Thesis

THE EFFECT OF RATE OF COOLING AND COLD WORK ON THE HARDNESS AND GRAIN SIZE OF TYPE METAL

by

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APPENDIX B

441 Beacon Street,
Boston, Mass.,
May 25, 1932.

Professor A.L.Merrill,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

In accordance with the requirements for graduation I herewith submit a thesis entitled, "The Effect of Rate of Cooling and Cold Work on the Hardness and Grain Size of Type Metal".

The investigation undertaken in this work was made possible by Prof. I.H.Cowdrey who was in charge, and by Mr. Kimbal Loring of the Machine Composition Company, Boston, who furnished material and valuable information. Prof. R.S.Williams was extremely helpful in the metallurgical part of the work and I want to take this opportunity to express my appreciation for what he has done.

Respectfully,

Joseph J.Winkler

INTRODUCTION

For the production of good type there are certain essentials that must be watched carefully by the manufacturer. One is the composition of the metal, a slight change in the antimony content resulting in a considerable change in hardness of the metal. Changes in the amounts of tin have similar results, although this function of the tin is in addition, to make the metal tough and make it flow well when hot. The tin content is also important.

A second necessary condition for good type is that the metal be cast at a correct temperature. The range of proper casting temperatures is quite wide but it has been found that for a certain machine there is another range within the large range that is correct for that machine.

It is also important to cool the mould while type is being cast. Usually the mould has water circulation through it but no effect is made to control the temperature of the mould by cooling the water.

In all the work which is done in an endeavor to produce a good type at as low a cost as possible, it has been difficult to try to attain a certain definite end because there are no real standards or specifications as there are in engineering materials. What is needed is a standard of wearing quality - the one thing desired by users of the type.

Considering the use to which the type is put and the way in which it has failed when it has become unfit for further use, it is certain that two of the essential factors are the hardness of the type and the fineness of the grain. If fatigue tests were made on type it is certain that a type which was harder and of finer grain would outwear a type which was softer and of coarse grain. These are well known facts pertaining to almost any metal.

A consideration of the situation showed that what was desired by type manufacturers was a method of improved manufacture whereby a type metal of a lower Sb and Sn content could be made equally good, from the standpoint of wearing quality, as a metal of higher Sb and Sn content. It is known that an increase in Sb will cause the metal to become harder and an increase in Sn within limits will cause it to become harder and to flow better. But these metals are considerably more expensive and so it is desired to reduce their percentage in the type metal.

It is generally true that the rate of cooling of the metal after it has been cast influences to a great extent its final hardness and size of grain - a more rapid rate giving a harder and finer grain material. It is also true that in the case of steel and brass, cold working increases the hardness. These two factors, rate of cooling and cold working were thought to be influential in the casting of type metal and so were selected as types in this investigation.

About six months ago there were some comparative hardness tests made for the Machine Composition Co. of Boston between the metal as it is received in the ingot form and the cast type. The results showed the ingot to be somewhat harder than the type, in spite of the latter's much finer grain.

As a preliminary to this investigation it was decided to check the relative hardness of ingot and type so as to obtain a basis for further work.

The metal used was of the composition; Sb 23%, Sn 12 1/2 %, Cn 1%, Pb 66.1/2%.

Purpose

The purpose of this investigation was to determine the effect of first, the rate of cooling and second, cold work, upon the hardness and grain size of type metal. The same composition of metal was used throughout. The purpose also included the determination of a proper method of obtaining the desired cooling rate, in the event that it should prove profitable.

Scope

The study of the physical behavior of the type metal is limited in this study to the changes effected in the material by different rates of cooling and by cold working. No attempt is made to cover the different phases of die casting, such as the effect of pressure or casting, effect of velocity of flow of the metal, spraying due to obstacles, the escape of air from the mould, or the material out of which the mould is made. These factors may be of importance in the production of type but they are not considered in this work. Also no account is taken of the chemical composition of the metal or the metallurgical methods in forming the alloy. A type metal of one composition is used throughout and the comparisons made on that basis.

Summary

The results of this investigation show that there is no appreciable difference in the hardness of the metal in ingot form and in type form. The differences that were shown by other investigations were due probably to the fact that the metal in the type was not from the same ingot as the one tested and consequently there was very likely a difference in the chemical composition of the two. The die casting does not, then, soften the material.

The hardness tests made on the specimens that were cast at different cooling rates showed that the hardness was not effected by the rate of cooling. The casting temperature of the metal was 650°F and the mould temperatures were varied from 1.5°F to 325°F. The hardness number of the former was found to be 36.0 and the latter 35.4, the difference being well within the range of experimental error. Specimens cast at intermediate mould temperatures did not very more than two points.

