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Report on

The Effect of Mass Upon the Mechanical Properties of Cast Steel

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ABSTRACT

Medium carbon cast steel and medium manganese cast steel were studied to show the effect of mass upon the mechanical properties. Coupons varying from 1/2 inch to 8 inches in cross section were cast and tensile bars were prepared and tested in both the as cast and annealed condition. Density measurements, segregation studies, and photomicrographs were also obtained on the various sections. A comparison was made between results obtained from the coupons and various diameter test bars cast to size. The effect of pouring temperatures on the mechanical properties was also studied, as was the effect produced by high temperature heat treatments.

TABLE OF CONTENTS

APPENDICES

AUTHORIZATION

1. The studies in steel castings were originally authorized by the Bureau of Engineering letter QP/Castings (6-19-Ds) of 13 July 1928.

STATEMENT OF PROBLEM

2. The object of this report is to present information on the effect of mass upon the mechanical properties of cast steel.

KNOWN FACTS BEARING ON THE PROBLEM

3. The purpose of this investigation was to study and set forth as simply as possible the effect of mass upon the mechanical properties of cast steel. This is a subject that is of practical importance to designing engineers, particularly those engaged in designing power plant equipment where steel castings are being installed in systems subject to greater pressures and higher temperatures than those previously used. There engineers have relied upon data collected on the properties of cast steel such as that assembled by Lorig and Williams (11)*. They realize, as was noted by Lorig and Williams, that such data are rarely complete in that the chemical analyses, size of casting, heat treatment, size of the specimen or the method of testing are not always known. As many of the data are obtained from laboratory heats produced under ideal conditions the results may not be comparable to those obtained in a commercial casting. In commenting on this condition Sisco, in his volume of the Alloys of Iron Monographs, pointed out that of all the variables which may affect the mechanical properties of cast steel, and one which is seldom mentioned in the compilation of data, the effect of mass is clearly the most important.

4. The lack of specific published information has led to the perennial controversy over the size of the test coupon, the use of separately cast or integrally cast coupons and the actual value of the data obtained from a coupon as applied to the acceptance and rejection of a particular steel casting.

5. As this is a problem which involves no special research equipment or complicated procedures it is interesting to note that there is practically no published data available that deals with the subject in a logical manner even though there must be many private sources of material similar to that presented here. Practically all of the authors who have discussed the subject have dealt with cast steel in the heat treated condition and have concentrated their efforts upon the effect of heat treatment upon the mechanical properties in various sections rather than the effect of the mass of the section upon the mechanical properties.

* The figures appearing in parentheses pertain to the references appended to this report.

6. Even though there has been no attempt to correlate the size of the section with mechanical properties it has been pointed out that there is considerable variation in the properties of different sections of steel castings (2,6). It has also been noted that the structure has differed (1,2,3,4,5,7,9) in various sections of castings and many attempts (1 to 9) have been made to obtain uniform mechanical properties or to improve the mechanical properties of heavy sections by means of heat treatment.

7. Merton (2) concluded from his experiments on core-drilled specimens obtained from heavy castings that silicon segregation caused low physical properties in heavy cast steel sections. He stated that better physical properties could be obtained by annealing the castings at temperatures higher than those normally employed as the dendritic structure was completely refined at these higher temperatures. He also concluded that casting at as low a temperature as possible produced the best physical properties.

8. Harper and Stein (3) compared the physical properties of test coupon bars with those of drilled specimens obtained from large steel castings and studied the effect of multiple heat treatments upon the physical properties. They found that higher ductility was obtained in specimens that were quenched or normalized as compared to specimens which were only annealed. They also noted the physical properties of specimens obtained from properly heat-treated castings compared favorably with the specimens obtained from test coupons.

9. MacPherran and Harper (4) in a study similar to that by Harper and Stein reported that good physical properties could be obtained in massive sections by a normalizing, annealing and spheroidizing treatment.

10. A. W. Lorenz (5) in a paper presented as a portion of the "Symposium on Steel Castings" discussed heat treatment of steel castings and presented results obtained on 4 inch sections. However, he made no comparison with the physical properties obtainable in cast coupons or sections of other sizes.

11. R. A. Bull (6) pointed out that different sections of the same steel casting may have entirely different physical properties due to different rates of solidification.

12. C. E. Sims (7) discussed the heat treatment of steel castings and pointed out that the empirical annealing time of 1 hour per inch of section was suitable for annealing at 1650° F. If, however, higher temperatures are used the time can be reduced considerably without affecting the result. He found that for each 100° F. increase in the annealing temperature the time could be reduced by one-half. He also stated that a double normalizing treatment is required to produce homogeneous, fine-grained cast steel. The first normalizing treatment at a high temperature produces homogeneity (lack of segregation); the second treatment at a lower temperature produces the fine grain structure desired.

13. T. N. Armstrong (8) conducted several experiments on the heat treatment of cast steel. His results are similar to those given above in

that in all cases multiple heat-treatments produced better ductility than that obtained with a simple annealing treatment.

14. White, Clark and Crocker (9) studied carbon-molybdenum cast steel valve bodies to determine if the material in the welding end was sound, if the properties in these ends differed materially from those obtained in the test coupons and if the physical properties throughout the castings were reasonably uniform.

15. Their results indicated that for the type of castings that they examined it is possible to obtain sound material in the welding ends, properties in the welding ends similar to those obtained in the test coupons and reasonably uniform properties throughout the valve body. These results could be obtained if the gates and runners were of the proper size and properly placed, if the pouring temperature was closely controlled and if a suitable heat treatment was used.

16. The Steel Division Committee on Test Coupons of the American Foundrymen's Association reported (10) that segregation of aluminum was responsible for lower physical properties in heavy sections of steel castings. The committee also pointed out that low mechanical properties should be expected in sections where it is impossible, or commercially unfeasible, to prevent "axial shrinkage" as microscopic voids are always present in these sections.

METHODS USED IN TESTING

17. A study of the previous work on this subject shows that no data have been reported upon the effect of mass on the mechanical properties of cast steels in both the as cast and annealed conditions. As the designing engineer should have some indication of what may be expected as mechanical properties in various sections, it was deemed advisable to study this effect. It should be noted, however, that these data can refer only to the analyses studied and can only be indicative of the properties of other cast steels produced in similar sections.

18. In order to study the effect of mass upon the mechanical properties, well-fed coupons were cast in medium carbon steel and medium manganese steel. The coupons were all 12 inches long and those cast in medium carbon steel were 1/2" x 1/2", 1" x 1", 2" x 2", 3" x 3", 4" x 4", and 8" x 8" in cross section. Only the 1" x 1", and 3" x 3" coupons and one of the 8" x 8" coupons were cast in medium manganese steel. Each coupon was top poured through the feed head. The feed head was large enough to permit the shrinkage cavity to form within it without extending into the coupon. The feed heads were sawed from the coupon prior to heat treating. One coupon of each size was annealed at 900° C. (1650° F.) for the customary time of one hour per inch of section. The coupons were then cut and tensile specimens machined from the locations shown on Plate 1. The specimens were all standard 0.505 inch diameter tensile specimens except those machined from the 1/2" x 1/2" coupon. These specimens were 0.313 inches in diameter with a gauge length of 1.25 inches.

19. After the tensile tests were obtained specimens were machined from the threaded portion of the bars for micrographic studies, density measurements and chemical analyses.

20. In another heat, bars 1/2", 1", 2" and 3" in diameter and coupons similar to those mentioned previously were cast from low carbon steel. One-half of the bars and one-half of the coupons were annealed as before. Tensile test bars were machined from the coupons and tested. The bars were tested in the unmachined condition in order that some indication of the actual strength of cast sections might be obtained.

21. In a third carbon steel heat several coupons were cast at as high and as low a temperature as was practical in order that the effect of pouring temperature upon the mechanical properties might be noted. The properties recorded were those obtained in the tensile and the Izod impact tests.

22. The methods of testing used on the medium manganese heat were similar to those employed on the medium carbon steel. Tensile specimens were obtained from the center of the 1" x 1" and 3" x 3" sections in both the as cast and annealed condition. The one 8" x 8" x 12" block of medium manganese steel was annealed at 900° C. (1650° F.). Thermocouples were placed in the center, skin and midway between these points and the temperature gradient noted. The temperature of the skin lagged about 40° F. behind the furnace temperature until the furnace reached its maximum temperature. The temperature of the skin remained about 20° F. below the furnace temperature throughout the annealing period. The temperatures of the midpoint and the center of the coupon were only about 10° F. apart and lagged approximately 60° F. behind the skin temperature during the heating cycle. The midpoint and the center of the coupon reached the annealing temperature one half hour after the skin had attained this temperature.

23. After the block had been annealed it was sectioned and specimens obtained at the places indicated on Plate 2. These specimens were grouped together in such a manner that, according to the data previously obtained on the medium carbon steel, the natural differences in physical properties would be slight. Some of these specimens were given further heat treatments and then all were machined into standard tensile test specimens.

DATA OBTAINED

24. The data obtained from the tensile bars machined from the locations shown on Plate 1 are given in Table 1. It will be noted that the yield point in the "as cast" condition is listed in only a few instances. The representative stress-strain curve shown on Plate 4 shows that in the "as cast" condition cast steel has no marked yield point. The yield point must, therefore, be determined from a stress-strain curve and as the only extensometer available at the Laboratory is the type that must be removed prior to breaking the bar, it was deemed advisable to determine but a few yield points in the "as cast" condition. The data ob-

tained in the tensile tests and a density curve for the medium carbon steel are shown diagrammatically on Plate 3.

