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INFLUENCE OF GRINDING TREATMENTS ON THE SURFACE HARDNESS OF INTAGLIO PRINTING PLATES OF 0.33-PERCENT CARBON STEEL

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ABSTRACT

A study was made of the surface-hardening effects in plates used for intaglio printing. These plates were of 0.33-percent carbon steels having different metallographic structures and finished under different grinding conditions. The influence of the following factors in the grinding conditions on the surface hardness of the steels was investigated: (1) cooling conditions during grinding, (2) grain size of the abrasive (3), depth of cut, and (4) rate at which the abrasive wheel passes over the specimens. Variations in the hardness of the steels at different levels beneath the ground surfaces were determined by applying different loads on an elongated pyramidal-diamond indenter. The geometrical irregularities of the surfaces of the ground specimens, evaluated by the "tracer" method, were considered with respect to their influence on the accuracy of measurement of surface hardness by the indentation means employed and their relationship to surface hardness.

CONTENTS

I. INTRODUCTION

Incised symbols, inscriptions, and pictorial representations in steel plates intended for intaglio printing may be cut with an engraving instrument or impressed from a hardened steel roll bearing the embossed design. These processes of cutting and impressing are usually designated as "engraving" and "mechanical-transferring," respectively. The response of plate steel to the engraving and mechanical-transferring treatments is influenced by the geometrical as well as the plastic deformation characteristics of the surface layers of the steel. The hardness of the steel at and near its surface, which may differ significantly from that of the underlying steel, is one of the factors believed to have an important bearing in respect to this behavior. The mechanical finishing of the surfaces of engraving and transfer-plate steels by machining, grinding, and polishing, affects the hardness of the surface layers. These effects may differ according to the severity of the plastic deformation and thermal effects caused by the finishing process and the response of the metal to work-hardening.

This paper presents results of hardness tests with indentations penetrating to different levels beneath the ground surfaces of plates of 0.33-percent carbon steels having different metallographic structures and finished under different grinding conditions. This is one phase of an investigation of surface finishes being conducted by the National Bureau of Standards in cooperation with the Bureau of Engraving and Printing.

Because the depth of penetration of the hardening effect below the ground surface of the steel was very small, hardness measurements had to be confined to the surface layers at correspondingly shallow depths. The depths of penetration of the ball and the conical or pyramidal-diamond indenters used with the well-known Brinell, Rockwell, and Vickers testers were entirely too great for the purpose. The elongated pyramidal-diamond indenter recently developed at the National Bureau of Standards to permit the accurate measurements of indentations made under small loads [1] [1] was used to evaluate the hardness changes in the surface layers of metals accompanying deformational and structural changes caused by grinding. The average depths of indentations made with this tool in the experiments were 0.0001, 0.00015, 0.00025, and 0.00035 inch at loads of 100, 200, 500, and 1,000 grams, respectively.

It is evident that the more shallow the indentation, the more significant becomes the influence of the geometrical irregularities of the surface on the depth of penetration of the indenter. In the present study, the surface finishes of the specimen plates were evaluated by the "tracer" method.

II. MATERIAL

The 0.33-percent plain carbon steel investigated is typical of the steel used for rotary-press printing plates by the Bureau of Engraving and Printing. Other than iron, the significant constituents determined by chemical analysis were as follows:

	Percent
Carbon	0.33
Manganese	.55
Phosphorus	.028
Sulfur	.027
Silicon	.23

All specimens for the various treatments were cut from a single plate of the steel to the dimensions 6 by 5 by ¼ inch thick. Five specimens, each heat-treated to produce a different microstructure, were used for each of the grinding conditions described below. The microstructures are shown in figure 1. A layer, at least 0.020 inch thick, was removed by grinding from the test surface of each specimen, after heat treatment, to eliminate the oxidized or decarburized metal that might have developed in this portion during heat treatment.

III. METHODS OF TEST

1. GRINDING TREATMENTS

All grinding tests were made on a hydraulically operated surface-grinding machine having a magnetic chuck of sufficient length to permit the simultaneous grinding of five specimens placed in tandem arrangement. In this manner, practically identical conditions were

[1] Figures in brackets indicate the literature references at the end of this paper.

