A STUDY OF MACHINING PARAMETERS AND THEIR EFFECT ON THE SURFACE TEXTURE OF PLATINUM ALLOYS FOR JEWELRY APPLICATIONS

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ABSTRACT

Machining is an important part of most jewelry manufacturing operations. Factorial designed experiments were used to investigate the effect of machining variables for three different cutting materials: ceramic, cubic boron nitride and polycrystalline diamond. The surface texture was examined with a scanning-electron-microscope.

KEY WORDS

Platinum, jewelry, machining, surface texture, ceramic, cubic boron nitride, polycrystalline diamond.

INTRODUCTION

Most jewelry products, with the exception of those cast to near-net shape, are subject to at least one metal cutting process. In spite of the many studies of metal cutting or machining, there remains a large gap in understanding the process and applying the knowledge at the manufacturing level. According to a recent CIRP (International Institution for Production Engineering Research) working paper(1), "A recent survey by a leading tool manufacturer indicates that in the U.S.A., the correct cutting tool is selected less than 50% of the time, the tool is used at the rated cutting speed only 58% of the time, and only 38% of the tools are used up to their full tool-life capability." These statistics are quoted for the general manufacturing industry. The situation is much worse for platinum jewelry alloys where there is little information available and manufactures tend to closely guard the information that is available.

An exception is the study of machining properties of platinum by Rushforth(2). Some of his conclusions were as follows:

- Adhesion of platinum to the tool is the most likely source of excessive tool wear during the machining of platinum.

- A contributing factor is the abnormally high hardness values observed in chips produced by the platinum machining operations.

- The use of more positive tool geometries has resulted in increasing tool life while retaining surface finish.

- Improvements in the platinum gloss can be brought about by changing the configuration of the diamond tool and using specific lubricants.

- He suggested that the behavior of platinum at high strains and high strain rates could be a fruitful area for further research.

Rushforth's work was done on the application side, let us now discuss the machining or cutting operations from a theory standpoint.

Astakhov[3] has published a recent book in which he describes the shortcomings of the orthogonal cutting (single shear plane) model which is generally referenced. It is not a good approximation for the real cutting process due to the requirements that the stress gradient in the single shear plane must be infinite and the acceleration of the particles would also be infinite. Hence, the chip forms by the process of simple (pure) shear. The resultant force on the tool face and the resultant force on the shear plane are equal in magnitude and opposite in direction. The model does not account for work piece materials which cannot be deformed by shearing and it cannot explain how chip formation can be accomplished by simple shearing.

Astakhov[3] indicates the appropriate model gives the configuration of the deformation zone based on a slip-line field consideration. This gives the deformation initial and outer boundary limits. Taken into consideration are chip formation and properties, chip separation and the behavior of the work piece material.

Another aspect of machining studies is the characterization of the machined surface. The reference we used was the ASME B46.1 – 1995[4]. We shall refer to their definitions of surface texture, roughness and waviness. Surface texture is the composite of certain deviations that are typical of a real surface. It includes roughness and waviness. Roughness is the finer irregularities of the surface texture that usually result from the inherent action of the production process or material condition. Waviness is the more widely spaced component of surface texture. Waviness may be caused by such factors as machine or work piece deflections, vibration and chatter. Roughness may be considered as superimposed on a wavy surface.

Reference 4 (Page 22) has a figure detailing the instruments used in measuring surface texture. The scanning-electron-microscope was chosen for this study to characterize the surface texture. However, the characterization was not done quantitatively but qualitatively. The surface was ranked from the least rough and wavy to the most rough and wavy (1 through 8).

EXPERIMENTAL PROCEDURE

All machining was done on a standard tool room lathe with automatic cross feed. Spindle speed was measured in RPM with an accuracy of ±10. The feed speed indicator on the lathe was in graduations from 0-100. Actual feed speed was determined by measured observations. Inserts and insert holder were supplied by Valenite. All inserts were clampdown types, with a diamond shape and 7 degrees of relief. No chip breaker features were used.

The samples were produced from drawn tubing with dimensions of 1.00" O.D., 0.75" I.D., and wall thickness of 0.25". The tubing was cut into 0.5" lengths. Hardness and microstructure measurements were made on the tubing.

The pieces were fixtured on the lathe with expanding arbors and the outside surface was trued using a PCD insert with an aqueous lubricant.

All inserts were not used for more than two runs so that tool wear was not a significant factor in our experiments.

To conserve metal, each sample was used for two runs. Each run covered half the length of the tube or .25".
When using the experimental Lubrajel, due to its thick viscosity, it was applied by hand with an oil-can type of dispenser. When using the TrimSol, the lathes pump directed a stream of lubricant down at the cutting edge of the insert. When a cold air gun was used, the cold air stream was directed at the cutting point of the insert pointing in the direction of the feed.

Once the cut was done, chips or strings were collected for SEM examination. After both runs were done on each piece, the piece was removed from the lathe and the runs were identified on the piece.

The experiment features the use of factorial design. This method provides a controlled way of assessing the influence of various variables on the outcome of the experiment. In our case, we want to look at feed speed, spindle speed, cutting depth, and lubricant choice.

For each factor, two levels were picked, a high (+) and a low (-). If we look at 3 factors at 2 levels each, then we have a 23 level experiment. This encompasses 8 separate runs under the following conditions:

	Feed Speed	Spindle Speed	Cutting Depth
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

Each run was done according to the above parameters. Runs 1 and 2 were done on one piece of tube, 3 and 4 on another, 5 and 6 on another, and finally, 7 and 8 on another. Therefore, each set consumed 4 pieces of tubing.

Once a good cut surface was achieved, to determine longevity cuts were taken along a measured length at the determined speed and feed. With each pass, the surface was examined and noted for loss of surface quality. Using the feed speed plus spindle speed along with the circumference of the tube, we can calculate the amount of linear feet the cutting tool "sees" before it degrades.

RESULTS

The Pt-4.8Ru alloy, which is the most popular of the 95 platinum alloys in the U.S., was chosen for the study. Tubing was chosen as the form. The grain size of the alloy was ASTM #6 in the longitudinal section and ASTM #7 in the transverse. The hardness was VHN_{100} 184. The microstructures are presented in Figures 1 and 2.

The first sets of experiments were carried out using the variables shown summarized in Table I. The two feeds used were 0.32 inches per minute (ipm) and 37.5 ipm and 50, the spindle speed 135 and 500, and the depth of cut 0.003 inches and 0.010 inches.

The results for the first set of experiments, which used a ceramic insert and no lubricant (dry) is summarized in Table II. Observations on the appearance of the cut surface are presented and the surfaces are qualitatively ranked from best (1) to worst (8). Scanning-electron-micrographs of the surfaces are presented in order of their ranking in Figures 3 through 10.

The descriptions were kept consistent with the definition of surface texture[(4)]. Figure 3 shows the best rated surface from Run #8 (maximum of the three variables). The surface is characterized as wavy but not rough.

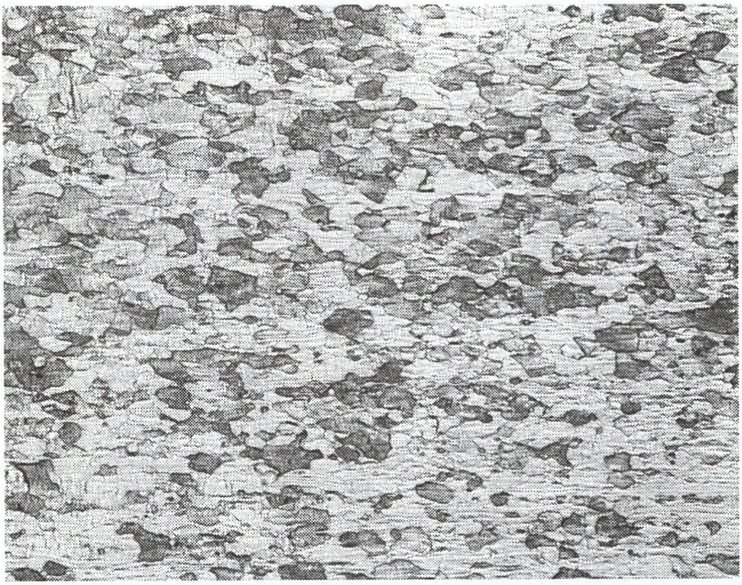

Figure 1 The longitudinal (parallel to the tube axis and tube radius) grain structure of the Pt-4.8Ru alloy tube is shown. The structure is elongated in the direction of tube drawing. The grain size is an ASTM #6. The hardness is VHN100 184. Magnification is 100x.

Figure 2 The transverse (perpendicular to the tube axis) grain structure of the Pt-4.8Ru alloy tube is shown. The grain size is an ASTM #7. Magnification is 100x.

TABLE I

VARIABLES FOR EXPERIMENTS

Runs	Feed Speed 0.37"ipm(-) 3.75 ipm(+)	Spindle Speed 135(-) 500(+)	Depth of Cut .003(-) .010(+)
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

TABLE II

RESULTS OF EXPERIMENT

CERAMIC INSERT USING TABLE I VARIABLES

DRY

Run	Observation	Rank*
1	Rough	8
2	Smooth with Roughness in Bottom of Waves	5
3	Dull, Smeared Chips	4
4	Bright, Some Roughness, Small Waves	2
5	Rough	7
6	Smooth Waves with Roughness in Trough	6
7	Dull, Smeared Chips	3
8	Bright, Very Small Waves	1

*A rank of #1 is the best finish to #8 for the worst.

Figure 4 (Run #4) is wavy, with intermittent roughness. Figures 5 and 6 (Run #7 and Run #3 respectively) shows the effect of the chips being smeared on the surface and causing a degree of roughness. Figures 7 and 8 (Run #2 and Run #6) show periodic waves and roughness. Figures 9 and 10 (Run #5 and Run #11) show varying degrees of a rough surface.