25. The chemical analyses on the center of the one inch coupon and the top, center and corner of the eight inch coupon are given in Table 5.

26. The data in Table 2 indicates the strengths of the machined tensile specimens cut from well-fed coupons of different sizes as compared to the strengths of unmachined bars of comparable sizes.

27. The effect of mass upon the mechanical properties of the medium manganese cast steel is shown on Plate 5 and in Table 4. The effect of heat treatment upon the mechanical properties of this steel is also shown in Table 4.

28. The chemical analyses which indicate the amount of segregation in the 8" x 8" block of medium manganese steel are given in Table 6.

MASS EFFECT ON MEDIUM CARBON CAST STEEL

29. The most outstanding feature exhibited by the curves is the sharp bends that are found in the tensile, yield and reduction of area curves in the neighborhood of the 2 inch section. In general, all of the mechanical properties in the 8 inch section were lower than those found in the 1/2 inch section. However, the loss was not as great in the annealed state as it was in the as cast condition. The density curve also shows a drop in value as the mass of the test block increases. In the 8 inch cross section it was possible to see small microscopic voids that must have resulted from the manner in which the heavy section solidified, since the heavy sections were as well fed as the light sections.

30. If the properties of any one section are considered, it may be noticed that the lowest results are obtained at the center of the section and the highest in the bottom corners where solidification has proceeded from two faces. The corner results are usually higher than those obtained elsewhere along the bottom where there is only one solidifying face. These conditions are more pronounced, of course, when the steel is tested in the as cast condition, but they are also noticeable in the heat treated material.

31. Since the mechanical properties varied to such a considerable degree, it was thought that perhaps segregation of chemical compositions was responsible for a large portion of the difference. Phosphorus and sulphur segregations were studied in the various sections by etching and sulphur prints, but no differences could be ascertained. This was perhaps due to the fact that they were both present in very low amounts in the steel as cast. As the steel was made by the basic process, these analyses were 0.02 per cent for the phosphorus and 0.03 per cent for sulphur. Segregation was also studied by chemical analysis. The centers of each section were analyzed for carbon, manganese, silicon and aluminum and the results are set forth in Table 5. The greatest difference appeared in the carbon content where 0.03 per cent was noted. The center of the one inch coupon

contained 0.27 per cent, while the center of the 8 inch coupon contained 0.24 per cent. The manganese, silicon and aluminum analyses showed that there was practically no segregation of these elements. The specimens were also studied microscopically in the unetched condition to see if the inclusions had formed an aluminum network which might tend to lower the physical properties in the larger cast sections. No network was evident. The inclusions were, however, slightly larger and fewer in the centers of the heavier sections.

32. Photomicrographs were taken of the sections in the as cast and the annealed condition. These micrographs are illustrated in Plates 6, 7 and 8. As would normally be expected, the original ferrite grain size in both the as cast and the annealed state is progressively larger as the section increases. The secondary ferrite grains in the annealed specimens are about the same size, but the original ferrite distribution is the dominant structure. The microstructure at various positions in the 8 inch coupon was also examined and in general it appeared quite similar. The maximum difference was as represented by a comparison of the microstructure of the center, Plate 7f, and the corner specimens, Plate 8f, of the 8 inch coupon

33. The authors have observed in their review of previous literature that trepanned specimens have been taken from large sections and then heat treated to show what changes may be effected in the microstructure by the various types of heat treatments. It was thought that the handling of specimens in this manner was not entirely comparable and that the mass would have a pronounced effect, even though the heavy sections received a considerably longer heat treatment than was accorded to the trepanned specimen. A specimen from the center of the as cast 8 inch coupon was annealed at 1650° F. for one hour, Plate 11e, and compared with the structure of the center of the annealed 8 inch coupon, (Plate 7f). The grain size of the trepanned specimen was so much smaller that it could not be illustrated properly at a magnification of 50 diameters, so that it would be strictly comparable with the other micrographs. The magnification was therefore increased to 100 diameters. This test, therefore, proves that heat treated trepanned specimens taken from heavy sections will not portray conditions that would be found if the entire coupon were given comparable heat treatments.

34. The 8 inch section was the only one that exhibited dendrites on micro-examination. The section was then machined and annealed at 2050° F. and again examined for dendrites. The dendritic structure appeared and was similar to that found in the as cast condition.

35. It appears from the above study that there are three conditions that bear upon the mechanical properties as effected by mass. These are: (1) the density, (2) the carbon segregation, and (3) the microstructure. It is difficult to ascertain from the data which of these is the most important. As the section increases the density drops, the carbon content drops and the original ferrite grain size increases. In regard to the tensile strength and the yield point values, the microstructure and the carbon segregation are probably the most important in causing the lower values. The density and the microstructure are responsible for the lower

ductility found in the heavier sections. From this it appears that the microstructure is the dominant controlling factor.

36. The properties listed at the center of the section are the poorest ones present in this section. The average properties over the entire section are better than those exhibited by the center, due to the preponderance of material having better properties, such as those exhibited by the corners and edges

37. Contrary to Merton's (2) conclusions, the present data failed to show that silicon segregation caused low mechanical properties in heavy cast steel sections. The segregation of aluminum, while amounting to an increase of 12 per cent between the centers of the 1 and the 8 inch sections, is only of the order of .005 per cent. The largest segregation occurs in the 8 inch coupon itself, which is .012 per cent. The mechanical properties in these two locations are, however, practically identical. This data fails to check the statement reported by the Steel Division Committee on Test Coupons of the American Foundrymen's Association (10) that segregation of aluminum is responsible for lower physical properties in heavy sections of steel castings.

COMPARISON OF COUPONS AND BARS CAST TO SIZE

38. One of the interesting points that has been continually stressed by designers is how do the mechanical properties of cast steel sections compare to those properties as exhibited by the well fed coupon. This point was investigated and the results are set forth in Table 2. In this experiment, bars were cast in the horizontal position while coupons were cast similar to those used previously. From the center of these as cast and annealed coupons, standard tensile bars were machined and tested. These specimens likewise showed the effect of mass on the mechanical properties.

39. The bars were tested in the condition they came from the sand mold except that one set was annealed before testing. The bars were not machined nor were the cast surfaces removed.

40. The yield and the tensile strengths were nearly the same in both bars and specimens machined from the coupons. The ductility, however, was much lower in the case of the bars. This is undoubtedly due to the rough surface of the bars. The decrease in ductility with increasing mass is much greater with the bars than it is with the coupons.

41. This data points out that while the strength properties in cast sections are nearly the same as those represented by the coupon, the ductility properties are much lower and should be borne in mind by the designer. The interesting point is that the ductility results are rather erratic and would depend a great deal on the surface of the casting and probably on the size of the axial weakness.

THE EFFECT OF POURING TEMPERATURE UPON THE MECHANICAL PROPERTIES OF CAST STEEL

42. It has been stated (2) that to obtain the best mechanical

properties from steel castings, the steel should be poured at as low a temperature as possible. The authors studied this effect by pouring, in the same heat one set of coupons at 2900° F. and another set at 2675° F. Tensile and impact specimens were obtained from these coupons in the as cast and annealed condition. The results obtained from these specimens indicated that there was practically no difference in the mechanical properties. The specimens poured at the higher temperature exhibited slightly better tensile properties and lower impact values than those poured at the lower temperatures (Table 3). The differences, however, were so slight that they probably would not be important commercially.

THE MASS EFFECT IN MEDIUM MANGANESE STEEL

43. The effect of mass upon the mechanical properties of the medium manganese steel studied (Plate 5) is similar to that found in the medium carbon steel. In each case the mechanical properties at the center of the test coupon decrease as the mass of the section increases. The variation in the tensile strength is, however, considerably greater in the manganese steel than it is in the plain carbon steel. The tensile strength in the plain carbon steel in the center of the 8 inch coupon is 5,000 pounds per square inch less than that in the 1 inch coupon, a drop of 6.5 per cent. In the medium manganese steel the decrease in similar coupons is 10,400 pounds per square inch, a change of 10.5 per cent. It should be noted that the change in the tensile strength of the manganese steel decreases gradually and rather uniformly with an increase in mass, whereas the tensile strength of the plain carbon steel decreases rapidly at first and then at a decreasing rate as the mass increases.

44. The other tensile properties of the medium manganese steel also decrease gradually and at a more uniform rate than in the plain carbon steels.

45. The tensile properties of various sections of the eight inch coupon vary in a manner similar to that found in the plain carbon steel. Table 4 indicates that the best tensile properties are found in the lower corner and the bottom of the test coupon. The topeof the coupon, immediately under the head, exhibits the poorest properties and the properties then increase gradually toward the bottom of the coupon. The Izod impact strength, however, increases as the mass of the section increases and is greater at the center of the 8 inch coupon than it is in the corner of the coupon.

46. The size of the original ferrite structure in the medium manganese steel increases as the mass of the section increases in a manner similar to that found in the carbon steel (Plate 9).

47. There have been many contradictory opinions expressed concerning the effect of annealing at high temperatures upon the mechanical properties of cast steel. Therefore, several 1 inch square sections were cut fro the central portion of the 8 inch coupon after it had been annealed and these specimens were, with on exception, annealing treatments. It was decided that the results obtained in annealing small sections, while not comparable to the heat treatment of heavy sections, would approach somewhat the results obtained in annealing large sections, whereas this would not be true of normalizing or quenching treatments where the cooling rate would depend upon the mass of the specimen.