In comparing the grain size of the different specimens, a difference was noted. As would be expected, the specimens cast at a lower mould temperature showed a somewhat smaller grain size throughout. On all the specimens the grain was much larger at the center than at the edge, the region of small grain extending for a short distance from the edge. It is in this depth of small grain area that the specimens distinguish themselves, those cast

at a lower mould temperature having a greater percentage of area of small grain. Considering all the specimens, then, the area of small grain varies inversely as the temperature of the mould. This increase in fine grain area does not, however, occur rapidly with decrease in mould temperature, the total change possible at these temperature limits being not very great.

MAIN SECTION

Method and Procedure in Making Comparative Hardness Tests of Ingot and Type.

As explained earlier, the purpose of making these comparative tests was to check the work done formerly which showed the type to be softer than the ingot. If it were true that this condition existed, it would be certain that some fault in the method of die casting would need correcting.

Samples of type ranging from 8 pt to 48 pt were cast in one of the regular machines used in production. The temperature of the melt was 650°F. Out of the same pot some of the metal was taken and cast in an open mould. In this way it was made certain that the same material was used in both cases. Hardness tests were then made on each size of type and on the ingot by the Vickers' machine. Before testing, the material was polished so that accurate ocular reading could be made. Six different readings were made at different points in the cross section of the ingot. The type was tested by taking a reading at the face, head and foot of five separate pieces of the same size type throughout the series.

Results of Comparative Hardness Test of Type and Ingot

Average Vickers Hardness Numbers

Size	Head	Face	Foot
48 pt Cap M	32.6	33.4	33.2
36 pt Cap M	32.1	32.5	31.6
24 pt Cap M	34.8	36.3	35.4
18 pt Cap M	35.2	37.7	35.1
14 pt Cap M	31.7	36.1	32.5
12 pt Cap M	33.0	33.2	30.9
10 pt Cap M	30.6	29.3	27.4
8 pt Cap M	25.8		30.1
Ingot 31.6			

Discussion of Results of Comparative Tests

From the results here shown it can be seen that there is practically no difference in hardness between this ingot and the type. Also there is practically no difference in hardness between the different size of type until the 8 pt size is reached. This difference is, however, only apparent, the cause being that when such a small mass of metal is used, it flows under the weight used for the diamond point impression. To verify this, an exact size was cut out of a piece of metal whose hardness had been tested, and this small piece put in the machine. It flowed just as the 8 pt did.

For data see Appendix (Page 18)

Conclusions from Comparative Tests

There is no difference in hardness between the different sizes of type or between the type and the ignot.

Method and Procedure in Casting at Different Cooling Rates

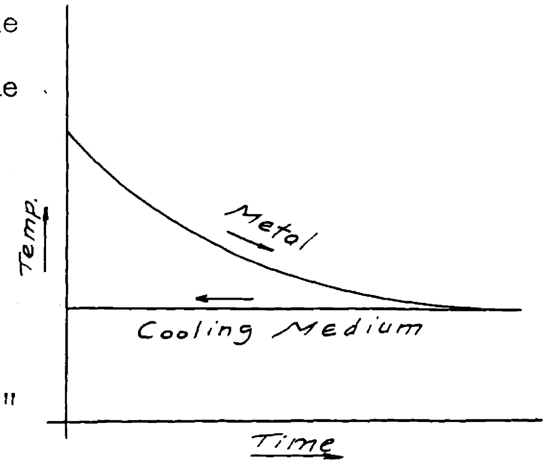


Figure IX indicates the time temperature relation for the casting and cooling medium. It was thought that this was the best method to use so as to make the comparison of specimens accurate. The metal casting 1/2" dia. and 1" deep being made in a steel mould whose sides were about 1/8" of an inch thick, and the volume of the oil being 1 gal; there was no appreciable rise in the temperature of the cooling medium. The casting was left in the turbulent medium for 20 minutes so that it would come to the temperature of the oil.

The apparatus was set up as shown on page 30 Appendix. The cooling medium was brought to the desired temperature with the mould immersed and held at that temperature for twenty minutes before the pouring was made. This was to insure the mould being at the same temperature as the oil. The metal was then heated to 650°F and poured into the mould. Immediately the oil was stirred violently and the mould and casting allowed to drop down onto a rack so that it would be totally immersed. The temperature was kept constant and the oil stirred for another twenty minutes, at which time the mould and casting were taken out and allowed to come to room temperature in the air. This was done for each specimen, and conditions were set for each casting separately. A new piece of metal was used for each casting. For the specimen that was cast at 1.5°F, an ice brine solution was used as a cooling medium in place of the oil. The procedure was identical.

<u>Hardness Testing of Specimens Cooled at Different Rates - Procedure</u>

The specimens were filed down flat and polished slightly so that accurate hardness tests could be made. Five readings were taken at both top and bottom of each casting.

