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DEVELOPMENT OF BERYLLIUM MIRROR TURNING TECHNOLOGY

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ABSTRACT

Because of the unique properties of beryllium (Be) and the advantages of single point turning, a development program has been instituted to single point turn beryllium as a means to produce optics. Initial efforts to diamond turn beryllium resulted in less than desirable results and development efforts were directed at finding a more suitable tool material. Both single and polycrystalline tool materials were evaluated and cubic boron nitride (CBN) was found to produce the better results. Tool wear has been the primary limitation in precision machining beryllium and advances have allowed a two order-of-magnitude reduction in this problem. After considerable efforts, results with CBN appear to be approaching a limit, and diamond, as tool material, was reevaluated with promising results. A development program is now under way to determine if diamond may be used to machine larger and more complex beryllium parts.

BACKGROUND

The development group at the Oak Ridge Y-12 Plant* has been actively involved with the development of precision diamond turning technology for over 25 years. Primarily soft face-center cubic metals such as aluminum, copper, silver, lead, and gold have been found to be diamond machinable; other metals such as electroless nickel, germanium and several infrared window material were also found to be diamond machinable. This technology has been used to fabricate a variety of nonferrous metal mirrors ranging in size from a fraction of an inch to two meters in diameter. The US Army Strategic Defense Command and Optics MODIL Program recognized the potential of this technology and are supporting efforts to extend it to include beryllium as a diamond machinable material. Several attempts, by various research facilities have been made during the past twenty years to diamond turn beryllium with limited success. The following paper reviews encouraging results obtained at Oak Ridge Y-12 Plant in this effort.

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RESEARCH AND RESULTS

Initial efforts to diamond turn beryllium using a single crystal natural diamond yielded less than desirable results. Catastrophic tool failure occurred shortly after initiation of the machining operation. An investigation was conducted to find a more compatible tool material. Both single and polycrystalline materials were evaluated. The alternative materials evaluated included single crystals of nitrogen doped diamond, titanium nitride coated diamond, cubic boron nitride (CBN), titanium carbide, titanium nitride, silicon carbide, tantalum carbide, polycrystals of tungsten carbide, and several CBN materials. The better results were obtain with the CBN materials. Figure 1 depicts flank wear which occurred during several experiments and how the flank wear was significantly reduced by using improved cutting tools, shallow depth-of-cuts, special lubricants, and slower cutting rates. Lower wear rates are needed to fabricate mirrors to a greater figure accuracy.

The finishes obtained using the best CBN tools were not as good as the finishes routinely obtained with diamond tools on aluminum and copper. An investigation was conducted to determine the reason for the poorer finishes produced by CBN tools. In the investigation, a two-inch diameter copper (OFHC) sample was first diamond turned and then CBN turned over half of its radius, using the same machining parameter for both operations (Figure 2). It can be seen from the figure that the diamond turned segment is significantly better than the CBN turned segment. Profilometer traces shown in Figure 3 confirm the results. An evaluation was then made of the edge of the CBN and diamond tools using a scanning electron microscope (SEM). Results from the SEM are shown in Figure 4. It can be seen that the diamond has a much smoother, sharper edge than does the CBN tool. These results lead to the conclusion that the existing CBN tools could not produce the quality of finish that has been obtained with diamond. These results encouraged reevaluation of diamond as a tool material for machining Be.

The reason for breakdown of the diamond while attempting to machine beryllium was not well understood. Several metallurgists and chemists were consulted in hopes that they may provide insight for the diamond failure. The concept that elevated temperature at the diamond's cutting edge may be a factor which causes this phenomena was expressed by several of these scientists. Temperature at the cutting edge is produced by friction from the chip and part sliding past the edge. The temperature could be reduced simply by reducing the forces and speeds that occur in the machining process. An experiment was then conducted with four two-inch diameter beryllium samples at very slow spindle and slide speeds and a very light depth-of-cut. Two of these samples were I-70A HIP Be material which were prepared by Hughes Danbury Optical Systems (formerly Perkin-Elmer) in Danbury, Connecticut. The other two samples were prepared by sputtering .001" of high purity Be on diamond-turned aluminum substrates. The sputtered coating was prepared by the coating lab at Y-12. One sample in each set was CBN turned, while the other sample of each set was first CBN turned and then diamond turned (Figure 5). It should be noted that only the center 1" diameter of the I-70A HIP Be sample was diamond turned.

