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Machinability Study of Aermet 100

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Abstract

Machinability of Aermet 100, an ultrahigh strength alloy developed for Navy by Carpenter Technology as a candidate material for aircraft landing gear application, was studied by performing single-point turning tests. Coated and uncoated carbides, ceramic, and cermet cutting tool inserts of a square geometry (SNG 432 type) were used. Round stock workpieces were tested in the as - received, unaged condition and without using any cutting fluid. The turning tests for each tool material were conducted by (i) first establishing the cutting conditions that would allow the continued generation of broken chips during a given cutting test, (ii) measuring intermittently the flank wear as a function of cutting time under such established cutting conditions for discontinuous broken chips, and (iii) determining the tool life using the criteria specified in the ISO Standard 3685: 1993(E). Cutting tools except some uncoated carbide and ceramic were used with a mechanical chip breaker to induce chip breakage and avoid the generation of long continuous chips. The results obtained include the optimal cutting conditions for discontinuous chips, tool wear - cutting time curves, and records of tool life and tool failure mode for each tool material. From the measured tool life and cutting conditions, the amount of material removed by each cutting material was calculated. Coated carbide with CVD tri-phase coating showed the longest tool life that exceeded the twelve minute criterion and removed the highest amount of material per tool. Other tools failed by cutting edge chipping and their lives were shorter.

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INTRODUCTION

Aermet 100 is an alloy steel developed for Navy by Carpenter Technology and a candidate material for next generation aircraft landing gear[1]. This material has high tensile strength[2, 3], good corrosion resistance[4], high fracture toughness[2, 3], and fatigue resistance[5]. However, the good properties make its machining rather difficult. Understanding of its machinability and establishment of optimum machining conditions are indispensable for cost-effective production of the landing gears and other engineering parts that can take advantage of its properties.

The present study was initiated to investigate the machining behavior and determine the optimum cutting conditions during single-point turning of this material. The cutting experiments were performed to determine which tool material was best suited and what combination of parameters (such as speeds, feeds, and depths of cut) works best for turning the material This was accomplished by measuring the tool flank wear and obtaining the tool life for each tool material. Carbide, ceramic, cermet, and coated carbide tools and some of these tools attached with a mechanical chip breaker were used. Amount of material removed (in cubic inches), flank wear and tool-life data for those tools were obtained.

The purpose of this report is to document the results of the single-point turning tests performed from July 1994 to October 1994. The main thrust during the period was to establish cutting conditions optimized for chip control in rough machining of Aermet 100 in the unaged state. This report provides tool-life data for carbide, ceramic, coated carbide and cermet cutting tools for single-point turning of the material. In addition, experimental test procedures, test conditions, problems encountered during machining, and recommendations for future work are discussed.

EXPERIMENTAL PROCEDURES

The cutting experiments were designed to closely follow the ISO 3685:1993(E)[6] Standard for tool-life testing with single-point turning tools. A few modifications were adopted due to constraints of the machine tool and work material availability. A full factorial experimental design consisting of 2 cutting speeds, 2 cutting tool materials, 2 cutting conditions, and 2 materials (Aermet & HyTuf) was initially sought. However, the preliminary testing to find the optimum cutting conditions for desirable chip control resulted in a shortage of material for the full factorial testing. As a result, experiments consisting of 1 cutting speed and 1 cutting condition for each cutting tool were performed. Cutting conditions were optimized to produce discontinuous chips for each tool.

Machine Tool

An Okuma Cadet turret lathe equipped with a 15 HP variable speed drive was used for the turning tests. It is a numerical control type machine tool with good rigidity and repeatability. It has a maximum spindle speed of 4200 RPM. The Okuma was selected because it was capable of maintaining the desired cutting speed as the diameter of the workpiece was reduced by successive cuts.

DISCLAIMER

Workpiece

Three different batches of Aermet 100 were received in the unaged condition. The first batch of material used for preliminary tests were rectangular (4.2"x2.1") bar stock with a surface hardness 40 HRc and was machined down to round stock. The second batch was round bars of 2" diameter and 9" length. The bars had an optimal surface hardness of 40 HRc for machining. The actual length of cut was 8 inches on each piece. The third batch was round stock with 9" radius and had surface hardness of 44 HRc. Most of the turning tests were done with the second batch material.

Tool Materials

Five different types of cutting tools listed below were used. The SNG series are square type inserts with 4 cutting edges on the top and 4 cutting edges on the bottom. These sturdy inserts were selected since they were good for straight turning and facing where there were no shoulders present.

