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GRINDING OF SILICON NITRIDE TURBINE BLADE SHAPES.(U)
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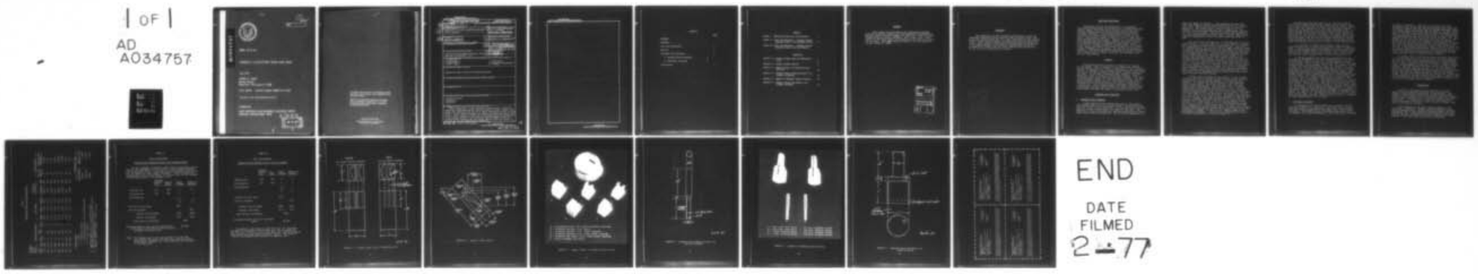

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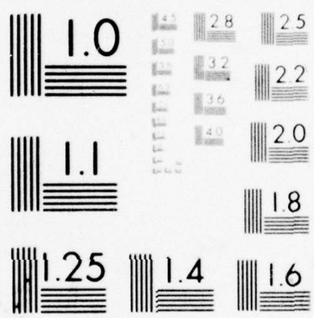

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ARMY MATERIALS AND MECHANICS RESEARCH CENTER

AMMRC CTR 76-16

GRINDING OF SILICON NITRIDE TURBINE BLADE SHAPES

June 1976

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Worcester, Massachusetts 01606

Final Report - Contract Number DAAG46-76-C-0024

Approved for public release; distribution unlimited.

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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The objectives of this research program were to develop machining techniques which could be used to grind a small, one piece gas turbine rotor out of a fully densified silicon nitride blank. Metal bonded diamond cup wheels and mounted points were used to drive abrasive slurries in accomplishing the machining. A few sample blades of fair quality were machined using the mounted point system, but the stock removal rate was found to be too low to be commercially feasible.

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FORWARD

This report was prepared by the Industrial Ceramics Division of Norton Company under Army Materials and Mechanics Research Center contract DAAG46-76-C-0024 and covers work performed during the period November, 1975 to May, 1976. This report is the final report and summarizes all activities under the contract. The AMMRC Technical Monitor for this project was Mr. George E. Gazza.

ABSTRACT

The objectives of this research program were to develop machining techniques which could be used to grind a small, one piece gas turbine rotor out of a fully densified silicon nitride blank. Metal bonded diamond cup wheels and mounted points were used to drive abrasive slurries in accomplishing the machining. A few sample blades of fair quality were machined using the mounted point system, but the stock removal rate was found to be too low to be commercially feasible.

AIMS AND OBJECTIVES

The object of this investigation is to determine the machining parameters and feasibility of machining simple airfoil shapes from fully dense silicon nitride by small diameter mounted point tracer machining and by multiple cup wheel machining. The mounted points and most of the cup wheels are metal bonded diamond tools of varying grit sizes. The material ground is Norton's NC-132, high density high strength silicon nitride. Because it is difficult to mold this material into complex shapes, this work is aimed at developing methods of machining a high speed ceramic rotor out of a single monolithic ceramic blank. This report covers wheel grit sizes, down feeds, surface feeds, surface finish, thickness of cup wheels, and amounts of chipping or fracture. The report specifies grinding conditions, cutting rates, wheel wear, finishes, accuracy, and estimated cost data for each method.

RESULTS

Hot pressed silicon nitride is difficult to machine by any method. This is because of its 2200 Knoop hardness, and its density which is close to theoretical. It is possible, however, to machine airfoil shapes by both mounted point grinding and by cup wheel grinding, but these grinding operations are slow. In the case of mounted point grinding, it took about four hours to machine a blade from a blank. Thus, for a 30 bladed rotor, about 150 hours would be required. The cup wheel grinding turned out to be unsuccessful in the case of diamond coated tooling wherein a good deal of chipping was witnessed due to the high pressure caused by a high wheel contact area. Resin bonded diamond cup wheels caused almost no chipping, but the operation was even slower than the diamond coated cup wheel due again to the high contact area.

