National Institute of Standards & Technology

Certificate of Analysis

Standard Reference Material® 2831

Vickers Hardness of Ceramics and Hardmetals

This Standard Reference Material (SRM) is intended for use in the calibration of all hardness and microhardness testing machines whereby a Vickers indentation is made and then measured with a microscope. The SRM has five NIST-made indents in the middle of a polished face (Figure 1) certified for the individual diagonal lengths, the average diagonal length, and the average hardness value for indentations made at a load of 9.8 N (1 kgf). A unit of SRM 2831 consists of a 25 mm D × 9.5 mm disk that has a nominal hardness of approximately 15.0 GPa (1530 kgf/mm^2) packaged in a wooden box. Each unit is individually certified and bears a serial number (the letter W followed by a hyphen and the disk number) scribed on the opposite (bottom) face of the disk.

Vickers hardness is calculated as $HV = \alpha\ P/d^2$, where P is the indentation load, d is the average diagonal size $[(d_1 + d_2)/2]$, and α is the indenter constant, which, for an ideal Vickers indenter is 1.8544. If P is in units of Newton, and d is in units of meters, then HV will be in units of N/m^2 or Pa. A conversion factor of 1×10^{-9} may be used to convert HV to units of GPa. In this certificate, older traditional units of hardness expressed as kgf/mm^2 are also included in parenthesis for the convenience of users.

Certified Values: The certified values for Individual Diagonal Lengths, Average Diagonal Length, and Average Vickers Hardness for the NIST indentations for each disk are provided in Table 1. Special notes regarding particular disks are also included in Table 1. The uncertainty for each certified value is given below.

Individual Diagonal Lengths: The certified individual diagonal lengths in units of micrometers for the 5 NIST indentations for this particular disk are shown in Table 1. The NIST indentations are identified as V1 to V5 (Figure 1). The average diagonal size $d = (d_1 + d_2)/2$ for each indentation is listed in Table 1. The uncertainty for an individual NIST indentation size is ± 0.32 μm (± 0.9 %) at a 95 % confidence level. The number in parenthesis is two times the coefficient of variation expressed as a percentage. The uncertainty for a single future (new) indentation is a little greater and is ± 0.35 μm (± 1.0 %) also at a 95 % confidence level.

Average Diagonal Length: The certified average diagonal length for the five NIST indentations is also listed in Table 1. The uncertainty for the average for the five NIST indentations is ± 0.14 μm (± 0.4 %) at a 95 % confidence level. The uncertainty for the average diagonal size of five future new indentations is ± 0.20 μm (± 0.6 %), also at a 95 % confidence level.

Average Vickers Hardness: The certified average Vickers hardness, HV_5 for the disk is also listed in Table 1. The uncertainty for the average of the five NIST indentions is ± 0.29 GPa (28 kgf/mm^2). The uncertainty for the average of five future (new) indentations is ± 0.41 GPa (40 kgf/mm^2). The uncertainties are at the 95 % confidence level.

Expiration of Certification: The certification of this SRM is valid indefinitely, within the measurement uncertainties specified, provided the SRM is handled in accordance with the instructions given in this certificate (see *Instruction for Use*). However, repolishing the surface, severe corrosion damage to the surface, or other mechanical damage to the surface will invalidate the certification.

This SRM was prepared and certified by G.D. Quinn and R.J. Gettings of the NIST Ceramics Division.

The technical and support aspects involved in the issuance of this SRM were coordinated through the NIST Standard Reference Materials Program by B.S. MacDonald of the NIST Measurement Services Division.

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Certificate Issue Date: 20 June 2003

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Statistical Analysis of the data was performed by N.F. Zhang of the NIST Statistical Engineering Division.

PREPARATION AND ANALYSIS

Disk Properties: The SRM is a hot-isostatically pressed tungsten carbide containing nominally 12 % cobalt binder phase, fabricated in the form of disks that have been ground and polished to provide a flat, parallel, polished surface. The average grain size (mean linear intercept) of the carbide grains is approximately 0.5 μm. The disks have a nominal diameter of 25 mm and a thickness between 9.4 mm and 9.6 mm. The hardness is uniform across the polished surface.