Tool	Type	Manufacturer
SNG 432-ST20E	Tungsten carbide	Sumitomo Electric
SNMG 432 ENZ-ST20E	Tungsten carbide with chip breaker	Sumitomo Electric
SNG 432T-K090	Ceramic (70% Al_2O_3 + 30% TiC)	Kennametal
SNMG 432-KC 850	CVD Tri-Phase coated carbide with chip breaker	Kennametal
SNMG 432A-6K-VC 671	Cermet (TiC + TiN) with chip breaker	Valenite

Tool Holder

The tool holder was a CSBNR-164-3 model from Sumitomo Electric. The length and the cross section of the holder were 6.3 inches and one inch square, respectively. This is a clamped-type, right hand tool holder with a matching Sumitomo mechanical chip breaker (#CBD4R) as shown in Figure 1. The front face of the chip breaker was sloping up 60° from the bottom edge. On its top surface the chip breaker has three notches parallel to its front edge. By setting the clamp of the tool holder at one of these three notches, the location of the chip breaker with respect to the cutting edge of the tool can be adjusted. The flow and breakage of the chip can be controlled by such adjustment. Figure 1 also shows a cutting tool insert mounted on it underneath the mechanical chip breaker.

Tool Geometry

The tool geometry used in the turning tests was:

Back Rake:	-6°
Side Rake:	-6°
Side Cutting Edge Angle:	15°
End Cutting Edge Angle:	15°
End Relief:	6°
Side Relief:	6°
Nose Radius:	1/32"

The tool geometry parameters are defined following the ISO 3685 Standard[6].

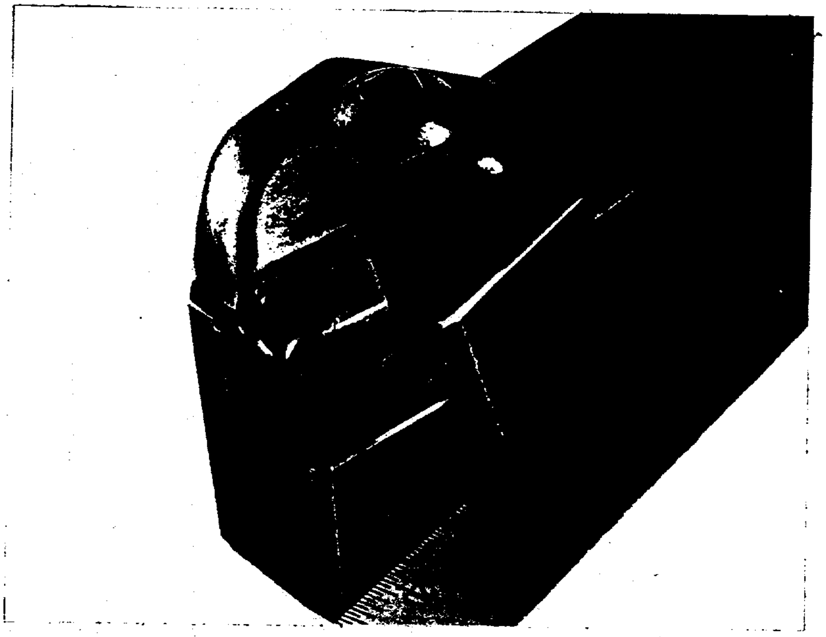

Figure 1. Tool holder with a mechanical chip breaker and cutting tool insert

Tool Wear Measurement

A Nikon microscope was used to measure and photograph the tool wear. The photographs were taken at a magnification of 50x. Width of the flank wear land was measured from the photographs. In this report, only the results of flank wear will be given.

Tool-Life Criteria

The ISO 3685 criteria[6] were used for both the carbide and ceramic tools wear as follows:

a) the maximum width of the flank wear land VB_{max} = 0.6 mm (24 mils) [see Figure 2 for definition of VB], if the flank face was not regularly worn in the flank wear zone;

b) the average width of the flank wear land VB = 0.3 mm (12 mils) if the flank wear land was considered to be regularly worn;

c) chipping and cracking was considered premature tool failure.

Cutting Fluid

Since the ISO 3685[6] requires dry cutting tests for tool life testing, all cutting tests were performed without using any cutting fluid.

Cutting Test Procedures

1. Cutting tool was selected.

2. Each cutting edge of the insert was examined for visual defects such as chips or cracks at a minimum magnification of 10x.

3. Insert was installed into tool holder. Insert was positioned such that the underside of the insert did not project over the supporting face of the tool holder by more than 0.3 mm (12 mils). The distance from the corner of the tool to the front of the lathe tool post holder (overhang) was maintained at 38 mm (approx. 1.5 inch).

4. The desired speed, feed, and depth of cut were selected.

5. Approximately 1/4 inch length of cut was taken.

6. The insert was removed from holder and inspected for chips, cracks, or other damage.

7. Step 3 was repeated.

8. The turning operation was continued from termination point in step 5.

9. Care was taken to avoid running the cutting tool into the shoulder formed from the previous cuts. This prevented additional, unwanted wear to the tool.

