OTTAWA November 9, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1960.

Flame Hardening of Naval Gun Racer Plates.

(Copy No. 16.)

Bureau of Mines
Division of Metallic
Minerals

Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

OTTAWA November 9, 1945.

REPORT
of the
ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1960.

Flame Hardening of Naval Gun Racer Plates.

==========

Introduction:

On September 25, 1945, Commander (E) G. Taylor, R.N.V.R., of the British Admiralty Technical Mission, Ottawa, Canada, requested the assistance of these Laboratories in determining the feasibility of flame hardening the races of naval gun racer plates. Commander Taylor's letter stated that Rear Admiral Greathed, Chief Inspector of Gun Mountings at the Admiralty, was greatly interested in the process and requested details of the procedures which would produce race hardnesses of 200, 250 and 300 Brinell and the maximum hardness possible.

In a letter dated July 31, 1945, Mr. I. M. Banham, of the British Admiralty Technical Mission, had supplied the physical properties and chemical analyses of 25 heats of racer plates made by the Canadian Car & Foundry Co. Ltd., Steel Foundry Division, Montreal, Que. It is believed that these

(Introduction, cont'd) -

data give the ranges of elements in the analyses of the greater part of regular production of racer plates. On September 24, 1945, a Bofors twin mounting's cast steel racer plate was received for experimental purposes. The analysis of the racer plate revealed a carbon content in excess of the range referred to above. In view of this, a second plate with a carbon content on the low side of the range was requested to permit experiments in flame-hardening a plate representative of the material of this kind.

Object of Investigation:

(1) To determine what flame-hardening procedures are necessary to develop the required hardnesses.

(2) To assess the practicability of the flame-hardening process as applied to naval gun racer plates of the type and analyses submitted for experimental work.

PROCEDURE:

(1). A chemical analysis was made of both racer plates, along the race surfaces. Table I, below, lists the analyses obtained and, for comparison, the ranges of elements extracted from the reports of racer plate production. In the remainder of this report the racer plates will be referred to as Racer Plates Nos. 1 and 2, as indicated in this table.

TABLE I.

	Ranges from Reports	Plate No. 1	Plate No. 2.
	- Per Cent -		
Carbon	0.22-0.33	0.35	0.26
Phosphorus	0.010-0.032	0.022	0.007
Sulphur	0.029-0.036	0.030	0.030
Manganese	0.65-0.85	0.59	0.65
Silicon	0.38-0.50	0.37	0.34

(Procedure, cont'd) -

Racer Plate No. 1.

(2). Racer Plate No. 1 was flame-cut into 10-inch sections, measured along the race, and all material was flame-cut away from the race. This was for convenience in handling. After cutting, all sample sections were annealed to eliminate any hardening effect from the flame-cutting operation. These samples were subsequently used for experimental runs.

(3). All flame hardening was done using a rhomboid, water-cooled flame head mounted on a 06 x 30 CM8 portable cutting machine (Dominion Oxygen Co. Ltd.). The machine is mounted on rails and its speed of travel, forward or backward, can be adjusted to any desired rate from 2 to 48 inches per minute. A water-spray quenching attachment was made and affixed to the back of the flame head so that the water spray struck the racer surface 1¼ inches behind the last row of flames. The quenching attachment was adjusted so that the orifices were ½ inch above the racer surface. The water pressure to the spray quench could be adjusted by means of a valve and the delivery pressure read on a water-pressure gauge in the line.

Figure 1 shows the equipment in operation and the general arrangement of the apparatus. The curve of the racer surface was followed by hand movement of the head in a lateral direction. Figure 2 shows the rhomboid flame head with 30 jets, drill size #56, available. For the work on the racer plates 10 jets were blocked off, the remainder giving complete flame coverage to the racer surface to within ½ inch of the sides. The position of the head at all times was such that the inner cones of the flames were 3/16 inch from the surface of the racer.

Figure 3 shows the spray quench attachment. This was made from brass pipe 1" I.D. capped at both ends. All

(Procedure, cont'd) -

drill holes were made with a #56 drill. Drill holes are 1/8 inch apart at their centres and the two rows, 2½ inches in length, are staggered to provide complete surface coverage. When the attachment is in use the two rows of holes are at an angle of 60° to the surface of the racer so that the water is propelled backwards and away from the flames. This arrangement, without the third row of holes, was tried first and found to be unsatisfactory in that the water impinged on the race surface 2½ inches behind the last row of flames. This permitted too great a drop in temperature of the racer surface from the time the flames passed a given point until the water spray reached the same point. The third row of holes was drilled so that the spray jets struck the surface at right angles and 1¼ inches behind the last row of flames. This was found to be satisfactory.

A preliminary run was made to establish the proper position of the flame head and spray quench. This piece was scrapped. Five more runs were made under the conditions laid down in the table below:

TABLE II. - Plate No. 1 Conditions.

Test No.	Acetylene Pressure, pounds	Oxygen Pressure, pounds	Water Quench Pressure, pounds	Speed of Travel, inches per minute
2	9[Φ]	5	1	3½
3	9[Φ]	8	1	4½
4	9	10	1	6
5	13[Φ]	12	1	8
6	13[Φ]	12	1	7

[Φ] Gauge reading at acetylene manifold. This pressure was reduced at the flame head to just secure a neutral flame. Oxygen pressures are those delivered to flame head without reduction by the flame head valve.

When operating at low gas pressures there is a tendency to "blowback" due to the regulators not holding a constant delivery pressure. This can be overcome by operating

(Procedure, cont'd) -

at higher pressures at which the regulators are capable of holding pressures constant and reducing the pressures delivered to the jets, by means of the valves on the flame head. A limit to the use of higher pressure to counteract increased speed of travel is imposed by the tendency of the gases to burn away from the tips due to their high velocity. This makes impossible precise control of the distance from end of cone to racer surface. The pressures used in Runs Nos. 5 and 6 are at the top limit for the apparatus used.

(4). After flame hardening, each section was cut through the centre and a ¼-inch-thick sample was removed. These samples were polished and etched and are shown in Figure 4.

(5). All samples were roughly checked for hardness of case by means of a Rockwell machine. The table below lists the results in Rockwell "C" readings:

TABLE III. - Hardness.

Test No.	Case, Rockwell "C"	Transition Zone, Rockwell "C"	Parent Metal, Brinell
2	45-51	20-40	180
3	50-53	20-42	"
4	48-53	20-38	"
5	50-52	20-39	"
6	49-51	18-38	"

(6). Small samples from each test were mounted, polished, and examined under the microscope. Figure 5 shows the typical structure of the annealed racer plate material. Figure 6 shows the typical transition zone structure where partial transformation has taken place. Figures 7 to 11 show the structures of the fully hardened zones of Samples 2 to 6 respectively.

(Procedure, cont'd) -

(7). All samples were subjected to a hardness traverse, using a Vickers machine and a 30-kilogram load. Distances of impressions from the hardened surface were measured with a Brinell microscope and converted to inches. The table below lists the results secured:

TABLE IV.

Vickers Hardness No.	Distance from hardened surface, inches.	Vickers Hardness No.	Distance from hardened surface, inches
Sample No. 2.			
635	0.0157	441	0.177
660	0.0354	385	0.208
626	0.0617	287	0.238
614	0.0856	200	0.268
543	0.118	180	0.311
499	0.145	180	0.350
Sample No. 3.			
652	0.0216	422	0.183
652	0.0472	326	0.214
614	0.0747	264	0.246
598	0.0995	212	0.279
550	0.122	190	0.350
467	0.155		
Sample No. 4.			
660	0.0197	406	0.150
644	0.0472	280	0.179
610	0.0715	191	0.211
517	0.0971	193	0.248
462	0.122		
Sample No. 5.			
583	0.0157	418	0.115
635	0.0373	200	0.150
561	0.0629	194	0.188
499	0.0905	187	0.222
Sample No. 6.			
594	0.0197	187	0.106
470	0.0453	187	0.138
333	0.0759		

Figure 12 shows the information of the above tables, in graph form.