PROBLEMS AND SOLUTIONS

A. MOUNTED POINT GRINDING

A small Gorton Tracer grinder was used to end grind a small blade shape out of an NC-132 billet. The NC-132 billet was 0.71 x 0.71 x 1-3/4 inch long. A 0.050 inch slice was made down the center of the billet to a depth of 3/4 inch. See Exhibit A. This billet was then used for machining two turbine blade shapes shown in Exhibit B. The billet was cemented in a steel cup shown in Exhibit C. The grinding was done with 3/16 inch diameter diamond coated mounted points of various grit sizes. The steel profile of this point is shown in Exhibit D. The coated point is shown in Exhibit E. The mounted point was guided manually by a blade shaped cam made to 10 to 1 for accuracy. The Gorton Grinder was equipped to vary the grinding RPM from about 1700 to 12,000, but we chose from past experience to test the speed range from 2700 to 5000.

The first test performed was at 2700 RPM with a 60 grit diamond point. A cut was made to 0.70 inch depth in a single pass with water coolant in the surrounding cup. See Table I for machining data. We were not able to apply enough pressure to maintain the grinding action and found that one point would only grind a length of cut of 0.010 inch before the sharpness of the diamond was lost. In this report we consider the measure of wheel wear to be equivalent to the length of cut a spindle can make before losing the cutting action of the single layer diamond coating. We found a stock removal rate of 0.006 in^3/hr. Excessive pressure only served to break the points, and would have broken a thin blade shape had we been able to progress that far. Because of the poor cutting action and heavy chipping with this system, the test was cancelled. Finer diamond sizes would have shown even poorer performance. Better surface finish and accuracy than demonstrated in this brief test can be reasonably easily reached with finer abrasives and more accurate tooling.

We then tried a system of introducing a loose diamond slurry in the cup and found that the cutting action could be maintained to give a greater length of cut with far less pressure. To suspend the loose diamond we used methalene iodide, quite toxic. The first test was with a 105 grit diamond point and 240 grit loose diamond. With a mounted point speed of 2700 RPM we were able to cut to a 0.15 inch length before loosing most of the cutting action. There was moderate chipping with a rate of cut of 0.05 in^3/hr. The same 0.70 inch depth of cut was maintained throughout all contouring tests except one as noted later. The blade finishing operation for the last 0.030 inch of stock removal was the same as the above roughing operation except that we used a 240 grit diamond point coupled with a 400 grit loose diamond slurry. We made a 0.15 inch length of cut at 2700 RPM before loosing the cutting action. This system gave 0.06 in^3/hr with only minor chipping at the top of the blade. A sample of two blades machined with the above roughing and finishing operations was transmitted to AMMRC, as were all the samples shown in the photograph in Exhibit C. The factory cost/blade was $319 or $12,500/30 blade wheel, as shown in Table II.

We then decreased the depth of cut from 0.70 inch to 0.10 inch in hopes of achieving a higher stock removal rate. In the test we found that we could continue the cutting action over a 0.22 inch length of cut but only with high pressure which finally broke the 3/16 inch 60 grit mounted point. The 0.10 inch end of the point was worn smooth by the abrading action of the 120 grit loose diamond. The stock removal rate decreased to 0.02 in^3/min. The previous roughing cut at the 0.70 inch depth with the 105 grit point coupled with 240 grit loose diamond had given us 0.05 in^3/min. We therefore abandoned the shallow cuts because of this low stock removal rate.

In a search for higher stock removal rates and less mounted point wear, we increased the RPM to 3300 and again to 5000. In both cases poorer performance was found. Both tests with the 240 diamond points and 400 grit loose diamond slurry yielded only 0.0025 in^3/hr stock removal, and in both tests the cutting action stopped after a 0.04 inch length of cut.

It became apparent that the loose diamond slurry was abrading the diamonds on the coated diamond points. In order to reduce this wear we turned to a softer abrasive slurry, boron carbide. Here we found the cutting rates about the same as those with a loose diamond slurry, but our wear was reduced to about one-third giving three times the length of cut for each spindle. On the second set of blades we used a roughing operation consisting of 120 grit boron carbide slurry. The suspension agent was cloroethoxyethane and tetrabromoethane, roughly 50/50. This roughing method gave a stock removal rate of 0.06 in^3/hr and a total length of cut of 0.36 inch before the point had to be changed. Chipping was moderate. The finishing cut was made with a 240 diamond coated point coupled with 400 grit boron carbide. Here the stock removal rate was 0.03 in^3/hr. This point cut 0.20 inch of material before needing replacement. The finishing operation was performed on the last 0.030 inch of stock around the blade contour. A sample of two blades machined with the above techniques is pictured in Exhibit C. The factory cost/blade was $169, or $6,400/30 blade wheel. See Table III. The RMS was the same as with the diamond slurry, about 100 RMS. Better surface finish is available by finer diamond grits on the points.