10. After the pass was completed, the insert was removed from holder and the flank wear was measured.

11. If the average flank wear didn't exceed 12 mils or the maximum flank wear didn't exceed 24 mils, then the flank wear was recorded and step 3 was repeated. Then another pass was taken, and steps 9 through 11 was repeated. If the tool life was less than 5 minutes for the carbide tool and 2 minutes for the ceramic tool, the cutting speed or feedrate was decreased and the tool was indexed, and steps 2 through 11 were repeated.

12. Once the tool life was established, a different tool material was selected and steps 2 through 11 were repeated.

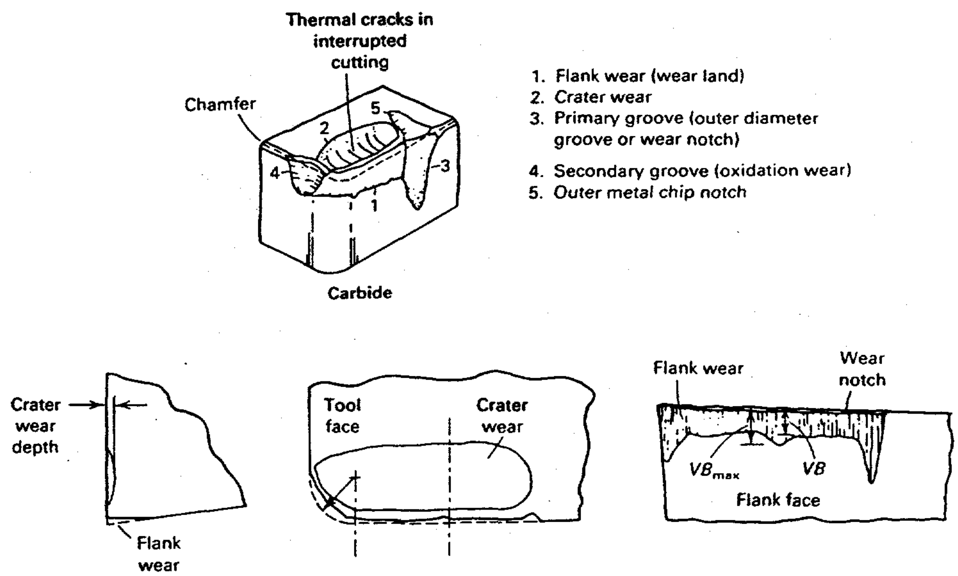

Figure 2. Typical tool wear pattern and measurement

RESULTS

Determination of Cutting Conditions for Chip Control

When the chip control was not used, undesirable long continuous springy chips as shown in Figure 3 were generated. Several preliminary variations of cutting parameters allowed to optimize the chip control as follows. Optimal chip control conditions varied with each cutting tool material. The depth of cut (d.o.c.) as defined in Figure 4 was the same for all the tools, but the feed and chip breaker were different for some.

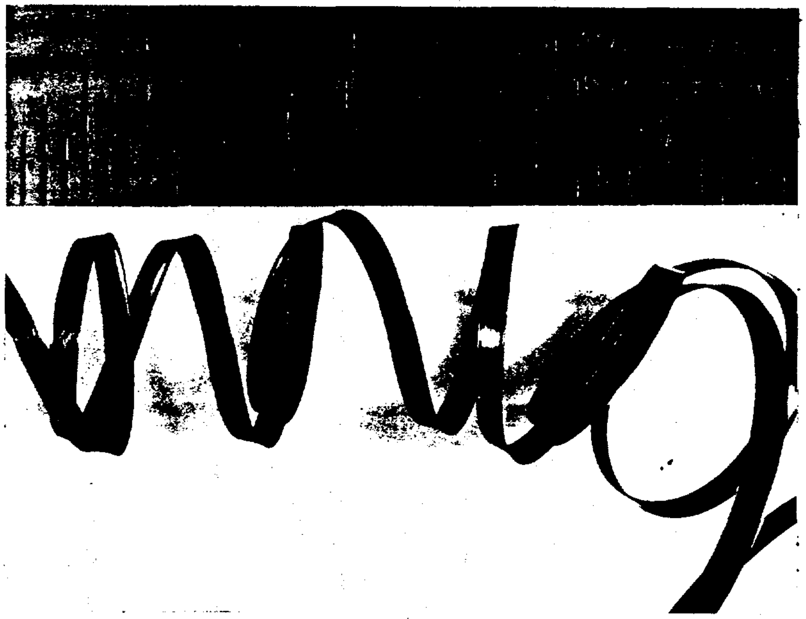

Figure 3. Typical continuous springy chip produced without chip control.

