QUENCHING CYCLES OF SOME

ALLOY STEELS

THESIS FOR DEGREE OF MET. E.

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THESIS

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- QUENCHING CYCLES -

OF SOME ALLOY STEELS

Thesis

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THESIS

- ABSTRACT -

A brief discussion of the development and use of the quenching cycle. Twelve types of alloy steel, representing three grades in general usage have been examined. The analysés, together with the hardness data, and the microscopic examination, illustrated by micrographs, are given.

INTRODUCTION

The discovery and subsequent patent of an alloy steel by Ketley in England in 1799 marked the beginning of a new era in the age-old manufacture of steel. Faraday and Stodart helped to pave the way to advancement with their comprehensive study, in 1820. In 1857, Mushet presented his air-hardening (tungsten) steel. The progress of alloy steel thru the years is marked by the names of Hadfield, Riley, Taylor and White, Brearley, Helouis, and many others.

In the United States, the advance of alloy steel has closely followed that of the automobile, until today, but a small percentage of plain carbon steel finds its way into these vehicles.

While the addition of alloying elements, of themselves, do show a marked effect on the physical properties of the alloy, over that of carbon steel, that alone would not be sufficient to warrant their great use. Their real value, in the increase of strength and resistance without additional weight, has only been brought about by what now is known as heat-treatment.

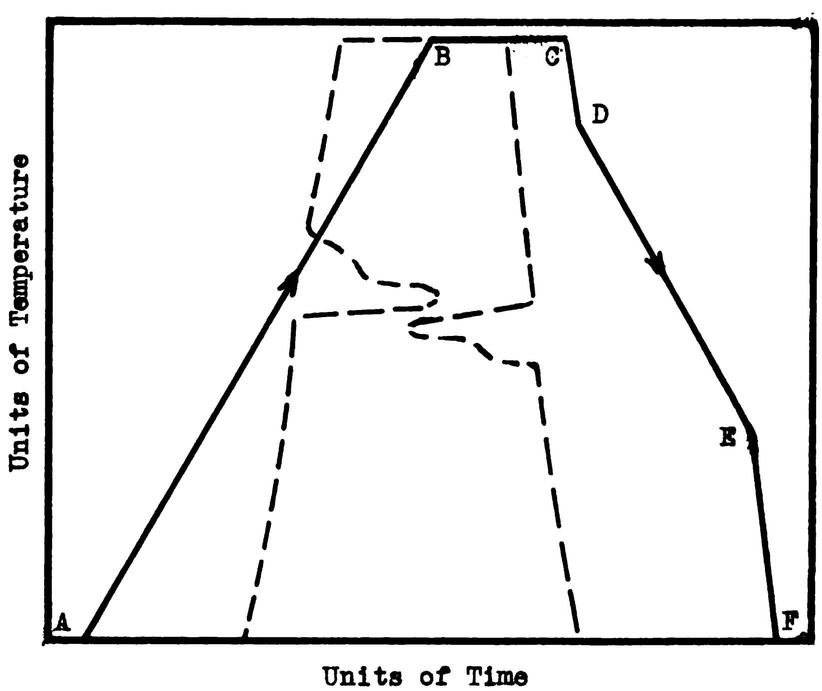
Just when and how the art of hardening steel or iron was discovered will ever remain a mystery of the past. Homer, in his Odyssey (800 B.C.), describes how "the glowing axe is dipped in cooling water, which spouts, hardening artfully." Quenching in oil likewise seems to have been known to the Greeks at an early date. Magnus gave his explanation in the 16th century - "Water, the principle of fusibility, which occurs in iron, gives it a certain softness. If the iron is made glowing hot, this most subtle aqueous part distills away and the rest becomes hardened."

Without entering into a very detailed discussion of the various explanations of this phenomena of hardening, which are being offered in the present day, suffice it to say, that all are based principally upon a phenomena known as allotropy. This may be defined, simply, as a change in energetic condition, unaccompanied by a change of state. If we heat a piece of pure iron to a high temperature and allow it to cool, observing the temperature, we find that at about 900° C, an arrest in the cooling occurs, an indication that a heat production has occurred. This heat production depends upon a change in energy condition, from the rich to a poorer. This critical point or recalescence in iron was first observed by the Swedish metallurgist, Angerstein, in 1778. We find the occurrence of these transformation points in some pure metals and alloys. Their position in the scale of temperature is peculiar to the metal, or in an alloy, to its metallic components and the relative quantity in which they exist. Experiments have shown that the reverse of this transformation and an absorbtion of heat occurs if the metal be heated instead of cooled.

As has been said, the greatest advantages of alloy steels, their increased properties, can only be brought about by the use of heat-treatment. This heat-treatment may not necessarily be one of hardening, but of placing the steel in a condition most suitable for its particular use. This heat-treatment can be accomplished only by knowing the exact position of this point of recalescence in one of the popular scales of temperature measurement. Likewise, it is pertinent that the various changes in metallographic structure, and corresponding specific hardness, preceding and succeeding these transformations, both from the heating and cooling, approach.

The exact position of this critical point can readily be determined by laboratory means or by the actual phenomena of recalescence by the trained observer. However, a practical method of finding all the necessary data including metallographic structure and hardness for each specific grade of steel has been devised. This method, for want of better, has been termed the quenching cycle. It was designed and worked up after a long series of experiments which had to do with the industrial development of various alloy steels. Later, it has been applied to various phases of mill practice necessary in the manufacture of steels, for the trade. Likewise, its use has found ready application by the trade in the fabrication of bars into the finished product, i.e. that part which has to do with heat-treatment.

The quenching cycle consists of a number of small pieces of a given material which have been quenched or cooled in some media from periodic temperatures which are on an ascending and descending scale from room temperature to a point well above the occurrence of the transformation or recalescence. This is more simply explained by the following schematic diagram.



The diagram is almost self-explanatory. A-B represents the heating portion of the cycle, and C-D-E-F, the cooling portion. The specimens are cooled rapidly in the furnace from C to D, since it has been found by experience that nothing is to be gained in adhering to the prescribed rate thru this stage. Upon this diagram, in dotted lines, has been superimposed a hypothetical inverse rate curve showing the position of the critical points.

PROCEDURE

Since the quenching cycle was designed with a practical purpose in mind, its operation involves but a small amount of material and the usual equipment found in the average routine laboratory. Of the steel involved in the experiment, a bar, preferrably one inch in diameter, about fifteen inches long, is cut up into a number of discs, one fourth inch in thickness. About forty such discs are necessary.

These discs are identified by a stenciled number and placed into the laboratory furnace, at room temperature. If the temperature of the furnace be automatically controlled, the experiment will be somewhat simplified. The furnace used in the preparation of this report was one manufactured by the Hoskins Manufacturing Company, designated as Type F H 207, electrically heated, and controlled by Brown Instrument Company equipment. The control equipment was adjusted so that the rate of heating was 1°F. per minute and the power applied. The specimens were left undisturbed until the temperature of the furnace had reached a point about 100° F. below the approximate occurrence of the first transformation point (Ac_1). This was usually 1300° F. At this point, the furnace was opened and the first piece was quenched in water. Care was taken to see that the piece was properly quenched which included a pre-heating of the tongs, etc. As the temperature of the furnace and discs increased, at every period of 20° F. and approximately twenty minutes time, one piece was quenched, until the maximum temperature was reached. This was at least 200° F. above the last transformation point or about 1600° F. The furnace was held at this maximum for thirty minutes to insure thorough solution. The temperature was then dropped from 150° to 200° at the rate of 150° per hour. It was learned after several trials that but little could be gained by slower cooling through this range. A point about 150° above the first decalescence point is now reached. The furnace control is adjusted so that the rate of cooling is 1° F. per minute. Periodically at every 20° F., a specimen is quenched, as in the first part of the cycle, until the end of the cycle is reached. This usually is about 200° F. below the last decalescence point or about 1000° F.

These specimens, representing a quench from every periodic temperature ascending to and descending from the maximum, were then carefully prepared for the hardness determination. About .030" of one flat side of each disc was removed by grinding. This was done to remove all scale and decarburization of the metal incident to the heat-treatment. By means of a standard Brinell machine, manufactured by the Aktiebolaget Alpha of Sweden, the Brinell number of each piece was determined. The impression was made by a 10 mm. ball under a load of 3000 kg. applied for 30 seconds.

After this data had been compiled, these same sections were prepared for micro-examination. Under the microscope, the changes in structure could be followed readily. To properly illustrate these changes for each cycle, at least four micrographs were found to be necessary and these have been included in this report. These were taken on a Leitz Metalloscope at the location and magnification indicated.

(1) 100° F. below first transformation, heating cycle, at 100 diameters.

(2) at the first critical point Ac_1, heating cycle, at 500 diameters.

(3) at the point of maximum hardness, the Ac_3 point, at 500 diameters.

(4) below the Ar_1 point, cooling cycle, usually the point of lowest hardness at 100 diameters.

DISCUSSION

In this report, three grades and twelve types or analyses of alloy steels have been considered. These are tabulated below:

GRADE	TYPE SYMBOL	ANALYSIS	
Carburizing	S.A.E. 2315	3.5% Nickel	.15% Carbon
"	" 2512	5.0% "	.12% "
"	" 3115	1.5% Ni. -.75% Cr.	.15% "
"	" 4615	1.5% Ni. -.25% Moly.	.15% "
Water Hardening	" 1330	1.5% Manganese	.30% "
"	" 2330	3.5% Nickel	.30% "
"	" 3130	1.5% Ni. -.75% Cr.	.30% "
"	" 4130	.75% Cr. -.20% Moly.	.30% "
Oil Hardening	" 2340	3.5% Nickel	.40% "
"	" 3140	1.5% Ni. -.75% Cr.	.40% "
"	" 5140	1.0% Cr.	.50% "
"	" 6140	1.0% Cr. -.15% Va.	.40% "

The type symbols used are those of the Society of Automotive Engineers and are conventional in the United States. The analyses indicated are of the major elements only and represent the mean of the range specified by the above organization. The analysis of the materials used will be found to vary but slightly from these mean values. These three grades were picked since they represent the three chief methods of heat-treatment in general usage today. The type of steels chosen for this report were taken as the ones most generally used in this country under the conditions of heat-treatment indicated. The relative merits of these types in each grade do not enter into this discussion, since individual fabricators express a preference for varying reasons, such as machinability, uniformity, sensitivity to heat-treatment, tensile strength, cost, etc.

On the following pages, each of these types, in the order mentioned, will be discussed. This will include the analysis, hardness data, and a brief description of the changes in microscopic structure together with the four micrographs, for each cycle.

Quenching Cycle No. 1.

Carburizing Grade.

Type - S.A.E. 2315 - 3-1/2% Nickel.

Analysis:

Carbon	Manganese	Nickel
.13%	.52%	3.38%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
AD-1	1280° F.	170	17	1400° F.	364
2	1300	183	18	1380	"
3	1320	207	19	1360	"
4	1340	212	20	1340	"
5	1360	228	21	1320	"
6	1380	241	22	1300	340
7	1400	248	23	1280	"
8	1420	268	24	1260	321
9	1440	283	25	1240	277
10	1460	364	26	1220	262
11	1480	364	27	1200	248
12	1500	364	28	1180	217
13	1520	364	29	1160	211
14	1540	364	30	1140	207
15	1560	364	31	1120	196
16	1580	364	32	1100	174
			33	1080	137

MICROSCOPIC EXAMINATION:

Refer to Fig. 1, 2, 3, 4. Fig. 1 represents the metallographic structure found at 100 diameters in Test No. 2 of the series. It is one of fine grained pearlite and ferrite, typical of all conditions below the transformation point. Fig. 2 illustrates the condition found just within the critical range, Test No. 7, at 500-X. This structure is that of troosto-sorbite, sometimes known as Osmondite. The white areas are ferrite. Fig. 3 is the metallographic structure of Test No. 11, at a point just above the transformation. The condition is one almost entirely martensitic with a very thin matrix of retained austenite (white) indicated. Fig. 4 represents Test No. 32 of the series, at 100-X. The condition is similar to that found in Fig. 1, pearlite and ferrite, of a somewhat larger grain size. All of these specimens were etched with a 5% solution of nitric acid in alcohol, nital etch.

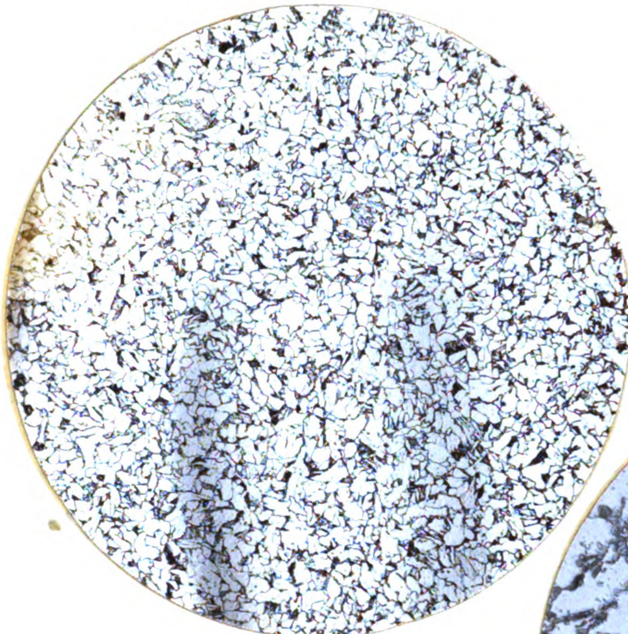


Fig.1.

