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O T T A W A April 13th, 1944.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1612.

An Investigation of Some Factors Affecting the Accuracy of Brinell Hardness Readings.

(Copy No. 10.)

Abstract

Brinell hardness impressions were made on samples of 12 mm., 10 mm., 7 mm., 6 mm., 5 mm., 4 mm., and 3 mm. bullet-proof plate. Two sets of samples of each thickness of plate were prepared, one set to demonstrate the effect of removing insufficient material from the face of the plate before making the Brinell impression and the other set to show the influence of uneven surfaces on the accuracy of Brinell readings.

Two Brinell impressions were made on each specimen with an electrically powered automatic Brinell machine. The samples were then grouped in such a manner that prejudice could not affect the results and the diameters of the impressions were measured with a standard Brinell microscope by seven different individuals.

An analysis of the data obtained in this manner resulted in the following conclusions:

1. It is necessary to remove at least 0.02 inch of metal from the surface of plates whose previous history is similar to the history of these plates, to be sure that decarburization is not affecting the result.

2. When the portion of the plate on which the test is being made is not flat, the accuracy of the determination decreases.

3. While according to theory, a plate having a hardness less than 250 B.H.N. should not be expected to give accurate Brinell values when tested with a 3,000-kilogram load and a 10-mm. ball if it is less than 3.8 mm. thick, the results of these tests showed no serious discrepancy or no loss of accuracy in the hardness determination of the 3 mm. plates by the standard Brinell test.

4. The statement in (3) is true only as long as the anvil supporting the sample is harder than the sample. When the supporting anvil is softer than the sample the hardness value determined on a sample 3 mm. thick by the standard Brinell hardness test is not correct.

Bureau of Mines
Division of Metallic
Minerals.

Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

O T T A W A April 13th, 1944.

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ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1612.

An Investigation of Some Factors Affecting the Accuracy of Brinell Hardness Readings.

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Origin of Request and Object of Investigation:

The present investigation was undertaken at the request of Dr. C. W. Drury, Director of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Toronto, Ontario. This request was made on August 25th, 1943, in Requisition No. 701, Report No. 12, Test 3.

The material, identified as AEDB Lot No. 646, was forwarded to these Laboratories by the International Harvester Company of Canada Limited, Hamilton, Ontario, and consisted of one sample each of 3, 4, 5, 6, 7, 10, and 12-mm. bullet-proof plate taken from standard production. Each plate was approximately one foot square.

The object of this investigation, as outlined in the requisition, was as follows:

> "To determine hardness readings on bullet-proof plate of various thicknesses, with the object of preparing a memorandum outlining the deficiencies of standard methods of determining hardness readings."

Outline of Procedure:

There were four factors entering into the standard methods of hardness testing that it was thought might be a source of error. These are:

1. The possibility that all decarburized metal is not removed from the surface before making a hardness test.

2. The possibility that failure to obtain a perfectly flat surface might be a source of error in measuring the diameter of the impression in Brinell hardness testing.

3. The effect of using the Brinell hardness test to determine the hardness of bullet-proof plate less than 4 mm. thick.

4. The effect of the hardness of the supporting anvil on the correctness of the Brinell test on very thin steel plate.

Ten samples, 2 inches square, were obtained from each thickness of plate. These samples were divided into two groups of five each.

One set of samples was used to determine the effect of incomplete removal of the decarburized metal from the surface being tested. This set of samples consisted of five samples of each thickness of plate. 0.01 inch was removed from one of the rolled surfaces of one sample of each thickness, 0.02 inch removed from another, 0.03 inch removed from another, 0.04 inch removed from another, and 0.05 inch removed from another. This set of samples is designated as "F". A sample in this group is identified by the following code, FTt, in which

T is thickness of plate, and
t is amount removed from surface;

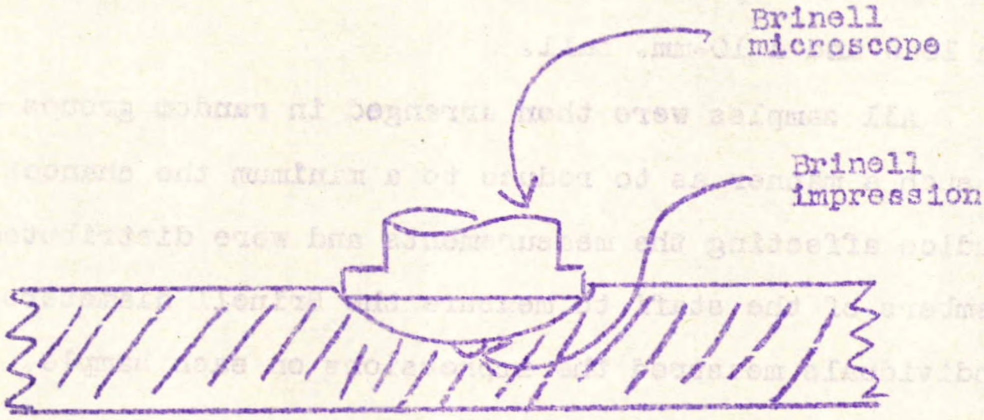
for example,

F-6-3 is the 6-mm. sample in Group "F" that has had 0.03 inch removed from one of its rolled surfaces.