The surface finish on all four samples was evaluated using a Talystep profilometer and the ORNL CASI Scatterometer. The two sputtered samples each had a "cloudy" wedge as depicted in Figure 6. The "cloudy" wedges were caused by crystal orientation and the direction-of-cut in the machining process. This type of cloudiness is commonly observed during the machining of single crystal materials. This cloudiness can be avoided by strategic positioning of a sample in the machining process or by producing a more amorphous coating. Surface finish and BRDF readings were taken on all four samples both parallel and perpendicular (Figure 7) to the machining direction. In the case of the sputtered samples, the BRDF was measured on both the "cloudy" and "shiny" sections. Surface finish results from the Talystep profilometer are shown in Figure 8, and BRDF graphs from the samples are shown in Figures 9, 10, and 11. Both sets of data indicate that the diamond turned samples have better finishes and better scatter characteristics.

These relatively low scatter (BRDF) values for the small bare Be coupons of the as-turned surfaces are comparable to the values needed for Be mirrors in some IR sensor systems. These relatively low BRDF values imply that the subsurface damage is not too severe, but more quantitative data is needed in order to determine if the subsurface damage is currently the limiting factor for achieving low scatter on single point turned Be surfaces. The figure accuracy that has been achieved to date with CBN SPT at normal (fast, i.e., near 850 rpm) turning speeds is still worse than that needed for most optical systems. The slower turning speeds used with the diamond cutting tool has improved the surface figure generated on small coupons, but the figure accuracy achievable on actual mirrors, and especially on large complex Be mirrors, still needs to be demonstrated.

FUTURE PLANS

The success obtained with diamond turning beryllium coupons has been very encouraging. Plans are to development this capability in order that larger more complex beryllium mirrors may be machined. We also plan to evaluate new diamonds for beryllium machining, such as isotopically pure synthetic diamonds. A study to determine the feasibility of grinding Be to obtain optimum finish and figure will also be conducted. The machinability of various forms of beryllium, such as O-50 Be, spherical powder Be, and high purity single crystal Be are to be investigated. Plans are to continue the development of the slow SPT technology and we will be looking for ways to accelerate this turning process while maintaining, or improving, the current quality of the surface figure and finish. It is anticipated that an improved single point turning Be technology will permit the generation of high-quality, nuclear-hardened, figured Be mirrors that will not require any additional cosmetic polish.