Fig.2.

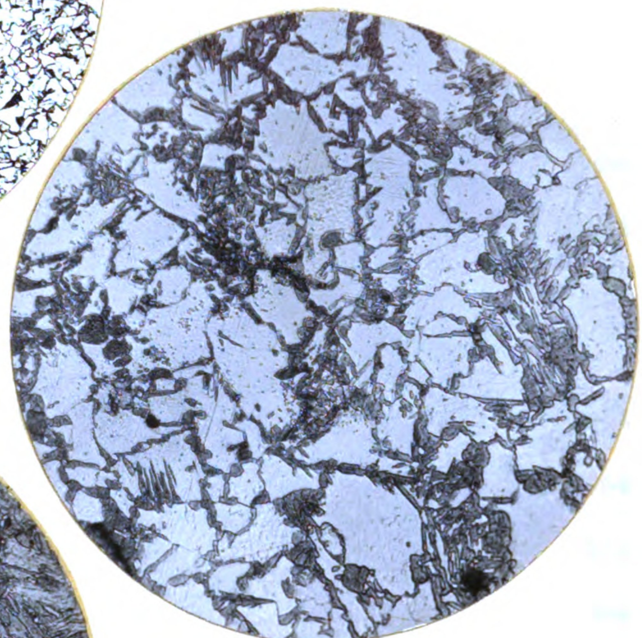
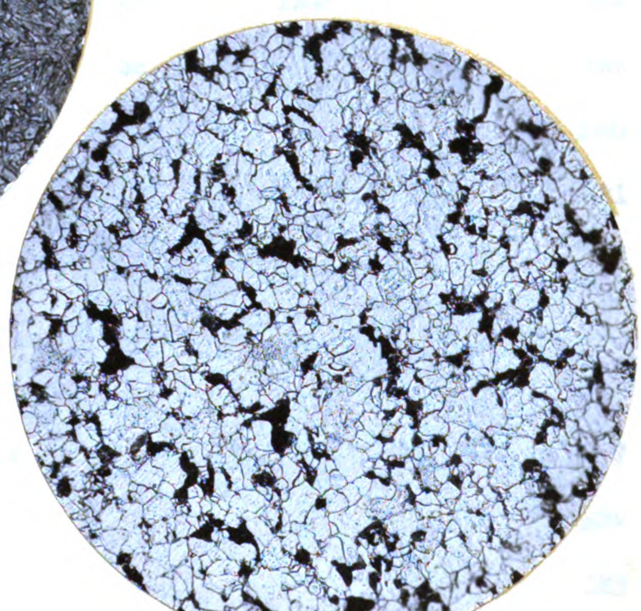


Fig.3.

Fig.4.



Quenching Cycle No. 2.

Carburizing Grade.

Type - S.A.E. 2512 - 5% Nickel.

Analysis:

Carbon	Manganese	Nickel
.12%	.41%	5.07%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
Z-1	1280° F.	217	Z-17	1400° F.	364
2	1300	241	18	1380	364
3	1320	241	19	1360	364
4	1340	241	20	1340	364
5	1360	269	21	1320	364
6	1380	293	22	1300	364
7	1400	332	23	1280	364
8	1420	340	24	1260	364
9	1440	340	25	1240	364
10	1460	351	26	1220	364
11	1480	364	27	1200	340
12	1500	364	28	1180	321
13	1520	364	29	1160	302
14	1540	364	30	1140	255
15	1560	364	31	1120	228
16	1580	364	32	1100	217
			33	1080	207
			34	1060	189

MICROSCOPIC EXAMINATION:

Refer to Fig. 5,6,7,8. Fig. 5 illustrates the condition found in Test No. 1 of this series. It is a structure of ferrite and some pearlite, very fine grained. The micrograph is at 100-X. Fig. 6 is that of Test No. 5 at 500-X. The condition is troosto-martensitic with large white areas of ferrite, all grains well defined. This is the condition within the transformation range. Fig. 7 is the micrograph of Test No. 12 at 500-X. The structure is that of coarse martensite. Note the slight retention of austenitic grain boundaries as well as that of some austenite. Fig. 8 illustrates the cooling phase of the cycle well before the Ar.1 point, Test No. 34 at 100-X. The structure is one of uniform fine grains of pearlite and ferrite.

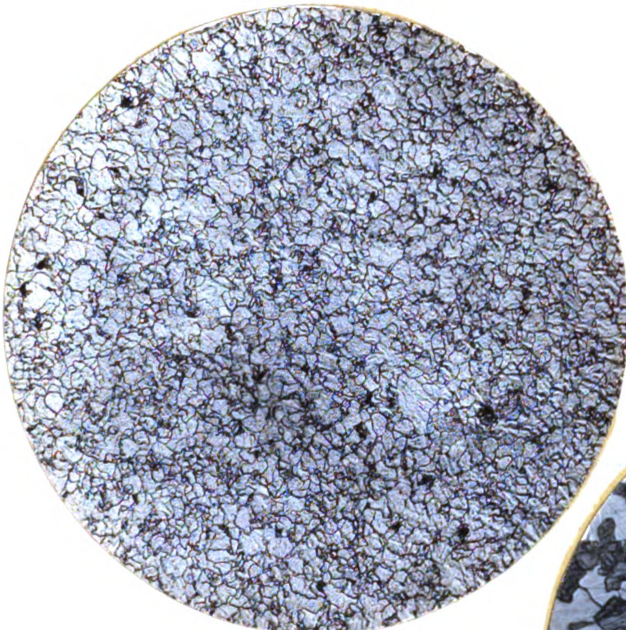
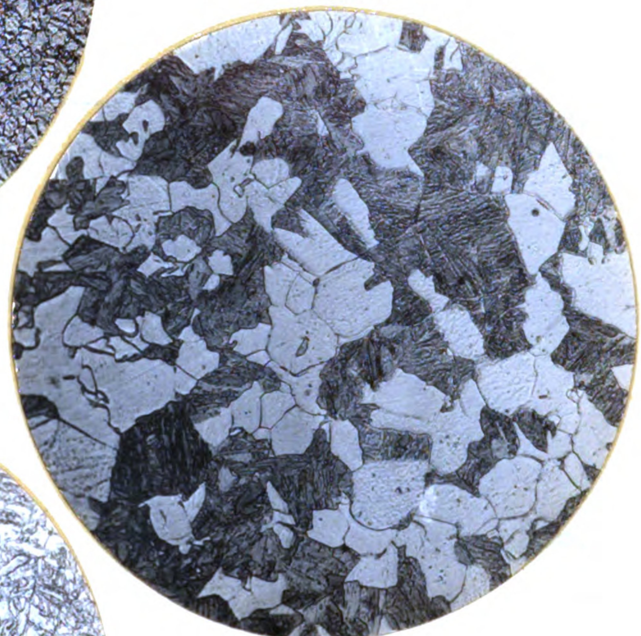


Fig.5.

Fig.6.



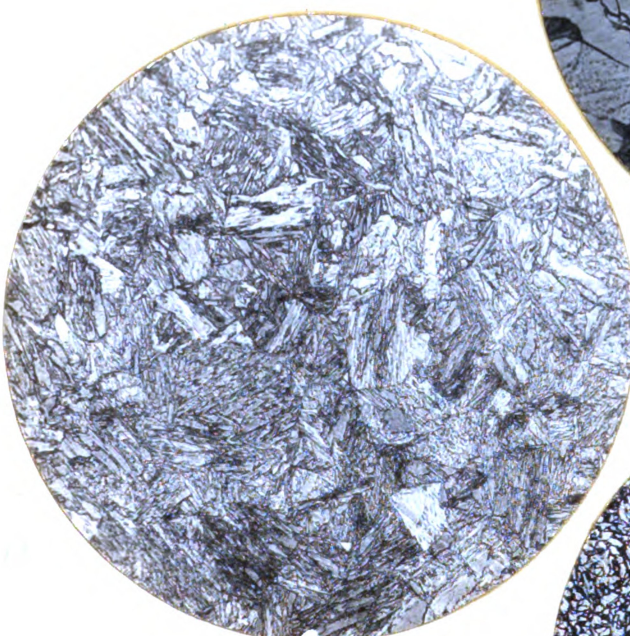
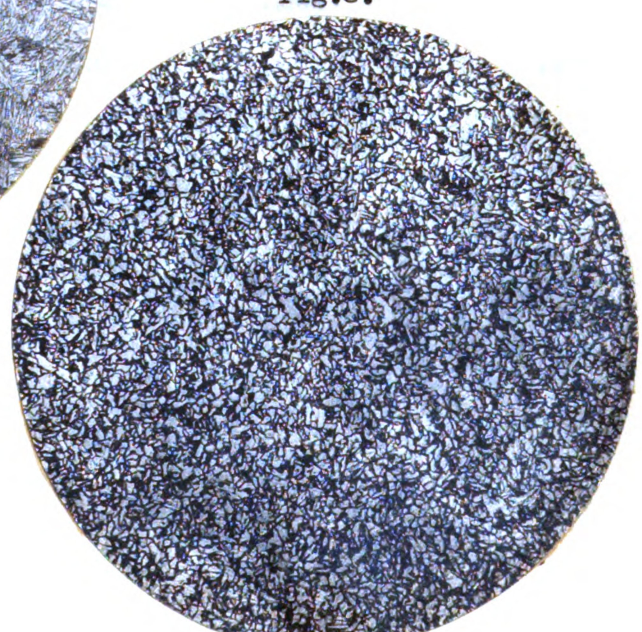


Fig.7.

Fig.8.



Quenching Cycle No. 3.

Carburizing Grade.

Type - S.A.E. 3115 - Nickel-Chromium

Analysis:

Carbon	Manganese	Nickel	Chromium
.17%	.60%	1.32%	.62%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
V-1	1300° F.	163	V-17	1400° F.	321
2	1320	163	18	1380	302
3	1340	179	19	1360	293
4	1360	255	20	1340	262
5	1380	279	21	1320	255
6	1400	286	22	1300	228
7	1420	302	23	1280	217
8	1440	321	24	1260	202
9	1460	364	25	1240	149
10	1480	"	26	1220	143
11	1500	"	27	1200	"
12	1520	"	28	1180	"
13	1540	"	29	1160	"
14	1560	"	30	1140	"
15	1580	"	31	1120	"
16	1600	"	32	1100	140

MICROSCOPIC EXAMINATION:

Refer to Fig. 9, 10, 11, 12. Fig. 9 represents the metallographic condition found in Test No. 1, of the series at 100 diameters. The structure is one of a medium-sized grain of dense pearlite and ferrite. Fig. 10 was taken of Test No. 4, at 500-X, and illustrates the condition just within the hardening range. It shows dark areas of sorbitic pearlite with white areas of ferrite. Fig. 11 shows the structure found at 500-X of Test No. 10 of the series. It is martensitic with quite an amount of retained austenite, the white areas. Note the rounded sides of the dark areas, showing the relatively close proximity of a troostitic state. Fig. 12 was taken in the cooling phase well below the critical range. -Test No. 27. Again we find pearlite and ferrite, in well defined grains, and uniform.

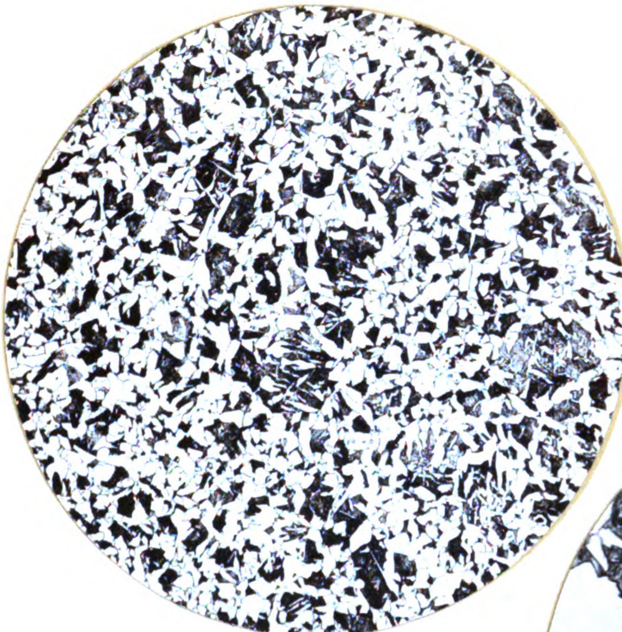
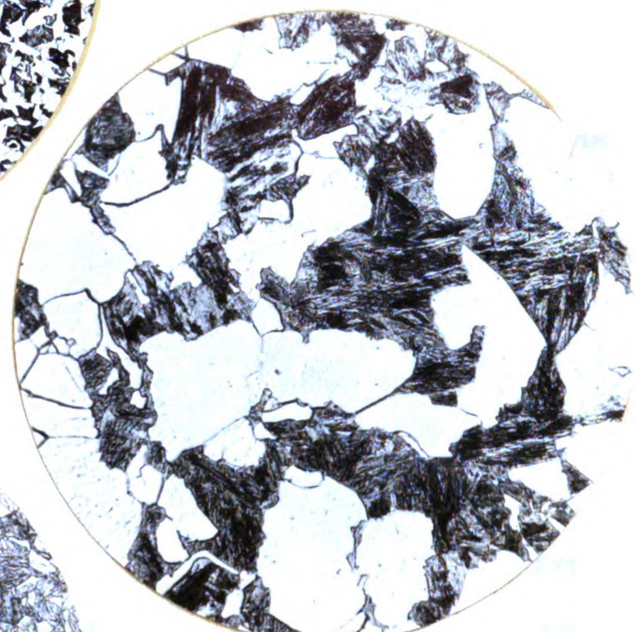


Fig.9.

