Honeywell

Evaluation of End mill Coatings
Federal Manufacturing & Technologies

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Contents

.

Photographs

Figures

Tables

Graphs

Graphs (<u>cont'd</u>)

Graph *Page*

Abstract

Milling tests were run on families of High Speed Steel (HSS) end mills to determine their lives while machining 304 Stainless Steel. The end mills tested were made from M7, M42 and T15-CPM High Speed Steels. The end mills were also evaluated with no coatings as well as with Titanium Nitride (TiN) and Titanium Carbo-Nitride (TiCN) coatings to determine which combination of HSS and coating provided the highest increase in end mill life while increasing the cost of the tool the least. We found end mill made from M42 gave us the largest increase in tool life with the least increase in cost. The results of this study will be used by Cutting Tool Engineering in determining which end mill descriptions will be dropped from our tool catalog.

Summary

Cutting Tool Engineering, Process Engineering, and Machining Operations have repeatedly raised the following questions. How can we reduce the number of perishable cutting tool stores descriptions, decrease the number of tools per description, increase the cutting tool inventory turnover, and have optimum cutting tool usage? What combination of base material and coating are the optimum perishable tool combinations?

A study was conducted to determine the relative tool life of end mills made from M7, M42, and T15-CPM HSS. These end mills were both uncoated and coated with titanium nitride (TiN) and titanium carbo-nitride (TiCN). The tests were conducted in annealed 304 stainless steel. End mill and corner wear were compared to the radius generated in the corner of a profiled milled part. Tool performance was ranked against tool cost so that the most cost effective tool could be selected. Failure criterion was based on the requirements of SS290029, General Requirements for Miniature Mechanisms. This specification limits corner radii generated in production parts to 0.005 inch. Additionally, this specification allows one-third the allowable tool wear of ISO 8688-2, Tool Life Testing in Milling – Part 2: End Milling; May, 1989.

Testing revealed that for a 6% premium in cost we could obtain a 24% increase in cutting tool life based on equivalent wear. By combing the description for M7 and M42 HSS we can find and remove duplicates. Thereby, we can reducing the number of descriptions and their inventories and giving the remaining tools more usage and increased inventory turnover.

Discussion

Scope and Purpose

In the last ten years, many new cutting tool coatings have been introduced and are available on many different types of perishable cutting tools. To determine the effects of coatings on perishable cutting tool performance, we must evaluate the cutting tools and coating together as a system. To gauge their effects on FM&T operations, we used coatings supplied by a cutting tool manufacturer on their tools and tested the tools in our manufacturing environment (machine tools, metal removal fluids, fixturing and manufacturing conditions). A cost to tool performance comparisons would then be valid for our unique conditions.

Over the past decade, we have set up cutting tools in our store's system using three types of HSS: High Speed Steel (M2/M7), Cobalt High Speed Steel (M42), and Premium Cobalt High Speed Steel (T15-CPM), as well as tools made from multiple grades of carbides and micrograin carbides. These tools were set up with a number of coatings (uncoated, Titanium Nitride, Titanium Carbo-Nitride, Titanium Aluminum Nitride, and Diamond, etc).

Today, we are also faced with decreasing machining schedules, smaller lot sizes and higher tooling costs. Thus, management wants us to decrease our inventories of stores tools. To do this, we need to know which combination of base material and coating gives the engineer the best tool life so we can reduce the direct machining cost.

These factors led us to attempt to answer the following basic questions. How can we reduce the number of stores descriptions for perishable cutting tools, increase the number of tools per description, increase the cutting tool inventory turnover; and have optimum cutting tool usage? What combination of base material and coating is the optimum perishable tool combination when machining stainless steels?

To answer these questions, a test program was designed based on the ISO test procedure (Ref. 1) for end milling. The performance of end mills made from various types of HSS and commonly available coatings was evaluated under rigid test procedures so comparisons could be made.

Activity

Evaluation of current tool catalog

Twenty-five years ago, we had over 12,000 standard cutting tools in our tool catalog. Without computer numerically controlled (CNC) machine tools, we stocked end mills in 0.0010 diameter increments to allow us to machine small groves and features. As different tool materials and coatings have become available, we have upgraded our tool inventory to utilize these longer life tools. Today's machine tools, with cutting tool compensation to the tool paths, allow us to make multiple passes and to control feature size in even smaller increments. Cutting Tool Engineering has reduced our standard tool inventory by fifty percent because our tool selection criteria have changed.

Cutting Tool Engineering has set up new tools so that process engineers can try out the newest tool technologies and optimize their machining parameters. Over the years, process engineers have migrated to these newer tools. The use of older technology tools has dropped off and these older tools have been slowly weeded out of the system, but at what cost? Today, it seems like every week some tool company has come up with a new combination of tool material and coatings. For example, a four-flute quarter-inch, high-speed steel, center-cutting end mill costs between $11 and $45 depending on the base material and coating combination. Most milling operations do not need a micrograin carbide end mill with a multi-layer coating to complete a small production run. In fact, in a number of cases, this tool is not worn out and the tooling cost per part is high. To use this tool at its maximum performance level, we must use very high cutting speeds and require rigid tooling to securely hold the part and prevent deflection. To make these tools economically feasible, you must use run them as they were designed at the highest cutting speeds on large lots.

The cutting tool life is a function of the combination of the tool material and its coating. Each HSS has unique properties (strength, toughness, ability to harden). The coatings are very hard with unique surface properties that can best be described as slippery. Since the coating materials do not contain iron, the chips tend to not weld to the tool at its tip where high pressures and temperature of metal cutting are generated. As a result, the built-up-edge (BUE) of the work piece material on the cutting tool is not as prevalent. Tool life is affected by this synthesis of properties of both materials.

Failure of the bond between the coating and the tool causes premature failure because we are depending on the combination of properties and not the individual properties. This was the reason we had our end mill vendor supply the coated tools for the test. In their catalog, they list their tools in three different versions (uncoated, TiN and TiCN coated) for each tool type of high speed steel.

Most of FM&T machining operations involve a profile, slotting and/or plunge milling operation. It was decided to evaluate the number of end mill descriptions currently stocked for eighth, quarter and half inch diameter end mills in our standard stores catalog. These common sizes offered the most variety in the catalog. We evaluated both HSS and carbide end mills. Even though we realize the part's geometry and operation (roughing or finishing) have an effect on tool selection, we did not consider the cutting length, number of flutes, or the configuration of the end mill.

The following tables show the variety of the current tool descriptions.

Number of descriptions per category All square end or flat bottom, 2, 3, 4 flute, center cutting and non-center cutting Includes single ended and double ended end mills						
Size	End Mill	Number of Descriptions				
0.125	Base Mat	Uncoated	TiN	TiCN	Total	15
	M7	6	1	1	8	
	M42	1			1	
	T15-CPM	2	1	2	5	
	Carbide	1			1	
0.250	Base Mat	Uncoated	TiN	TiCN	Total	38
	M7	9	2	1	12	
	M42	2	1		3	
	T15-CPM	4		5	9	
	Carbide				0	
	Micro Grain Carbide	8	2	4	14	
0.500	Base Mat	Uncoated	TiN	TiCN	Total	54
	M7	15	6		21	
	M42	7	1		8	
	T15-CPM	5	1	5	11	
	Carbide				0	
	Micro Grain Carbide	7	3	4	14	

Table 1, End Mill Variety Available from Stores

Table 2 shows the mechanical properties of the tool steels and coatings obtained from several references (Ref 2, 5, 7). The 400 C temperature is referenced as a common tool tip temperature in end milling (Ref. 12) and the coating manufacture's (Ref. 2) literature.

Most end mill and coating manufactures recommend the use of metal removal fluids (MRFs) to control the buildup of heat in both the tool and the work piece material during milling. Some end mill manufacturers have developed combinations of tool material and multilayered coatings that can be used to machine work piece material dry. Honeywell FM&T's Environmental, Safety and Health Department (ES&H) recommends the use of MWFs to mitigate the hazards associated with generation of dusts from nickel and chrome in the machining of stainless steels. If machined dry, the use of a HEPA dust collector is also required.

Material/Coating	Cutting Tool Material HSS M7	Cobalt HSS M42	Tungsten HSS T-15	Coatings TiN	TiCN
Type/Layers	None	None	None	Mono	Multi/Grad
Wear Resistance	6	11.5	14.5		
Heat Treated Toughness Izod	64	38	20		
Hardness @ 400 F	64	66	68		
Micro hardness (HV 0.05)				2300	3000
Coef Friction on Dry Steel				0.4	0.4
Coating Thickness um				1 to 4	1 to 4
Max Working Temp ©				600	400

Table 2, Cutting Tool Material and Coating Properties

M7 is a second generation HSS developed for cutting tools. To make M42, cobalt was added to M7 and slight adjustments were made to the other alloying elements to increase the hardness, hot hardness, toughness, and strength. T15-CPM (Crucible's Powder Metallurgy) is a totally different type of tool steel. It is a tungsten high speed steel. During solidification in the wrought condition, the tungsten and vanadium carbide, which are formed in the steel, separate and form large networks or bands and segregate from the rest of the alloy because of the differential in melting and transition temperatures. To counteract this separation of the tungsten carbide, the liquid steel is atomized into fine droplets and rapidly cooled into a powder. Because of the small size of the liquid drops, it solidifies rapidly and remains homogenous in the particles. The carbides are fine in size (2 to 4 microns). To make the powder into a wrought steel the powder is evacuated and then hot isostatically pressed (HIP) at forging temperatures. The extreme high pressures consolidate the powder into a fully dense compact. The compact can then be processed into a bar. T15-CPM and carbide are similar in that both start with powders, T15-CPM is prone to breakdown between the particles (similar to carbides), and T15-CPM is not as tough as M7 and M42.

Evaluation of the Cost of HSS End Mills

FM&T currently has a long-term contract with Niagara Cutter, Inc. to supply HSS end mills to FM&T. Niagara has a long track record of supplying quality tools and delivering them in a timely manner. Since the inception of this long term agreement, they have been recognized by FM&T as having high performance.

We compared their catalog costs (Ref 4) to the cost of the same end mill made from different grades of HSS and the two primary coatings used in FM&T manufacturing operations. Table 3 shows the cost differential for the same end mill made from the least expensive HSS without a coating to all the other end mills they supply. You can see that the most expensive tool in each size category can cost over 200% more than the least expensive depending on tool material and coating. The question that now arises is: Does the tool that costs more than double the cost of a HSS uncoated tool also have twice the cutting tool life?

Relative Cost of an End Mill Based on Tool Material & Coating							
Size	Tool Material	uncoated	% increase uncoat-M7	TiN Coated	% increase uncoat-M7	TiCN Coated	% increase uncoat-M7
0.125	M7	$12.80	0	$15.30	20	$16.20	27
	M42	$13.40	5	$15.90	24	$16.80	31
	T15-CPM	$23.00	80	$25.50	99	$26.40	106
0.25	M7	$11.60	0	$14.10	22	$15.00	29
	M42	$12.30	6	$14.80	28	$15.70	35
	T15-CPM	$23.00	98	$25.50	120	$26.40	128
0.5	M7	$18.10	0	$20.60	14	$21.50	19
	M42	$20.90	15	$25.20	39	$26.80	48
	T15-CPM	$32.50	80	$36.80	103	$38.40	112

Table 3, Relative Cost of an End Mill Based on Tool Material & Coating

<u>Designing the Testing Sequence</u>

To make this evaluation, we were very careful to set up the test sequence so as not to introduce any new variable into the test and influence the test plan. Cutting tool, process, and test engineers decided on a set of variables to be used. The group decided to use machining parameters suggested by the cutting tool manufacturers as long as the feeds and speeds recommended were within the capabilities of our machine tools. We planned to use one of the older Monarch Cortland VMC 75's Machining Centers.

Photo 1, Dataloger by VMC 75

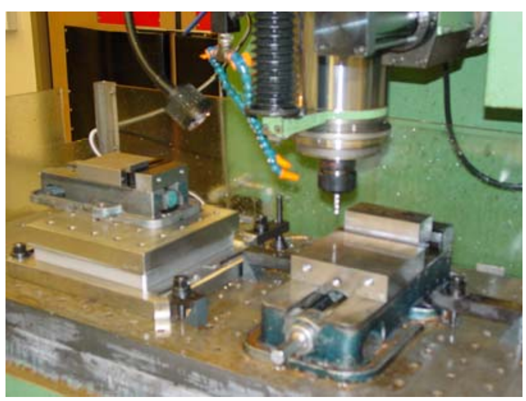


Photo 2, Detail of Machining Setup w/Dynamometer

The test tools, machining parameters, setup requirements and cutting sequences are listed in Appendix 1. Intervals when dynamometers runs were made and wear measurements were taken are also specified in Appendix 1. We use metalworking fluid for this test. Fluid mix was checked on a daily basis. Adjustments were made daily to maintain the concentration. Coolant nozzle position was noted and maintained throughout the day.

<u>Wear Measurement</u>

The dimensional performance of an end mill is the average of the wear of the multiple cutting edges. Figure 1 shows the multiple cutting edges of a four fluted center cutting end mill. Note: It doesn't matter weather you are plunging or profiling, the outside corners are wearing. When plunging, the cutting edges of the bottom face and the corners wear. Also, two of the cutting edges overlap the center so that the cut is across the face when plunging. When profile milling, the side-cutting edges and corner surfaces wear. Since one of the failure criteria was corner wear on the end mill and/or the corner radius on the part, we thought we could measure only two of the flutes to determine the average wear. We found that both the slight misalignment of the end mill-tool holder system (test specification requires less than 0.0010 in TIR) and chipping required that we measure all the flutes and average the results together to obtain a measurement representative of the true performance of the end mill. Data for all end mills used to evaluate a specific cutting tool and coating were averaged together and used to generate the wear graphs.

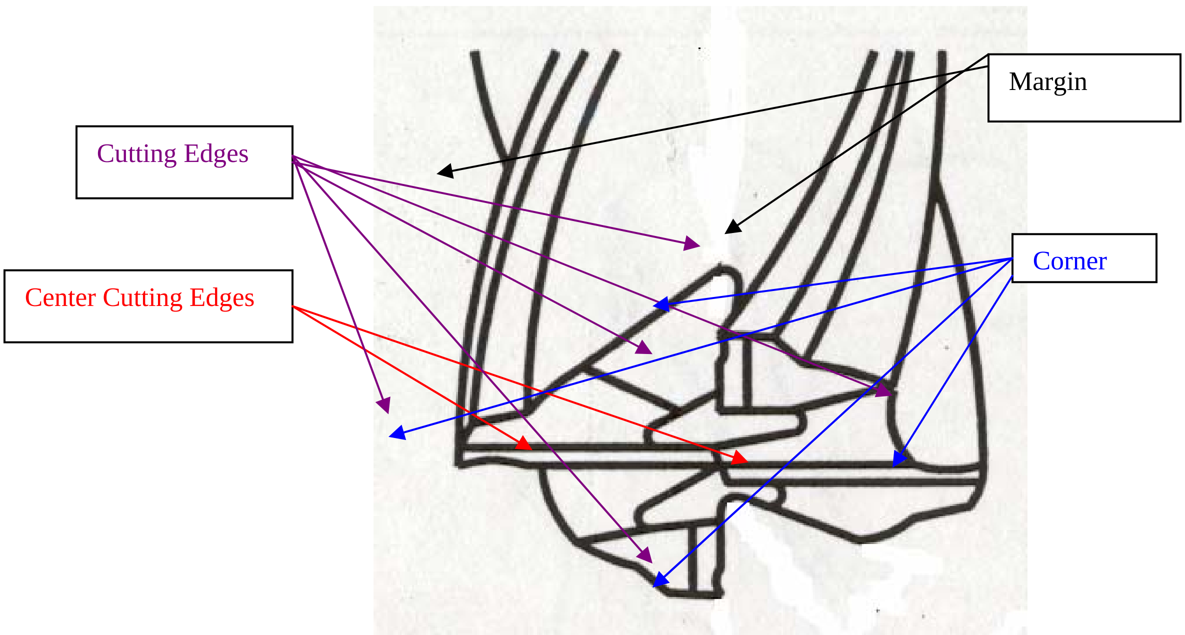


Fig. 1, End Configuration of a Four Flute, Center Cutting, Square Corner End Mill

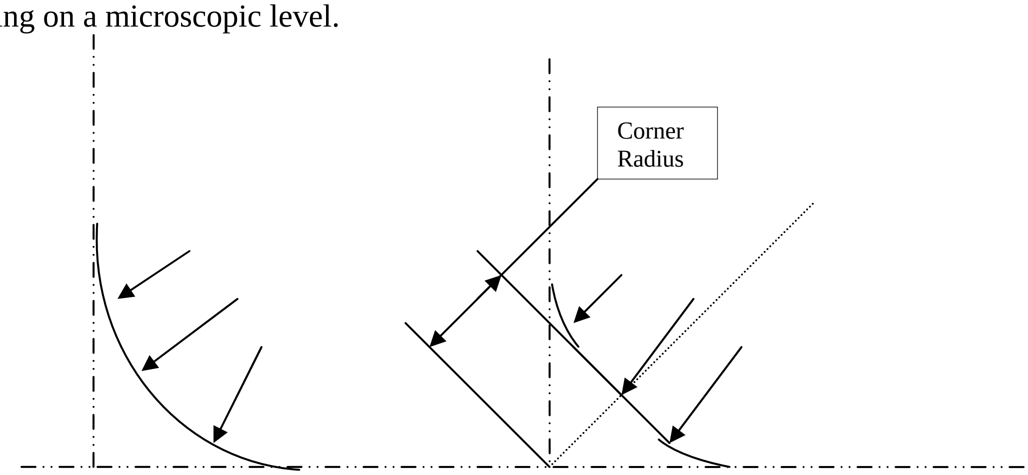
We thought it was very important to compare the wear of the tool to the surfaces the tool generates in the part. D/93 has several parts that only allow a maximum corner radius of 0.0050 inch. We decided that we would measure the corner radius of the sample at the end of the dynamometer run. To accomplish this, a 0.400 inch slice of the work piece material was mounted in a vise on the dynamometer.

This sample could be removed at the end of the run, moved to the measuring microscope and the radius generated in the part measured. In this way we could make a comparison of the corner wear on the end mill (Fig. 2a) to the corner radius generated by the end mill in the part. These measurements could be associated with each dynamometer run and then could be used as a failure criterion for the test.

When going through the data from the test runs you can see that although one corner of the end mill is chipped (Fig. 2b), the corner radius generated by the end mill does not change significantly. What happens is the end mill is advancing by a small amount (0.0005 to 0.0200 inch depending on whether you are making a roughing or finishing cut) as each flute advances into the cut. If one flute is chipped, the next flute will remove most of the material left by the chipped flute. When two consecutive flutes chip, the change becomes more visible.