B. <u>CUP WHEEL GRINDING</u>

We attempted to contour blades out of Norton's NC-132 material by the use of cup wheels. For this test we tried both the diamond coated metal cup wheels and a resin bonded cup wheel. The diamond coated cup wheels were about 1 inch in diameter with wall thicknesses of 0.020 inch and 0.040 inch as shown in Exhibit F. One set of cups of the two wall thicknesses was coated with 105 grit diamond, the other with 120 grit. Based on the best abrasive system developed during the mounted point contouring test we chose to try the 1 inch cup x 0.040 inch wall coated with the 105 grit diamond operating in a slurry of 240 grit boron carbide. The 500 RPM gave 130 SFPM about the same as the best point grinding test. We plunge cut the cup into the top of the 0.71 inch x 0.71 inch billet and cut to a 0.70 inch depth as shown in Exhibit C. The first cut was made in 15 minutes, the second in 30 minutes. The third cut could only be made to 0.150 inch depth in 30 minutes. Microscopic examination showed that the diamonds on the end of the cup were worn flat. Because of the cost of the cup wheels, $142 each, the high level of fracturing of the piece, and the slow cutting action, we discontinued further tests with this type of diamond coated tooling.

We then tried a 3 inch resin bonded cup wheel made specifically for this test at a cost of $130. The wall thickness was 1/8 inch with a 1/8 inch diamond depth in 3D120-R100B69. The 1/8 inch x 1/8 inch diamond section had a slight reverse wedge to avoid jamming in the cut. We used a normal grinding speed of 5300 RPM to give 4200 SFPM. Water was used as the coolant. We were only able to cut to a 1/2 inch depth in 4 hours even when we applied constant dressing to the wheel face. During this test we lost 0.020 inch of the usable diamond depth. As with the diamond coated cut wheels, the surface area we were trying to cut was found to be too great. However, the resin bonded core drill cut cleanly with minor chipping as can be seen in the sample shown in Exhibit C.

CONCLUSIONS

Neither of the mounted point grinding techniques appear to be economically feasible for production. The diamond coated points coupled with a loose diamond slurry showed an out-of-pocket cost of $319/blade while the diamond coated points coupled with a loose boron carbide slurry at $169/blade. It is difficult to envision improvements in either technique sufficient to make grinding of blade rings from a solid billet feasible.

Stock removal by cup wheel grinding appears to be altogether inadequate. Diamond coated cup wheels coupled with an abrasive slurry chip the workpiece badly, an effect undoubtedly due to the dulling of the diamonds on the thin base of the cup. Resinoid cup wheels grind far too slowly because of the high contact area of the workpiece.

TABLE I

Machining Data and Calculations

Diamond Coated 3/16" Point		Abrasive Slurry			Cut Made			Condition of Piece		Time Values	
Grit Size	RPM	Type	Grit Size	Fluid	Depth	Width	Length[1]	Chipping	RMS[2]	Per Cut (min.)[3]	Cutting Rate (in^3/hr)[4]
60	2700	D	-	A	0.70	0.22	0.01	heavy	500	15	0.006
105	2700	D	240	B	0.70	0.22	0.15	mod.	250	30	0.05
240	2700	D	400	B	0.70	0.22	0.11	light	100	15	0.06
60	2700	D	120	B	0.10	0.18	0.22	mod.	500	10	0.02
240	3300	D	400	B	0.70	0.22	0.04	light	100	15	0.0025
240	5000	D	400	B	0.70	0.22	0.04	light	100	15	0.0025
120	2700	B_4C	240	C	0.70	0.22	0.36	mod.	250	60	0.06
240	2700	B_4C	400	C	0.70	0.22	0.20	light	100	60	0.03

Letter Codes

A - water

B - methalene iodide

C - cloroethoxyethane and tetrabromoethane

D - SD type diamond

Chipping Codes

Description	Approx. Size
Heavy	0.040"
Moderate	0.010"
Light	0.003

1 - maximum length of cut for diamond points
2 - RMS measured across scratches at 0.030" cutoff
3 - Time for maximum length of cut(1)
4 - (Depth) (Width) (Length) ÷ Time in hours

TABLE II

COST CALCULATIONS

Diamond Coated Mounted Points with Diamond Slurry

The only methods of grinding small blade configuration which seem at all reasonable are those which involved point grinding with an abrasive slurry. The time to do the machining seems slow, but the quality at least seems reasonable. Below is shown the calculation of the out-of-pocket, or factory cost for the diamond coated mounted points with diamond slurry.