Fig.10.



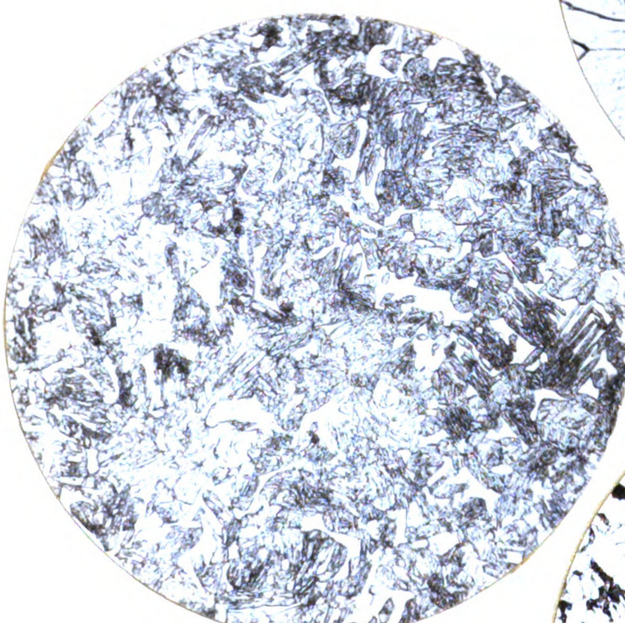
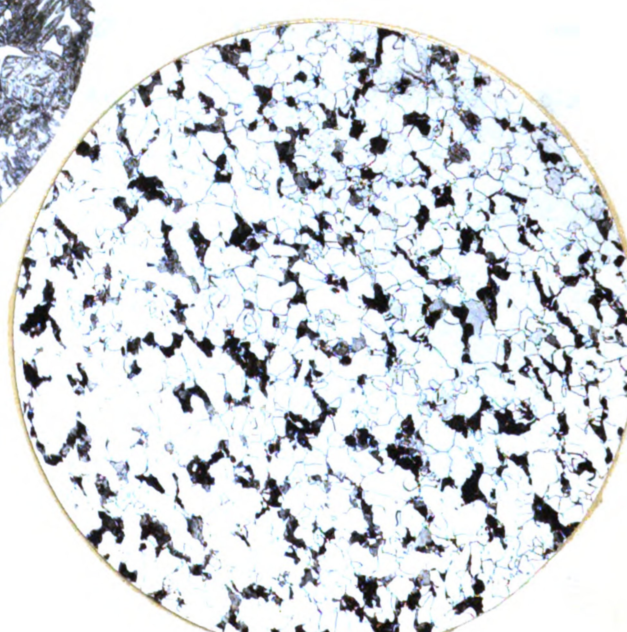


Fig.11.

Fig.12.



Quenching Cycle No. 4.

Carburizing Grade.

Type - S.A.E. 4615 - Nickel - Molybdenum.

Analysis:

Carbon	Manganese	Nickel	Molybdenum
.17%	.45%	1.59%	.27%

Hardness Data:

HEATING CYCLE			COOLING CYCLE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
S-1	1300° F.	183	S-17	1400° F.	418
2	1320	187	18	1380	387
3	1340	207	19	1360	364
4	1360	262	20	1340	317
5	1380	311	21	1320	286
6	1400	321	22	1300	277
7	1420	341	23	1280	269
8	1440	351	24	1260	255
9	1460	356	25	1240	228
10	1480	364	26	1226	218
11	1500	379	27	1200	207
12	1520	418	28	1180	179
13	1540	418	29	1160	163
14	1560	418	30	1140	156
15	1580	418	31	1120	149
16	1600	418	32	1100	149

MICROSCOPIC EXAMINATION:

Refer to Fig. 13, 14, 15 & 16. These four micrographs represent the cyclic changes of this series. Fig. 13, of Test No. 1, at 100-X, shows a granular state of sorbitic pearlite and ferrite. The grains are somewhat ill-defined. Fig. 14 shows the state of Test No. 4 at 500-X. Here we find a troosto-martensitic condition with considerable free ferrite. Fig. 15, also at 500-X, is that of Test No. 12. This condition is typical above the critical point. It is almost entirely martensitic with a small amount of retained austenite. Fig. 4 is somewhat different from that of Fig. 1 in this series. The structure is that of Test No. 30 at 100-X. It is of uniform medium-sized grains of pearlite and ferrite.

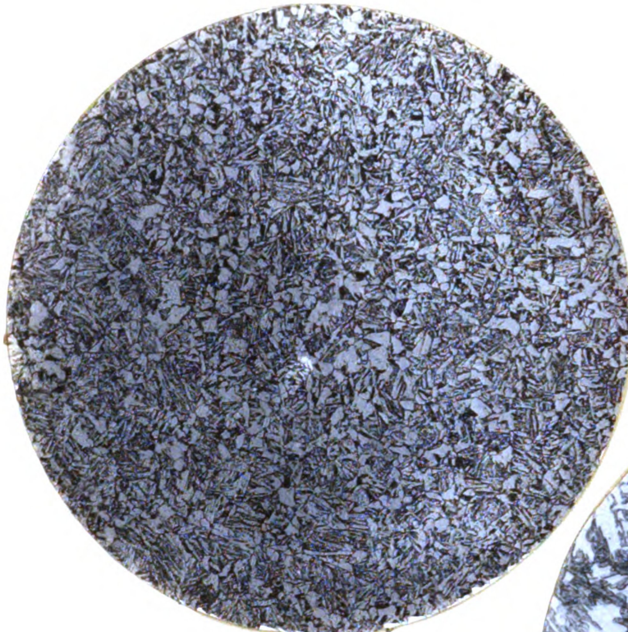
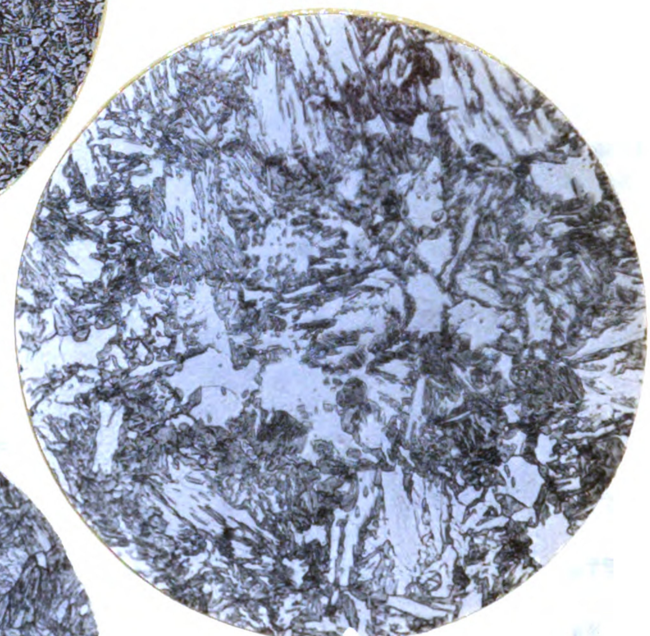


Fig.13.

Fig.14.



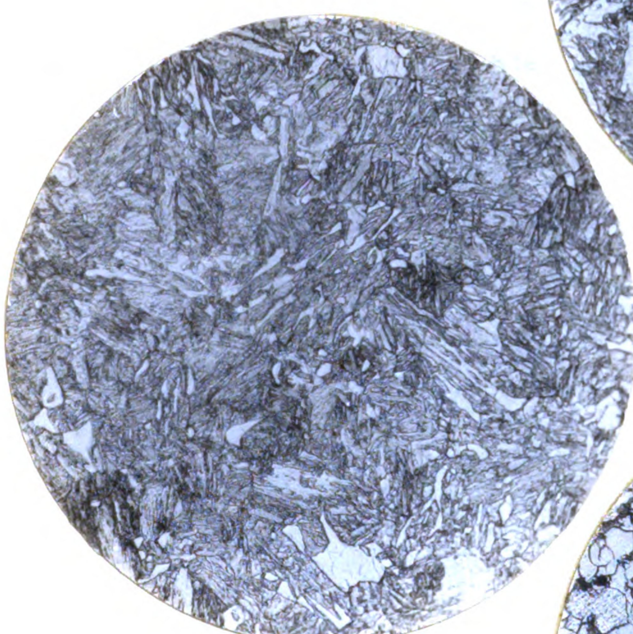
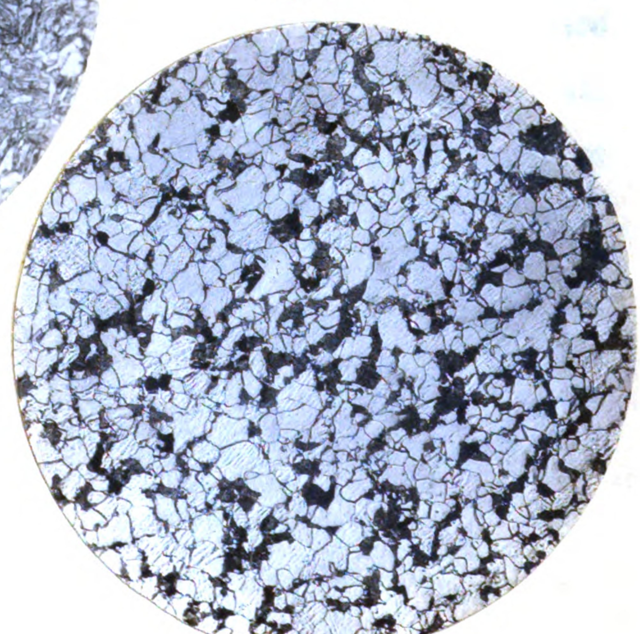


Fig.15.

Fig.16.



Quenching Cycle No. 5.

Water-hardening Grade.

Type - S.A.E. 1335 - Carbon Manganese

Analysis:

Carbon	Manganese	Silicon
.34%	1.72%	.22%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
I-1	1300° F.	187	I-15	1420° F.	512
2	1320	187	16	1400	512
3	1340	196	17	1380	512
4	1360	302	18	1360	512
5	1380	387	19	1340	477
6	1400	430	20	1320	477
7	1420	444	21	1300	477
8	1440	444	22	1280	444
9	1460	460	23	1260	430
10	1480	512	24	1240	418
11	1500	512	25	1220	387
12	1520	512	26	1200	364
13	1540	512	27	1180	179
14	1520	512	28	1160	179

MICROSCOPIC EXAMINATION:

Refer to Fig. 17, 18, 19 & 20. Fig. 17 shows a rather unusual condition. This was taken of Test No. 2, at 100-X. It represents a condition below the critical heating phase. It is one of very fine grained sorbitic pearlite and free ferrite. Fig. 18 shows the metallographic structure of Test No. 4 of the series, at 500-X. This structure is one of pearlitic sorbite, with some free ferrite in well defined grains. Fig. 19 is of Test No. 11, at 500-X. Again we find mostly martensite, just short of the acicular condition. This is the state typical above the critical. In Fig. 20, which is representative of Test No. 27, at 100-X, we again find a condition of equilibrium. This is a fine grained dense sorbitic pearlite and ferrite, intermixed. The grain boundaries are well defined.

