NATIONAL BUREAU OF STANDARDS REPORT

9411

Progress Report

on

A Comparison of Brinell and Vickers Hardness Tests on Dental Gold Casting Alloys

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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A Comparison of Brinell and Vickers Hardness Tests on Dental Gold Casting Alloys

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A Comparison of Brinell and Vickers Hardness Tests on Dental Gold Casting Alloys

Abstract

A large group of dental casting gold alloys representing all four types listed in American Dental Association Specification No. 5 were indented using the Brinell and Vickers methods. The relationship between Vickers and Brinell hardness numbers was found to be linear with the addition of 19 to the Brinell number approximating the Vickers number fairly well. The coefficient of variation for the Brinell test was found to be about one per cent less than that of the Vickers test. Surface preparation, grain size, and the position of the indentation with respect to grain structure did not effect the precision of the Vickers method. The effects of reading error and sample inhomogeneity on the precision of the Vickers values were also evaluated. The reading error was a large portion of the total error for types I, II, and III, but only about 35 per cent of the total error for type IV alloys. Vickers limits of 50 to 90 for type I, 90 to 120 for type II, 120 to 160 for type III, and a minimum of 160 in the quenched condition and a minimum of 220 in the hardened condition for type IV alloys were proposed for American Dental Association Specification No. 5.

1. Introduction

The primary purpose of this investigation was to determine the relationship between Brinell hardness numbers and Vickers Diamond Pyramid hardness numbers for dental gold casting alloys. It has been suggested that the Brinell test currently used in American Dental Association Specification No. 5 for dental casting gold alloys should be changed to the Vickers test. Since the Vickers method for determining hardness is widely accepted in other parts of the world while the Brinell method is commonly used for dental gold alloys in this country, a reliable procedure for converting from one type of hardness number to the other would be desirable. One objection to the Brinell test is that it is often difficult to measure precisely the diameter of the penetration due to the raised edge or "piling up" of metal around the impression. Also, false hardness values may occasionaly be introduced due to subsurface voids in the specimen, with the Brinell test. It has been suggested that the Vickers test tends to diminish or eliminate the preceding errors.[1]

Secondary objectives of this study were to compare the reproducibility of the Vickers values with that of the Brinell values and to determine the effects of various factors such as surface preparation of the specimen, the grain size of the alloy, the position of the indenter with respect to the grain structure, the reading error of the observer, and the sample inhomogeneity on the precision of the Vickers method.

2. Materials and Methods

2.1 Materials

Fifty-six representative gold alloys were selected from the four types listed in American Dental Association Specification No. 5 for dental casting alloy.

2.2 Apparatus

The Rockwell Superficial Hardness Tester fitted with a one-sixteenth inch diameter steel ball for making Brinell indentations, the Kentron Micro Hardness Tester with a 136° diamond pyramid indenter, and a measuring microscope were employed in this investigation.

The Rockwell Tester and the Kentron Tester were calibrated using an Instron testing machine so that true applied loads of 15 ± 0.001 Kg for the Rockwell instrument and 1 ± 0.001 Kg for the Kentron Tester were produced. The filar micrometer eyepiece on the Kentron Tester was calibrated using a 16 mm objective and a certified length standard with 100 filar units being equal to 75 ± 0.8 microns. The measuring microscope was calibrated by comparing a line standard to the length measured by the microscope, with corrections found to range from 0.2 to 1.0 micron per millimeter.

2.3 Procedure

Two disks of each alloy, approximately 0.8 mm thick and 32 mm in diameter which had previously been prepared for x-ray emission analysis were used for this study.[2]

Polishing was accomplished using 240, 320, 400, and 600 silicon carbide metallographic papers with a water lubricant. The specimens were further polished using a 600 soft microcloth followed by a MgO slurry on a felt covered wheel revolving at approximately 160 rpm. Five Brinell indentations were placed approximately 7.6 mm apart near the center of the casting (Figure 1). A 10 second load application time with an additional 30-second load dwell was used. The load was removed and measurement was made using the measuring microscope. The diameter of the penetration was determined by measuring two diameters perpendicular to each other and the average was used to calculate the Brinell hardness number.

After the Brinell measurements were completed, five Vickers Diamond Pyramid indentations were made. The indentations were placed approximately 3.8 mm from each Brinell penetration (Figure 1). A 7-second load application time and a 20-second load dwell were used. The two diagonals of the impression were measured employing the filar micrometer eyepiece of the Kentron Tester. The average length of the two diagonals was used to calculate the Vickers hardness number. The Vickers and Brinell indentations were positioned in pairs as shown in Figure 1 to minimize the effects of sample inhomogeneity.

The type IV alloys were first indented and measured in a quenched condition. They were then removed from the mounting material and recast. These specimens were then heat treated in a salt bath of 50 percent sodium nitrate and 50 percent potassium nitrate by weight for 30 minutes at 320°C and quenched in room temperature water.(3) The specimens were mounted, polished, and indented as described above.