(Procedure, cont'd) -

(8). Samples of each section were drawn at 500° F., 600° F., and 700° F. After drawing, the samples were subjected to a hardness traverse, using a Vickers machine and a 30-kilogram load. Distances of impressions from the flame-hardened surface ('d' in the table below) were measured with a Brinell microscope and converted to inches. Table V, below, lists the results secured. Samples from Tests Nos. 2, 3 and 4 only were used, since the microstructures and depth of hardness of the remainder of the runs were unsatisfactory.

TABLE V.

Test No. 2.		Test No. 3.		Test No. 4.	
Vickers Hardness No.	d, inches	Vickers Hardness No.	d, inches	Vickers Hardness No.	d, inches
Samples Drawn at 500° F.:					
554	0.0216	520	0.0179	530	0.0157
550	0.0460	505	0.0413	520	0.0373
540	0.0728	467	0.0630	550	0.0630
473	0.0982	449	0.0885	505	0.0905
462	0.126	387	0.112	467	0.117
393	0.157	387	0.138	358	0.138
282	0.189	329	0.161	298	0.157
197	0.230	324	0.187	185	0.193
180	0.266	287	0.216		
		216	0.248		
		187	0.280		
Samples Drawn at 600° F.:					
511	0.0196	444	0.0157	465	0.0157
511	0.0432	467	0.0452	496	0.0460
502	0.0660	449	0.0740	496	0.0766
478	0.0900	396	0.104	476	0.112
454	0.110	344	0.137	351	0.153
439	0.135	314	0.163	196	0.198
383	0.162	261	0.203	181	0.235
277	0.208	186	0.256		
181	0.252				
Samples Drawn at 700° F.:					
459	0.0157	427	0.0118	476	0.0157
441	0.0354	444	0.0397	470	0.0472
459	0.0590	427	0.0670	462	0.0670
449	0.0825	406	0.0982	434	0.0982
429	0.114	377	0.121	415	0.138
387	0.138	325	0.150	314	0.185
336	0.165	368	0.189	190	0.220
280	0.204	189	0.256		
191	0.244	181	0.275		

The data contained in the above table were put into graph form and are shown in Figures 13 and 14.

(Procedure, cont'd) -

(9). Sections of the flame-hardened, but not drawn, samples, approximately 4 inches in length and the total width of the racer surface, were subjected to crude impact tests as follows: The sample was supported on a flat anvil and struck by a 50-pound weight falling through a distance of 8 feet. The area of impact was approximately 0.05 square inch, so that the impact was in the order of 8,000 foot pounds per square inch. Each sample was subjected to three blows and examined for cracks between each blow. No cracks were detected.

(10). After impact tests, the samples were magnafluxed and again examined for cracks. No cracks were found. Surface indentations at the area of impact indicated good shock-absorbing properties.

-

Racer Plate No. 2.

(11). Sections of the race were removed by flame cutting from the castings. These sections were then annealed to eliminate any hardening effect due to the flame-cutting operation. These sections were subsequently used for flame-hardening experiments. The following table lists the conditions for the various samples:

TABLE VI.

Test No.	Acetylene Pressure, pounds	Oxygen Pressure, pounds	Water Quench Pressure, pounds	Speed of Travel, inches per minute	Comments
7	10⊕	8	½	4	End of cones 1/8 inch above surface.
8	10⊕	8	½	5	" " "
9	10⊕	8	1	6	" " "
10	12⊕	10	1	7	End of cones 3/16 inch above surface.

⊕ Gauge reading at acetylene manifold. This pressure reduced at flame head to just secure a neutral flame. Oxygen pressures are those delivered to flame head without reduction by the flame head valve.

(Procedure, cont'd) -

(12). The remaining steps of the procedure are precisely the same as for Racer Plate No. 1. For the sake of brevity these steps will not be described in detail.

Figure 15 shows transverse sections of Tests Nos. 7 to 10 inclusive, after polishing and etching.

Figure 16 shows the typical structure of the annealed racer plate material.

Figure 17 shows the typical structure of all transition zones.

Figures 18 to 21 show the structures of the hardened case of Tests Nos. 7 to 10 respectively.

Hardness traverses, using a Vickers machine and a 30-kilogram load, were run on as-quenched samples. Table IX, below, lists the results secured:

TABLE IX. - 'As Quenched' Samples.

SAMPLE NO. 7.		SAMPLE NO. 8.	
Vickers Hardness No.	d, inches	Vickers Hardness No.	d, inches
490	0.0157	434	0.0157
511	0.0433	444	0.0511
502	0.0708	404	0.0826
493	0.0945	320	0.114
427	0.122	252	0.181
362	0.165	184	0.279
228	0.260		
184	0.330		
165	0.405		

SAMPLE NO. 9.		SAMPLE NO. 10.	
467	0.0315	413	0.0118
364	0.0670	434	0.0433
308	0.106	308	0.0865
234	0.149	254	0.134
168	0.200	160	0.200

The data in the above tables are shown in graph form in Figure 22.

Samples were drawn at 500° F. and subjected to hard-

(Procedure, cont'd) -

ness tests as above. Table X, lists the results secured. Figure 23 shows the data in the table in graph form.

TABLE X. - Drawn Samples.

SAMPLE NO. 7.		SAMPLE NO. 8.	
Vickers Hardness No.	d, inches	Vickers Hardness No.	d, inches
406	0.0157	328	0.0118
434	0.0472	427	0.0475
409	0.0708	353	0.0825
362	0.104	260	0.138
298	0.145	183	0.197
351	0.212		
216	0.283		
160	0.354		

SAMPLE NO. 9.		SAMPLE NO. 10.	
339	0.0157	409	0.0157
355	0.0475	404	0.0475
227	0.106	336	0.0787
160	0.165	268	0.126
		198	0.173
		160	0.224

Sections of these samples were subjected to rough impact tests in the same manner as Racer Plate No. 1. After impact tests the sections were magnafluxed, but no cracks were detected.

DISCUSSION:

The analysis of Racer Plate No. 1 reveals a carbon content slightly higher, and a manganese content slightly lower, than that noted in the test reports submitted. The remainder of the analysis shows nothing unusual.

Racer Plate No. 1 -

This racer plate may be considered to be representative of those plates on the high side of the analysis range.

It can be shown that, with regard to the top surface, almost the full potential hardness of the steel is developed in Samples 2 to 5 inclusive. With the apparatus used, (Discussion, Racer Plate No. 1, cont'd) -

increasing gas pressures only partially offsets the increase in speed of travel. Since the desired thickness of hardened case (1/8 to 3/16 inch) cannot be obtained at speeds over 6 inches per minute, the effects of decrease of hardness with increasing drawing temperature were confined to Samples 2 to 4, inclusive.

It should be pointed out that all flame-hardened material which is to be used where service conditions involve impact must be stress-relieved at a minimum temperature of 500° F. There is danger that if this is not done the highly stressed hardened surface may crack and spall. As previously noted, the as-quenched hardness of Samples 2 to 4 is in the order of 550 Brinell and at a distance of 0.15 inch from the surface is still in the order of 400 Brinell. After drawing at 500° F. the surface hardness has decreased to approximately 500 Brinell; the hardness at 0.15 inch from the surface ranges between approximately 350-400 Brinell. These latter figures, then, indicate the maximum degree of surface and sub-surface hardness obtainable where the service life is to involve impact.

The effect of drawing Samples 2 to 4 at temperatures of 600° F. and 700° F. is a steady reduction in hardness all over the hardened zone. At the latter temperature the hardness has dropped, at the surface, to approximately 415 Brinell and, at 0.15 inch, to approximately 350 Brinell. The figures represent a considerable increase in hardness above that of the annealed casting (180 Brinell). It is, of course, apparent that any desired surface hardness, below that 'as quenched', can be obtained by selection of the proper drawing temperature. The purpose of the experiments herein reported was to determine the method which would develop the maximum possible hardness. The selection of proper drawing temperature for a racer plate to be put into service would be determined by the hardness of the rollers, their wear resistance, etc. The decision should properly be left to those familiar with naval gun design and service conditions.