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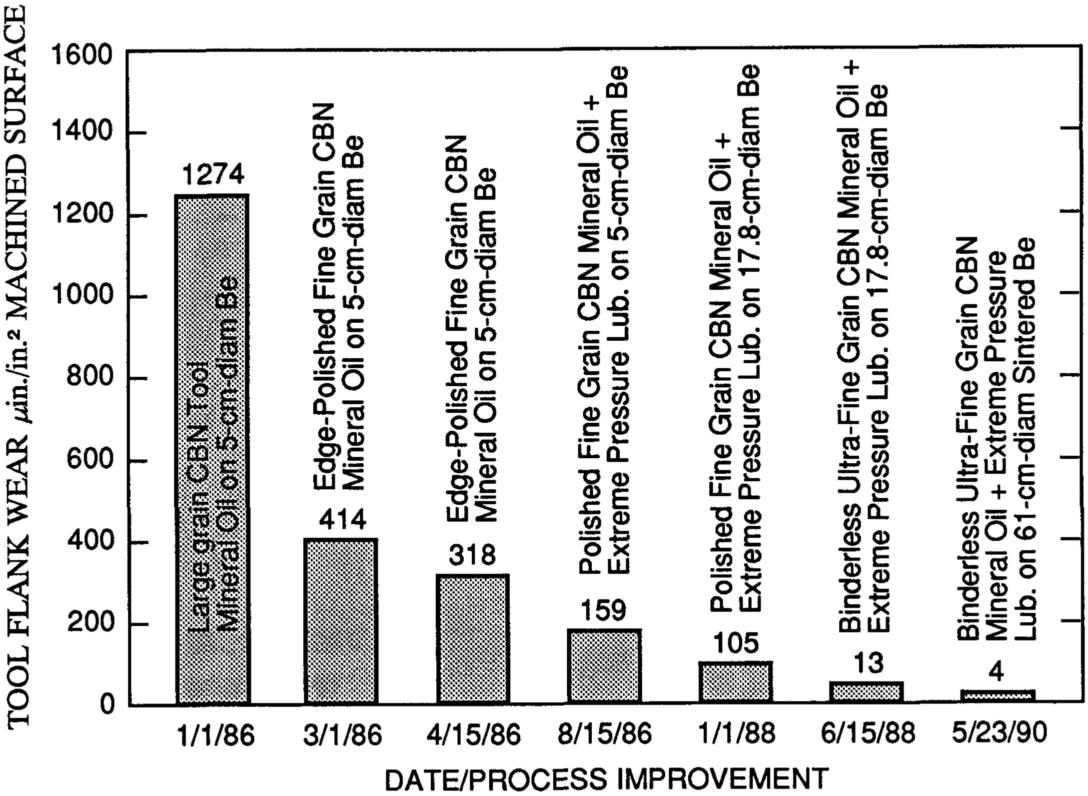
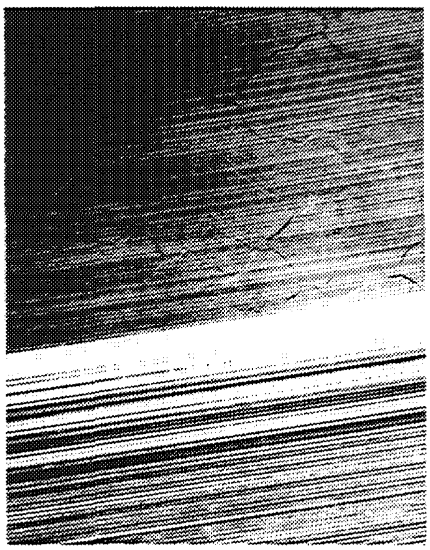
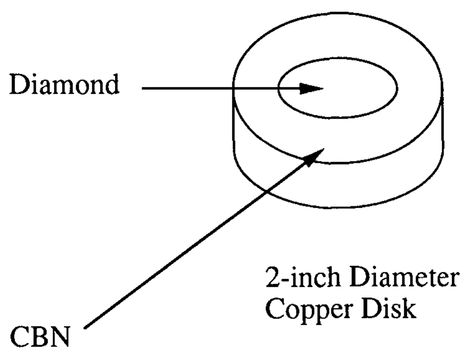