The paired Vickers and Brinell values were plotted and first, second, and third order equations were fitted to the data. The precision of the Vickers and Brinell indentations as expressed by the coefficient of variation was calculated for each sample.

Several investigations to determine the precision of the Vickers values were performed. The first study dealt with the effects of surface treatment on Vickers values. Two specimens of each type listed in American Dental Association Specification No. 5 were selected. One casting was polished using 600 silicon carbide metallographic paper and a water lubricant, 600 soft microcloth, and a MgO slurry. The other casting was polished using 600 silicon carbide metallographic paper and water, 600 soft microcloth, and 15, 7, and 1 micron diamond paste on a rotating cloth. Ten diamond pyramid indentations, approximately 3.8 mm apart were made on each specimen and measured.

A second study involved the positioning of the diamond indenter with respect to the grain structure. One specimen of each type of gold was polished through one micron diamond paste and etched to bring out the grain structure. An etchant of equal parts of 20 percent potassium cyanide and 20 percent ammonium peroxydisulfate was used for varying lengths of time (30 seconds to 8 minutes) depending upon the type of alloy being etched.(4) Ten diamond pyramid indentations were made on each specimen within a grain, and ten indentations crossing grain boundaries were also made on the same specimen. These penetrations were spaced approximately 7.6 mm apart.

The effects of grain size were investigated by comparing the hardness values of fine and coarse grained alloys. One fine grained and one corresponding coarse grained alloy of the same chemical composition of each of the four types of golds were polished through a MgO slurry. Ten diamond pyramid indentations approximately 3.8 mm apart were made on each specimen and measured. The data from these three studies were analyzed using an F test at the 99 percent confidence level.

A final study of the precision of the Vickers values involved determining the reading error of the observer in the measurement of the indentation. Four specimens, one representing each type of gold, with surfaces which had been prepared with a MgO slurry and indented ten times, were selected. Measurements were made on these specimens by four individuals using the same instrument. All horizontal readings were completed in a random sequence, before vertical readings were begun.

This design enabled the true reading error of the individual to be separated from the total error which was a combination of reading error and errors due to sample inhomogeneity and surface defects. The data were then analyzed using a two way classification analysis of variance at the 95 percent confidence level.[5,6]

3. Results

A total of 612 points which represented each pair of Vickers and Brinell values, exclusive of values which varied by more than ± 15 percent from the average of the five indentations on each specimen, were plotted. First, second, and third order equations were fitted to the data with the results shown in Figures 2 and 3. It is evident from Figure 3 that there was only a slight difference between each order of fit.

The equations for the first, second, and third order fits were:

1. $V = 19.42 + 0.983\ (B)$
2. $V = 14.52 + 1.076\ (B) - 0.00036\ (B)^2$
3. $V = -3.46 + 1.610\ (B) - 0.0049\ (B)^2 + 0.000012\ (B)^3$

where V = Vickers number, B = Brinell number

The standard deviations of each fit were 15.70, 15.69, and 15.61, respectively.

A determination of the precision among the five Vickers and five Brinell indentations on each specimen was calculated. The average coefficient of variation for each type of alloy for all the data and for values which did not vary more than ± 15 percent are given in Table 1. The elimination of values which varied more than ± 15 percent decreased the average coefficient of variation about 0.5 percent for both the Brinell and Vickers measurements. The average coefficient of variation for the Brinell method was approximately one percent less than that of the Vickers method.

The effects of various factors on the precision of the Vickers method were also investigated. The effect of surface preparation on the coefficient of variation for the Vickers hardness numbers is shown in Table 2. An F test at the 99 percent confidence level indicated that there was no significant difference in the precision of the Vickers test when specimens were surfaced through a MgO slurry and specimens polished through one micron diamond paste.

Vickers hardness numbers from both coarse grained and fine grained specimens of the same alloy are listed in Table 3. The effect of indenting within a grain or at the grain boundary is shown in Table 4. An F test at the 99 percent confidence level indicated that there was no significant difference in the precision of the Vickers test between a coarse and fine grained alloy of the same chemical composition or between the interior of a grain and the grain boundaries.

A final study was undertaken to determine the error involved in measuring an indentation by an observer and to establish what amount of the total error was due to this reading error. Four observers were instructed to make all horizontal readings first following a prescribed random design and then to make all vertical readings following another prescribed random sequence. The same four specimens with ten indentations each were measured by each observer.

Since the same indenter was used throughout the experiment, the difference between the horizontal and vertical diagonal was independent of position on the specimen and was characteristic of the reading error. The sum of the horizontal and vertical diagonals was dependent upon the position of the indentation, however, and reflected the total error which was a combination of reading error and errors due to sample inhomogeneity and surface defects.