Certification Procedures: Five NIST Vickers indentations are located in the disk center on the polished surface and are arranged in a pattern as shown in Figure 1. A single Knoop indentation serves as a pointer-marker. Some disks have both the top and bottom surfaces polished. Do not use the surface with the scribed number. The indentations were made in accordance with ASTM E 384-99 [1], ASTM C 1327-96a [2], CEN prEN 843-4 (2001) [3], and ISO 14705-2000 [4]. The five NIST indentations were made by a dedicated Wilson Tukon 300 table model hardness testing machine. The hardness machine applied load through a fixed mass ("dead weight") attached to a lever beam. The load on the indenter was nominally 9.801 N (1.000 kgf). Load was repeatedly verified with a load cell and was within 0.1 % of the specified value. The gravitational constant at the site where the indentations were made was 9.801 m/s^2. The Vickers diamond had average face angles of 135° 57' 13" and a tip offset of 0.19 μm. The indenter constant was therefore 1.8541 and was thus within 0.02 % of the ideal 1.8544 value.

The indentations were examined and digitally photographed with a high resolution Diagnostic Instruments Spot Insight digital camera (3 color CCD, 11.8 mm × 8.9 mm chip, 1600 × 1200 pixels) on a Leica DMRM laboratory research microscope using a 40X objective lens with a numerical aperture of 0.6. Bright field illumination with a green filter was used with properly adjusted aperture and field diaphragms. A 1.6X slider and a 3.2X camera magnifier magnified the image further. The image was projected onto a Hitachi CM 771 high-resolution (1600 × 1280 pixel) SVGA flat monitor with 0.22 mm pitch. The indentations appeared 68 mm large (≈ 2000 magnification) on the monitor, but were digitally enlarged to 200 mm (≈ 5 700 magnification) for close inspection of the diagonals and the tips.

The horizontal (d_1) and vertical (d_2) diagonal lengths were measured on the computer digital image to a resolution of 0.1 μm. The average diagonal size was computed as $d = (d_1 + d_2)/2$. The indentations were symmetric and the two diagonal lengths usually concurred to 0.0 μm to 0.3 μm. Some were different by 0.4 μm or 0.5 μm. Only in a few instances were the diagonals different by 0.6 μm – 0.8 μm. The repeatability uncertainty for making the average optical microscope diagonal length d reading for a single indentation was 0.13 μm at the 95 % confidence level (2σ). This uncertainty estimate was from five repeat optical microscope measurements of single indentations. The repeat measurements were done on fifty different indentations (ten indentations in five different disks).

An optical stage micrometer (WILD model 31045) was used to calibrate and frequently recheck the length calibration measurements. The stage micrometer was calibrated by the NIST calibration services to an accuracy uncertainty of better than 0.01 % for a length of 140 μm, which covered the entire camera field of view with the 40X objective.

The polished surface was also inspected by an optical microscope at magnifications of 50X to 400X for the general condition and evidence of any polishing or material defects.

Diagonal lengths of five indentations in selected prototype SRM disks were also measured with calibrated scanning electron microscope (SEM) photographs. The average SEM lengths readings agreed with the average optical readings to 0.1 μm or better. Additional details on the preparation of this SRM are in references 5-7. Subsequent to those publications, it was determined that a high-resolution digital camera attached to an optical microscope achieved the same resolution and equivalent uncertainties than measurements from calibrated SEM photos for Vickers indentations.

Discussion of Uncertainties

The uncertainty estimates were made in accordance with the NIST and ISO Guides [8,9]. Uncertainties were either evaluated through statistical means, type A, or by other means, type B. Uncertainties listed are the 95 % confidence intervals (2σ) in each instance. The values in parenthesis are the uncertainties as a percentage and are two times the coefficient of variation. Uncertainties for the average values of d and HV for the 5 NIST indentations were estimated by dividing the uncertainty for an individual measurement by the square root of 5, which was the sample size.