Peripheral end milling requires the cutting edges to make one interrupted cut per revolution. The repetitive impact as the tool advancing into the material during the cut causes the corner to wear, fatigue, and/or chip or flake. The fracture surface is usually straight and occurs on the corner. After the initial flake, two corners are created and will be the next points to flake. Eventually, a curved surface is formed. This is because the high points of the tool, which receive the most wear, will chip or flake.

Using the slightly aggressive speeds selected for the test, we noticed some corners chipping. The chips tended to have a flat breaking surface. Figure 2 shows two curved surfaces. The one on the left has a perfect radius and the one on the right is similar to what can be seen on a microscope when measuring corner wear of end mill at 500 x magnification. One of the modes on the Microcalc-1 (microscope digital display that automatically calculates radius) allows the researcher to select three points (right pointing arrows) and the unit will calculate the radius and locate its center. This method is acceptable in most cases but not for measuring early wear on end mills. If we select three points on the wear surface, the Microcalc-1 will calculate a very large radius. As the corner continues to wear, the high point where the flat surface joints the worn surface will chip or wear away. The straight segments become smaller. When we have a series of very small flat surfaces with some corner round at the intersection we begin to approach the perfect radius. This problem was observed when looking at the graphed 0.250 end mill data. Initially we got very large corner radii and then the radius would get smaller. The radius getting shorter is counter to the normal logic an engineer uses when interrupting this data but matches what is happening on a microscopic level.

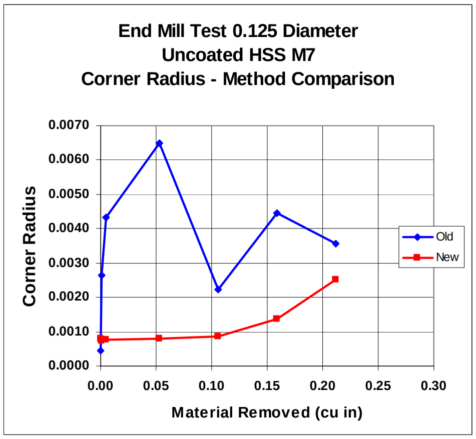


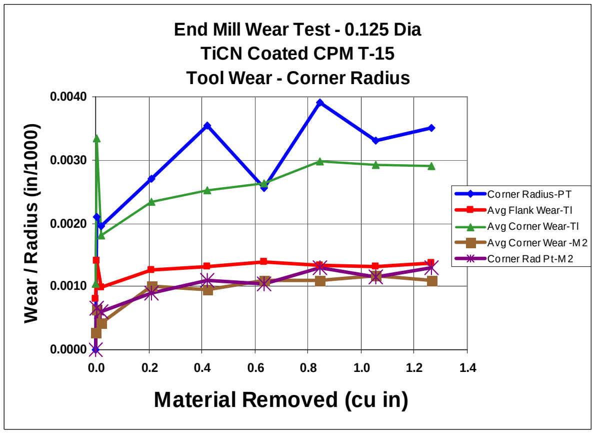
A. Perfect Radius B. Corner Wear with Chipped Cutting Edge

Fig. 2, Measuring the corner wear of an end mill at 500x

During the runs on quarter inch ends mills, we devised a different measurement method and measured the end mill corner wear by two different methods. When a corner chips using the old measurement method, we get a very large radius measurement. As the new corners chip, the radius gets smaller. During the hour of run time the chip will finally wear into a radius.

We reexamined our measurement method and came up with a second approach. Under 500 x magnifications, we find the vertical and horizontal edges of the end mill, place them on the display cross hairs, and make the intersection our zero point (x-00000, y-00000) (Fig. 2b). Then, move the stage at 45 degrees and record the X and Y distance to the tool surface. Using this method, we don't care if there is wearing or chipping. If either leg exceeds 0.005 inches, the tool is considered failed. The hypotenuse distance is reported. If the chipped tooth is the last cutting edge to leave the part, it will also affect the corner radius measurement.





Graphs 1a & b, Comparison of Wear Measurement Methods for Two Test Conditions

The graphical representations of the tool wear (Graphs 1a & b) and part radius show corner measurements using both methods. You can easily see the effect of a chip on the tool. Fig.1a shows the comparison of the two methods while Fig. 1b shows the representation on the reduced data sheets in Appendix 3. Therefore, we decided to use this method to measure both the part and the tool. The old method is designated Corner Radius Part and Avg Flank Wear Tool (diamond and small squares) while the new method is Avg Corner Wear M2 and Pt Wear M2 (large squares and x). Using the new method, we had excellent agreement between the corner radius and part radius.

Also, this method is in keeping with the intent of 9900000 General Requirements, Section 5.2 Fillets Measure in the X & Y Dimension and SS290029 General Requirements for Miniature Mechanisms, Section 5.2 Edge Condition.

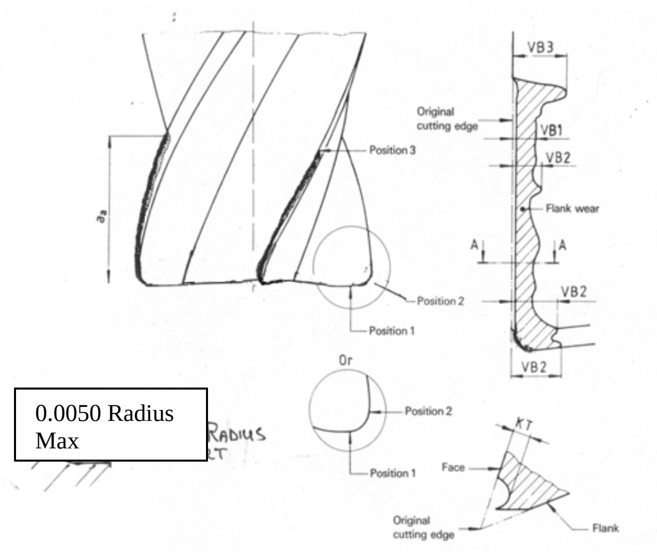


Fig 3, Definitions of Wear Scar Surfaces of an End Mill Under Test From ISO 8688-2 Fig. 8

Figure 8 of ISO Standard 8688-2, Tool Life Testing in Milling – Part 2 End Milling, defines the measure criteria used in this study. The average flank wear VB1 middle, the corner radius by method two and entry scar VB3 on the end mill on the data sheet. A reproduction of this figure is shown in Fig.3. All end mills show uniform flank wear (ISO classification VB1) on the sides and bottom cutting edges. Typical wear patterns on the corners were a combination of non-uniform chipping (CH2) and flank wear (VB1). Initially, corner wear is VB1 type with the possibility of a small chip on one flute. As the test progressed, additional chipping occurs on additional flutes.

<u>Test Results</u>

The individual composite spreadsheets for the eighth and quarter inch diameter end mills tested are included in Appendix 3. The summary graphs for quarter-inch end mills are discussed below. Test on the eighth inch end mills verified the conclusions. End mills were compared by the type of HSS (M7, M42, and T15-CPM). The same end mill could be supplied either uncoated, TiN, or TiCN coated.

Data was compared in four ways.

- Average wear on the cutting edges
- Change in diameter of the end mill
- Change in specimen radius
- Change in end mill corner radius

Please note all machining tests were run on annealed 304 stainless steel. This is the most prominent steel encountered in the Precision Machining Department. Results varied with changes in workpiece material grade and hardness. Grade 304 stainless steel is an austenitic stainless steel that is prone to work hardening. The specimen block was milled square by face milling all six sides. The test was conducted by moving the table one quarter the diameter of the end mill being tested and removing the previously generated wall. This means all cuts were made though a work hardened surface, which models production processes.

Tests were run for one hour and measurements were made on the initial cut and again at 1, 10, 20, 30, 40, 50, and 60 minutes. In all cases, for the quarter-inch end mill, after 60 minutes there were no failures. One corner of the M42 end mill (with the TiCN) chipped severely enough on the 60 minute measurement that it was above the failure criteria; but, the average was still below 0.005 inch.

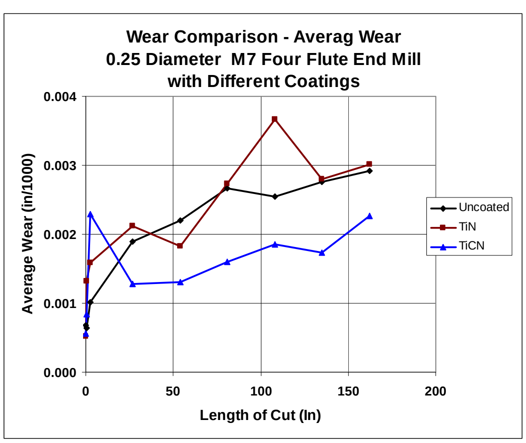
On the quarter-inch end mills we used our old method of measuring the radius.In some cases, we initially measured higher than 0.005 early in the run because the Microcalc-1 was calculating large tool radius. The radius in the work piece measured less than 0.005. Previously, we described this phenomena and how we developed an alternative method to measure the corner wear. Corner measurements on the eighth inch end mills were obtained using both methods and proved this was a false observation.

Graphs shown below are for the 0.25 inch end mills. Graphs are plotted using the distance traveled. Table 4 gives the equivalents in time and cubic inches of material removed.

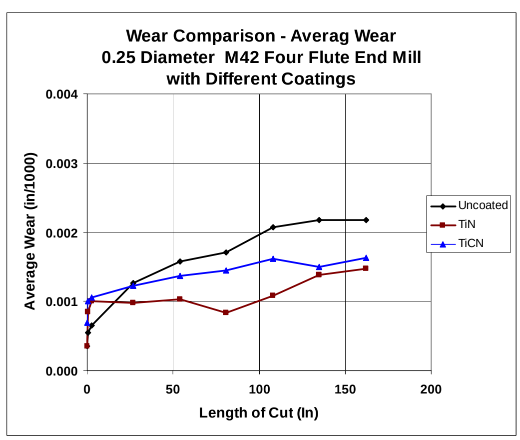
	Quarter Inch Diameter End Mill							
Time (min)	0.17	1	10	20	30	40	50	60
Length of Cut (in)	0.4	2.7	27	54	81	108	135	162
Material Removed (cu in)	0.003	0.021	0.21	0.42	0.63	0.84	1.05	1.27
	Eighth Inch Diameter End Mill							
Length of Cut (in)	0.4	4.9	49	98	147	196	245	294
Material Removed (cu in)	0.001	0.01	0.10	0.19	0.29	0.38	0.48	0.58

Table 4, X-Axis Conversion factor to different units of measure

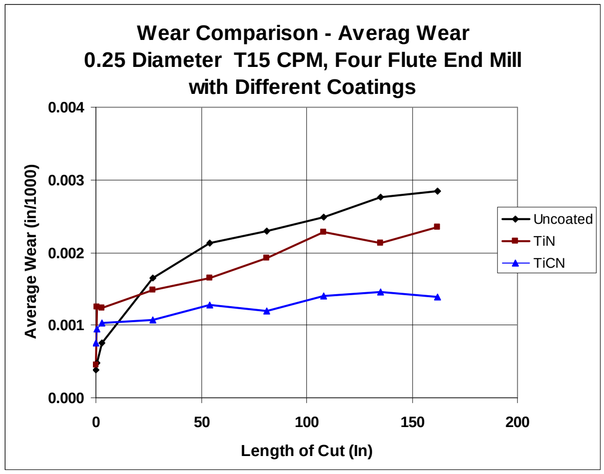
Below are the wear curves for the three groups of HSS (M7, M42 and T15-CPM)



Graph 2a, Wear M7 HSS



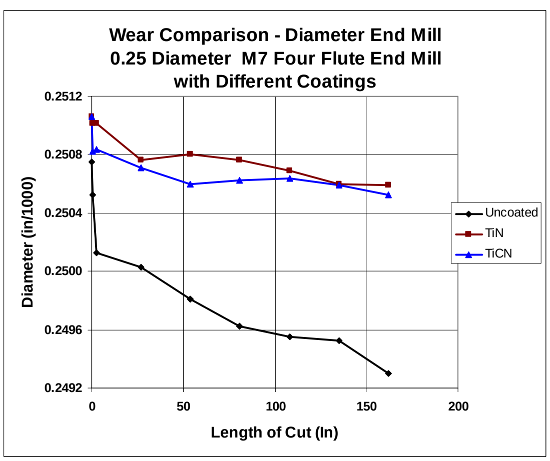
Graph 2b, Wear M42



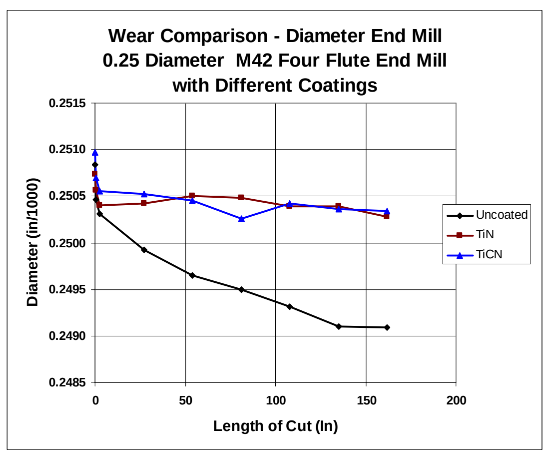
Graph 2C, Wear T15-CPM

In all cases, the uncoated end mill had the most wear. Wear decreased as the complexity of the tool steel increased. In most cases the TiCN coating had slightly better performance.

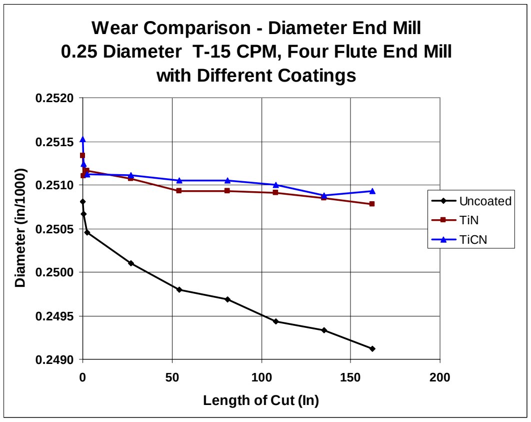
The diameter of the end mill was measured on the Ram Optical Instruments, Measuring Microscope at 400x approximately 0.017 above the base or slightly above the corner of the tool. The ISO standard uses 0.015 wear as the failure criteria so this was slightly above the allowable wear band for the corner. In this case we used a 0.005 radius so the corner wear would not effect this measurement. The results are shown on Graph 3 a, b, c.



Graph 3a, End Mill Diameter M7 HSS



Graph 3b, End Mill Diameter M42

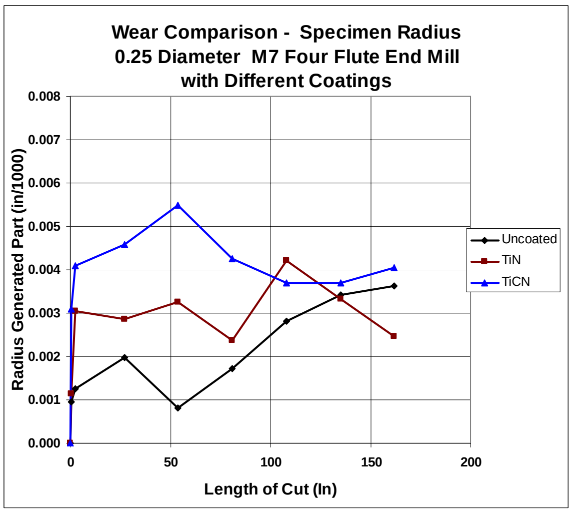


Graph 3c, End Mill Diameter T15-CPM

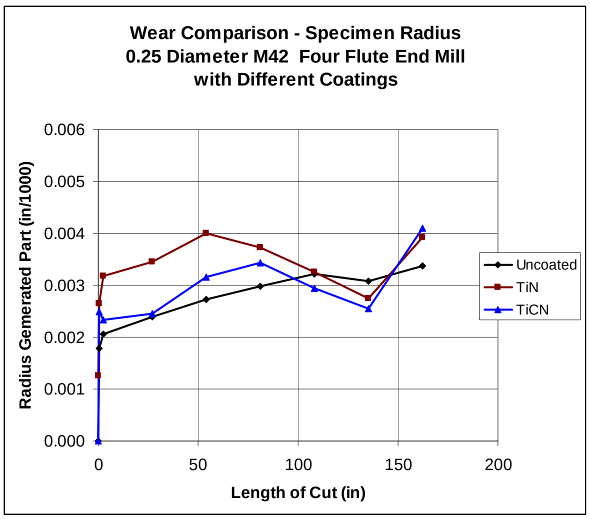
Again the results indicated that the coatings prevented the end mill diameter from wearing. The graphs show little differences between the TiN and TiCN coatings under this set of test circumstances.

Graphs 4 a, b, and c show the response of the work piece to the end mill as the end mill wears. Remember that we modified the measuring method when measuring the eight inch end mills and the early high spikes are not present. Data generated at the end of 100 inches of cutting does not show the influence of the early chipping.

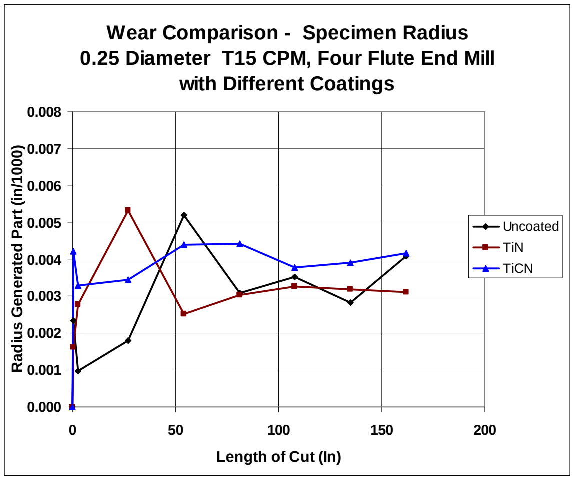
After the corner has chipped multiple times a radius forms; therefore, the initial large chip does not influence the measurement as much.