<u>Results of Hardness Tests of Specimens Cooled at Different Rates</u>

Spec. No.	Mould Temp.	Av. Hard. No.
10	1.5	35.8
0	32	36.3
8	40	36.4
7	75	36.0
3	107	37.9
6	125	35.2
1	155	35.8
2	200	35.1
5	225	36.2
4	261	36.0
9	325	35.4

Discussion of Results of Hardness Tests on Specimens cooled at Different Rates

The results indicate conclusively that the hardness of type metal is independent of the rate of cooling. This is a very surprising fact because in general the hardness increases with the rate of cooling. The average hardness for all the castings was 36.02, the lowest was 35.1 and the highest 37.9, all within the range of experimental error. The individual hardness numbers that were used in calculating the average hardness for each specimen did not vary more than a few prints from the average, as seen from the data on page (21) Appendix. The reason for this condition is due to the inherent characteristics of this particular alloy itself. It is, of course, advantageous in the casting of type because it then becomes unnecessary to control the mould temperature, at least from the standpoint of hardness.

In making the hardness determinations the prints chosen on the specimen were as widely spread as possible. Points chosen out near the edge would be of no value due to the flowing of the metal. It was necessary to choose all points at least 3/32" from the edge of the casting.

Conclusions from Hardness Tests on Specimens Cooled at Different Rates

The hardness of type metal is independent of the rate of cooling.

Method and Procedure in Determining Relative Grain Sizes of Specimens Cooled at Different Rates

The specimens were polished and prepared for microscopic inspection by polishing on No. 1 paper, then No. oo, and then the three grades of polishing wheels, after which they were etched with ferric chloride. After inspection in the microscope, four specimens were selected for photographing. These had mould temperatures of 1.5°F, 32°F, 107°F, and 325°F respectively. Photographs were then taken at 100 magnification. Two photographs were taken of each specimen, one photograph at the center and the other at some other point on the casting.

Results Concerning Cooling Rate

The results of the microscopic examination of the specimens are as follows. The cooling rate produces very little overall change in the grain size of the material. The grain structure is totally unchanged. As would be expected, the grain size is much larger at the center of the specimen. This is due to the slower rate of cooling of the inner metal. On all the specimens the outside is of a very fine grain structure. Where the difference occurs is in the depth of this fine grain region and the rapidity with which the size of the grain increases as the inside of the casting is approached. The specimens cast at the lower mould temperature had a greater fine grain area and this area varied progressively as the cooling rate increased.

This condition was uniform throughout the group so only four specimens were photographed. The following photomicrographs were taken. See Appendix page (26).

Discussion

The photomicrographs shown indicate the relative grain sizes of the metal under different rates of heat flow. As mentioned before, the grain formation is the same throughout. The larger white finger-like areas are the antimony tin eutectic, and the few white square areas are the Sb Sn compound. The black area indicates the lead. The white area is what lends hardness to the metal, the black being simply the matrix. The combination is the same in all specimens.

The difference is in the size of grain and in the amount of small grain area, this area increasing with the rate of cooling. Considering all the specimens, although there is some increase in this fine grain area, the maximum change is not very great. This difference of penetration does not exceed 3/32" radially.

The failure of type is the wearing round and wearing away of the edges or outside portion of the type. It is then, the outside of the type that must be the more resistive to wear.

Conclusions Concerning Cooling Rate

The effect of the rate of cooling of the grain of the metal is as follows: The greater the rate of cooling the finer will be the grain throughout, to a slight degree; the depth of fine grain boundary from the outside of the casting will be somewhat greater. These differences are only small, and from a commercial or production standpoint, it would not be profitable to effect a rapid rate of cooling to achieve these differences.

Cold Working of Metal - Procedure

Three specimens of type metal were cast at a casting temperature of 650°F and mould temperature of 73°F. To one a load of 3000 lbs, or 15,300 #/sq.in. was applied; to another 21,800 #/sq.in; and the last 22,800 #/sq.in., the ultimate strength of the material. Hardness tests were made in the usual way. The specimens were also polished and inspected by micrcscope. Data on page (25) Appendix.

Results

Spec.	Comp. Load lbs.	Stress lbs./sq.in.	Av.Vickers Hard.
T	3000	15,300	36.8
W	4280	21,800	36.0
F	4476	*22,800	35.8

* Ultimate Strength in Compression.

Discussion and Conclusions Concerning Cold Work

The results show that cold working has no effect upon the hardness of the type metal. A microscopic examination showed nothing new and an examination of longitudinal section showed the grain closely packed at top and bottom, as would be expected.

Cold work, therefore has no effect upon the hardness or grain size.

General Discussion and Conclusions

The results of this study show that the rate of cooling, an extremely important physical factor in the treatment of nearly all metals, has no effect upon the hardness or grain size of type metal. The hypothesis that was assumed in the beginning, in the mind of the author at least, that the rate of cooling had important effects, has been proven false. It was hoped that improved methods of casting type could be derived from this study but the result has been that, from this standpoint, the methods now in use cannot be improved appreciably.

To effect a very rapid rate of cooling so as to obtain a greater area of fine grain would require large and expensive refrigerating machinery, the cost of which would certainly not warrant its use.