The average Vickers hardness numbers for each observer and for each type, together with the standard deviation of the total error are listed in Table 5. Table 6 contains the coefficients of variation for the reading errors and Table 7 lists the coefficients of variation for the total error. The data in Tables 6 and 7 were analyzed using a two-way classification analysis of variance at the 95 percent confidence level. This analysis indicated that there was no significant difference between observers or between types for an individual observer with respect to reading error (Table 6). Similarly, there was no significant difference between observers with respect to total error (Table 7), however, there was a significant difference between the types.

From Tables 6 and 7 it may be seen that the average reading error constitutes approximately 70 percent of the total error for types I, II, and III. The reading error is less than 35 percent of the total error, however, for type IV alloys. It is also evident from Table 7 that type IV has the largest total error and the greatest error due to sample inhomogeneity and sample defects.

4. Discussion

From Figure 3 it is apparent that there is little difference between the three orders of fit. Based upon the fact that there was no significant statistical difference between the first and second order of fit (F ratio 2.35) and that the F ratio between the second and third order of fit was rather low (7.44), the first order equation is the most desirable choice. The equation for this line indicates that if 19 is added to the Brinell number, the Vickers number is approximated fairly well.

The assumption that the Vickers test was a more precise test than the Brinell test was not verified in this investigation. The coefficient of variation for the Brinell test was approximately one per cent less than that of the Vickers test for all the data and also when values which varied by more than ± 15 per cent of the average of the five indentations on each specimen were discarded. The Vickers indentation is much smaller and apparently surface defects, inhomogeneity of the sample, and reading errors effect the precision of this test to a greater extent.

Figure 4 shows a good and a poor Brinell indentation. Figure 5 pictures a satisfactory and a poor Vickers indentation. From these photographs it is apparent that "piling up" and distortion may occur with both indentation methods.

The effects of surface preparation, grain size, and grain structure on the Vickers hardness numbers did not seem to vary the precision of the Vickers method. It was established, however, that the reading error constituted a large percentage of the total error for types I, II, and III. The type IV alloy which is a more complicated alloy metalurgically gave the least precise Vickers values and about 65 per cent of this error probably was due to surface defects and sample inhomogeneity. The mere fact that the Vickers indentation is the smallest in the type IV alloys would indicate that any defect in the sample or microstructure would effect the overall precision of this method to the greatest extent.

One of the objectives of this investigation was to determine if dental gold casting alloys currently classified in American Dental Association Specification No. 5 by means of the Brinell test, could be classified by means of Vickers hardness numbers. The fact that the Vickers test is a much more widely used method indicates that this conversion might be desirable. On the basis of the data obtained in this investigation it is suggested that the proposed Vickers limits be set at 50 to 90 for type I, 90 to 120 for type II, 120 to 160 for type III, and a minimum of 160 in the quenched condition and a minimum of 220 in the hardened condition for type IV alloys. The proposed limits, which eleminate the overlapping hardness ranges in the present American Dental Association Specification No. 5, might cause some alloys to be shifted from one type to another when classified according to hardness. It is believed, however, that the number of alloys affected would be small. Future experience with hardness specimens prepared in accordance with the specification may suggest some revision of the proposed limits.

5. Summary and Conclusion

The relationship between Vickers and Brinell hardness numbers of dental gold casting alloys was found to be linear. The coefficient of variation for the Brinell test was found to be approximately one percent less than that of the Vickers test. Surface preparation, grain size, and grain structure did not effect the precision of the Vickers method. The reading error for the Vickers method constituted a large portion of the total error for types I, II, and III. The type IV alloy gave the least precise Vickers values and only about 35 per cent of this error was due to reading error. Vickers limits of 50 to 90 for type I, 90 to 120 for type II, 120 to 160 for type III, and a minimum of 160 in the quenched condition and a minimum of 220 in the hardened condition for type IV alloys, are proposed for American Dental Association Specification No. 5.

The authors would like to thank Dr. W. J. Youden for his assistance with the statistical considerations.

6. References

1. C. E. Ingersoll. "IADR Abstract No. 256" (1965).

2. J. D. Eick, H. J. Caul, D. L. Smith, and S. D. Rasberry. "National Bureau of Standards Report 8639" (1964).

3. F. A. Peyton,, D. H. Anthony, K. Asgar, G. T. Charbeneau, R. G. Craig, and G. E. Myers. "Restorative Dental Materials." St. Louis, Missouri: C. V. Mosby Co., 1960.

