" An Investigation of the Effects of Different Heat Treatments on the Physical Properties (including Hardness) and Microstructure of Specimens of Crucible Cast Steel"

Thesis Submitted by J. E. Opinsky, June 26, 1919, as One of the Requirements for the M. E. Degree.

(The Thesis originally planned, on another engineering subject, proving impracticable, the following work was carried out in the Metallurgical Laboratory of the V. P. I. as a substitute — with Professor J. S. A. Johnson's permission)

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An Investigation of the Effects of Different Heat Treatments on the Physical Properties (including Hardness) and Microstructure of Specimens of Crucible Cast Steel.

The material used was a cast steel from the Crucible Steel Company of America, said to contain 0.35 to 0.40% carbon.

Eight bars, 3/8" by 3/8" by about 5-1/2" long were prepared for test bars by turning down a space of 1-3/4" at the middle of each bar to a diameter of 5/16".

The bars were then given the heat treatment outlined in Table 1. The furnace used was a Hoskins' gasoline-heated muffle, nine inches long inside. It was necessary, in order to be sure that every part of the bar under treatment has reached the desired temperature and had remained at this temperature for some time, to turn the bars end to end. For this purpose one end of the bar had to be withdrawn slightly from the furnace before turning. (At the time of these tests the larger Hoskins electric heat-treating furnace had not been set up. In this furnace bars six or eight inches long can be turned over end to end without withdrawing any part from the furnace. This will greatly increase the control of the treatments)

After heat treating, a smoothly filed surface at each end of each test-bar was tested for hardness by means of the Brinell Meter. The results of these tests are included in Table 1.

The bars were then submitted to a tensile test in the Riehle testing machine. The result of these tests are given in Table 1.

The original plan of the work was to first ascertain the

two upper critical points of the steel (Ar_3 and Ar_2), and then give quenching treatments above Ar_3 between Ar_3 and Ar_2, and between Ar_2 and Ar_1.

The first attemps to determine these points by cooling-curve observations were unsuccessful because the gasoline-heated furnace could not be made to cool slowly enough. Later very satisfactory results were obtained as follows: the piece of steel, bored to receive the junction of the platinum: platinum-iridium thermo-couple, was set on the middle of the floor of the new Hoskins furnace, electrically heated, and the furnace was heated to about 950 C. It was then found possible by adjusting the rheostat to allow the furnace to cool at the rate of about <u>two degrees Centigrade in thirty seconds</u> -- an admirable rate of cooling for the purpose. The temperatureswwere read directly on the dial of a millivoltmeter for which the thermo-couple had been calibrated, every half minute. The mean of two sets of observations located the uppermost critical point (Ar_3) very plainly at 840 C. The point Ar_2 was not so clearly marked (but lay between 780 and 800 C.) (The comparative faintness of Ar_2 as compared with Ar_3 was to have been expected with steel of about the carbon-constant of the specimens used.) The lowest point was, of course, about 680 C.

One of the cooling-curve results is given in Plate 1. The ink lines are drawn so as to idealize the curve by covering up irregularities due to inaccurate reading or slight hanging and slipping of the needle of the indicating instrument. Considering that fractions of twenty degrees had to be estimated by eye on a rather close scale, and considering also that the retardations due to the changes at the critical points are very slight, the results are very satisfactory indeed. (Greater accuracy is of course possible

with a differential pyrometer and automatic recording device)

It is to be regretted that these reliable determinations of the critical points were not made until after the heat treatments had been given — using estimated critical points which were somewhat too high. The temperatures used certainly brought out the related variations in physical properties, but the desired transition products could have been better formed and retained by using somewhat different temperatures.

After fracturing the bars, and making the necessary measurements, the fragments were assembled and outlines were drawn so as to show the location and general nature of the fracture. These are given in Plate 2.

Small pieces were then sawn from the fractured ends at the points marked with an ink cross. The end of each sawn piece towards the fracture was then filed, polished and etched for microscopic examination.

Details of the Hardness Measurements.