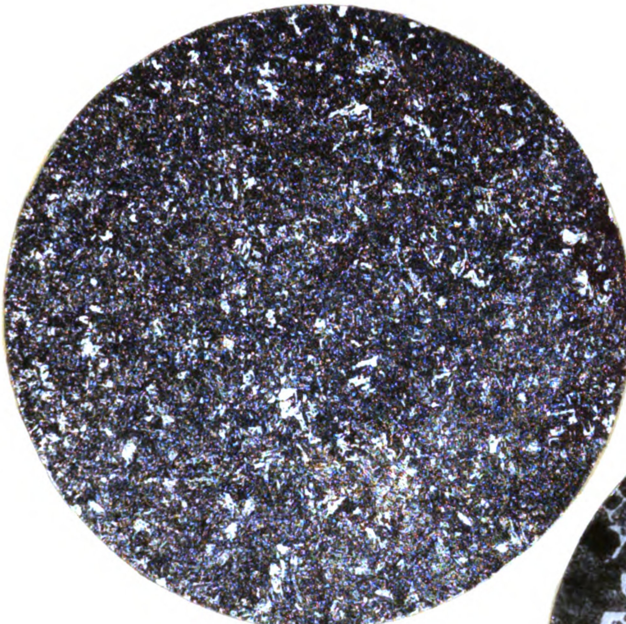
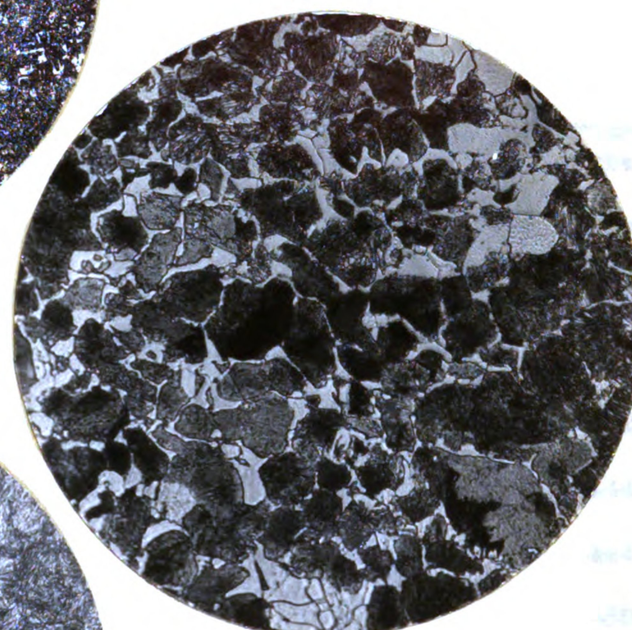


Fig.17.

Fig.18.



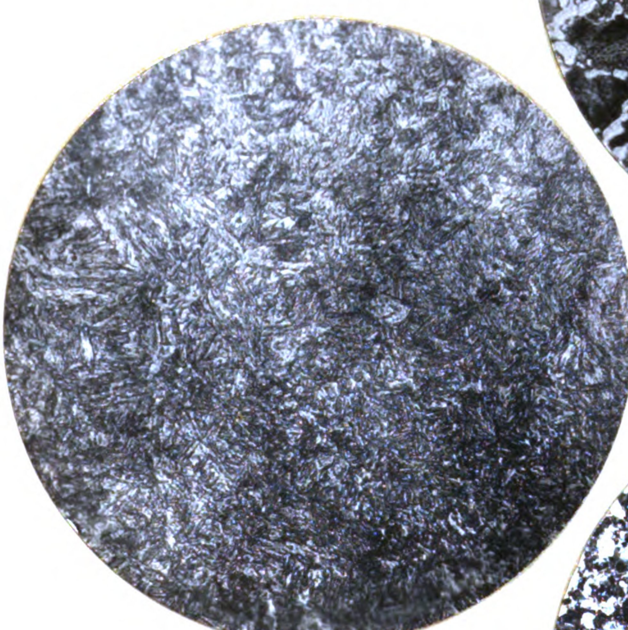
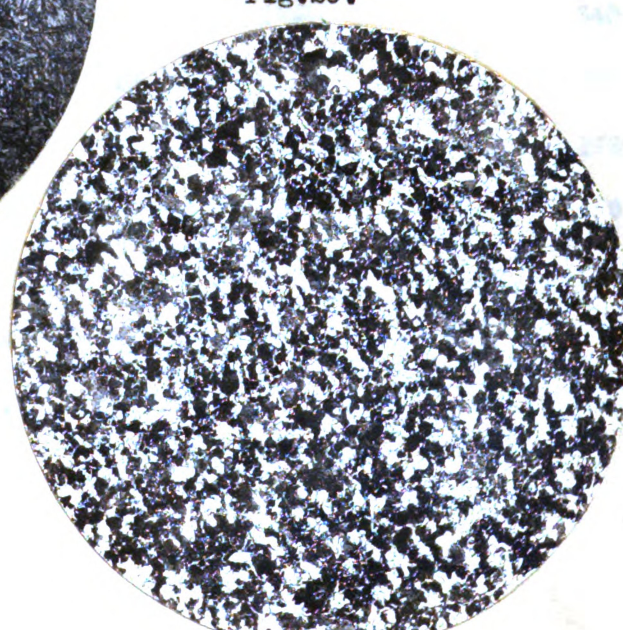


Fig.19.

Fig.20.



Quenching Cycle No. 6.

Water-hardening Grade.

Type - S.A.E. 2330 - 3-1/2% Nickel.

Analysis:

Carbon	Manganese	Nickel
.32%	.59%	3.42%

Hardness Data:

HEATING PHASE				COOLING PHASE		
Test	Quenching Temperature	Brinell Number		Test	Quenching Temperature	Brinell Number
B-1	1220° F.	207		B-16	1300° F.	532
2	1240	207		17	1280	532
3	1260	207		18	1260	532
4	1280	223		19	1240	512
5	1300	241		20	1220	444
6	1320	340		21	1200	444
7	1340	418		22	1180	430
8	1360	477		23	1160	402
9	1380	495		24	1140	340
10	1400	512		25	1120	203
11	1420	512		26	1100	179
12	1440	512		27	1080	179
13	1460	532		28	1060	174
14	1480	532		29	1040	166
15	1500	532		30	1020	163

MICROSCOPIC EXAMINATION:

Refer to Fig. 21, 22, 23 & 24. Fig. 21 represents the structural condition of Test No. 3 at 100-X. It is a rather non-uniform grain of dense sorbitic pearlite interspersed with some free ferrite. Fig. 22 is of Test No. 6 at 500-X. It represents almost true Osmondite. We find some free ferrite together with sorbitic troostite, Careful examination shows some slight evidence of the formation of martensite. This micrograph represents a condition found rather infrequently, especially in this type of steel. Fig. 23 shows the structure usually found about the critical in all types of steel. It is of Test No. 14 at 500-X. The structure is that of coarse martensite. Note the retention of the austenitic grain boundaries. Fig. 24 is of Test No. 28 at 100-X. It is a structure of very fine grained pearlite and ferrite, rather uniform.

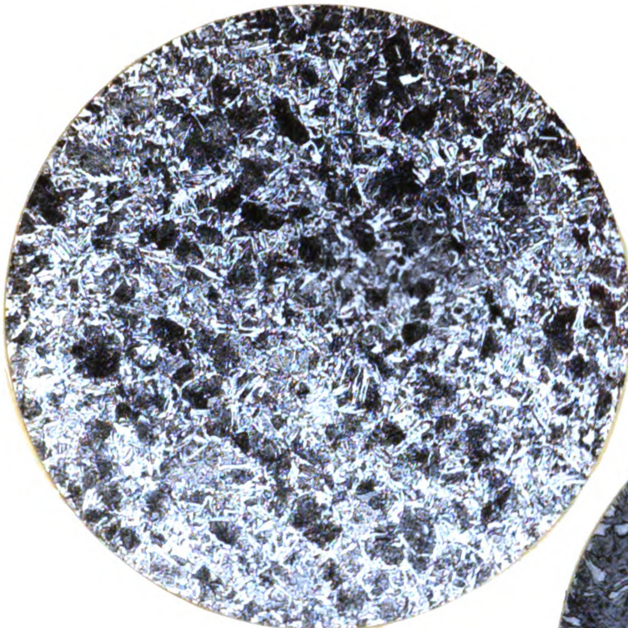


Fig.21.

Fig.22.

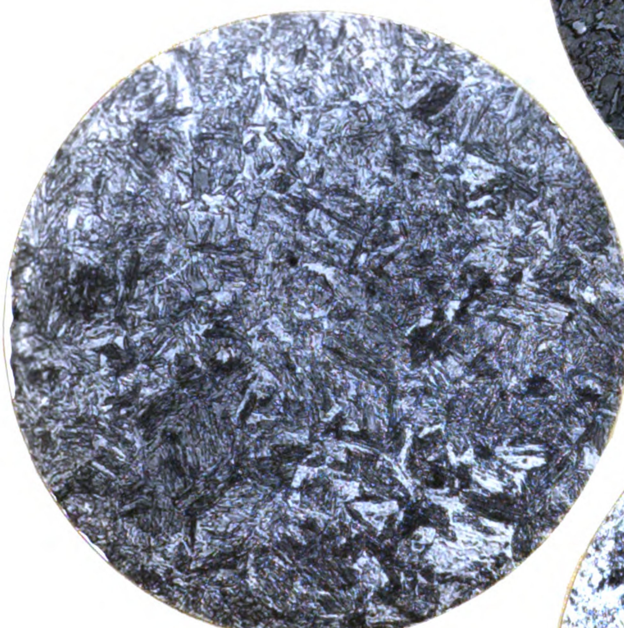
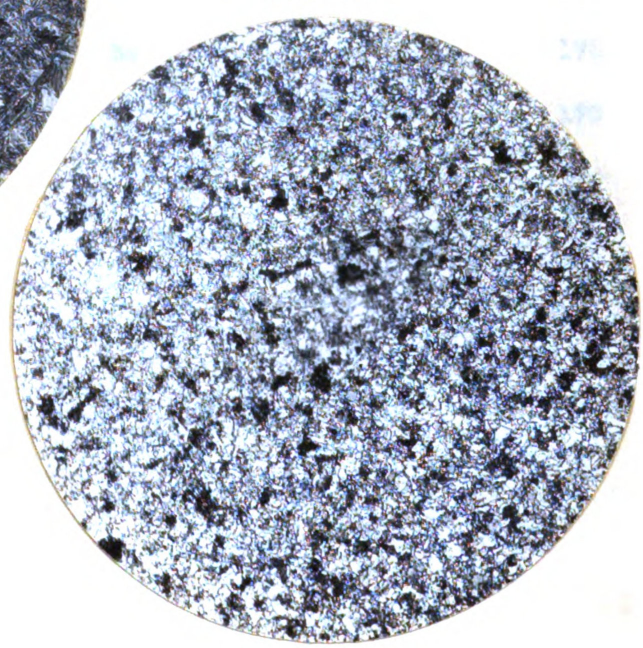


Fig.23.

Fig.24.



Quenching Cycle No. 7.

Water-hardening Grade.

Type - S.A.E. 3130 - Nickel Chromium.

Analysis:

Carbon	Manganese	Nickel	Chromium
.30%	.65%	1.18%	.67%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
X-1	1280° F.	179	X-15	1360° F.	477
2	1300	179	16	1340	477
3	1320	187	17	1320	444
4	1340	187	18	1300	402
5	1360	223	19	1280	364
6	1380	340	20	1260	196
7	1400	387	21	1240	179
8	1420	444	22	1220	174
9	1440	460	23	1200	170
10	1460	477	24	1180	170
11	1480	477	25	1160	170
12	1500	477	26	1140	170
			27	1120	170

MICROSCOPIC EXAMINATION:

Refer to Fig. 25, 26, 27, & 28. The first of these, Fig. 25, is a micrograph of Test No. 4 of this series, taken at 100-X. It is a structure of fine pearlite, with grain envelopes of ferrite. The grains are medium-sized and well defined. Fig. 26 is of Test No. 6 at 500-X. The condition is troosto-martensitic, chiefly the latter, and represents the structure found well up in the hardening range. Fig. 27 is similar to the structure found in most hardened untempered steel of this carbon content. It is largely martensitic, almost acicular. The micrograph is of Test No. 10, at 500-X. Fig. 28 is of Test No. 24 at 100-X. It represents a condition of metastable equilibrium, i. e. fine pearlite and free ferrite of rather small grain.

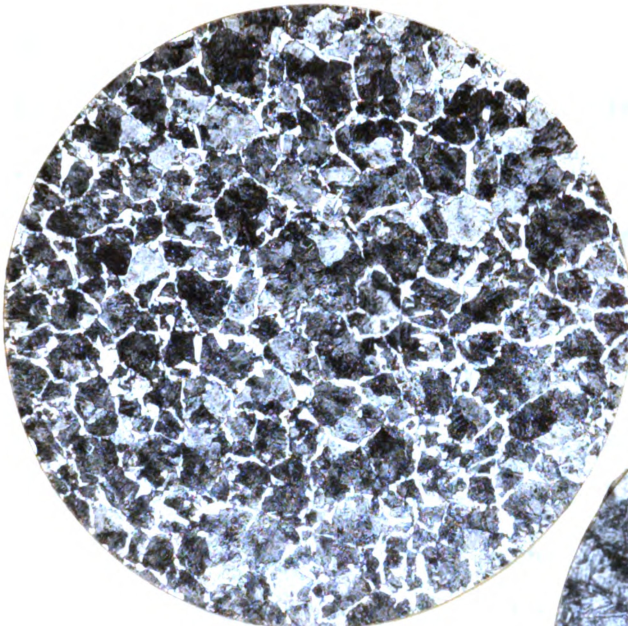


Fig.25.