48. The sections cut from the central portion of the 8 inch coupon (Plate 2) were annealed for one hour at 1650°, 1850°, 2050° and 2250° F. (Plate 10). The results obtained from the tensile tests of these specimens (Table 4) indicate that higher annealing treatments increase the ultimate tensile strength, but cause a decrease in ductility. Several additional specimens were annealed for shorter periods at higher temperatures, 1850° F. for 15 minutes, 2050° F. for 5 minutes and 2250° F. for 5 minutes. The results obtained from these specimens were similar to those given above in that an increase in tensile strength and a decrease in ductility over that obtained in the original 8 hour anneal were noted. There was practically no difference in the yield point, tensile strength or elongation in the long and short time high temperature annealing treatments. However, the reduction of area and the impact values were higher in the specimens annealed at high temperatures for short periods of time.

49. Several specimens were given an additional double anneal (Plate 11) at 1650° F. for one hour, 1525° F. for one hour, and additional specimens were given the heat treatment recommended by Merton (2). It is interesting to note that none of the heat treatments used produced properties superior to those obtained with the double 1650° F. anneal (Specimen C 4, Plate 19b) and that in no case was it powwible to produce in the specimens obtained from the central portion of the 8 inch coupon mechanical properties that were much better than those obtained with a single 1650° F. anneal in a 1 inch coupon.

50. The photomicrographs obtained from the specimens annealed at high temperatures (Plates 10 and 11) show that as the annealing temperature is increased the original structure is gradually obliterated until at 2250° F. the austenitic grain size is revealed.

51. Chemical analyses were obtained from the center of the 1 inch and 3 inch sections and from the top, center, bottom and corner of the 8 inch section in order that the amount of segregation could be determined (Table 6). Segregation of carbon can be seen in that the carbon content at the center of the coupon decreases as the mass of the section increases. The carbon content at the corner of the 8 inch section is the same as that at the center of the 1 inch coupon. There is slight segregation of manganese but no segregation of silicon or aluminum.

52. This segregation of carbon and manganese will probably account for the decrease in tensile strength as the mass is increased.

CONCLUSIONS

53. The effect of mass on the mechanical properties of cast steel is as follows:

(1) There is a loss in strength and ductility, as measured at the center of the section, as the mass increases.

(2) In carbon steel the loss is pronounced for the first 2 inches of cross section after which it tapers off gradually. In the manganese steel there is no decided knee to the curve.

(3) There is a decrease in density and carbon content, and an increase in Izod impact value as the mass increases.

(4) Microstructure, carbon segregation and density values are responsible for the decrease of mechanical properties as the mass increases.

(5) Segregations of silicon, aluminum, phosphorus and sulphur were small and had no apparent effect as to producing low mechanical properties.

(6) Trepanned specimens from large sections when heat treated do not exhibit the same microstructure as when the section is heat treated under comparable conditions. The effect of mass is to produce a larger grain structure.

(7) A comparison of bars cast to size and standard tensile test specimens from well fed coupons show that the strength properties are quite similar but that the ductility of the bars is much lower than that exhibited by the coupons.

(8) Differences in pouring temperature have no marked effect on the mechanical properties.

(9) High temperature annealing treatments increase the ultimate tensile strength, but cause a decrease in ductility.

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Table 1

The Effect of Mass Upon the Mechanical Properties of Medium Carbon Cast Steel

Specimen		Yield Point Lbs./sq.in.		Tensile Strength Lbs./sq.in.		Elongation %		Reduction in Area %	
		As Cast	Annealed	As Cast	Annealed	As Cast	Annealed	As Cast	Annealed
Center 1/2" Block	A	38,200	49,000	77,600	75,450	25	30	35	47
Center 1" Block	B	-	48,000	75,500	75,000	25	28	30	46
Center 2" Block	C	-	46,750	73,000	74,500	21	30	26	40
Top 3" Block	D	-	44,750	71,750	71,500	18	28	19	35
Center 3" Block	E	-	45,200	72,300	72,000	20	29	23	39
Bottom 3" Block	F	-	45,000	74,000	72,400	21	28	26	40
Lower Corner 3" Block	G	-	45,250	73,500	73,250	23	29	30	42
Top 4" Block	H	-	45,250	71,000	70,000	15	29	21	43
Center 4" Block	I	-	44,500	71,200	70,500	19	29	23	39
Bottom 4" Block	J	-	45,750	73,250	72,250	22	30	21	46
Lower Corner 4" Block	K	-	45,500	73,700	73,000	25	30	33	46
Top 8" Block	L	-	41,750	70,000	70,125	8	26	9	40
Center of upper half 8" Block	M	-	43,000	71,000	68,250	9	26	9	40
Center 8" Block	N	33,500	42,000	70,500	68,500	9	27	10	36
Center of lower half 8" Block	O	-	41,750	74,250	68,750	16	28	18	41
Bottom 8" Block	P	-	43,750	76,100	70,750	18	29	21	44
Lower Corner 8" Block	R	-	43,500	76,750	72,125	22	29	30	44

Table 2

The Comparison of the Mechanical Properties of Well Fed Test Coupons and Bars Cast to Size

Carbon 0.21 Manganese 0.60 Silicon 0.31

Section	Gauge Length	Yield Point As Cast	Yield Point Annealed	Tensile Strength As Cast	Tensile Strength Annealed	Percent Elongation A.C.	Percent Elongation Ann.	Percent Red. Area A.C.	Percent Red. Area Ann.
1/2" coupon	Standard Tensile Spec.	-	44,600	69,800	70,700	29	34	40	50
1" "		-	42,500	69,000	69,700	28	33	38	48
2" "		-	41,750	67,000	69,000	20	32	23	44
3" "		-	40,750	64,500	67,750	18	32	24	40
1/2" Dia. Bar	2"	-	43,000	69,000	69,500	11	20	13	25
1" " "	4"	58,500	40,000	67,100	64,600	12	16	12	30
2" " "	8"	54,200	39,200	61,800	64,000	8	13	8	23
3" " "	12"	-	39,500	-	63,550	-	14	-	13

Table 3

The Effect of Pouring Temperature Upon the Physical Properties of Carbon Cast Steel

Carbon 0.29 Manganese 0.70 Silicon 0.32

Pouring Temp.	Yield Point As Cast	Yield Point Annealed	Tensile Strength As Cast	Tensile Strength Annealed	Percent Elongation A.C.	Percent Elongation Ann.	Percent Red. Area A.C.	Percent Red. Area Ann.	Izod Ft.Lbs. A.C.	Izod Ft.Lbs. Ann.
2675° F.	-	54,000	78,000	81,625	20	27	23	38	8.8	36.3
2900° F.		55,500	78,250	82,000	21	27	25	38	7.1	33.9

Table 4

The Effect of Mass Upon the Mechanical Properties
of Medium Manganese Cast Steel

Specimen	Heat Treatment	Lbs. Per Sq. In. Yield Point	Lbs. Per Sq. In. Tensile Strength	Percent Elongation	Percent Reduction of Area	Ft. Lbs. Izod
Center 1" coupon	Annealed 1650° F. - 1 hr.	60,750	99,000	25	49	17.7
Center 3" coupon	" 1650° F. - 3 hr.	56,750	94,750	22	42	18.6
Center 8" coupon	" 1650° F. - 8 hr.	52,250	88,625	18	31	22.3
Top 8" coupon	" " "	52,750	88,125	18	31	-
Bottom 8" coupon	" " "	56,000	95,000	23	41	-
Corner 8" coupon	" " "	56,000	95,000	24	50	19.2
Midpoint 8" coupon	" " "	55,750	92,250	21	35	-
* C-4	Annealed 1650° F. - 1 hr.	61,375	91,375	20	52	-
* C-5	" 1850° F. - "	56,000	88,650	20	50	-
* D-3	" 2050° F. - "	58,625	99,125	22	46	14.6
* D-4	" 2250° F. - "	60,000	99,675	17	36	-
* D-6	" 1850° F. - 15 min.	60,650	96,125	22	42	-
* E-4	" 2050° F. - 5 min.	60,750	96,875	22	41	16.3
* E-5	" 2250° F. - 5 min.	-	99,650	18	40	-
* F-4	" 1650° F. - 1 hr. 1525° F. - 1 hr.	68,250	96,375	22	48	-
* F-5	Merton's Treatment	51,500	90,000	25	50	-

* Specimens previously annealed in coupon at 1650° F. for 8 hours.