Graph 4a, Specimen Radius, M7



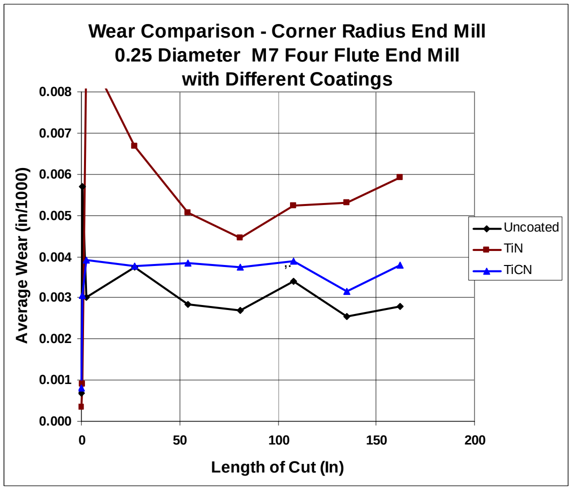
Graph 4b, Specimen Radius, M42



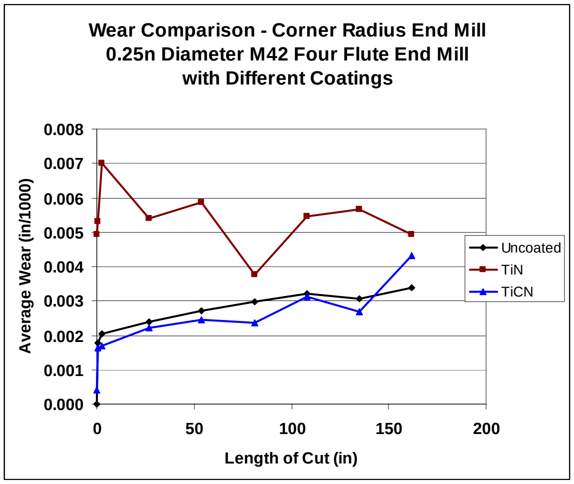
Graph 4c, Specimen Radius, T15-CPM

The corner wear of the quarter inch end mills for the three different HSS are shown on Graphs 5a, b, and c. Graph 1 show the effects of the different measurement methods. These graphs show we had less wear on the corners with the TiCN coating over all the materials.

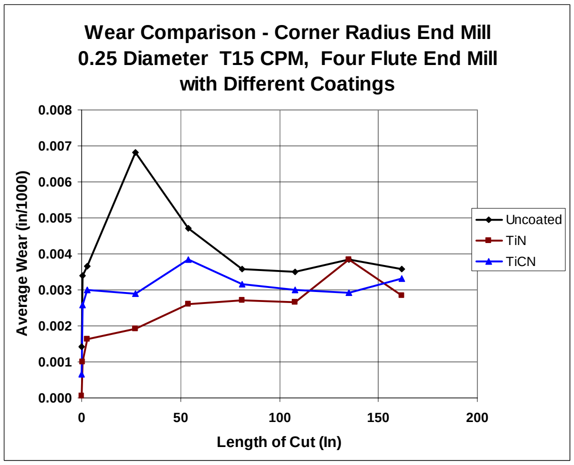
When testing the 0.125 diameter M42-TiN coated end mills we had a premature chipping failure of the end mill. There is a possibility that the end mill had some hidden damage under the coating because it started to chip on the initial run. We had no substitute end mill available. We did not have any failures of the identical TiCN coated end mill. Coating suppliers indicate that the TiCN is a stronger coating, which is why we would recommend a TiCN over a Tin coated end mill.



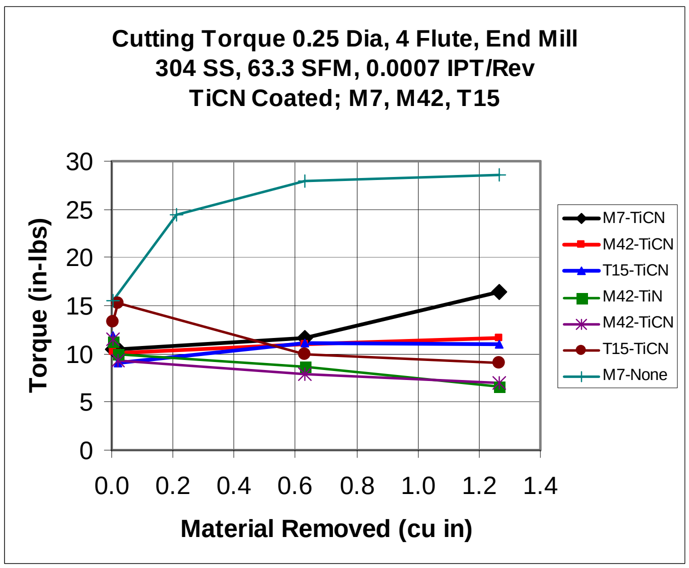
Graph 5a, Corner Radius End Mill, M7



Graph 5b, Corner Radius End Mill, M42



Graph 5c, Corner Radius End Mill, T15-CPM



Graph 6, Quarter Inch Diameter End Mill Cutting Torques

We measured the torque applied by the end mill to the material while cutting. The workpiece was mounted in a vise bolted to a cutting force dynamometer. Data was obtained at a rate of 100 points/sec. As you can see from the graph, the coated end mill required between 7 to 15 inch pounds to cut the 304 SS. The uncoated end mill started to cut at 15 and increased to 27 in-lbs. The coatings controlled the growth of the wear land on the cutting tool and kept the cutting edge sharp. The coatings also prevented the formation of built up edge and the resulting breaking of the welded material from the cutting edge. As the uncoated tool wore, this land got bigger and the pressures higher resulting in a larger built up edge.

Conclusions

The most important finding (summarized in Table 5) answers the questions presented at the beginning of this project:

- We know the relationship of the costs for the individual end mills.
- We pay approximately 6% more for the M42 end mill over one made from M7 tool steel.
- The cost of an end mill made with T15 tool steel is almost double the cost of an end mill made with M7 tool steel.
- T-15 is harder to grind because of the tungsten and vanadium carbides in the matrix.
- To maintain tolerances, the grinding wheel has to be dressed frequently.
- The cost of applying the TiN and TiCN coating is standard across all three high speed steels and is 22% for a TiN and 29% for a TiCN coating.
- For the 6% premium we paid for the M42 we got a 24% increase in tool life based on flank wear. When the end mill is coated we break even in increased tool life for the cost. This means, we get our return when we use an M42 end mill with a coating.
- In the case of the T15 end mill we never recovered the additional cost of making the tool from this material. For smaller end mills we would recommend using the TiCN coating over TiN coating because of its additional strength.

Coating		**---------- Perishable End Mill Material ---------**				
Type		**M7**	**M42/M7**	**M42/M42**	**T15/M7**	**T15/T15**
Uncoated	**Cost**	100%	106%		198%	
Uncoated	**Life**	100%	124%	100%	103%	100%
TiN	**Cost**	122%	128%		220%	
TiN	**Life**	97%	148%	132%	117%	114%
TiCN	**Cost**	129%	135%		228%	
TiCN	**Life**	121%	145%	127%	*208%*	200%

Table 5, Life & Cost Comparison

End mill savings have to be weighed against the labor cost associated with making tool changes when the end mills are worn. When we add in the cost for the labor spent making a tool change, measuring the new tool offsets, and entering the offsets into the CNC control of the machine tool, the tool change cost me be added to the new tool cost to obtain the total cost.

It is the author’s opinion that FM&T should not purchase end mill made from M7 steel. For only an additional 6% in cost, we can buy M42 and get a significant improvement in life. This improvement would also hold true for PH stainless steels. By combining the M7 and M42 grouping of end mills into one M42 group, we can remove duplicate tool descriptions and ultimately reduce inventory.

Appendix 1

End Mill Test Specification

Specimen:
Bar 1.00 in x 12.0 in 304 L, Annealed

Cutting Tools:

- Niagara End Mill, All materials, Profile and slotting, Helix angle 30 Deg;
- Flute Diameter Tolerance + 0.001/0.000; Shank Diameter Tol: -0.0001/-0.0005 (Ref 4)
- Primary Relief Angle 16 Deg, Secondary Relief Angle 27 Deg,
  Depth of cut:
  3/8 inch, Dish Angle 3 Deg
  1/8 dia, 4 flute, center cutting, HSS, uncoated; EDP#40041
  1/8 dia, 4 flute, center cutting, HSS, TiN coated; EDP# 40040
  1/8 dia, 4 flute, center cutting, HSS, TiCN coated; EDP#88275
  1/8 dia, 4 flute, center cutting, M42 Cobalt, uncoated; EDP# 52041
  1/8 dia, 4 flute, center cutting, M42 Cobalt, TiN coated; EDP# 52040
  1/8 dia, 4 flute, center cutting, M42 Cobalt, TiCN coated; EDP# 88604
  1/8 dia, 4 flute, center cutting, T15 Cobalt, uncoated; EDP# 55041
  1/8 dia, 4 flute, center cutting, T15 Cobalt, TiN coated; EDP# 55040
  1/8 dia, 4 flute, center cutting, T15 Cobalt, TiCN coated; EDP# 88700

- Primary Relief Angle 13 Deg, Secondary Relief Angle 24 Deg
  Depth of cut:
  5/8 inch, Dish Angle 2 deg.
  1/4 dia, 4 flute, center cutting, HSS, uncoated; EDP#40081
  1/4 dia, 4 flute, center cutting, HSS, TiN coated; EDP# 40080
  1/4 dia, 4 flute, center cutting, HSS, TiCN coated; EDP#40084
  1/4 dia, 4 flute, center cutting, M42 Cobalt, uncoated; EDP# 52081
  1/4 dia, 4 flute, center cutting, M42 Cobalt, TiN coated; EDP# 52080
  1/4 dia, 4 flute, center cutting, M42 Cobalt, TiCN coated; EDP# 88608
  1/4 dia, 4 flute, center cutting, T15 Cobalt, uncoated; EDP# 55081
  1/4 dia, 4 flute, center cutting, T15 Cobalt, TiN coated; EDP# 55080
  1/4 dia, 4 flute, center cutting, T15 Cobalt, TiCN coated; EDP# 88702

Machine Type:

- Monarch Cortland Machining Center
- HP Available: 7.5 HP
- Max Spindle Thrust: 2000 lbs
- Max Speed: > 3,600 RPM
- Max Feed: > 40 IPM

Tooling Setup:
Tool Holder: Monarch Cortland Single Angle Collet Holder using a 0.375 collet.

Milling Pattern:

- Radial Depth of Cut: 25% of diameter
- Axial Depth of Cut: 50% of diameter

Machining Parameters:

- Speed: ~60 SFM (0.125 – 1767 RPM; 0.25 – 967 RPM)
- Feed: 0.0007 in/rev/tooth

Metal Removal Fluid:

Milacron 3700T (Semi synthetic water based fluid), 5% solution

Equipment Used:

- KIAG SWISS (Kistler) Force Table, CE# 51078
- KIAG SWISS (Kistler), Charge Amplifiers, Model 5001, CE# 51078 (A, B, C)
- Kistler Type 9275 Torque Dynamometer
- Kistler Model 5841B1 3-Channel Charge Amplifier CE#201756 (Model 5010)
- Kistler Model 5350 Transducer Simulator WITH Model 5371A Calibration Capacitors
- ROI Measuring Microscope, CE67517, with rotary mounting stage with attached 3 jaw chuck. Mast extensions (4 inch extension when using solid tool holder
- Equipment specified by Fig.1 attached.

Measurement Interval:

1. Cut a 0.40 wide slice from the side of the specimen bar.
2. Install slice in vise on dynamometer and the large portion of the specimen in milling vice.
3. Inspect the end mill on ROI Microscope under a minimum of 300 x looking for flaws in cutting lips, especially the corner between the margin and bottom cutting edge. If any chips are found on the lips do not use the end mill for test.
4. Measure TIR of end mill in spindle. Must be less than 0.001 TIR
5. Mill slice (~ 3 sec)
6. Measure wear at minimum 400x
7. Mill block on vise for ~54 seconds
8. Cut small block and make cutting force run
9. Measure wear on tool and block
10. Next cut
    - If wear is under 0.001 at corner/specimen cut ~2 min less 3 seconds (~12 inches) or if in the time increment it changes less than 0.001
    - Then cut 0.25 in block and make dynamometer run
    - If wear is over 0.001 at corner/specimen run 1 min less 3 seconds (~5.9 inches)
    - Then cut 0.250 in block and make dynamometer run
    - If wear is over 0.002 or corner wear changes over 0.001 in the time increment, repeat steps 7 & 8 until 5 minutes of cutting time is achieved.
    - If wear is under 0.003 run 2 minutes of cut less 3 seconds (~12 inches)and then mill sample
    - If wear at the end of 5 minutes of cutting is under .001 at corner or changes under .001 at the corner within the time increment, mill an additional 5 minutes less 3 seconds
    - Then cut 0.25 in block and make dynamometer run
    - If wear is over 0.002 at corner/specimen run 3 min less 3 seconds (~17.9 inches)
    - Then cut 0.250 in block and make dynamometer run

- If wear has not changed more than a .001 in the last 5 minutes or a total of 0.002 at the corner after 10 minutes run an additional 10 minutes -3 seconds and run dynamometer run on sample block.

11. Repeat step 13 until 0.005in corner wear is achieved or 60 minutes total time
12. Measure end mill and sample.

Milling Loads:
Record the X, Y, and Z force for each milling pass. Save the digital data for the initial pass and the last pass before a wear measurement is made. Retain data files until the 50%, 75% and failure points are determined. The initial file will be designated as the A run. Runs at the 50% (B), 75% (C) additional runs will be designated alphabetically starting with E and noted on the data sheet.

Controlling Document:
ISO Procedure 8688-2; Tool life testing in milling – Part 1: Face Milling

Appendix 2

Bibliography

ISO, Tool Life Testing in Milling – Part 2: End Milling; ISO 8688-2; May, 1989

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12. DoAll, End Milling Handbook, 1977, DoAll Company
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Appendix 3

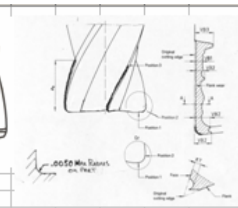
Test Data

Cutting Conditions:

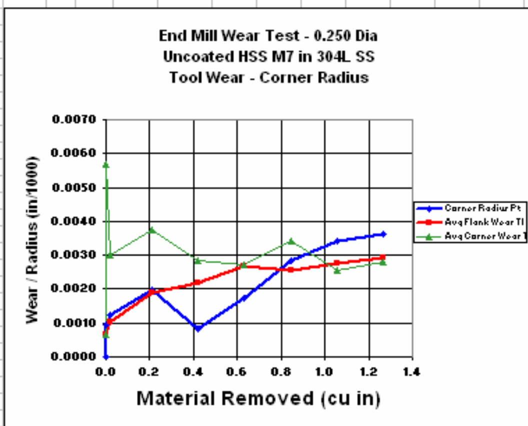
Profile Milling - Climb Cutting

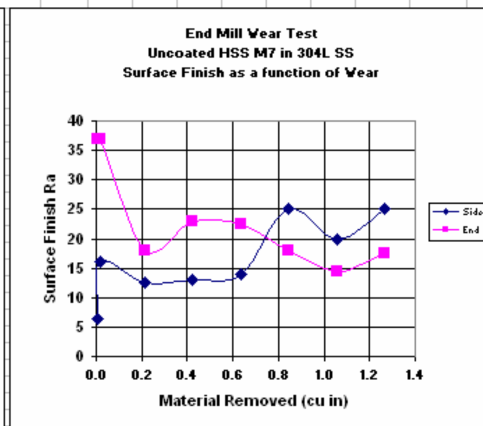
Tool No.:	Avg HSS1 & 2	Speed:	967	RPM	63.3	SFM	
Tl Mat:	HSS - M7	Feed:	2.7	IPM	0.0007	I/T	
Tl Coat:	None	Rad DOC:	0.0625	in	25	%D	
Tl Size:	0.250	Axl DOC:	0.1250	in	50	%D	
Date:	J-04	Technician(s):	K. L. Mitchell				
File Name:	250U-HSS1,250U-HSS2						

Specimen Material: 304 L Stainless Steel, Annealed Condition



Material Remove cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0.0					0.0005	0.0006	0.0006	0.2507	0.0007	0.0007	0.0004	0.2508	0.0006	0.0009	0.0012	0.0006	0.0005	0.0005	0.0000	0.00057	0.00068	0.00068	0.25075	
0.0031	0.4	D1	7	37	0.0020	0.0009	0.0008	0.0030	0.2506	0.0011	0.0006	0.0068	0.2505	0.0011	0.0007	0.0049	0.0009	0.0006	0.0082	0.0010	0.00099	0.00064	0.00569	0.25053	
0.0211	2.7	D2	16	37	0.0020	0.0012	0.0012	0.0058	0.2501	0.0010	0.0008	0.0022	0.2502	0.0011	0.0011	0.0021	0.0011	0.0011	0.0021	0.0013	0.00108	0.00101	0.00300	0.25013	1
0.2109	27.0	D3	13	18	0.0020	0.0017	0.0022	0.0044	0.2499	0.0016	0.0019	0.0056	0.2501	0.0018	0.0016	0.0029	0.0020	0.0019	0.0021	0.0020	0.00178	0.00189	0.00374	0.25003	
0.4219	54.0	D4	13	23	0.0025	0.0022	0.0025	0.0030	0.2496	0.0027	0.0019	0.0043	0.2501	0.1257	0.0024	0.0023	0.0024	0.0020	0.0018	0.0008	0.03325	0.00219	0.00283	0.24981	
0.6328	81.0	D5	14	23	0.0025	0.0024	0.0028	0.0037	0.2498	0.0026	0.0024	0.0024	0.2495	0.0025	0.0029	0.0031	0.0023	0.0026	0.0017	0.0017	0.00246	0.00266	0.00270	0.24963	
0.8438	108.0	D6	25	18	0.0030	0.0024	0.0027	0.0062	0.2495	0.0032	0.0025	0.0020	0.2496	0.0031	0.0025	0.0030	0.0027	0.0025	0.0024	0.0028	0.00282	0.00255	0.00341	0.24955	
1.0547	135.0	D7	20	15	0.0030	0.0048	0.0030	0.0018	0.2495	0.0031	0.0028	0.0018	0.2496	0.0033	0.0030	0.0030	0.0029	0.0023	0.0036	0.0034	0.00350	0.00276	0.00255	0.24953	
1.2656	162.0	D8	25	18	0.0035	0.0028	0.0031	0.0019	0.2493	0.0030	0.0028	0.0038	0.2493	0.0040	0.0034	0.0025	0.0029	0.0023	0.0030	0.0036	0.00315	0.00292	0.00279	0.24930	
	1 - 1 minute run not made on this end mill																								

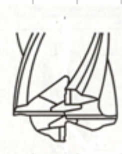
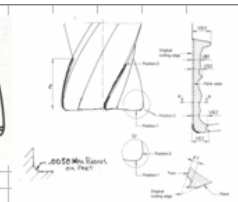