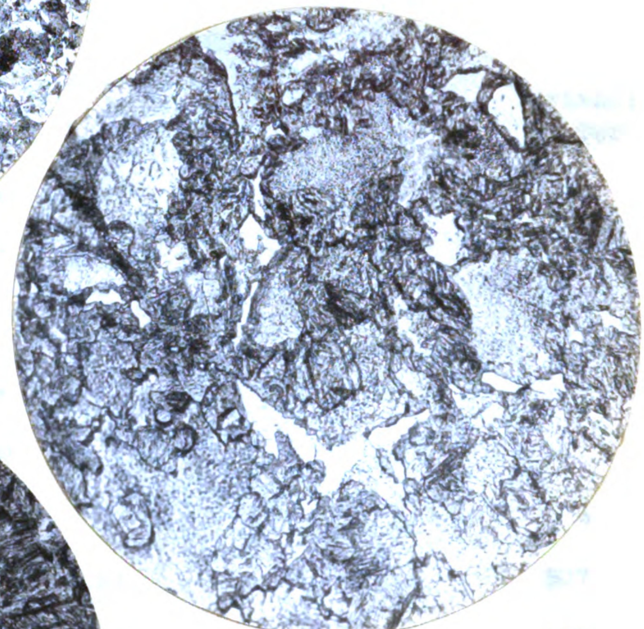


Fig.26.

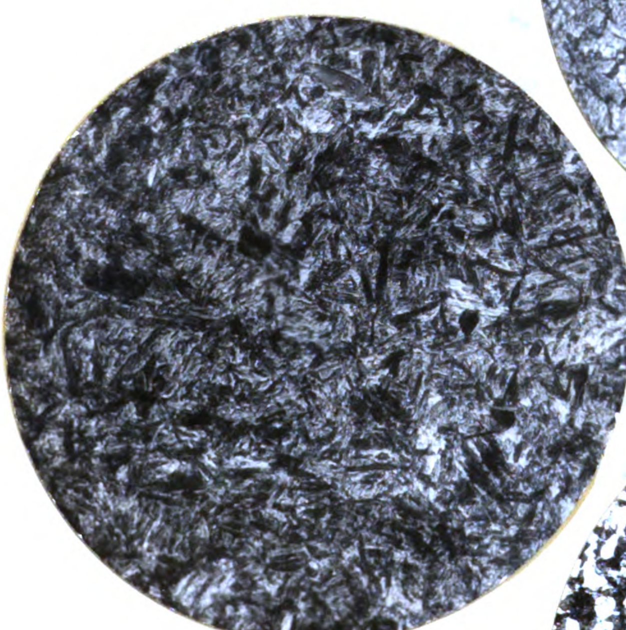


Fig.27.

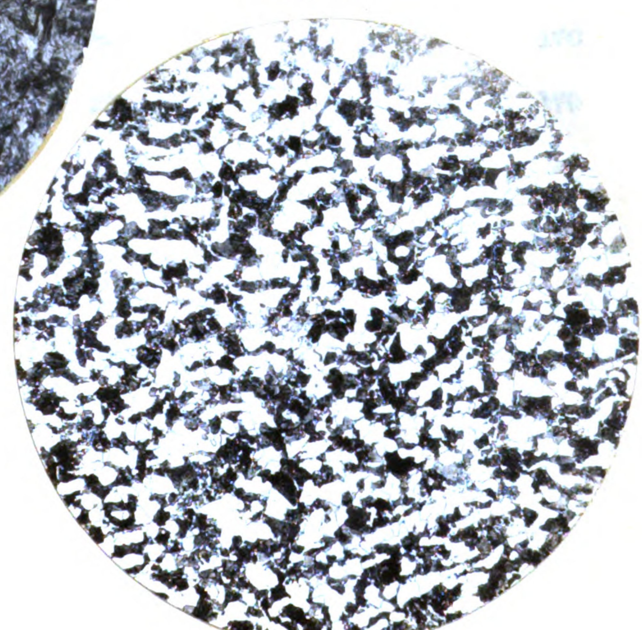


Fig.28.

Quenching Cycle No. 8.

Water-hardening Grade.

Type - S.A.E. 4130 - Chromium-Molybdenum.

Analysis:

Carbon	Manganese	Chromium	Molybdenum
.32%	.52%	.64%	.22%

Hardness Data:

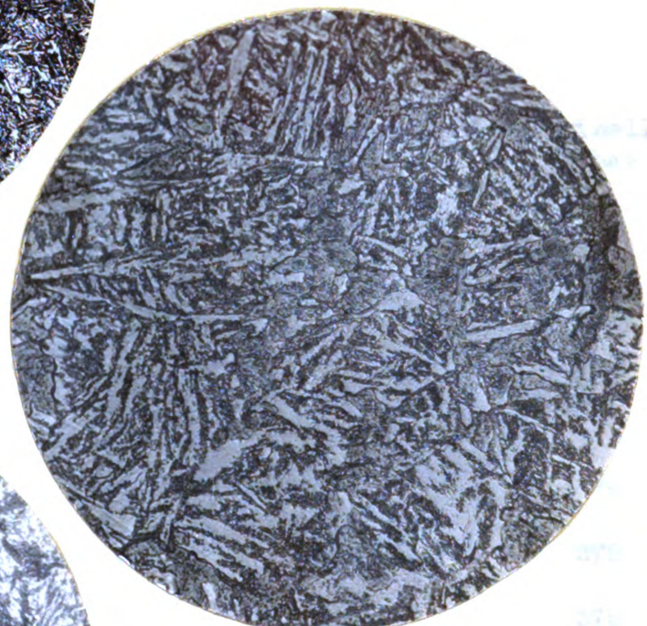
HEATING PHASE		Brinell	COOLING PHASE		Brinell
Test	Quenching Temperature	Number	Test	Quenching Temperature	Number
0-1	1300° F.	170	0-15	1420° F.	512
2	1320	179	16	1400	495
3	1340	179	17	1380	418
4	1360	183	18	1360	418
5	1380	196	19	1340	364
6	1400	255	20	1320	364
7	1420	418	21	1300	207
8	1440	477	22	1280	170
9	1460	477	23	1260	170
10	1480	477	24	1240	170
11	1500	512	25	1220	170
12	1520	512	26	1200	170

MICROSCOPIC EXAMINATION:

Refer to Fig. 29, 30, 31 & 32. The first, Fig. 29, is at 100-X, of Test No. 3. This structure is one of sorbitic pearlite and the needle-like arrangement of grains is somewhat peculiar to the type of steel among others. Fig. 30 is of Test No. 6 at 500-X and indicates the general structure well up in the critical range of temperature. It is one of troosto-martensite. Note the beginning of the needle-like formation peculiar to martensite. The structure is somewhat coarse. Fig. 31, also at 500-X, is of Test No. 12. This is a martensitic condition with a small amount of retained austenite showing through. Fig. 32 is of Test No. 24 at 100-X. Again, we find the usual structure of dense pearlite and free ferrite, well defined.

Fig.29

Fig.30.



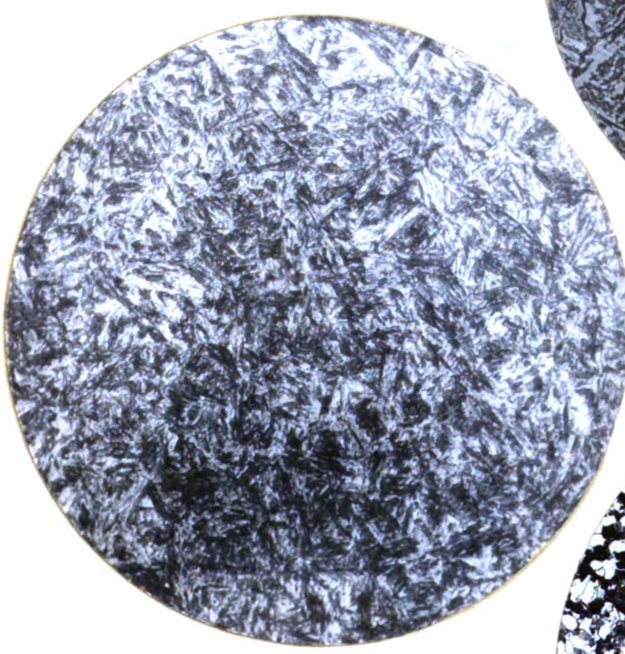
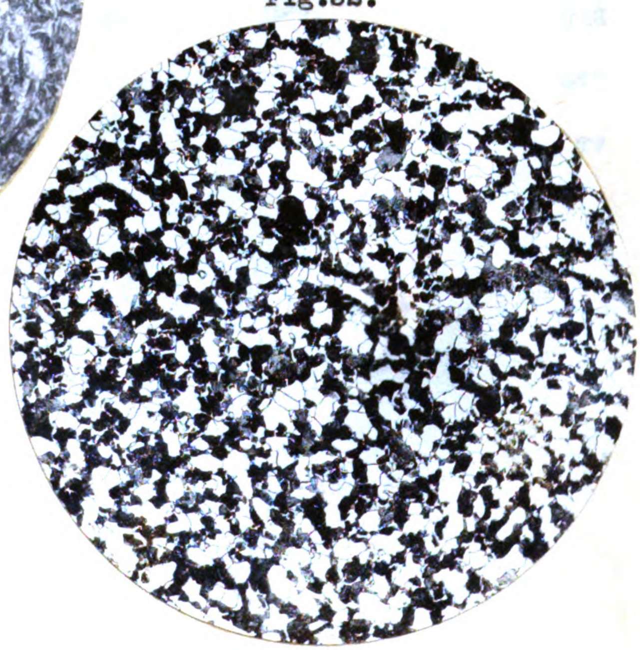


Fig.31.

Fig.32.



QUENCHING CYCLE NO. 9.

Oil-Hardening Grade.

Type - S.A.E. 2340 - 3-1/2% Nickel.

Analysis:

Carbon	Manganese	Nickel
.44%	.62%	3.38%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
T-1	1240° F.	223	T-16	1360° F.	600
2	1260	223	17	1340	600
3	1280	228	18	1320	578
4	1300	302	19	1300	578
5	1320	321	20	1280	578
6	1340	495	21	1260	578
7	1360	578	22	1240	578
8	1380	600	23	1220	555
9	1400	600	24	1200	512
10	1420	600	25	1180	477
11	1440	600	26	1160	477
			27	1140	286
			28	1120	196
			29	1100	196

QUENCHING CYCLE NO. 9.

Oil-Hardening Grade.

Type - S.A.E. 2340 - 3-1/2% Nickel.

Analysis:

Carbon	Manganese	Nickel
.44%	.62%	3.38%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
T-1	1240° F.	223	T-16	1360° F.	600
2	1260	223	17	1340	600
3	1280	228	18	1320	578
4	1300	302	19	1300	578
5	1320	321	20	1280	578
6	1340	495	21	1260	578
7	1360	578	22	1240	578
8	1380	600	23	1220	555
9	1400	600	24	1200	512
10	1420	600	25	1180	477
11	1440	600	26	1160	477
			27	1140	286
			28	1120	196
			29	1100	196

MICROSCOPIC EXAMINATION:

Refer to Fig. 33, 34, 35 & 36. The first of these is of Test No. 1 at 100-X. The structure is a granular condition of fine sorbitic pearlite surrounded for free ferrite. The grain boundaries are definite. Fig. 34, at 500-X, is of Test No. 5 of the series. Here we find Osmondite, i. e., troosto-sorbite, with a small amount of free ferrite interspersed. Fig. 35, also at 500-X, is of Test No. 9, which is rather well up above the critical range of temperature. Themartensite is acicular, very slightly tempered. The last micrograph, Fig. 36, of Test No. 28, is at 100-X. This is near the bottom of the cooling phase. We find dense pearlite and ferrite in a rather stable condition, well defined uniform grains. Note that the ferrite is more freely dispersed than in Fig. 33.

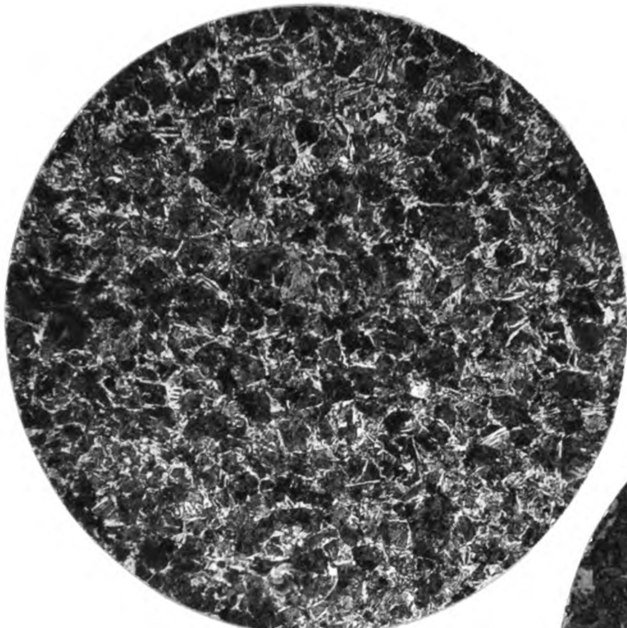


Fig.33.

Fig.34.