Table 5

Chemical Analyses of Sections of Medium Carbon Steel

Location of Specimen	Percent			
	Carbon	Manganese	Silicon	Aluminum
Center 1" coupon	0.270	0.634	0.212	0.035
Top 8" coupon	0.265	0.634	0.229	0.028
Center 8" coupon	0.243	0.623	0.228	0.040
Corner 8" coupon	0.268	0.637	0.230	0.032

Table 6

Chemical Analyses of Sections of Medium Manganese Steel

Location of Specimen	Percent			
	Carbon	Manganese	Silicon	Aluminum
Center 1" coupon	0.340	1.46	0.322	0.057
Center 3" coupon	0.323	1.46	0.320	-
Top 8" coupon	0.320	1.46	0.319	-
Center 8" coupon	0.297	1.41	0.312	0.056
Bottom 8" coupon	0.333	1.47	0.322	
Corner 8" coupon	0.342	1.48	0.321	-

Table 7

The Effect of Mass Upon the Density of Cast Steel

- - - -

Location of Specimen	Density
Center 1" coupon	7.8379
Center 3" coupon	7.8306
Top 8" coupon	7.8106
Center 8" coupon	7.8114
Bottom 8" coupon	7.8122
Lower Corner 8" coupon	7.8175

LOCATION OF TEST SPECIMENS IN CARBON CAST STEEL BLOCKS

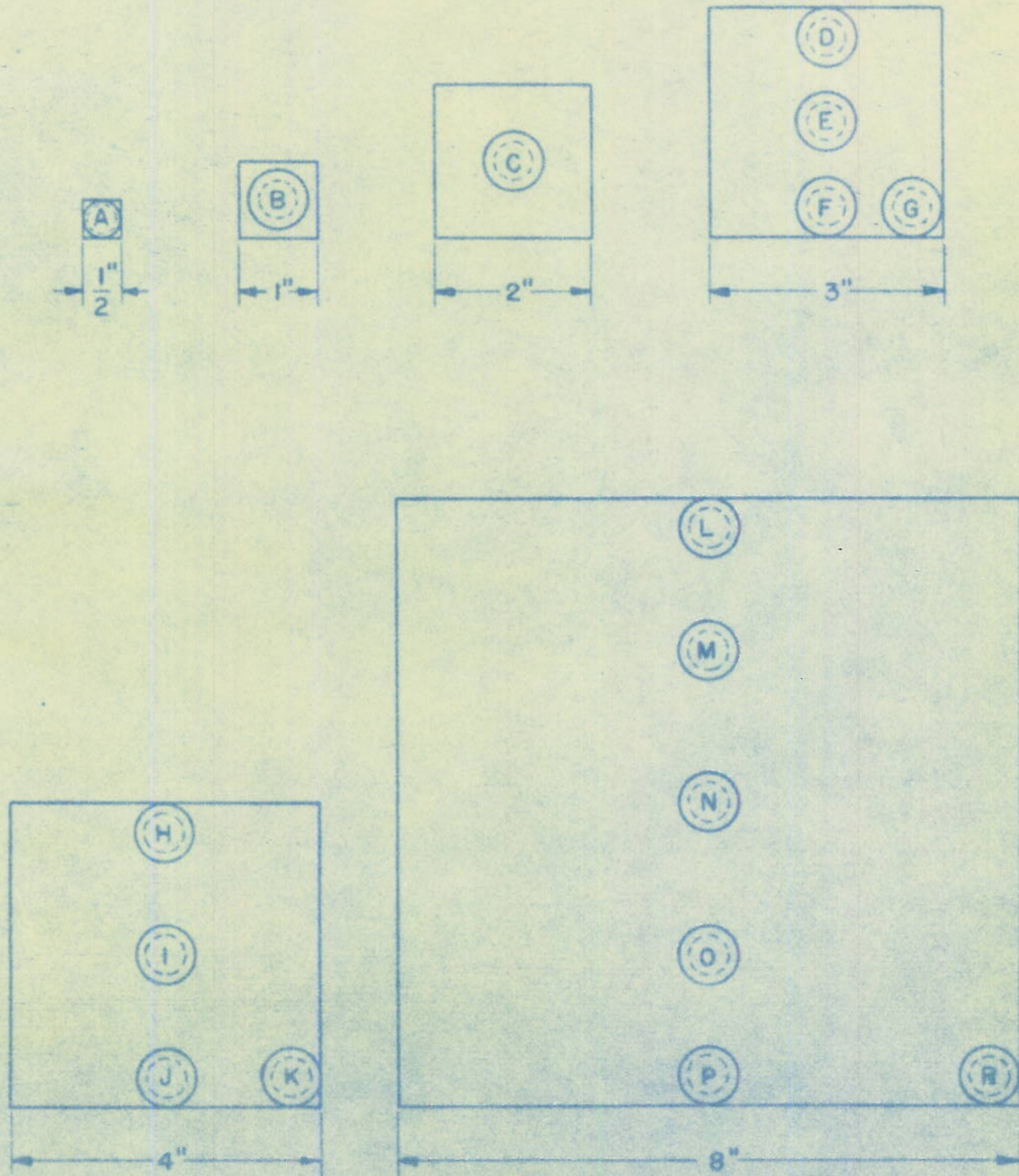

PLATE I

LOCATION OF SPECIMENS IN MEDIUM MANGANESE
CAST STEEL BLOCK

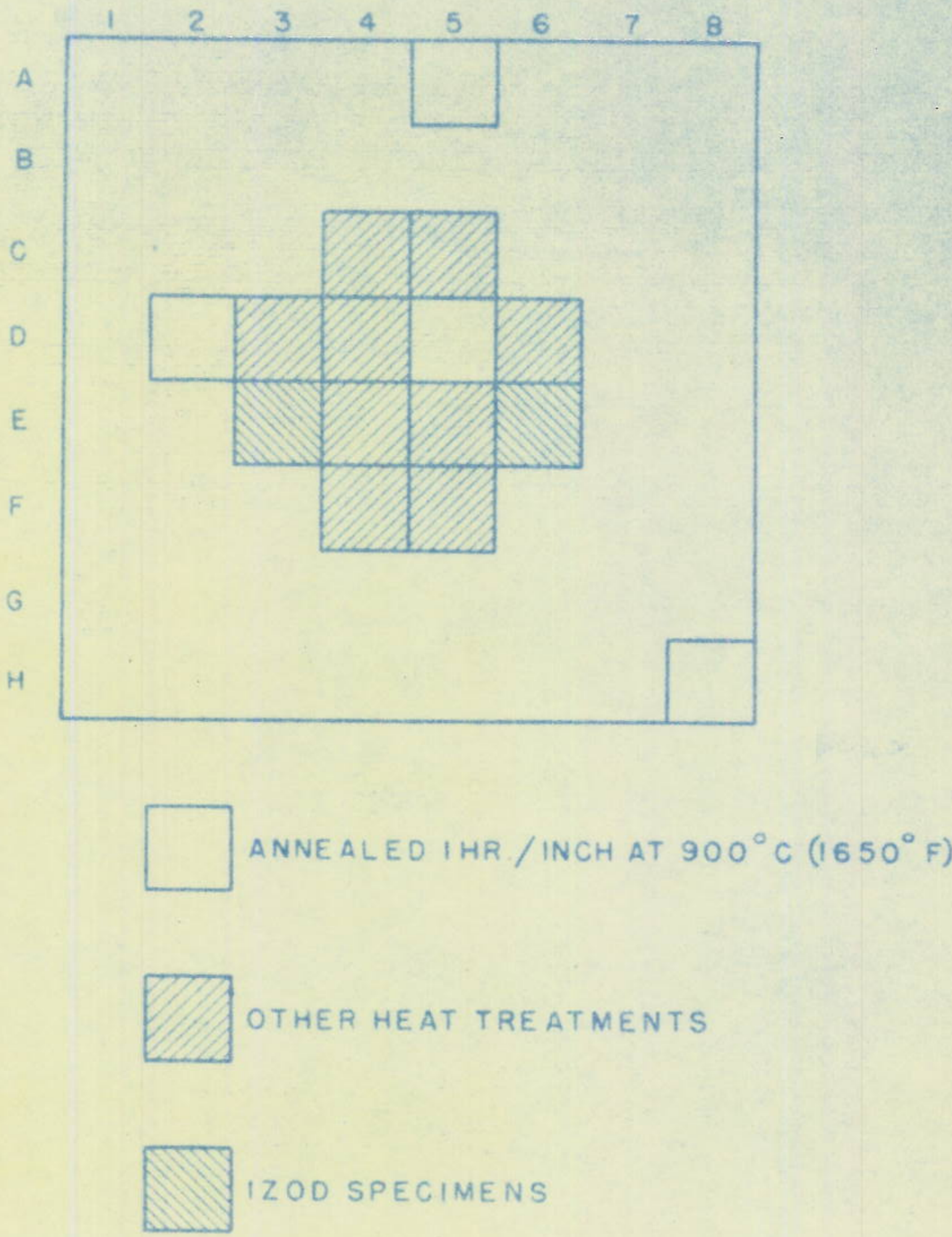

PLATE 2

THE EFFECT OF MASS UPON THE MECHANICAL PROPERTIES OF CAST STEEL
AT THE CENTER OF TEST BLOCK

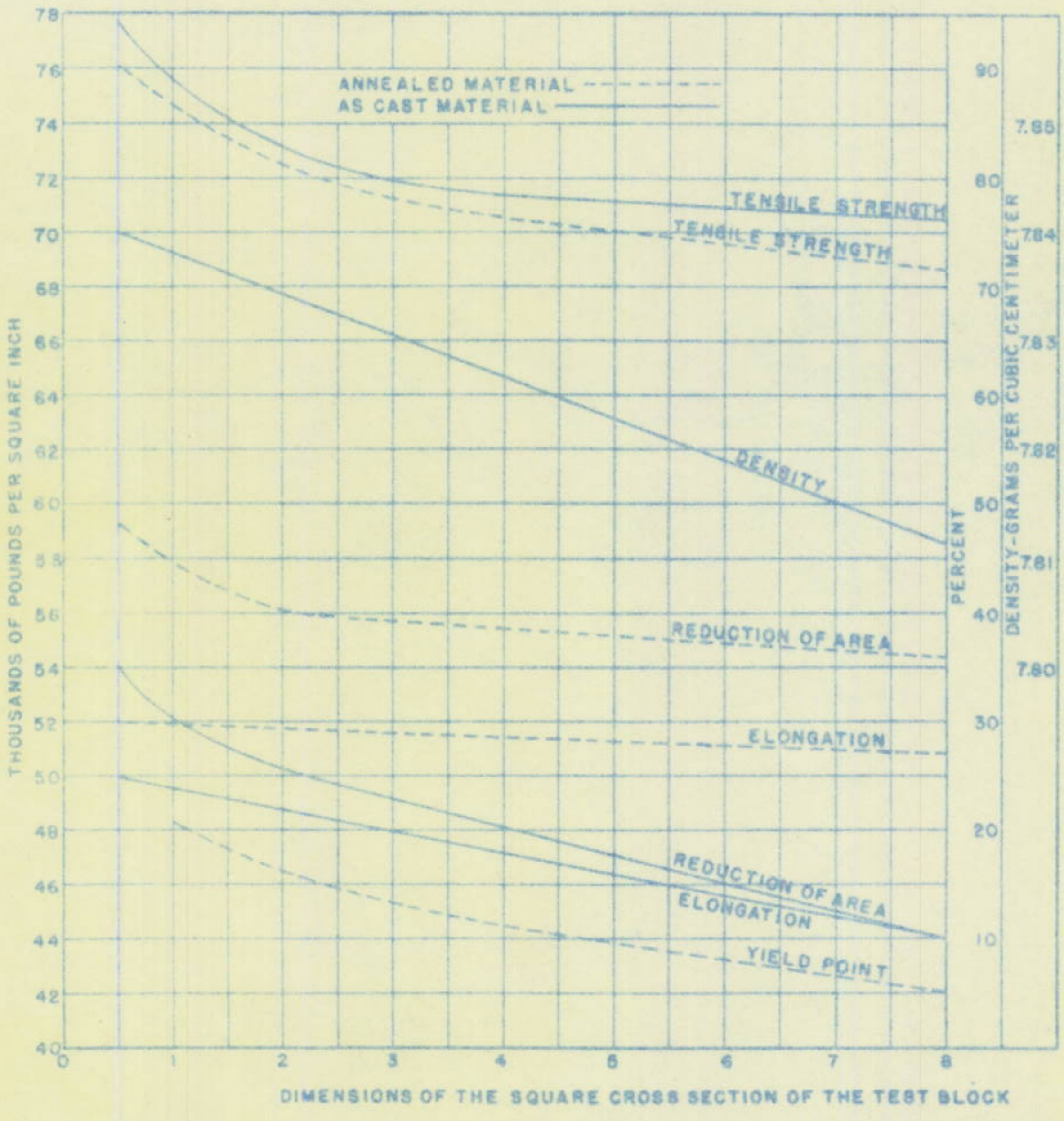

PLATE 3

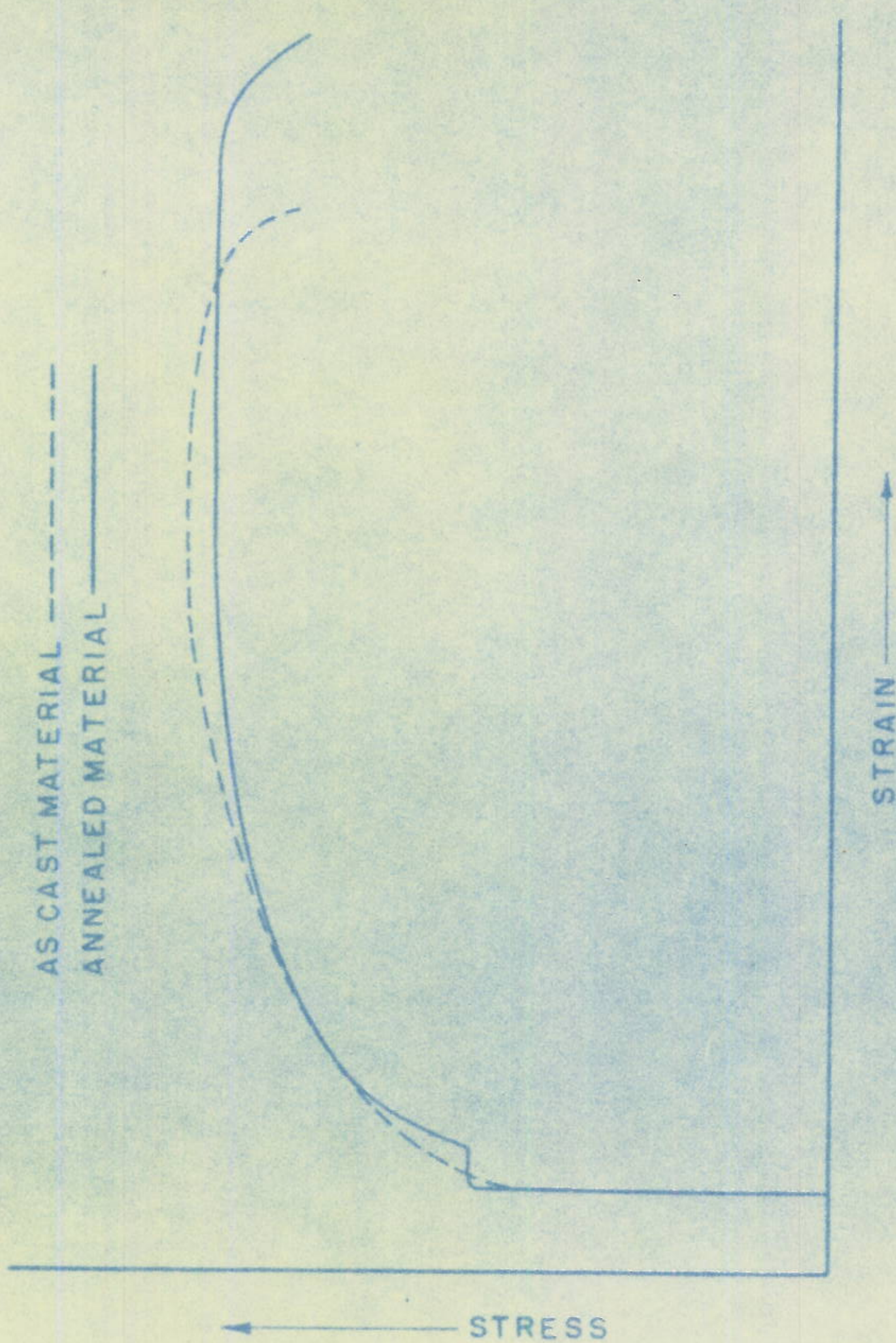

PLATE 4

THE EFFECT OF MASS UPON THE MECHANICAL PROPERTIES OF CAST MEDIUM MANGANESE STEEL

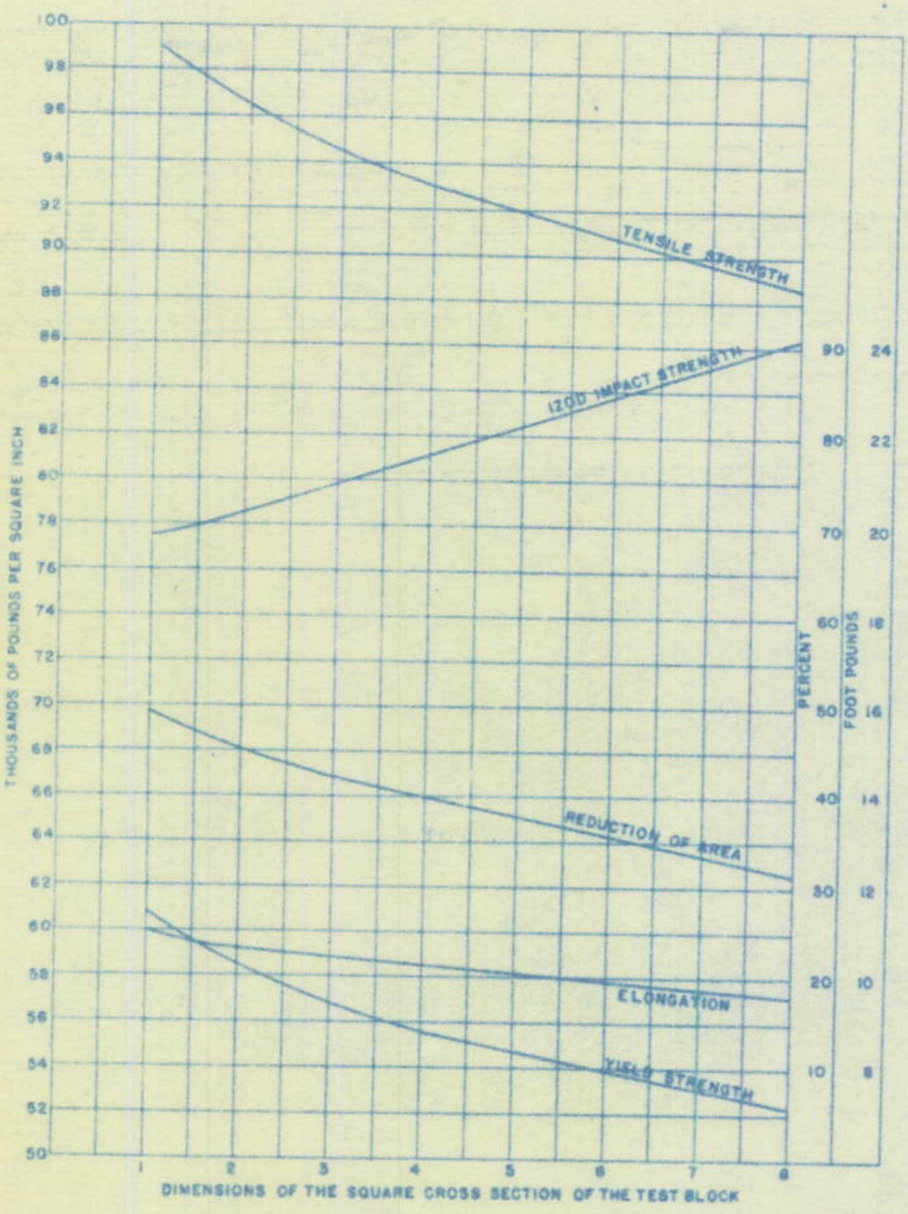

PLATE 5

Plate 6

Medium Carbon Cast Steel

As Cast

Plate 6a
Center of 1/2 inch section
As Cast (X50)