The next set of experiments used a cubic boron nitride insert and the same variables as outlined in Table I. The results are summarized in Table III. The scanning-electron-micrographs of the surface texture are displayed in Figures 11 through 18. The surface in Figure 11 is smooth with only very small waves. This was Run #6 with the high feed speed and depth of cut, and the low spindle speed. The next best surface was Run #2 (Figure 12). The waves are larger with a small amount of localized roughness. The texture of Figure 13 (Run #4) has smaller waves but more roughness than Run #2. The waves are larger for Run #8 with a rough, smeared surface. The remainder of this set of experiments has increasing roughness Figures 15 through 18 (Runs #1, #7, #3 and #5 respectively.

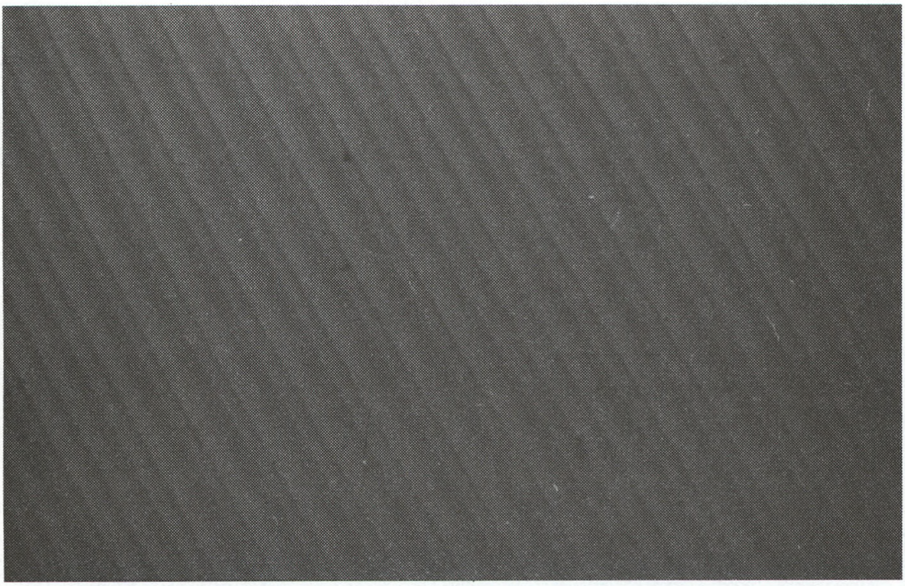

Figure 3 The scanning-electron-micrograph show the result of the machining trial using the ceramic insert, no lubricant and the high value of the three variables (Run #8 - Table II). Magnification is 20x.

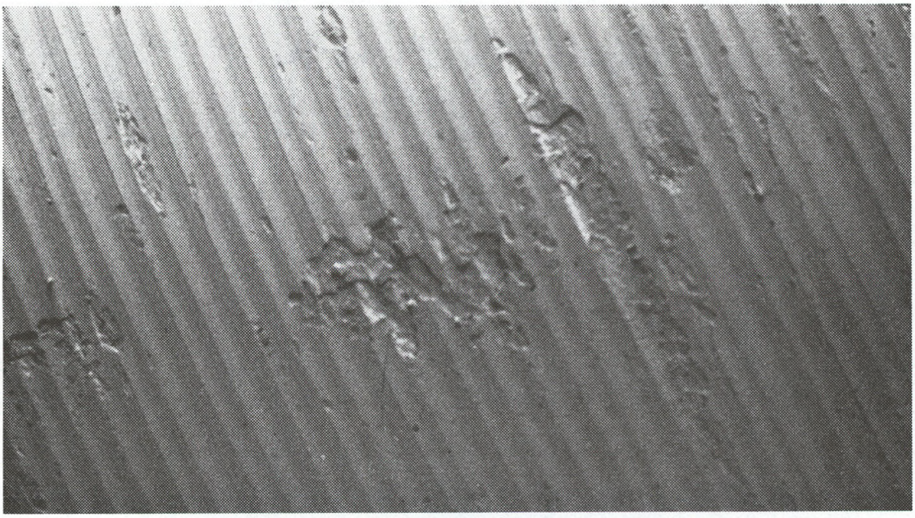

Figure 4 The scanning-electron-micrograph shows the result of the machining trial using the ceramic insert, no lubrication and parameters for Run #4 in Table I. The rank was 2 in Table II. Magnification is 20x.

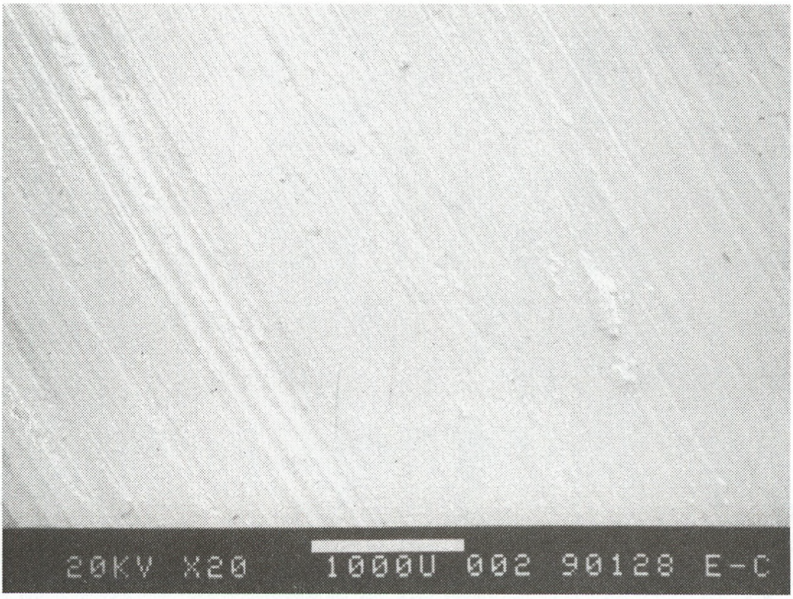

Figure 5 Same as Figure 5 except Run #7 and the rank was #3.

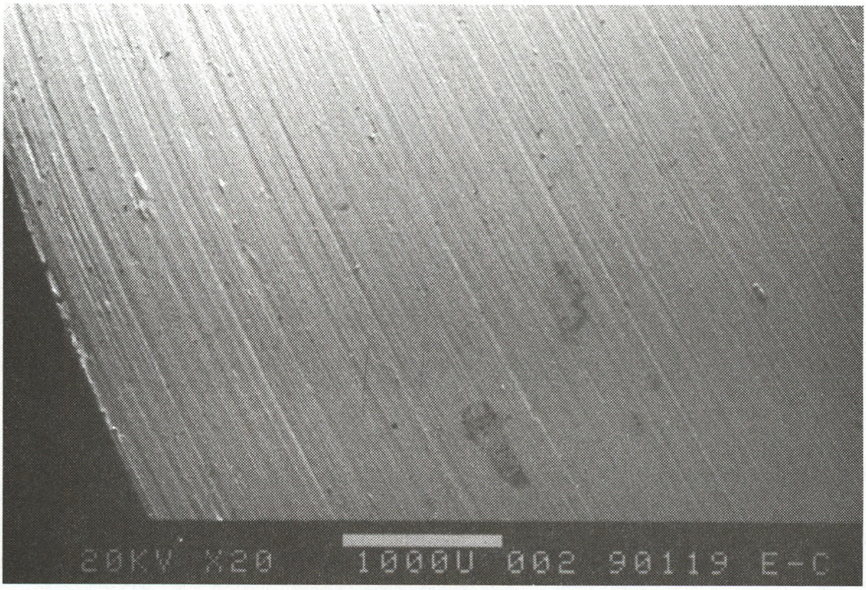

Figure 6 Same as Figure 5 except Run #3 and the rank was# 4.

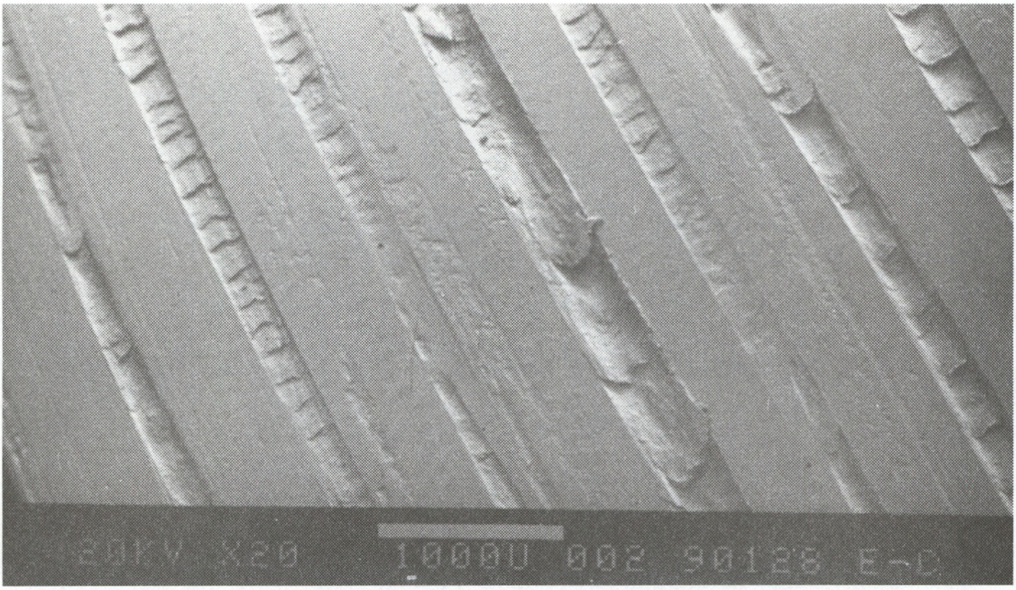

Figure 7 Same as Figure 5 except Run #2 and the rank was #5.

Figure 8 Same as Figure 5 except Run #6 and the rank was #6.