The other set of samples was used to determine the amount of error introduced by not obtaining a perfectly flat surface for Brinell hardness determinations. The

(Outline of Procedure, cont'd) -

surface might be prepared by grinding a "gouge" in it, as illustrated in the sketch below:



If this is done, the base of the Brinell microscope is not on the same plane as the Brinell impression but is raised some distance above it. This increases the distance between the objective lens of the microscope and the Brinell impression, thereby throwing it out of focus.

With the standard Brinell microscope the objective cannot be adjusted, the focus of the microscope being fixed. Therefore, if the above condition exists it is not possible to compensate for it by adjusting the focus of the microscope. If the image of the Brinell impression cannot be brought into sharp focus, then it will not be possible to measure its diameter with accuracy.

This condition was simulated in this investigation by grinding grooves in one of the rolled surfaces of the remaining set of samples. These grooves were ½ inch wide and varied in depth from 0.01 to 0.05 inch for each thickness of plate. This set of samples was designated as group "G". A sample identified as G-10-4, for example, is a sample of 10-mm. plate having a groove 0.04 inch deep ground in one

(Outline of Procedure, cont'd) -

face.

Two Brinell impressions were made in each sample with the electrically powered Brinell machine using a 3,000-kilogram load and a 10-mm. ball.

All samples were then arranged in random groups of five in such a manner as to reduce to a minimum the chances of prejudice affecting the measurements and were distributed among members of the staff to measure the Brinell diameters. Seven individuals measured the impressions on each sample. The results are recorded in Table I.

TABLE I.

GROUP NUMBER	BRINELL HARDNESS NUMBERS RECORDED				STANDARD DEVIATION,	LIMIT OF ERROR OF AVERAGE,
	Maximum	Minimum	Average	Range	σ	$3\frac{\sigma}{\sqrt{n}}$
F-12-1	388	369	381	19	6.7	± 5.4
F-12-2	394	375	384	19	6.2	± 5.0
F-12-3	415	363	389	52	12.9	±10.4
F-12-4	388	369	381	19	5.9	± 4.7
F-12-5	388	341	377	47	14.4	±11.6
F-10-1	352	321	342	31	7.5	± 6.0
F-10-2	394	358	377	36	11.7	± 9.4
F-10-3	388	363	378	25	9.3	± 7.5
F-10-4	388	381	387	7	2.5	± 2.0
F-10-5	388	375	385	13	4.7	± 3.8
F-7-1	285	269	274	16	5.4	± 4.3
F-7-2	285	269	280	16	6.1	± 4.9
F-7-3	285	269	279	16	5.4	± 4.3
F-7-4	285	266	278	19	6.2	± 5.0
F-7-5	285	266	274	19	5.1	± 4.1
F-6-1	341	321	328	20	7.1	± 5.7
F-6-2	363	341	355	22	9.0	± 7.2
F-6-3	363	341	359	22	7.7	± 6.2
F-6-4	363	347	357	16	6.3	± 5.1
F-6-5	363	326	345	37	8.8	± 7.1
F-5-1	285	277	284	8	2.2	± 1.8
F-5-2	297	277	287	20	4.7	± 3.8
F-5-3	302	273	286	29	7.9	± 6.3
F-5-4	293	281	286	12	2.7	± 2.2
F-5-5	285	269	276	16	6.0	± 4.8

(Continued on next page)

(Outline of Procedure, cont'd) -

TABLE I. (Continued)