4. E. M. Wise, "Gold, Recovery, Properties, and Applications." New York, Van Nostrand, 1964.

5. W. J. Youden. Personal Communications.

6. M. G. Natrella. "Experimental Statistics," National Bureau of Standards Handbook 91 (1963).

TABLE I

AVERAGE COEFFICIENT OF VARIATION

	BRINELL†	BRINELL‡	VICKERS†	VICKERS‡
TYPE I	4.12	5.20	5.45	6.42
II	3.62	4.00	4.30	6.82
III	3.91	3.86	3.69	4.38
IV	3.82	3.85	4.33	4.37
IV*	4.56	5.18	6.93	7.61
AVERAGE	4.00	4.42	4.94	5.52

† Values which varied by more than ± 15 per cent of the average of the five indentations on each specimen were discarded.

‡ All data.

* Heat treated.

$$\text{Coefficient of variation} = \frac{\text{Standard Deviation}}{\bar{X}}$$

$$\text{Standard deviation} = \sqrt{\frac{\Sigma\,(X - \bar{X})^2}{N - 1}}$$

TABLE II

EFFECT OF SURFACE PREPARATION ON

VICKERS HARDNESS NUMBERS

Type	MgO	1 micron diamond
I	62.4 ± 1.3†	65.8 ± 2.7
II	107.4 ± 4.1	107.8 ± 4.3
III	129.5 ± 3.3	139.8 ± 7.6
IV	202.4 ± 9.9	207.0 ± 16.6

† Standard deviation

TABLE III

EFFECT OF GRAIN SIZE ON

VICKERS HARDNESS NUMBERS

Type	Coarse Grained	Fine Grained
I	60.4 ± 2.2†	60.8 ± 1.0
II	103.0 ± 3.4	94.1 ± 2.6
III	116.0 ± 3.2	135.7 ± 4.3
IV	221.0 ± 7.2	229.3 ± 5.0

† Standard deviation

TABLE IV

EFFECT OF INDENTING WITHIN A GRAIN OR AT THE GRAIN BOUNDARY
ON VICKERS HARDNESS NUMBERS

Type	Within a Grain	Grain Boundary
I	61.9 ± 2.7†	58.8 ± 1.6
II	103.7 ± 4.2	102.5 ± 2.5
III	115.8 ± 2.9	116.3 ± 3.6
IV	226.4 ± 9.5	215.4 ± 5.0

† Standard deviation

TABLE V

AVERAGE VICKERS HARDNESS NUMBER OBTAINED
BY FOUR OBSERVERS

Observers	Type I	Type II	Type III	Type IV
A	62.9 ± 2.3†	110.7 ± 8.2	131.7 ± 8.8	240.9 ± 25.3
B	61.6 ± 2.2	107.4 ± 8.6	128.5 ± 8.7	231.3 ± 21.9
C	62.0 ± 1.8	106.7 ± 8.7	128.3 ± 6.4	236.8 ± 22.2
D	62.2 ± 3.2	107.8 ± 6.9	130.6 ± 8.3	237.6 ± 22.1

† Standard deviation.

TABLE VI

COEFFICIENTS OF VARIATION FOR READING ERRORS†

Observer	Type I	Type II	Type III	Type IV
A	3.39	4.35	3.26	2.61
B	2.01	3.82	4.54	5.09
C	1.77	4.60	4.12	1.81
D	4.39	5.25	6.14	3.91

† Difference between horizontal and vertical diagonals

TABLE VII

COEFFICIENTS OF VARIATION FOR TOTAL ERRORS†

Observer	Type I	Type II	Type III	Type IV
A	3.61	7.38	6.68	10.50
B	3.52	8.01	6.75	9.47
C	2.85	8.16	5.03	9.38
D	5.14	6.38	6.38	9.30