Plate 6b
Center of 1 inch section
As Cast (X50)

Plate 6c
Center of 2 inch Section
As Cast (X50)

Plate 6d
Center of 3 inch Section
As Cast (X50)

Plate 6e
Center of 4 inch Section
As Cast (X50)

Plate 6f
Center of 8 inch Section
As Cast (X50)

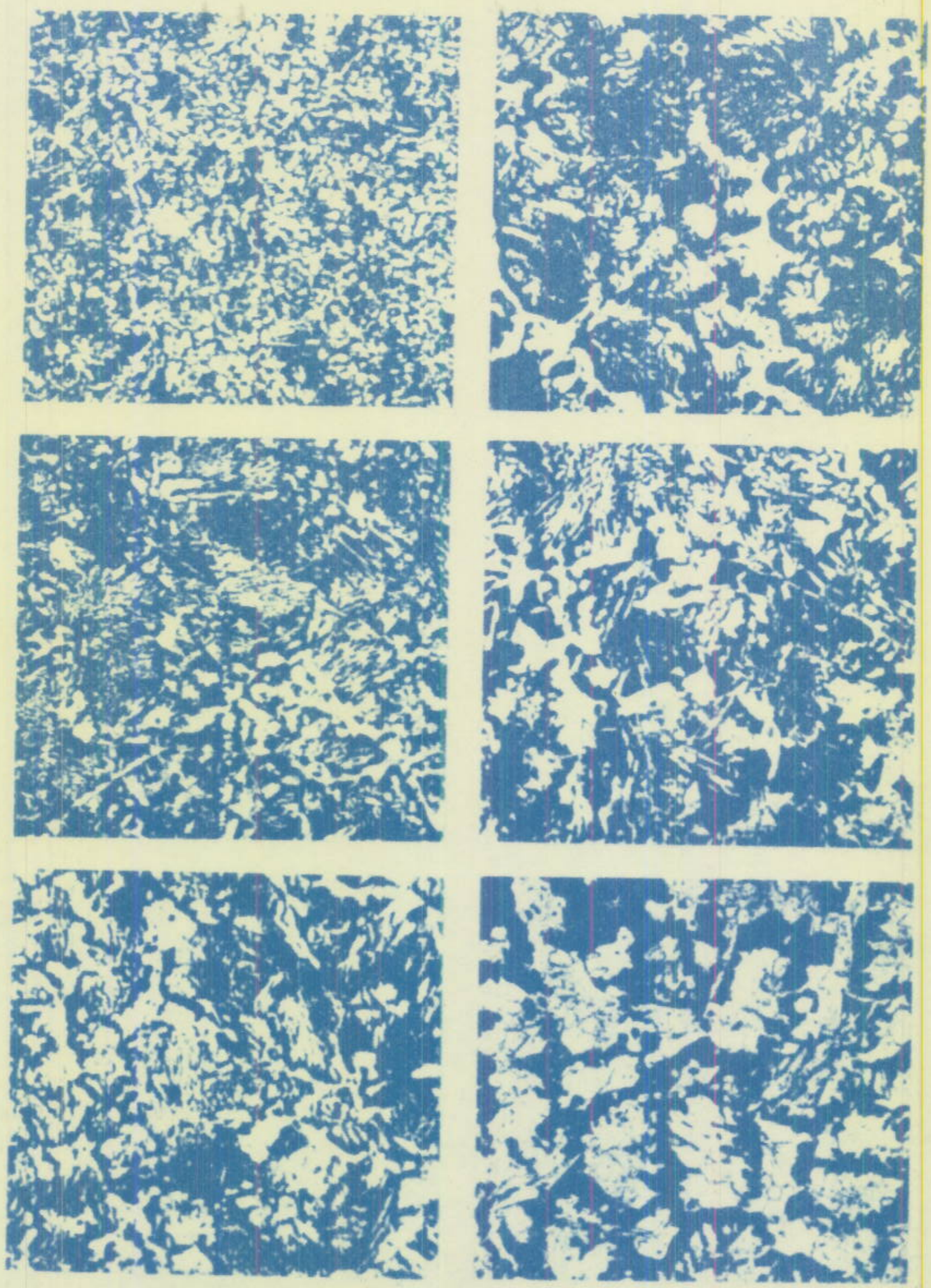

PLATE 6

Plate 7

Medium Carbon Cast Steel

Annealed

Plate 7a
Center 1/2 inch Section
Annealed 1/2 hr. 1650° F.
(X50)

Plate 7b
Center 1 inch Section
Annealed 1 hr. 1650° F.
(X50)

Plate 7c
Center 2 inch Section
Annealed 2 hrs. 1650° F.
(X50)

Plate 7d
Center 3 inch Section
Annealed 3 hrs. 1650° F.
(X50)

Plate 7e
Center 4 inch Section
Annealed 4 hrs. 1650° F.
(X50)

Plate 7f
Center 8 inch Section
Annealed 8 hrs. 1650° F.
(X50)

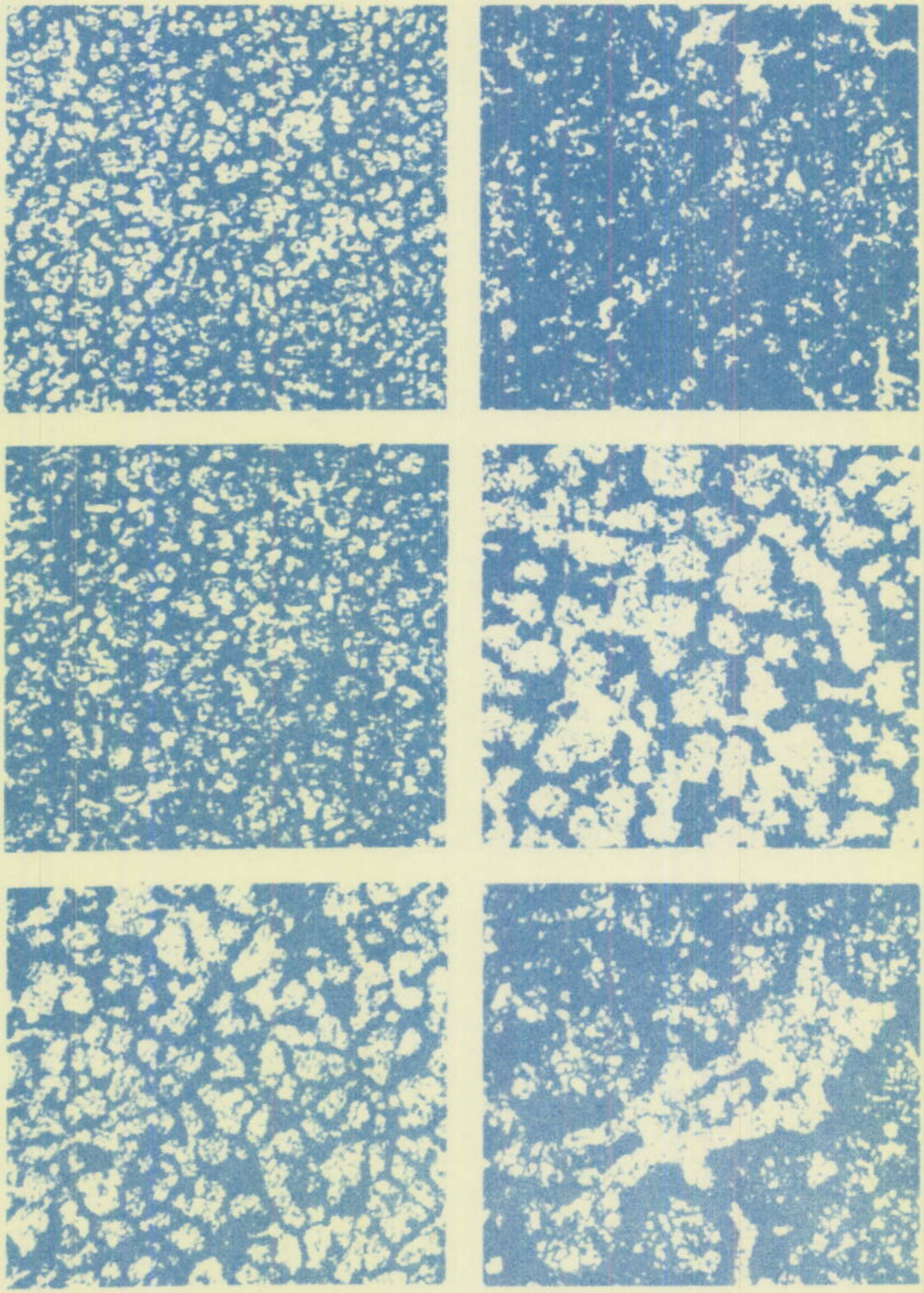

PLATE 7

Plate 8

Medium Carbon Cast Steel

Plate 8a
Top 8 inch Section
As Cast (X50)