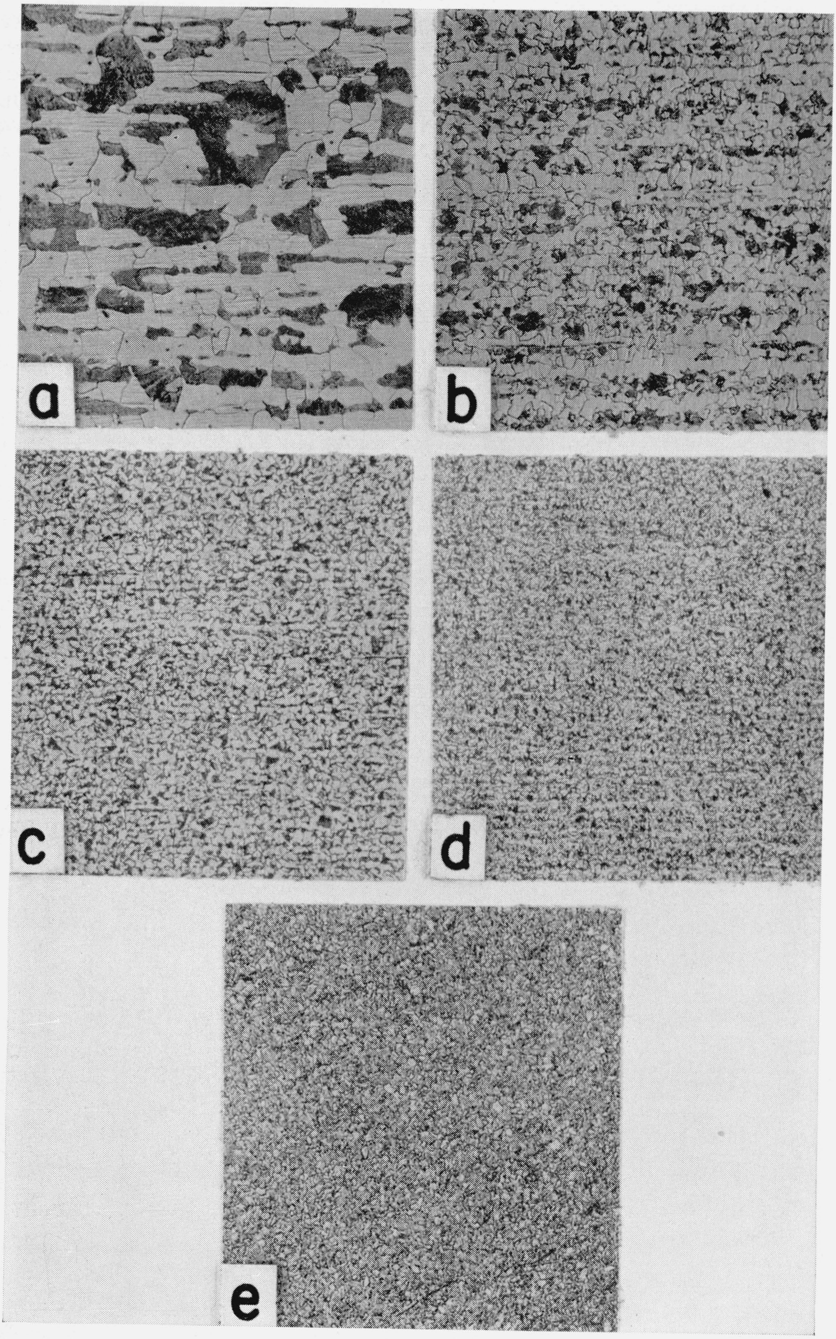

FIGURE 1.—*Characteristic microstructures of 0.33-percent carbon steel developed by different heat treatments.*

Etched in 1-percent Nital. Magnification ×100. *a*, Furnace-cooled from 1,925° F (1,050° C); *b*, furnace-cooled from1,600° F (870° C); *c*, air-cooled from 1,600° F (870° C); *d*, water-quenched from 1,600° F (870° C) and drawn at 1,400° F (760° C); *e*, water-quenched from 1,600° F (870° C) and drawn at 1,200° F (650° C).

maintained for all of the specimens during each grinding treatment. The machine was equipped with controls for varying the table speed, cross feed, and depth of cut, but the peripheral speed of the abrasive wheel was approximately the same (5,600 feet per minute) for all tests.

Wheels of three different grit sizes were employed. All wheels were 12 inches in diameter with cutting faces 1 inch wide. Further details of the wheels are given in table 1.

TABLE 1.—*Grinding conditions employed on specimens*

Grinding test designation	Abrasive-wheel specification	Table speed, ft/min, for cut number [1]—				Cross feed for cut number [1]—				Wheel feed for cut number [1]—			
		1	2	3	4	1	2	3	4	1	2	3	4
						in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
a	Alundum abrasive, No. 46 grain, vitrified bond, soft.	45	45	---	---	0.04	0.04	----	----	0.001	.0002	----	----
b [2]	Alundum abrasive, No. 60 grain, vitrified bond, soft, open structure.	45	45	45	45	.02	.02	0.02	0.01	.0004	.0003	.0002	.0001
c [3]	Alundum abrasive, No. 80 grain, vitrified bond, soft, open structure.	35	35	35	25	.02	.015	.015	.01	.0004	.0003	.0002	.0001
d	Alundum abrasive, No. 46 grain, vitrified bond, soft.	35	35	35	30	.02	.015	.015	.015	.0004	.0003	.0002	.0001
e [4]	Alundum abrasive, No. 46 grain, vitrified bond, soft.	35	35	35	30	.02	.015	.015	.015	.0004	.0003	.0002	.0001
-------	Alundum abrasive, No. 46 grain, vitrified bond, soft.	45	45	---	---	.010	.010	----	----	.0002	.0001	----	----
g	Alundum abrasive, No. 46 grain, vitrified bond, soft.	70	70	70	---	.010	.010	.010	----	.0002	.0001	.0001	----

[1] Last cut indicated represents finishing cut.
[2] Specimens preground with No. 46 grit wheel, same as conditions test "*a*".
[3] Specimens preground with Nos. 46 and 60 grit wheels, same as conditions "*a*" and "*b*" respectively.
[4] Ground dry, that is, without liquid coolant. A liquid commercial grinding compound was employed for all other tests.

Each wheel was mounted on a separate hub, which fitted within close tolerance on the spindle of the grinding machine. The wheels were carefully balanced to permit the interchange of wheels with a minimum influence of the vibration factor. Prior to each grinding test, the wheels were dressed with a sharp diamond tool.

One series of grinding tests was made dry, that is, without the use of a cooling liquid. For all other tests, a commercial grinding compound was used. This liquid, or "coolant", was fed in two opposite directions from a forced-circulation system to the cutting face of the wheel at approximately the area of contact with the specimen. A suitable filter in the circulation system effectively removed abrasive matter from the used liquid prior to its recirculation to the work.

The specimens were dressed before each grinding test in order to eliminate the effects of the previous tests and to insure continued flatness of the surfaces. The depth of these cuts was considerably less than the initial cut for the following test, thus minimizing the influence of the dressing treatment on the test results.