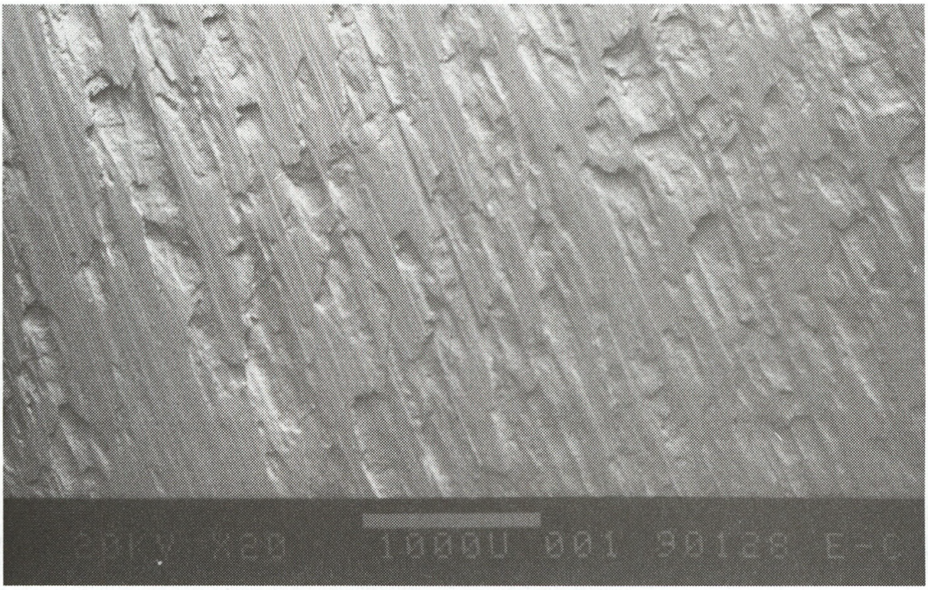

Figure 9 Same as Figure 5 except Run #5 and the rank was #7.

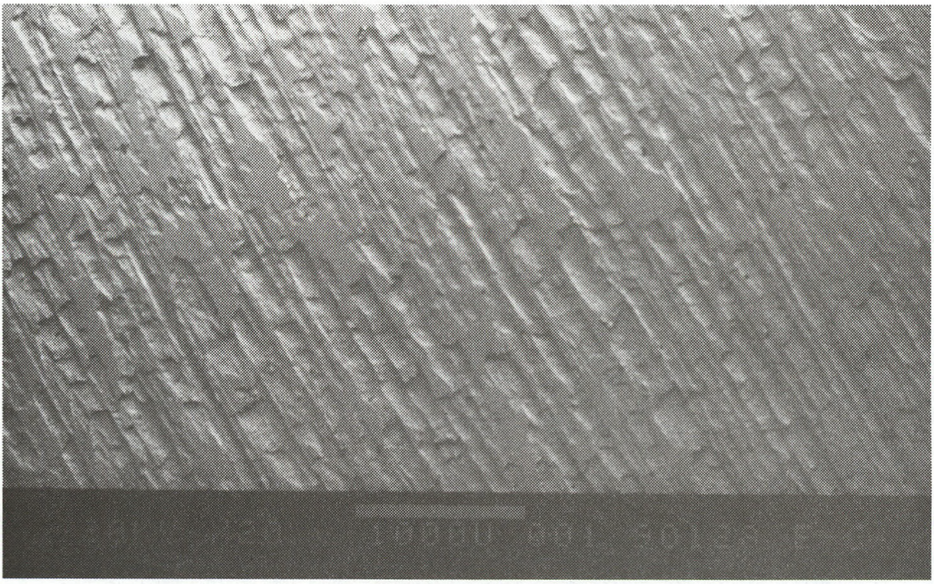

Figure 10 Same as Figure 5 except Run #1 and the rank was #8.

TABLE III

RESULTS OF EXPERIMENT

CUBIC BORON NITRIDE INSERT USING TABLE 1 VARIABLES

DRY

Run	Observation	Rank
1	Rough	5
2	Bright, Waves, Slight Roughness	2
3	Dull, Embedded Chips, Rough	7
4	Bright, Waves, Some Roughness	3
5	Very Rough	8
6	Bright, Slight Wave	1
7	Dull, Small Waves, Smeared Chips	6
8	Bright, Large Waves with Roughness in Trough	4

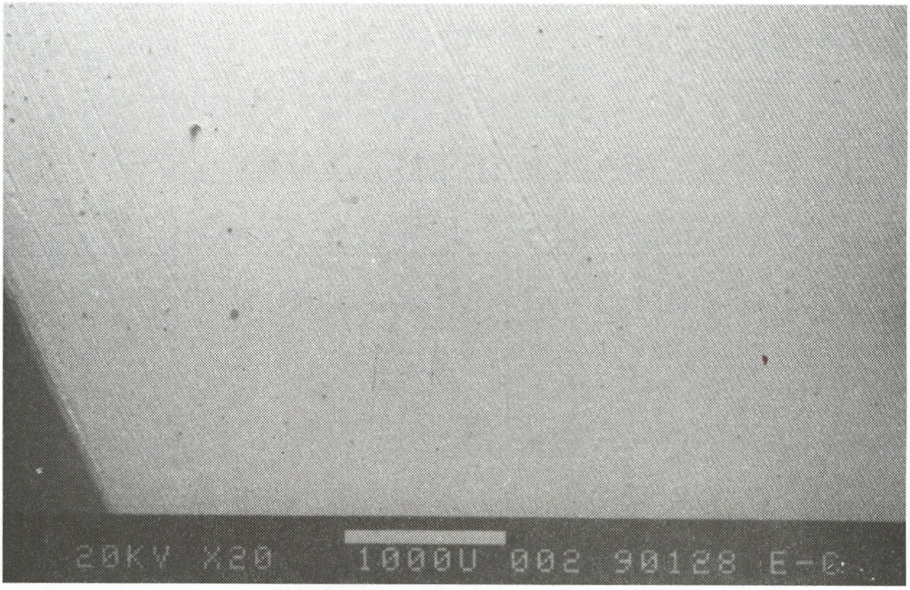

Figure 11 The scanning-electron-micrograph shows the result of the machining experiment using the cubic boron nitride insert, no lubrication and the parameters for Run #6 in Table I. The rank is 1 in Table III. Magnification is 20x.

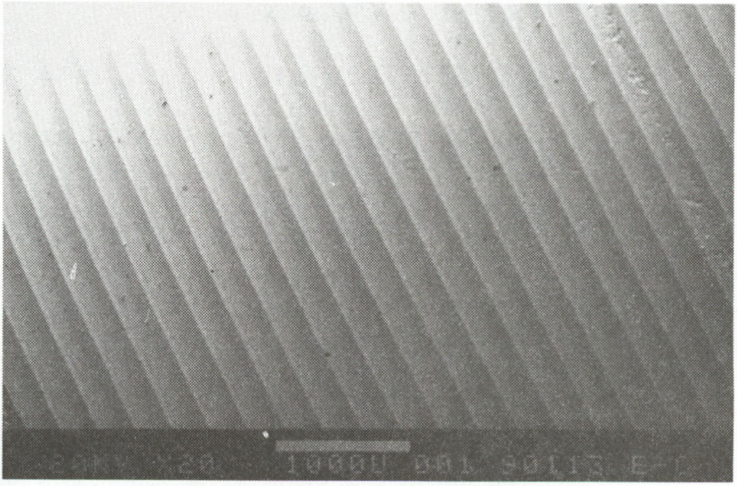

Figure 12 Same as Figure 12 except Run #2 and the rank was #2.

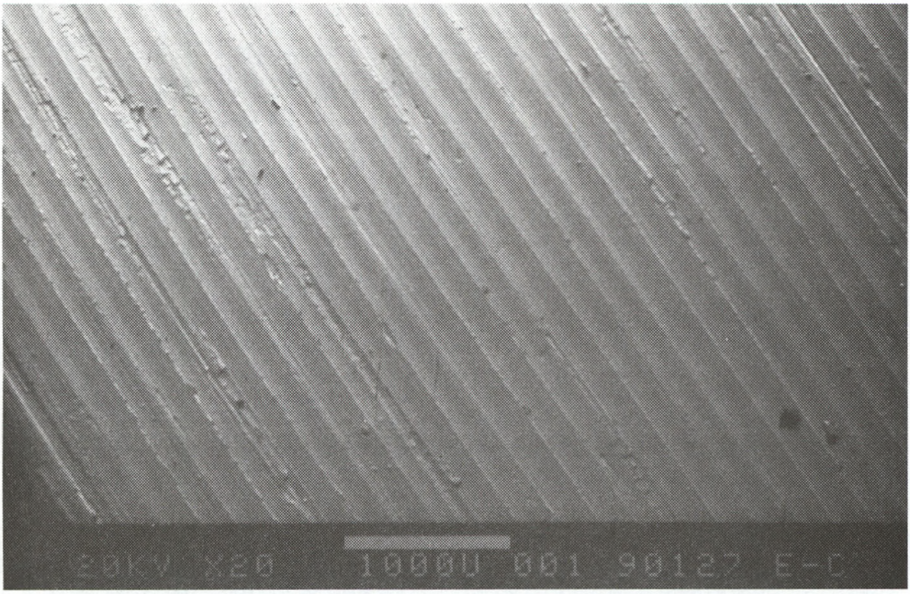

Figure 13 Same as Figure 12 except Run #4 and the rank was #3.

