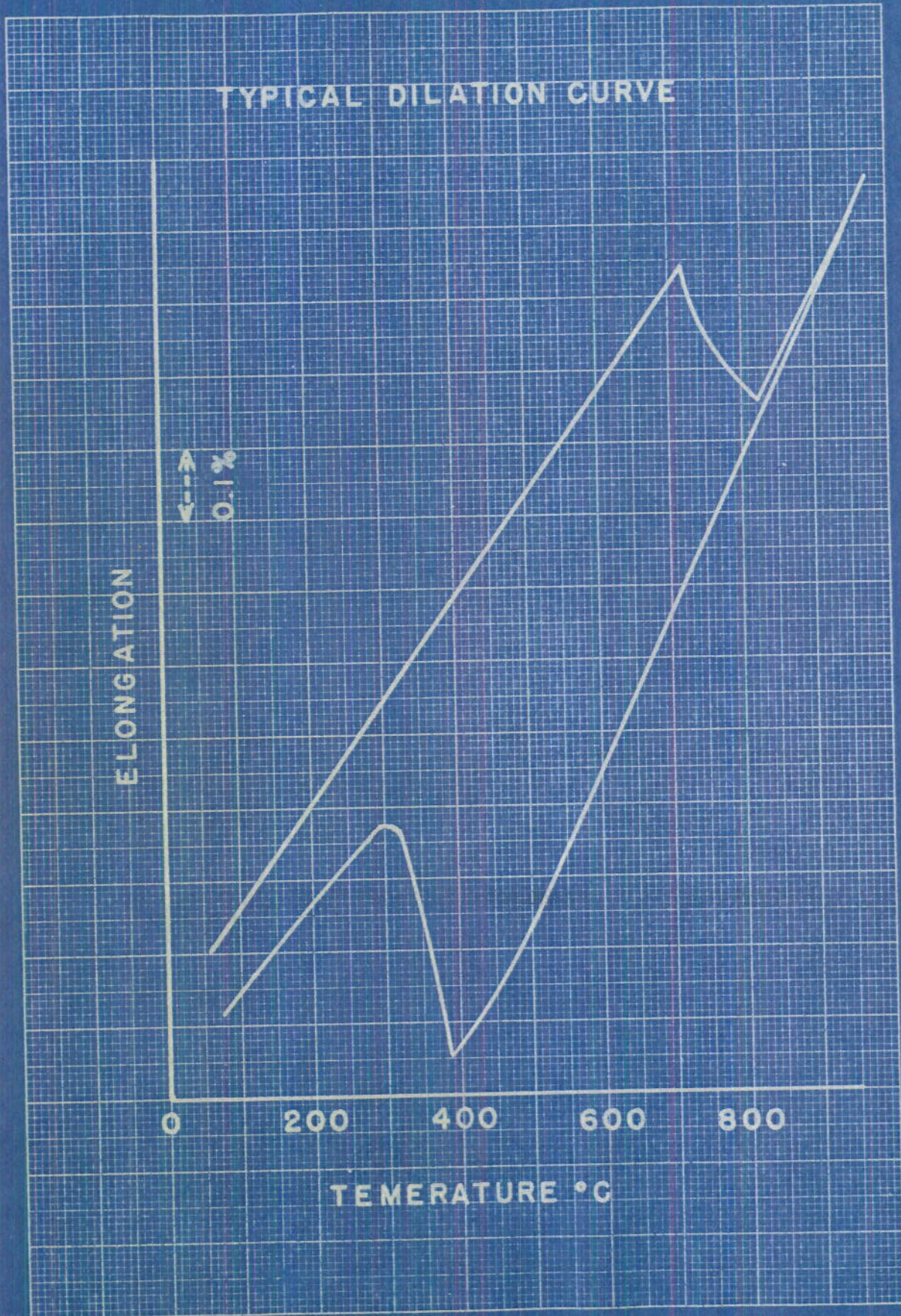
PI ATF 6

EFFECT OF TEMPERING ON AUSTENITE FORMATION

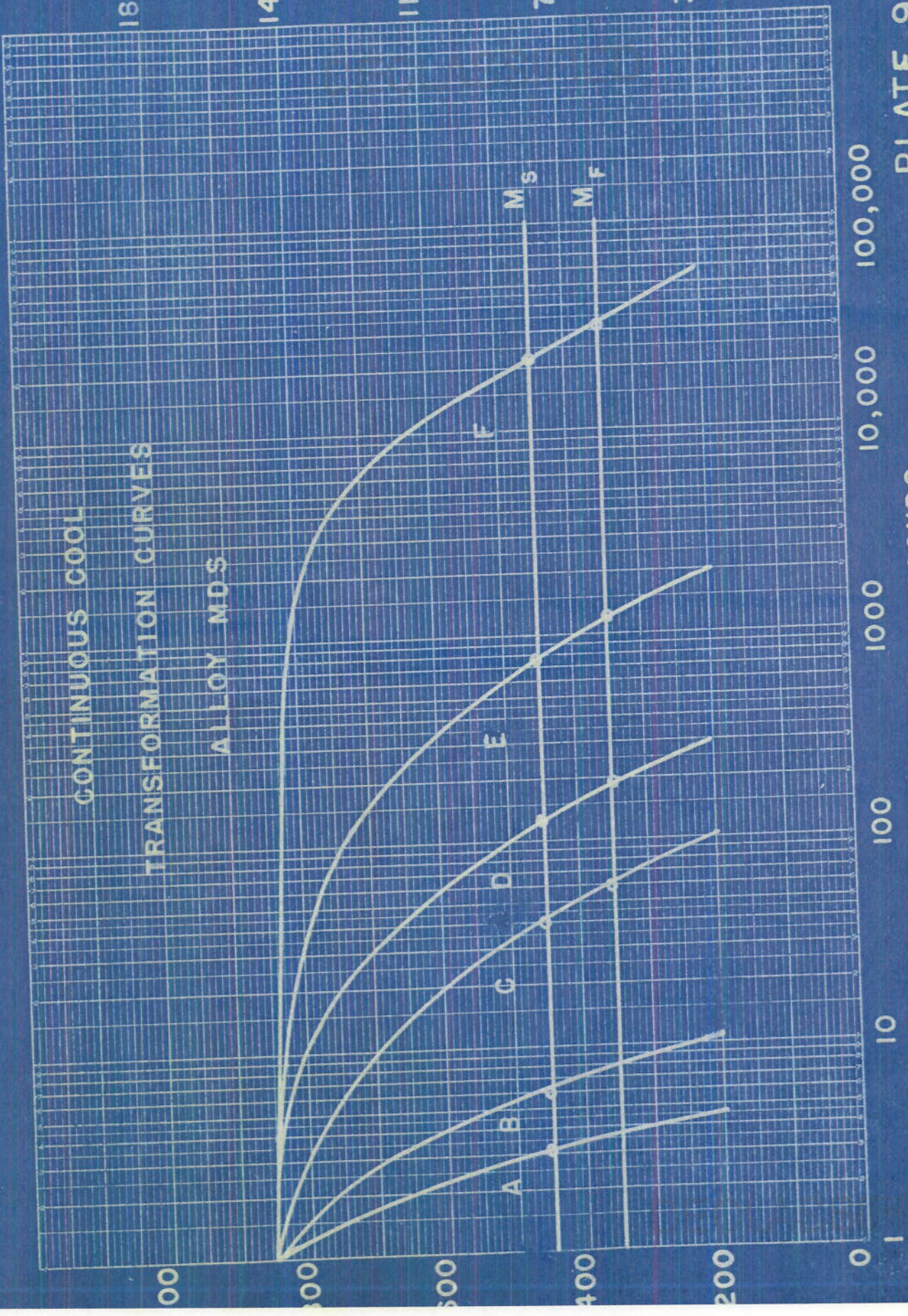


DECLASSIFIED

TYPICAL DILATION CURVE



CONTINUOUS COOL