The effects of the following factors in the grinding conditions on the surface hardness of the specimens were investigated: (1) oscillating rate of the specimen with respect to the abrading surface of the wheel, (2) depth of cut, (3) grain size of the abrasive, and (4) cooling conditions during grinding. Further details of the individual test conditions are given in table 1.

2. HARDNESS INDENTATION TESTS

Important factors influencing the accuracy of surface-hardness tests are the effect of elastic recovery on small indentations and variations of this effect for metals of different hardness. It has been demonstrated that hardness measurements made with the elongated pyramidal-diamond indenter used in this investigation are not significantly influenced by these factors [1]. Since, with different loads, the same indentation numbers are secured on metal of uniform hardness, the existence of hardness gradients in different levels of the surface layers is readily detected.

Indentation determinations were made under four different loads, namely 100, 200, 500, and 1,000 grams, with the indenting apparatus described in a previous Bureau publication [1]. The time of contact of the indenter with the specimen for each indentation test was 20 seconds. In every case the indentations were made with the long axis of the indenter approximately parallel to the direction of the grinding marks. The hardness indentation numbers were computed by dividing the load, in kilograms, by the unrecovered projected area, in square millimeters [1]. The constant Cp, which relates the length of the indentation to its projected area, was 0.0694 for the indenter used. Decrease in identation number with increase in load was an indication of the depth of the hardening effect for the grinding treatment. Data supplementing this information were obtained by making similar indentation tests after the removal of layers from the ground surface by polishing with 3/0 emery paper under light pressures until the grinding marks were barely visible. The thickness of the surface metal thus removed was estimated by the measure of the depths of the grinding marks determined by the tracer method.

Microstructural inhomogeneities of the specimens influenced the depth of penetration of the indenter. This is illustrated in figure 2 by the differences in the sizes of the indentations in the ferritic- and carbon-rich areas, respectively. In order to secure a representative average value of each of the surfaces tested, 10 or more indentations were made with each load on the indenter.

3. SURFACE MEASUREMENTS

It was essential, for the proper interpretation of the results of the indentation tests, to evaluate the surface "roughness" of the ground specimens. Such data also served to reveal any existing correlation of the factor of surface finish with surface hardness.

The profilometer, embodying the tracer principle, used for evaluating the surface finishes did not directly determine the "peak to valley" heights of the surface markings, which are characterized in figure 3, but rather indicated the root-mean-square average values in microinches (10^{-6}) of the deviations from the nominal surface. According to Abbott [2], the actual "peak to valley" heights are 3 to 4 times the root-mean-square values. The higher factor is considered more nearly correct for the limits of finish dealt with in this study.

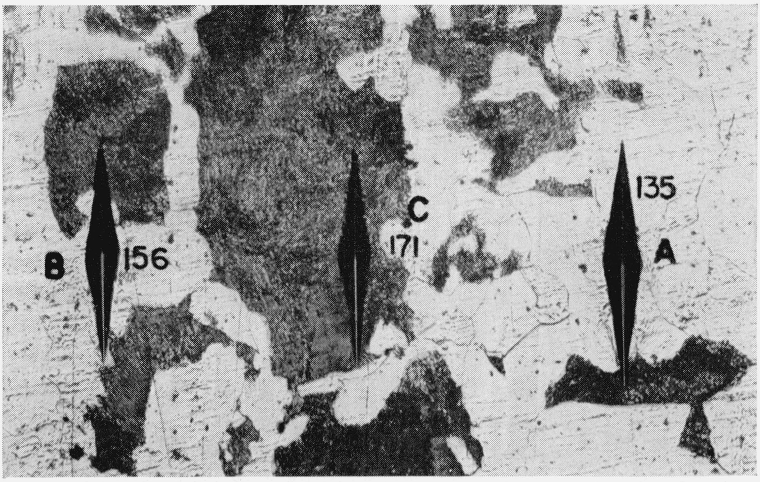

FIGURE 2.—*Effect of microstructural inhomogeneity of steel on the magnitude of indentation made with the elongated pyramidal-diamond indenting tool.*

The length of the indentation and the corresponding hardness indentation number for each of the areas indicated by letters in the micrograph were as follows:

Area	Predominating microstructural constituent	Length of indentation	Computed hardness indentation number
		micro inches	
A	Ferrite	325	135
B	Ferrite and pearlite	305	156
C	Pearlite	290	171

Etched in 1-percent Nital. Magnification ×100.