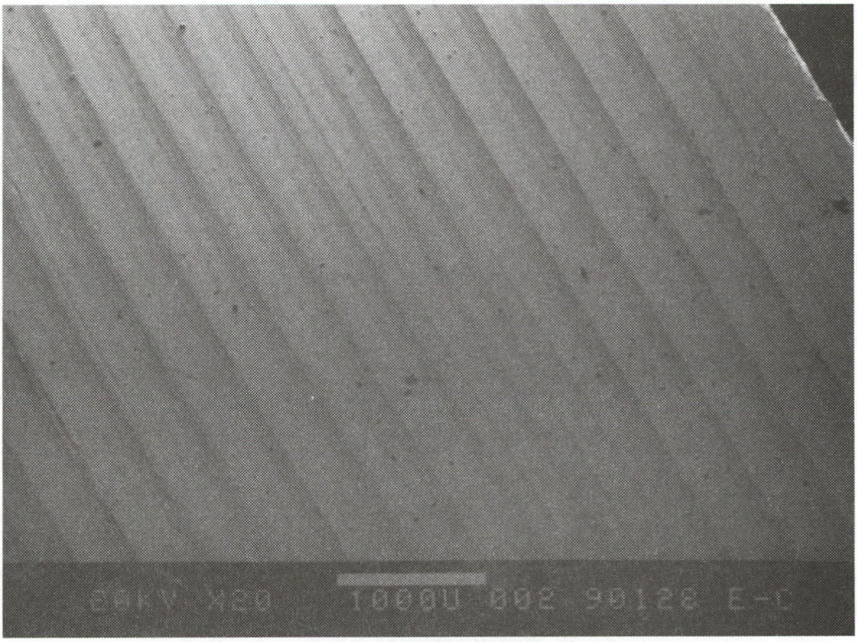

Figure 14 Same as Figure 12 except Run #8 and the rank was #4.

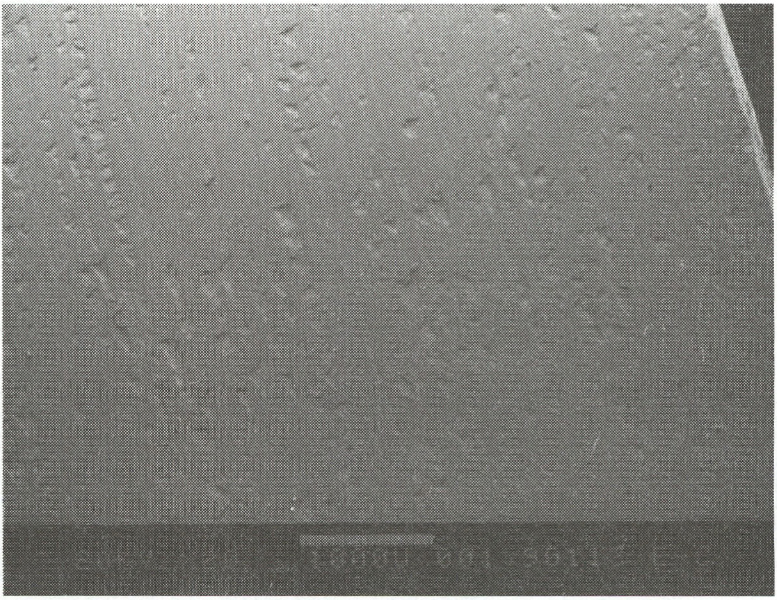

Figure 15 Same as Figure 12 except Run #1 and the rank was #5.

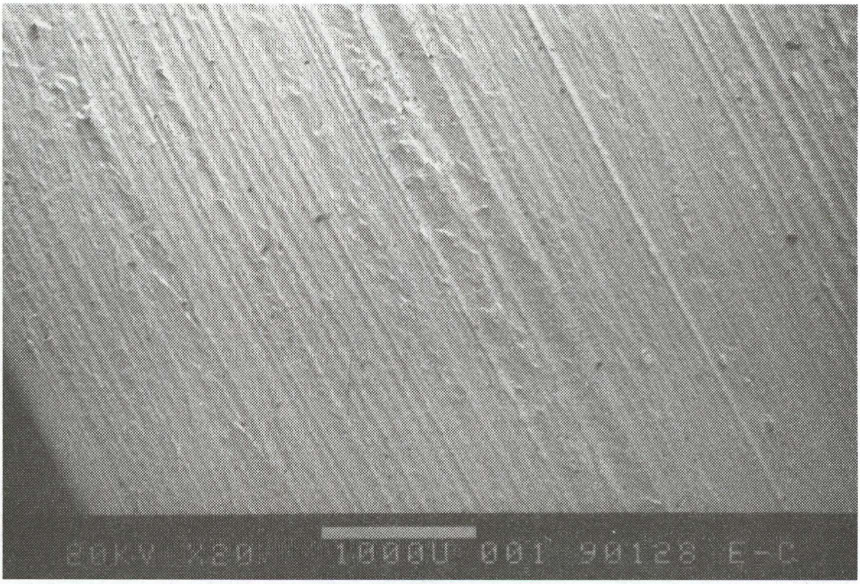

Figure 16 Same as Figure 12 except Run #7 and the rank was #6.

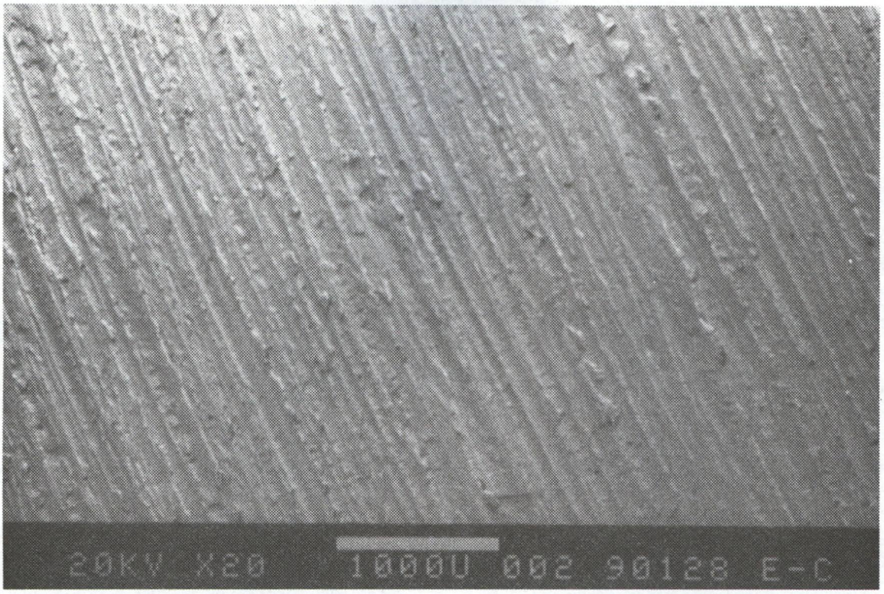

Figure 17 Same as Figure 12 except Run #3 and the rank was #7.

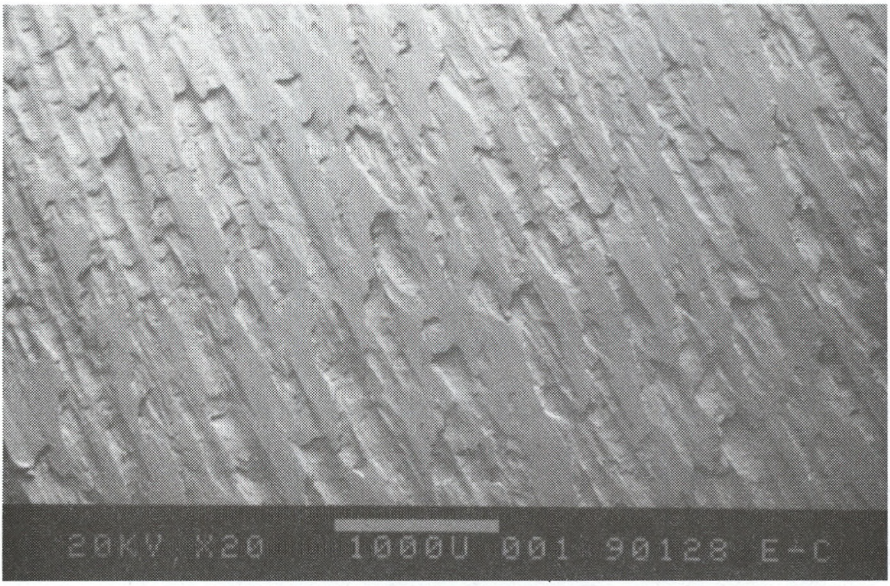

Figure 18 Same as Figure 12 except Run #5 and the rank was #8.

The tip of the cubic boron nitride-cutting tool is shown in the scanning-electron-mircrograph of Figure 19. The adhesion to the tip of the platinum alloy and subsequent breakdown is seen.

The experiments using the polycrystalline diamond insert without a lubricant for the variables in Table I are summarized in Table IV. The sample with the best surface texture was Run #8 (Figure 20) with the highest level of all three variables. Run #5 (Figure 21) has some roughness. Run #4 (Figure 22) has waves in addition to the roughness. Figure 23 (Run #7) has increased roughness. The surface texture of Run #2 (Figure 24) has large waves with roughness in the troughs. The next two Runs, #1 and #3, (Figures 25 and 26) have increased roughness. The worst surface from Run #6 is characterized by deep waves and a rough surface.

The next set of experiments involved the use of cold air gun with the ceramic insert again using the parameters from Table I. The data is summarized in Table V and the scanning-electron-micrographs of the surface texture appear in Figures 28 through 35. The best surface was

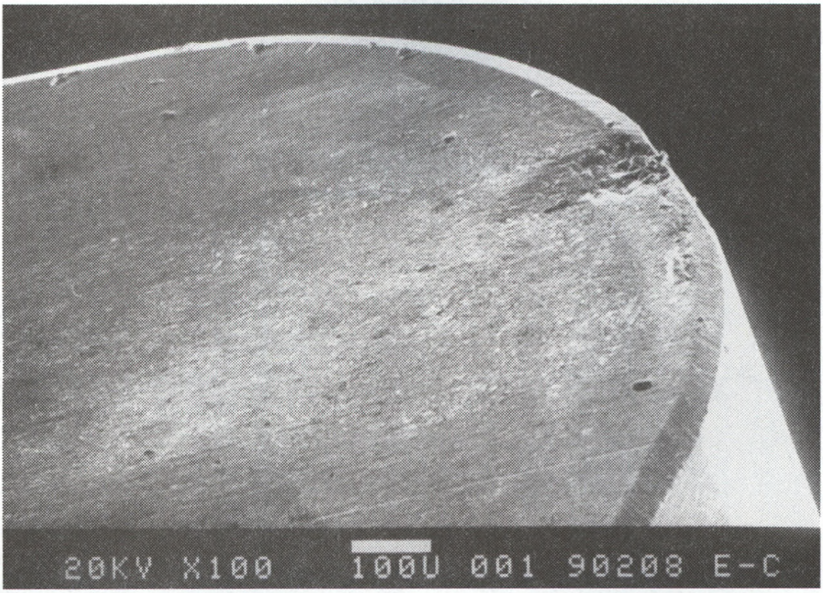

Figure 19 Scanning-electron-micrograph of the cubic boron nitride insert after use. Magnification is 100x.