Also, from the standpoint of hardness, it was surprising to find that the hardness was not effected by the rate of cooling. To cool more rapidly would not give any advantage here.

What seems to be the case is, that to produce a better grade of type, better material must be used. That is, to obtain a harder and better wear resisting type more antimony and tin must be used. Of course there are definite limits to the amounts of these metals that must be used, but that is a problem in metallurgy and is beyond the scope of this work.

A possible means of improving the grain size in the method of die casting is to increase the pressure. Experiments in variation of pressure have shown that the greater the pressure the finer will be the grain. The limit to this is set by the ability of the mould to hold the metal without leaking.

As a recommendation for further study of the manufacture of type metal, it is to urge that investigation be in the methods of die casting, dealing with pressures,rates of flow and mould materials. It is highly possible that improvements can be made if this is done.

APPENDIX A

Ingot

Test No.	Hardness No.
1	30.2
2	32.1
3	30.9
4	31.3
5	33.8
6	31.3
Av.	31.60

Vickers Hardness Numbers

Type Cast From Ingot

48 pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. NO.
1		33.0		33.0		33.0
2		30.2		32.5		33.0
3		33.4		33.0		33.0
4		33.0		33.0		33.8
5		33.4		35.3		33.4
	Av.	32.60	Av.	33.36	Av.	33.24

36 Pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. NO.
1		32.1		33.0		32.7
2		32.5		32.1		32.7
3		32.7		32.1		30.5
4		30.9		32.5		31.7
5		32.1		33.0		30.5
	Av.	32.06	Av.	32.54	Av.	31.62

24 Pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. NO.
1		35.8		36.8		35.8
2		34.8		36.3		36.3
3		34.8		35.8		34.8
4		34.8		35.8		34.8
5		33.8		35.8		35.3
	Av.	34.80	Av.	36.30	Av.	35.40

18 pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. No.
1		35.8		37.3		34.8
2		37.3		37.9		36.3
3		35.3		37.9		35.3
4		33.0		37.9		34.3
5		34.8		37.3		34.8
	Av.	35.24	Av.	37.66	Av.	35.10

14 pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. No.
1		28.2		36.3		32.5
2		30.9		37.3		33.4
3		30.9		34.3		31.7
4		35.3		36.8		33.8
5		33.4		35.8		30.9
	Av.	31.74	Av.	36.10	Av.	32.46

12 pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. No.
1		33.4		34.3		29.4
2		33.4		33.8		32.1
3		31.7		33.0		31.3
4		32.5		31.7		29.8
5		33.8		33.0		31.7
	Av.	32.96	Av.	33.16	Av.	30.86

10 pt. Cap M

Test No.		Head Hard. No.		Face Hard. No.		Foot Hard. No.
1		30.2		29.0		27.3
2		30.2		30.5		27.6
3		31.3		29.4		27.3
4		29.0		28.6		27.3
5		32.1		29.0		27.3
	Av.	30.56	Av.	29.30	Av.	27.36

8 pt. Cap M

Test No.	Head Hard. No.	Foot Hard. No.
1	27.6	29.4
2	25.7	31.3
3	25.1	31.3
4	25.1	31.7
5	25.4	30.9
Av.	25.78	Av. 30.12

Cold Work

Temperature of Melt 650 deg. F.   Cooling 73 deg. F

F		T		W	
Ocular Read.	Hard. No.	Ocular Read.	Hard. No.	Ocular Read.	Hard. No.
144	35.8	140	37.9	144	35.8
144	35.8	143	36.3	144	35.8
144	35.8	143	36.3	143	36.3
Av.	35.8	Av.	36.8	Av.	36.0

VICKER'S HARDNESS TYPE METAL DIAMOND PYRAMID 10KG 1 1/2" OBJ.

Spec. No. 0 Cooling Medium 32 degrees F (Water)

Read. No.	Ocular Read.		Hard. No.
1	143		36.3
2	143		36.3
3	143	Bottom	36.3
4	143		36.3
5	143		36.3
			Av. 36.3
1	144		35.8
2	141		37.3
3	143	Top	36.3
4	143		36.3
5	144		35.8
			Av. 36.3

Av. top & bottom 36.3

Spec. No. 8 Cooling Medium 40 degrees F (Oil)

1	146		36.3
2	145		34.8
3	143	Bottom	35.3
4	145		36.3
5	143		35.3
			Av. 35.6
1	141		37.3
2	141		37.3
3	140	Top	37.9
4	141		37.3
5	143		36.3
			Av. 37.2

Av. top & bottom 36.4

Spec. No. 7 Cooling Medium 75 degrees F (Oil)

Read. No.	Ocular Read.		Hard. No.
11	143		36.3
2	145		35.3
3	145	Bottom	35.3
4	143		36.3
5	145		35.3
		Av.	35.7
1	142		36.8
2	142		36.8
3	142	Top	36.8
4	142		35.8
5	145		35.3
		Av.	36.3