TRANSFORMATION CURVES
ALLOY MDS



1832

1472

1112

752 °F

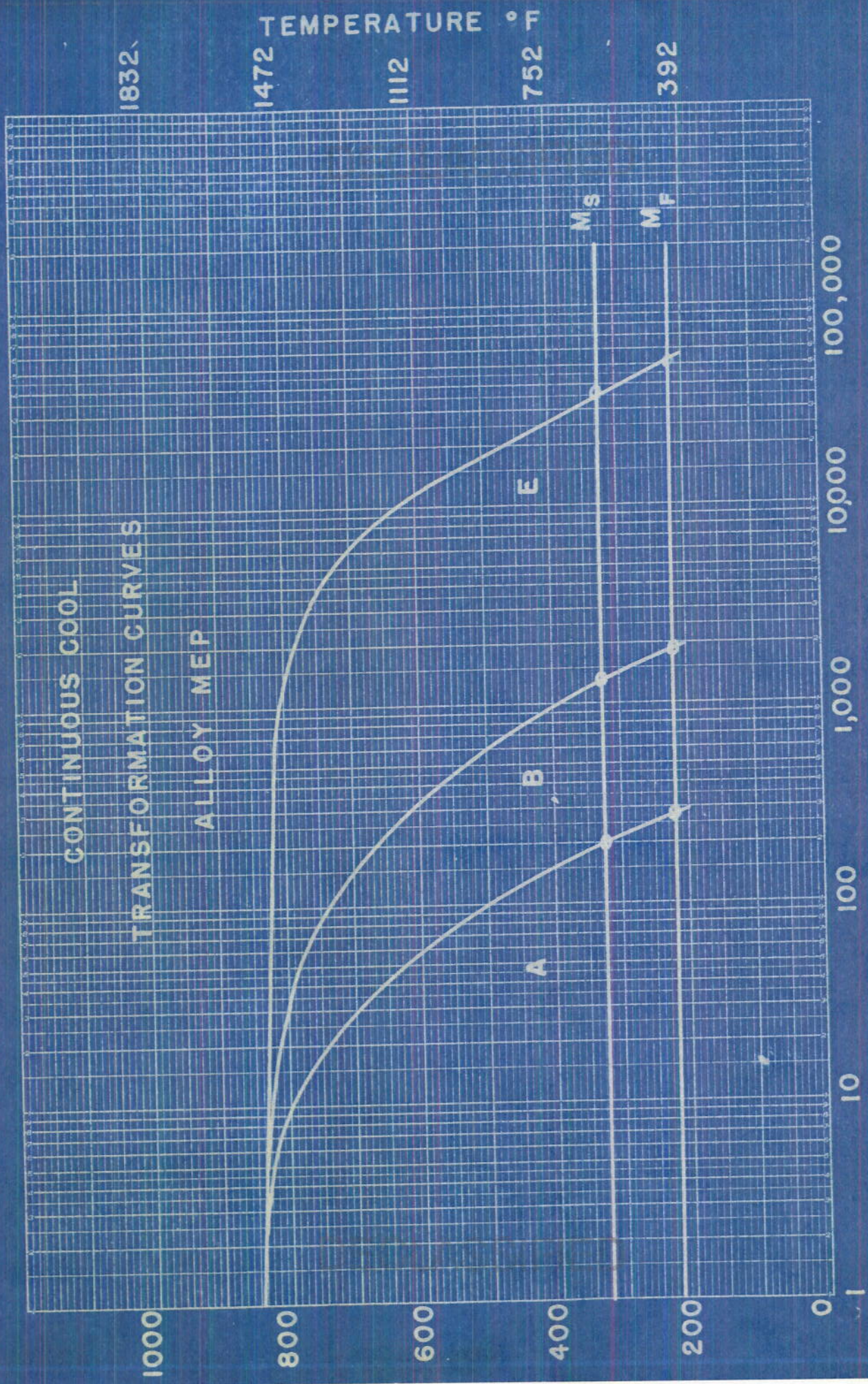
392

100,000
10,000
1000
100
10
1

TIME - SECONDS

PLATE 9

CONTINUOUS COOL
TRANSFORMATION CURVES
ALLOY MEIP



1832
1472
1112
752
392

COMPARISON OF FE-MN-NI ALLOYS
 WITH STS AT EQUAL HARDNESS
 (FINGER TEST)



-400 -200 0 200 400

VELOCITY FT/SEC

PLATE II

EFFECT OF TEMPERATURE ON
CHARPY V-NOTCH IMPACT