The Brinell-meter is an ingenious and simple device for producing simultaneously, and with the same blow, depressions on a bar of known hardness and on a bar of unknown hardness, by driving two opposite sides of the same hardened steel ball into the two bars.

Assuming that depressions made in this way bear the same relation to hardness as depressions produced by static pressure, the results are calculated as follows:

$$\frac{\text{Brinell Hardness of test pieces} = \dfrac{\text{loads in kilos}}{\text{area of depression (t)}}}{\text{B. H. of standard bar} = \dfrac{\text{load in kilos}}{\text{area of depression (s)}}} = \frac{s}{t}$$

In this work the areas were calculated from the diameters as measured by means of an accurate measuring microscope. The ratios of two sets of diameters were not near enough to unity to make it possible to read off the hardness values on the tables supplied with the instrument

Test Pieces	Diameters of Test piece	Depressed areas Standard bar	Brinell Numbers calculated from $2\pi rh$ or $2\pi r(r - \sqrt{r^2 - m^2})$	Stand Hard-ness
A 1	3.2565mm	2.406	134	
A 2	2.8085	2.081	136 ----------250	
B 1	2.650	2.2765	184	
B 2	2.843	2.364	171 ----------250	
C 1	2.138	2.0875	163	
C 2	2.6235	2.4835	153 ----------170	
D 1	2.938	1.960	110	
D 2	2.731	2.138	152 ----------250	
E 1	2.5975	2.2975	134	
E 2	2.8570	2.328	112 ----------170	
F 1	?2.380	2.1245		
F 2	2.309	2.094	202 ----------250	
G 1	3.008	2.426	161 ----------	
G 2	3.0424	2.358	148 ----------250	
H 1	1.9275	1.7175	202	
H 2	?2.497	?1.916	? ----------250	

Test Piece	Original Diameter (inches)	Original Cross-sectional area (7 in.)	Diameter of fracture	Area at Fracture	Observed load drop of beam	Observed Max. Load	Observed working load	Original length (Gauged)	Final length (Gauged)
F	0.322"	0.081436	.250	.0491	5800	9000	9000	1.75"	1.875
B	0.325	0.082956	.250	.04909	5800	7860	5850	"	1.972
C	0.3355	0.08844	.172	.0232	4600	5960	3980	"	2.187
G	0.3315	0.08631	.156	.01911	3600	5980	3900	"	2.219
E	0.3285	0.08475	.156	.01911	3600	5490	3260	"	2.3125
D	0.3315	0.08631	.156	.01911	3000	5520	3290	"	2.3125
A	0.326	0.08347	1187	.275	3160	4840	3365	"	2.359
H	0.3285	0.08475	.312	.06073	5600	9450	9450	"	1.8437

Test Piece	Per cent reduction of Area	Per cent elongation	Load at drop per sq. inch of original area	Max. load per sq. in of original area	Breaking load per sq. in of original area	Approx. Brinell (H) (by Brinell meter)
F	39.6	7.1	71,220	110,520	110,520	- 202
B	40.7	24.1	69,916	94,750	70,520	- 171 - 184
C	73.7	25.0	52,012	67,390	45,000	- 153 - 163
G	77.8	26.5	41,710	69,280	45,190	- 148 - 161
E	77.4	32.1	42,480	64,780	38,466	- 112 - 134
D	77.8	32.1	34,760	63,950	38,120	- 110 - 152
A	67.0	34.8	37,860	57,986	40,315	- 134 - 136
H	28.3	5.4	66,080	111,530	111,530	- - 202

Table I

Material: Crucible steel, purported to contain 0.35 to 0045% C
(An analysis is to be made)

Heat Treatments:

A -- no treatment
F -- heated to 950 C and quenched in water. (110° above Ar_3)
B -- heated to 880 C, held 15 minutes, quenched in water (40° above Ar_3)
C -- " " " " quenched in water then reheated to 500 C for 15 minuted and cooled in furnace