Plate 8b
Bottom 8 inch Section
As Cast (X50)

Plate 8c
Bottom Corner 8 inch Section
As Cast (X50)

Plate 8d
Top 8 inch Section
Annealed 8 hrs. 1650° F.
(X50)

Plate 8e
Bottom 8 inch Section
Annealed 8 hrs. 1650° F.
(X50)

Plate 8f
Bottom Corner 8 inch Section
Annealed 8 hrs. 1650° F.
(X50)

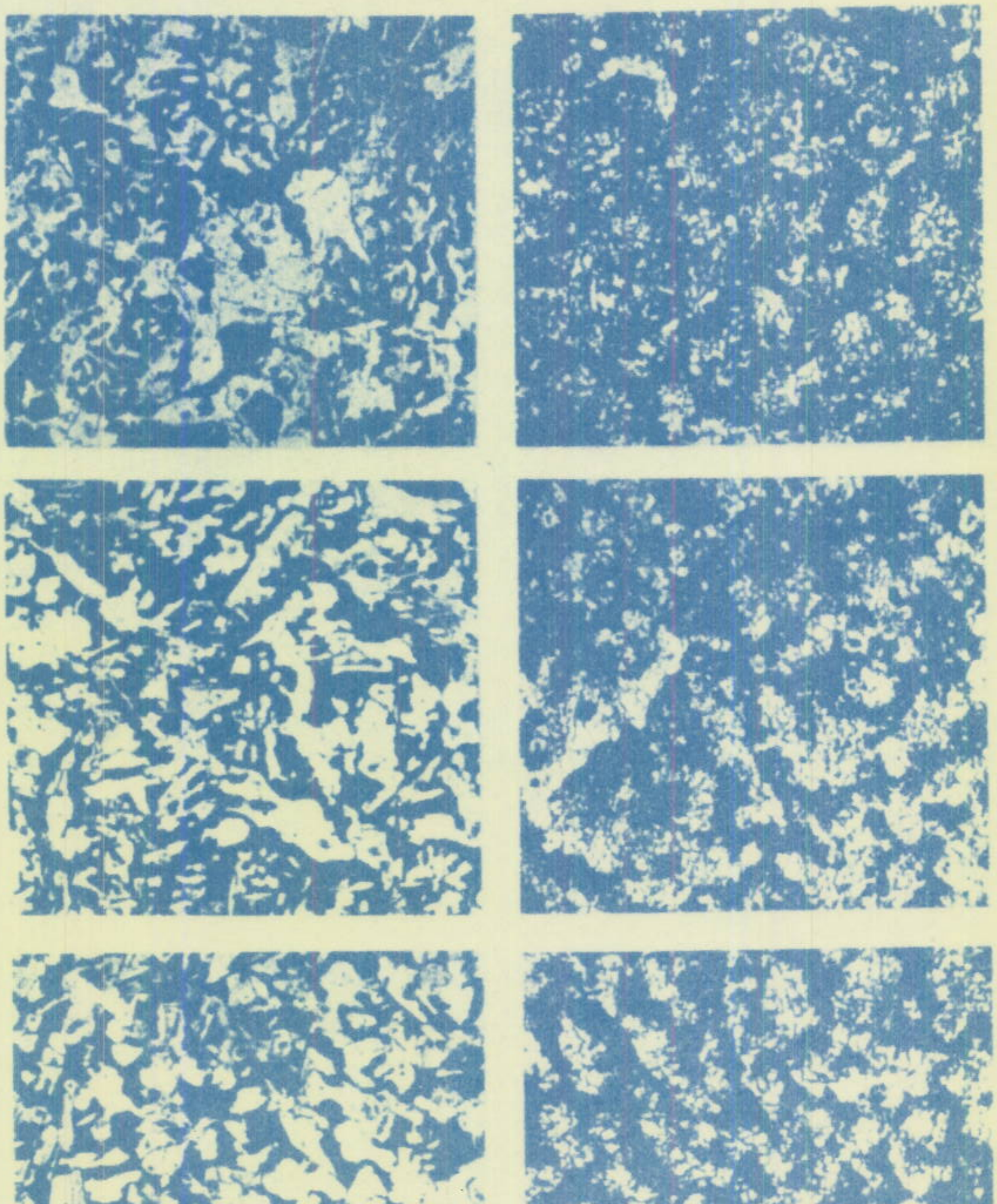

PLATE 8

Plate 9

Medium Manganese Cast Steel

Annealed

Plate 9a
Center 1 inch Section
Annealed 1 hr. - 1650° F.
(X 100)

Plate 9d
Top 8 inch Section
Annealed 8 hrs. - 1650° F.
(X 100)

Plate 9b
Center 3 inch Section
Annealed 3 hrs. - 1650° F.
(X 100)

Plate 9e
Bottom 8 inch Section
Annealed 8 hrs. - 1650° F.
(X 100)

Plate 9c
Center 8 inch Section
Annealed 8 hrs. - 1650° F.
(X 100)

Plate 9f
Bottom Corner 8 inch Section
Annealed 8 hrs. - 1650° F.
(X 100)

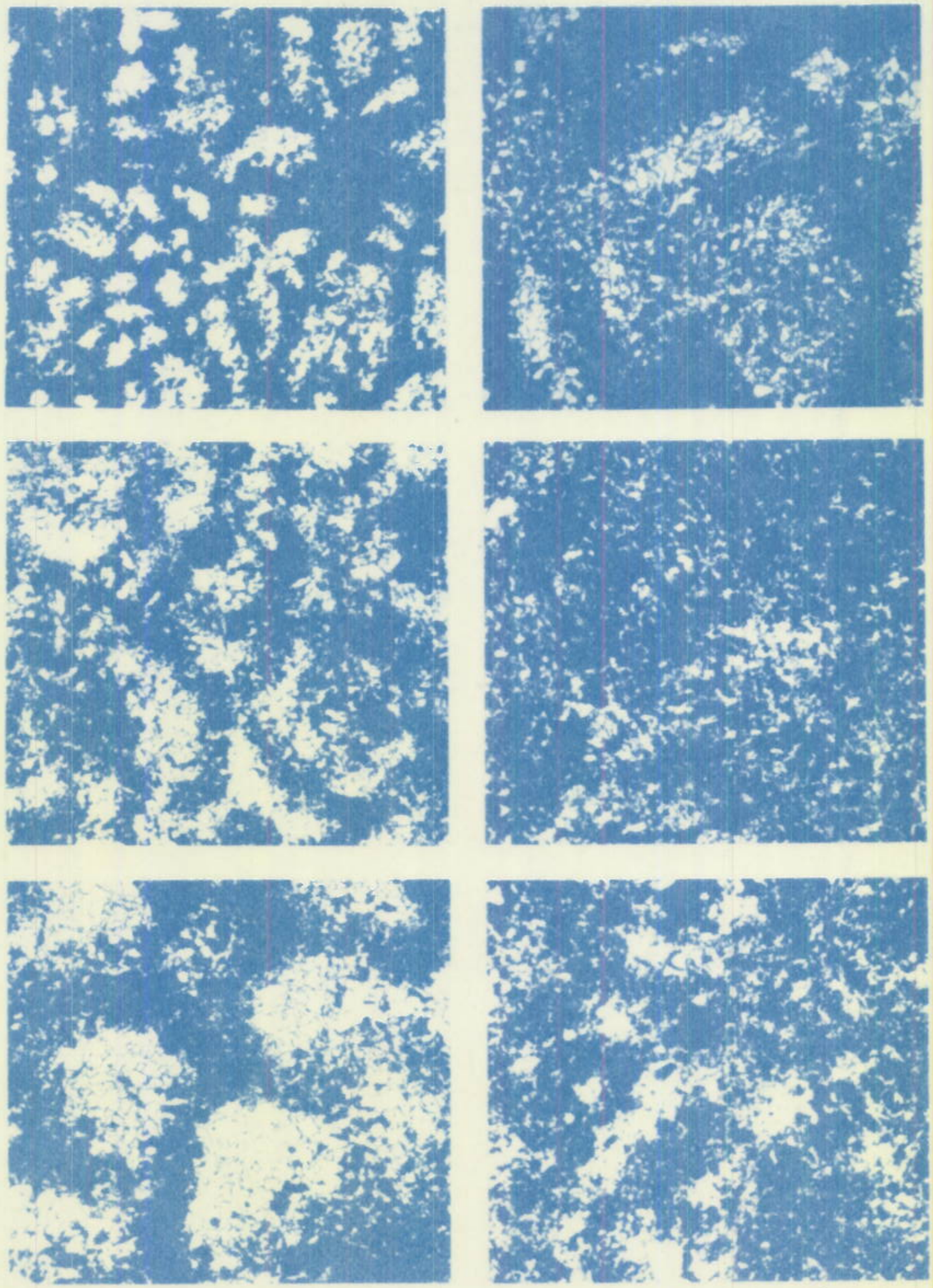

PLATE 9

Plate 10

Medium Manganese Cast Steel

Plate 10a
Midpoint of Center and Side of 8 inch Section
Annealed 8 hrs. 1650° F.
(X 100)