GROUP NUMBER	BRINELL HARDNESS NUMBERS RECORDED				STANDARD DEVIATION, σ	LIMIT OF ERROR OF AVERAGE, $3\frac{\sigma}{\sqrt{n}}$
	Maximum	Minimum	Average	Range		
F-4-1	321	293	311	28	10.3	± 8.3
F-4-2	321	302	309	19	6.9	± 5.6
F-4-3	306	273	289	33	9.0	± 7.2
F-4-4	306	285	294	21	9.3	± 7.5
F-4-5	321	289	308	32	9.1	± 7.3
F-3-1	248	232	241	16	4.4	± 3.5
F-3-2	273	244	261	29	7.9	± 6.4
F-3-3	269	251	261	18	5.9	± 4.6
F-3-4	269	248	253	19	6.7	± 5.4
F-3-5	285	262	273	23	8.2	± 6.6
F-X-1	363	347	360	16	6.0	± 4.8
F-X-2	388	347	365	41	12.6	±10.1
F-X-3	388	357	371	31	11.6	± 9.3
F-X-4	369	363	363	6	1.6	± 1.3
F-X-5	375	336	357	39	10.5	± 8.5
G-12-1	388	363	383	25	7.8	± 6.2
G-12-2	415	363	387	52	16.2	±13.0
G-12-3	408	369	398	39	11.6	± 9.3
G-12-4	415	375	397	40	11.9	± 9.6
G-12-5	415	375	395	40	13.5	±10.9
G-10-1	394	352	379	42	12.1	± 9.8
G-10-2	401	363	390	48	9.4	± 7.6
G-10-3	422	388	403	34	11.8	± 9.5
G-10-4	415	388	398	27	11.3	± 9.1
G-10-5	444	363	398	81	18.2	±14.6
G-7-1	289	269	279	20	6.0	±14.3
G-7-2	297	281	286	16	3.5	± 2.8
G-7-3	302	285	293	17	7.3	± 5.8
G-7-4	302	281	291	21	7.1	± 5.7
G-7-5	311	277	290	34	10.9	± 8.8
G-6-1	363	321	345	42	18.8	±15.1
G-6-2	388	347	365	41	11.7	± 9.4
G-6-3	382	341	361	41	9.0	± 7.2
G-6-4	401	363	376	38	14.0	±11.3
G-6-5	388	363	373	25	10.1	± 8.1
G-5-1	302	281	286	21	5.3	± 4.3
G-5-2	302	285	288	17	4.4	± 3.5
G-5-3	302	281	294	21	8.1	± 6.5
G-5-4	311	285	299	26	7.1	± 5.7
G-5-5	321	289	306	32	9.4	± 7.6
G-4-1	321	302	313	19	8.5	± 6.8
G-4-2	341	306	321	35	8.9	± 7.1
G-4-3	348	311	327	37	9.4	± 7.5
G-4-4	321	289	306	32	9.2	± 7.4
G-4-5	341	302	319	39	14.0	±11.3
G-3-1	277	248	257	29	7.9	± 6.4
G-3-2	269	241	254	28	6.3	± 5.1
G-3-3	302	282	287	20	4.9	± 3.9
G-3-4	277	251	265	26	7.8	± 6.3
G-3-5	302	273	291	29	11.7	± 9.4

Average σ, Group F. = 7.31
" ", Group G. = 9.88

(Continued on next page)

(Outline of Procedure, cont'd) -

A hardness survey, using the Vickers hardness tester, was conducted on a cross-section of a sample from each thickness of plate, to determine the actual depth of decarburization. These results are presented in the the chart in Figure 1 (see Page 13) and in Table II below:

TABLE II. - DEPTH OF DECARBURIZATION CALCULATED FROM VICKERS HARDNESS SURVEY.

Plate thickness, millimetres	Depth of total decarburization, in inches	Depth at which hardness is 95 % of true hardness, in inches
12	0.04	0.018
10	0.03	0.025
7	0.03	0.02
6	0.035	0.024
5	0.03	0.02
4	0.03	0.02
3	0.025	0.015

There are two methods of determining the accuracy of the Brinell values obtained. The more obvious, though less exact, method is to calculate the range between the maximum value and minimum value of each set of values. This is done in the column headed "Range" in Table I. The distribution frequency of the ranges is given in Table III (below) and shown graphically in the chart in Figure 2 (see Page 14).

TABLE III. - FREQUENCY DISTRIBUTION OF RANGE.

Flat Plate		Grooved Plate	
Range Group	Range values, per cent	Range Group	Range values, per cent
0- 5	0	0-15	0
6-15	15	16-20	17.1
16-30	60	21-40	63
31-45	20	41-60	17.1
46-60	2	61-80	2.8

A more exact method to determine the accuracy of these Brinell values is to calculate the standard deviation

(Outline of Procedure, cont'd) -

for each set of values. This standard deviation is represented by the Greek symbol for "sigma" (σ). The "sigma" values for each set of readings have been calculated and recorded in the column headed "Standard Deviation" in Table I (on Pages 4 and 5). By using the "sigma" value in the formula, $3\frac{\sigma}{\sqrt{n}}$, where "n" is the number of readings taken, the limits of accuracy of the average Brinell value for each set of readings may be determined. It is therefore evident that the limits of accuracy of these averages vary directly as the value of the standard deviation of each group represented by each average. The values for $3\frac{\sigma}{\sqrt{n}}$ are given in the last column in Table I.

A "control chart" for the standard deviation values, for both the flat and the grooved samples, is presented in Figure 3 (see Page 15). The limits shown on this control chart are obtained by using the data on Page 50 of the American Society for Testing Materials' Manual on Presentation of Data.