† Sum of horizontal and vertical diagonals

ARRANGEMENT OF VICKERS AND BRINELL INDENTATIONS

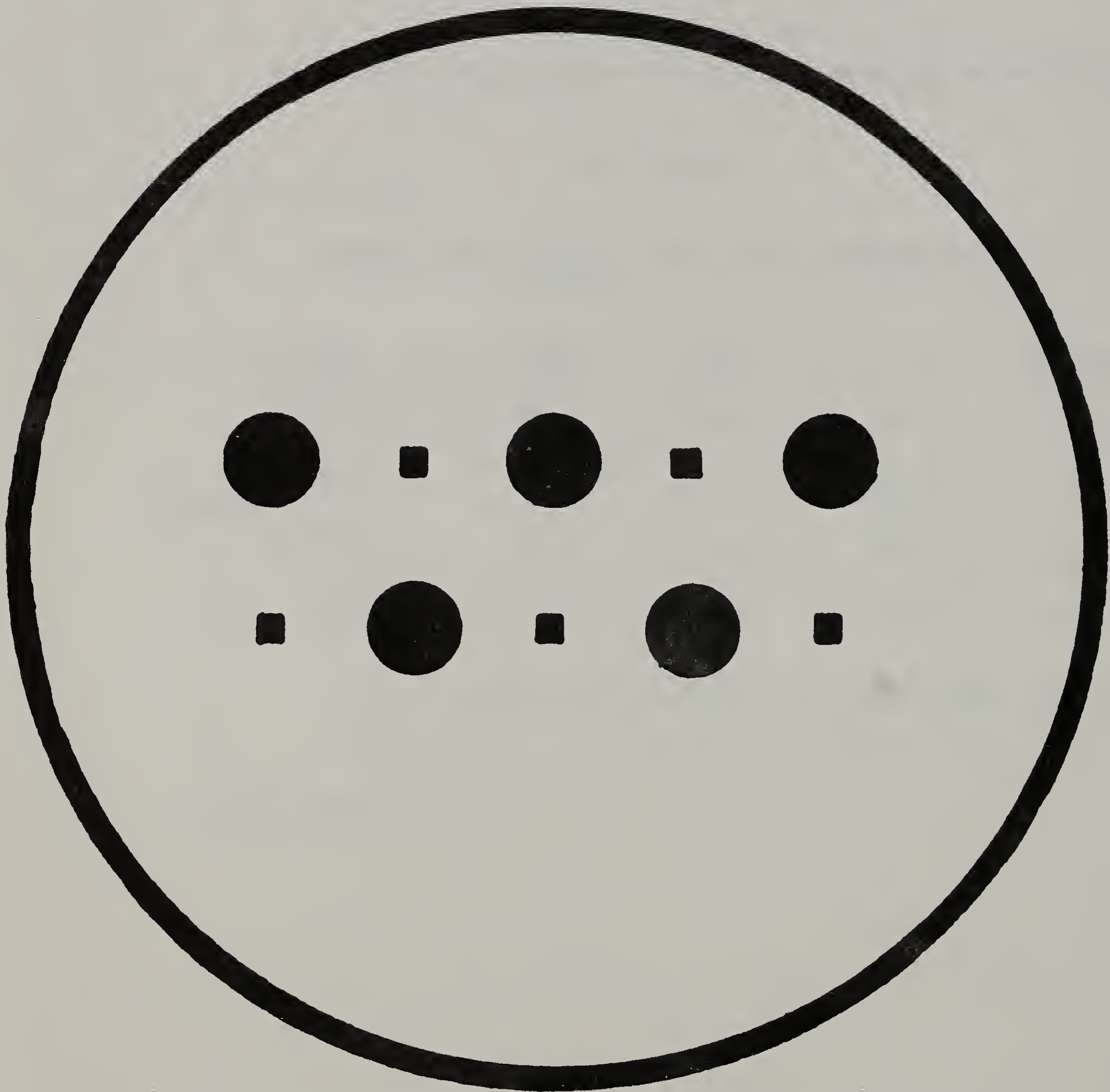


Figure 1. Arrangement of Vickers and Brinell Indentations.