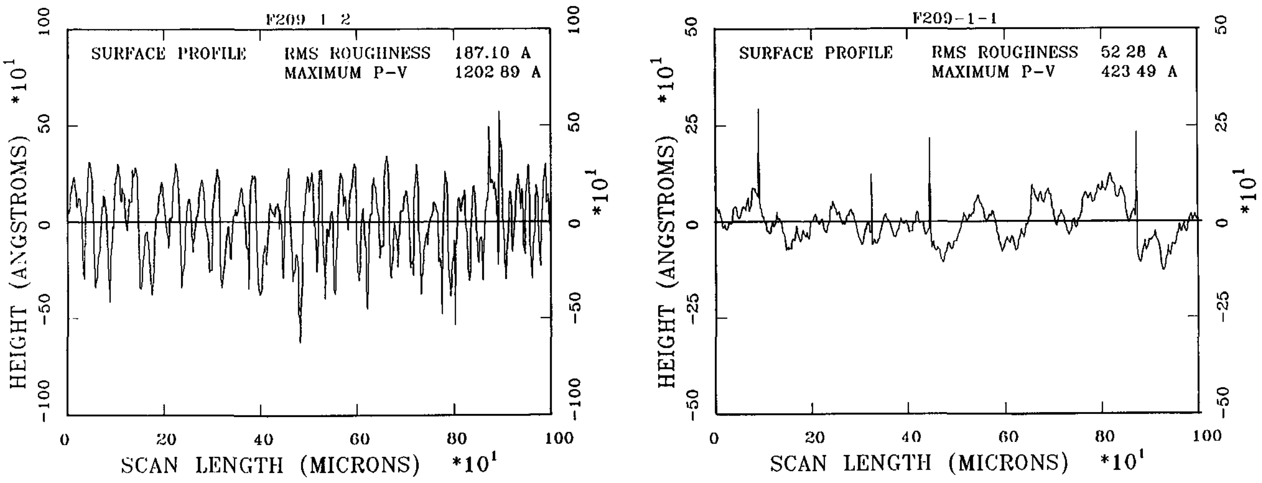
FIGURE 1. Major reductions in CBN tool wear have been achieved for "fast" SPT of Be by the the indicated techniques.





Conditions:
200 microinch depth of cut
850 RPM @ 0.15 inch/min feed rate
Gulf Cut Oil (Coolant
Vacuum pulled chip

FIGURE 2. Comparison of the surface features of diamond and CBN SPT zones on copper suggest a large difference in cutting tool quality.



CBN Tool

Diamond Tool

FIGURE 3. RMS roughness profiles of the two zones shown in Figure 2 clearly show that the diamond tool gave the better results.

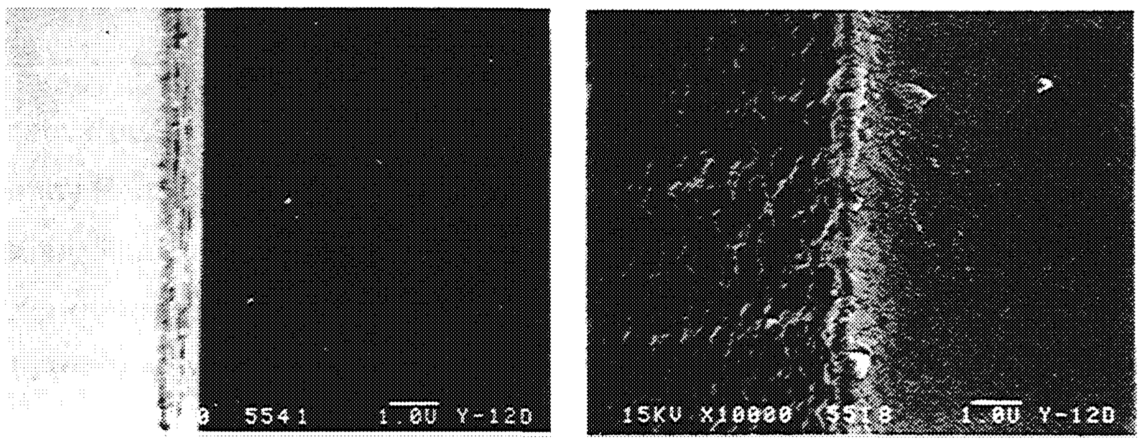


FIGURE 4. Photomicrographs of the cutting tool edges show that the diamond tool edge is much sharper than the CBN tool edge.