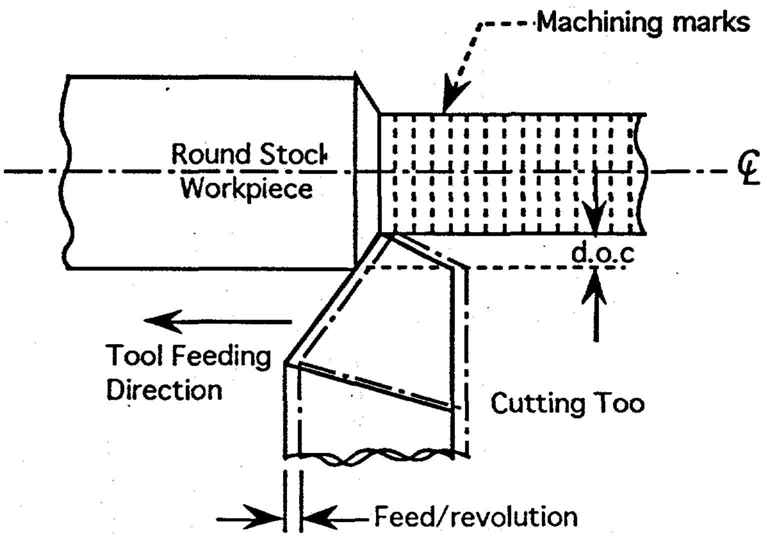

Figure 4. Definition of depth of cut and feed.

The resultant cutting conditions for the optimal chip control for different tools were as follows:

Uncoated carbide tool:

Cutting speed:	350 sfpm (surface feet per minute)
Depth of cut:	0.063 inches
Feed:	0.015 inch per revolution (ipr)
Chip breaker location:	last notch (close to tool edge as possible)

Uncoated carbide tool with chip breaker:

Cutting speed:	350 sfpm
Depth of cut:	0.063 inches
Feed:	0.015 ipr
Chip breaker location:	last notch

Ceramic tool (Al_2O_3+TiC):

Cutting speed:	950 sfpm
Depth of cut:	0.063 inches
Feed:	0.010 ipr
Chip breaker location:	middle notch

Coated carbide tool with chip breaker:

Cutting speed:	420 sfpm
Depth of cut:	0.063 inches
Feed:	0.013 ipr
Chip breaker location:	first notch (far from tool edge as possible)

Cermet tool with chip breaker:

Cutting speed:	420 sfpm
Depth of cut:	0.063 inches
Feed:	0.012 ipr
Chip breaker location:	first notch (far from tool edge as possible)

As stated previously, the chip formation changed as the workpiece diameter was reduced. For the uncoated carbide tool both with and without a chip breaker, the chips went from loose arc chips and connected arc chips, respectively, to short and sometimes long helical chips. However, the chips still broke and did not interfere with the cutting tools. The ceramic and coated carbide tools produced consistent chip formation throughout the experiment. The ceramic tool produced snarled, ribbon chips and the coated carbide tool produced loose arc chips as shown in Figures 5 and 6.

Tool Life

Figures 7 through Figure 10 are plots of flank wear versus cutting time. The tool life of the chip breaker-attached carbide tools exceeded both the ceramic tool and the uncoated carbide tool. Figure 7 shows that the tool life of the uncoated carbide tool with and without chip breaker, and that the tool life was almost doubled with the chip breaker, under the same cutting conditions.