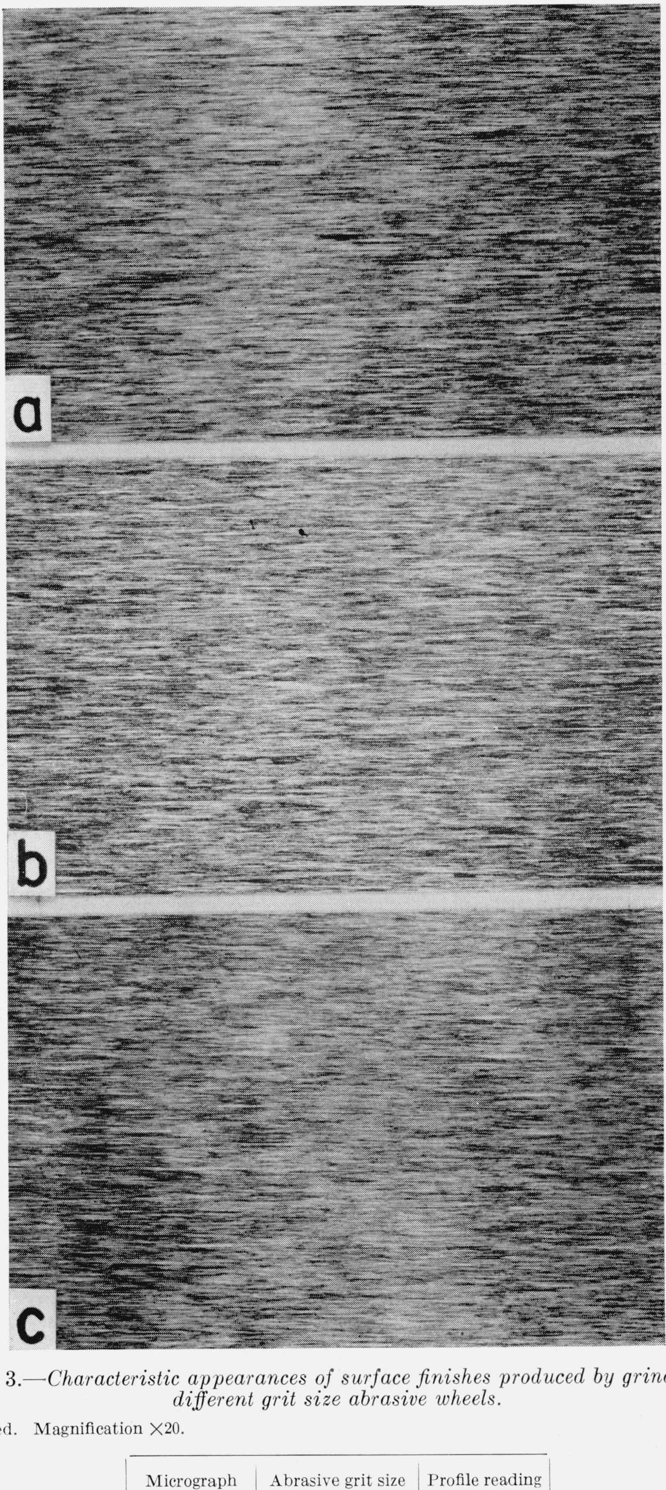

FIGURE 3.—*Characteristic appearances of surface finishes produced by grinding with different grit size abrasive wheels.*

Unetched. Magnification ×20.

Micrograph	Abrasive grit size	Profile reading
		rms micro in.
a	46	6 to 9
b	60	8 to 14
c	80	3 to 4.5

IV. RESULTS AND DISCUSSION

The results of the indentation tests and the evaluations of surface "roughness" for each of the specimens prepared by the several grinding treatments are listed in table 2. The changes of indentation numbers with increased load on the indenter for the different grinding and heat treatments are shown in figures 4 to 8. These curves, in general, show a decrease of indentation number with increasing load. This indicates a decrease of hardness with increasing depths of the surface layers. These data must, however, be interpreted with respect to the influences of the geometrical characteristics of the surface finishes.

TABLE 2.—*Average surface-hardness values of 0.33-percent carbon steel specimens heat treated to develop different structural conditions: (1) "as ground," (2) after removal of superficial layer of metal from ground surface by light polishing with 3/0 emery paper*

Grinding[1] treatment	Specimen identification	Heat treatment	Hardness indentation number (elongated pyramidal—diamond indenter)[2]: "As ground" surfaces, Test load, grams				Polished surfaces[3], Test load, grams				Evaluations of surface finish
			100	200	500	1,000	100	200	500	1,000	*rms* *10⁻⁶ in.*
a	*MB-8*	Heated to 1,925° F, held at temperature for 1 hr, and furnace-cooled.	222	219	191	187	178	169	159	157	6 to 9
b	*MB-8*		194	177	173	157	183	170	159	152	5 to 11
c	*MB-8*		188	176	176	152	177	165	163	148	3 to 6
d	*MB-8*		220	198	183	164	176	184	162	158	6 to 9
e	*MB-8*		175	165	161	159	196	175	172	161	6 to 8
f	*MB-8*		216	196	171	164					4 to 7
g	*MB-8*		216	197	182	172					6 to 10
a	*MB-4*	Heated to 1,600° F, held at temperature for 1 hr, and furnace-cooled.	228	207	185	176	193	194	177	165	6 to 10
b	*MB-4*		195	184	171	156	179	172	157	155	8 to 14
c	*MB-4*		199	179	165	153	177	169	160	153	2 to 4
d	*MB-4*		209	200	172	166	194	184	167	158	6 to 9
e	*MB-4*		178	175	158	150	189	175	161	154	4 to 6
f	*MB-4*		208	199	178	171					5 to 7
g	*MB-4*		236	203	180	168					7 to 11
a	*MB-6*	Heated to 1,600° F, held at temperature for 1 hr, and air-cooled.	241	223	214	190	222	212	203	187	6 to 11
b	*MB-6*		205	208	193	189	187	184	182	170	7 to 12
c	*MB-6*		210	202	189	177	199	191	182	176	3 to 5
d	*MB-6*		223	209	202	187	210	200	193	180	6 to 8
e	*MB-6*		188	186	174	172	191	189	182	177	4 to 7
f	*MB-6*		217	210	192	186					5 to 7
g	*MB-6*		231	231	194	192					7 to 9
a	*MB-7*	Heated to 1,600° F, quenched in water, and drawn for 1 hr at 1,400° F.	254	253	231	208	235	230	214	202	6 to 10
b	*MB-7*		219	218	195	186	203	192	190	184	8 to 13
c	*MB-7*		215	218	198	188	206	202	189	183	3 to 6
d	*MB-7*		237	217	205	189	205	204	193	187	6 to 9
e	*MB-7*		209	204	186	182	207	201	189	183	5 to 7
f	*MB-7*		228	212	198	192					5 to 8
g	*MB-7*		231	219	206	198					6 to 9
a	*MB-5*	Heated to 1,600° F, quenched in water, and drawn for 1 hr at 1,200° F.	295	269	241	239	270	241	226	223	6 to 9
b	*MB-5*		246	236	222	222	207	207	208	202	7 to 14
c	*MB-5*		232	226	216	214	213	214	209	202	3 to 4
d	*MB-5*		247	246	241	233	219	216	228	226	6 to 9
e	*MB-5*		222	219	222	219	217	217	213	208	4 to 6
f	*MB-5*		240	243	232	234					5 to 7
g	*MB-5*		238	244	224	215					7 to 10

[1] See table 1 for details of grinding treatments.
[2] Each value given is the average of 10 or more readings.
[3] Polishing was continued until grinding marks were barely visible to unaided eye.

