Advanced Cryogenics for Cutting Tools

Federal Manufacturing & Technologies

L. J. Lazarus

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Final Report

L. J. Lazarus and R. K. Albright, Project Leaders

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Project Team:

S. D. Nance

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Contents

<i>Section</i>	<i>Page</i>
Abstract	1
Summary	2
Discussion	5
Scope and Purpose	5
Prior Work	5
Activity	6
Testing.....	6
Survey	10
Testing Results.....	12
Survey Results	12
Accomplishments.....	16
References	17
Appendix. Test Results	18

Table

<i>Number</i>	<i>Page</i>
1 Test Data Summary.....	13

ABSTRACT

The purpose of the investigation was to determine if cryogenic treatment improved the life and cost effectiveness of perishable cutting tools over other treatments or coatings. Test results showed that in five of seven of the perishable cutting tools tested there was no improvement in tool life. The other two tools showed a small gain in tool life, but not as much as when switching manufacturers of the cutting tool. The following conclusions were drawn from this study:

(1) titanium nitride coatings are more effective than cryogenic treatment in increasing the life of perishable cutting tools made from all cutting tool materials, (2) cryogenic treatment may increase tool life if the cutting tool is improperly heat treated during its origination, and (3) cryogenic treatment was only effective on those tools made from less sophisticated high speed tool steels. As a part of a recent detailed investigation, four cutting tool manufacturers and two cutting tool laboratories were queried and none could supply any data to substantiate cryogenic treatment of perishable cutting tools.

SUMMARY

The purpose of this investigation was to determine if cryogenic treatment improved the life and cost effectiveness of perishable cutting tools and whether this method was more cost effective than other treatments or coatings.

The eight perishable cutting tools selected for this investigation were ones that were widely used throughout the plant. They were selected using the Coded Traveler Usage report and included four end mills, two drills, one combination drill and countersink, and one tap. These tools were made from high speed steel (HSS), cobalt HSS, carbide, and micrograin carbide.

Test lots were obtained from central stores. Each lot was from the same cutting tool manufacturer. All tools were marked and inspected. Several tools from each test lot were sent to ACTOM Midwest where they were cryogenically treated. The lots of treated tools were re-examined after cryogenic treatment for any damage before being recombined into the original test lots.

Tests were run in production materials (303 Se, 416, and 17-4Ph stainless steel, 6061-T6 aluminum, and beryllium copper. Process and Machining Evaluation Laboratory personnel were unaware of which tools were treated. The tools were run in the above materials on production type machine tools using the appropriate cutting fluid to simulate the production environment at Allied-Signal Inc., Kansas City Division (KCD)*.

Machining parameters were selected from The Machining Data Handbook and held constant throughout the testing of each lot. Wear was measured in accordance with ISO/DIS 86881/2, Tool Life Testing - Part 2: End Milling, on the Ram Optical Measurements, OMIS, measuring microscope. Optical magnifications used for the wear measurement were between 250 and 500 times, depending on the width of the wear scar.

The survey questioned testimonials of users of cryogenically treated tools, four cutting tool manufacturers, and two cutting tool laboratories. Questions to the people supplying testimonials concerned the method of test sample preparation, test methods, and equipment used for the investigation. They were also asked if they made comparison of coating methods to cryogenically treated tools. Questions to the tool manufacturers concerned any previous evaluations of cryogenic

*This report was originally published in 1990. The current corporate name is AlliedSignal Inc., Federal Manufacturing & Technologies.

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treated tools and comparisons to other coating methods. Other cutting tool laboratories were asked if they had evaluated cryogenically treated tools. If they answered affirmatively, they were requested to supply their results.

Testing on this project showed that five of the tools decreased in life after cryogenic treatment. The tools that showed slight improvement in life were made from the less sophisticated tool steels (M-2 and 7). There was a much larger change in life when the tools from two different manufacturers were compared without cryogenic treatment.

The survey revealed that a majority of the people supplying testimonials were not careful in conducting their tests, and the magnitude of their results was doubtful. Others were quite careful and indeed saw an increase in perishable cutting tool life. The best results were obtained with the less sophisticated tool steels. None of these companies have switched over exclusively to cryogenic treatment of perishable cutting tools. In one case, the company is now having the tools treated by the ACTOM process.

The cutting tool manufacturers' responses varied. Cleveland Twist Drill Co. had evaluated cryogenic processing many times over the past 40 years. They contend that, if the tool steels are properly heat treated, cryogenic processing will not affect the life of the cutting tool. Greenfield Industries (Putnam) responded in the same way. Other manufacturers said they do not cryogenically treat tools. All manufacturers contacted said they do not know of others that treat perishable cutting tools cryogenically.