Av. top & bottom 36.0

Spec. No. 3 Cooling Medium 107 degrees F (Oil)

1	143		36.3
2	143		36.3
3	139	Bottom	38.4
4	133		42.0
5	138		39.0
		Av.	38.9
1	136		40.2
2	142		36.8
3	142	Top	36.8
4	145		35.3
5	145		35.3
		Av.	36.9

Av. top & bottom 37.9

Spec. No. 6 Cooling Medium 125 degrees F (Oil)

Read. No.	Ocular Read.		Hard. No.
1	145		35.3
2	145		35.3
3	145	Bottom	35.3
4	145		35.3
5	144		35.8
		Av.	35.4
1	146		34.8
2	145		35.3
3	142	Top	36.8
4	147		34.3
5	147		34.3
		Av.	35.1

Av. top & bottom 35.2

Spec. No. 1 Cooling Medium 155 degrees F (Oil)

1	144		35.8
2	141		37.3
3	146	Bottom	34.8
4	145		35.3
5	143		36.3
		Av.	35.9
1	143		36.3
2	141		37.3
3	144	Top	35.8
4	144		35.8
5	141		37.3
		Av.	35.9

Av. top & bottom 35.9

Spec. No. 2 Cooling Medium 200 degrees F (Oil)

Read. No.	Ocular Read.			Hard. No.
1	148			33.8
2	150			33.0
3	144	Bottom		35.8
4	148			33.8
5	148			33.8
			Av.	34.0
1	142			36.8
2	142			36.8
3	140	Top		37.9
4	146			34.8
5	146			34.8
			Av.	36.2

Av. Top & Bottom 35.1

Spec. No. 5 Cooling Medium 225 degrees F (Oil)

1	148			33.8
2	144			35.8
3	142	Bottom		36.8
4	142			36.8
5	146			34.8
			Av.	35.6
1	140			37.9
2	142			36.8
3	140	Top		37.9
4	144			35.8
5	145			35.3
			Av.	36.7

Av. Top & Bottom 36.2

Spec. No. 4. Cooling Medium 261 degrees F (Oil)

Read. No.	Ocular Read.		Hard. No.
1	142		36.8
2	144		35.8
3	144	Bottom	35.8
4	143		35.8
5	143		36.3
		Av.	36.2
1	145		35.3
2	143		36.3
3	143	Top	36.3
4	144		35.8
5	144		35.8
		Av.	35.9

Av. Top & Bottom 36.0

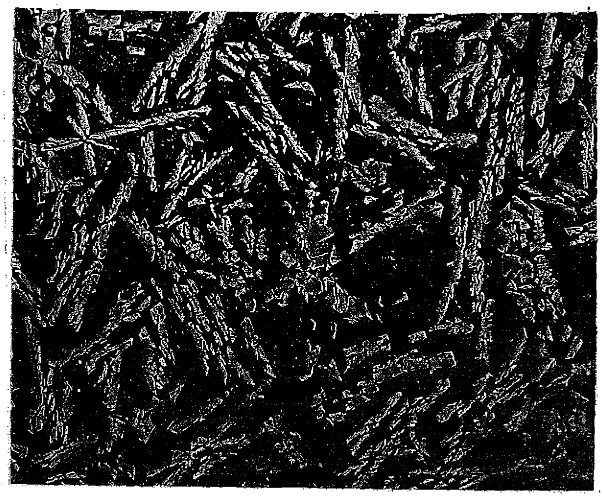
Spec. No. 9 Cooling Medium 325 degrees F (Oil)

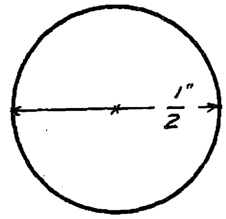
1	145		35.3
2	146		34.8
3	146	Bottom	34.8
4	146		34.8
5	145		35.3
		Av.	35.0
1	148		33.8
2	143		36.3
3	144	Top	35.8
4	142		36.8
5	144		35.8
		Av.	35.7