	Diamond Spindle Grit	Diamond Slurry	Hours 2 Blades	Number of Spindles
Roughing Cut	105	240	5	12
Finishing Cut	240	400	2	5
Miscellaneous			1	
			8	17
Assumed cost per hour			$18	
Cost per spindle				$29
Factory cost/2 blades			$144	$493
Factory cost/blade			$ 72	$247
Total Factory Cost/blade			$319	

Estimated Factory Cost per 30 bladed wheel (including a better blade and root finish at double finishing cost) $12,500

NOTE: The factory cost is an out-of-pocket cost and does not contain the normal overhead cost, rejection rates, setup costs, jigging, etc., and should not be construed as selling price.

TABLE III

COST CALCULATIONS

Diamond Coated Mounted Points with B_4C Slurry

	Diamond Spindle Grit	B_4C Slurry	Hours 2 Blades	Number of Spindles
Roughing Cut	120	240	5	4
Finishing Cut	240	400	2	2
Miscellaneous			1	
			8	6
Assumed cost per hour			\$ 18	
Cost per spindle				\$ 29
Factory cost/2 blades			\$144	\$174
Factory cost/blade			\$ 72	\$ 97
Total factory cost/blade			\$169	
Estimated Factory Cost per 30 bladed wheel			\$6,400	

It should be noted that a 0.050 inch slot 3/4 inch deep was made in the center of the billet at a cost of around \$8 for each cut. Had this cut not been made, the spindle grinding costs would have been about 10 percent higher. The abrasive slurries are reusable and considered a neglible cost.