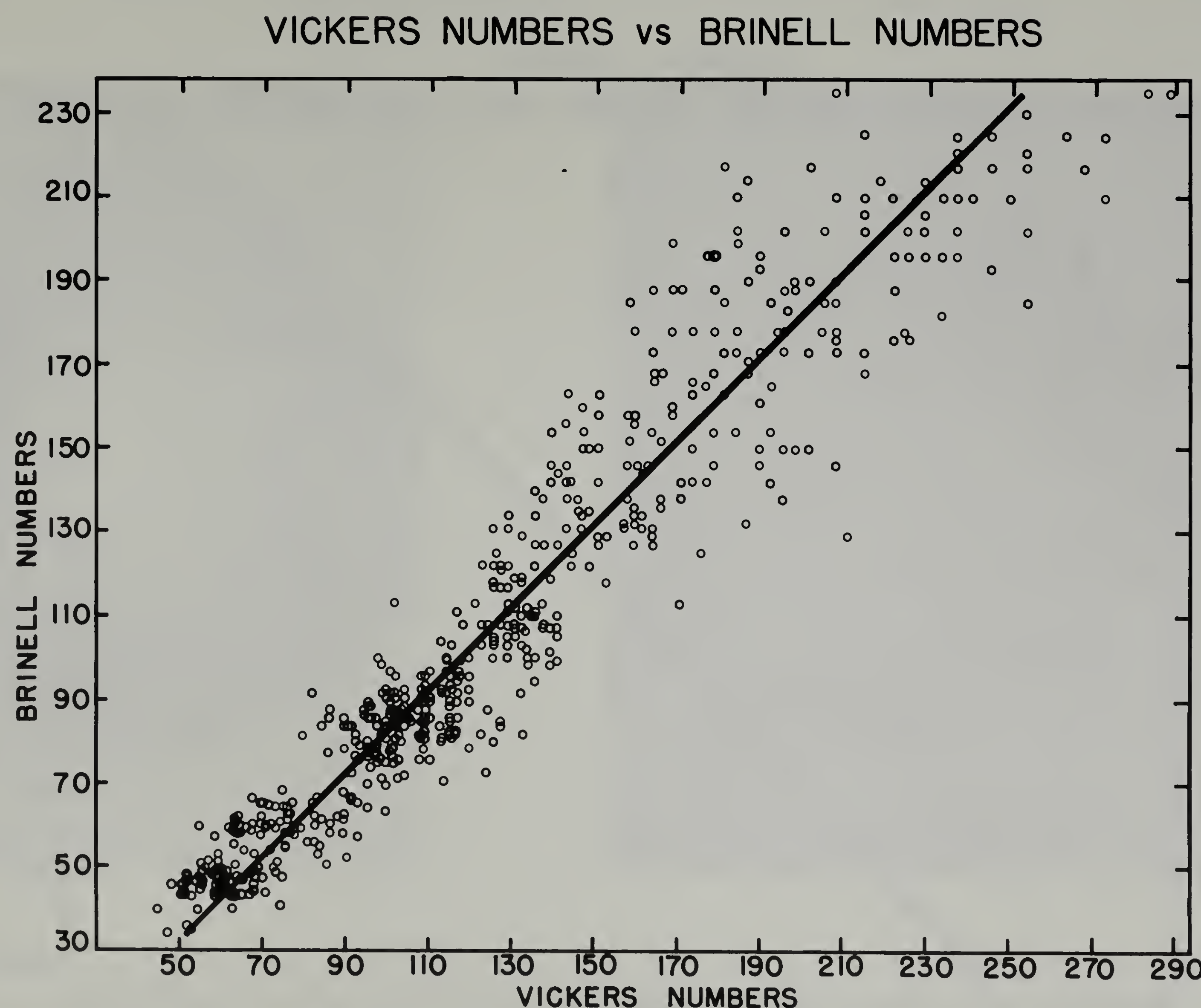


Figure 2. Comparison of Brinell and Vickers numbers of dental gold casting alloys. Each point represents the average Brinell number and Vickers number on a single specimen. The straight line was fitted to the data by the method of least squares.