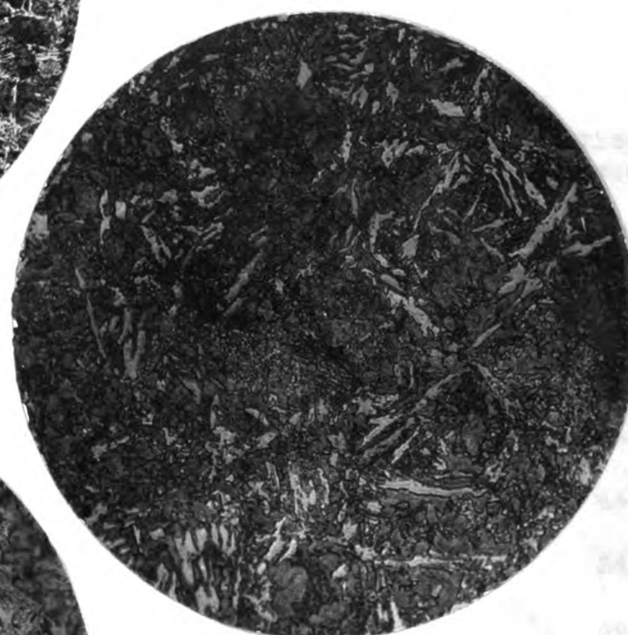
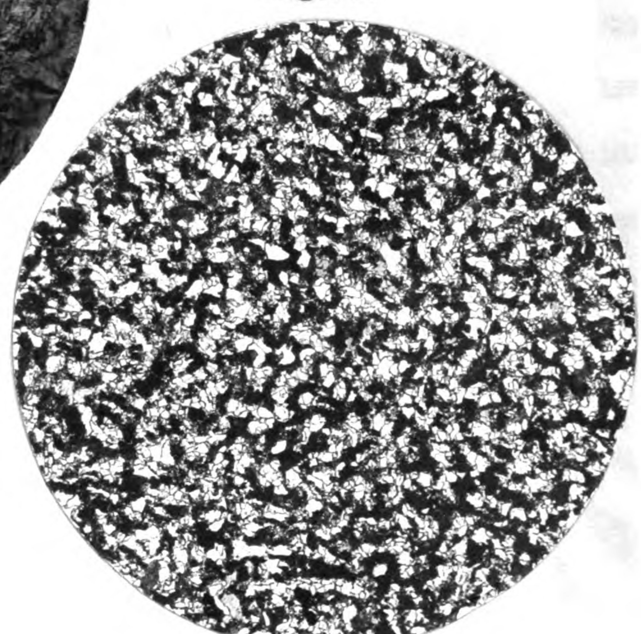


Fig.35.

Fig.36.



Quenching Cycle No. 10.

Oil Hardening Grade.

Type - S.A.E. 3140 - Nickel-Chromium.

Analysis:

Carbon	Manganese	Nickel	Chromium
.43%	.64%	1.18%	.56%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
F-1	1280° F.	217	F-16	1340° F.	578
2	1300	217	17	1320	555
3	1320	217	18	1300	555
4	1340	241	19	1280	512
5	1360	277	20	1260	444
6	1380	512	21	1240	241
7	1400	537	22	1220	196
8	1420	555	23	1200	196
9	1440	555	24	1180	196
10	1460	555	25	1160	183
11	1480	555	26	1140	183
12	1500	578	27	1120	183
13	1520	578	28	1100	183

MICROSCOPIC EXAMINATION:

Refer to Fig. 37, 38, 39 & 40. Fig. 37 of these four micrographs is an illustration of the condition found in Test No. 2 at 100-X. We find the usual condition of dense sorbitic pearlite with a network grain boundary of free ferrite. In Fig. 38, which is of Test No. 5, at 500-X, we again find the transitory stage, but rather low in the range. Here we observe a sorbitic troostite rather poorly defined, in a ground mass of what appears to be ferrite. This structure might well be termed a primary Osmondite. In Fig. 39, we find an illustration of the structure found in Test No. 9 at 500 diameters. Here we find rather coarse acicular martensite in a ground mass of austenite. This, of course, is typical of the hardened state. Fig. 40 is of Test No. 26 at 100-X, much similar to the first micrograph of this series. We again find pearlite and ferrite with the latter well and uniformly dispersed, due to the slow cooling rate.

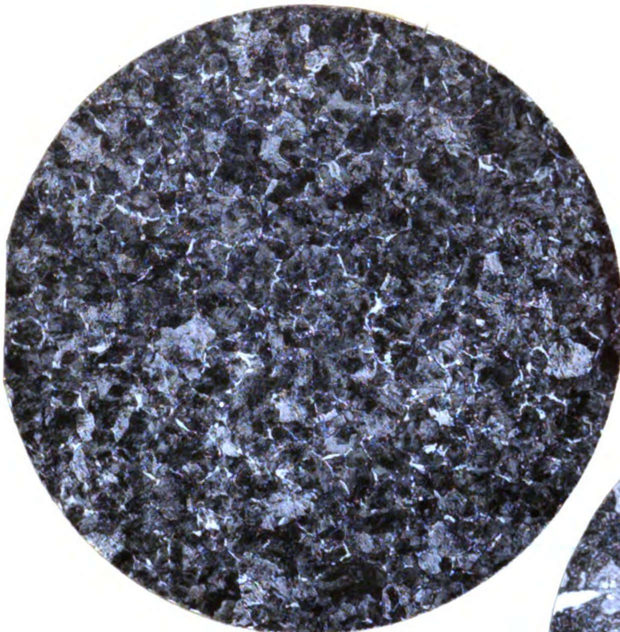
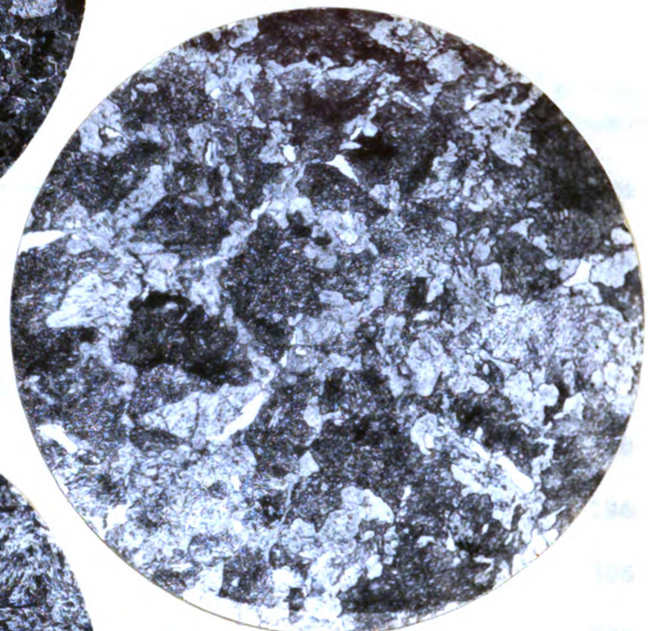


Fig.37.

Fig.38.



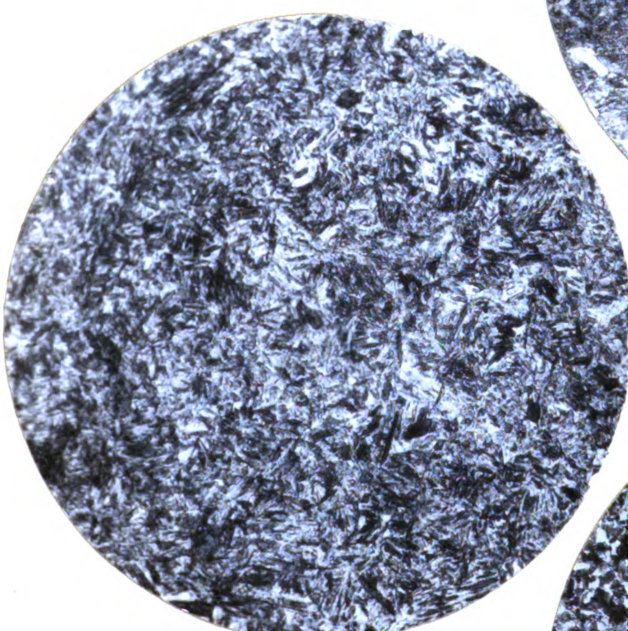
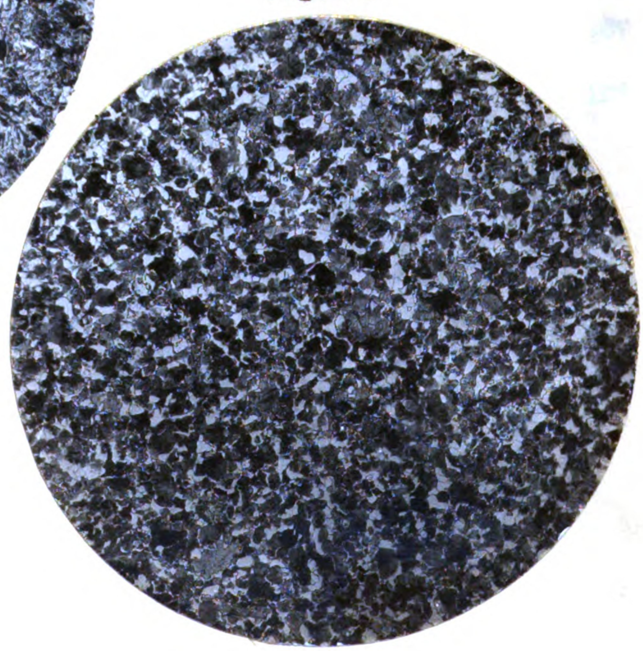


Fig.39.

Fig.40.



Quenching Cycle No. 11.

Oil Hardening Grade.

Type - S.A.E. 5140 - 1% Chromium.

Analysis:

Carbon	Manganese	Chromium
.44%	.83%	.98%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
J-1	1300° F.	217	J-18	1360° F.	578
2	1320	223	19	1340	578
3	1340	228	20	1320	512
4	1360	241	21	1300	241
5	1380	286	22	1280	196
6	1400	341	23	1260	196
7	1420	477	24	1240	196
8	1440	578	25	1220	196
9	1460	578	26	1200	196
10	1480	578	27	1180	187
11	1500	578	28	1160	187

MICROSCOPIC EXAMINATION:

Refer to Fig. 41, 42, 43 and 44. In Fig. 41, which is Test No. 2 at 100-X, we find the usual pearlitic-ferritic condition. The ferrite is rather uniformly dispersed. In Fig. 42, we examine Test No. 4 at 500-X. Here we find a rather unusual condition, peculiar to this steel. We find the ferrite network, very large grained. We find a sorbitic condition with a great tendency toward spheroidization and the formation of carbides, or double carbides. This condition is usually found in the critical range, which range is very narrow and often overlooked. Fig. 43 is of Test No. 9 at 500-X. Nothing unusual is noted except that a comparatively large amount of retained austenite is present. Fig. 44, of Test No. 23, at 100-X, is very much similar to that of Fig. 40. The grain size is somewhat larger, but not as well defined as in the former.

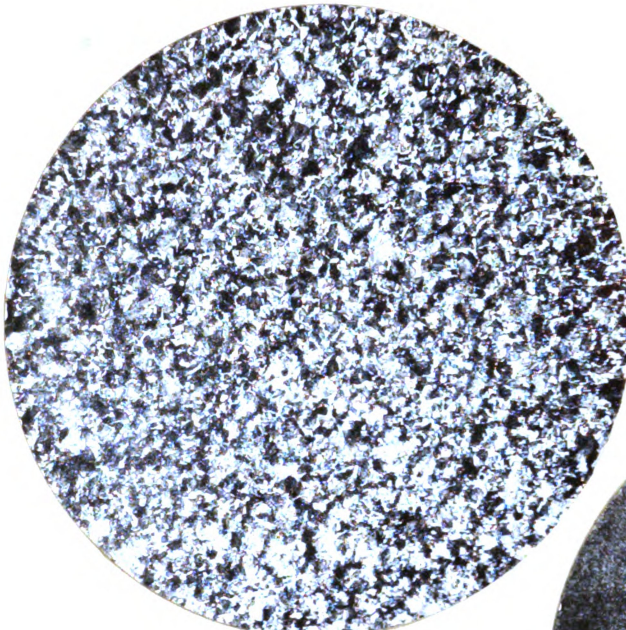
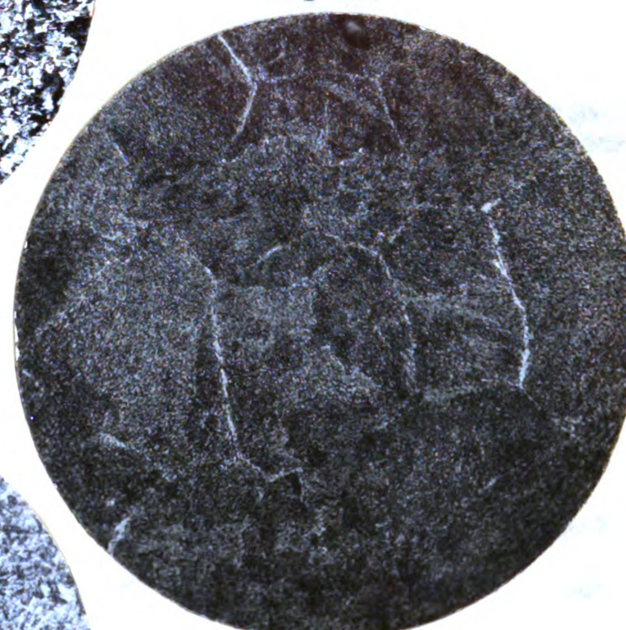


Fig.41.