McDonnell-Douglas cutting tool lab has tested cryogenic treatment four times in the last 15 years and reported no significant gain in cutting tool life. General Dynamics lab reported the use of one cutting tool that is cryogenically treated. They cannot explain the success of this tool. They will evaluate cryogenically treated tools only in difficult situations when other methods have proved unsuccessful.

The following conclusions were drawn from this study.

- Cryogenic treatment may increase tool life if the cutting tool is improperly heat treated during its origination.

- Cryogenic treatment was only effective on those tools made from less sophisticated high speed tool steels.
- Titanium nitride coatings are more effective than cryogenic treatment in increasing the life of perishable cutting tools made from all cutting tool materials.
- As a part of a recent detailed investigation, four cutting tool manufacturers and two cutting tool laboratories were queried and none could supply any data to substantiate cryogenic treatment of perishable cutting tools.

DISCUSSION

SCOPE AND PURPOSE

The object of this study was to determine if cryogenic treatment improved the life of perishable cutting tools and whether this treatment was more cost effective than other treatments or coatings. Tests would be performed on controlled perishable cutting tools selected as test specimens. Tests will be run on production materials and production machine tools, together with cutting fluids, to simulate the KCD production environment.

PRIOR WORK

Cryogenic treatment of perishable cutting tools was first attempted before World War II as a method to increase their life. In some cases improvement in the life of the perishable cutting tool was noted. Metallurgists cannot explain exactly what happens during this treatment. They do say the treatment will cause any retained austenite, a soft structure, in high speed steel and cobalt high speed steel to transform into martensite (bainite, etc.), a hard structure. Another advertised advantage of cryogenic treatment is that it will refine the grain structure of all perishable cutting tool materials. The grain refinement has led to the claim that cryogenic treatment will increase the life of carbide cutting tools.

Early methods of treatment include dipping the tools in liquid nitrogen (LN_2). Dipping was bad for the tools. The thermal shock caused by the contact of the liquid nitrogen with the cutting tool damaged the cutting edges. Recently, a number of cryogenic researchers have developed processes that slowly cool the tools in a gas atmosphere, almost to LN_2 temperature (-320°F). They state that the advantage of their process is that the cutting tool is never contacted by the liquid nitrogen. Both cooling and warming cycles of commercially available processors vary from the extremes of 6 hours to 20 hours. Soak times at -310°F are as short as 48 hours to as long as 168 hours.

These treatment suppliers, some of which are also manufacturers of treating equipment, have included numerous testimonials as to the effectiveness of their process. Included are claims of

increased life of perishable cutting tools. What is interesting is that the treaters included articles that warn that metallurgists cannot explain why this process works. The results are not always consistent in increasing the perishable cutting tool life.

Members of the Cutting Tool Engineering group have previously tried cryogenically treated cutting tools on an informal basis. In both investigations, the cryogenically treated tools have not demonstrated any improvement in cutting tool life. These tests were comparisons of treated and untreated cutting tools run in production areas. Cutting Tool Engineering felt that a formal program should include the following considerations:

- Stringent sample preparation,
- A documented sampling plan that would prevent any bias, and
- Evaluation of cutting tool wear after a set amount of use.

ACTIVITY

Testing

To determine the effect of a treatment to a cutting tool on its life, one has to be very careful that the treatment is the only variable tested. This can only be done when identical tools (except for the treatment) are tested. Great care must be taken not to bias the testing. One engineer took responsibility for amassing the test lots of tools, marking, and data reduction; another engineer was responsible for the testing in the Process and Machining Evaluation Laboratory (PMEL). None of the PMEL personnel had any knowledge of the sample preparation that was done before the test tools were shipped to the PMEL. The project team was confident that no one involved in testing the cutting tools would know which cutting tools were cryogenically treated.

If cryotreating were to prove successful, one wanted to be in a position to implement this improvement as soon as possible. Therefore the following criteria were used for the cutting tool selection:

- Tools that were used on a large number of parts;

- Tools that were known, in certain instances, to have below average lives in the KCD production environment; and
- A variety of different cutting tool types made from different cutting tool materials (high speed steels [HSS], cobalt HSS, and carbide).

The Coded Traveler Usage Cross Reference report was used extensively in making the selection of the cutting tools to be tested.

The following cutting tools were selected for this test:

0.0625 in., two-flute, carbide, end mill

0.156 in., four-flute, M-42, titanium nitride (TiN) coated, end mill

0.105 in., four-flute, micrograin carbide, TiN coated, end mill

0.500, in., four-flute, T-15 CPM, TiN coated, end mill

Number 3 drill and countersink, HSS

(0.290 in.), 135° point, cobalt HSS, drill

Number 29 (0.136 in.), 118° point, HSS, drill

6-32 UNC, three-flute bottom tap, HSS, tap

Test lots of cutting tools were pulled from stores. A test lot was at least 10 tools from the same cutting tool manufacturer. Where lot identification could be made, all tools selected were from the same manufacturer's lot. The tools then were closely examined for any chips or flakes. Only tools without any damage were selected for the test. Sample tools were given serial numbers and marked accordingly. Test lots were broken up into half-lots. A blind draw was made to determine which tools were in each half-lot.