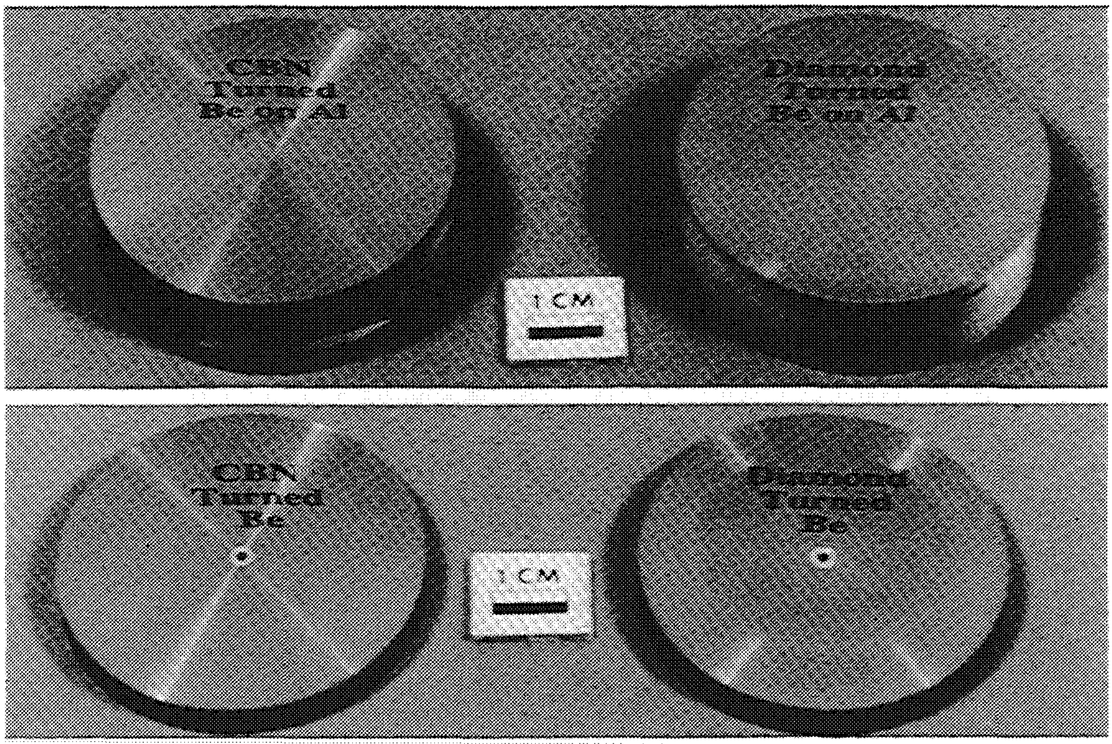


FIGURE 5. One sample in each set was finished with a CBH tool while the other sample was finished with a diamond tool.

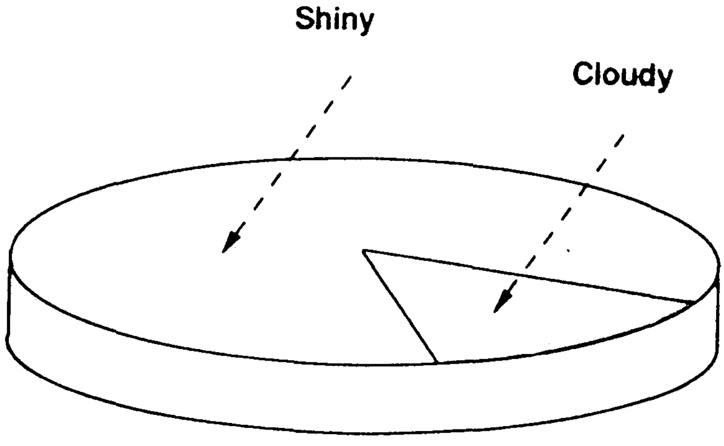


FIGURE 6. Both of the sputtered Be-on-Al samples produced a cloudy region visible to the eye after machining, possibly indicating a grain orientation effect.