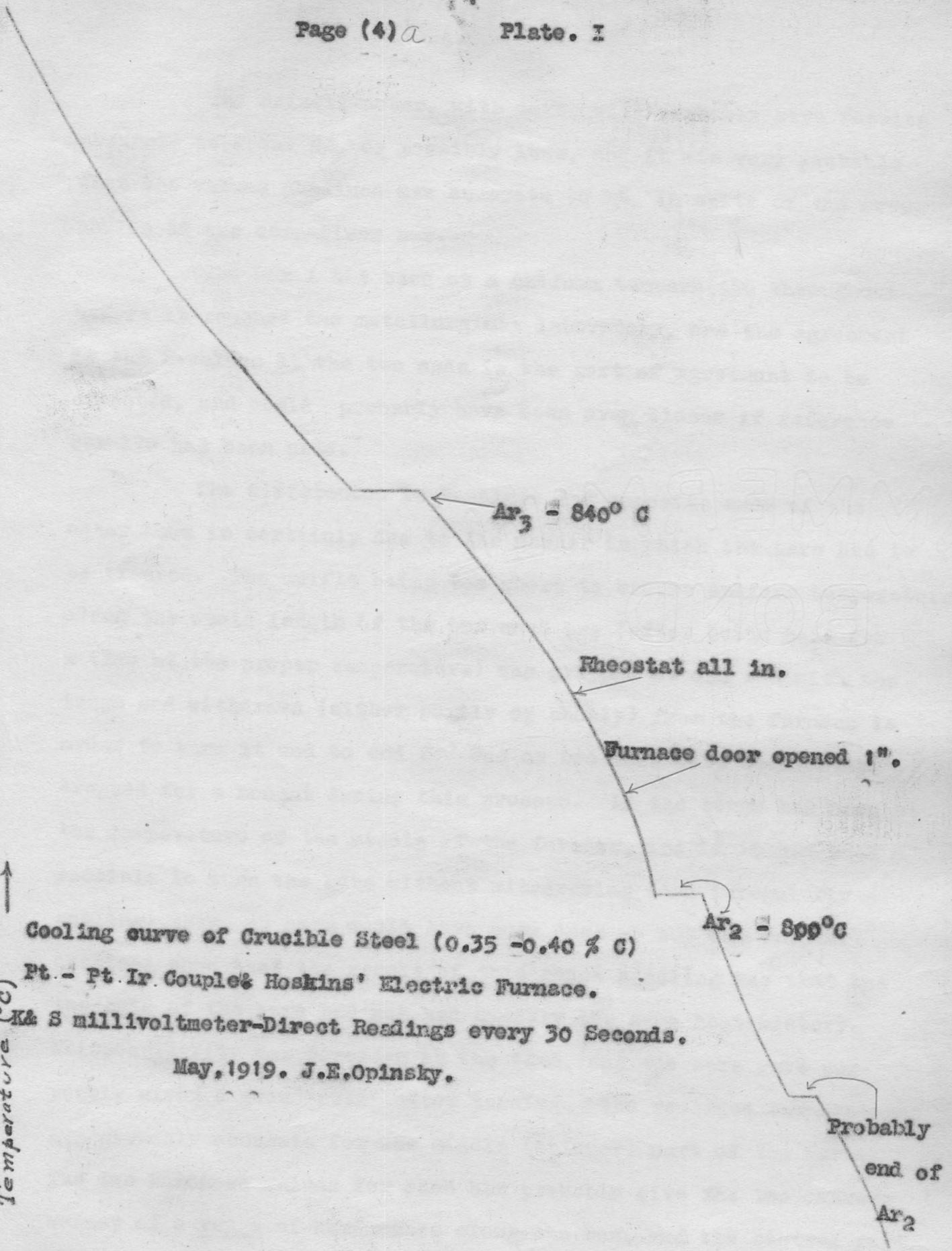
G -- heated to 880 C, held 15 minutes, quenched in oil (40° above Ar_3)
E -- like G, then reheated to 500 C for 15 minutes and cooled in furnace.
D -- heated to 880, held 15 minutes, and cooled slowly in furnace
H -- heated to 880 C, held 15 minutes, cooled slowly to 750 C and then quenched in water (Just below the upper limit of the Ar_1- Ar_2 range)

Discussion of Results.