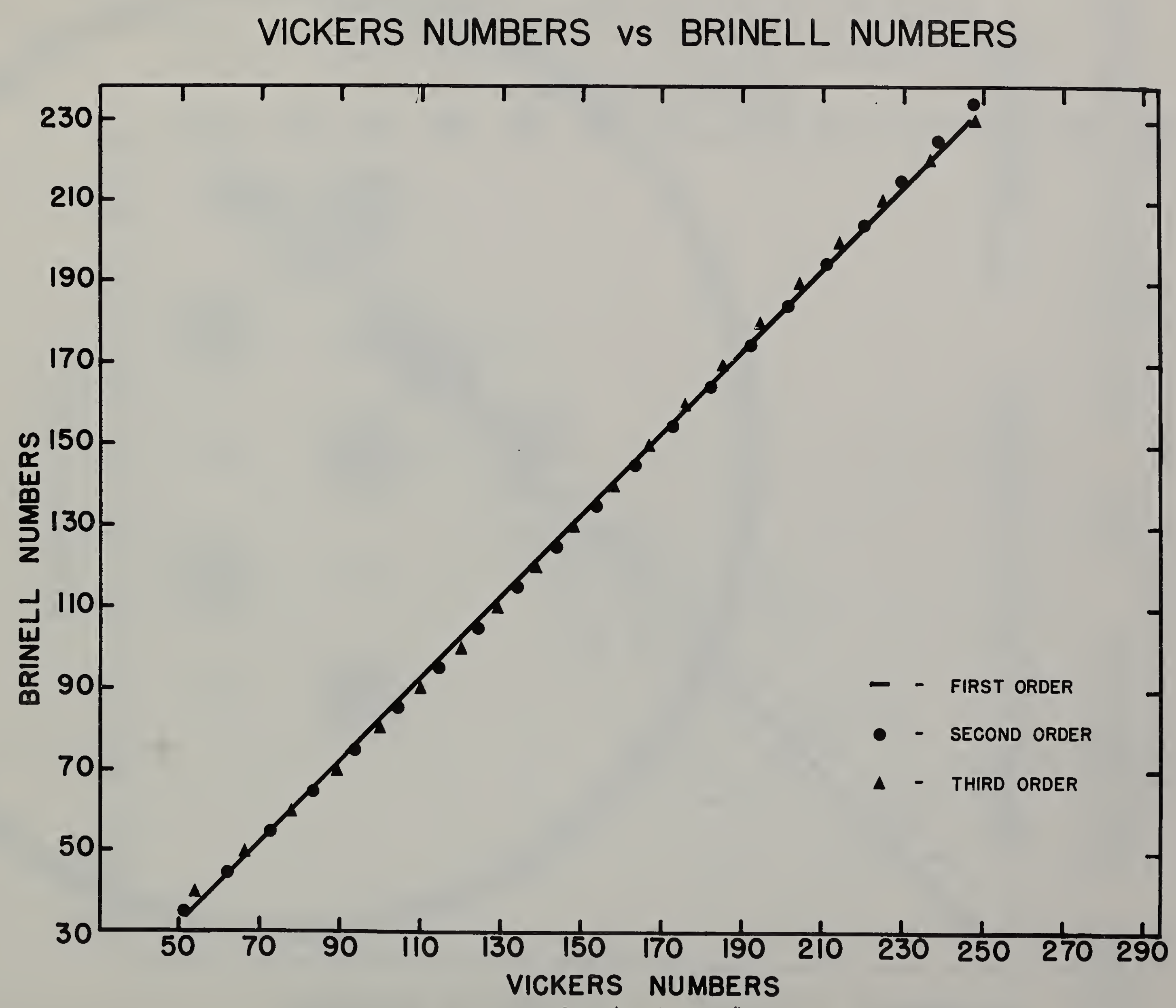
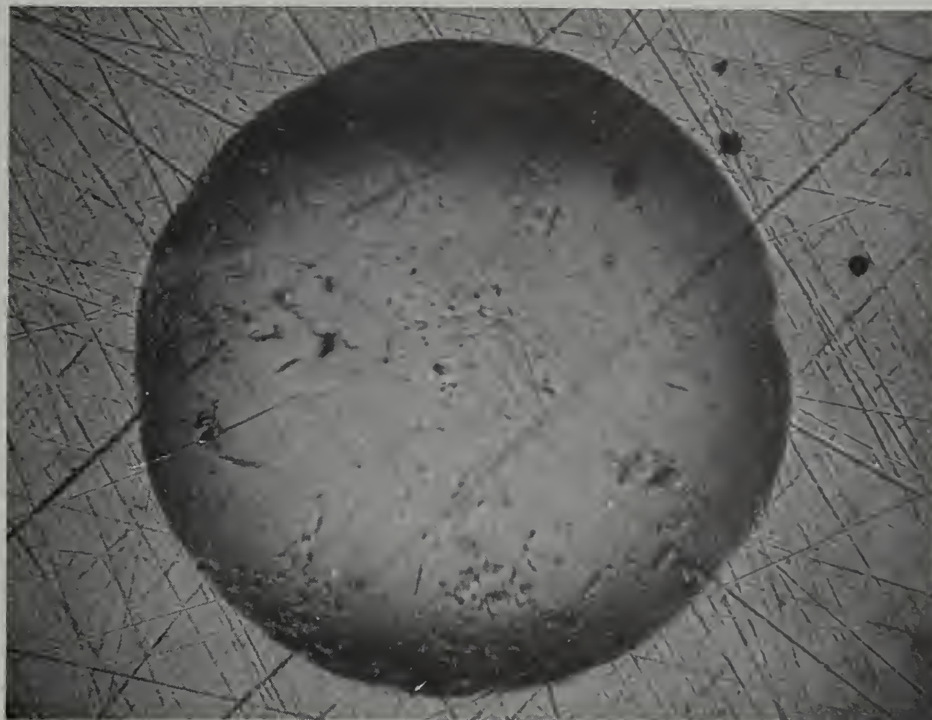


Figure 3. Comparison of first, second and third order curves fitted to data shown in Figure 2.