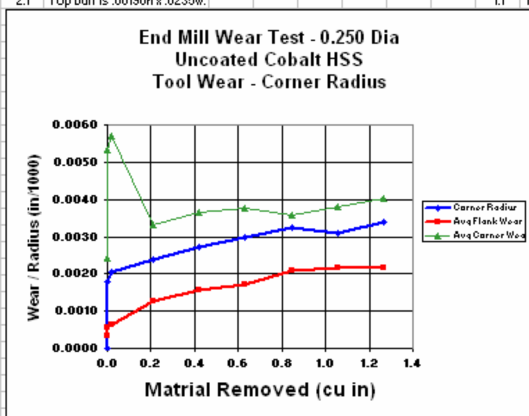
Cutting Conditions:

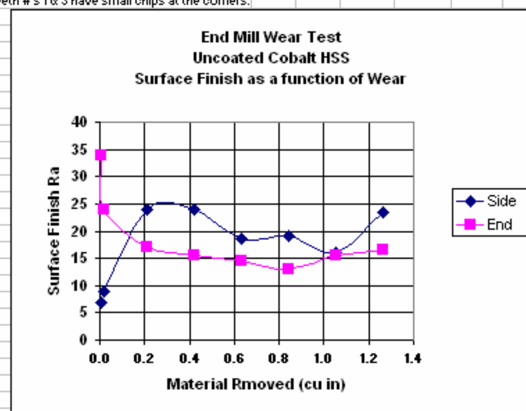
Profile Milling - Climb Cutting

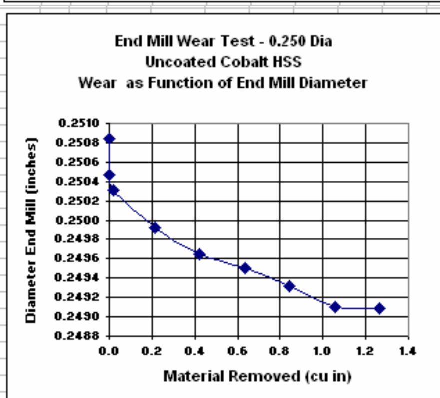
Tool No.:	Avg Co1 & 2	Speed:	967	RPM	63.3 SFM
Tl Mat:	Cobalt HSS	Feed:	2.7	IPM	0.0007 I/T
Tl Coat:	None	Rad DOC:	0.0625	in	25 %D
Tl Size:	0.250	Axl DOC:	0.1250	in	50 %D
Date:	D-03	Technician(s):	K. L. Mitchell		
File Name:	250U-Co1,250U-Co2				

Material Removed cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0.0					0.0004	0.0003	0.0005	0.2508	0.0003	0.0003	0.0077	0.2509	0.0004	0.0003	0.0012	0.0004	0.0006	0.0004	0.0000	0.00037	0.00035	0.00242	0.25084	
0.0031	0.4	D1	7	34	0.0020	0.0007	0.0005	0.0032	0.2505	0.0007	0.0007	0.0136	0.2504	0.0007	0.0006	0.0034	0.0003	0.0005	0.0012	0.0018	0.00059	0.00055	0.00534	0.25046	1.1,2.1
0.0211	2.7	D2	9	24	0.0030	0.0007	0.0008	0.0033	0.2505	0.0007	0.0008	0.0047	0.2502	0.0007	0.0006	0.0098	0.0007	0.0006	0.0051	0.0021	0.00069	0.00065	0.00571	0.25031	1.2,2.2
0.2109	27.0	D3	24	17	0.0030	0.0018	0.0015	0.0030	0.2500	0.0016	0.0012	0.0042	0.2499	0.0017	0.0012	0.0040	0.0017	0.0012	0.0021	0.0024	0.00168	0.00127	0.00332	0.24993	
0.4219	54.0	D4	24	16	0.0030	0.0021	0.0017	0.0024	0.2498	0.0022	0.0016	0.0040	0.2496	0.0018	0.0014	0.0050	0.0020	0.0016	0.0033	0.0027	0.00203	0.00158	0.00364	0.24965	
0.6328	81.0	D5	19	15	0.0030	0.0023	0.0019	0.0031	0.2496	0.0026	0.0018	0.0042	0.2494	0.0023	0.0016	0.0044	0.0025	0.0015	0.0034	0.0030	0.00242	0.00171	0.00376	0.24950	
0.8438	108.0	D6	19	13	0.0035	0.0024	0.0023	0.0029	0.2494	0.0027	0.0023	0.0044	0.2493	0.0026	0.0019	0.0041	0.0028	0.0019	0.0030	0.0032	0.00259	0.00208	0.00358	0.24931	
1.0547	135.0	D7	16	16	0.0035	0.0026	0.0022	0.0029	0.2491	0.0031	0.0024	0.0042	0.2491	0.0030	0.0021	0.0050	0.0032	0.0021	0.0031	0.0031	0.00296	0.00218	0.00380	0.24910	
1.2656	162.0	D8	24	17	0.0030	0.0029	0.0024	0.0032	0.2492	0.0032	0.0024	0.0039	0.2490	0.0036	0.0018	0.0057	0.0033	0.0021	0.0033	0.0034	0.00326	0.00218	0.00402	0.24909	
	2.2	Teeth 2 & 3 have small chips on the corner near position 2. (see diagram)										1.2	Teeth #'s 2 & 4 have small chips at the corners.												
	2.1	Top burr is .00190h x .0235w.										1.1	Teeth #'s 1 & 3 have small chips at the corners.												







Cutting Conditions:

Profile Milling - Climb Cutting

Tool No.:	Avg Co1 & 2	Speed:	967	RPM	63.3	SFM
TI Mat:	CPM T-15	Feed:	2.7	IPM	0.0007	I/T
TI Coat:	None	Rad DOC:	0.0625	in	25	%D
TI Size:	0.250	Axl DOC:	0.1250	in	50	%D
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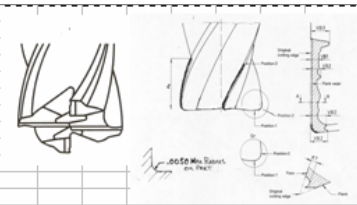


Materia Remov cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thicknes	Flank Face 1 Entry Notch Max.	Flank Face 1 A₂ Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A₂ Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A₂ Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A₂ Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A₂ Avg. Height	Average All Flutes Corner Radius	Average Diameter	
	D = The associated dynamometer run.																								
0.0000	0.0					0.0004	0.0003	0.0000	0.2508	0.0002	0.0003	0.0016	0.2509	0.0004	0.0006	0.0040	0.0003	0.0004	0.0002	0.0000	0.00031	0.00039	0.00143	0.25081	1.1, 2.1
0.0031	0.4	D1	7	22	0.0025	0.0006	0.0004	0.0085	0.2506	0.0004	0.0004	0.0011	0.2508	0.0008	0.0007	0.0024	0.0006	0.0005	0.0017	0.0024	0.00058	0.00048	0.00341	0.25066	
0.0211	2.7	D2	13	23	0.0025	0.0007	0.0007	0.0071	0.2504	0.0007	0.0008	0.0043	0.2505	0.0008	0.0009	0.0022	0.0008	0.0007	0.0011	0.0010	0.00071	0.00075	0.00367	0.25045	1.2
0.2109	27.0	D3	20	19	0.0030	0.0017	0.0016	0.0061	0.2501	0.0019	0.0016	0.0171	0.2501	0.0018	0.0018	0.0033	0.0021	0.0016	0.0008	0.0018	0.00187	0.00164	0.00681	0.25010	
0.4219	54.0	D4	29	20	0.0030	0.0026	0.0018	0.0057	0.2497	0.0024	0.0022	0.0077	0.2499	0.0022	0.0024	0.0016	0.0028	0.0022	0.0038	0.0052	0.00249	0.00213	0.00471	0.24980	2.2
0.6328	81.0	D5	18	19	0.0030	0.0026	0.0020	0.0048	0.2497	0.0024	0.0026	0.0027	0.2497	0.0024	0.0023	0.0035	0.0026	0.0024	0.0033	0.0031	0.00246	0.00230	0.00358	0.24969	2.3
0.8438	108.0	D6	25	14	0.0035	0.0032	0.0019	0.0061	0.2493	0.0029	0.0027	0.0033	0.2496	0.0027	0.0028	0.0022	0.0032	0.0026	0.0025	0.0035	0.00299	0.00249	0.00351	0.24944	
1.0547	135.0	D7	29	16	0.0035	0.0036	0.0023	0.0062	0.2494	0.0033	0.0028	0.0048	0.2493	0.0030	0.0031	0.0016	0.0034	0.0029	0.0028	0.0028	0.00330	0.00276	0.00384	0.24934	
1.2656	162.0	D8	25	16	0.0035	0.0040	0.0023	0.0047	0.2491	0.0035	0.0029	0.0043	0.2492	0.0030	0.0032	0.0024	0.0037	0.0030	0.0030	0.0041	0.00356	0.00284	0.00358	0.24913	

1.2 Corners 1&2 are chipped. 3 pts are selected between horizontal & vertical surface & the microscope calculates the radius. Corner chips are flat

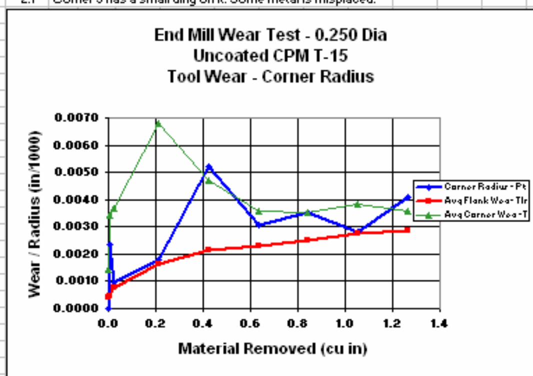
1.1 The corners are very good. So little material is missing/displaced that the measurements are inaccurate for the corner radius measurements.

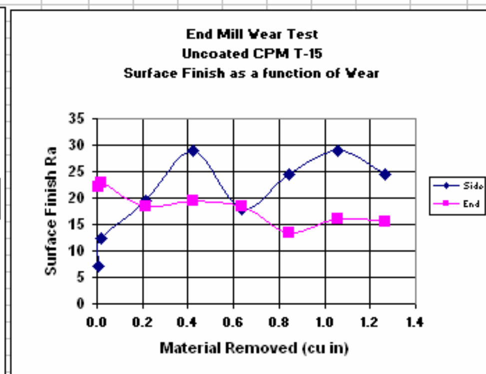
Values were changed because of the small size of chip and its biasing the data the average was used as the replacement.

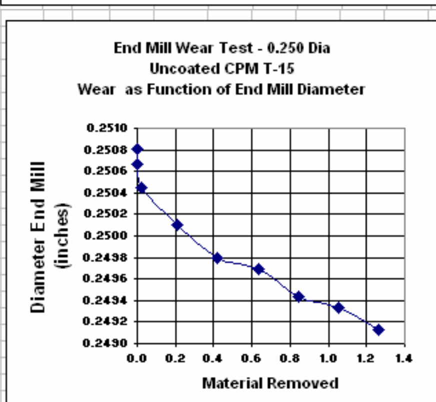
2.3 Corner 2 has a small flake.

2.2 Corner 4 has a small flake.

2.1 Corner 3 has a small ding on it. Some metal is misplaced.



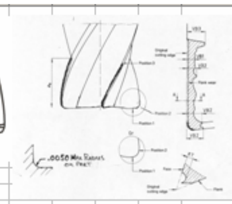




Cutting Conditions:

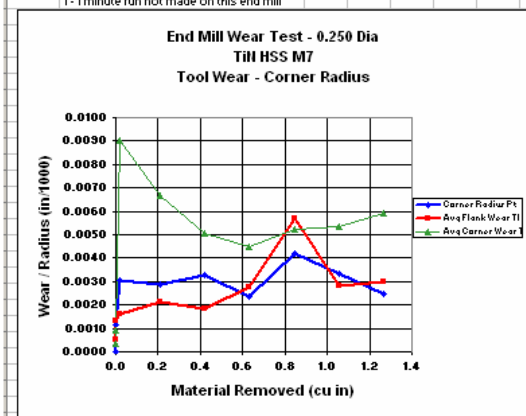
Profile Milling - Climb Cutting

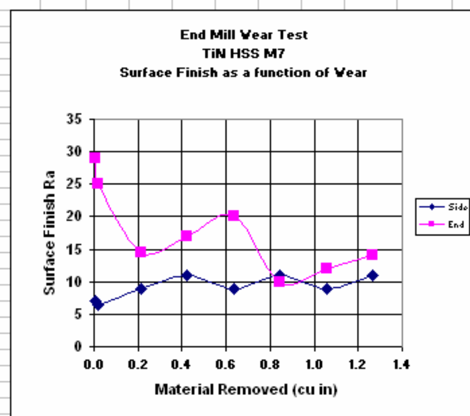
Tool No.:	Avg HSS1 & 2	Speed:	967	RPM	63.3 SFM
TI Mat:	HSS - M7	Feed:	2.7	IPM	0.0007 I/T
TI Coat:	TiN	Rad DOC:	0.0625	in	25 %D
TI Size:	0.250	Axl DOC:	0.1250	in	50 %D
Date:	J-04	Technician(s):	K. L. Mitchell		
File Name:	250T-HSS1,250T-HSS2				

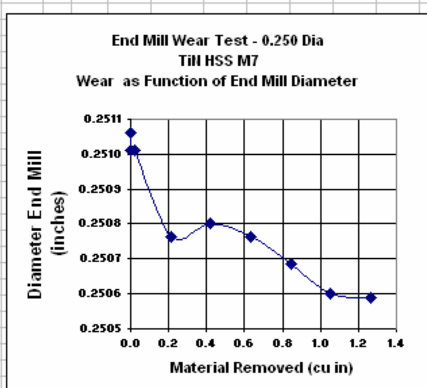


Material Remove cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0.0					0.0005	0.0005	0.0002	0.2509	0.0006	0.0005	0.0002	0.2513	0.0005	0.0005	0.0003	0.0006	0.0006	0.0007	0.0000	0.00053	0.00053	0.00033	0.25106	
0.0031	0.4	D1	7	29	0.0025	0.0009	0.0011	0.0007	0.2512	0.0013	0.0013	0.0008	0.2509	0.0012	0.0016	0.0011	0.0014	0.0014	0.0011	0.0012	0.00119	0.00132	0.00091	0.25101	
0.0211	2.7	D2	7	25	0.0025	0.0027	0.0015	0.0290	0.2511	0.0028	0.0014	0.0022	0.2510	0.0019	0.0016	0.0032	0.0023	0.0018	0.0017	0.0031	0.00240	0.00158	0.00903	0.25101	1
0.2109	27.0	D3	9	15	0.0030	0.0018	0.0024	0.0138	0.2509	0.0022	0.0017	0.0039	0.2507	0.0019	0.0025	0.0057	0.0022	0.0019	0.0033	0.0029	0.00200	0.00213	0.00668	0.25076	
0.4219	54.0	D4	11	17	0.0030	0.0019	0.0019	0.0032	0.2509	0.0036	0.0022	0.0028	0.2508	0.0030	0.0017	0.0123	0.0022	0.0016	0.0020	0.0033	0.00268	0.00183	0.00508	0.25080	
0.6328	81.0	D5	9	20	0.0030	0.0036	0.0027	0.0039	0.2509	0.0028	0.0028	0.0022	0.2507	0.0029	0.0029	0.0098	0.0027	0.0025	0.0020	0.0024	0.00299	0.00273	0.00446	0.25076	
0.8438	108.0	D6	11	10	0.0030	0.0030	0.0022	0.0033	0.2507	0.0036	0.0026	0.0028	0.2507	0.0026	0.0028	0.0118	0.0028	0.0150	0.0031	0.0042	0.00299	0.00566	0.00523	0.25069	
1.0547	135.0	D7	9	12	0.0030	0.0040	0.0024	0.0031	0.2507	0.0039	0.0028	0.0030	0.2506	0.0030	0.0031	0.0123	0.0031	0.0029	0.0029	0.0033	0.00349	0.00280	0.00532	0.25060	
1.2656	162.0	D8	11	14	0.0030	0.0025	0.0025	0.0046	0.2507	0.0029	0.0030	0.0027	0.2505	0.0039	0.0039	0.0145	0.0028	0.0027	0.0019	0.0025	0.00301	0.00301	0.00593	0.25059	

1 - 1 minute run not made on this end mill

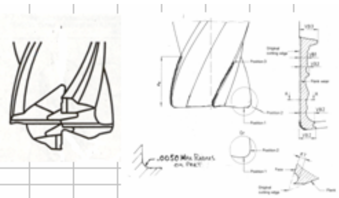




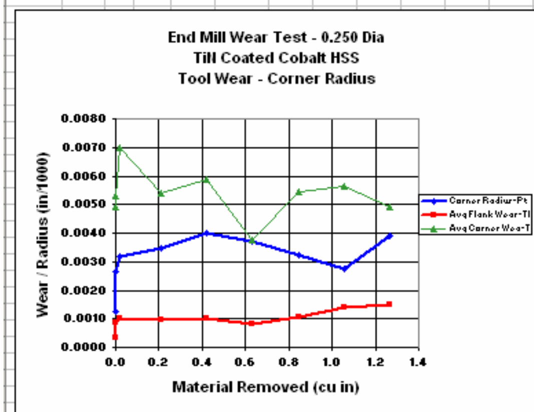


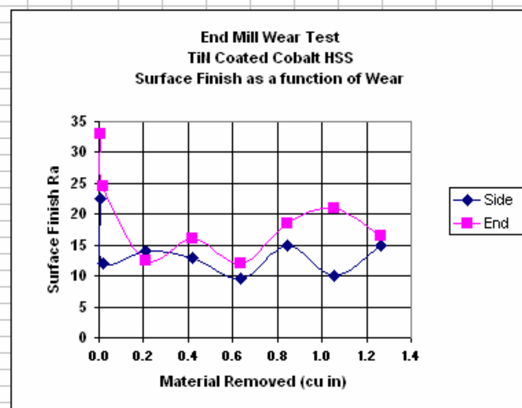
Cutting Conditions:
Profile Milling - Climb Cutting