(1) The results for hardness are unsatisfactory. In testing bars A, B, D and G the standard bar of known Brinell hardness 170 should have been used for comparison, instead of the 350 bar, since the smaller the difference between the hardness of the standard bar and test-piece the more reliable is the hardness value found for the test-piece.

Attention Patron:

The following page 4a is misnumbered but in the correct order.



Cooling curve of Crucible Steel (0.35 -0.40 % C)

Pt - Pt Ir Couple & Hoskins' Electric Furnace.

K& S millivoltmeter-Direct Readings every 30 Seconds.

May, 1919. J.E.Opinsky.

The Brinell-meter, with care, will probably give results accurate to about 2%, or possibly less, and it wis very probable that the values obtained are accurate to 2%, in spite of the wrong choice of the comparison bar.

The bar A had been at a uniform temperature throughout before it reached the metallurgical laboratory, and the agreement in the H-valves at the two ends is the sort of agreement to be expected, and would probably have been even closer if reference bar 170 had been used.

The differentes in H-values for opposite ends of the other bars is certainly due to the manner in which the bars had to be treated. The muffle being too short to ensure uniform temperature along the whole length of the bar each bar (after being held for a time at the proper temperature) was gripped at one end with the tongs and withdrawn (either partly or wholly) from the furnace in order to turn it end to end . One or two bars were accidently dropped for a moment during this process. If the tongs had been at the temperature of the middle of the furnace, and if it had been p possible to turn the bars without withdrawing (and irregularly cooling) them, no harm would have baen done -- but the values obtained show that the result of this rough handling was that the <u>two ends</u> of the bars had not had exactly the same heat-history. Thispossibility was foreseen at the time, and the bars were purposely given a goos "soak" after turning. The recorded temperatures are probably accurate for the middle (thinner) part of the bars. The two hardness values for each bar probably give the two extreme values of a <u>range</u> of hardnesses along the bar, and the central part will probably be found to have a hardness somewhere near the

average of the values for the ends.

The hardness test are to be repeated -- using the proper reference bar in each case, and testing a filed place near the fracture instead of at the end.

(The newly installed electric furnace for heat treatments is large enough to obviate any complications of this sort in future work)

Considering the H values as representing ranges they agree very well, in general, with the other physical properties as determin d by the tensile strength test. (see below)

(2) Other Physical Properties. It could have been predicted that the heat-treatments given,(neglecting H, which can not be accounted for at present) arranged in order of diminishing severity, would for, the series: F,B,C,G,E,D, The only real uncertainty would be as to the position of C in the series.

A close study of the reduction of area, elongation, elestic limit and breaking load values, as shown in Table 1, shows that the values agree very well indeed with this arrangement.

The untreated bar A comes in the series as follows:

judged by the			reduction of area	--	between	B and	C
"	"	"	elongation	--	"	G "	E
"	"	"	elastic limit	--	"	G "	D
"	"	"	breaking load	--	"	G "	E
"	"	"	hardness	--	"	G "	E

It is evident that it has been possible, by these heat treatments, not only to greatly alter the tensile strength, hardness, etc., but also to modify to a considerable extent the relations between the values for the different properties.