Since the diagonal length for an indentation is the average of two readings (d_1 and d_2), the uncertainty in the average diagonal length is less than the uncertainty for making a single diagonal length reading (d_1 or d_2) for a single indentation The uncertainty of the average of the two readings is $\sqrt{2}/2 = 0.707$ times the single diagonal length uncertainty assuming the same uncertainty of d_1 and d_2.

Uncertainty estimates were made by analysis of the indentations made in each of the 96 disks that are certified for this SRM as well as a subset of five additional disks that were set aside from the production sets. The subset of 5 disks was studied in greater detail and received more indentations.

For the subset of 5 disks from the production set, the within disk, between disk, and the measurement method repeatabilities were determined by indenting five disks with five indentations in two different locations, and then measuring the same indentations on 5 separate days. An ANOVA analysis showed that the disk effect was statistically significant, while the day and location effects were not significant. From the one-way analysis and using disk as the factor, the mean square error (MSE) was 0.0254 μm^2 with 245 degrees of freedom. The test for homogeneity of variances showed that variances between the disks were not significantly different.

A one-way analysis of the diagonal length readings of the indentations in all 96 disks to be certified indicated that the disk effect was significant. Therefore each disk is individually certified. The MSE, using disk as the factor, was 0.0262 μm^2 with 384 degrees of freedom, an estimate very close to the one obtained from the five disks studied in the previous paragraph. The test for homogeneity of variances showed that the variances between the 96 disks were not statistically significant.

The pooled variance from the two paragraphs above is 0.0259 μm^2, and thus the uncertainty for each NIST indentation is $\sigma_e = 0.32$ μm ($\pm$ 0.9 %), at a 95 % confidence level where the subscript "e" denotes each. The uncertainty for the average of the five NIST indentations σ_{avg} is 0.32 $\mu m / \sqrt{5} = 0.14$ μm ($\pm$ 0.4 %).

The uncertainty for a single future (new) indentation is 0.35 μm ($\pm$ 1.0 %).
The uncertainty for the average of five future (new) indentations is 0.20 μm ($\pm$ 0.6 %).

Overall uncertainties were estimated by combining the variances of individual sources of uncertainty from the indentation load and the diagonal length measurements, with the exception of the uncertainty in HV, wherein the variance in diagonal length was weighted by a factor of 4 in accordance with the law of propagation of error.

The uncertainty for the average hardness HV of the five NIST indentations is 0.29 GPa (28 kgf/mm^2) or $\pm$ 1.9 %.

The uncertainty for average hardness HV of five future (new) indentations is 0.41 GPa (40 kgf/mm^2) or $\pm$ 2.7 %.

INSTRUCTIONS FOR USE

This SRM may be used with all hardness and microhardness testing machines whereby a Vickers indentation is made and then measured with a microscope.

The user may measure the sizes of the 5 NIST indentations to within 0.1 μm (0.0001 mm) or 0.2 μm (0.0002 mm) with an optical microscope in order to verify that the test machine optics and the length measuring apparatus are optimized. A total magnification of 400X or higher is recommended and in accordance with ASTM C 1327 and ISO 14705. 400X or 500X magnifications are commonly available with most hardness machines, many of which have 40X or 50X objectives and 10X eyepieces. The SRM may also be used with optical microscopes with cameras that display the image on a computer monitor, or with scanning electron microscopes.

Magnifications and length measuring equipment should be checked by the use of a calibrated stage micrometer.

The tips of the indentations may be slightly rounded or distorted by the tungsten carbide grains, which have an average size of 0.5 μm. Grains near the tip may dislodge and cause the indentation edge to be slightly irregular as shown in Figure 2. This is unavoidable, but is much less a problem with this SRM than for many ceramics. In a few rare instances, a tiny hairline crack may extend from the tip of the indent as shown in Figure 2, but these usually are very thin and at an angle to the diagonal length axis and can be easily discounted.

Pay special attention to the *Storage and Handling* requirements. Keep the blocks clean and free from fingerprints, body oils or salts, lab dust contamination and water. Avoid corrosion damage to the polished surface.