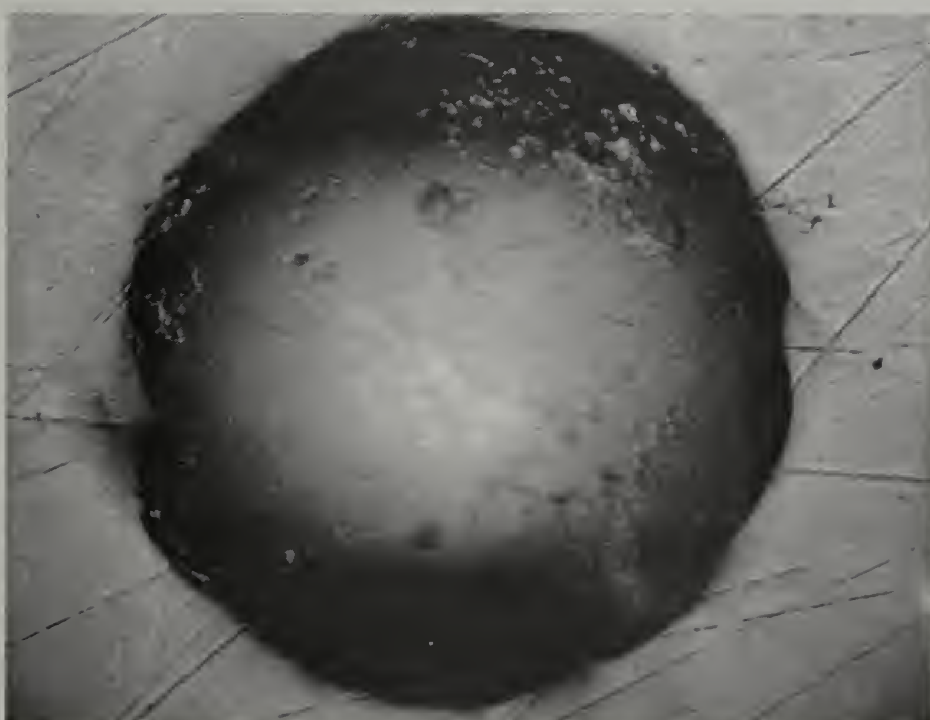


Figure 4. Examples of good (top) and poor (bottom) Brinell indentations.
Magnification: 200 X
Surface preparation: MgO

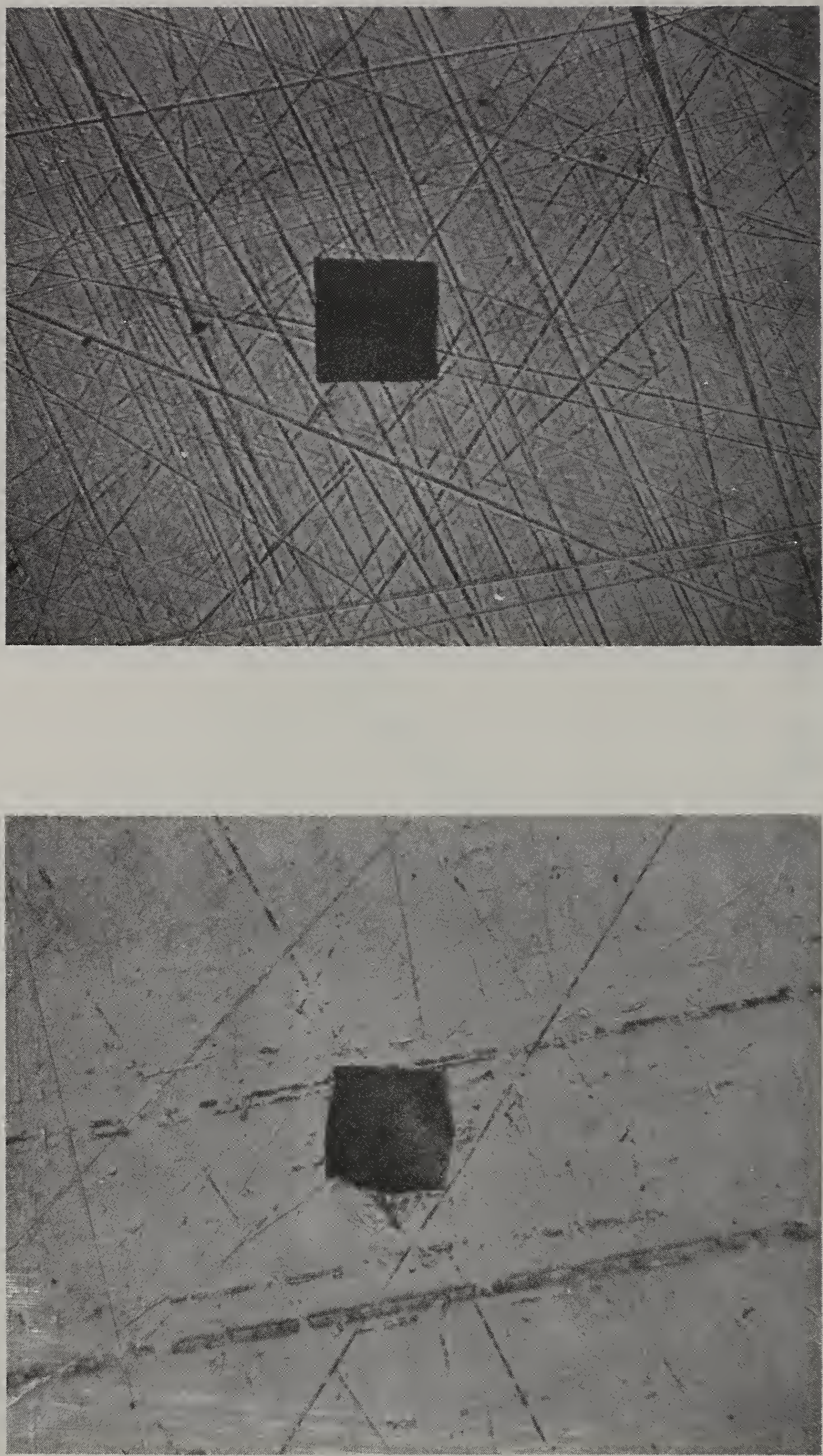


Figure 5. Examples of good (top) and poor (bottom) Vickers indentations.
Magnification: Top 200 X
Bottom 300 X
Surface preparation: MgO

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