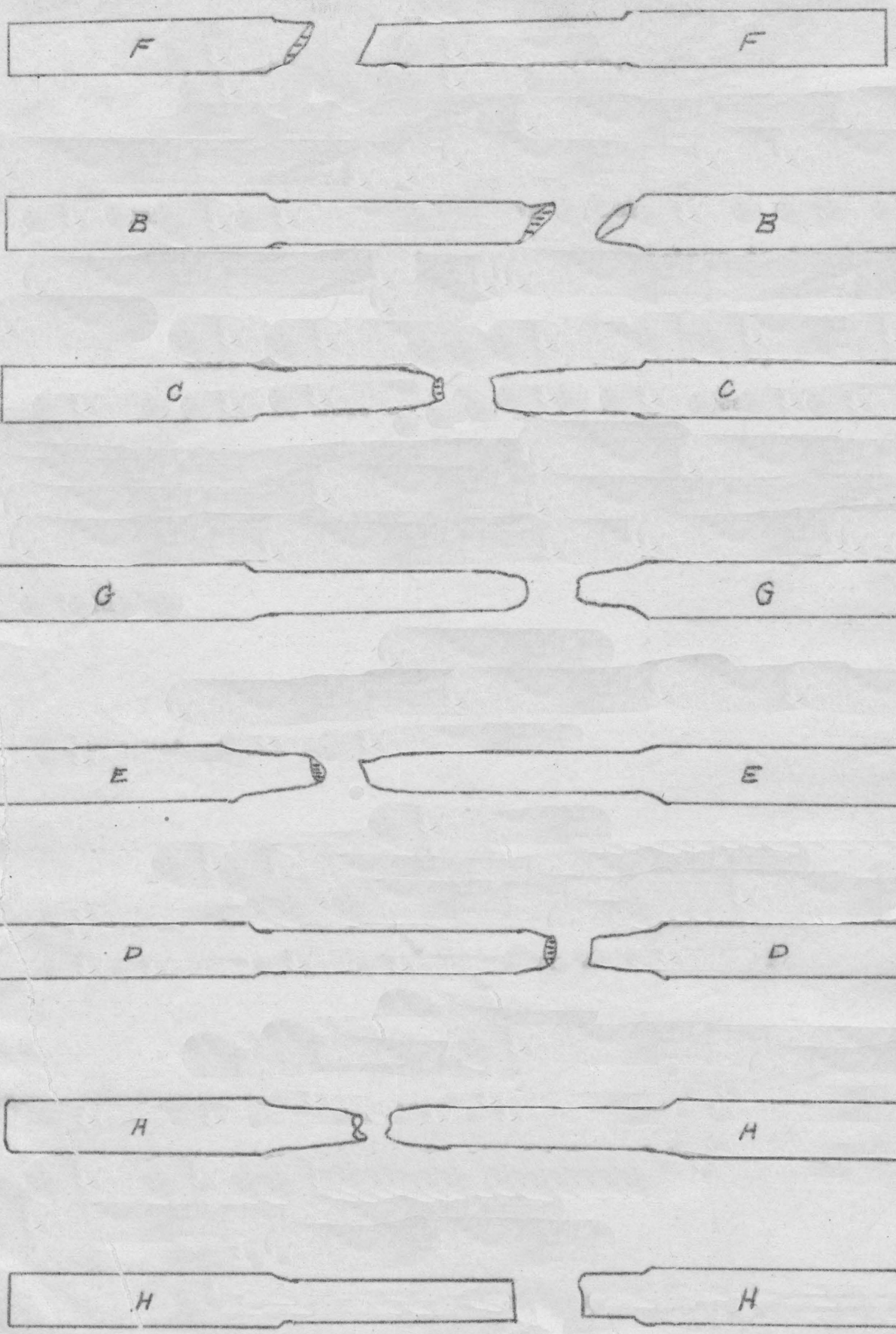


Plate. II.

(3) Structure and Constitution.

Taking the general severity of the trestments as in the order F, B, C, G, E, D, decreasing, and retarding this order as being well confirmed ny the results shown in Table 1, we should expect the maximum change in consitution and microstructure to be shown by bar F.

This is certainly the case: the microscopic specimen shows that this piece is made up entirely of large areas of martensite surrounded by narrower barders of troostite, and this constitution agrees with the fact that the highest hardness in the series is that of bar F --- martensite begin decidedly the hardest of the transition products.

Specimen - D -

Contained a large number of scratches due to polishing, it was not etched deep and tarnished.

Specimen - B -

Variable in different parts and in some places almost troostite. In other places a mixture of martensite and troostite with much more minute structure than the specimen F.

Specimen - C-

The structure of "C" resembles that of "F" more than that of "B". This is presumable due to the fact that the products formed during tempering have simply formed Pseudomorphs after Martensite and (possible troostite)

Specimen - G -

This specimen shows svidence of having had milder quenching than "F", it is composed more largely of troostite.

Specimen - E -

This specimen should be largely ferrite and either sorbite or pearlite, but the structure is obscure and possible re-etching will help in differentiating the constituents.