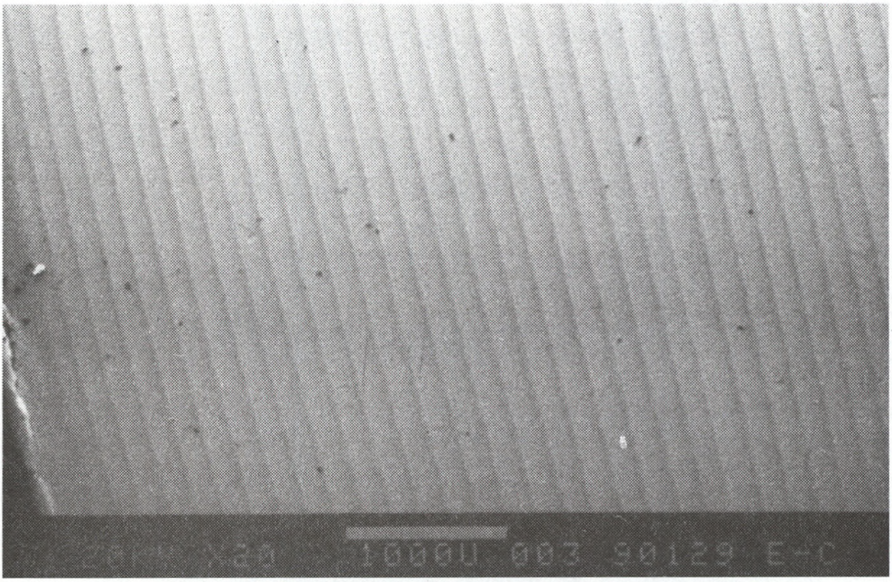

Figure 20 The scanning-electron-micrograph shows the result of the machining trail using the polycrystalline insert, no lubrication and parameters for Run #8 in Table I. The rank was #1 in Table IV. Magnification is 20x.

TABLE IV

RESULTS OF EXPERIMENTS

POLYCRYSTALLINE DIAMOND INSERT

USING TABLE I VARIABLES

DRY

Run	Observation	Rank
1	Dull, Rough, Embedded Chips	6
2	Waves, Rough in Troughs	5
3	Dull, Rough, Embedded Chips	7
4	Bright, Waves, Some Roughness	3
5	Bright, Slight Roughness	2
6	Severe Waves, Rough	8
7	Some Roughness, Embedded Chips	4
8	Bright, Slight Waves, Slight Roughness	1

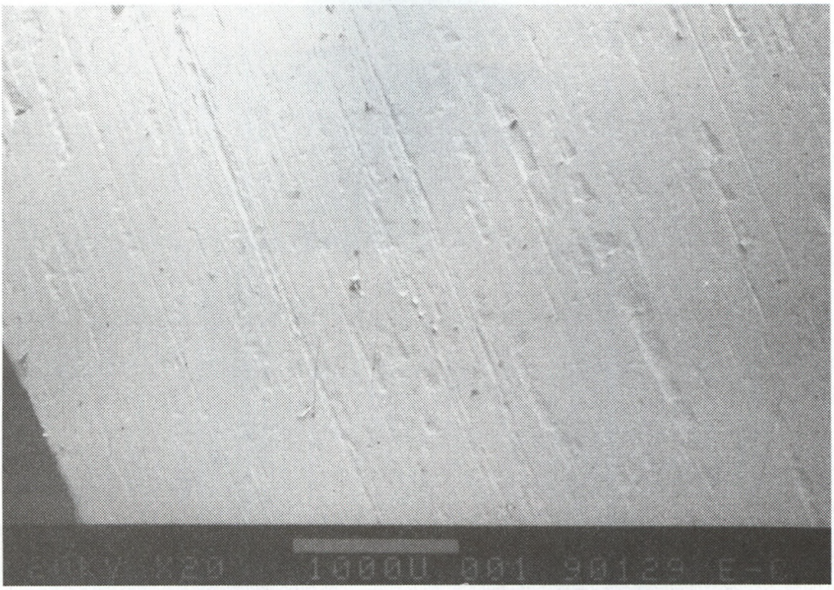

Figure 21 Same as Figure 20 except Run #5 and the rank was #2.

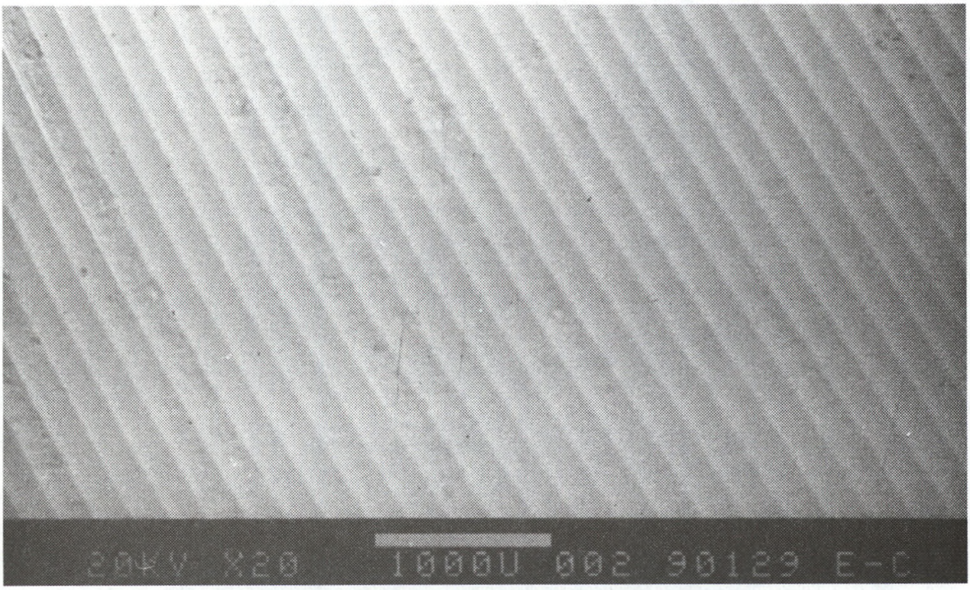

Figure 22 Same as Figure 20 except Run #4 and the rank was #3.

Figure 23 Same as Figure 20 except Run #7 and the rank was #4.

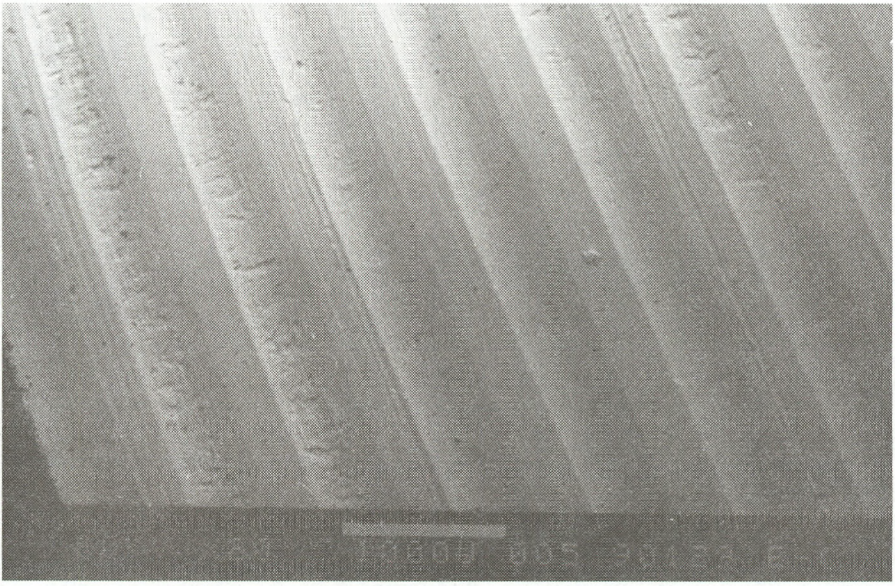

Figure 24 Same as Figure 20 except Run #2 and the rank was #5.

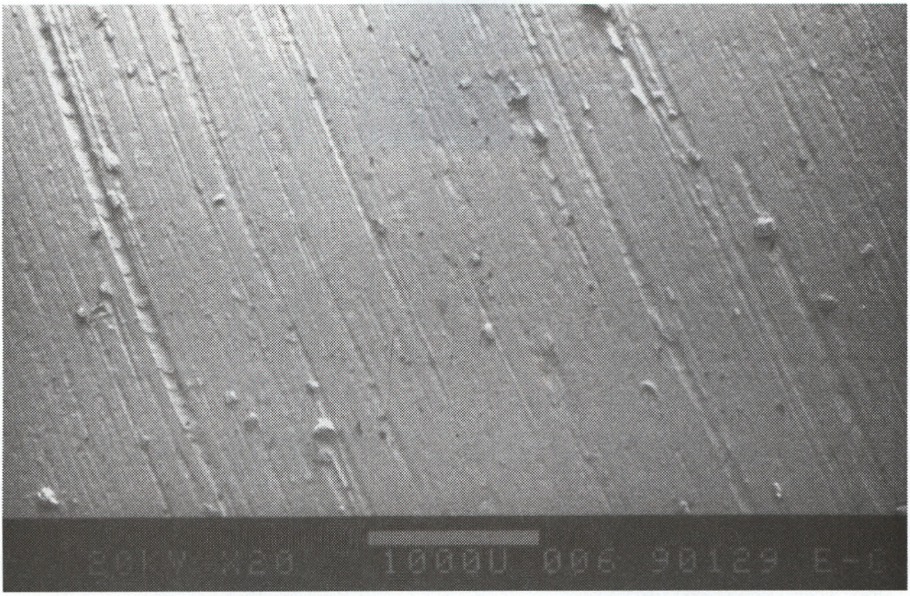

Figure 25 Same as Figure 20 except Run #1 and the rank was #6.