The microscopic examination of Samples 2 to 6 reveals the effects of a combination of (a) gradually reducing severity of quench and (b) decreasing time at the austenitizing temperature. In each sample the surface layers contain martensite. As the speed increases the martensite becomes progressively finer as the critical cooling rate is approached, until in Samples 5 and 6 (Figures 10 and 11) ferrite is found even in the surface layers. This ferrite may be the result of either too short a time at the austenitizing temperature and/or too slow a quench. The presence of ferrite in the case means that the steel is not fully 'quenched out'.

It should be stated that in nearly every sample there was evidence of surface decarburization close to the race surface. The effect of the low carbon skin on hardness readings may be seen on some of the graphs where the first reading close to the surface is lower than the second further from the surface. The ferrite in the hardened case is well below the decarburized area and is definitely the result of incomplete solution. The presence of ferrite in the case cannot be tolerated due to non-uniform hardness and excessive wear in soft spots. Where fatigue is a factor, ferrite is undesirable since cracks will form in this weak constituent at a much lower stress than in the surrounding martensite.

In very short cycle heat treating operations the effect of prior metallographic structure is quite marked. Greater hardness and greater depth of hardness will result from prior structures, such as sorbite, in which the distribution of carbide and ferrite is more even. However, this type of structure is available only from quenching and drawing operations. The annealed structure used in this experiment is more sluggish in going into solution, but this can be overcome to a great extent by increasing the maximum temperature. It is for this reason that ferrite appears in the hardened zones at the higher rates of speed of travel as the maximum temperature attained decreases. It should be borne in mind also that the decreasing severity of quench at the higher speeds is probably accentuating this effect.

The impact tests, while admittedly crude, would, it is believed, have revealed any undue sensitivity to cracking under shock. As-quenched material was purposely used for this test in order to obtain the worst possible conditions. The failure to detect cracks, either by visual examination or by magnaflux, and the surface indentations at the area of impact both indicate that the material, even in the as-quenched condition, has fair shock-absorbing properties. Unfortunately, it is impossible to duplicate, under laboratory conditions, the impact resulting from the discharge of the gun.

(Discussion, cont'd) -

Racer Plate No. 2 -

This racer plate may be considered to be representative of those plates on the low side of the analysis range.

In this case the lower speeds of travel result in development of virtually the full potential hardness of the steel. Sample 10 shows that in this case also the effect of increasing speed of travel can be partially offset by increasing gas pressures. Naturally the lower hardenability of the plate necessarily precludes securing the high level of hardnesses of Racer Plate No. 1. However, a useful increase in hardness from the surface to a depth of 0.15 inch can be obtained. The hardness patterns obtained with Samples 9 and 10 are such as to make their value doubtful. The following remarks apply only to Samples Nos. 7 and 8.

With this plate also, a stress-relieving treatment at 500° F. would be necessary. A maximum as-quenched hardness in the order of 415-460 Brinell was obtained with a hardness at a depth of 0.15 inch in the range of 277-363 Brinell. After drawing at 500° F., the surface hardness decreased to approximately 415 Brinell; the hardness at 0.15 inch from the surface, to a range of 240-300 Brinell. These last figures, then, indicate the maximum hardness obtainable over the hardened area in the condition in which the plate could be put into service.

It was considered that drawing these samples at successively higher temperatures would result in too great a drop in hardness and thereby defeat the purpose of flame hardening. However, the increase in hardness over that of the annealed casting (160 Brinell) is considerable and should prove to be of value in this application. In this case also, it is suggested the selection of the proper surface hardness should be made by those familiar with design and service conditions.

As in Racer Plate No. 1, the microscopic examination of Samples 7 to 10 reveals the effects of gradually reducing severity of quench and decreasing time at the austenitizing temperature as the speed of travel increases. In each sample the surface layers contain martensite. As the speed of travel increases the martensite becomes progressively finer as the time at austenitizing temperature decreases and the critical cooling rate is approached. Sample 9 shows ferrite in the case, which may be the result of too short a time at the austenitizing temperature and/or too slow a quench. Sample 10 shows that increasing the gas pressures has reversed this trend and the case is fully martensitic again. The presence of ferrite in the case of Sample 9, and the shallow depth of penetration of Sample 10, eliminate these two samples from further consideration.

It should be pointed out that the greater apparent depth of heat penetration shown in the lower-carbon material (Figure 15) as compared to that of the higher-carbon material (Figure 4) is due to the greater range of temperature between the upper and lower critical points as the carbon content decreases. This means that a relatively greater volume of metal will be heated to within

(Discussion, Racer Plate No. 2, cont'd) -

the temperature ranges in which partial transformation takes place. Small additions of alloys would increase depth of total hardening.

Impact tests, as with Racer Plate No. 1, indicate good shock-absorbing properties even in the 'as-quenched' condition.

General -

It has been shown that plates of both high and low analysis can be flame-hardened to give valuable increases in hardness, above that of the annealed casting, with speeds of travel between 2½ and 5 inches per minute. It cannot be stressed too highly that this limitation on speed of travel applies only to the apparatus used in these experiments. It is most probable that a wider flame head, using larger-sized jets and higher gas pressures, could increase both the depth of total hardening (if this is deemed desirable) and the speed of travel. This would necessarily be accompanied by a change of quench fixture design to yield an increase in the severity of the quench. These changes, or the use of equipment differing from that used in these experiments, would entail a set of experiments to determine speeds of travel, depth of complete hardening, etc., necessary to give the desired results. This being the case, as previously pointed out these experiments provide only the basic knowledge that flame hardening can be performed on racer plates, in that the response of the material to the thermal cycle is satisfactory.

Irrespective of the apparatus used, standardization on any flame-hardening technique on material having such a wide range of analysis would require knowledge of the analysis of each individual plate in order to select the proper drawing temperature to give the desired level of hardness. Should other conditions permit, this could be eliminated and a standardized flame-hardening technique and standardized drawing temperature could be used, if the carbon range were restricted to 0.30-0.40 per cent and the manganese range to 0.65-0.85 per cent. It is realized, however, that other considerations might make this impossible.

Racer plates should be normalized or annealed before flame hardening to reduce or eliminate casting stresses. This should permit flame hardening with virtually no distortion. This last statement, however, is an expression of opinion, as these experiments on small samples could not provide conclusive evidence.

CONCLUSIONS:

1. Two racer plates representative of the high and low extremes of the analysis ranges have been satisfactorily flame-hardened.

2. The plate representative of the high side of the range had, after drawing at 500° F., a surface hardness of approximately 500 Brinell, and 350-400 Brinell at a depth of 0.15 inch. By drawing at 700° F., a hardness at the surface of approximately 415 Brinell, and, at a depth of 0.15 inch, 350 Brinell, can be obtained.

(Conclusions, cont'd) -

3. The plate representative of the low side of the range had, after drawing at 500° F., a surface hardness of approximately 415 Brinell and, at a depth of 0.15 inch, a hardness range of 240-300 Brinell. Lower hardnesses, obtainable at higher drawing temperatures, are considered to be too low for this application.

4. On both plates, speeds of travel in excess of 5 to 6 inches per minute result in ferrite in the hardened case, and/or too low heat penetration. The reduction in heat penetration can only be partially offset by increasing gas pressures.

5. Rough impact tests on as-quenched material from both plates indicate fair shock-absorbing properties.

6. The limitations on speed of travel reported herein apply only to the apparatus used in these experiments. Larger gas jets, higher gas pressures, etc., would permit higher speeds of travel with satisfactory results.

7. The use of apparatus of different design would require a series of experiments, similar to those reported above, to determine the optimum operation conditions.