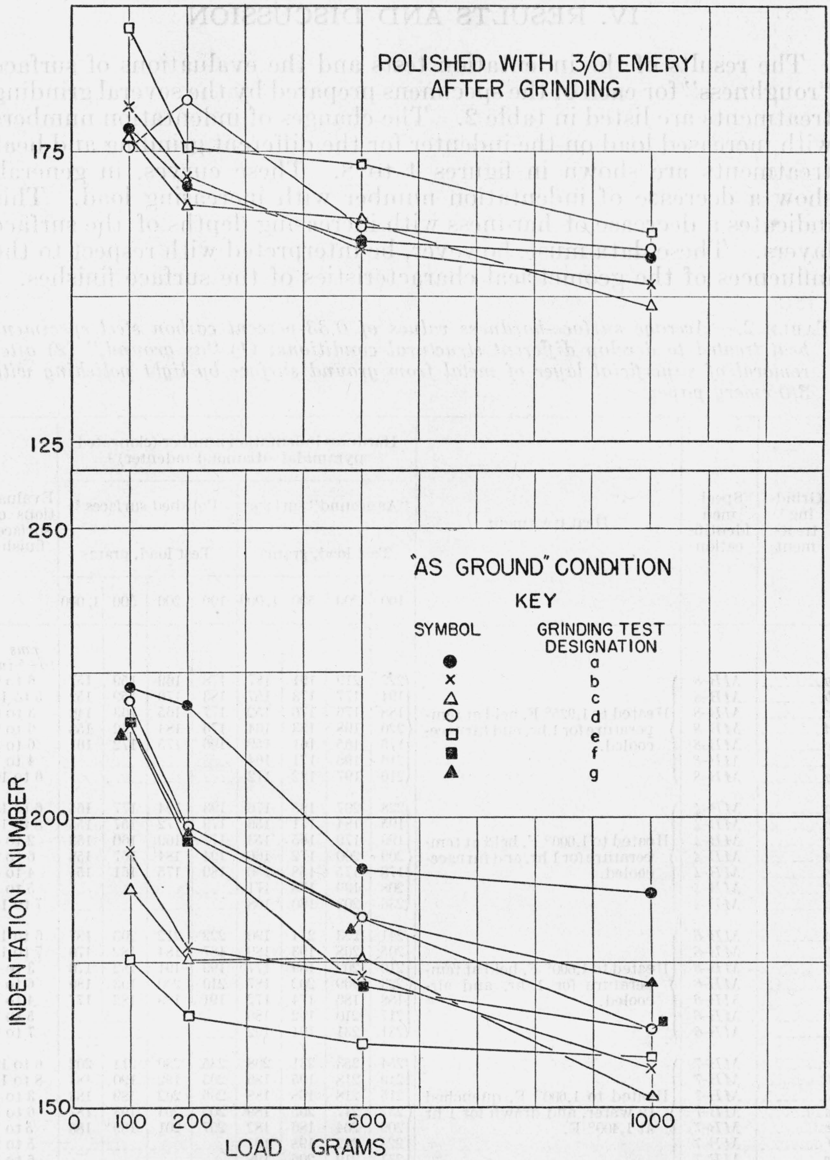

FIGURE 4.—*Effect of different conditions of grinding on the surface-indentation (hardness) values of 0.33-percent carbon steel, furnace-cooled from 1,925° F (1,050° C), as determined under different loads on the indenter.*

The curves in the upper portion of the figure indicate the surface-hardness values after removing a superficial layer of metal from each of the ground surfaces by light polishing with 3/0 emery paper. (See table 1 for details of test conditions corresponding to the grinding-test designations listed in the "key.")

Applying the factor of 4 to the surface-finish values given in table 2, the average "peak to valley" heights of the surface contours were estimated to be about 0.000012 to 0.000024 inch for the smoother surfaces and approximately 0.00003 to 0.00005 inch for the coarser ones. Comparing the dimensions of the surface serrations with those