Producing New Indentations: The user may make new indentations in the disk. Be careful not to indent over the NIST indentations. Some disks have a few microstructural irregularities (small spots) or polishing scratches, which may be avoided when selecting a site to be indented. Even if an indentation is made over a small polishing scratch, the scratches are so shallow that they do not alter the hardness response and the indentations are valid. Indentations may be placed in any region of the polished surface, except within 1 mm of the outer rim since slight edge rounding from the polishing may distort the indentation shape. Some disks have a greater concentration of polishing scratches at the rim. The indentations should not be made too close to each other, lest they interfere with each other. A minimum spacing of 4d between centers is specified in ASTM E 384, ASTM C 1327, and ISO 14705.

Special care should be taken to ensure that the loading rates and load duration are as prescribed by the appropriate standard. There shall be no vibrations or impact imparted to the machine during the indentation cycle. The surface must be clean. Methanol should be used to clean the surface in accordance with the storage and handling instructions above.

Storage and Handling: The tungsten carbide disk is hard and durable but the polished surface should be protected from damage or abuse.

CAUTION: ***The polished surface is susceptible to corrosion from water, finger oils, body salts, or laboratory dust.***

It should be kept clean.

The disk should be stored in a container or envelope when not in use, but such container need not be airtight. The disk should be wrapped in a simple clean white tissue. Anti corrosion paper also may be used, but if the paper has ink labeling or printing on one side, then that side should not contact the disk.

The disk should be handled by the rim, with care that finger oil or salts do not contact the polished surface around the rim. Latex gloves may be used. If the surface is contacted with the fingers, water, or other contaminant, clean the surface. It is very easy to clean the surface. The polished surface may be cleaned with simple white tissue paper and, if necessary, use **methanol.**

CAUTION: ***DO NOT use water or ethyl alcohol (ethanol) to clean the surface***. (Ethyl alcohol has water solubility.)
DO NOT heat the blocks in an oven,

If the polished surface is contaminated by contact with water, finger oils, or finger salts for a protracted period, (days or weeks), corrosion damage will occur. Such damage will manifest itself as small white patches, or in extreme cases, as a milky white haze across the entire disk surface. The disk may still be used for indentations provided that indentations are placed in uncorroded regions. If the disk surface is entirely corroded, then the disk may be repolished but the certification of the NIST indentations is invalidated since their dimensions and appearance will be altered.

REFERENCES

[1] ASTM E 384-99 *Standard Test method for Microhardness of Materials*; ASTM Annual Book of Standards: Vol. 3.01 (2002).

[2] ASTM C 1327-96a Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics, ASTM Annual Book of Standards, Vol. 15.01 (2002).

[3] European Standard, prEN 843-4, Advanced Technical Ceramics – Monolithic Ceramics – Mechanical properties at Room Temperature – Part 4: Vickers, Knoop and Rockwell Superficial Hardness Tests.

[4] ISO 14705 (2000) Fine Ceramics (Advanced Ceramics, Advanced Technical Ceramics) – Test Method for Hardness of Monolithic Ceramics at Room Temperature.

[5] Gettings, R.; Quinn, G.; Ruff, W.; Ives, L.; *New Hardness Standard Reference Materials (SRM's) for Advanced Ceramics*; Ceram. Eng. and Sci. Proc., Vol. 15, #5, pp. 717-826 (1994).

[6] Gettings, R.J.; Quinn, G.D.; Ruff, A.W.; Ives, L.K.; *Development of Ceramic Hardness Reference Materials*; pp. 617-624 in *New Horizons for Materials*, ed. P. Vincenzini, Proceedings of the 8th World Ceramic Congress, CIMTEC, Florence, Italy, July 1994, Techna, Florence (1995).

[7] Gettings, R.J.; Quinn, G.D.; Ruff, A.W.; Ives, L.K.; *Hardness Standard Reference Materials (SRM's) for Advanced Ceramics*; in proceedings of the 9th International Symposium on Hardness Testing in Theory and Practice, Dusseldorf, Nov. 1995, VDI Berichte #1194, pp. 255-264 (1995).

[8] Taylor, B.; Kuyatt, C.; *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*; NIST Tech. Note 1297, September (1994).