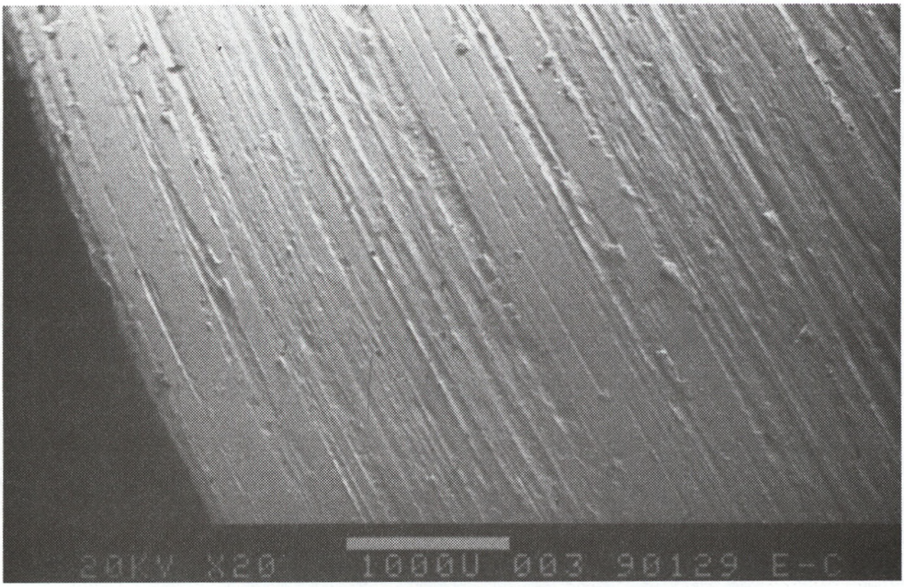

Figure 26 Same as Figure 20 except Run #3 and the rank was #7.

TABLE V

RESULTS OF EXPERIMENTS

CERAMIC INSERT – COLD AIR GUN – TABLE I VARIABLES

DRY

Run	Observation	Rank
1	Dull, Rough	6
2	Large Waves, Some Roughness	5
3	Not Uniform, Very Rough	8
4	Bright, Small Waves, Slight Roughness	1
5	Bright, Slight Roughness	2
6	Large Waves, Slight Roughness	3
7	Dull, Not Uniform, Rough	7
8	Dull, Not Uniform, Chips Smeared	4

achieved with Run #4, the higher feed and spindle speed but the low depth of cut. The surface texture is characterized by small waves. Run #5 was ranked second (Figure 29) and shows some roughness. Runs #6, #8 and #2 have waves with increasing roughness (Figures 30 through 31). The remaining Runs, #1, #7 and #3 have increased roughness. (Figures 33 through 35).

The results for the four sets of experiments are summarized in Table VI. Calculations that resulted in the effect matrix for these experiments are presented in Table VII. These effects will be dealt with in the discussion.

Additional experiments were carried out in which lubricants were used, either Lubrajel or Trimsol. The results using the ceramic inserts are summarized in Table VIII. Run #3 and Run #7 were judged the best. This represented low feed (40) and high spindle speed (900). The texture was characterized as smooth with only light waves.

PCD inserts were used with the same parameters and lubricants. The data is summarized in Table IX. Runs #3 and #7 were the best, both

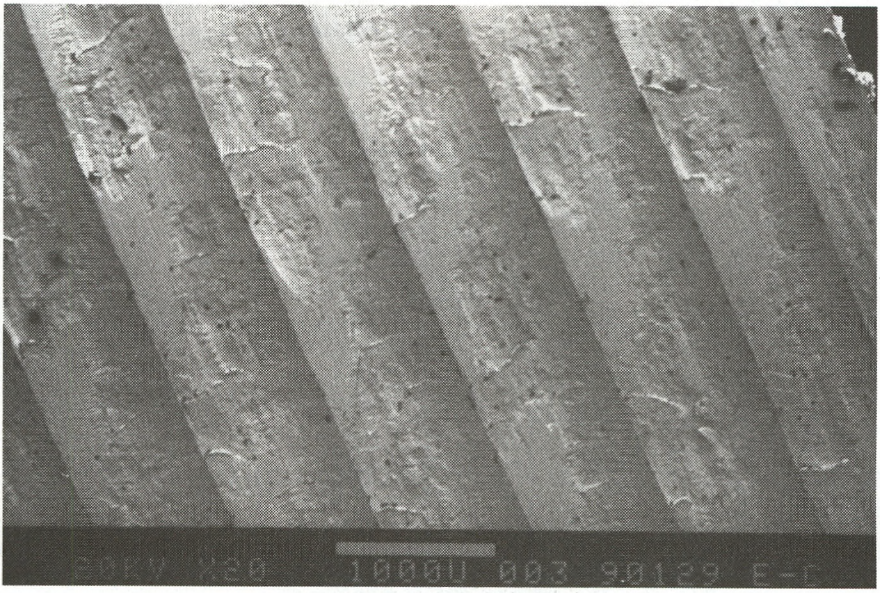

Figure 27 Same as Figure 20 except Run #6 and the rank was #8.

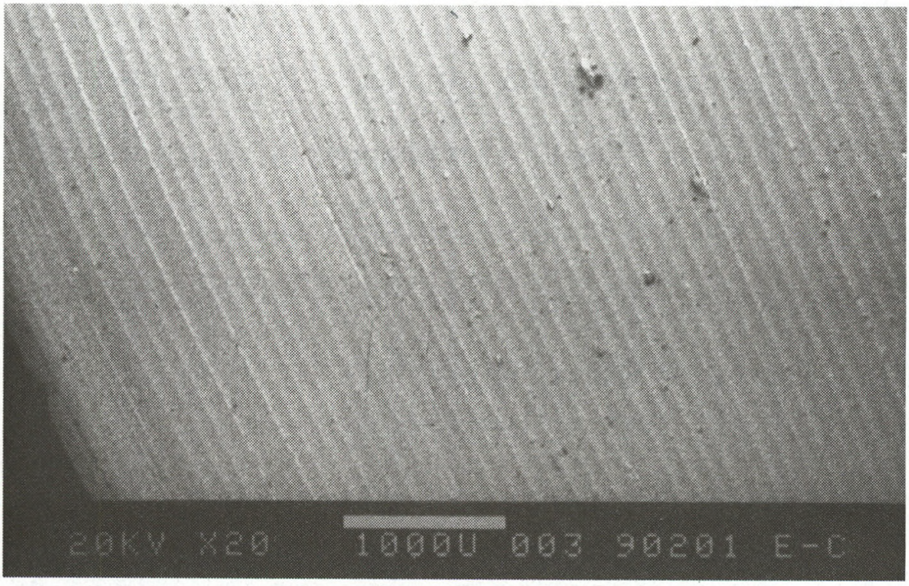

Figure 28 The scanning-electron-micrograph shows the result of the machining trail using the ceramic insert, cold air gun, no lubrication and parameters for Run #4 in Table I. The rank was #1 in Table V. Magnification is 20x.

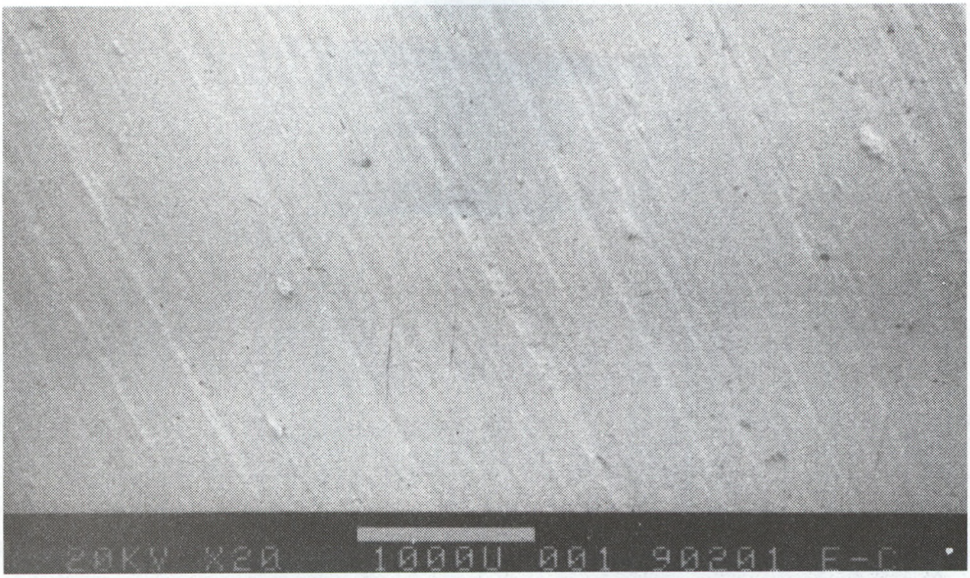

Figure 29 Same as Figure 28 except Run #5 and the rank was #2.