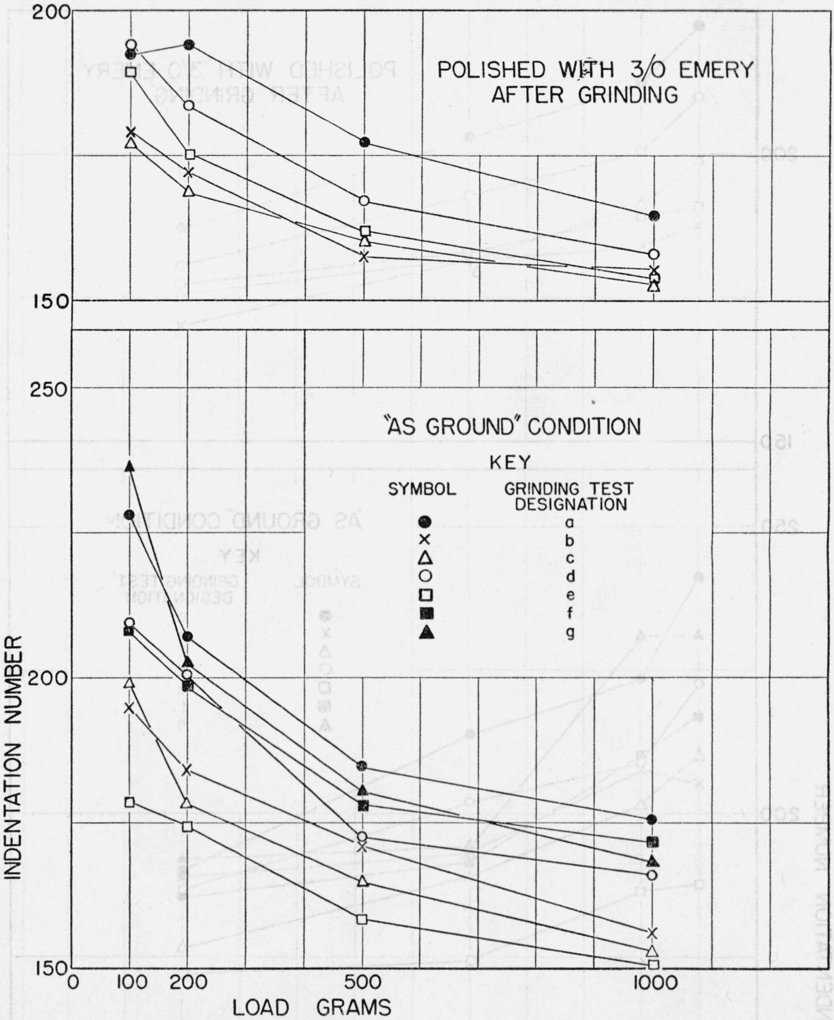

FIGURE 5.—*Effect of different conditions of grinding on the surface-indentation (hardness) values of 0.33-percent carbon steel, furnace-cooled from 1,600° F (870° C), as determined under different loads on the indenter.*

The curves in the upper portion of the figure indicate the surface-hardness values after removing a superficial layer of metal from each of the ground surfaces by light polishing with 3/0 emery paper. (See table 1 for details of test conditions corresponding to the grinding-test designations listed in the "key.")

of the depths of the indentations made with the 100- and 200-gram loads, it is apparent that only partial contact was maintained between the metal and the surface of the penetrating portion of the indenter. Under such conditions, a longer indentation would be obtained than if a more complete bearing contact were maintained. Therefore, the indentation numbers, particularly for the lighter loads, were undoubtedly smaller than the true values. Nevertheless, the distinct decrease in indentation number with increase in load (figures 4 to 8) indicated that the hardening effect was superficial.

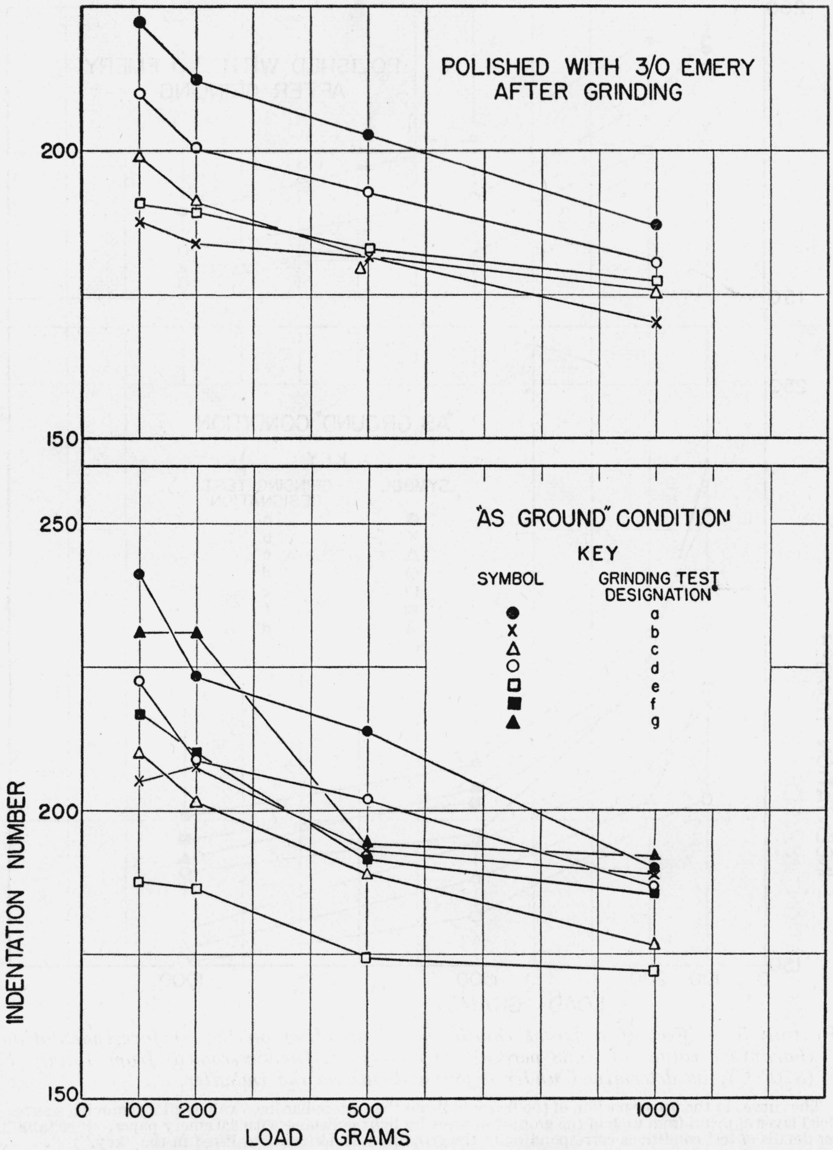

FIGURE 6.—*Effect of different conditions of grinding on the surface. indentation (hardness) values of 0.33-percent carbon steel, air-cooled from 1,600° F, (870° C) as determined under different loads on the indenter.*

The curves in the upper portion of the figure indicate the surface-hardness values after removing a superficial layer of metal from each of the ground surfaces by light polishing with 3/0 emery paper. (See table 1 for details of test conditions corresponding to grinding-test designations listed in the "key.")