Fig.42.



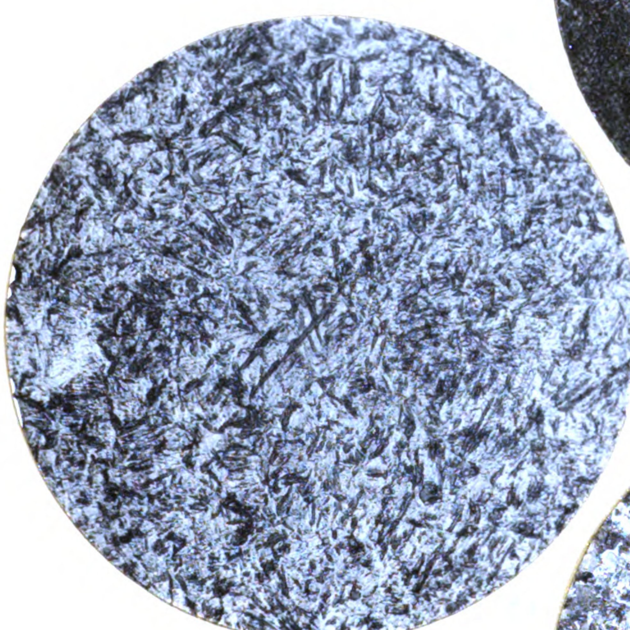
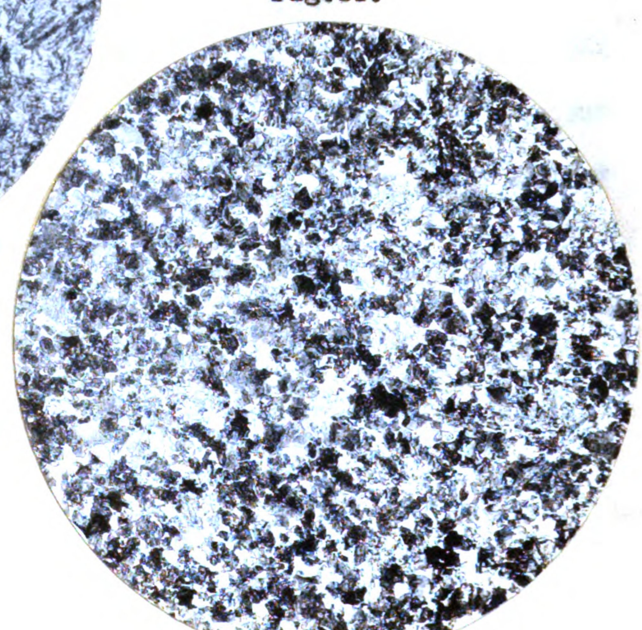


Fig.43.

Fig.44.



Quenching Cycle No. 12.

Oil Hardening Grade.

Type - S.A.E. 6140 - Chromium- Vanadium.

Analysis:

Carbon	Manganese	Chromium	Vanadium
.42%	.73%	1.09%	.19%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
M-1	1300° F.	277	M-17	1420° F.	555
2	1320	269	18	1400	555
3	1340	255	19	1380	477
4	1360	241	20	1360	444
5	1380	235	21	1340	418
6	1400	223	22	1320	269
7	1420	255	23	1300	187
8	1444	402	24	1280	187
9	1460	477	25	1260	187
10	1480	477	26	1240	187
11	1500	512	27	1220	187
12	1520	512	28	1200	187
13	1540	532	29	1180	187
14	1560	532	30	1160	187
15	1580	555	31	1140	187
16	1600	555	32	1120	179

Quenching Cycle No. 12.

Oil Hardening Grade.

Type - S.A.E. 6140 - Chromium- Vanadium.

Analysis:

Carbon	Manganese	Chromium	Vanadium
.42%	.73%	1.09%	.19%

Hardness Data:

HEATING PHASE			COOLING PHASE		
Test	Quenching Temperature	Brinell Number	Test	Quenching Temperature	Brinell Number
M-1	1300° F.	277	M-17	1420° F.	555
2	1320	269	18	1400	555
3	1340	255	19	1380	477
4	1360	241	20	1360	444
5	1380	235	21	1340	418
6	1400	223	22	1320	269
7	1420	255	23	1300	187
8	1444	402	24	1280	187
9	1460	477	25	1260	187
10	1480	477	26	1240	187
11	1500	512	27	1220	187
12	1520	512	28	1200	187
13	1540	532	29	1180	187
14	1560	532	30	1160	187
15	1580	555	31	1140	187
16	1600	555	32	1120	179

MICROSCOPIC EXAMINATION:

Refer to Fig. 45, 46, 47 & 48. The first of these, Fig. 45, depicts, at 100-X, the structure found in Test No. 5 of the series. Here we find pearlitic sorbite, with the granular network rather ill-defined. What little free ferrite remains is in a very finely divided state. In Fig. 46, we have the structure of Test No. 8 at 500-X. Again we find a good specimen of the so-called Osmondite, in which we find sorbitic troostite with some little martensite poorly formed. In Fig. 47, also at 500-X, we examine Test No. 16, which is well above the critical point in the heating phase. Here we find, chiefly, martensite, with a very little retained austenite. In Fig. 40, which is of Test No. 20, at 100-X, we come to the common condition, found in this portion of the phase. Here we find dense pearlite with free ferrite, uniformly dispersed thruout.

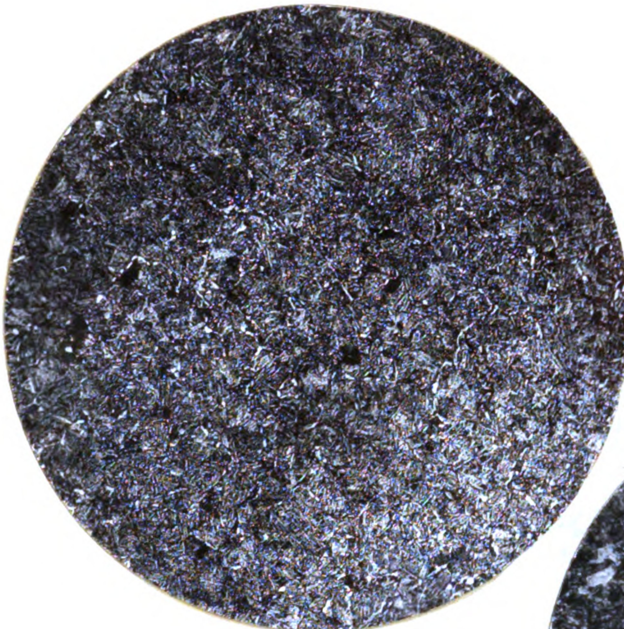
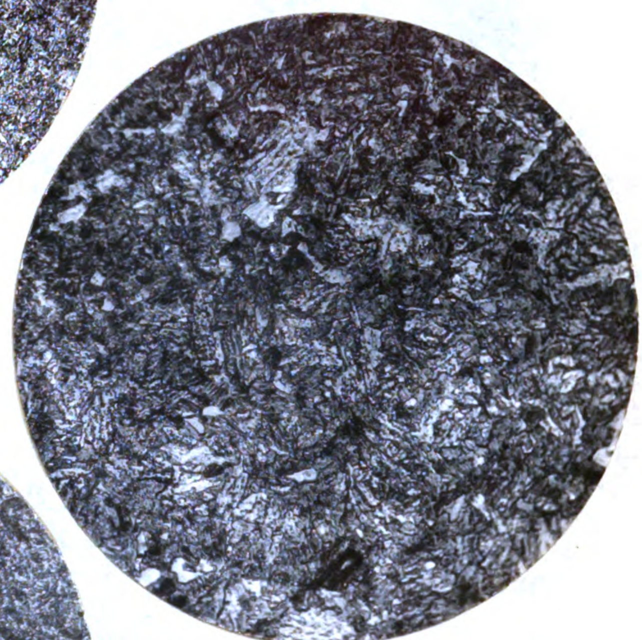


Fig.45.

Fig.46.



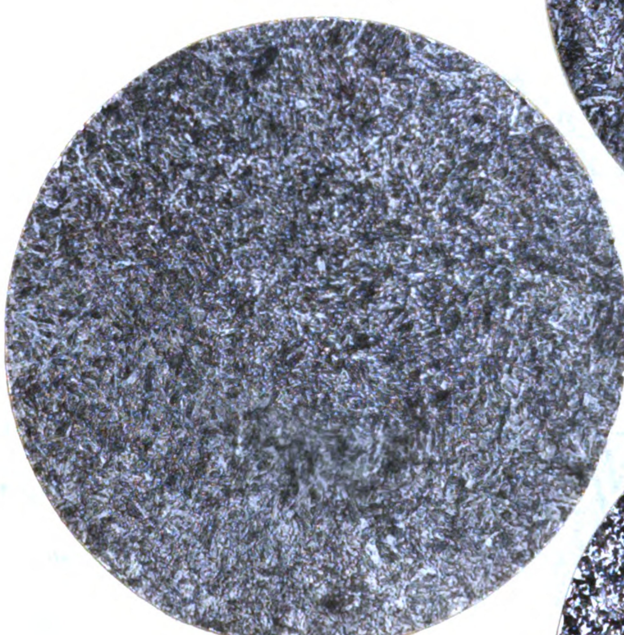
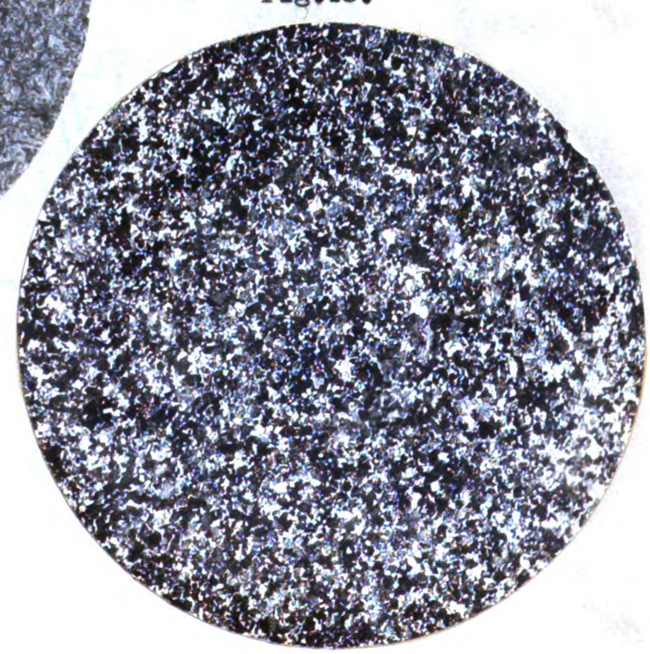


Fig.47.

Fig.48.