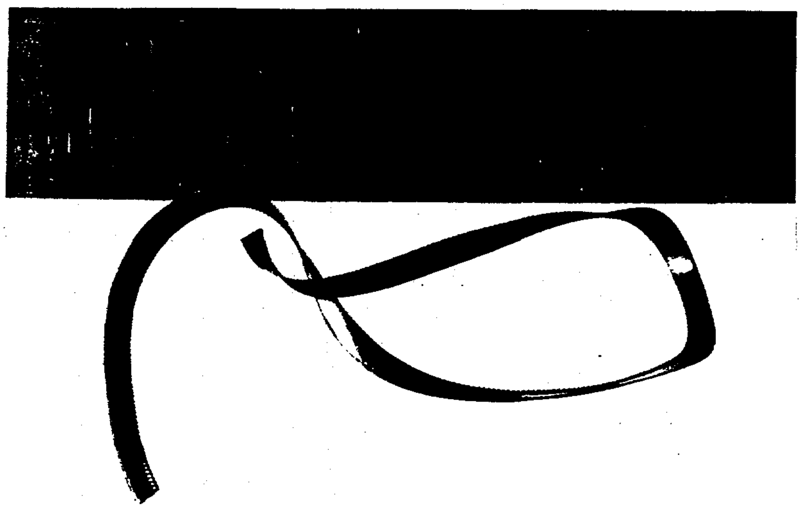

Figure 5. Snarled ribbon chip by ceramic tool

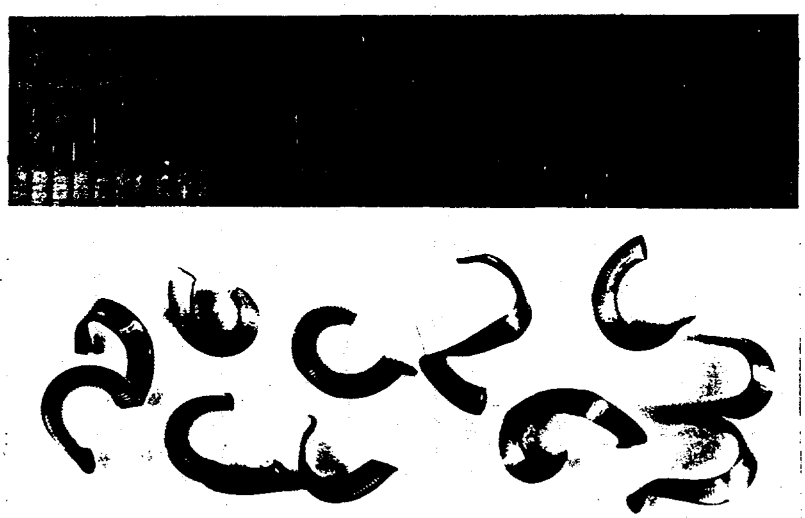

Figure 6. Loose broken arc chips by coated carbide tool with chip breaker.

Ceramic tools are known for their high cutting speed capability, which was verified by the experiments performed. Figure 8 shows that the cutting speed for the ceramic tool more than doubles the cutting speed for any other tool. The tool life of the ceramic tool was lower than expected. However, the minimum tool life of 2 minutes (as required and stated in the ISO Standard) was achieved.

Figure 9 shows the flank wear for the coated carbide tool with a chip breaker for two different tests. In the first test [curve (a) in Figure 9] performed with a workpiece of a 2" diameter, the coated carbide tool did not fail, the test was aborted due to the expenditure of material. The second test [curve (b) in Figure 9] was conducted with a workpiece of 4.125" diameter. The second test was stopped when the flank wear exceeded the 12 mil limit as defined in the ISO standard.

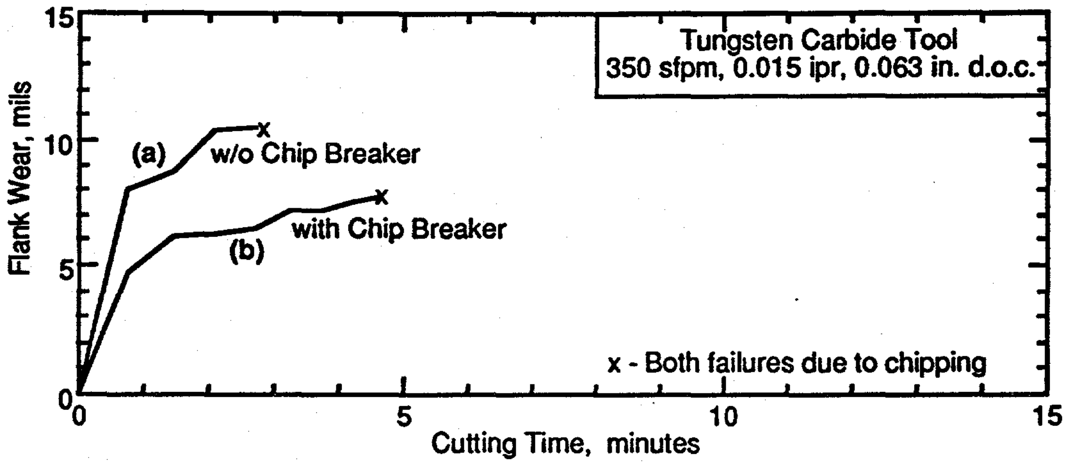

Figure 7. Tool life comparison between uncoated carbide tools with and without chip breaker.