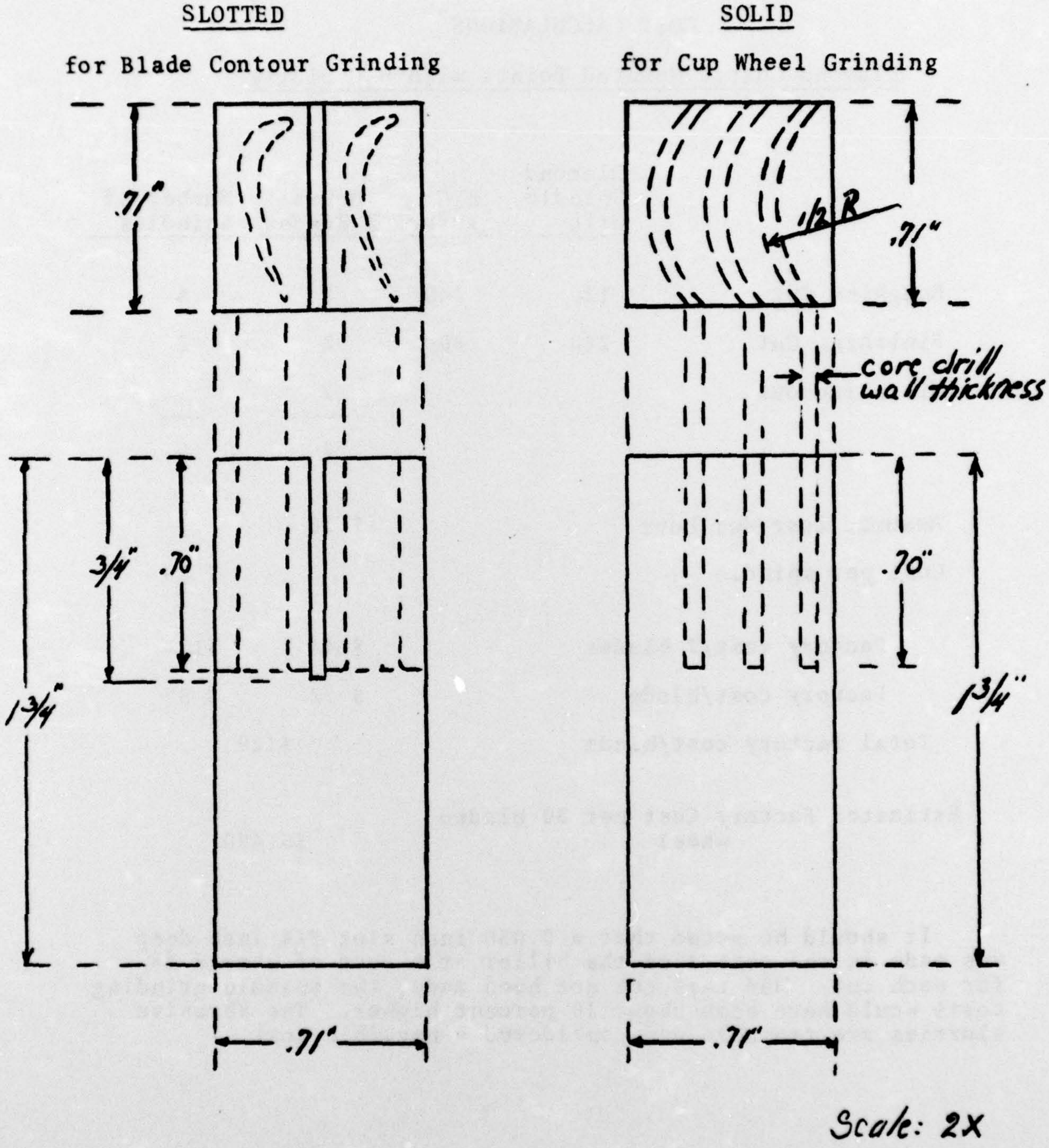


EXHIBIT A Ceramic Blanks Used in Machining Test

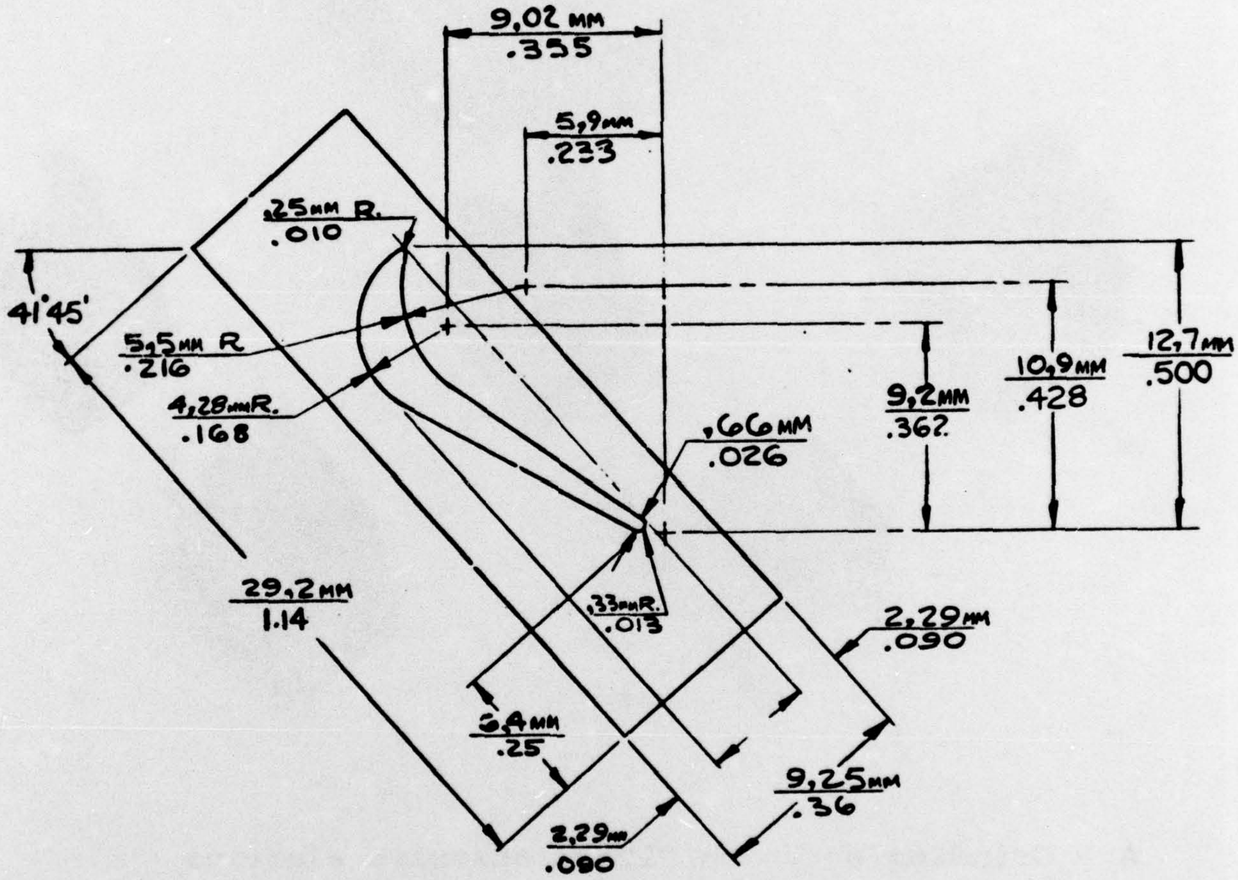