8. With material of such wide analysis ranges, standardization of flame-hardening technique is possible but standardization of drawing temperatures cannot be used. A knowledge of the analysis of each individual racer plate would be necessary in order to select the proper drawing temperature to yield the desired surface

(Conclusions, cont'd) -

and subsurface hardness.

Recommendations:

1. All castings should be normalized or annealed prior to flame hardening. This should permit of flame hardening with virtually no distortion, since casting stresses would be either eliminated or greatly reduced. It is immaterial when the heat treatment is carried out prior to flame hardening. An experiment designed to detect distortion on a complete racer plate might be desirable in view of the importance of maintenance of dimensions to a high degree of accuracy.

2. Standardization of flame-hardening technique and drawing temperatures would be possible if the carbon content were restricted to 0.35-0.40 per cent and the manganese content to 0.65-0.85 per cent.

Acknowledgment:

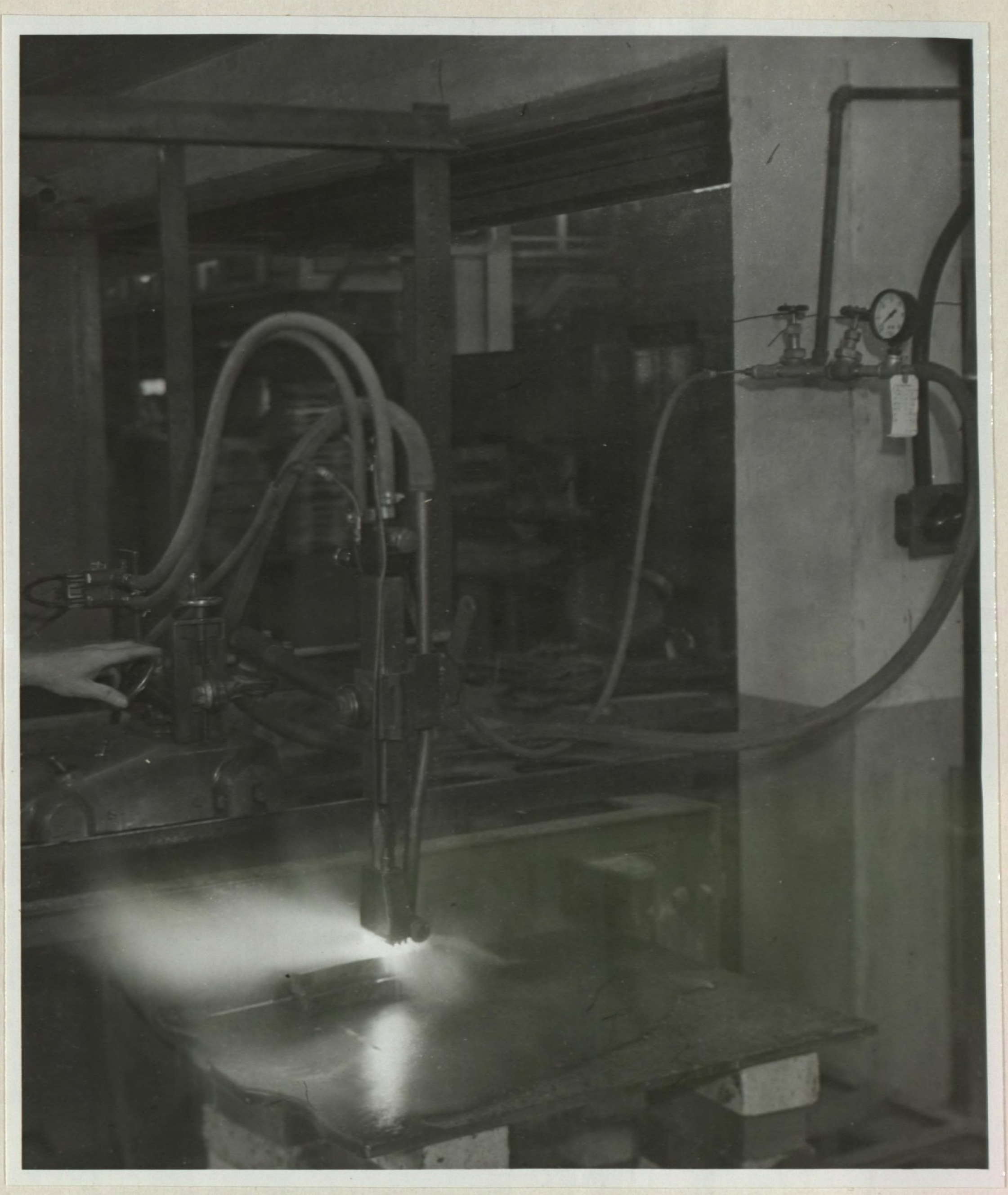
It is a pleasure to acknowledge the very kind co-operation of the Dominion Oxygen Company Limited. This company made available the services of Mr. O. W. Graham for the setting-up and operation of the flame-hardening apparatus.

oooooooooooo
oooooooo
oo

HJN:LB.

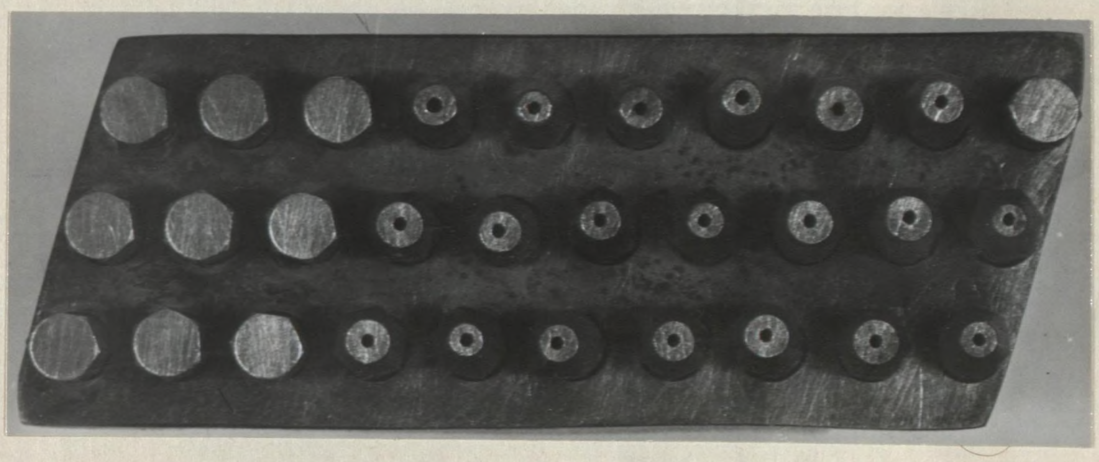
(Figures 1 to 23 follow,)
(Pages 20 to 35.)

Figure 1.



GENERAL VIEW OF APPARATUS IN OPERATION.

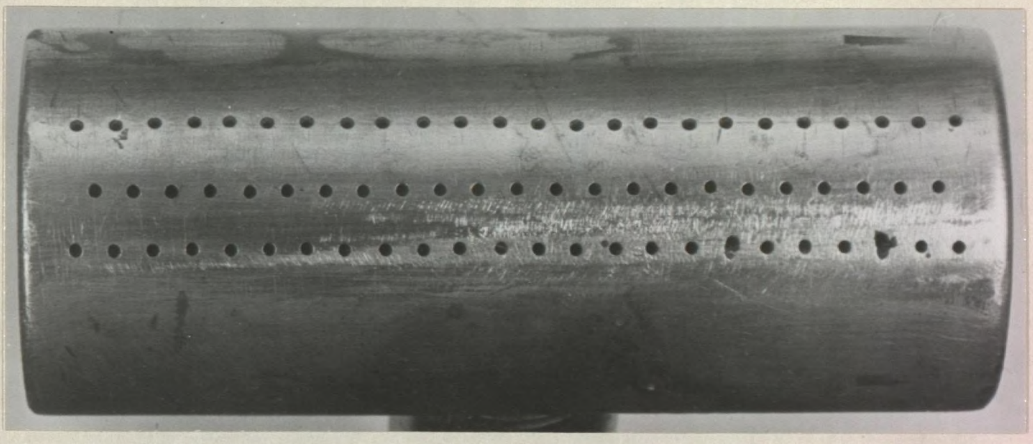
Figure 2.