Av. Top & Bottom 35.4

APPENDIX B

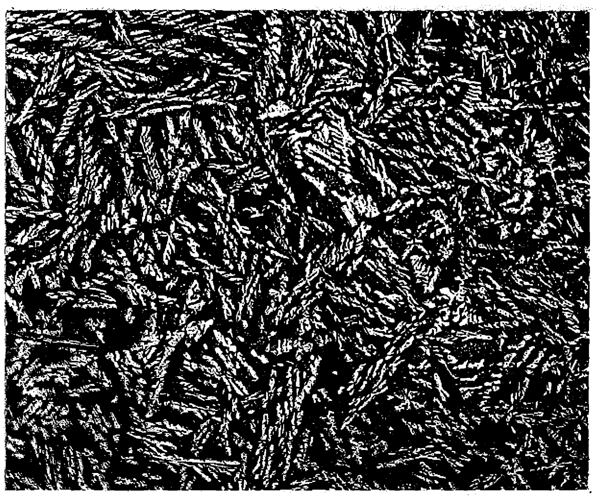
Mag. 100 X

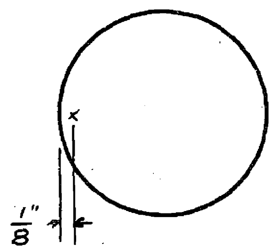




I

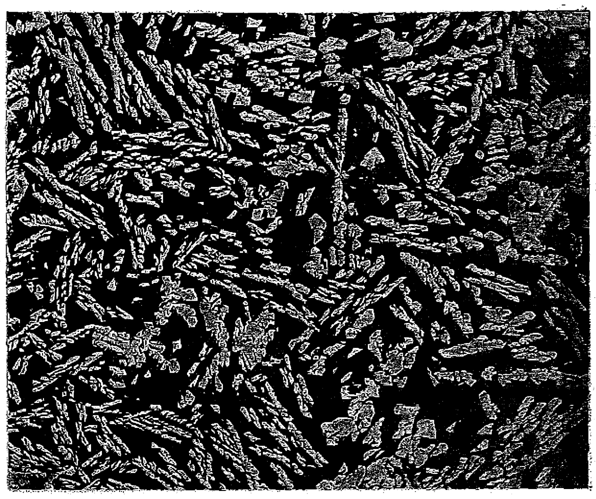
Casting Temperature 650 deg. F
Mould Temperature 325 deg. F
Position - Center of Casting

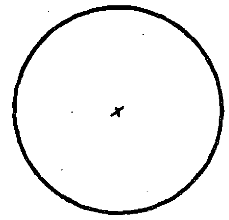




II

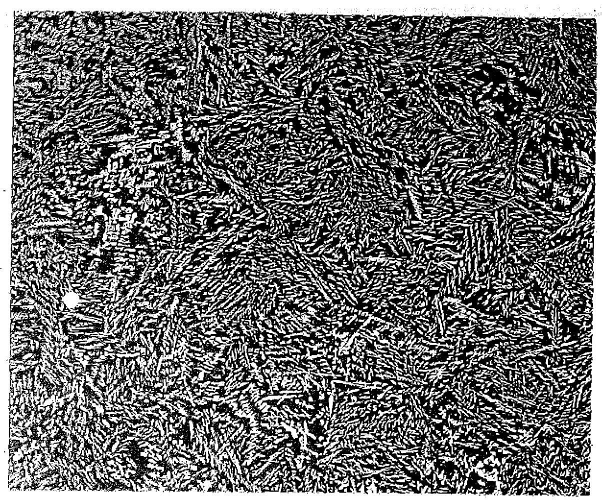
Casting Temperature 650 deg. F
Mould Temperature 325 deg. F
Position - as indicated

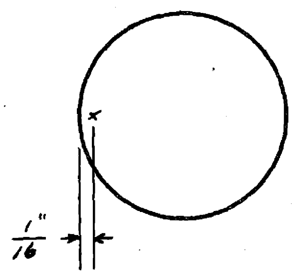




III

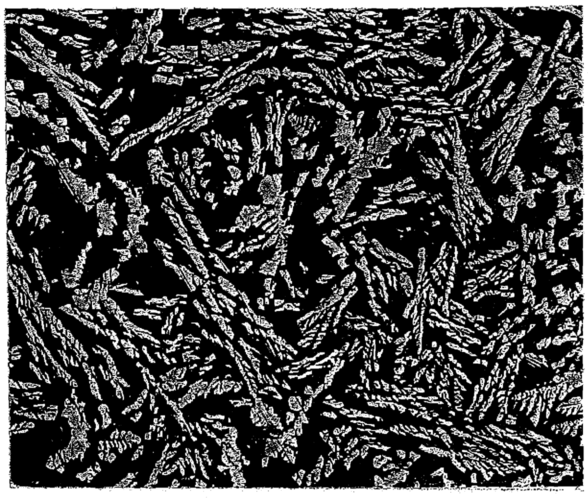
Casting Temperature   650 deg. F
Mould Temperature   107 deg. F
Position - Center of Casting

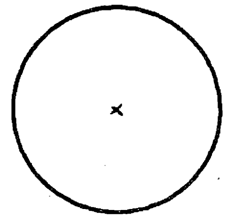




IV

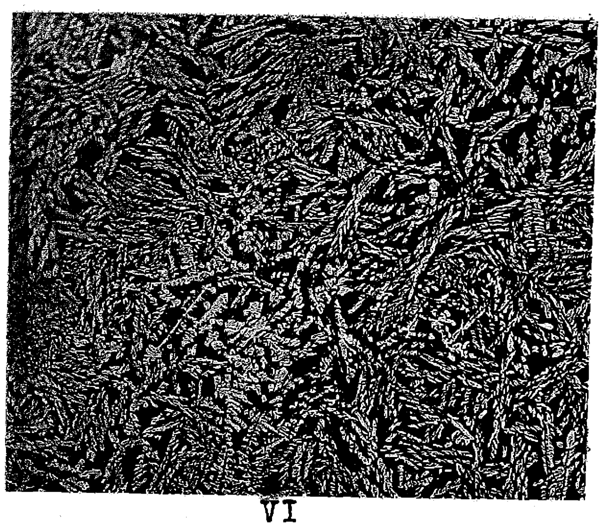
Casting Temperature   650 deg. F
Mould Temperature   107 deg .F
Position - as indicated