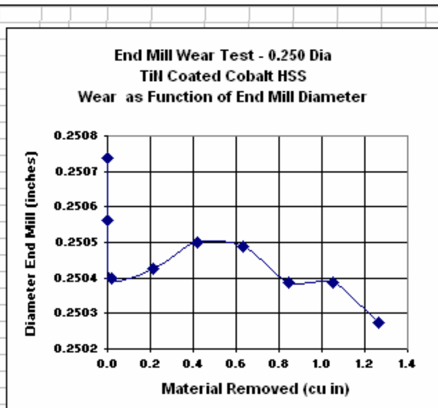
Tool No.:	Avg Co1 & 2	Speed:	967 RPM	63.3	SFM
Tl Mat:	Cobalt HSS	Feed:	2.7 IPM	0.0007	I/T
Tl Coat:	TiN	Rad DOC:	0.0625 in	25	%D
Tl Size:	0.250	Axl DOC:	0.1250 in	50	%D
Date:	D-03	Technician(s):	K. L. Mitchell		
File Name:	250T-Co1,250T-Co2				



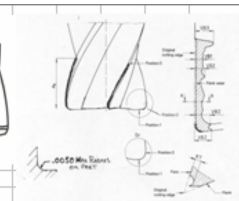
Material Removed cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0.0					0.0002	0.0006	0.0133	0.2507	0.0003	0.0001	0.0016	0.2508	0.0004	0.0004	0.0025	0.0004	0.0004	0.0023	0.0013	0.00034	0.00035	0.00493	0.25074	
0.0031	0.4	D1	23	33	0.0025	0.0008	0.0011	0.0034	0.2505	0.0009	0.0012	0.0036	0.2506	0.0009	0.0006	0.0109	0.0008	0.0005	0.0034	0.0027	0.00083	0.00084	0.00531	0.25056	
0.0211	2.7	D2	12	25	0.0020	0.0012	0.0015	0.0036	0.2505	0.0014	0.0013	0.0077	0.2504	0.0010	0.0006	0.0117	0.0011	0.0006	0.0050	0.0032	0.00115	0.00100	0.00700	0.25040	
0.2109	27.0	D3	14	13	0.0020	0.0011	0.0010	0.0040	0.2504	0.0011	0.0015	0.0059	0.2505	0.0011	0.0008	0.0048	0.0011	0.0006	0.0070	0.0035	0.00110	0.00098	0.00541	0.25043	
0.4219	54.0	D4	13	16	0.0020	0.0016	0.0012	0.0068	0.2505	0.0011	0.0014	0.0048	0.2505	0.0015	0.0009	0.0069	0.0010	0.0006	0.0049	0.0040	0.00128	0.00103	0.00586	0.25050	
0.6328	81.0	D5	10	12	0.0025	0.0016	0.0012	0.0048	0.2505	0.0016	0.0010	0.0036	0.2505	0.0010	0.0006	0.0033	0.0011	0.0006	0.0035	0.0037	0.00132	0.00084	0.00378	0.25049	
0.8438	108.0	D6	15	19	0.0030	0.0012	0.0014	0.0074	0.2503	0.0013	0.0014	0.0058	0.2505	0.0012	0.0008	0.0038	0.0013	0.0008	0.0049	0.0033	0.00121	0.00108	0.00545	0.25039	
1.0547	135.0	D7	10	21	0.0030	0.0016	0.0018	0.0063	0.2504	0.0019	0.0016	0.0048	0.2504	0.0015	0.0012	0.0068	0.0014	0.0009	0.0048	0.0028	0.00159	0.00138	0.00566	0.25039	
1.2656	162.0	D8	15	17	0.0025	0.0014	0.0016	0.0056	0.2502	0.0018	0.0017	0.0039	0.2504	0.0017	0.0013	0.0058	0.0019	0.0012	0.0045	0.0039	0.00170	0.00148	0.00493	0.25028	







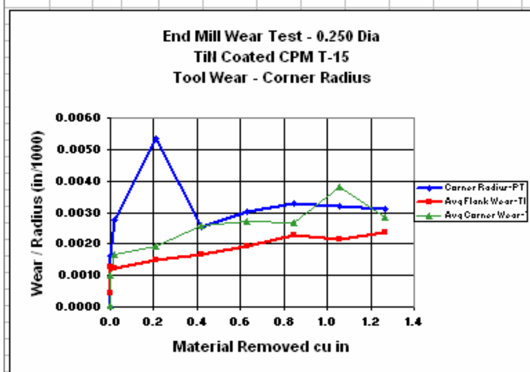
	Cutting Conditions:			
	Profile Milling - Climb Cutting			
Tool No.: Avg TCPM1	Speed:	967	RPM	63.3 SFM
Tl Mat: CPM T-15	Feed:	2.7	IPM	0.0007 I/T
Tl Coat: TiN	Rad DOC:	0.0625	in	25 %D
Tl Size: 0.250	Axl DOC:	0.1250	in	50 %D
Date: D-03	Technician(s):	K. L. Mitchell		
File Name: 250T-CPM1,250T-CPM2				

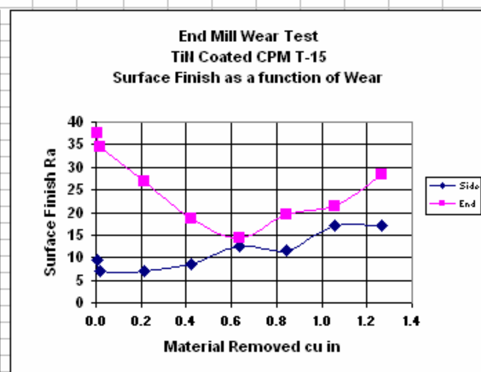


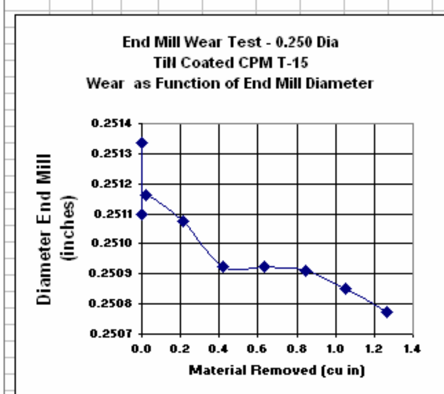
Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia
	D = The associated dynamometer run.												
0.0000	0.0					0.0006	0.0004	0.0000	0.2514	0.0005	0.0004	0.0000	0.2513
0.0031	0.4	D1	10	38	0.0025	0.0012	0.0013	0.0013	0.2511	0.0014	0.0014	0.0014	0.2511
0.0211	2.7	D2	7	35	0.0030	0.0013	0.0010	0.0018	0.2512	0.0017	0.0014	0.0020	0.2512
0.2109	27.0	D3	7	27	0.0030	0.0024	0.0014	0.0018	0.2511	0.0015	0.0015	0.0020	0.2511
0.4219	54.0	D4	9	19	0.0025	0.0022	0.0013	0.0023	0.2510	0.0024	0.0016	0.0024	0.2509
0.6328	81.0	D5	13	15	0.0020	0.0024	0.0021	0.0025	0.2509	0.0023	0.0020	0.0031	0.2510
0.8438	108.0	D6	12	20	0.0025	0.0027	0.0021	0.0025	0.2509	0.0026	0.0023	0.0023	0.2509
1.0547	135.0	D7	17	22	0.0025	0.0021	0.0023	0.0025	0.2509	0.0021	0.0023	0.0022	0.2508
1.2656	162.0	D8	17	29	0.0025	0.0028	0.0023	0.0031	0.2508	0.0021	0.0025	0.0030	0.2508

Mat Remv cu in	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	
0.0000	0.0006	0.0006	0.0001	0.0006	0.0004	0.0001	0.0000	0.00056	0.00045	0.00004	0.25134	
0.0031	0.0013	0.0012	0.0004	0.0015	0.0012	0.0010	0.0016	0.00136	0.00126	0.00101	0.25110	2-1
0.0211	0.0014	0.0013	0.0014	0.0022	0.0013	0.0014	0.0028	0.00164	0.00124	0.00164	0.25116	
0.2109	0.0017	0.0016	0.0021	0.0022	0.0015	0.0018	0.0053	0.00192	0.00148	0.00192	0.25108	
0.4219	0.0019	0.0017	0.0021	0.0018	0.0020	0.0036	0.0025	0.00206	0.00164	0.00259	0.25093	
0.6328	0.0020	0.0018	0.0028	0.0022	0.0018	0.0024	0.0030	0.00222	0.00192	0.00272	0.25093	
0.8438	0.0028	0.0021	0.0037	0.0020	0.0026	0.0023	0.0033	0.00251	0.00228	0.00267	0.25091	1-1, 2-2
1.0547	0.0021	0.0021	0.0076	0.0019	0.0018	0.0030	0.0032	0.00206	0.00213	0.00383	0.25085	
1.2656	0.0025	0.0020	0.0026	0.0025	0.0026	0.0028	0.0031	0.00246	0.00235	0.00284	0.25078	

1-1	Picture of edge #1 at the entry notch area.
2-2	Picture. Coating is flaking. Picture is of the periphery of corner #1.
2-1	Tool height improperly set. Actual axial depth of cut is .211". Tool cut .400" incorrectly. Tool set properly for rest of test.



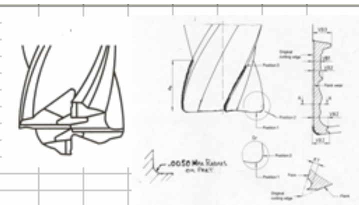




Cutting Conditions:

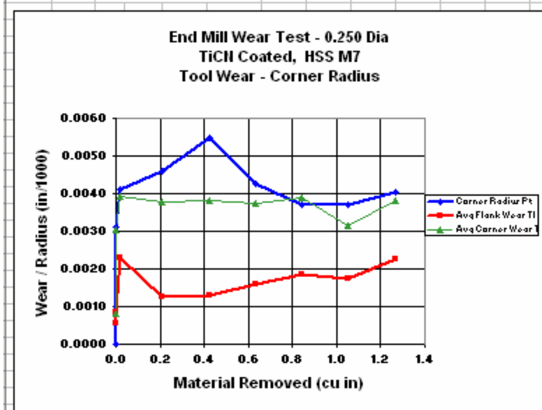
Profile Milling - Climb Cutting

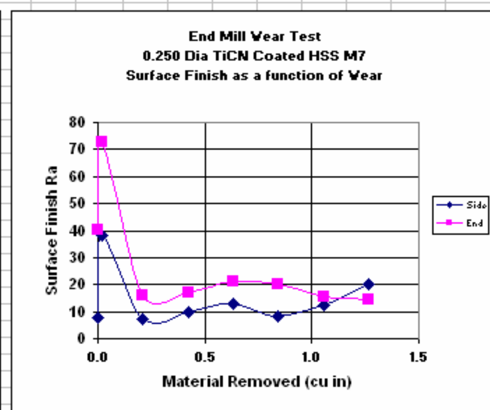
Tool No.:	Avg HSS1 & 2	Speed:	967	RPM	63.3	SFM	
Tl Mat:	HSS - M7	Feed:	2.7	IPM	0.0007	I/T	
Tl Coat:	TiCN	Rad DOC:	0.0625	in	25	%D	
Tl Size:	0.250	Axl DOC:	0.1250	in	50	%D	
Date:	J-04	Technician(s):	K. L. Mitchell				
File Name:	250C-HSS1,250C-HSS2						

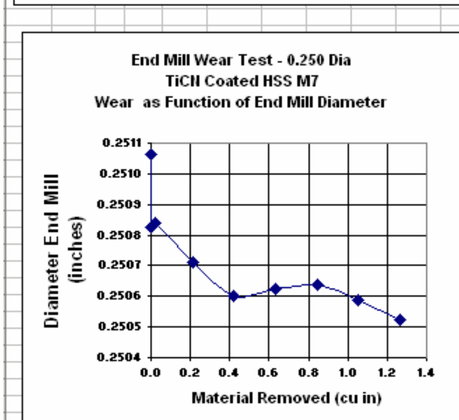


Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0.0					0.0006	0.0006	0.0005	0.2510	0.0008	0.0007	0.0004	0.2511	0.0006	0.0005	0.0005	0.0009	0.0006	0.0019	0.0000	0.00071	0.00056	0.00081	0.25106	
0.0031	0.4	D1	8	41	0.0020	0.0013	0.0011	0.0025	0.2508	0.0015	0.0009	0.0034	0.2509	0.0012	0.0004	0.0029	0.0013	0.0010	0.0034	0.0031	0.00132	0.00084	0.00305	0.25083	
0.0211	2.7	D2	38	73	0.0060	0.0023	0.0020	0.0029	0.2508	0.0028	0.0025	0.0048	0.2509	0.0023	0.0029	0.0035	0.0021	0.0019	0.0046	0.0041	0.00235	0.00229	0.00393	0.25084	1-4
0.2109	27.0	D3	7	16	0.0030	0.0010	0.0011	0.0034	0.2507	0.0010	0.0013	0.0035	0.2507	0.0010	0.0012	0.0026	0.0015	0.0015	0.0057	0.0046	0.00113	0.00128	0.00378	0.25071	1-2
0.4219	54.0	D4	10	17	0.0030	0.0015	0.0012	0.0025	0.2506	0.0010	0.0016	0.0032	0.2506	0.0014	0.0011	0.0034	0.0012	0.0014	0.0063	0.0055	0.00129	0.00131	0.00383	0.25060	
0.6328	81.0	D5	13	21	0.0030	0.0020	0.0017	0.0030	0.2506	0.0133	0.0013	0.0036	0.2507	0.0017	0.0019	0.0035	0.0021	0.0015	0.0048	0.0043	0.00478	0.00161	0.00373	0.25063	1-3,4
0.8438	108.0	D6	9	20	0.0030	0.0020	0.0016	0.0033	0.2506	0.0125	0.0015	0.0037	0.2507	0.0015	0.0019	0.0039	0.0024	0.0024	0.0047	0.0037	0.00459	0.00185	0.00388	0.25064	
1.0547	135.0	D7	13	16	0.0030	0.0016	0.0014	0.0030	0.2506	0.0017	0.0015	0.0030	0.2506	0.0022	0.0021	0.0034	0.0021	0.0019	0.0033	0.0037	0.00189	0.00174	0.00315	0.25059	
1.2656	162.0	D8	20	15	0.0030	0.0020	0.0016	0.0035	0.2505	0.0022	0.0022	0.0036	0.2506	0.0030	0.0026	0.0032	0.0025	0.0027	0.0050	0.0041	0.00243	0.00227	0.00380	0.25053	

4	Picture showing edge wear and coating erosion (wear)
3	Picture of coating missing from corner #1
2	BUE on edge #4 @ average height area.
1	Flake on corner #4.



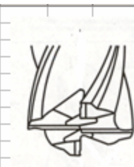


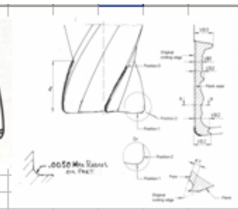


Cutting Conditions:

Profile Milling - Climb Cutting

Tool No.:	Avg Co1 & 2		Speed:	967	RPM	63.3	SFM
Tl Mat:	Cobalt HSS		Feed:	2.7	IPM	0.0007	I/T
Tl Coat:	TiCN		Rad DOC:	0.0625	in	25	%D
Tl Size:	0.250		Axl DOC:	0.1250	in	50	%D
Date:		D-03	Technician(s):	K. L. Mitchell			
File Name:	250C-Co1,250C-Co2						





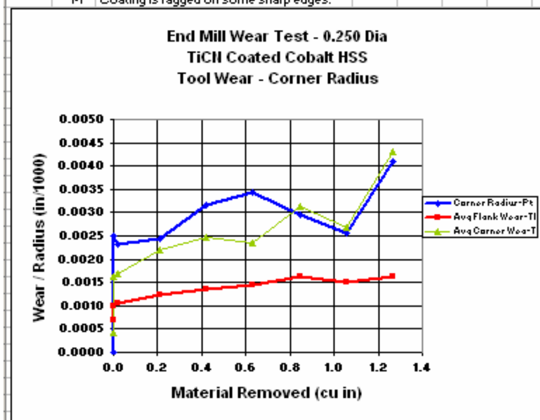
D = The associated dynamometer run.

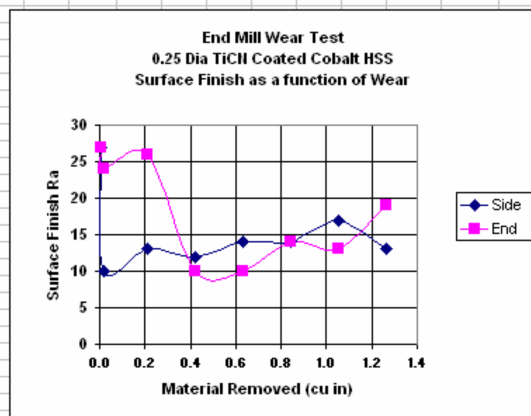
Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia
0.0000	0.0					0.0009	0.0009	0.0007	0.2510	0.0082	0.0005	0.0005	0.2510
0.0031	0.4	D1	27	27	0.003	0.0009	0.0009	0.0012	0.2508	0.0011	0.0010	0.0014	0.2506
0.0211	2.7	D2	10	24	0.003	0.0015	0.0013	0.0013	0.2505	0.0014	0.0008	0.0014	0.2506
0.2109	27.0	D3	13	26	0.002	0.0019	0.0015	0.0025	0.2505	0.0013	0.0009	0.0019	0.2505
0.4219	54.0	D4	12	10	0.003	0.0016	0.0015	0.0038	0.2504	0.0016	0.0013	0.0013	0.2505
0.6328	81.0	D5	14	10	0.003	0.0017	0.0015	0.0032	0.2502	0.0014	0.0013	0.0019	0.2503
0.8438	108.0	D6	14	14	0.003	0.0018	0.0016	0.0034	0.2504	0.0015	0.0014	0.0018	0.2505
1.0547	135.0	D7	17	13	0.003	0.0020	0.0014	0.0033	0.2504	0.0016	0.0015	0.0018	0.2504
1.2656	162.0	D8	13	19	0.003	0.0023	0.0017	0.0045	0.2503	0.0018	0.0015	0.0020	0.2504

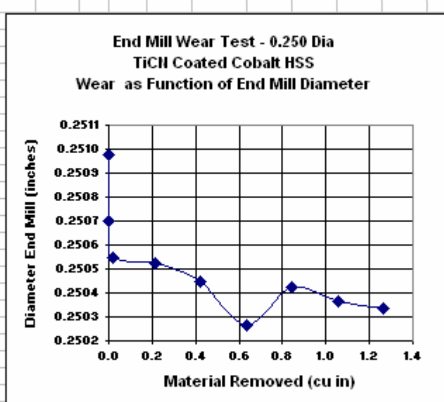
Mat Remv cu in	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
0.0000	0.0008	0.0007	0.0001	0.0009	0.0007	0.0004	0.0000	0.00269	0.00069	0.00041	0.25098	1-1
0.0031	0.0007	0.0007	0.0022	0.0008	0.0014	0.0017	0.0025	0.00088	0.00100	0.00163	0.25070	2-1
0.0211	0.0013	0.0009	0.0026	0.0012	0.0013	0.0014	0.0023	0.00134	0.00106	0.00168	0.25055	
0.2109	0.0011	0.0014	0.0025	0.0012	0.0012	0.0020	0.0025	0.00135	0.00123	0.00221	0.25053	1-2
0.4219	0.0013	0.0010	0.0019	0.0018	0.0016	0.0028	0.0032	0.00157	0.00136	0.00246	0.25045	
0.6328	0.0014	0.0015	0.0020	0.0019	0.0014	0.0024	0.0034	0.00159	0.00145	0.00236	0.25026	
0.8438	0.0013	0.0017	0.0030	0.0016	0.0019	0.0044	0.0030	0.00152	0.00161	0.00313	0.25043	
1.0547	0.0011	0.0015	0.0027	0.0017	0.0017	0.0030	0.0026	0.00158	0.00150	0.00269	0.25036	
1.2656	0.0012	0.0015	0.0031	0.0023	0.0019	0.0078	0.0041	0.00188	0.00163	0.00432	0.25034	

1-2 Small flakes on corners #1 & 4. 2-1 Flake on corner # 2.