To determine the effect of the thickness of the plate on the accuracy of the Brinell value obtained, the average Brinell value of the flat samples of the seven thicknesses of plate are compared with the Brinell equivalent of the maximum Vickers hardness value obtained from the cross-sectional survey, shown in Figure 1. This comparison is made in Table IV.

TABLE IV.

Thickness of plate, in millimetres	Average Brinell hardness value obtained on flat samples	Brinell equivalent of average maximum Vickers hardness value on cross-section.
12	382	393
10	379	375
7	277	281
6	352	350
5	284	295
4	302	316
3	258	259

(Continued on next page)

(Outline of Procedure, cont'd) -

To determine the effect of a very soft anvil on the correctness of the Brinell hardness value obtained on very thin plate when using the standard 3,000-kg. load and 10-mm.-diameter ball, the following experiment was conducted:

1. The hardness of the standard anvil supplied with the Brinell hardness testing machine was determined as being R_C 40 (B.H. No. 375).

2. An anvil was prepared from cold rolled steel. This was found to have a Brinell hardness number of 111.

3. Using the "F-3" series of samples, two impressions were made on each sample using the standard 3,000-kg. load and 10-mm.-diameter ball and supporting the sample on the cold rolled steel anvil. The diameters of each of these impressions was measured by only one person. The resulting Brinell hardness numbers are tabulated in Table V, together with an analysis of their variance.

TABLE V. - BRINELL HARDNESS MEASUREMENTS OF 3-mm. SAMPLES ON SOFT ANVIL.

SAMPLE NO.	BRINELL HARDNESS NUMBER	AVERAGE BRINELL HARDNESS NUMBER	RANGE	STANDARD DEVIATION	LIMIT OF ERROR OF AVERAGE
F-3-1	197 201				
F-3-2	212 207				
F-3-3	207 192	200	25	8.4	± 6.5
F-3-4	187 192				
F-3-5	212 197				

A comparison between Brinell hardnesses obtained on 3-mm. plate using a soft anvil and a hard anvil is made in Table VI below:

TABLE VI. - COMPARISON OF EFFECT OF HARD AND SOFT ANVIL ON HARDNESS MEASUREMENT OF 3-mm. PLATE.

AVERAGE BRINELL HARDNESS OBTAINED USING A HARD ANVIL (ANVIL HARDNESS, 375 B.H. NO.)	AVERAGE BRINELL HARDNESS OBTAINED USING A SOFT ANVIL (ANVIL HARDNESS, 111 B.H. NO.)
258	200

Discussion of Results:

(1). - Effect of Decarburization -

An examination of the column of average Brinell values in Table I will show that in almost every case the Brinell value of the samples, with only 0.01 inch of metal removed from the surface is slightly lower than the Brinell value of the other samples. However, a mathematical analysis of these values shows that only in the case of the 10-mm. plate is the difference great enough to be significant. It would appear that in all cases, if 0.02 inch of metal is removed the decarburized metal left is not enough to affect the correctness of the Brinell hardness test.

(2). - Effect of Uneven Surface on Accuracy -

An analysis of the range between maximum and minimum B.H.N. obtained on the flat samples and the grooved samples indicates that there is a tendency for the range to be greater when the sample is grooved. This tendency is confirmed when the accuracy is analysed by means of the standard deviation method.

A general rule for ascertaining the accuracy of a single measurement from the average standard deviation of a number of groups of measurements is that the expected accuracy will be $\pm 3\bar{\sigma}$ where $\bar{\sigma}$ is the average standard deviation. According to this rule, therefore, the accuracy of a single Brinell determination made under the same conditions as those which existed for the flat samples would be

$$\pm 3 \text{ times } 7.3 = \pm 22,$$

while the accuracy for a single Brinell determination made under the same conditions as those which existed for the grooved samples (i.e., when the surface is not flat) would be

$$\pm 3 \text{ times } 9.9 = \pm 30.$$

This accuracy, expressed in units of diameter of the Brinell impression, would be roughly $\pm$ 0.10 mm. for a

(Discussion of Results, cont'd) -

flat surface and ± 0.15 mm. for the uneven surface.

(3). - Effect of Too Thin a Sample -

A chart is shown in Figure 4 (see Page 16) to illustrate the relationship existing between the Brinell hardness number and minimum plate thickness allowable when the hardness is to be measured by the standard Brinell method. This chart was constructed on a purely theoretical basis from information contained on Page 253 of "The Hardness of Metals and Its Measurements", by O'Neill.

From this chart it would appear that the thinnest plate, having a hardness of 250 Brinell, whose hardness could be measured by means of the standard Brinell hardness test is about 3.8 mm. However, it is evident from Table IV that the hardness value obtained on even the 3-mm. plate by the standard Brinell test is in good agreement with the hardness value obtained by the Vickers pyramid hardness test on the cross-section of the plate.