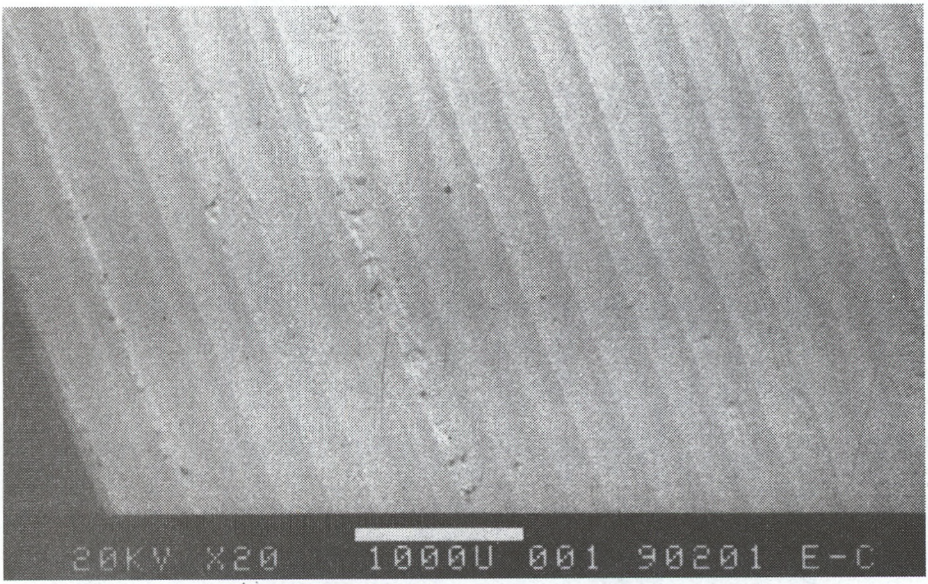

Figure 30 Same as Figure 28 except Run #6 and the rank was #3.

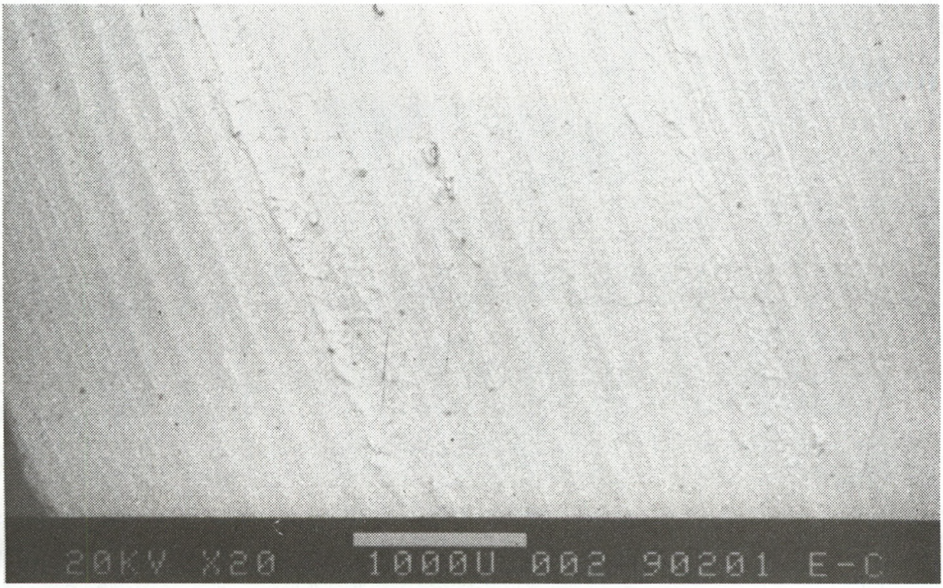

Figure 31 Same as Figure 28 except Run #8 and the rank was #4.

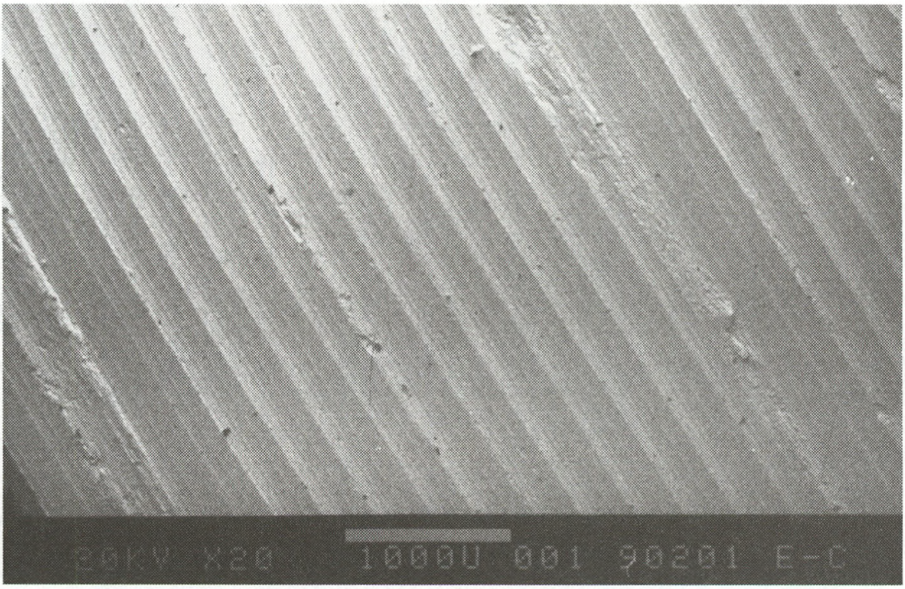

Figure 32 Same as Figure 28 except Run #2 and the rank was #5.

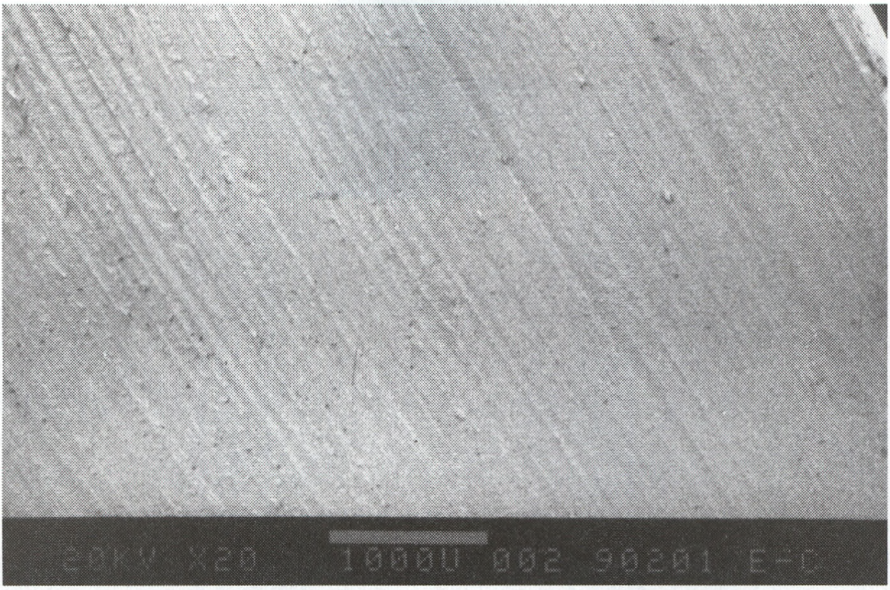

Figure 33 Same as Figure 28 except Run #1 and the rank was #6.

Figure 34 Same as Figure 28 except Run #7 and the rank was #7.

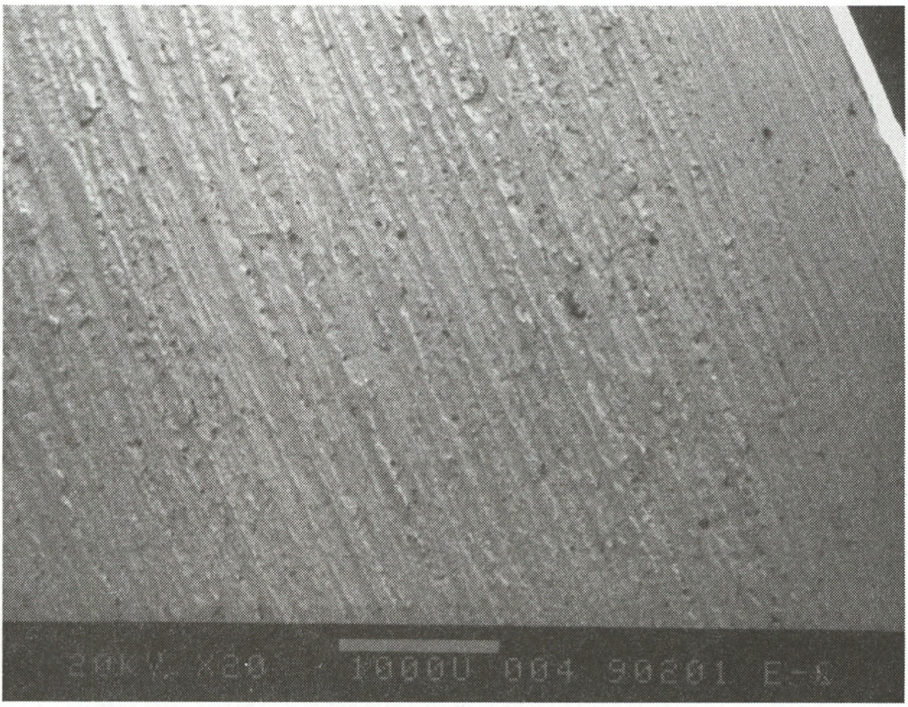

Figure 35 Same as Figure 28 except Run #3 and the rank was #8.