EXHIBIT B Ceramic Blade Contour

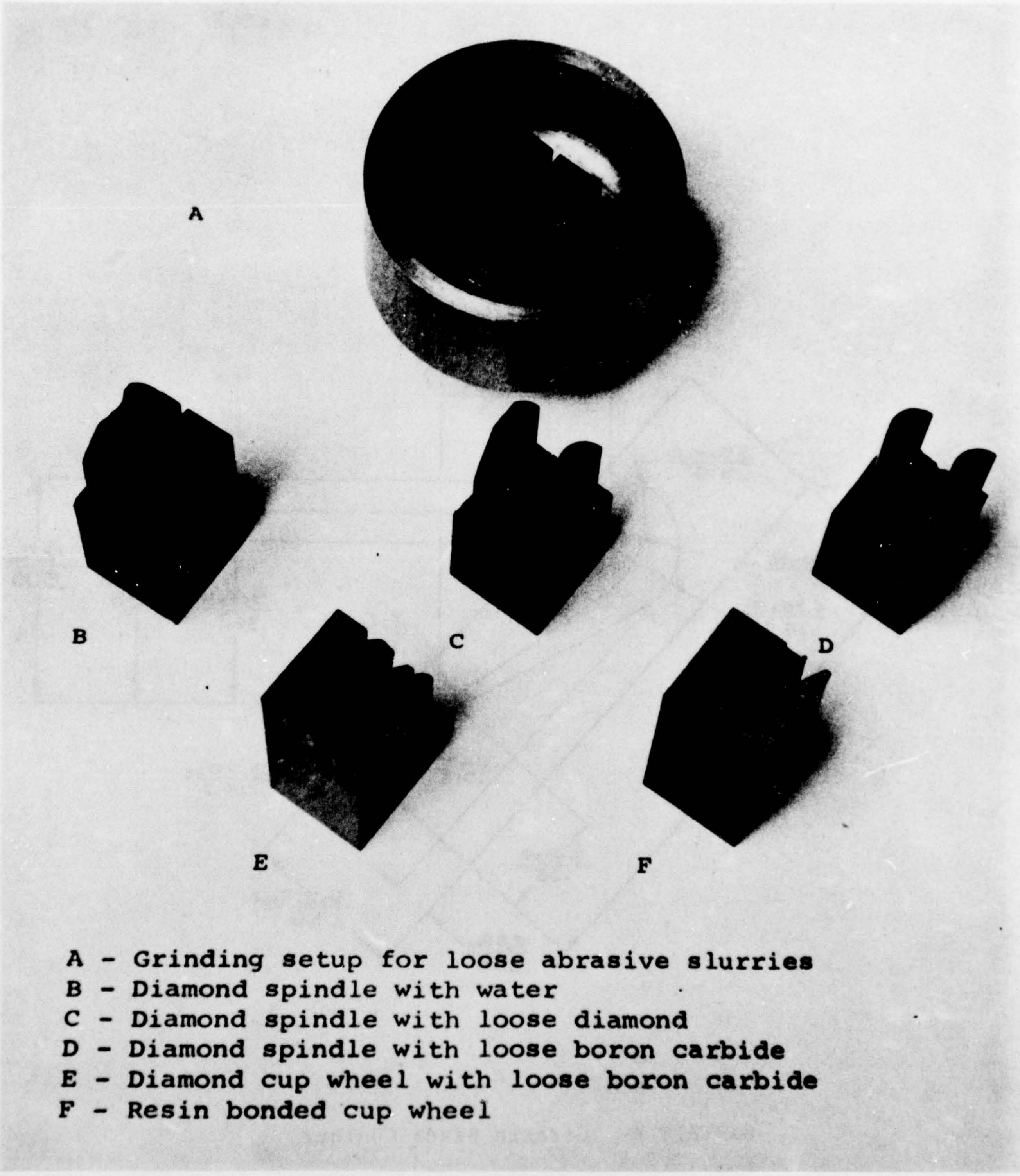


EXHIBIT C Sample