(4). - Effect of Soft Anvil -

It is evident from a study of Tables V and VI that a soft supporting anvil has a very great effect on the correctness of the hardness measurement of 3-mm.-thick steel plate by the standard Brinell hardness test. It is also indicated that as long as the anvil is harder than the sample whose hardness is being determined, the error introduced by a thin sample is, to all intents and purposes, negligible. However, if a soft supporting anvil is to be used, the hardness-thickness relationship shown in Figure 4 could be expected to hold good in practice.

CONCLUSIONS:

1. Decarburization has not affected the correctness of the Brinell hardness determination when 0.02-inch minimum of metal has been removed from the surface.

2. An uneven surface lowers the accuracy of hardness measurements by the standard Brinell hardness test.

3. An accuracy in Brinell hardness values of ± 20 may be expected from single determinations on a perfectly flat, well-prepared surface.

4. An accuracy in Brinell hardness values of ± 30 may be expected from single determinations on an uneven surface.

5. The correctness of the hardness value as determined by the standard Brinell test is not adversely affected by plates down to 3 millimetres in thickness when their hardness is 250 Brinell or greater.

6. Conclusion No. 5 is valid only when the supporting anvil is harder than the sample being tested. When the anvil is much softer than the sample, the hardness value measured by the standard Brinell hardness test is not correct on samples thinner than the minimum thickness shown in Figure 4.

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HVK:GHB.

APPENDIX.

Standard deviation of a set of n numbers, X_1, X_2, ----- X_n.

$$\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{n}}$$

where $\bar{X}$ = average.

Limits of Error for average $= 3\frac{\sigma}{\sqrt{n}}$

Standard Error of difference

$$= \sqrt{\left(3\frac{\sigma_1}{\sqrt{n_1}}\right)^2 + \left(3\frac{\sigma_2}{\sqrt{n_2}}\right)^2}$$

To determine if there is a significant difference between two average values $\bar{X}_1$ and $\bar{X}_2$, apply the following rule:

$$\text{If} \quad \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(3\frac{\sigma_1}{\sqrt{n_1}}\right)^2 + \left(3\frac{\sigma_2}{\sqrt{n_2}}\right)^2}} > 3,$$

there is a significant difference between $\bar{X}_1$ and $\bar{X}_2$.

HVK:GHB.