TABLE VI

DATA RANKING

MACHINE TRIALS

Run	Ceramic Rank	Cubic BN Rank	PCD Rank	Ceramic Cold Air Gun Rank
1	8	5	6	6
2	5	2	5	5
3	4	7	7	8
4	2	3	3	1
5	7	8	2	2
6	6	1	8	3
7	3	6	4	7
8	1	4	1	4

TABLE VII

EFFECT MATRIX

Effect	Ceramic	Cubic BN	PCD	Ceramic Cold Air Gun
A	-2	-4	-0.5	-2.5
B	-4	1	-1.5	1.0
C	-0.5	0.5	-1.5	-1.0
AB	0	1	-3	-2.5
AC	0.5	-0.5	-2	1.5
BC	-0.5	-0.5	-1	2.0
ABC	-0.5	1.5	1.5	0.5

TABLE VIII

CERAMIC INSERT – 0.010" DEPTH OF CUT WITH LUBRICATION

	Feed IPM	Spindle Speed	Lubricant	Observation	Rank	Chips
1	2.25	700	Lubrajel	Light Waves	3	Slight Curl
2	3.37	700	Lubrajel	Light Waves	4	Straight
3	2.25	900	Lubrajel	Light Waves	1	Tight Curl
4	3.37	900	Lubrajel	Light Waves	2	Medium Spiral or Curl
5	2.25	700	Trimsol	Light Waves	3	Slight Curl
6	3.37	700	Trimsol	Light Waves	4	Straight
7	2.25	900	Trimsol	Light Waves	1	Tight Curl
8	3.37	900	Trimsol	Light Waves	2	Medium Spiral or Curl

TABLE IX

PCD INSERT – 0.010" DEPTH OF CUT

WITH LUBRICATION

	Feed IPM	Spindle Speed	Lubricant	Observation	Rank	Chips
1	2.25	700	Lubrajel	Very Fine	3	Medium Curl
2	3.37	700	Lubrajel	Slightly Wider Grooves	4	Open Curl
3	2.25	900	Lubrajel	Very Smooth	1	Medium Curl
4	3.37	900	Lubrajel	Smooth	2	Medium Curl
5	2.25	700	Trimsol	Very Fine	3	Medium Curl
6	3.37	700	Trimsol	Slightly Wide	4	Medium Curl
7	2.25	900	Trimsol	Very Smooth	1	Medium Curl
8	3.37	900	Trimsol	Smooth	2	Open Curl

being characterized as very smooth. The scanning-electron-micrograph of Run #7 is shown in Figure 36.

The final experiment was done with a ceramic insert, the depth of cut was kept constant and two kinds of lubricants were used. The factorial experiment is outlined in Table X. The results of the experiments are summarized in Table XI. The surface texture was very good for all samples but Run #3 was ranked the best. The scanning-electron-micrographs of Run #3 is displayed in Figure 37.

The effect matrix for the last three experiments is summarized in Table XII. Their meaning will be interpreted as part of the discussion.

DISCUSSION

These observations were made during the dry machining. The dry machining produced the predictable worse results due to the fact that there was quite a bit of heat built up at the cutting edge. This along with lack of

TABLE X

FACTORIAL VARIABLES

	2.62 ipm(-) 3.37 ipm(+)	800(-)1000(+)	.007(-) .012(+)
Runs	**Feed Speed**	**Spindle Speed**	**Depth of Cut**
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

TABLE XI

RANK DATA CERAMIC INSERT TRIMSOL LUBRICANT

Run	Observation	Rank
1	Light Waves	5
2	Light Waves	6
3	Smooth	1
4	Smooth	2
5	Light Waves	7
6	Light Waves	8
7	Light Waves	3
8	Light Waves	4

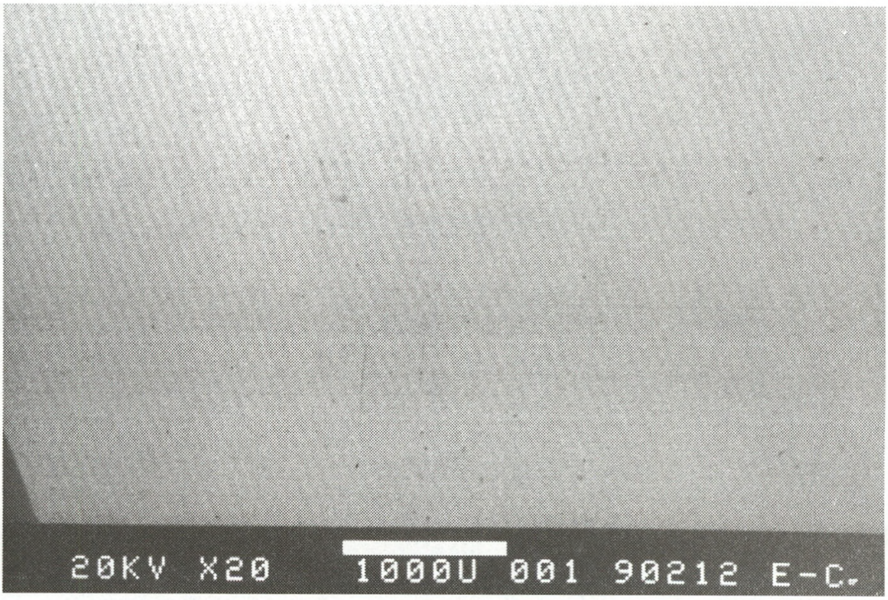

Figure 36 Scanning-electron-micrograph shows the result of the machining trial using the polycrystalline diamond insert, 0.010 inch depth of cut and the parameters for Run #7 in Table IX. Magnification is 20x.

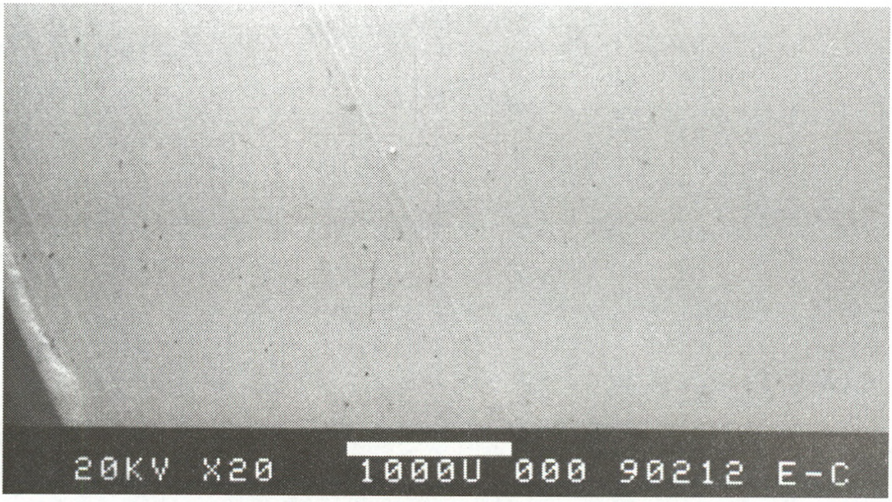

Figure 37 Scanning-electron-micrograph shows the result of the machining trail using the ceramic insert, Trimsol lubricant and variables for Run #3 in Table X. Magnification is 20x.

TABLE XII

EFFECT MATRIX

	Ceramic Insert Lubrication Depth of Cut 0.010"	PCD Insert Lubrication Depth of Cut 0.010"	Ceramic Insert TrimSol
A	1	1	1
B	-2	-2	-4
C	0	0	2
AB	0	0	0
AC	0	0	0
BC	0	0	0
ABC	0	0	0

lubrication, caused the chips to stay at the cutting point, not only contributing to further heat buildup but marring the newly cut surface. The dull, smeared surface texture is a result of this phenomenon.

Very thin cuts were not as effective because the chips tended to stay at the cutting point of the tool, folding over themselves and building up along the O.D. of the tube before breaking away. This was especially true at low speeds and feeds.

How do these observations match with the calculated effects in Table VIII? Except for one example (PCD effect (AB)) the interactions were negligible. This makes sense since most of the runs were so poor that it would be difficult to separate minor interactions between effects.

For the ceramic insert, no lubrication, the fact that all the effects for a, b, and c were negative, means that to get the best results we would want to keep all levels at the low end. This would seem to make sense since increasing speed feed and depth would rapidly increase heat buildup and the ceramic insert doesn't provide any heat conduction. In fact, samples cut during this run were all very hot, especially at the high levels.

The PCD insert showed that we would want the feed and the speed toward the high level as indicated by the positive response but the depth of cut kept at the low level, once again, probably relating to heat buildup. Since the PCD insert could wick away some heat we were okay as long as we kept the cuts very light.

The PCBN showed kind of the opposite response with a negative effect on the feed effect and positive on the spindle effect and depth of cut. It is not evident why this would be so different from the PCD.

Using the ceramic with the cold air gun to keep the tool and work piece cool, switched the effect of the spindle speed from a large negative effect to a small positive effect. Interestingly, it slightly increased the negative effects of a and c by the same amount. The cooling allowed us to increase spindle speed as long as we didn't overdo it by increasing feed and depth of cut.

Examination of the effect matrix in Table XII indicates an interesting thing happed once the use of lubrication was begun. First of all, the effect from lubrication was so negligible that it was zero.* Interaction effects were also driven to zero. This shows that really what counts is feed and spindle speed. With the PCD insert the influences show that we would want to keep the spindle speed down and feed speed high at a cut depth of .010". The ceramic insert showed the exact same effects.

We then looked at cut depth again as a c factor. With the ceramic insert, we once again would want to keep the spindle speed on the low side of the range (800) and the feed speed near the high-end (45). Cut depth does show a positive influence meaning we would want to stay near the .012" depth.

It seemed like an ideal situation was to have a long uninterrupted string come off the piece and trail away from the cutting edge. This was effectively done with deeper cuts and higher feeds. However, one runs the risk of having these very long strings wrap around the tool holder or work piece, once again marring the newly machined surface. This would especially be a problem in automated CNC machines.

The problem with using a ranking from 1-8 in place of quantitative data is that it is easier for the formula to drive the equations for interactions to zero. If we used a surface roughness tester that gave us numbers like 22.6, 25.3, 21.9, it would show effects, even very small ones easily. We probably would have gotten better effect numbers had we used a scale of 1-100.

SUMMARY

Since cutting or machining is important in jewelry operations, a study was undertaken to demonstrate the methodology to use in determining proper conditions. The experiments demonstrated that cutting materials other than diamond can give acceptable surface textures. Further studies are required to compare the life of the cutting materials and to evaluate the economics.

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