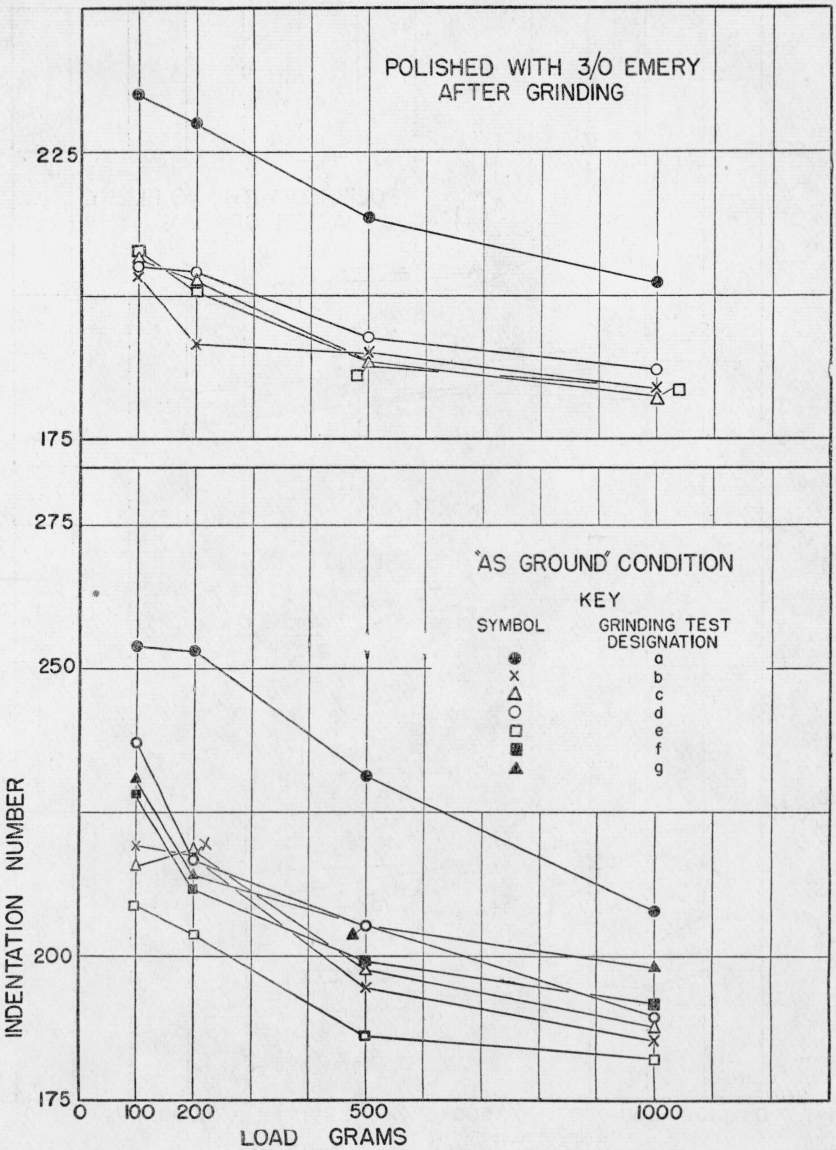

FIGURE 7.—*Effect of different conditions of grinding on the surface-indentation (hardness) values of 0.33-percent carbon steel, water-quenched from 1,600° F (870° C), and drawn at 1400° F (760° C), as determined under different loads no the indenter.*

The curves in the upper portion of the figure indicate the surface hardness values after removing a superficial layer of metal from each of the ground surfaces by light polishing with 3/0 emery paper. (See table 1 for details of test conditions corresponding to grinding-test designations listed in the "key.")