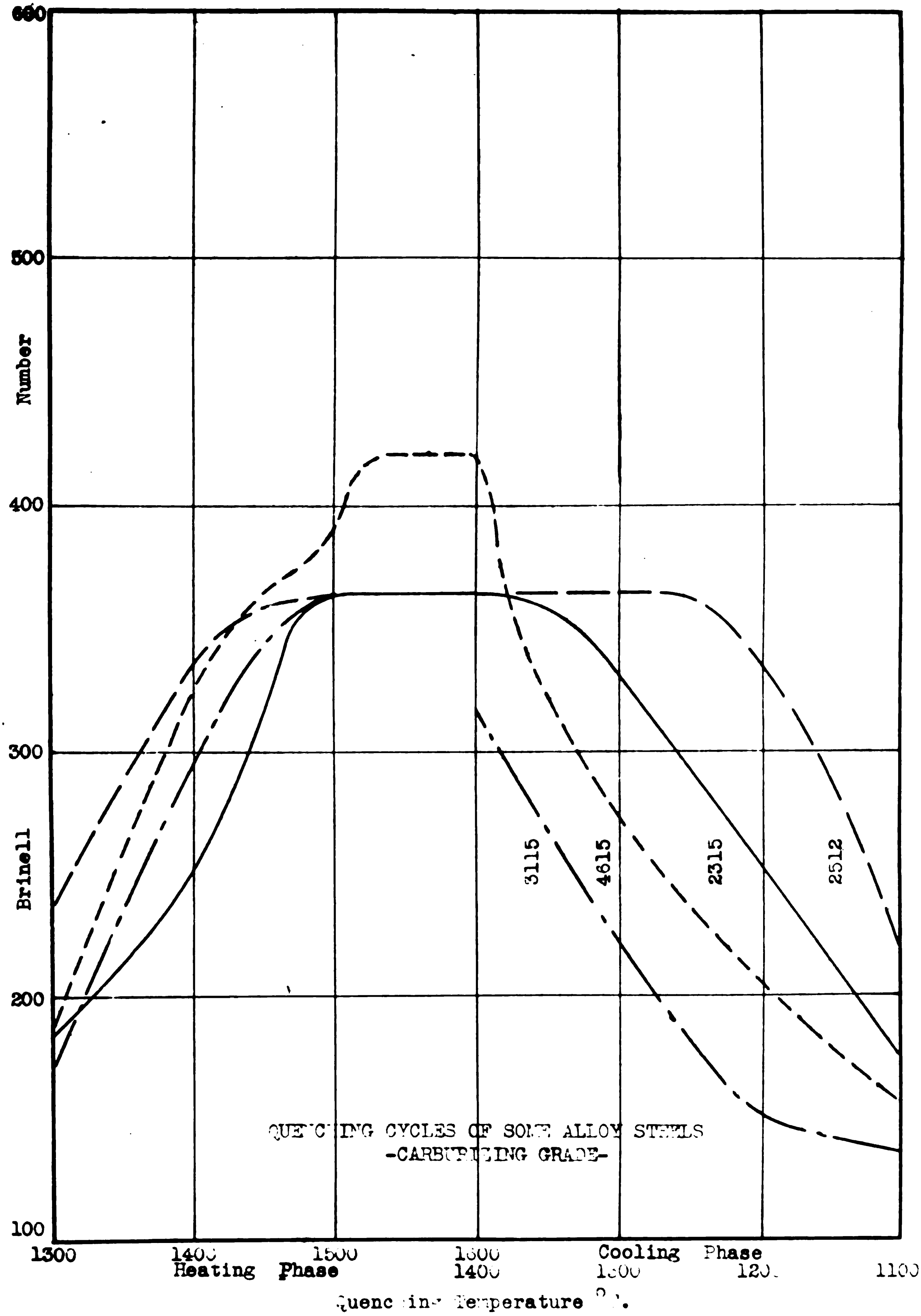
- SUMMARY -

The better to present the large amount of data given in this report, a series of graphs have been constructed and are to be found below. Three pages are given, one for each grade of alloy steel discussed. On each page, are found four curves, which represent each type of material in that particular grade. The type and curve have been designated by the conventional numbers assigned by the Society of Automotive Engineers.

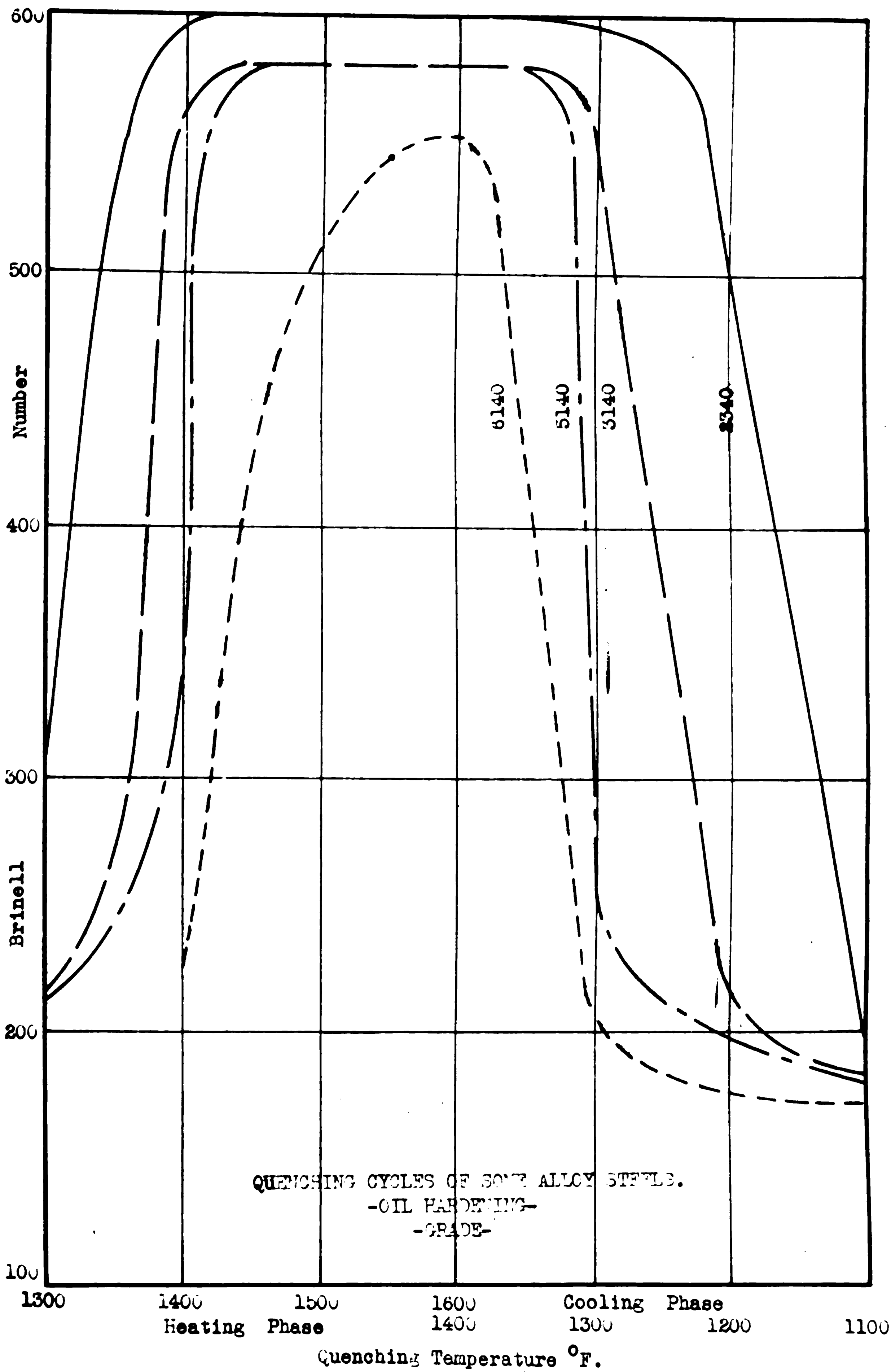
The curves themselves are almost self-explanatory. The Brinell numbers have been plotted against the quenching temperatures in degrees Fahrenheit. A close examination will show that the middle ordinate on the sheet is really a dividing line, since it separates the heating and cooling phases of the cycles. It will also be noted that this ordinate likewise serves for two values, 1600° F. and 1400° F. being the end of the heating and beginning of the cooling phases, respectively. In order that the separate curves may be the more clearly seen both solid and broken lines have been used.

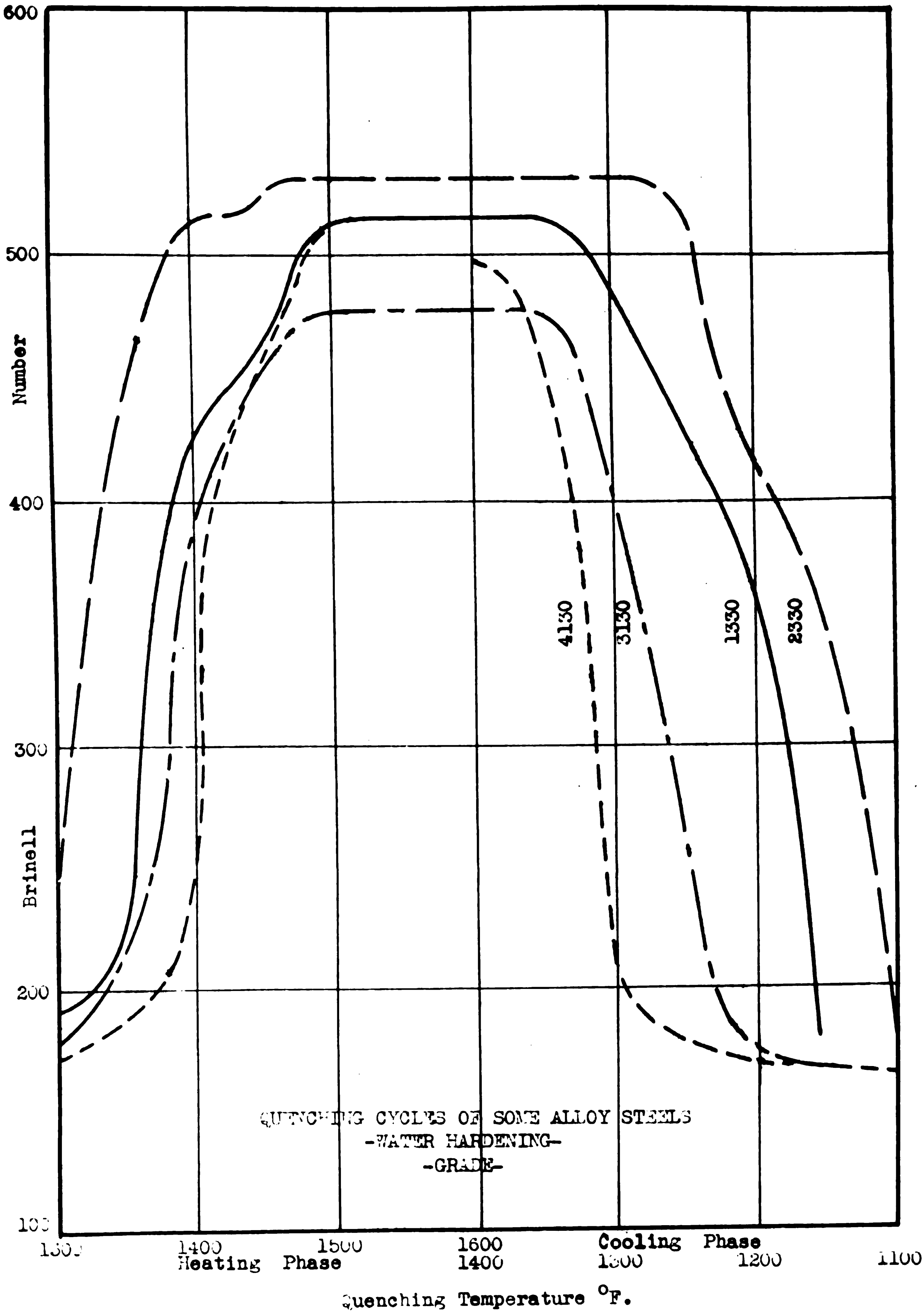
The individual graphs need but little comment. In the series on the carburizing grade, three types have the same maximum hardness. The nickel molybdenum, S.A.E. 4615, shows a somewhat higher maximum. However, the actual hardening range is about 100° shorter than those of the other three types. The curves, in shape, are very similar, especially in three curves. In the S.A.E. 4615, the appearance of the Ac_1 transition point or the beginning of the hardening range is much more distinct. This feature is peculiar to this type, along with several other types.

The second sheet of graphs represents the water hardening grade. Here the S.A.E. 2330, 3-1/2% Nickel shows the highest maximum Brinell number. It also shows the broadest hardening range. For these two reasons, it has been adopted by the automotive trade for a great many uses. We would



600
500
400
300
200
100
Brinell Number
3115
4615
2315
2512
QUENCHING CYCLES OF SOME ALLOY STEELS
-CARBURIZING GRADE-
1300
1400
1500
1600
Heating Phase
Cooling Phase
1400
1300
1200
1100
Quenching Temperature °F.


600
500
400
300
200
100
Brinell Number
6140
5140
3140
2340
QUENCHING CYCLES OF SOME ALLOY STEELS.
-OIL HARDENING-
-GRADE-
1300
1400
1500
1600
Heating Phase
Cooling Phase
1400
1300
1200
1100
Quenching Temperature °F.



600
500
400
300
200
100
Brinell Number
4130
3130
1330
2330
QUENCHING CYCLES OF SOME ALLOY STEELS
-WATER HARDENING-
-GRADE-
1300
1400
1500
1600
Heating Phase
1400
Cooling Phase
1300
1200
1100
Quenching Temperature °F.

call attention to the curve shown by the solid line, S.A.E. 1330. It differs but little in appearance from that of the 3-1/2% nickel. This type is coming into greater prominence at the present time, largely because of its reduced cost, and general adaptability.

The third sheet of graphs represents the oil hardening grade. The maximum Brinell numbers are considerably higher than those of either of the preceding pages. In general, the curves are very similar. Again we find that the 3-1/2% Nickel grade shows the greater hardness as well as the broadest hardening range. This type, too, is used considerably by the automotive industries largely because of these two advantages which lend to rapid handling and treatment in production.

In the preceding pages, we have attempted to carry on the work and collect and present the data in such a way that it might find a ready practical use. We make no specific mention of its application. The data on the heating phase should find its place in the heat-treating of the material where hardness, wearing quality and physical properties are of essential importance. This applies more particularly to the two grades of higher carbon content. The cooling phase data should find application in all process where lower hardness is essential. This covers all annealing and normalizing which may precede cold drawing or machine work, cold working, such as bending, forming, and upsetting. The micrographs were made, the better to illustrate the metallographic structural changes which take place, and which should be taken into consideration by one who is fully aware of their importance in adaptation.

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