[9] ISO, *Guide to the Expression of Uncertainty in Measurement*; International Organization for Standardization, Geneva, Switzerland (1993).

Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at: Telephone (301) 975-6776 Fax (301) 926-4751, e-mail srminfo@nist.gov, or via the Internet http://www.nist.gov/srm.

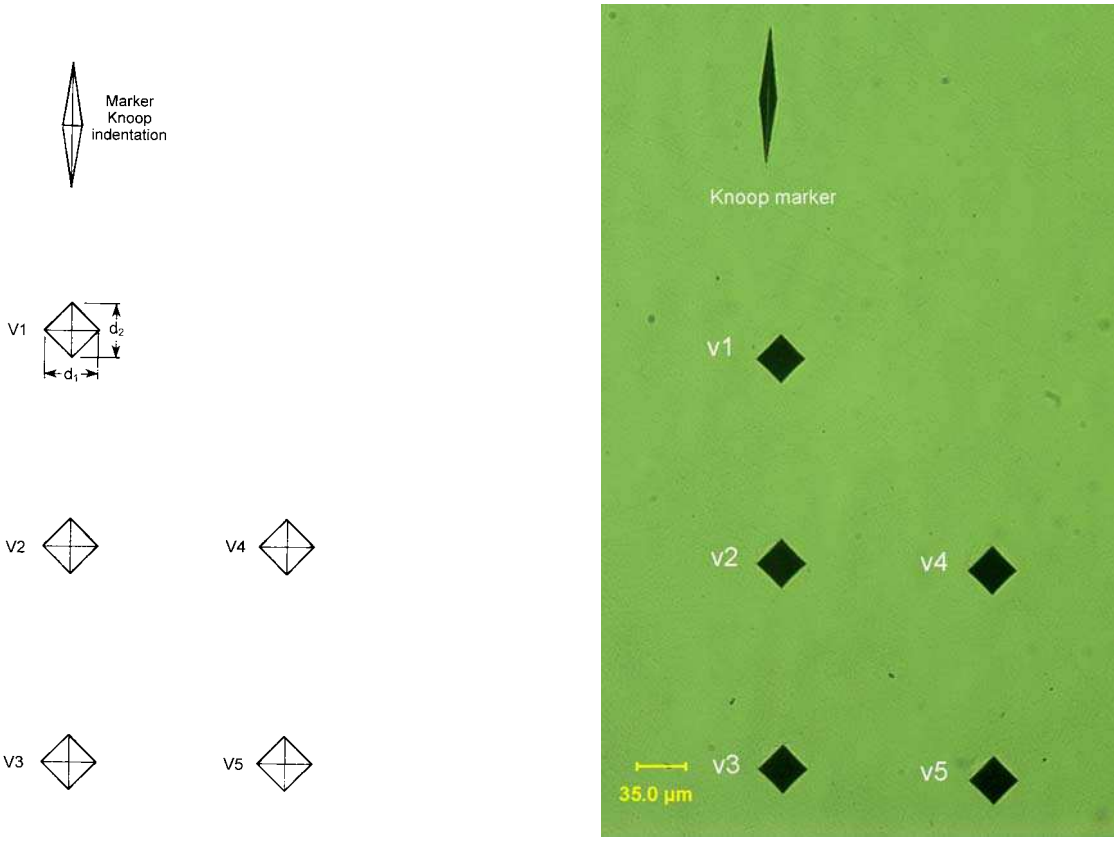

Figure 1. The five NIST Vickers indentations are located in the middle of the block. A single marker Knoop indentation helps identify the NIST cluster.