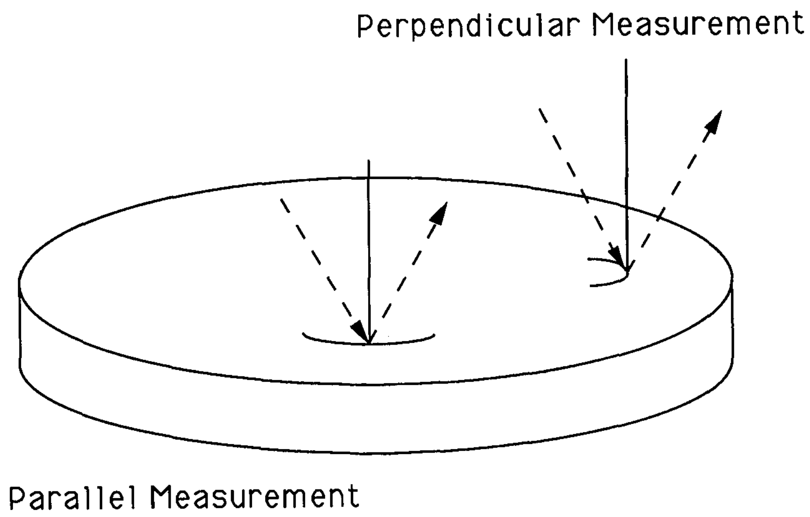


FIGURE 7. BRDF measurements were made both perpendicular and parallel to the SPT grooves to provide an assessment of the optical scatter and machining quality.

	Be (I-70 HIP) (HDOS Samples)		Sputtered Be on Al (Y-12 Samples)	
	CBN 33-1	Diamond 33-3	CBN	Diamond
Instr. Noise	1.06/6.85	1.45/9.82	1.04/7.14	1.02/7.13
Shiny Perp.	218/1585	149/1417	247/1600	101/989
Shiny Para.	240/1802	213/1903	234/1973	106/1468
Cloudy Perp.			484/3129	117/1306
Cloudy Para.			524/3213	141/2432

Data given as RMS/Peak-to-Valley in Angstroms

All Samples machined at 60 RPM and 0.006 in/min, 40-100 microinch depth

FIGURE 8. A comparison of the Talystep profilometry data shows that the diamond tool resulted in the lowest RMS surface roughness values.

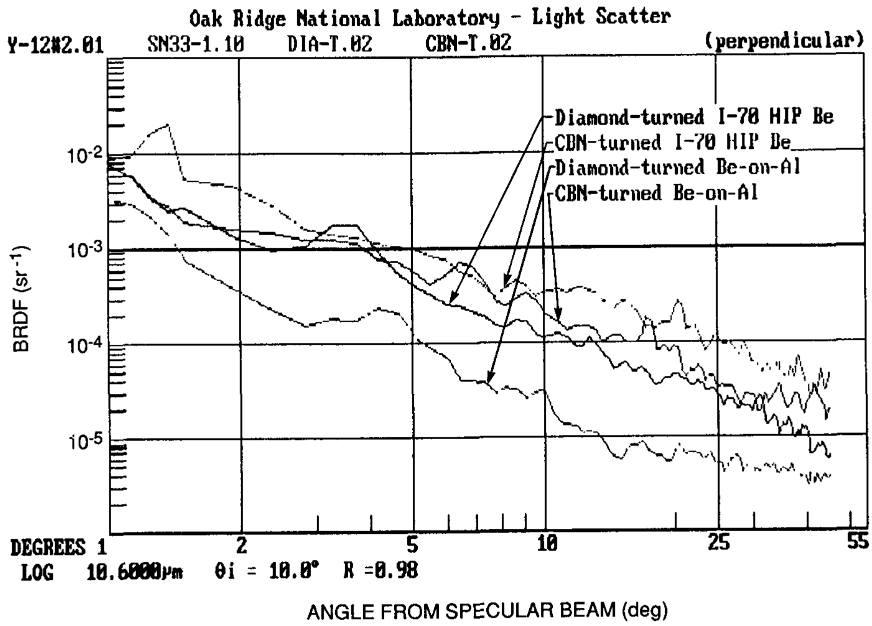


FIGURE 9. The BRDF scatter data of the SPT Be surfaces measured perpendicular to the grooves indicated that diamond gave better results than the CBN tool under similar turning conditions.