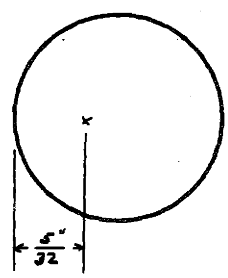




V

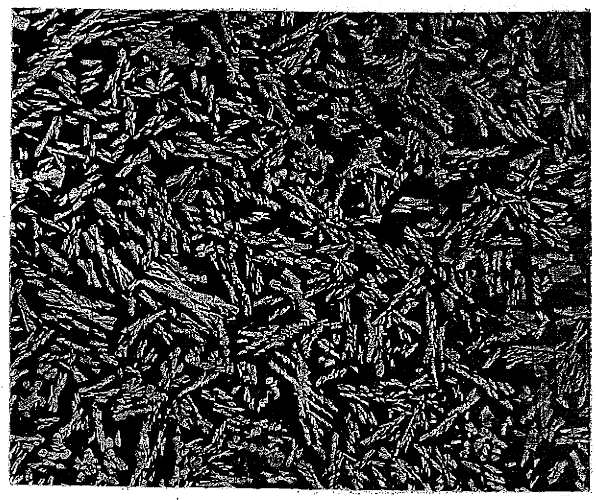
Casting Temperature 650 deg. F
Mould Temperature 32 deg. F
Position - Center of Casting

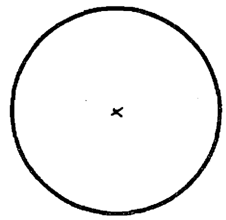




VI

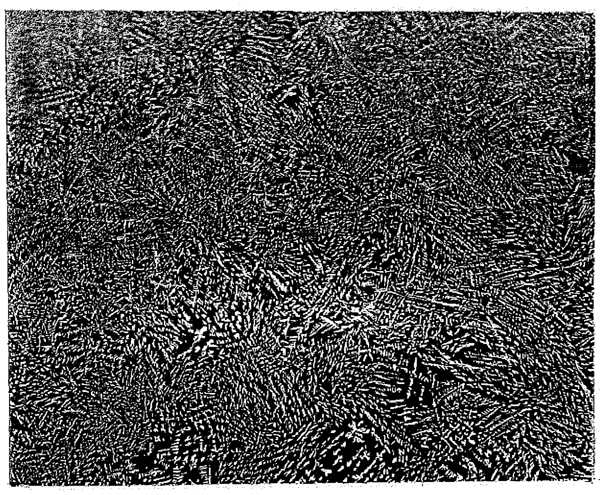
Casting Temperature 650 deg. F
Mould Temperature 32 deg. F
Position - as indicated