FLAME HEAD WITH 30 JETS
(WITH 10 JETS BLOCKED OFF).

Jet size that of #56 drill. Note staggered arrangement of jets.

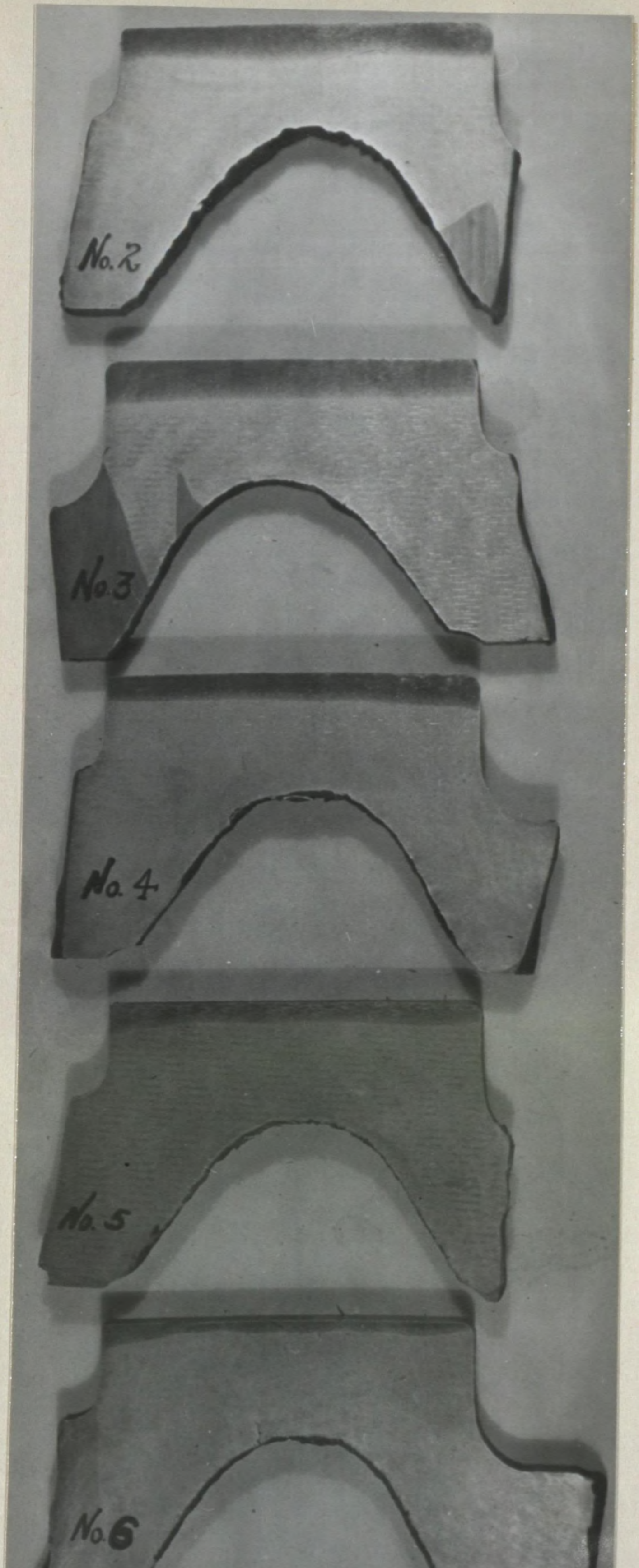
Figure 3.



WATER-QUENCHING FIXTURE SHOWING
3 ROWS OF STAGGERED HOLES.

Hole size is that of a #56 drill.

Figure 4.

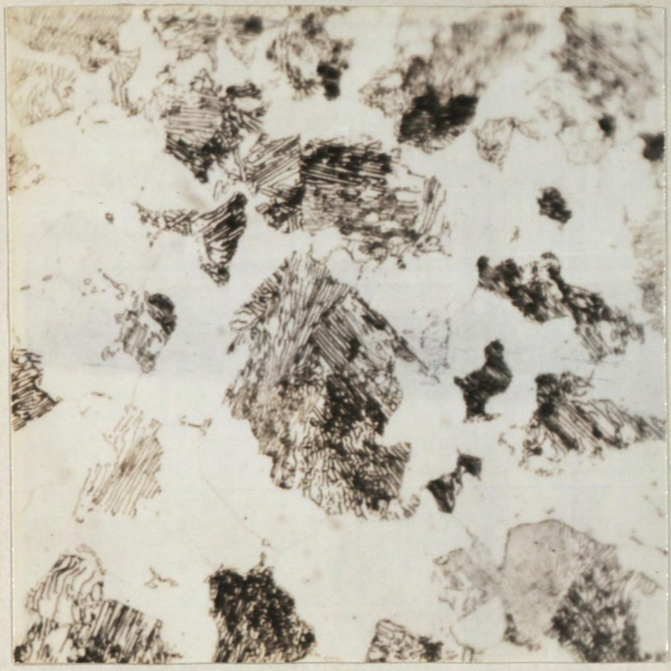


Etched with 10 per cent ammonium persulphate solution.

TRANSVERSE SECTIONS OF FLAME-HARDENED SAMPLES OF RACER PLATE NO. 1.

Note depth of penetration of heat.

Figure 5.

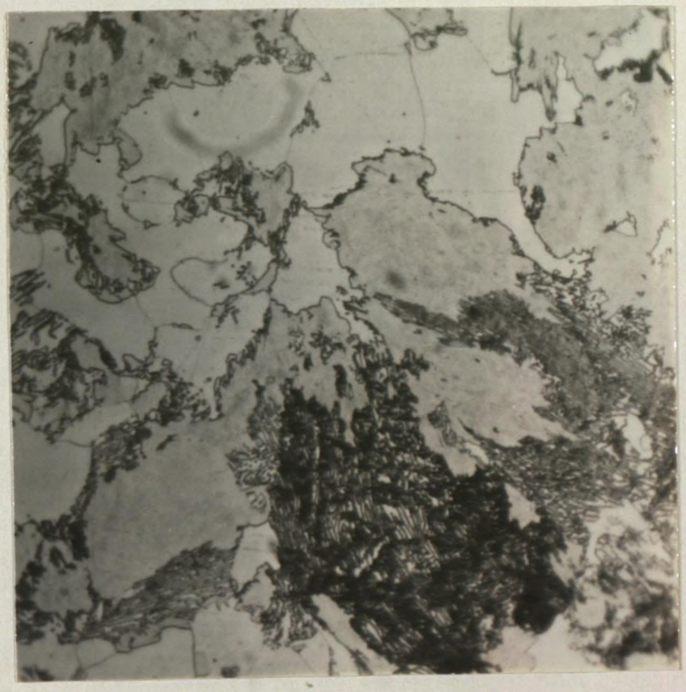


X1000, etched in
2 per cent nital.

TYPICAL STRUCTURE OF ANNEALED RACER PLATE NO. 1.

Pearlite in a matrix of ferrite.

Figure 6.



X1000, etched in
2 per cent nital.

TYPICAL STRUCTURE OF ALL TRANSITION ZONES.

Martensite (light grey), partially transformed pearlite (darker grey), untransformed pearlite, and ferrite (white).