Shapes of Ground Silicon Nitride

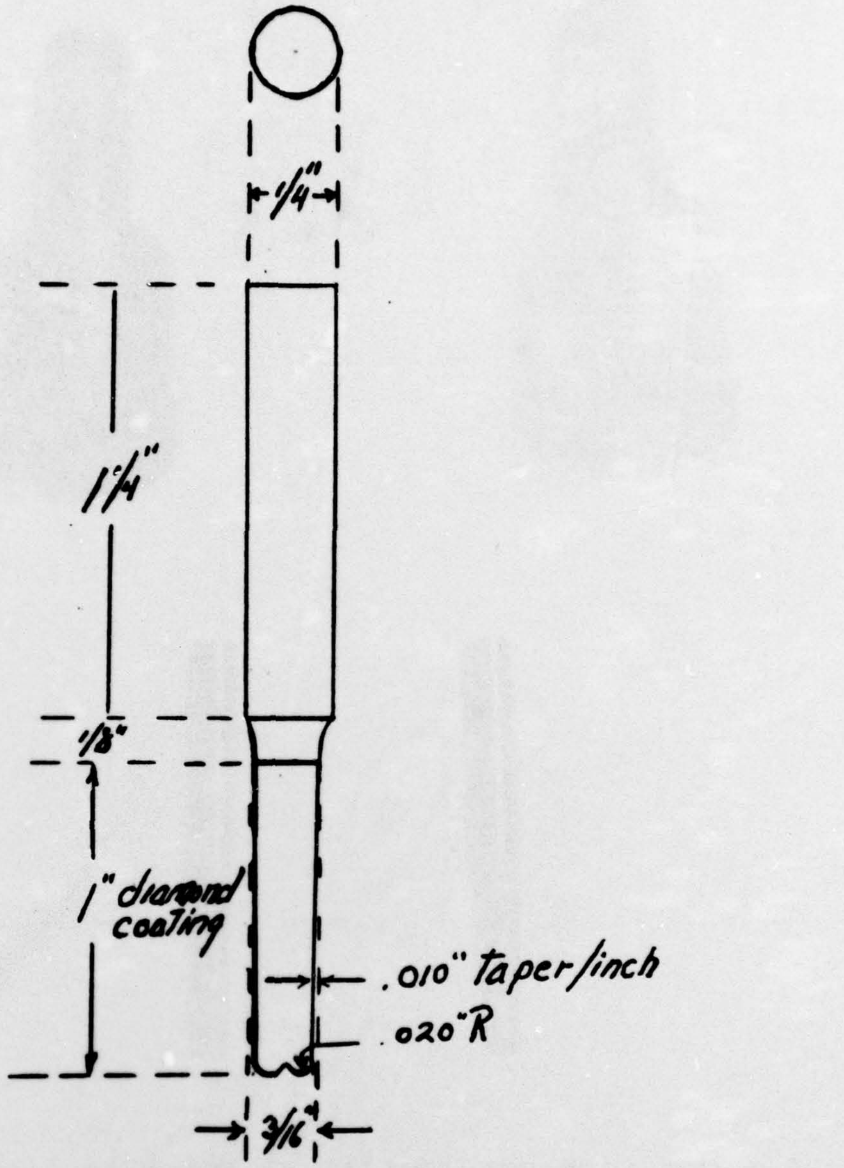
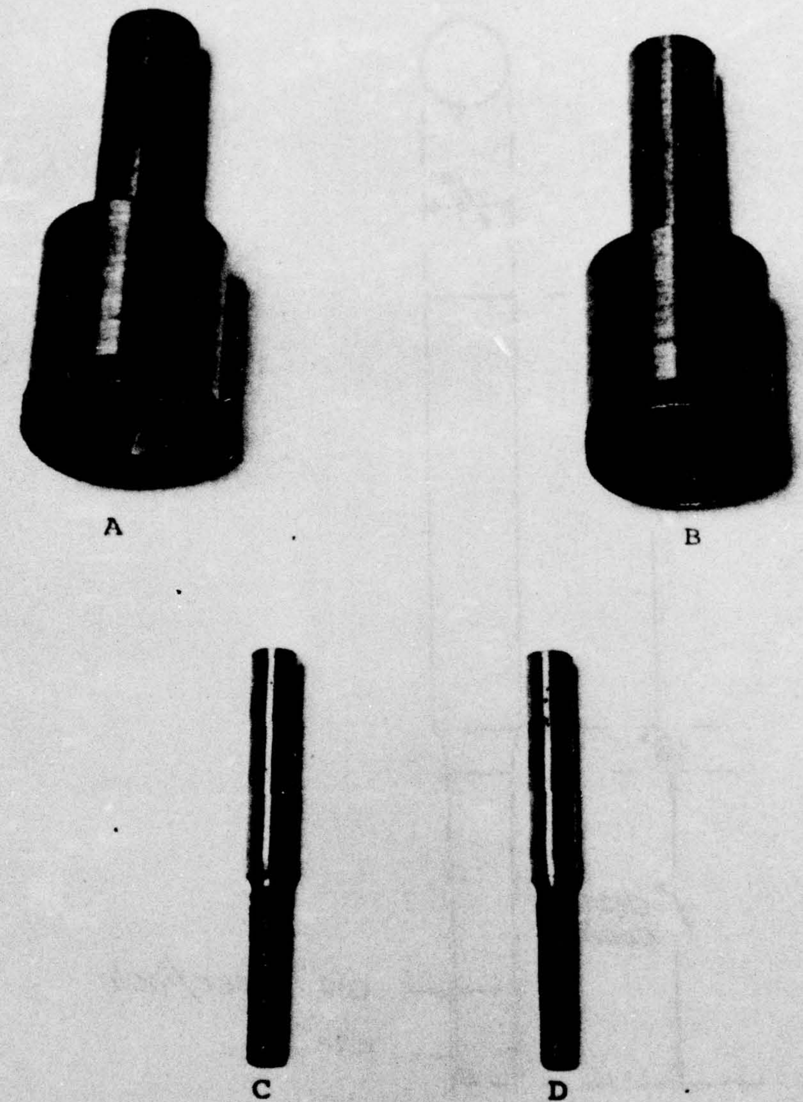