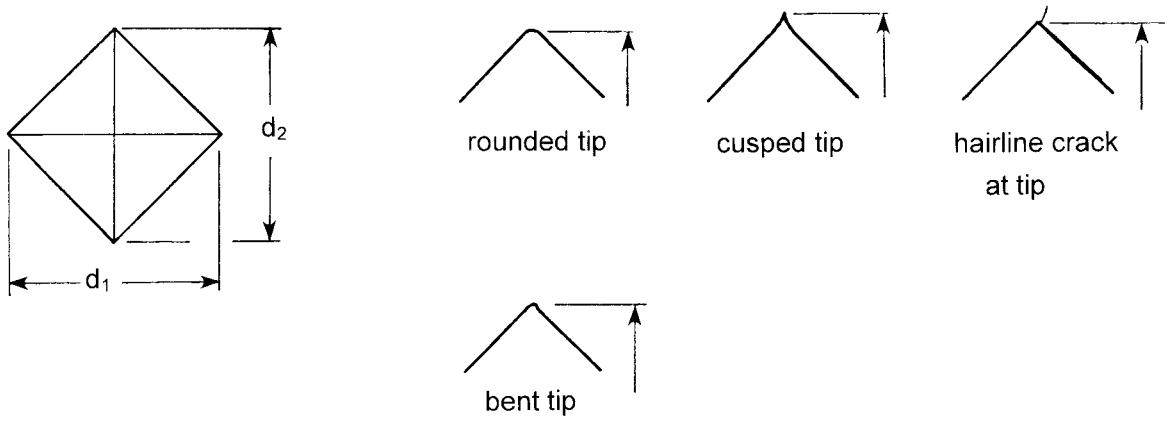

Figure 2. Details of the indentation tips.

Table 1. Certified Diagonal Lengths, Average Diagonal Lengths, and Vickers Hardness for the 96 Disks of SRM 2831

NOTE: A few disks from the numerical sequence (e.g, disk W-1) are not included since they were set aside for archival purposes or were rejected for inclusion in the SRM set.

Disk Number W-	Size of NIST Reference Indentations V1 μm	V2 μm	V3 μm	V4 μm	V5 μm	Average (V1-V5) Diagonal Size μm	Average HV1 (9.8N) GPa	Average HV1 kgf/mm^2	Special comments
2	34.70	34.80	34.85	34.65	35.10	34.82	14.99	1530	Rim scratches
3	34.50	34.75	34.95	34.70	34.65	34.71	15.09	1539	
4	34.40	34.60	34.50	34.65	34.55	34.54	15.23	1554	
5	34.40	34.55	34.90	34.45	34.65	34.59	15.19	1550	Rim scratches
6	35.15	35.10	35.10	35.05	35.20	35.12	14.74	1503	
7	34.40	34.70	34.55	34.75	34.75	34.63	15.16	1546	
8	34.85	35.05	35.05	34.80	34.75	34.9	14.92	1523	
9	34.70	34.70	34.75	35.20	35.05	34.88	14.94	1524	Minor chip on rim; 1 spot; harmless shallow scratches in middle
10	34.70	34.75	34.95	34.75	34.75	34.78	15.03	1533	
11	34.30	34.50	34.50	34.60	34.50	34.48	15.29	1560	Pore at rim
12	34.60	34.45	34.45	34.60	34.50	34.52	15.25	1556	
13	34.80	34.55	34.55	34.40	34.50	34.56	15.22	1553	One small spot 2 mm in from rim
14	34.40	34.80	34.55	34.35	34.35	34.49	15.28	1559	A few minor polishing scratches
15	34.55	34.75	34.75	34.60	34.70	34.67	15.12	1543	
16	34.45	34.35	34.35	34.55	34.55	34.45	15.31	1563	
17	34.85	35.25	35.00	35.05	35.05	35.04	14.80	1510	
18	34.45	34.20	34.45	34.70	34.55	34.47	15.30	1561	
19	34.55	34.30	34.75	34.60	34.85	34.61	15.17	1548	One minor polishing scratch
21	34.65	34.75	34.80	34.90	35.05	34.83	14.98	1529	
22	34.90	34.60	34.75	34.70	34.70	34.73	15.07	1537	A few harmless minor scratches in the middle; one larger scratch can be avoided.
23	34.80	34.55	34.65	34.60	34.85	34.69	15.10	1541	
24	34.55	34.55	34.65	34.70	34.55	34.6	15.18	1549	
25	34.80	34.90	34.80	34.75	34.80	34.81	15.00	1530	
26	34.90	34.60	34.90	34.65	34.90	34.79	15.02	1532	
27	34.60	34.75	34.80	34.85	34.80	34.76	15.04	1535	
28	34.65	34.70	34.90	34.90	34.70	34.77	15.03	1534	
29	34.40	34.40	34.60	34.60	34.60	34.52	15.25	1556	
30	34.80	34.80	34.55	34.95	34.65	34.75	15.05	1536	