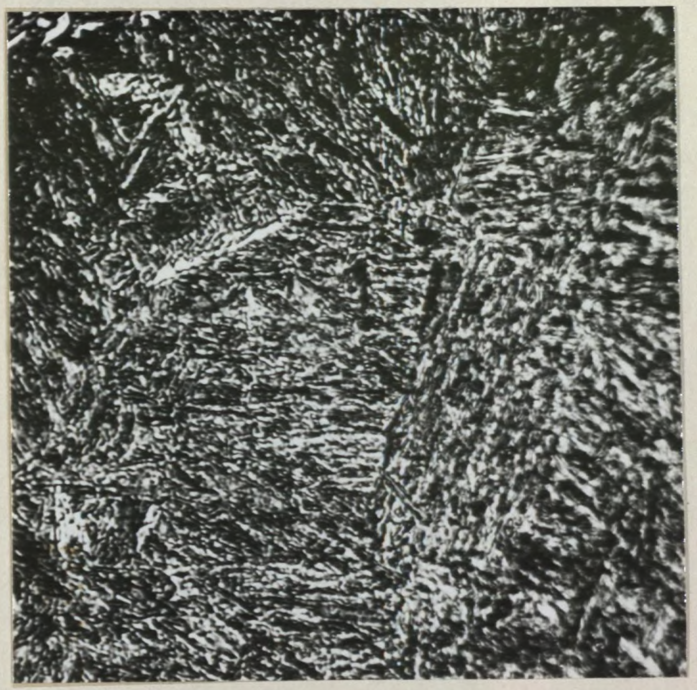
Figure 7.

X1000, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF HARDENED CASE
OF SAMPLE NO. 2.

-

Figure 8.



X1000, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF HARDENED CASE
OF SAMPLE NO. 3.

-

Figure 9.

X1000, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF HARDENED CASE
OF SAMPLE NO. 4.

-

Figure 10.

X1000, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF HARDENED CASE
OF SAMPLE NO. 5.

Note white areas - undissolved ferrite.

-

Figure 11.

X1000, etched in
2 per cent nital.

STRUCTURE OF HARDENED CASE
OF SAMPLE NO. 6.

Martensite with some undissolved ferrite.

(Figures 12, 13 and)
(14, charts, comprise)
(Pages 27, 28 and 29.)