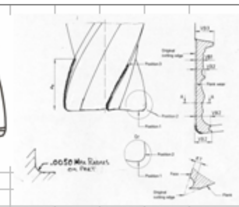
1-1 Coating is ragged on some sharp edges.







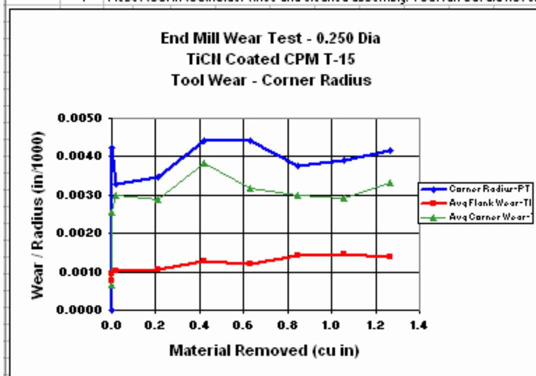
	Cutting Conditions:
	Profile Milling - Climb Cutting
Tool No.:	Avg C-CPM1&2 · Speed: 967 RPM · 63.3 SFM
Tl Mat:	CPM T-15 · Feed: 2.7 IPM · 0.0007 I/T
Tl Coat:	TiCN · Rad DOC: 0.0625 in · 25 %D
Tl Size:	0.250 · Axl DOC: 0.1250 in · 50 %D
Date:	D-03 · Technician(s): K. L. Mitchell
File Name:	250C-CPM1,250C-CPM2

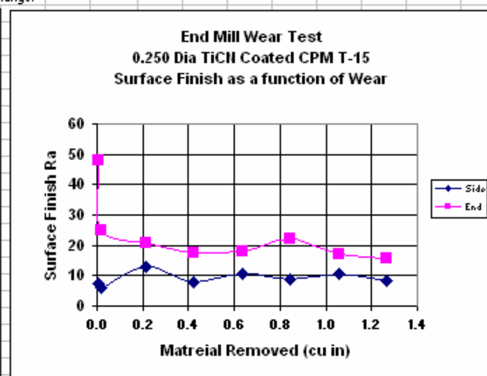


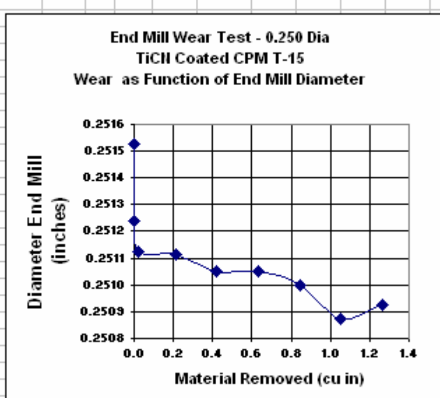
Material Remove cu in	Linear Inches Cut		Surface Finish Side Ra	End Cut Ra	Chip Thicknes:	Flank Face 1: Entry Notch Max.	A_z Avg. Height	Corner Radius	Dia	Flank Face 2: Entry Notch Max.	A_z Avg. Height	Corner Radius	Dia
	D = The associated dynamometer run.												
0.0000	0.0					0.0004	0.0006	0.0009	0.2515	0.0007	0.0006	0.0004	0.2516
0.0031	0.4	D1	8	48	0.0025	0.0013	0.0009	0.0036	0.2513	0.0019	0.0010	0.0025	0.2512
0.0211	2.7	D2	6	25	0.0030	0.0017	0.0010	0.0033	0.2511	0.0014	0.0011	0.0033	0.2512
0.2109	27.0	D3	13	21	0.0030	0.0012	0.0010	0.0028	0.2511	0.0015	0.0013	0.0027	0.2511
0.4219	54.0	D4	8	18	0.0030	0.0013	0.0012	0.0031	0.2511	0.0012	0.0016	0.0057	0.2511
0.6328	81.0	D5	11	18	0.0030	0.0012	0.0011	0.0023	0.2510	0.0014	0.0014	0.0039	0.2511
0.8438	108.0	D6	9	22	0.0030	0.0065	0.0013	0.0032	0.2511	0.0013	0.0012	0.0035	0.2510
1.0547	135.0	D7	11	17	0.0030	0.0019	0.0015	0.0026	0.2508	0.0014	0.0015	0.0035	0.2510
1.2656	162.0	D8	9	16	0.0030	0.0020	0.0015	0.0030	0.2510	0.0016	0.0015	0.0037	0.2509

Material Remove cu in	Flank Face 3: Entry Notch Max.	A_z Avg. Height	Corner Radius	Flank Face 4: Entry Notch Max.	A_z Avg. Height	Corner Radius	Spec Radius in.	Average All Flutes: Entry Notch Max.	A_z Avg. Height	Corner Radius	Average Diameter	
0.0000	0.0006	0.0007	0.0009	0.0008	0.0012	0.0006	0.0000	0.00060	0.00076	0.00066	0.2515	
0.0031	0.0013	0.0011	0.0018	0.0015	0.0009	0.0024	0.0042	0.00151	0.00094	0.00257	0.2512	1-2
0.0211	0.0012	0.0011	0.0027	0.0011	0.0009	0.0028	0.0033	0.00134	0.00103	0.00299	0.2511	
0.2109	0.0013	0.0010	0.0024	0.0064	0.0010	0.0037	0.0035	0.00259	0.00107	0.00290	0.2511	1-3
0.4219	0.0011	0.0013	0.0038	0.0012	0.0011	0.0028	0.0044	0.00118	0.00128	0.00384	0.2511	
0.6328	0.0013	0.0013	0.0036	0.0011	0.0010	0.0030	0.0044	0.00124	0.00119	0.00317	0.2511	
0.8438	0.0017	0.0019	0.0030	0.0017	0.0013	0.0023	0.0038	0.00278	0.00141	0.00299	0.2510	
1.0547	0.0017	0.0015	0.0033	0.0014	0.0014	0.0022	0.0039	0.00158	0.00146	0.00292	0.2509	
1.2656	0.0016	0.0014	0.0036	0.0016	0.0013	0.0030	0.0042	0.00168	0.00139	0.00331	0.2509	1-4

4 While trying to remove the tool from the toolholder the holder came out of the fixture and chipped one of the flutes.
3 Flake on corners 2 & 3.
2 Tool length compensation set incorrectly. Actual Axial Depth of cut is about .147".
1 Reset tool in toolholder twice and cleaned assembly. Tool run out did not change.



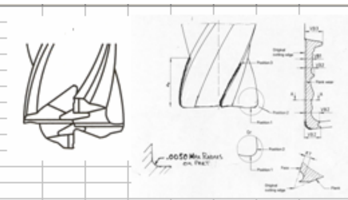




Cutting Conditions:
Profile Milling - Climb Cutting

Tool No.:	Avg HSS1 & 2	Speed:	1767 RPM	63.3	SFM
Tl Mat:	HSS - M7	Feed:	2.7 IPM	0.0007	I/T
Tl Coat:	None	Rad DOC:	0.0313 in	25	%D
Tl Size:	0.125	Axl DOC:	0.0625 in	50	%D
		Technician(s):	K. L. Mitchell		
File Name:	125U-HSS1,125U-HSS2				

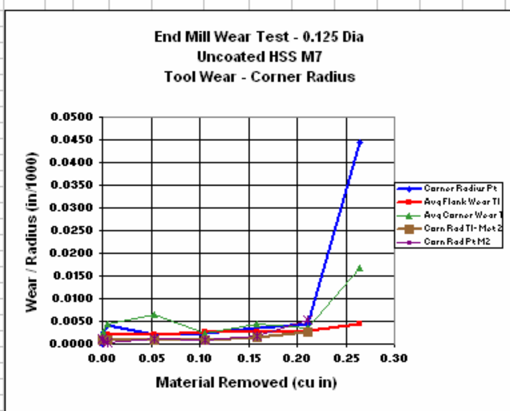
First end mill failed 196 inches and the second end mill at 245 inches

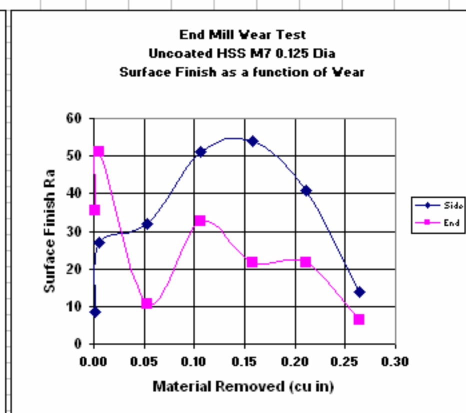


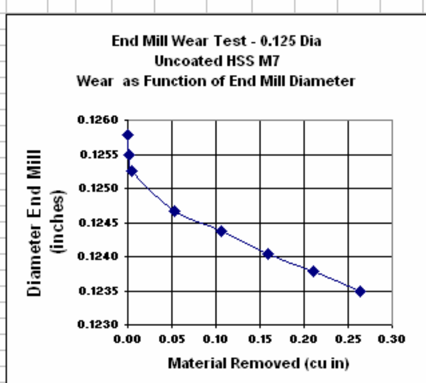
D = The associated dynamometer run.

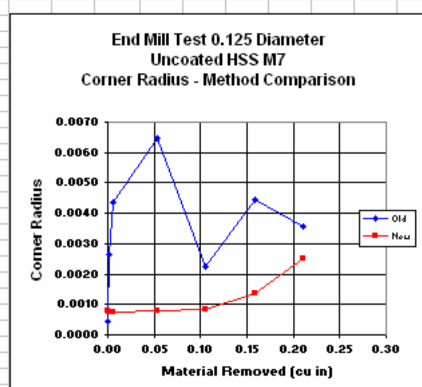
Material Remove cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thicknes	Flank Face 1 Entry Notch Max.	Flank Face 1 A_z Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_z Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_z Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_z Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_z Avg. Height	Average All Flutes Corner Radius	Average Diameter	Meth 2 EM Corner Rad	Com
0.0000	0.0					0.0005	0.0004	0.0004	0.1257	0.0005	0.0004	0.0006	0.1259	0.0004	0.0002	0.0001	0.0005	0.0004	0.0008	0.0000	0.00044	0.00034	0.00045	0.12578	0.0008	
0.0008	0.4	D1	9	36	0.0020	0.0006	0.0008	0.0025	0.1255	0.0006	0.0008	0.0039	0.1255	0.0006	0.0008	0.0020	0.0005	0.0007	0.0022	0.0026	0.00058	0.00076	0.00264	0.12549	0.0007	
0.0053	2.7	D2	27	51	0.0030	0.0024	0.0024	0.0038	0.1252	0.0023	0.0024	0.0048	0.1253	0.0024	0.0021	0.0036	0.0020	0.0020	0.0053	0.0042	0.00226	0.00219	0.00434	0.12525	0.0008	1
0.0528	27.0	D3	32	11	0.0025	0.0015	0.0019	0.0026	0.1247	0.0019	0.0022	0.0019	0.1247	0.0020	0.0021	0.0203	0.0017	0.0020	0.0012	0.0021	0.00176	0.00204	0.00649	0.12466	0.0008	
0.1056	54.0	D4	51	33	0.0020	0.0021	0.0026	0.0028	0.1244	0.0012	0.0026	0.0021	0.1244	0.0025	0.0025	0.0023	0.0022	0.0027	0.0018	0.0025	0.00196	0.00258	0.00224	0.12438	0.0009	
0.1585	81.0	D5	54	22	0.0030	0.0020	0.0028	0.0024	0.1241	0.0022	0.0024	0.0117	0.1240	0.0025	0.0024	0.0020	0.0027	0.0033	0.0018	0.0037	0.00234	0.00273	0.00446	0.12404	0.0014	
0.2113	108.0	D6	41	22	0.0025	0.0024	0.0027	0.0035	0.1237	0.0026	0.0029	0.0035	0.1238	0.0028	0.0032	0.0033	0.0024	0.0034	0.0039	0.0044	0.00256	0.00305	0.00355	0.12378	0.0025	
0.2641	135.0	D7	14	7	0.0030	0.0026	0.0048	0.0130	0.1235	0.0032	0.0041	0.0288	0.1235	0.0027	0.0041	0.0115	0.0037	0.0044	0.0142	0.0444	0.00304	0.00433	0.01685	0.12350	0.0000	

1 - 1 minute run not made on this end mill





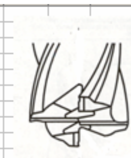




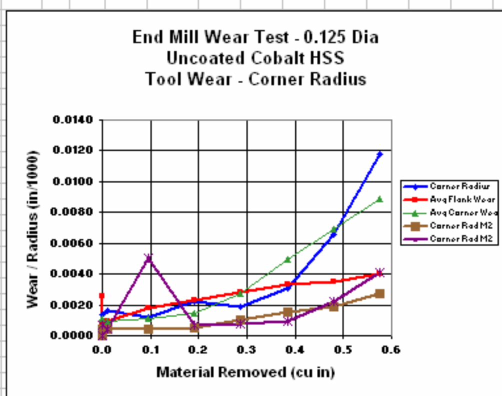
Cutting Conditions:

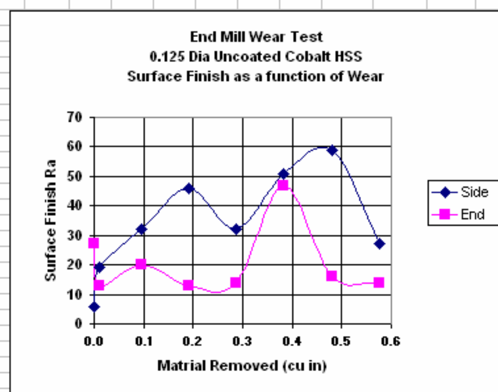
Profile Milling - Climb Cutting

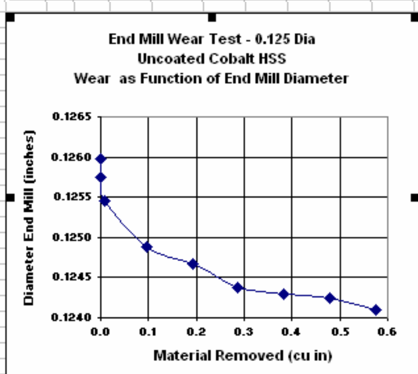
Tool No.:	Avg Co1 & 2	Speed:	1767 RPM	63.3 SFM
Tl Mat:	Cobalt HSS	Feed:	2.7 IPM	0.0007 I/T
Tl Coat:	None	Rad DOC:	0.0313 in	25 %D
Tl Size:	0.125	Axl DOC:	0.0625 in	50 %D
Date:	D-03	Technician(s):	K. L. Mitchell	
File Name:	125U-Co1, 125U-Co2(Damaged in setup and not run)			



Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thicknes:	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Meth 2 EM Corner Rad	Com
	D = The associated dynamometer run.																									
0.0000	0.0					0.0006	0.0005	0.0000	0.1259	0.0005	0.0004	0.0000	0.1261	0.0007	0.0005	0.0000	0.0007	0.0090	0.0010	0.0000	0.00060	0.00259	0.00025	0.12598	0.0000	
0.0008	0.4	D1	6	27	0.0020	0.0008	0.0007	0.0008	0.1257	0.0007	0.0007	0.0005	0.1259	0.0006	0.0009	0.0012	0.0008	0.0006	0.0020	0.0014	0.00070	0.00073	0.00110	0.12575	0.0004	1.1,2.1
0.0096	4.9	D2	19	13	0.0020	0.0011	0.0011	0.0011	0.1254	0.0013	0.0012	0.0009	0.1255	0.0011	0.0010	0.0009	0.0013	0.0007	0.0008	0.0017	0.00119	0.00098	0.00090	0.12545	0.0004	1.2,2.2
0.0959	49.0	D3	32	20	0.0030	0.0009	0.0020	0.0013	0.1248	0.0010	0.0017	0.0015	0.1250	0.0020	0.0017	0.0011	0.0017	0.0019	0.0006	0.0012	0.00136	0.00183	0.00110	0.12488	0.0005	
0.1917	98.0	D4	46	13	0.0020	0.0016	0.0022	0.0014	0.1246	0.0022	0.0022	0.0017	0.1248	0.0025	0.0024	0.0015	0.0022	0.0024	0.0012	0.0023	0.00211	0.00226	0.00144	0.12468	0.0005	
0.2876	147.0	D5	32	14	0.0020	0.0020	0.0025	0.0027	0.1243	0.0022	0.0030	0.0029	0.1245	0.0023	0.0031	0.0028	0.0022	0.0026	0.0025	0.0019	0.00214	0.00280	0.00273	0.12438	0.0010	
0.3834	196.0	D6	51	47	0.0020	0.0021	0.0030	0.0041	0.1241	0.0020	0.0035	0.0046	0.1245	0.0026	0.0035	0.0069	0.0022	0.0032	0.0042	0.0031	0.00221	0.00329	0.00491	0.12430	0.0015	
0.4793	245.0	D7	59	16	0.0030	0.0023	0.0031	0.0085	0.1242	0.0023	0.0035	0.0075	0.1244	0.0028	0.0039	0.0019	0.0029	0.0036	0.0098	0.0066	0.00255	0.00348	0.00693	0.12425	0.0019	
0.5751	294.0	D8	27	14	0.0030	0.0028	0.0031	0.0099	0.1241	0.0027	0.0040	0.0087	0.1241	0.0037	0.0062	0.0051	0.0032	0.0030	0.0118	0.0118	0.00309	0.00404	0.00885	0.12410	0.0028	

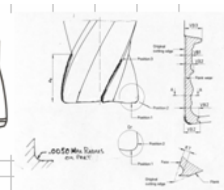






Cutting Conditions:
Profile Milling - Climb Cutting

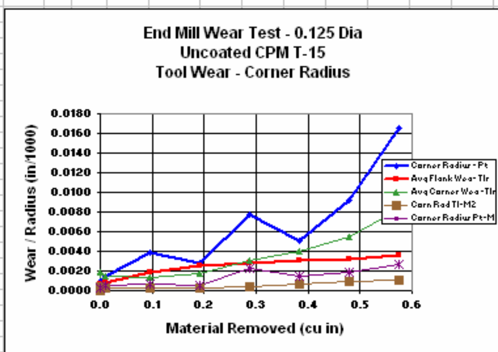
Tool No.:	Avg CPM 1 &	Speed:	1767	RPM	57.86 SFM
Tl Mat:	CPM T-15	Feed:	4.9	IPM	0.0007 I/T
Tl Coat:	None	Rad DOC:	0.0313	in	25 %D
Tl Size:	0.125	Axl DOC:	0.0625	in	50 %D
		Technician(s):	K. L. Mitchell		
File Name:	125U-CPM1,125U-CPM2				

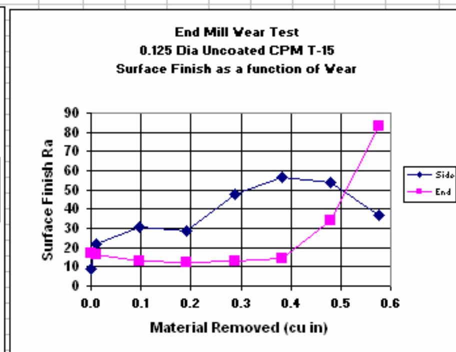



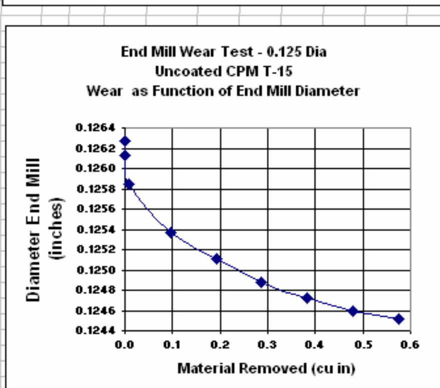
D = The associated dynamometer run.