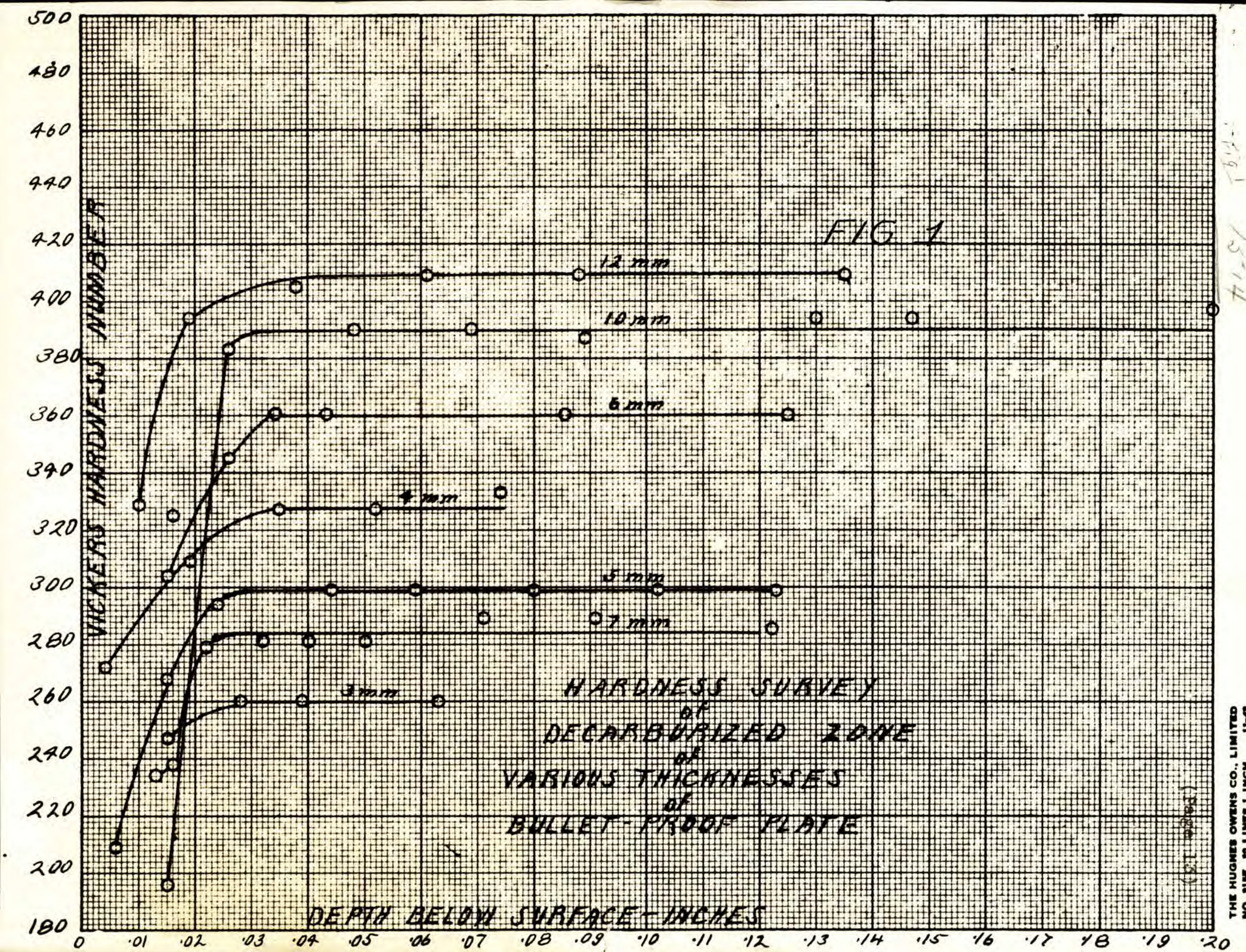

VICKERS HARDNESS NUMBER
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
12 mm
10 mm
6 mm
4 mm
5 mm
7 mm
3 mm
HARDNESS SURVEY
of
DECARBURIZED ZONE
of
VARIOUS THICKNESSES
of
BULLET-PROOF PLATE
DEPTH BELOW SURFACE - INCHES
0
·01
·02
·03
·04
·05
·06
·07
·08
·09
·10
·11
·12
·13
·14
·15
·16
·17
·18
·19
·20
THE HUGHES OWENS CO., LIMITED
NO. 31W 20 LINES 1 INCH 11-48