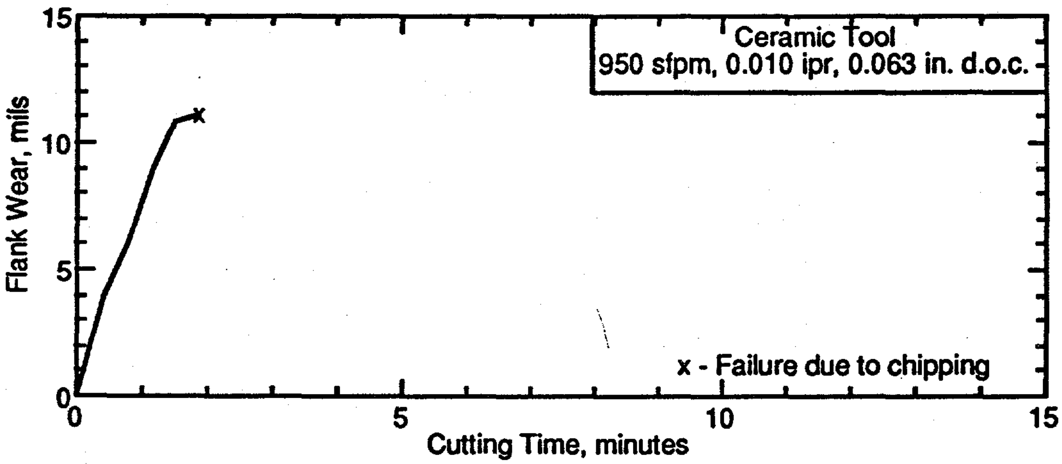

Figure 8. Tool life for ceramic cutting tool.

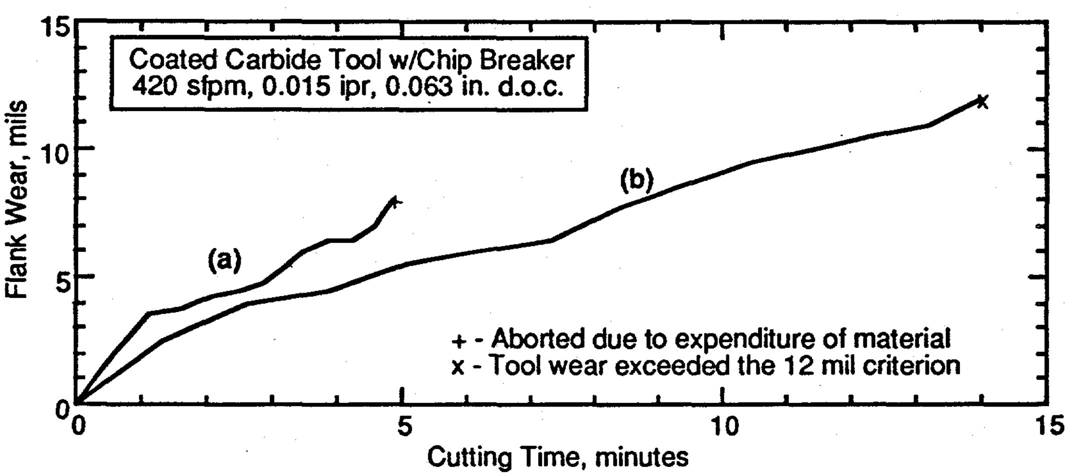

Figure 9 Flank wear for the coated carbide tool.

The cermet tool was used on a 9 inch long by 4.125 inch diameter piece of round stock. Figure 10 shows the tool life for the cermet tool. It can be seen in Figures 9 and 10 that the wear is about the same for the cermet and coated carbide tool. This is likely due to the fact that they both have built-in chip breakers more so than the difference in tool materials.

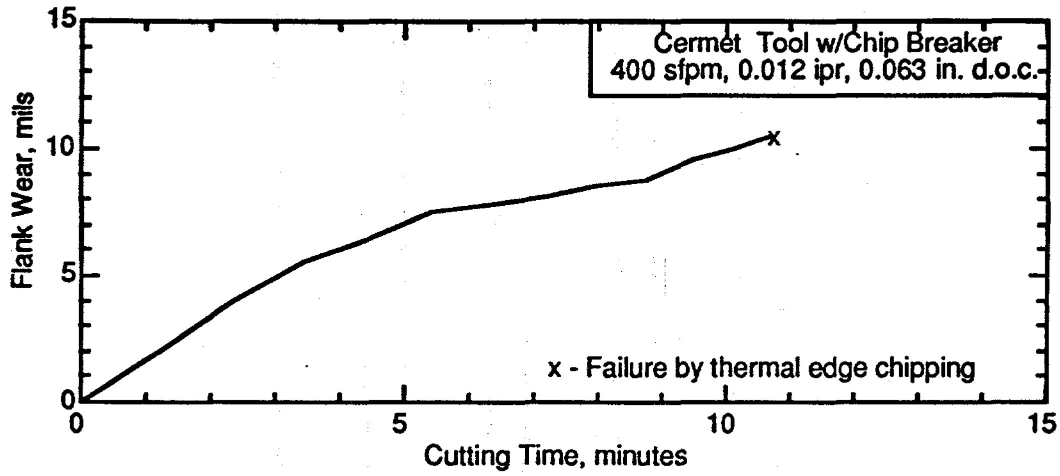

Figure 10. Tool life for cermet tool.