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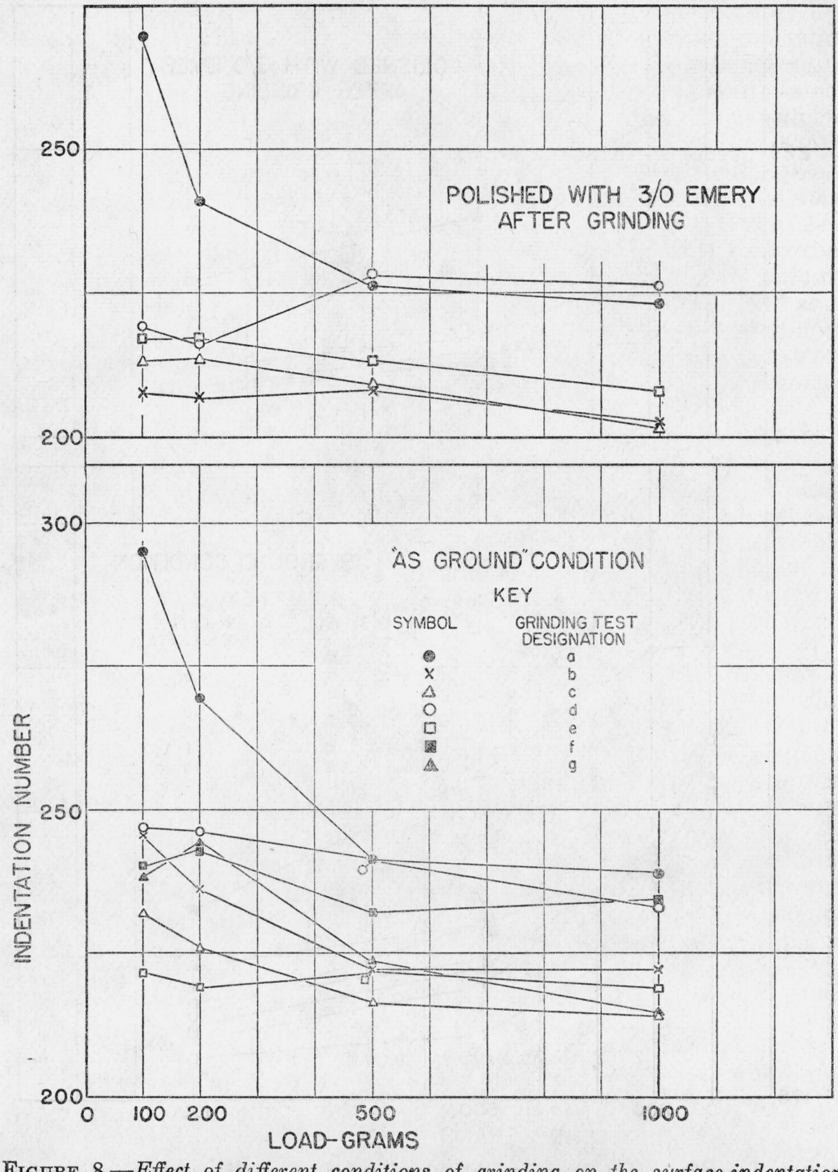

FIGURE 8.—*Effect of different conditions of grinding on the surface-indentation (hardness) values of 0.33-percent carbon steel, water-quenched from 1,600° F (870° C) and drawn at 1,200° F (650° C), as determined under different loads on the indenter.*

The curves in the upper portion of the figure indicate the surface hardness values after removing a superficial layer of metal from each of the ground surfaces by light polishing with 3/0 emery paper. (See table 1 for details of test conditions corresponding to grinding-test designations listed in the "key.")

Evidence in further support of this view was secured from the indentation tests on the specimens polished with 3/0 emery paper after grinding. The polishing treatments removed a thickness of metal from the ground surfaces equivalent to the "peak to valley" heights of the grinding marks, which in no case appreciably exceeded 0.00005 inch. Despite the work-hardening effects of the polishing treatments, the results of the indentation tests on the polished surfaces were consistently lower than those for the ground conditions (table 2 and figures 4 to 8). It is worthy of note that the variations of the individual indentation numbers from the average values were no greater for the "as ground" surfaces than for the polished surfaces. It is likely that the true differences in indentation number for corresponding loads between the ground and polished specimens were greater than indicated, because more complete contact was obtained between the indenter and the smoother polished surfaces.

Although the degree of finish may influence the accuracy of small indentation hardness tests of a metal, the results listed in table 2 did not show any correlation between hardness and degree of finish of the surface. In some cases, similar hardness numbers were obtained on the same specimen having surfaces of significantly differing finishes produced with different grinding conditions (treatments *b* and *c*, table 2). On the other hand, there were a number of tests in which different hardness results were obtained, despite the similarity of surface finish (table 2).

The hardness curves (figs. 4 to 8) in most cases show that the factors of cooling, depth of cut, and grain size of the wheel significantly influenced the surface hardness of the steel. Within the limitations of the tests made, the surface hardening appeared to be independent of the microstructural characteristics of the material. The differences in the indentation numbers of the "dry" and "wet" ground specimens (curves *d* and *e*, respectively) may be attributed in a large measure to the thermal influences, as the other factors controlling the work-hardening effects were the same for both cases. The hardness data obtained for the surfaces, which were ground under identical conditions except as to the depth of cut (curves *a* and *d*), showed that a higher degree of hardening was obtained as the depth of cut was increased. The surface-hardening effect produced with the No. 46 grain abrasive (curve *a*) was considerably greater than was obtained by grinding with either the Nos. 60- and 80-grain abrasives (curves *b* and *c*). The hardening effects produced with the last two abrasives were approximately the same.

The indentation tests made on the specimens ground at oscillating speeds ranging from 38 to 71 feet per minute (table 1) indicated that this factor exerted no appreciable influence. The results are presented in curves *d*, *f*, and *g*, figures 4 to 8.

V. SUMMARY

Mechanical-transfer plates of 0.33-percent carbon steel having different metallographic structures were investigated to determine the influence of different grinding conditions on the surface hardness of the steel. Hardness indentation tests were made with different loads on an elongated pyramidal-diamond indenter developed at the

National Bureau of Standards. The geometrical irregularities of the ground surfaces evaluated by the "tracer" method as the root-mean-square average deviation from a nominal surface were considered with respect to their influence on the accuracy of the hardness measurements.

Experimental data are presented to show that the hardness of the surface metal, distinguished from that of the underlying metal, may be significantly influenced by (1) the cooling conditions during grinding, (2) the depth of cuts, and (3) the grain size of the abrasive. However, the rate at which the stone passed over the specimens did not appear to influence the hardening effects.

The results obtained within the limitations of the tests suggested that surface hardness is independent of the geometrical condition of the surface. However, the accuracy of the measurements of surface hardness by indentation means may be influenced by the degree of finish of the surface.

The hardening effects of the grinding treatments on the steel investigated did not appear to be influenced by differences of the microstructures of the material.

The hardness data secured suggested that the most significant hardening effects of grinding are superficial and that these influences are progressively less for the successively deeper adjacent layers of the steel.

VI. REFERENCES

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