Material Removed cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia
0	0.0					0.0004	0.0006	0.0006	0.1263	0.0003	0.0006	0.0005	0.1263
0.0008	0.4	D1	9	17	0.0020	0.0006	0.0007	0.0024	0.1261	0.0006	0.0008	0.0014	0.1262
0.0096	4.9	D2	22	17	0.0020	0.0011	0.0006	0.0018	0.1259	0.0010	0.0011	0.0016	0.1259
0.0959	49.0	D3	31	13	0.0025	0.0013	0.0020	0.0014	0.1253	0.0022	0.0012	0.0020	0.1254
0.1917	98.0	D4	29	12	0.0030	0.0011	0.0025	0.0020	0.1251	0.0018	0.0028	0.0016	0.1251
0.2876	147.0	D5	48	13	0.0025	0.0018	0.0028	0.0049	0.1249	0.0021	0.0032	0.0023	0.1248
0.3834	196.0	D6	57	15	0.0030	0.0020	0.0034	0.0065	0.1247	0.0024	0.0031	0.0037	0.1248
0.4793	245.0	D7	54	34	0.0035	0.0025	0.0035	0.0090	0.1246	0.0025	0.0034	0.0050	0.1247
0.5751	294.0	D8	37	83	0.0030	0.0030	0.0039	0.0090	0.1245	0.0028	0.0037	0.0052	0.1246

Material Removed cu in	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Method 2 Ed Ml Corner Radius	
0	0.0004	0.0006	0.0002	0.0005	0.0006	0.0004	0.0000	0.00038	0.00060	0.00041	0.12628	0.0000	1.1, 2.1
0.0008	0.0006	0.0006	0.0025	0.0005	0.0005	0.0012	0.0009	0.00056	0.00064	0.00187	0.12613	0.0004	
0.0096	0.0007	0.0008	0.0012	0.0010	0.0007	0.0013	0.0015	0.00094	0.00080	0.00144	0.12585	0.0003	1.2
0.0959	0.0021	0.0022	0.0011	0.0016	0.0021	0.0011	0.0038	0.00179	0.00187	0.00139	0.12536	0.0003	
0.1917	0.0025	0.0026	0.0016	0.0013	0.0025	0.0018	0.0029	0.00166	0.00259	0.00175	0.12511	0.0003	2.2
0.2876	0.0021	0.0027	0.0026	0.0014	0.0024	0.0023	0.0077	0.00185	0.00274	0.00303	0.12488	0.0004	2.3
0.3834	0.0025	0.0030	0.0029	0.0016	0.0027	0.0028	0.0051	0.00209	0.00303	0.00399	0.12473	0.0006	
0.4793	0.0026	0.0030	0.0037	0.0019	0.0029	0.0043	0.0092	0.00236	0.00318	0.00551	0.12460	0.0010	
0.5751	0.0025	0.0039	0.0115	0.0023	0.0030	0.0074	0.0165	0.00264	0.00362	0.00828	0.12451	0.0010	

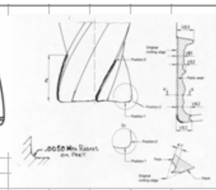






Cutting Conditions:
Profile Milling - Climb Cutting

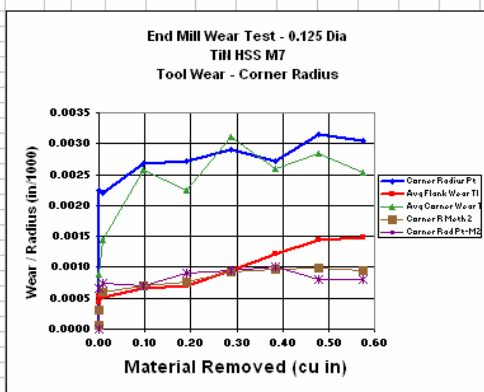
Tool No.:	Avg HSS1 & 2	Speed:	1767 RPM	63.3	SFM
Tl Mat:	HSS - M7	Feed:	2.7 IPM	0.0007	I/T
Tl Coat:	TiN	Rad DOC:	0.0313 in	25	%D
Tl Size:	0.125	Axl DOC:	0.0625 in	50	%D
Date:	J-04	Technician(s):	K. L. Mitchell		
File Name:	125T-HSS1,125T-HSS2				

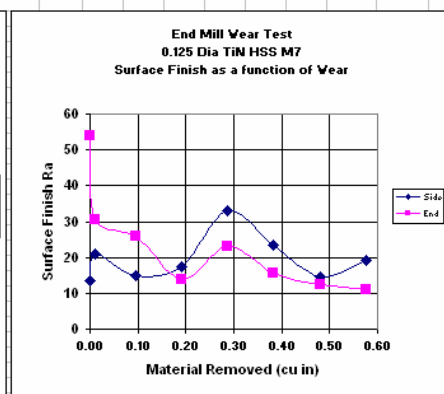


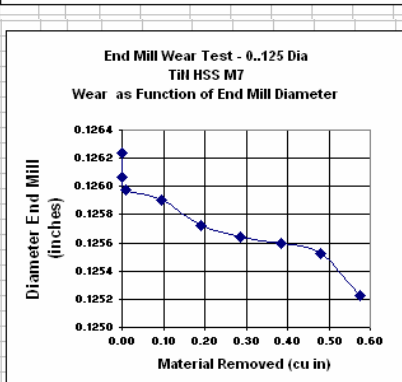
Matreial Removed cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_z Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_z Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia
	D = The associated dynamometer run.												
0.0000	0					0.0006	0.0006	0.0001	0.1261	0.0001	0.0004	0.0000	0.1264
0.0008	0.4	D1	14	54	0.0020	0.0005	0.0006	0.0012	0.1259	0.0004	0.0006	0.0008	0.1262
0.0096	4.9	D2	21	31	0.0020	0.0006	0.0006	0.0015	0.1259	0.0005	0.0005	0.0010	0.1261
0.0959	49.0	D3	15	26	0.0012	0.0011	0.0007	0.0050	0.1258	0.0007	0.0006	0.0021	0.1260
0.1917	98.0	D4	18	14	0.0015	0.0030	0.0008	0.0031	0.1256	0.0007	0.0008	0.0022	0.1259
0.2876	147.0	D5	33	23	0.0020	0.0008	0.0009	0.0027	0.1255	0.0007	0.0012	0.0024	0.1258
0.3834	196.0	D6	24	16	0.0020	0.0011	0.0014	0.0032	0.1256	0.0010	0.0014	0.0024	0.1256
0.4793	245.0	D7	15	13	0.0030	0.0015	0.0017	0.0026	0.1255	0.0015	0.0018	0.0033	0.1256
0.5751	294.0	D8	19	11	0.0020	0.0017	0.0022	0.0025	0.1253	0.0014	0.0014	0.0024	0.1252

Matreial Removed cu in	Flank Face 3 Entry Notch Max.	Flank Face 3 A_z Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_z Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_z Avg. Height	Average All Flutes Corner Radius	Average Diameter	Method 2 End Mill Corner Radius	Com
0.0000	0.0002	0.0003	0.0007	0.0004	0.0005	0.0004	0.0000	0.00031	0.00044	0.00028	0.12624	0.0001	
0.0008	0.0006	0.0005	0.0010	0.0006	0.0006	0.0006	0.0023	0.00051	0.00053	0.00089	0.12606	0.0003	
0.0096	0.0005	0.0005	0.0015	0.0007	0.0005	0.0017	0.0022	0.00056	0.00051	0.00143	0.12598	0.0006	1
0.0959	0.0006	0.0007	0.0015	0.0008	0.0007	0.0019	0.0027	0.00080	0.00066	0.00258	0.12590	0.0007	
0.1917	0.0011	0.0007	0.0016	0.0011	0.0006	0.0021	0.0027	0.00145	0.00070	0.00225	0.12573	0.0008	
0.2876	0.0009	0.0009	0.0039	0.0010	0.0008	0.0034	0.0029	0.00086	0.00094	0.00310	0.12564	0.0009	
0.3834	0.0009	0.0011	0.0026	0.0010	0.0011	0.0022	0.0027	0.00096	0.00123	0.00260	0.12560	0.0010	
0.4793	0.0014	0.0011	0.0031	0.0010	0.0012	0.0024	0.0032	0.00136	0.00144	0.00284	0.12553	0.0010	
0.5751	0.0020	0.0012	0.0026	0.0015	0.0012	0.0026	0.0031	0.00166	0.00148	0.00253	0.12523	0.0009	

1 - 1 minute run not made on this end mill





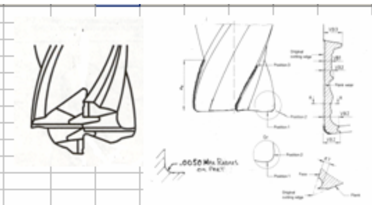


Cutting Conditions:

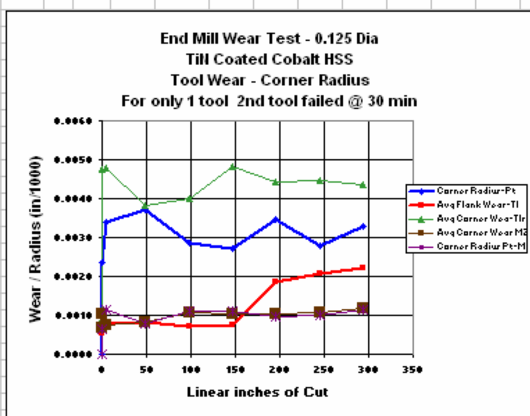
Profile Milling - Climb Cutting

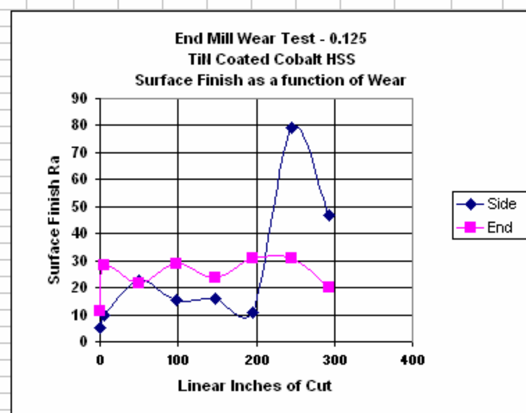
Tool No.:	Avg Co1 & 2	Speed:	1767	RPM	63.3 SFM
Tl Mat:	Cobalt HSS	Feed:	2.7	IPM	0.002 I/T
Tl Coat:	TiN	Rad DOC:	0.0625	in	25 %D
Tl Size:	0.125	Axl DOC:	0.1250	in	50 %D
Date:	D-03	Technician(s):	K. L. Mitchell		
File Name:	250T-Co1,250T-Co2				

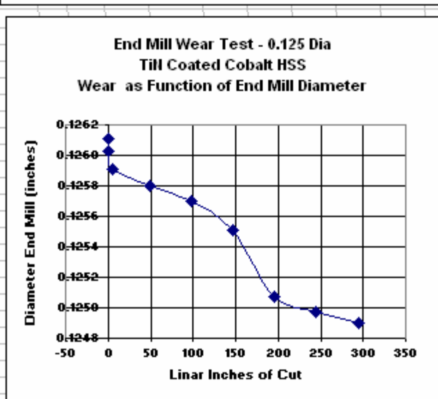
Note: Tool 2 failed after 30 min corner failure of all flutes
Combined data avg for first 30 min.
Data for 40, 50, 60 for 1 tool.
Graphs for tool 2 only



Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0					0.0005	0.0004	0.0000	0.1260	0.0005	0.0004	0.0007	0.1262	0.0007	0.0008	0.0024	0.0003	0.0007	0.0086	0.0000	0.00047	0.00055	0.00291	0.12611	
0.0031	0.4	D1	5	12	0.0020	0.0008	0.0006	0.0008	0.1260	0.0007	0.0008	0.0065	0.1261	0.0010	0.0007	0.0037	0.0006	0.0005	0.0129	0.0043	0.00079	0.00064	0.00594	0.12603	
0.0383	4.9	D2	10	29	0.0015	0.0012	0.0007	0.0027	0.1259	0.0012	0.0007	0.0067	0.1259	0.0013	0.0010	0.0039	0.0010	0.0006	0.0129	0.0047	0.00113	0.00074	0.00657	0.12591	
0.3828	49.0	D3	23	22	0.0015	0.0012	0.0010	0.0043	0.1259	0.0013	0.0009	0.0080	0.1257	0.0011	0.0006	0.0031	0.0012	0.0006	0.0105	0.0048	0.00121	0.00078	0.00646	0.12580	
0.7656	98.0	D4	16	29	0.0015	0.0009	0.0009	0.0052	0.1257	0.0014	0.0010	0.0080	0.1257	0.0009	0.0012	0.0033	0.0012	0.0008	0.0097	0.0049	0.00108	0.00094	0.00656	0.12570	
1.1484	147.0	D5	16	24	0.0020	0.0015	0.0011	0.0060	0.1255	0.0013	0.0014	0.0074	0.1256	0.0014	0.0010	0.0049	0.0014	0.0010	0.0108	0.0046	0.00139	0.00113	0.00727	0.12551	
1.5313	196.0	D6	11	31	0.0020	0.0014	0.0021	0.0023	0.1252	0.0016	0.0024	0.0087	0.1250	0.0014	0.0016	0.0043	0.0125	0.0014	0.0025	0.0017	0.00420	0.00185	0.00443	0.12508	
1.9141	245.0	D7	79	31	0.0020	0.0015	0.0018	0.0024	0.1250	0.0011	0.0027	0.0091	0.1250	0.0019	0.0022	0.0037	0.0016	0.0016	0.0027	0.0014	0.00149	0.00206	0.00448	0.12498	
2.2969	294.0	D8	47	20	0.0020	0.0028	0.0020	0.0027	0.1249	0.0120	0.0029	0.0089	0.1249	0.0028	0.0023	0.0033	0.0029	0.0017	0.0027	0.0017	0.00509	0.00221	0.00436	0.12490	



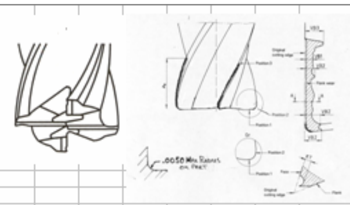




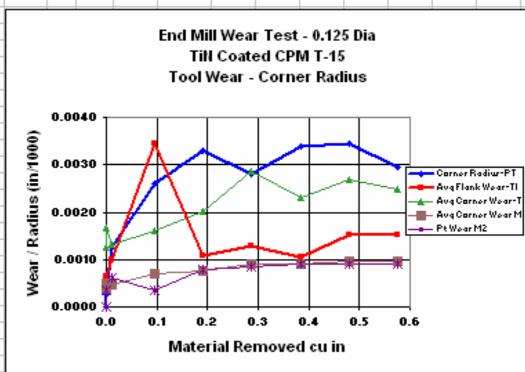
Cutting Conditions:

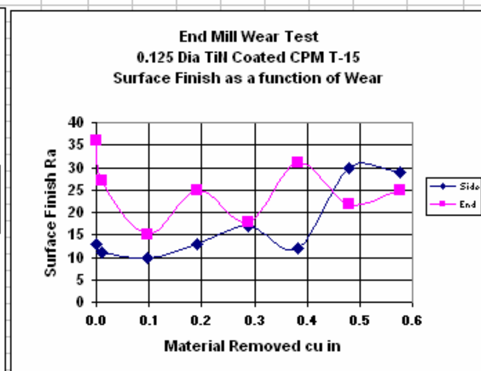
Profile Milling - Climb Cutting

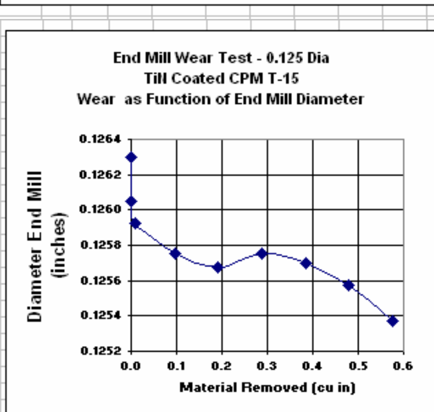
Tool No.:	Avg TCPM1 8	Speed:	967	RPM	63.3	SFM
Tl Mat:	CPM T-15	Feed:	2.7	IPM	0.0007	I/T
Tl Coat:	TiN	Rad DOC:	0.0313	in	25	%D
Tl Size:	0.125	Axl DOC:	0.0625	in	50	%D
Date:	D-03	Technician(s):	K. L. Mitchell			
File Name:	125T-CPM1					



Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	
	D = The associated dynamometer run.																								
0.0000	0.0					0.0000	0.0004	0.0011	0.1263	0.0003	0.0005	0.0012	0.1263	0.0004	0.0003	0.0013	0.0004	0.0004	0.0015	0.0000	0.00024	0.00036	0.00126	0.12630	
0.0008	0.4	D1	13	36	0.0020	0.0011	0.0007	0.0017	0.1261	0.0010	0.0007	0.0021	0.1260	0.0008	0.0009	0.0014	0.0011	0.0004	0.0015	0.0003	0.00095	0.00065	0.00165	0.12605	2-1
0.0096	4.9	D2	11	27	0.0010	0.0015	0.0012	0.0014	0.1260	0.0011	0.0008	0.0015	0.1259	0.0013	0.0010	0.0009	0.0014	0.0011	0.0016	0.0013	0.00131	0.00099	0.00130	0.12593	
0.0959	49.0	D3	10	15	0.0010	0.0020	0.0010	0.0019	0.1258	0.0010	0.0012	0.0013	0.1257	0.0012	0.0105	0.0016	0.0012	0.0011	0.0017	0.0026	0.00131	0.00344	0.00160	0.12575	
0.1917	98.0	D4	13	25	0.0020	0.0013	0.0011	0.0015	0.1257	0.0012	0.0011	0.0023	0.1257	0.0011	0.0010	0.0025	0.0012	0.0012	0.0019	0.0033	0.00118	0.00108	0.00203	0.12568	
0.2876	147.0	D5	17	18	0.0010	0.0013	0.0015	0.0031	0.1258	0.0010	0.0013	0.0023	0.1257	0.0013	0.0011	0.0027	0.0012	0.0013	0.0034	0.0028	0.00116	0.00128	0.00285	0.12575	
0.3834	196.0	D6	12	31	0.0020	0.0011	0.0011	0.0027	0.1258	0.0014	0.0010	0.0019	0.1256	0.0015	0.0011	0.0026	0.0014	0.0011	0.0022	0.0034	0.00133	0.00105	0.00231	0.12570	1-1, 2-2
0.4793	245.0	D7	30	22	0.0020	0.0011	0.0016	0.0026	0.1257	0.0015	0.0016	0.0026	0.1255	0.0015	0.0013	0.0032	0.0013	0.0017	0.0025	0.0035	0.00133	0.00151	0.00269	0.12558	
0.5751	294.0	D8	29	25	0.0020	0.0016	0.0020	0.0027	0.1254	0.0013	0.0015	0.0025	0.1254	0.0019	0.0010	0.0027	0.0017	0.0017	0.0021	0.0030	0.00159	0.00153	0.00249	0.12538	

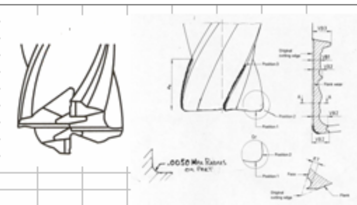






Cutting Conditions:
Profile Milling - Climb Cutting

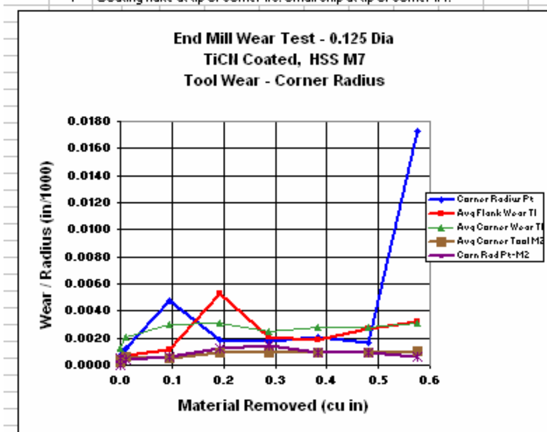
Tool No.:	Avg HSS1 & 2	Speed:	1767 RPM	63.3	SFM
Tl Mat:	HSS - M7	Feed:	2.7 IPM	0.002	I/T
Tl Coat:	TiCN	Rad DOC:	0.0313 in	25	%D
Tl Size:	0.125	Axl DOC:	0.0625 in	50	%D
Date:	J-04	Technician(s):	K. L. Mitchell		
File Name:	125C-HSS1,125C-HSS2				

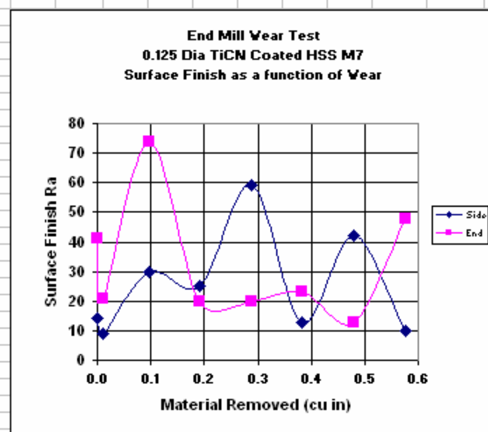


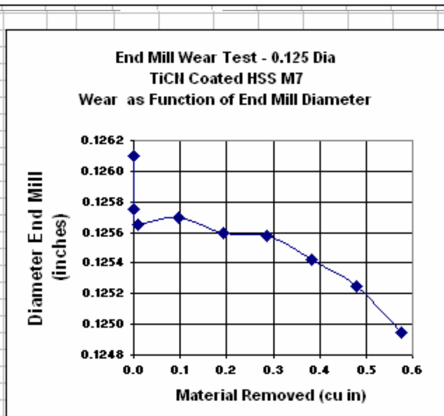
Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia
	D = The associated dynamometer run.												
0.0000	0					0.0005	0.0000	0.0004	0.1261	0.0005	0.0000	0.0000	0.1261
0.0008	0.4	D1	14	41	0.0010	0.0013	0.0005	0.0013	0.1257	0.0005	0.0004	0.0013	0.1258
0.0096	4.9	D2	9	21	0.0010	0.0016	0.0009	0.0014	0.1257	0.0017	0.0008	0.0015	0.1256
0.0959	49.0	D3	30	74	0.0010	0.0016	0.0012	0.0032	0.1257	0.0013	0.0011	0.0023	0.1257
0.1917	98.0	D4	25	20	0.0020	0.0019	0.0018	0.0030	0.1256	0.0017	0.0160	0.0021	0.1256
0.2876	147.0	D5	59	20	0.0020	0.0015	0.0025	0.0031	0.1256	0.0021	0.0016	0.0021	0.1256
0.3834	196.0	D6	13	23	0.0020	0.0021	0.0021	0.0031	0.1254	0.0023	0.0016	0.0031	0.1255
0.4793	245.0	D7	42	13	0.0020	0.0026	0.0021	0.0029	0.1253	0.0027	0.0030	0.0034	0.1253
0.5751	294.0	D8	10	48	0.0020	0.0026	0.0032	0.0030	0.1249	0.0041	0.0039	0.0038	0.1250

Mat Remv cu in	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
0.0000	0.0004	0.0003	0.0003	0.0002	0.0000	0.0014	0.0000	0.00039	0.00008	0.00050	0.12610	
0.0008	0.0007	0.0009	0.0015	0.0007	0.0005	0.0010	0.0007	0.00079	0.00053	0.00126	0.12575	
0.0096	0.0012	0.0008	0.0018	0.0011	0.0006	0.0037	0.0013	0.00140	0.00076	0.00208	0.12565	1
0.0959	0.0015	0.0009	0.0026	0.0015	0.0013	0.0039	0.0048	0.00146	0.00113	0.00296	0.12570	
0.1917	0.0022	0.0013	0.0025	0.0024	0.0020	0.0048	0.0019	0.00204	0.00525	0.00309	0.12560	
0.2876	0.0025	0.0022	0.0021	0.0023	0.0021	0.0025	0.0017	0.00208	0.00208	0.00244	0.12558	
0.3834	0.0018	0.0019	0.0023	0.0024	0.0018	0.0029	0.0021	0.00214	0.00181	0.00281	0.12543	
0.4793	0.0029	0.0027	0.0023	0.0037	0.0030	0.0027	0.0017	0.00295	0.00269	0.00281	0.12525	2
0.5751	0.0032	0.0026	0.0027	0.0038	0.0034	0.0029	0.0173	0.00341	0.00325	0.00309	0.12495	

2 This coating shows wear markings on the margins but there is not much wear on the cutting edges.
1 Coating flake at tip of corner #3. Small chip at tip of corner #4.

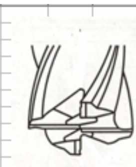


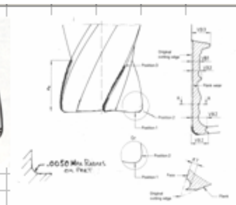




Cutting Conditions:
Profile Milling - Climb Cutting

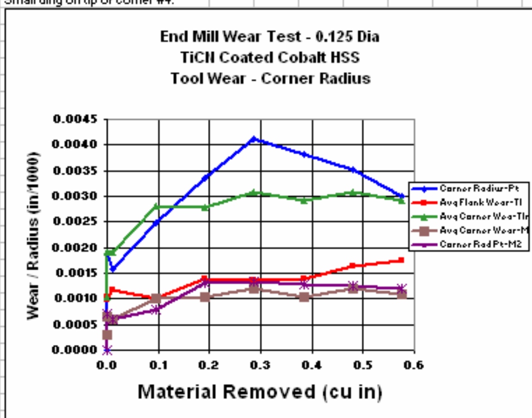
Tool No.:	Avg Co1 & 2	Speed:	1767 RPM	63.3	SFM
Tl Mat:	Cobalt HSS	Feed:	4.9 IPM	0.0007	I/T
Tl Coat:	TiCN	Rad DOC:	0.0313 in	25	%D
Tl Size:	0.125	Axl DOC:	0.0625 in	50	%D
Date:	D-03	Technician(s):	K. L. Mitchell		
File Name:	125C-Co1, 125C-Co2				

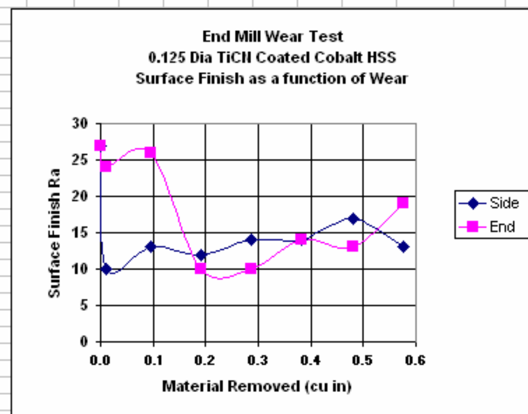


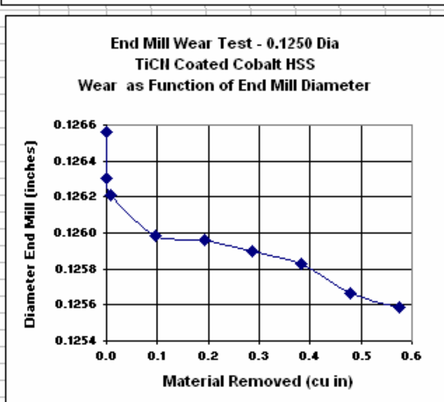


Mat Remv cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	Com
	D = The associated dynamometer run.																								
0.0000	0					0.0008	0.0006	0.0009	0.1265	0.0003	0.0011	0.0011	0.1266	0.0010	0.0007	0.0007	0.0008	0.0018	0.0015	0.0000	0.00071	0.00104	0.00104	0.12656	1-1
0.0008	0.4	D1	27	27	0.003	0.0008	0.0009	0.0014	0.1262	0.0042	0.0010	0.0017	0.1264	0.0008	0.0008	0.0019	0.0008	0.0012	0.0027	0.0019	0.00164	0.00098	0.00191	0.12630	
0.0096	4.9	D2	10	24	0.003	0.0013	0.0013	0.0018	0.1261	0.0016	0.0011	0.0018	0.1264	0.0014	0.0010	0.0018	0.0013	0.0013	0.0024	0.0016	0.00138	0.00117	0.00191	0.12621	
0.0959	49.0	D3	13	26	0.002	0.0007	0.0010	0.0027	0.1259	0.0011	0.0010	0.0030	0.1261	0.0009	0.0010	0.0025	0.0014	0.0011	0.0032	0.0025	0.00104	0.00100	0.00282	0.12599	
0.1917	98.0	D4	12	10	0.003	0.0014	0.0017	0.0030	0.1259	0.0012	0.0011	0.0029	0.1260	0.0011	0.0014	0.0023	0.0044	0.0014	0.0030	0.0034	0.00202	0.00138	0.00278	0.12596	
0.2876	147.0	D5	14	10	0.003	0.0018	0.0016	0.0029	0.1259	0.0013	0.0014	0.0035	0.1260	0.0013	0.0014	0.0030	0.0022	0.0011	0.0030	0.0041	0.00163	0.00136	0.00308	0.12590	
0.3834	196.0	D6	14	14	0.003	0.0017	0.0014	0.0026	0.1258	0.0021	0.0014	0.0034	0.1259	0.0018	0.0013	0.0030	0.0018	0.0015	0.0027	0.0038	0.00184	0.00139	0.00291	0.12583	
0.4793	245.0	D7	17	13	0.003	0.0027	0.0018	0.0032	0.1257	0.0029	0.0016	0.0031	0.1257	0.0031	0.0016	0.0031	0.0053	0.0016	0.0030	0.0035	0.00349	0.00164	0.00307	0.12566	2-1
0.5751	294.0	D8	13	19	0.003	0.0021	0.0018	0.0026	0.1256	0.0030	0.0019	0.0031	0.1256	0.0029	0.0018	0.0032	0.0033	0.0015	0.0028	0.0030	0.00281	0.00175	0.00292	0.12559	1-2

1-2 Entry scar just forming.
2-1 There is a discoloration across the width of the margin. Some areas appear to have depth but some do not.
1-1 Small ding on tip of corner #4.



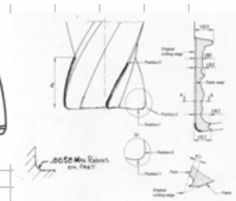




Cutting Conditions:

Profile Milling - Climb Cutting

Tool No.:	Avg C-CPM1&2	Speed:	1767	RPM	57.9 SFM
Tl Mat:	CPM T-15	Feed:	4.9	IPM	0.0007 I/T
Tl Coat:	TiCN	Rad DOC:	0.0313	in	25 %D
Tl Size:	0.125	Axl DOC:	0.0625	in	50 %D
Date:	D-03	Technician(s):	K. L. Mitchell		
File Name:	125C-CPM1				



Material Remove cu in	Linear Inches Cut		Surface Finish Side Ra	Surface Finish End Cut Ra	Chip Thickness	Flank Face 1 Entry Notch Max.	Flank Face 1 A_2 Avg. Height	Flank Face 1 Corner Radius	Flank Face 1 Dia	Flank Face 2 Entry Notch Max.	Flank Face 2 A_2 Avg. Height	Flank Face 2 Corner Radius	Flank Face 2 Dia
	D = The associated dynamometer run.												
0.0000	0.0					0.0004	0.0004	0.0003	0.1275	0.0004	0.0010	0.0031	0.1279
0.0031	0.4	D1	13	34	0.0010	0.0010	0.0006	0.0018	0.1272	0.0011	0.0021	0.0079	0.1272
0.0211	2.7	D2	11	23	0.0020	0.0018	0.0007	0.0011	0.1270	0.0009	0.0011	0.0022	0.1272
0.2109	27.0	D3	11	33	0.0010	0.0011	0.0011	0.0024	0.1268	0.0024	0.0019	0.0027	0.1272
0.4219	54.0	D4	11	32	0.0020	0.0013	0.0011	0.0027	0.1267	0.0014	0.0018	0.0032	0.1272
0.6328	81.0	D5	19	21	0.0020	0.0018	0.0014	0.0030	0.1268	0.0019	0.0016	0.0032	0.1272
0.8438	108.0	D6	15	29	0.0020	0.0020	0.0013	0.0029	0.1266	0.0017	0.0018	0.0045	0.1271
1.0547	135.0	D7	20	13	0.0020	0.0020	0.0013	0.0029	0.1266	0.0015	0.0016	0.0037	0.1269
1.2656	162.0	D8	18	20	0.0020	0.0031	0.0013	0.0035	0.1263	0.0033	0.0016	0.0029	0.1267

Material Remove cu in	Flank Face 3 Entry Notch Max.	Flank Face 3 A_2 Avg. Height	Flank Face 3 Corner Radius	Flank Face 4 Entry Notch Max.	Flank Face 4 A_2 Avg. Height	Flank Face 4 Corner Radius	Spec Radius in.	Average All Flutes Entry Notch Max.	Average All Flutes A_2 Avg. Height	Average All Flutes Corner Radius	Average Diameter	
0.0000	0.0007	0.0010	0.0005	0.0008	0.0009	0.0003	0.0000	0.00054	0.00080	0.00105	0.12770	1
0.0031	0.0014	0.0017	0.0016	0.0020	0.0013	0.0021	0.0021	0.00136	0.00140	0.00334	0.12718	1
0.0211	0.0014	0.0014	0.0019	0.0015	0.0009	0.0021	0.0020	0.00138	0.00099	0.00181	0.12710	1
0.2109	0.0014	0.0012	0.0018	0.0015	0.0010	0.0025	0.0027	0.00156	0.00126	0.00234	0.12695	1
0.4219	0.0015	0.0015	0.0022	0.0016	0.0010	0.0021	0.0036	0.00143	0.00131	0.00253	0.12695	1
0.6328	0.0014	0.0015	0.0017	0.0018	0.0012	0.0026	0.0026	0.00169	0.00139	0.00263	0.12695	1
0.8438	0.0023	0.0013	0.0024	0.0022	0.0010	0.0023	0.0039	0.00201	0.00134	0.00298	0.12683	1
1.0547	0.0015	0.0014	0.0022	0.0026	0.0010	0.0029	0.0033	0.00185	0.00131	0.00293	0.12670	1
1.2656	0.0011	0.0013	0.0025	0.0018	0.0014	0.0027	0.0035	0.00231	0.00138	0.00290	0.12650	1

1 The initial inspection showed jagged edges on the flutes, as the test progressed the edges smoothed but still are not as good as an uncoated endmill.