DISCUSSION

Tool Wear and Failure Behavior

Uncoated Carbide: Uncoated carbide tools failed by cutting edge chipping during the cutting tests and were removed as the tests should be stopped. Tool life was doubled when used with chip breaker.

Ceramic Tool: Tool was short-lived and failed by chipping. The wear rate was fast when compared with other tools used in the present study but the cutting speed was much faster than for other tools. The workpiece cut with ceramic tools remained cool while the pieces cut with other cutting tools were too warm to touch. This indicates that ceramic tools may be preferable when the thermal distortion is of concern. Further tests with ceramic tools seem to be in order.

Coated Carbide: A comparison between the curve (b) of Figures 7 and curve (a) of Figure 9 shows that the tool wear is about the same for both coated and uncoated carbide tools attached with chip breaker. However, the initial wear rate and tool failure mode are different. The uncoated carbide tool [curve (b) in Figure 7] showed a rapid tool wear initially, while the coated carbide [curve (a) in Figure 9] wore at a much slower rate. Another difference is that the uncoated carbide tools failed due to chipping, which was probably caused by thermal breakdown. The coated carbide tool did not chipped. The tri-phase (TiC/TiCN/TiN) ceramic coating extended the life of the carbide tool by increasing its resistance to temperature and decreasing the friction coefficient between the tool and the chip. The coated carbide was much tougher than the uncoated ones. The coated carbide tool has a cobalt-enriched substrate for an added strength. The uncoated tool was of a P10 grade and the coated carbide was of a P25 grade. The P10 grade is mostly used for finishing whereas the P25 is used for roughing and interrupted cutting. The transverse rupture strength of a tool increases with the grade, thus making it a tougher tool. The KC 850 tool was used because it is widely used in the machine shops at LLNL and it was available for comparison.

Figure 9 shows also the tool life for the coated carbide tool used in a turning test of a 9 inch long by 4.125 inch diameter piece of round stock. It can also be seen in Figure 9 that the coated carbide tool wore at a slower rate than it did for the smaller workpiece. The difference in results could be a result of the 4.125 inch diameter piece having a hardness of 44 HRc and the 2 inch diameter piece, which was used for the other tests, having a hardness of 40 HRc.

Cermet: The cermet tool failed by cutting edge chipping. The tool wear rate up to the point of the failure, however, was rather similar to that of the coated carbide when the results in Figures 9 and 10 were compared to each other. This suggests that the edge chipping resistance of the coated carbides may be superior to that of the cermet tools.

Chip Control

During the preliminary testing, there was a major chip control problem because of the high tensile strength and composition of the material. Preliminary testing was conducted to find cutting speeds and feeds that would allow the tool life to exceed 5 minutes for the carbide tool and 2 minutes for the ceramic tool. Conditions that were good for tool life were not necessarily good for chip control. Under some conditions, long stringy, continuous chips wrapped around the workpiece and caused the cutting tools to chip and fail prematurely. The chips that wrapped around the workpiece were fed back into the path of the cutting tool.

Determining cutting conditions to obtain good chip control was time consuming. Even though good chip control was obtained at the start of a test, it deteriorated as the diameter of the workpiece decreased. The cutting tool tended to push the material away and as a result the true depth of cut was smaller than the selected one. This was proven by taking a clean-up cut with the machine set at the same parameters it was on the previous pass. The change in chip formation could also have been due to the change in the material work hardening behavior at elevated temperature. It was noticed that the work material seemed to get hotter as the diameter decreased. The chip control seemed to be out of control when the workpiece diameter was approximately 1.622 inches or smaller.

Long, continuous chips (shown in Figure 3) are hazardous to the machine operator, can cause premature tool failure, can damage the machine if abrasive, and produce surface damage to the workpiece, especially when they wrap around the workpiece. Their sharp edges and high tensile strength make their removal from the work area very difficult and hazardous, particularly when the machine is in operation. The short, broken chips shown in Figures 5 and 6 are much easier to remove from the machine and dispose of. Therefore, it is apparent why good chip control is important.

A chip breaker provides an additional leveraging force to cause a tighter curling of chip and promote chip breakage at the point where the chip just separates from the workpiece. The chip breakage and its prompt removal will reduce the friction between the chip and the tool and will lead to a lower cutting temperature, less thermal breakdown of the tool, and therefore a longer tool life.

Amount of Material Removed

Figure 11 shows the amount of material removed for each cutting tool. The amount was calculated from the depth of cut, feed rate, and cutting speed used for each tool. The coated carbide tool with the chip breaker is shown to be far superior to other tools. Thus, it will be a logical choice to use the coated carbide tools at least in the rough machining of Aermet 100.