FIGURE 12
VICKERS HARDNESS NOS: DISTANCE FROM SURFACE

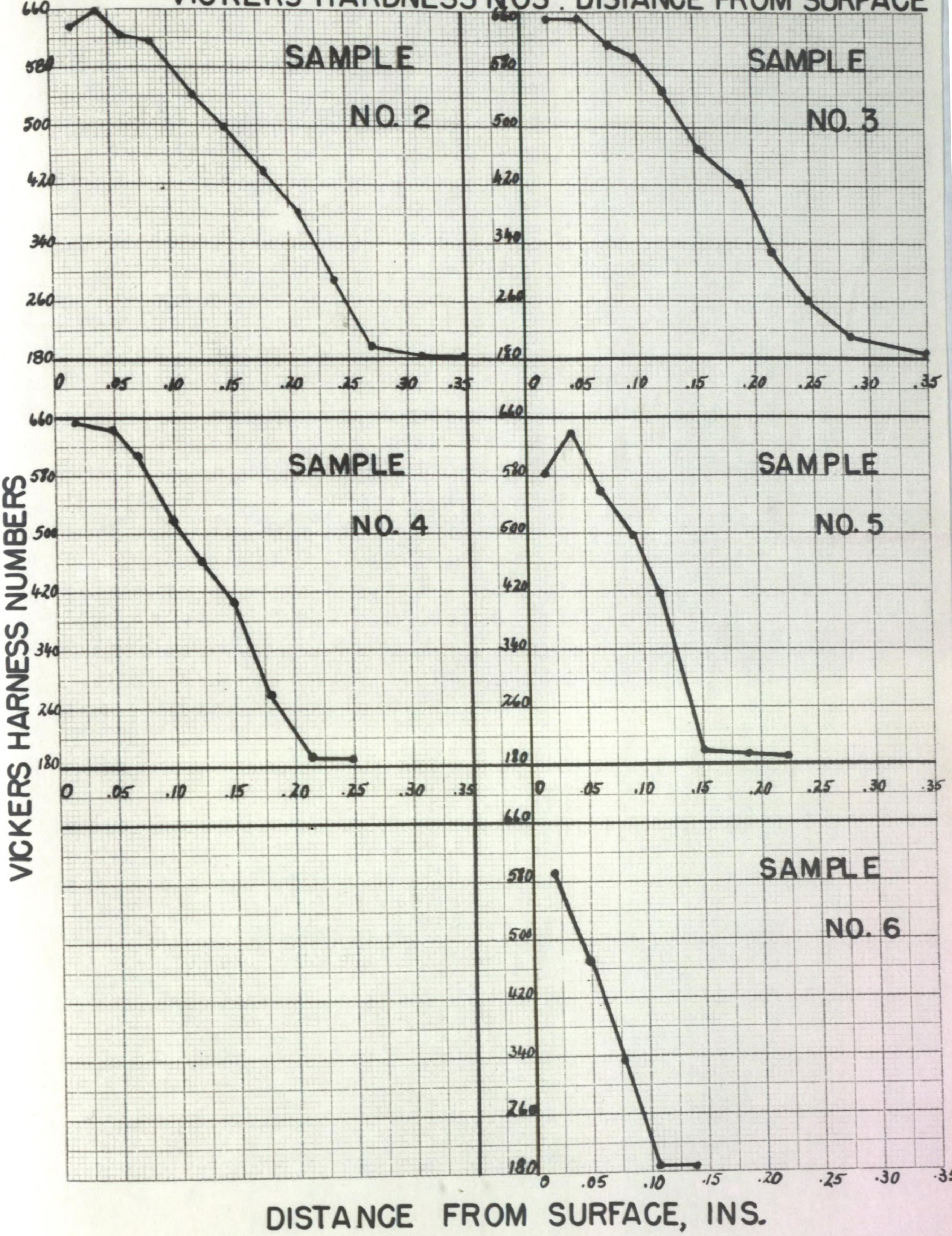


FIGURE 13
VICKERS HARDNESS NOS.:DISTANCE FROM SURFACE

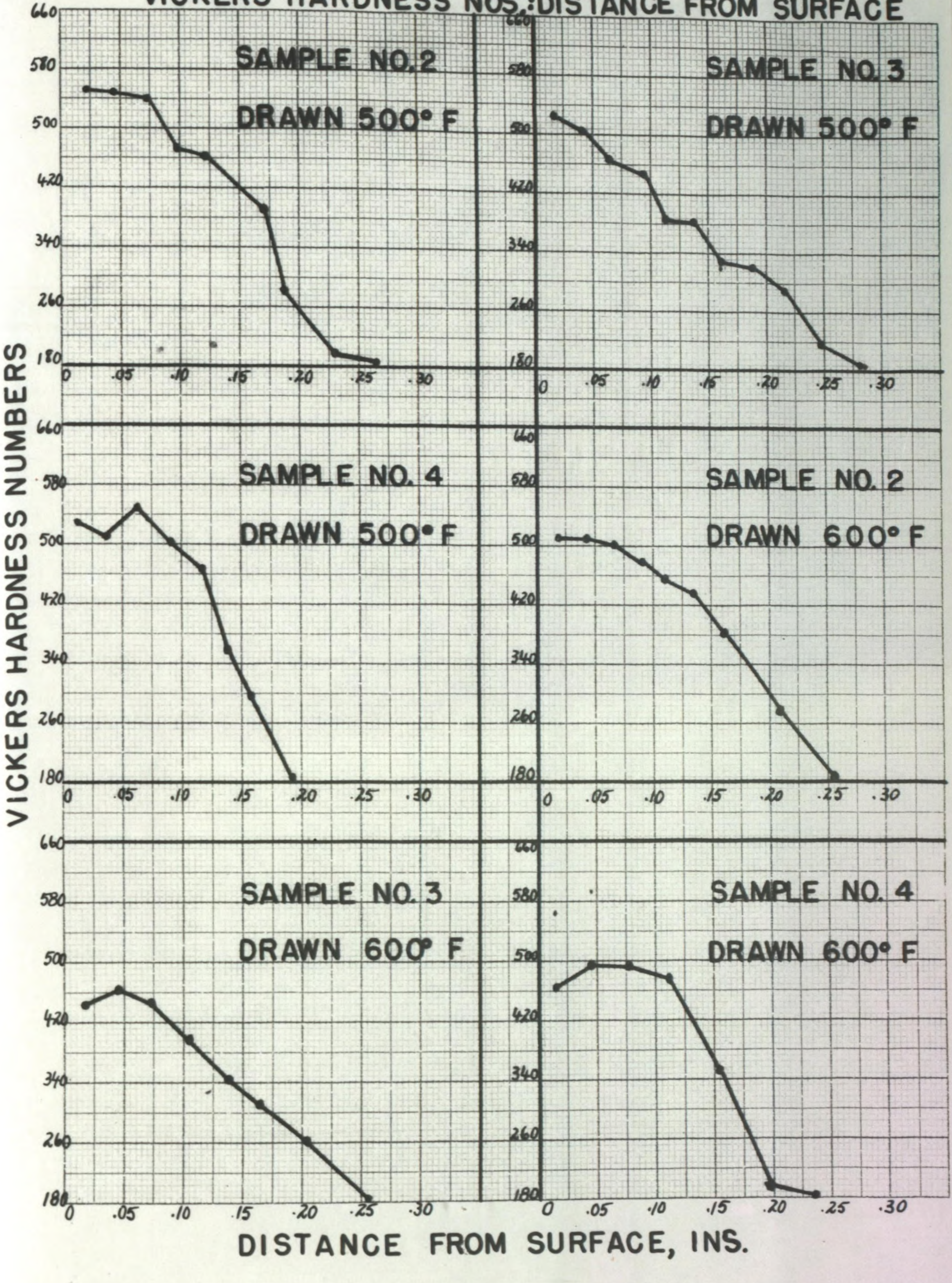


FIGURE 14
VICKERS HARDNESS NOS.: DISTANCE FROM SURFACE

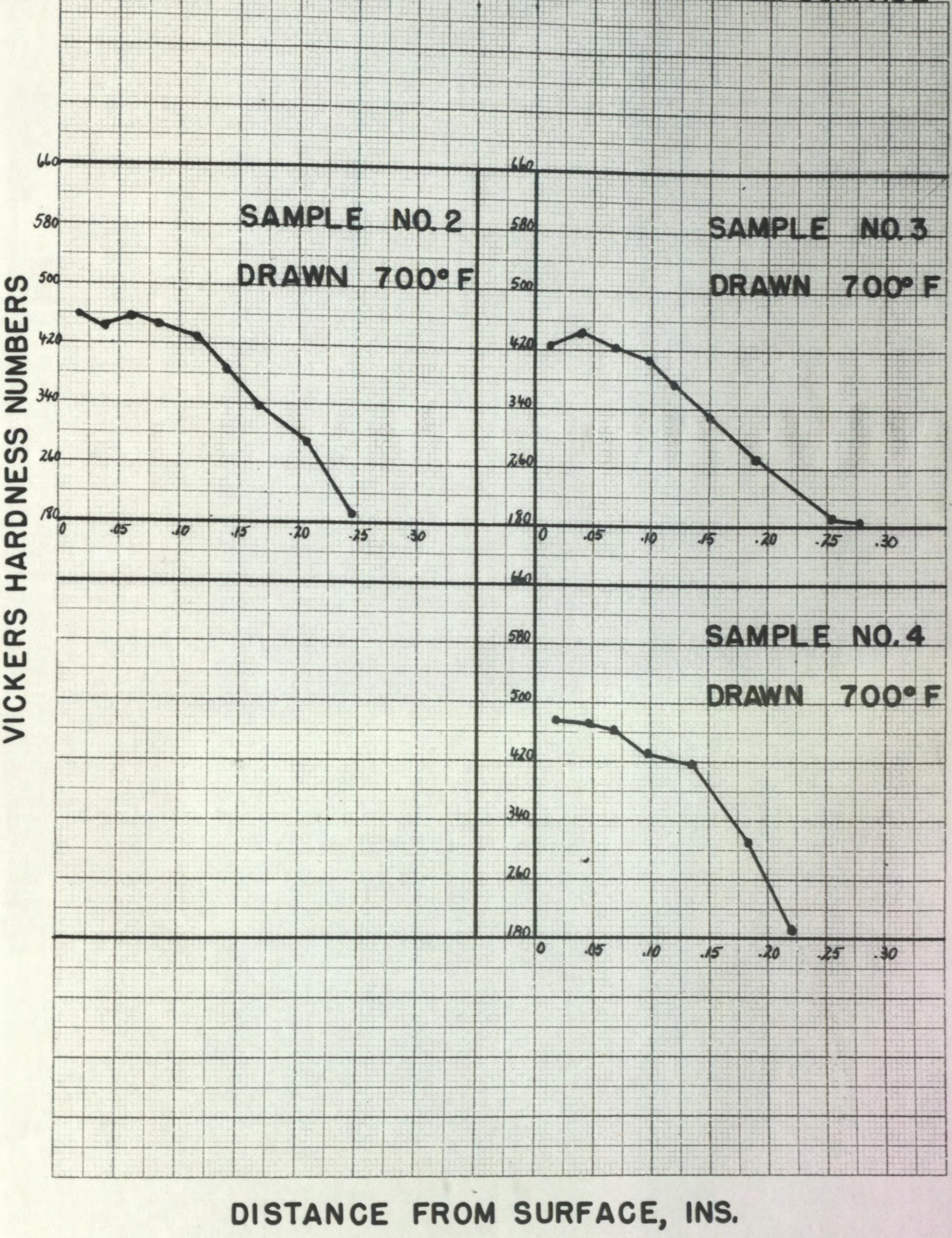
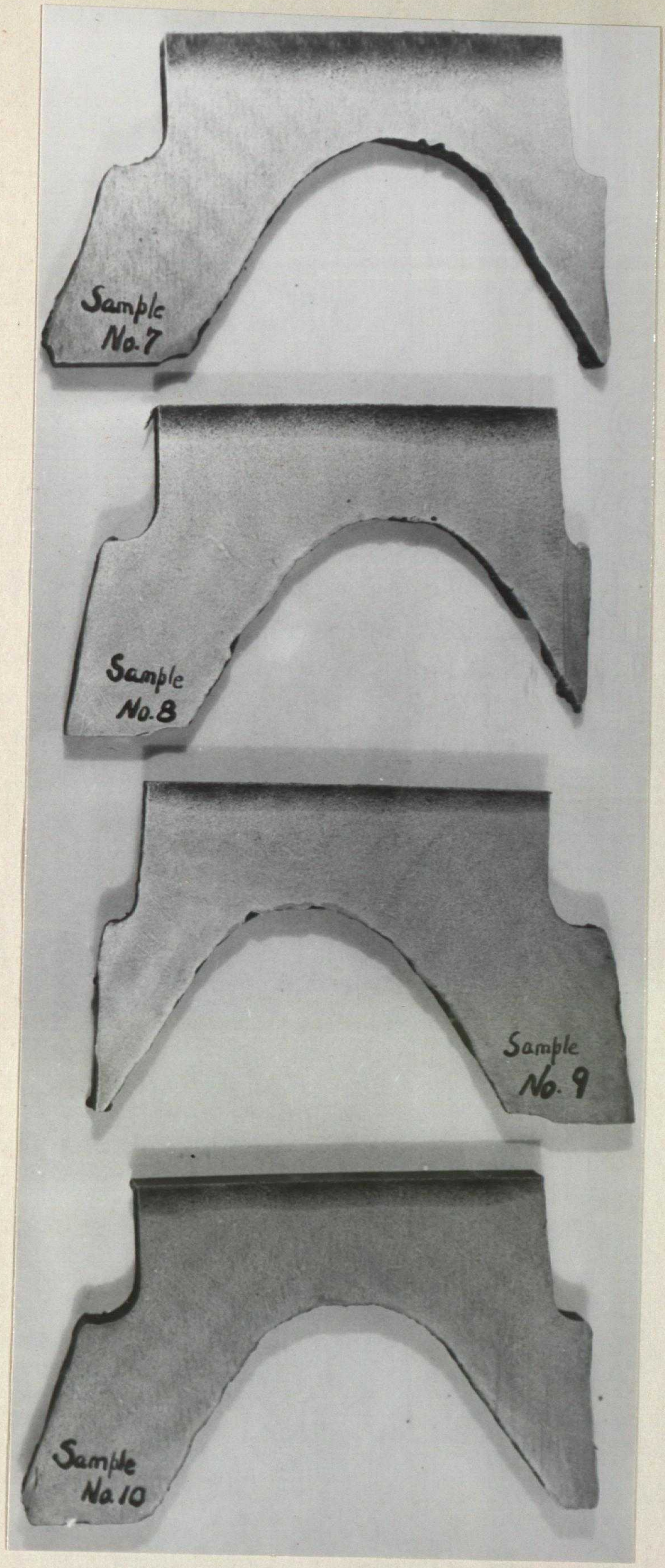


Figure 15.