FIG 1

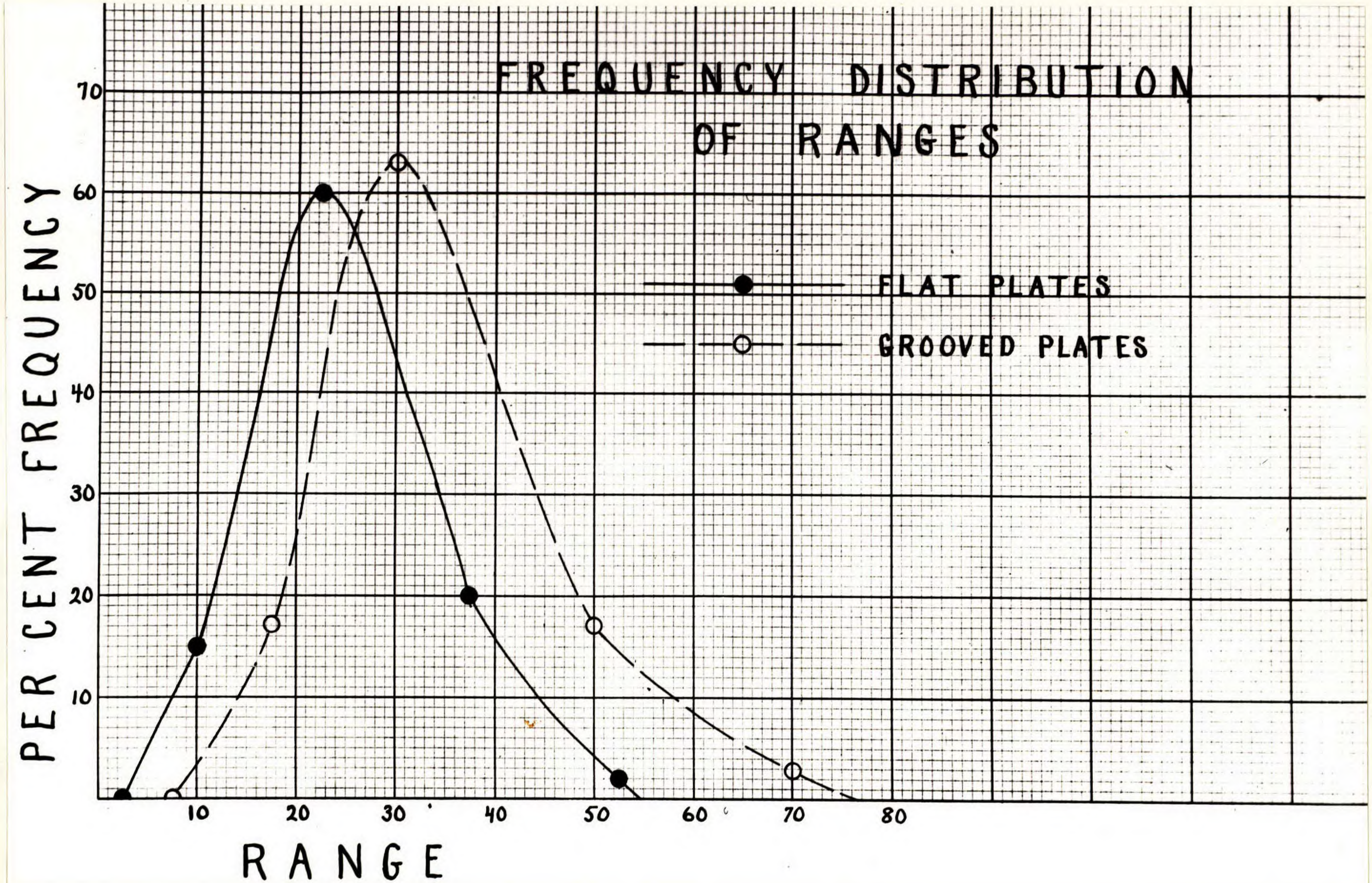
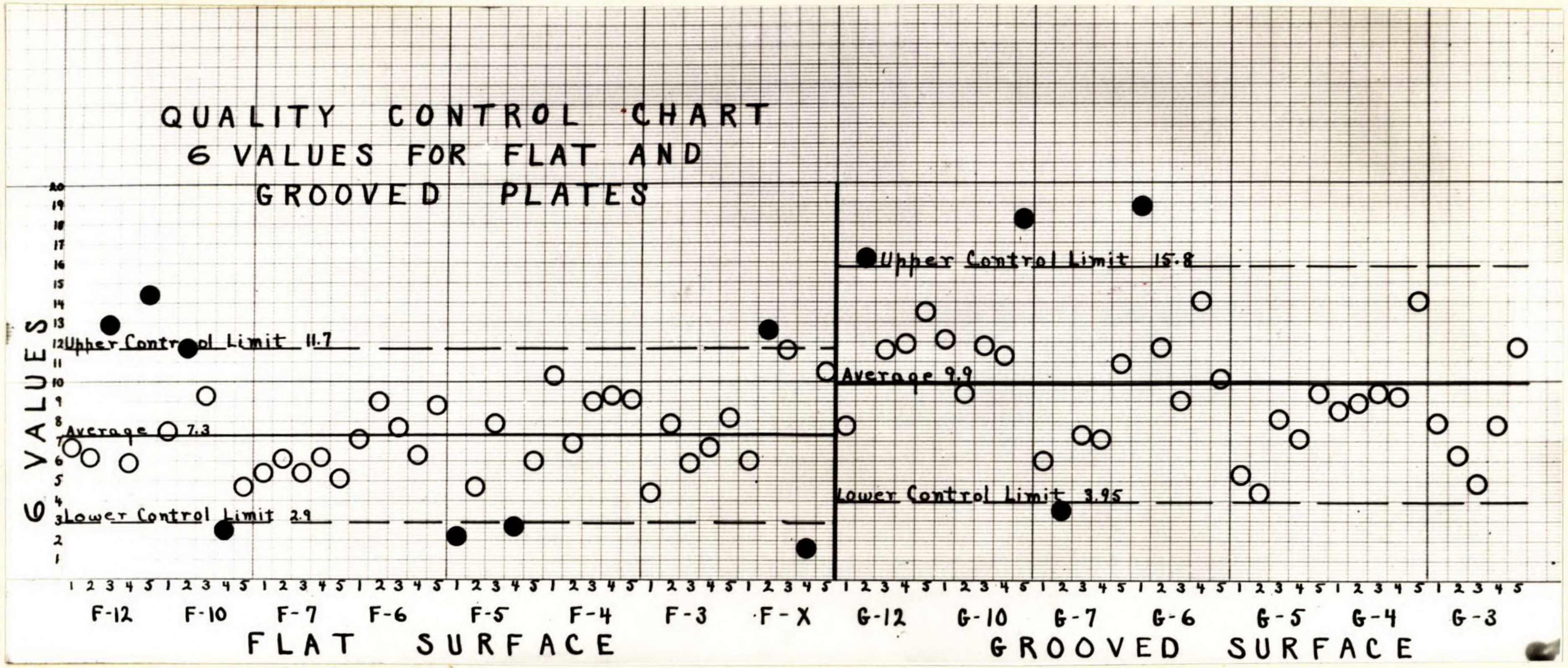

FREQUENCY DISTRIBUTION
OF RANGES
FLAT PLATES
GROOVED PLATES
PER CENT FREQUENCY
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
RANGE

Figure 2.