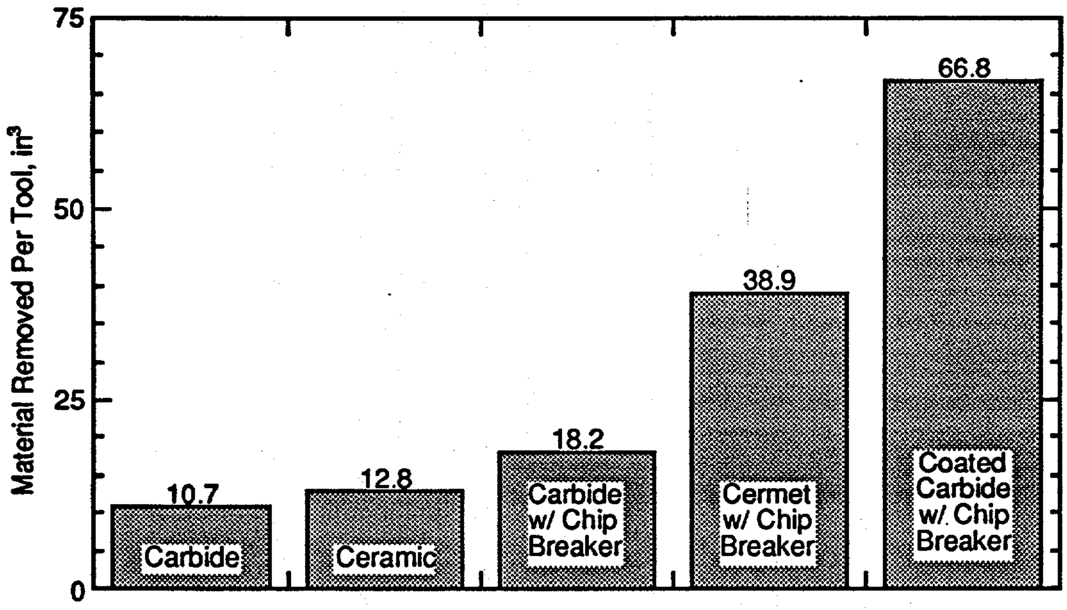

Figure 11. Volume of material removed by each tool.

Deviations from ISO Standard

The recommended tool overhang of 1 inch in the ISO Standard was not obtained due to the configuration of the Okuma. With a tool overhang of 1 inch, the turret would hit the tail stock at the beginning of the turning operation. A tool overhang of 1.5 inches was the minimum achieved.

The ISO Standard recommended that the cutting speed be calculated based on the workpiece surface (diameter before turning) and not the machined surface (diameter after turning). However, the cutting speed reported in the Results section was calculated based on the machined surface. Thus the actual cutting speed calculated according to the ISO Standard would be higher by two to four percent depending on the diameter of the workpieces.

Further study and Recommendations

It is planned that turning experiments be done on Aermet 100 in its age hardened state (50 to 55 HRc), especially for finish machining. It is proposed to conduct those experiments using CBN tools for the finishing operation as well as investigating the use of the other advanced cutting tools. Surface finish and underlying microstructure will be charcterized both in aged and unaged conditions. It is also planned that residual stress and stress-induced distortion after both rough and finish machining be characterized and evaluated.

Presently, there are advanced cutting tools specifically designed for specific parts for the aerospace industry and high-temperature alloy materials. These tools were claimed to have been designed with effective chip control and extended tool-life as priorities. It is recommended that some turning tests be done on Aermet 100 using those advanced cutting tools. It would be interesting to see if the tool life for those cutting tools falls within the optimum range of 10 to 20 minutes. This range is optimal when production machining is performed. Furthermore, the advanced cutting tools may not require cutting speeds and feeds as high those required for the tools used during the present study. This could be crucial when small diameter parts are turned.

It is important to note that ceramic tools should be used if there is concern for temperature rise in the workpiece during machining. When machining with ceramic tools, 80% of the heat generated is dissipated into the chip leaving 10% dissipation into the tool and 10% dissipation into the workpiece. The temperature of the workpiece was cool to the touch after each pass with the ceramic tool, unlike the case with the carbide tools. The elevated speed capability of ceramic tools can also lend gains in productivity.

SUMMARY AND CONCLUSION

A machinability study was performed on Aermet 100, a candidate material for aircraft landing gear. Ceramic, cermet, uncoated tungsten carbide, and tri-phase coated carbide tools were used for the experiments. These tools were square-shaped indexable inserts, with four cutting edges on the top and four on the bottom. At least one cutting condition appropriate for maintaining good chip control was established for each tool material. The experiments closely followed the ISO 3685:1993(E) Standard for tool-life testing with single-point turning tools. It was found that the coated carbide tool with the chip breaker was the best tool for machining Aermet 100. It had the longest tool life, least flank wear, and was effective in producing broken chips consistently.

ACKNOWLEDGMENT

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