Disk Number W-	Size of NIST Reference Indentations V1 μm	V2 μm	V3 μm	V4 μm	V5 μm	Average (V1-V5) Diagonal Size μm	Average HV1 (9.8N) GPa	Average HV1 kgf/mm^2	Special comments
31	34.60	34.75	34.90	34.95	34.60	34.76	15.04	1535	
32	34.70	34.80	34.70	34.70	34.70	34.72	15.08	1538	One small spot 4 mm in from rim
33	35.30	35.25	34.95	34.95	35.00	35.09	14.76	1506	Many small pits-spots. Scratch and chatter mark area on one side.
34	34.55	34.70	34.50	34.55	34.65	34.59	15.19	1550	
35	35.15	35.05	34.90	34.85	34.95	34.98	14.85	1516	Two spots on the rim
36	34.45	34.65	34.40	34.25	34.65	34.48	15.29	1560	
37	34.75	34.55	34.75	34.90	34.90	34.77	15.03	1534	A few black spots
38	34.80	34.65	34.90	34.85	35.05	34.85	14.97	1527	
39	35.35	35.00	34.90	35.35	35.20	35.16	14.70	1500	
40	34.75	35.00	34.85	34.85	35.10	34.91	14.91	1522	The marker Knoop indenter was inadvertently dragged. Disk is OK.
42	34.35	34.15	34.75	34.35	34.55	34.43	15.33	1564	A few polishing scratches
43	34.65	34.55	34.45	34.70	34.45	34.56	15.22	1553	
44	34.90	34.90	34.80	34.80	35.00	34.88	14.94	1524	Harmless tiny crack on right of V5
45	34.45	34.60	34.60	34.55	34.70	34.58	15.20	1551	
47	35.00	34.55	34.40	34.35	34.40	34.54	15.24	1555	
48	34.65	34.60	34.95	34.80	34.80	34.76	15.04	1535	
49	34.70	34.45	34.55	34.50	34.55	34.55	15.23	1554	One small pit near the rim; a couple of small spots
50	35.15	34.70	34.90	35.20	35.05	35	14.84	1514	A small chatter pattern from polishing and one scratch near the rim should be avoided.
52	34.20	34.35	34.85	34.95	34.80	34.63	15.16	1547	One small spot 3 mm in from rim
53	34.70	34.75	34.65	34.75	34.60	34.69	15.10	1541	Chip on rim
54	34.50	34.80	35.15	34.60	34.85	34.78	15.03	1533	
55	34.45	34.70	34.45	34.55	34.70	34.57	15.21	1552	
56	34.25	34.55	34.60	34.55	34.75	34.54	15.24	1554	
57	34.80	34.90	34.95	34.95	34.95	34.91	14.91	1522	One large scratch
58	34.30	34.50	34.50	34.85	34.90	34.61	15.17	1548	One small scratch near the middle
60	34.65	34.97	34.56	34.46	34.52	34.632	15.15	1546	Six small spots which may be avoided. There is a second set of 5 NIST indentations.
61	34.80	34.75	34.80	34.70	34.60	34.73	15.07	1537	
62	34.53	34.77	34.70	34.85	34.73	34.716	15.08	1539	Three spots may be avoided. There is a second set of 5 NIST indentations.
63	34.85	34.90	34.85	34.85	34.85	34.86	14.96	1526	One minor spot halfway between the rim and center. Hairline crack on top of V5.