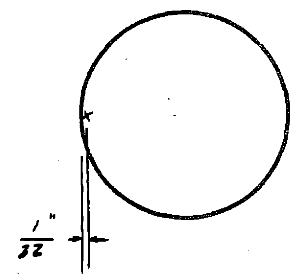




VII

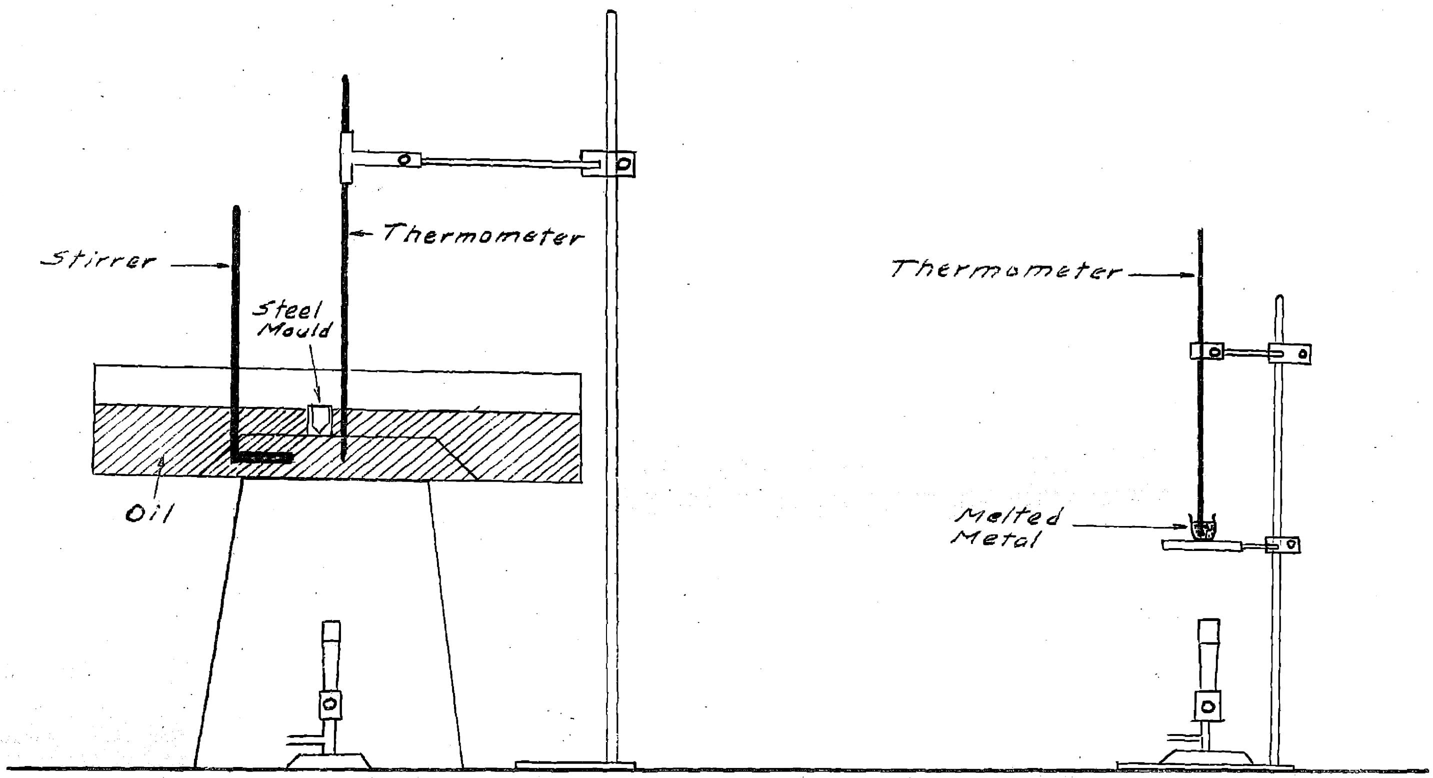
Casting Temperature 650 deg. F
Mould Temperature   1.5 deg. F
Position - Center of Casting

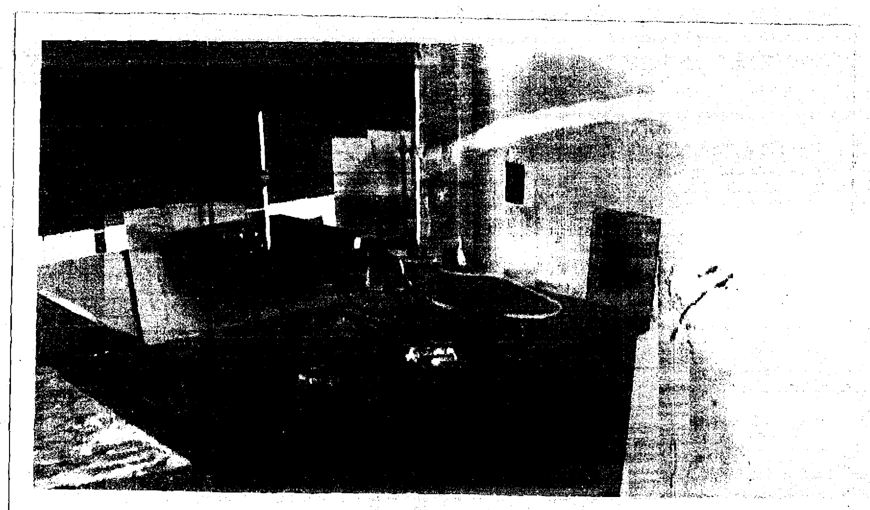




VIII

Casting Temperature 650 deg. F
Mould Temperature   1.5 deg. F
Position - as indicated


Stirrer
Thermometer
Steel Mould
Oil
Thermometer
Melted Metal



Apparatus.

Vickers Hardness Testing Machine, made by, Vickers Armstrongs, Ltd., Erith Kent, England. Machine No. 250170. Located in Room 1-215 Massachusetts Institute of Technology.

Compression machine, made by, Riehle Bros., Philadelphia, Pa. 10,000 lbs. capacity, located in Room 1-210 Massachusetts Institute of Technology.

The casting apparatus consisted of: a medium carbon steel mould, oil, S.A.E.No. 20, two mercury thermometers, one alcohol thermometer, iron crucible, burners, ring stands, tripod, oil tank with trays. This material is located in Room 8-424 Massachusetts Institute of Technology.

In the hardness testing the 136 degree diamond point pyramid was used with a 10 kilogram load and 1½" objective.

The photomicrograph work was done in Room 8-420, where the camera and developing and printing apparatus is located.