Plate 10b
Center 8 inch Section
Double Annealed.
1650° F. - 8 hrs.
1650° F - 1 hr.
(X 100)

Plate 10c
Center 8 inch Section
Double Annealed:
1650° F. - 8 hrs.
1850° F. - 1 hr.
(X 100)

Plate 10d
Center 8 inch Section
Double Annealed:
1650° F. - 8 hrs.
2050° F. - 1 hr.
(X 100)

Plate 10e
Cen[illegible] inch [illegible]ection
Do[illegible]nealed:
16[illegible] - 8 hrs.
2050° [illegible] - 1 hr.
(X 100)

Plate 10f
Center 8 inch Section
Triple Annealed:
1650° F. - 8 hrs.
1650° F. - 1 hr.
1525° F. - 1 hr.
(X 100)

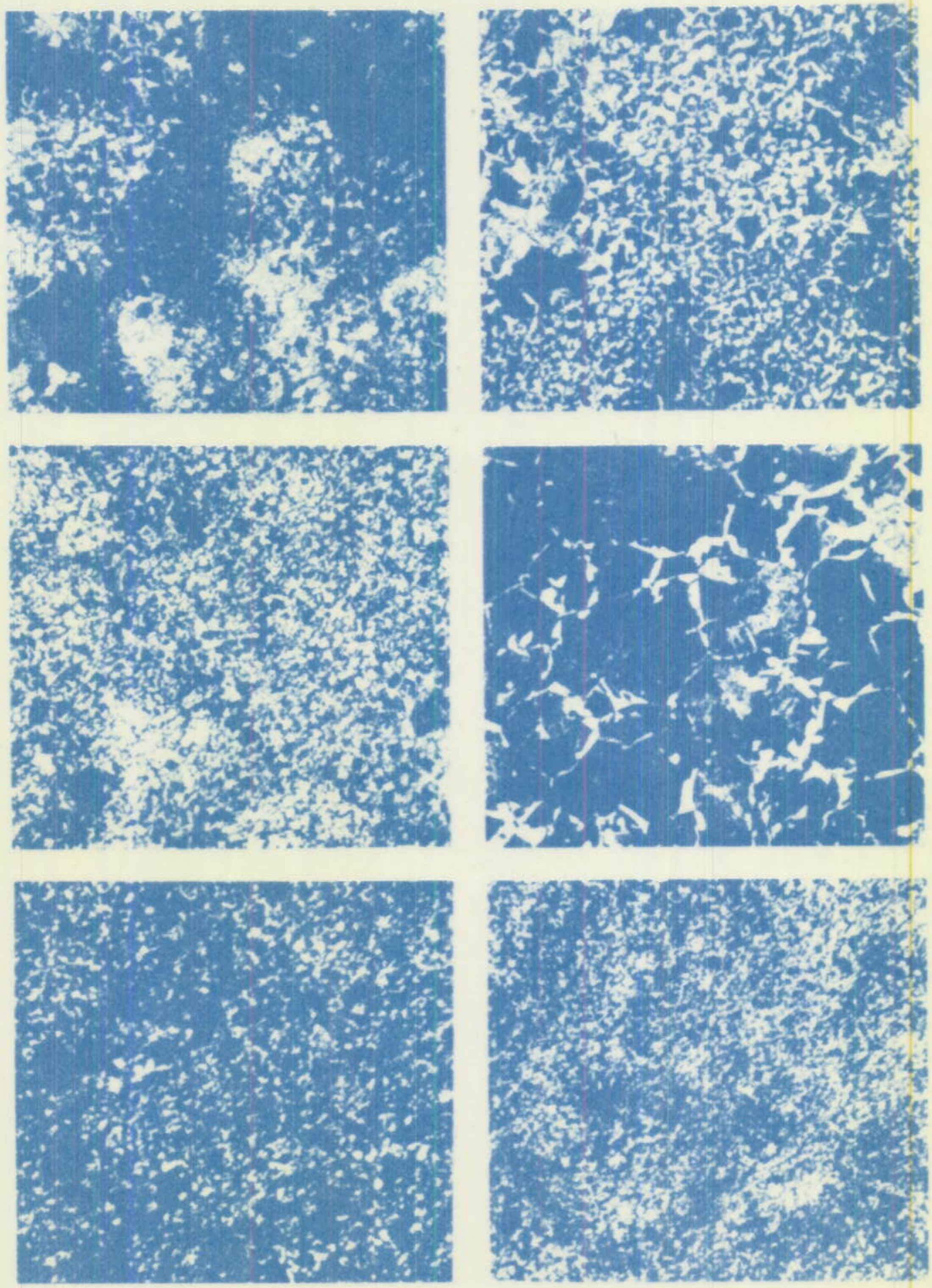

PLATE 10

Plate 11

Medium Manganese Cast Steel

Plate 11a
Center 8 inch Section
Double Annealed:
1650° F. - 8 hrs.
1850° F. - 15 min.
(X 100)

Plate 11c
Center 8 inch Section
Double Annealed:
1650° F. - 8 hrs.
2250° F. - 5 min.
(X 100)

Plate 11b
Center 8 inch Section
Double Annealed:
1650° F. - 8 hrs.
2050° F. - 5 min.
(X 100)

Plate 11d
Center 8 inch Section
Merton's Heat treatment
Annealed 1650° F - 8 hrs.
2012° F. - 2 hrs., cooled
in furnace to 800° F.,
annealed 1650° F. - 1 hr.,
reheat to 1275° F. and cool
in furnace to 600° F.
(X 100)

Plate 11e
Center 8 inch Section
Medium Carbon Steel
As Cast - Annealed 1650° F.
1 hr. (X 100)

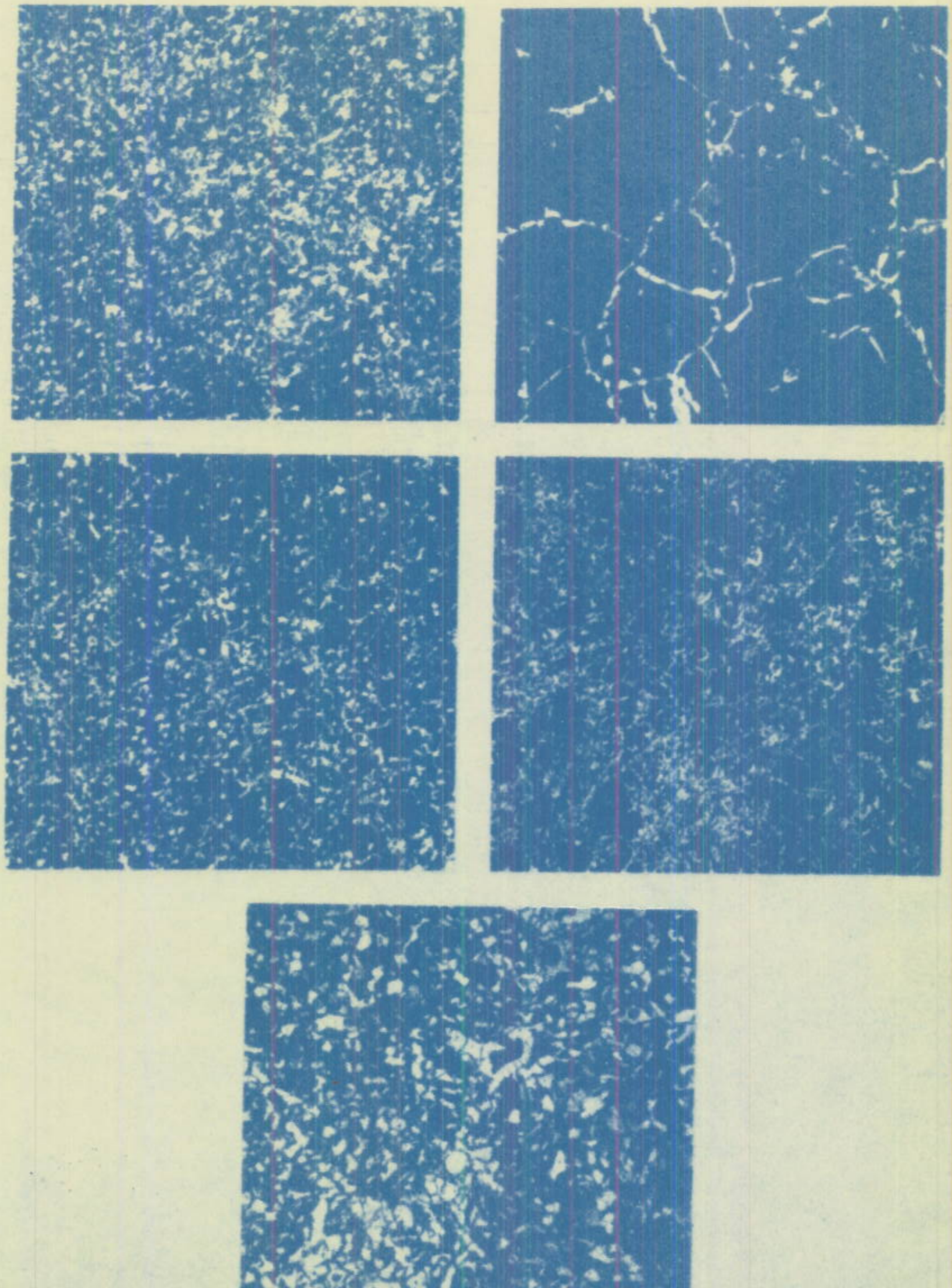

PLATE II