Disk Number W-	Size of NIST Reference Indentations V1 μm	V2 μm	V3 μm	V4 μm	V5 μm	Average (V1-V5) Diagonal Size μm	Average HV1 (9.8N) GPa	Average HV1 kgf/mm^2	Special comments
64	34.20	34.10	34.20	34.65	34.55	34.34	15.41	1573	
66	35.10	35.00	35.30	35.20	35.35	35.19	14.68	1498	
67	34.75	34.50	34.70	34.55	34.60	34.62	15.16	1547	
68	34.60	34.80	34.75	34.65	34.60	34.68	15.11	1542	
69	34.45	34.40	34.65	34.50	34.65	34.53	15.24	1555	
70	34.60	34.50	34.60	34.55	34.55	34.56	15.22	1553	
71	34.60	34.80	34.80	34.75	34.85	34.76	15.04	1535	
72	34.60	35.00	35.05	34.85	34.80	34.86	14.96	1526	
73	34.45	34.60	34.95	34.65	34.75	34.68	15.11	1542	
74	34.35	34.50	35.05	34.80	34.75	34.69	15.11	1541	
75	34.40	34.35	34.60	34.50	34.85	34.54	15.24	1555	One small polishing scratch near middle
76	34.45	34.40	34.75	34.50	34.75	34.57	15.21	1552	One spot 3 mm from rim; a few irregularity spots on one side; small crack on left of V2
77	34.45	34.40	34.75	34.50	34.75	34.57	15.21	1552	
78	34.85	34.60	35.05	34.50	34.75	34.75	15.05	1536	A few minor polishing scratches
80	34.80	34.70	34.95	34.75	34.70	34.78	15.03	1533	A few minor harmless scratches, one of which goes through the Knoop marker indent.
81	34.85	34.80	34.95	35.15	35.05	34.96	14.87	1517	Many small scratches
82	34.95	35.25	35.15	34.95	34.95	35.05	14.79	1510	
83	34.75	34.70	35.05	35.00	34.85	34.87	14.95	1525	
84	34.50	34.95	34.65	34.80	35.05	34.79	15.02	1532	One small spot-pit 3 mm in from rim
86	34.95	35.25	35.15	34.95	34.95	35.05	14.79	1510	A couple of tiny spots on one side
88	34.15	34.60	34.40	34.90	34.70	34.55	15.23	1554	Some polishing scratches
89	34.75	34.95	34.80	34.75	35.00	34.85	14.97	1527	One small scratch near middle
90	34.35	34.60	34.55	34.65	34.75	34.58	15.20	1551	
91	34.40	34.70	34.65	34.85	34.80	34.68	15.11	1542	Two small spots
92	34.60	34.75	34.80	34.70	34.75	34.72	15.08	1538	Crack and small bulge on right side of V4. Tip OK.
93	34.75	35.15	34.70	35.10	34.85	34.91	14.91	1522	
94	34.50	34.80	34.55	34.95	34.65	34.69	15.10	1541	
95	34.50	34.65	34.75	35.05	34.80	34.75	15.05	1536	A few black spots or microstructural irregularities and a few scratches may be avoided.
96	34.60	34.60	34.75	34.50	34.75	34.64	15.15	1545	
97	35.20	34.90	35.10	34.95	34.95	35.02	14.82	1512	Small minor scratches
98	35.25	35.20	35.30	34.90	35.40	35.21	14.66	1496	Minor scratches

Disk Number W-	Size of NIST Reference Indentations V1 μm	V2 μm	V3 μm	V4 μm	V5 μm	Average (V1-V5) Diagonal Size μm	Average HV1 (9.8N) GPa	Average HV1 kgf/mm^2	Special comments
99	34.35	34.80	34.55	34.75	34.80	34.65	15.14	1545	
100	34.80	34.60	34.80	34.45	34.90	34.71	15.09	1539	One tiny spot 4 mm in from rim; a few polishing scratches
101	34.30	34.70	34.75	34.55	34.65	34.59	15.19	1550	
102	34.50	34.80	34.55	34.70	34.95	34.7	15.10	1540	One tiny spot 3 mm in from rim
103	34.65	34.85	34.80	34.45	34.65	34.68	15.11	1542	One spot near rim
106	35.25	35.10	35.20	34.85	35.00	35.08	14.77	1507	A few spots
107	34.85	34.90	35.10	34.95	35.15	34.99	14.85	1515	
108	35.10	35.40	35.55	35.25	35.85	35.43	14.48	1478	