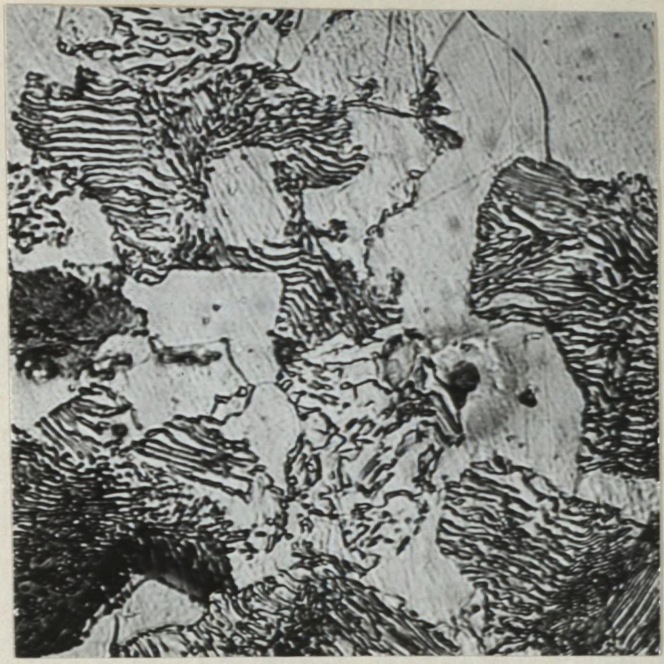


Etched in 10 per cent
ammonium persulphate solution.

TRANSVERSE SECTIONS OF FLAME-HARDENED SAMPLES
OF RACER PLATE NO. 2.

Note depth of penetration of heat.

Figure 16.



X1000, etched in
2 per cent nital.

TYPICAL STRUCTURE OF ANNEALED RACER PLATE NO. 2.

Pearlite in a matrix of ferrite.

-

Figure 17.

X1000, etched in
2 per cent nital.

TYPICAL STRUCTURE OF ALL TRANSITION ZONES.

Martensite (light grey), fine pearlite
(dark areas), and ferrite (white).

-

Figure 18.

X1000, etched in
2 per cent nital.

COARSE MARTENSITIC STRUCTURE OF SAMPLE NO. 7.

Figure 19.

X1000, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF SAMPLE NO. 8.

Figure 20.

X1000, etched in
2 per cent nital.

STRUCTURE OF HARDENED CASE OF SAMPLE NO. 9.

Martensite and some undissolved ferrite.

Figure 21.

X1000, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF HARDENED CASE
OF SAMPLE NO. 10.

= = = = = = =

HJN:LB.

(Figures 22 and 23,)
(charts, comprise)
(Pages 34 and 35.)

FIGURE 22
VICKERS HARDNESS NOS: DISTANCE FROM SURFACE

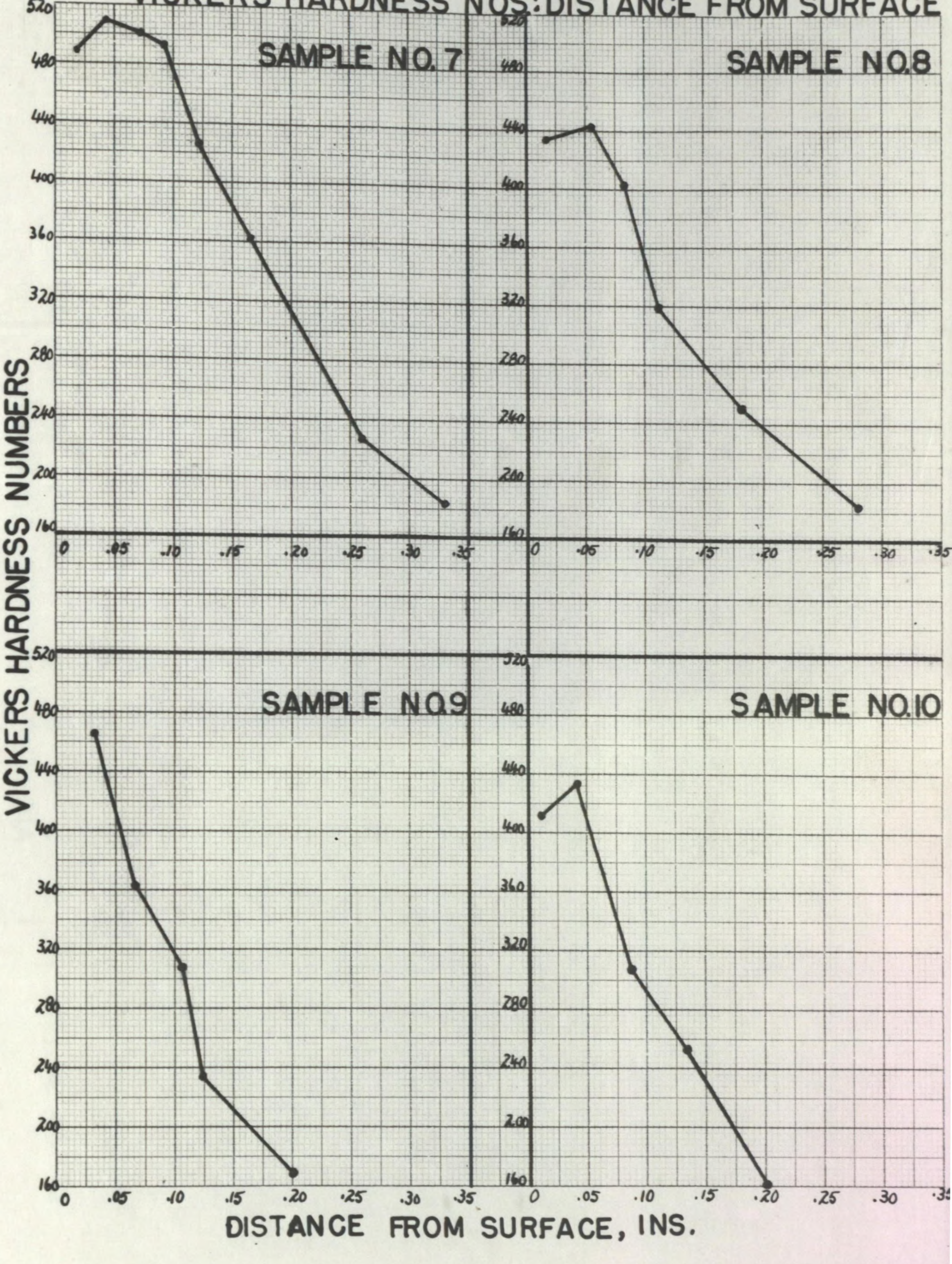


FIGURE 23
VICKERS HARDNESS NOS.: DISTANCE FROM SURFACE