EXHIBIT D Diamond Coated Mounted Points for Contour Grinding



A - One inch core drill - 105 grit diamond coated
B - One inch core drill - 120 grit diamond coated
C - 3/16" mounted point - 120 grit diamond coated
D - 3/16" mounted point - 240 grit diamond coated

EXHIBIT E Samples of Diamond Coated Tooling

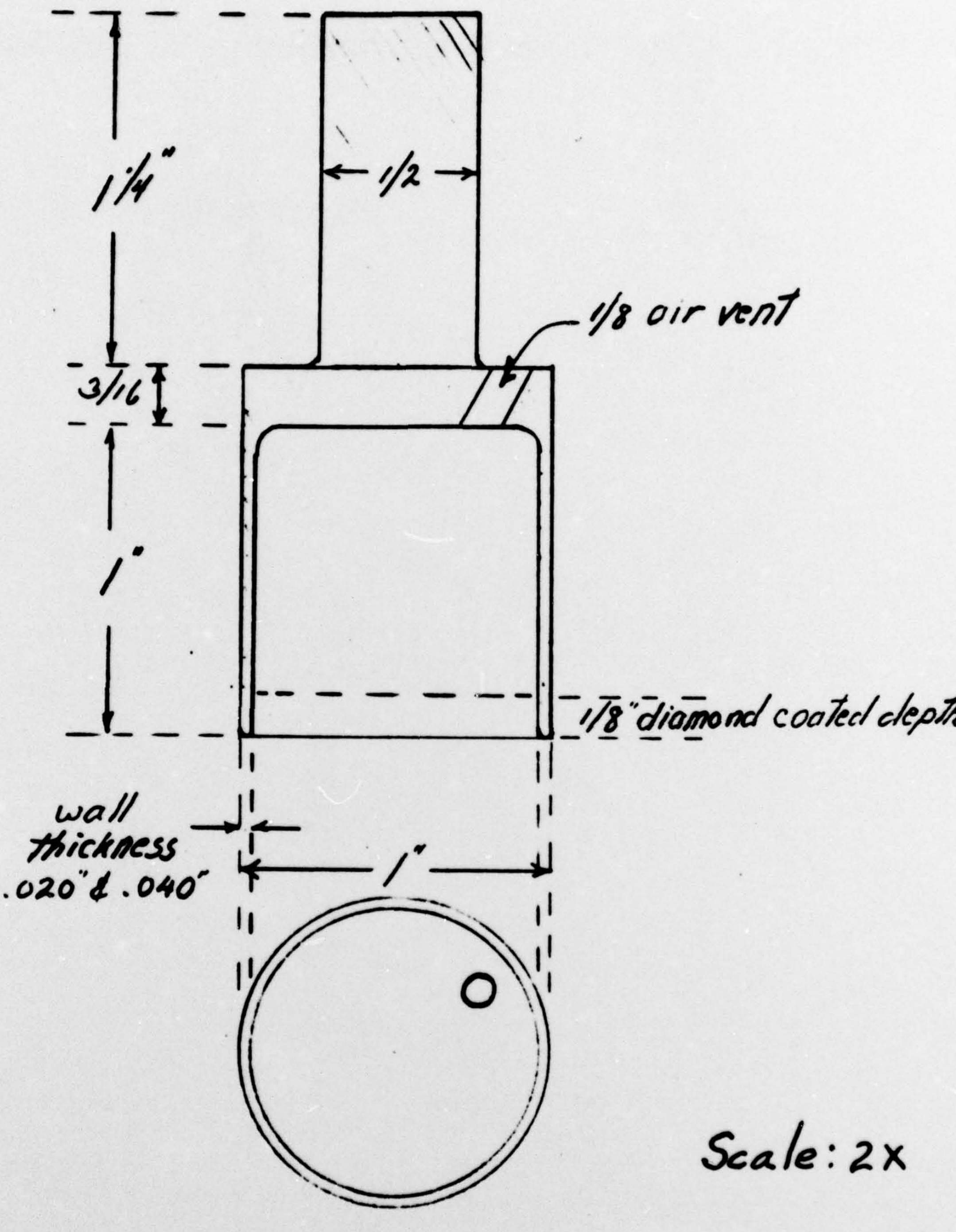


EXHIBIT F   Diamond Coated Cup Wheels for Plunge Grinding

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