QUALITY CONTROL CHART
6 VALUES FOR FLAT AND
GROOVED PLATES
6 VALUES
Upper Control Limit 11.7
Average 7.3
Lower Control Limit 2.9
Upper Control Limit 15.8
Average 9.9
Lower Control Limit 3.95
F-12
F-10
F-7
F-6
F-5
F-4
F-3
F-X
G-12
G-10
G-7
G-6
G-5
G-4
G-3
FLAT SURFACE
GROOVED SURFACE

Figure 3.

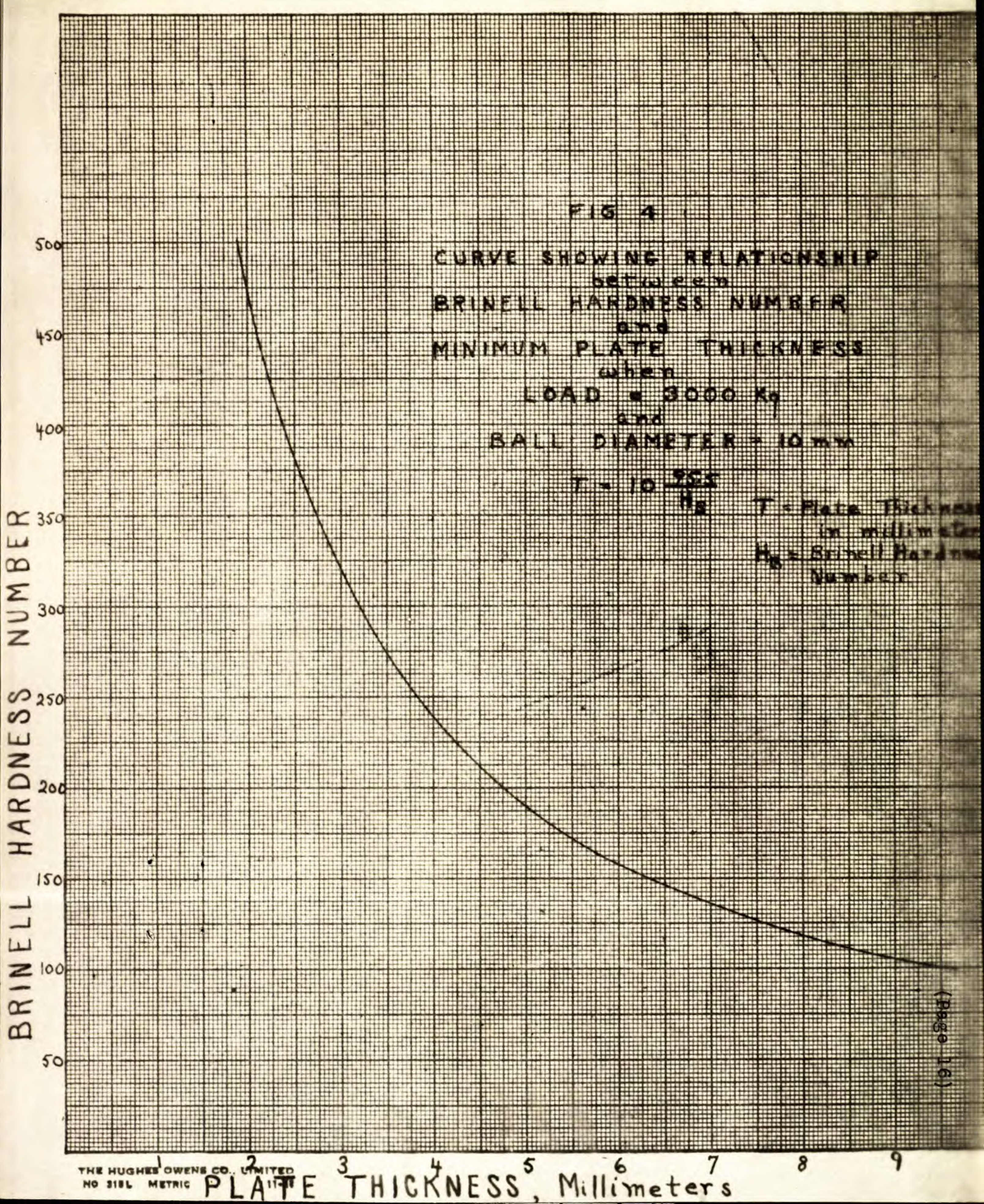


FIG 4
CURVE SHOWING RELATIONSHIP
between
BRINELL HARDNESS NUMBER
and
MINIMUM PLATE THICKNESS
when
LOAD = 3000 Kg
and
BALL DIAMETER = 10 mm
T = 10 955 / HB
T = Plate Thickness in millimeters
HB = Brinell Hardness Number
BRINELL HARDNESS NUMBER
500
450
400
350
300
250
200
150
100
50
PLATE THICKNESS, Millimeters
1
2
3
4
5
6
7
8
9
THE HUGHES OWENS CO. LIMITED
NO 318L METRIC