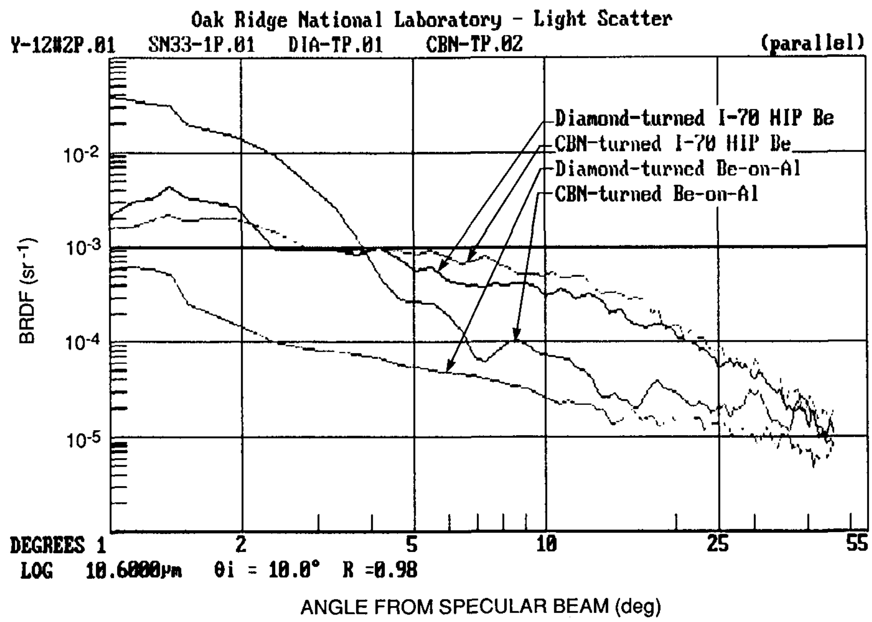


FIGURE 10. The BRDF data of the SPT Be surfaces measured parallel to the grooves is lower than the perpendicular data indicating a smoother surface.

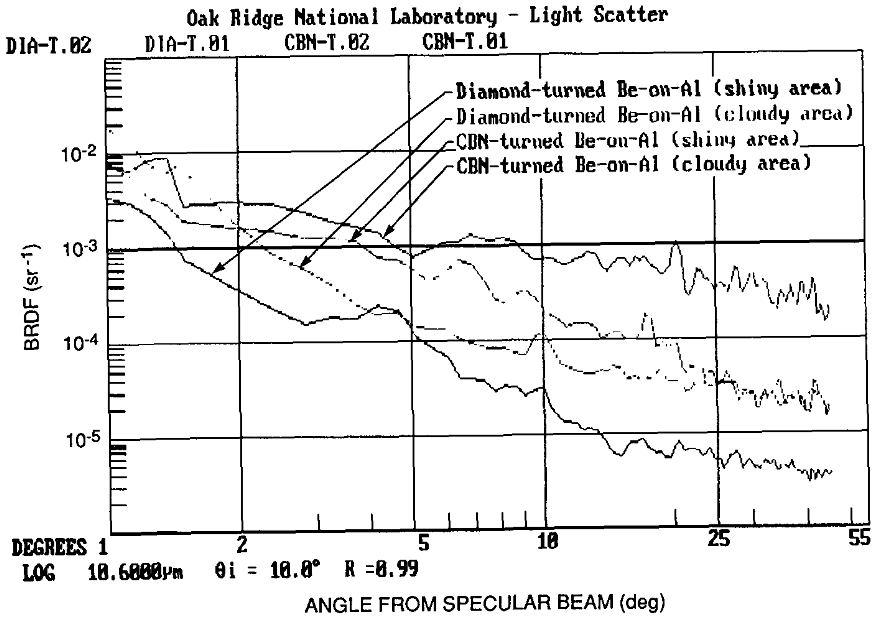


FIGURE 11. A comparison of the BRDF data for the Be-on-Al samples shows the importance of high quality material.