To further clarify the results of this testing, one lot of end mills was selected from two manufacturers. In this way, it could be determined if the effects of cryogenic treatment had

more impact than simply getting the same cutting tool made by a different manufacturer.

One of the half-lots for each tool lot tested was sent out for cryotreatment. Tools were sent to ACTOM (Advanced Cryogenic Treatment of Materials) Midwest, whose plant is located in Kansas City, KS. ACTOM was selected because it is a local vendor. If this project proved successful, it would be more cost effective and consume less shipping time to deal with a local supplier.

ACTOM Midwest processed the sample tools as follows:

1. Loaded treatment chamber was partially evacuated to remove moisture.
2. Chamber was cooled at a rate of 1°F every 3 minutes or 20°F/h to a temperature of -310 to -319°F.
3. The chamber was held at -310 to -319°F for 168 hours (7 days).
4. Chamber was warmed at 20°F/h to room temperature.
5. Chamber was heated to 300°F at 2°F/min.
6. Chamber was held at 300°F for 1 hour.
7. Tools were air cooled to room temperature.

Similar treatment is available from Applied Cryogenics of Newton, MA. Applied Cryogenics cools the tools to -300°F at 0.8°F/min, or 46°F/h, and holds at that temperature for 10 to 20 hours. Warming back to room temperature is at 0.2°F/min or 12.3°F/h. Applied Cryogenics also evacuates their chamber before starting the process and has a 300°F bake after cryogenic treatment. Applied Cryogenics also manufactures a line of cryogenic treating equipment.

The tool serial numbers in each half-lot were recorded and sealed in an envelope. The tools were again checked for damage when returned after cryogenic treatment. The half-lots were recombined into the test lots that were sent to the PMEL for testing. Only one engineer knew which tools were cryogenically treated until all the testing was completed.

The cutting tools were tested in the materials that were prevalent on the production travelers. Blocks of materials were used so that the workpiece setups were as rigid as possible. In this way, workpiece deflection and geometry would not affect the results of the testing. Cutting fluid selection was based on the prevalent cutting fluid of the machining department where the production parts would be machined. Machining parameters were based on recommendations found in the Machining Data Handbook.¹ Workpiece materials, cutting fluids, and machining parameters used are listed on the individual data sheets for each cutting tool.

Wear measurements were made using a Ram Optical Measurements (OMIS) measuring microscope system with digital display. Measurements were made in compliance with a published test specification on end milling.² This test specification defines

- Three types of flank wear,
- Three types of chipping damage,
- One type of flaking damage,
- Three types of cracking,
- One type of catastrophic failure, and
- The method for measuring the wear land.

The type of wear identification and measuring method was adapted for the measurement of the wear lands on the lips of the drills, countersinks, and taps.

Wear measurements were taken for each flute at the same distance from the axial face or the corner (junction of side and end cutting faces of an end mill) and the chisel edge of a drill and countersink. The wear land was magnified from 250 to 500 times so an accurate measurement could be made.

The data sheets are very specific as to the location of the point of measurement for all tools in that lot. The measurements for all flutes on a specific tool were averaged together to obtain the average wear for that particular sample tool. After the envelope was opened and the identification of the cryogenically treated tools was made, test data on all the tools that were treated and untreated were averaged together to determine the wear for that tool category.

In all cases, the cutting tools within each test lot were tested using the same tools holder. In this way, the effect of the tool holder on the test results was minimized.

The data sheets on the individual tools are included in Appendix A of this report.

Survey

A cost savings suggestion was resubmitted on cryogenically treating all KCD perishable cutting tools to increase their life. The submitter had seen a technology update on the Cable News Network (CNN) sponsored by AT&T.

The contention of the submitter of the cost savings was that if AT&T was using this method to increase their tool life, KCD should be taking advantage of this same technology.

AT&T was only an advertiser and did not condone or support the finding of the program. Currently, they are not using cryogenically treated perishable cutting tools. In addition to contacting all of the people supplying testimonials, this writer also consulted with cutting tool manufacturers and other cutting tool laboratories. The questions asked of these individuals included the following.

- Were sample treated and untreated tools from the same manufacturer?
- Were the machining parameters held constant for the testing on the treated and untreated tools?
- Was the workpiece material used in the test from the same lot of material?
- Do you use titanium nitride (TiN) coated tools?
- Have you compared the improvement in life of cryogenically treated tools to the life gained with TiN coated tools?
- Do you continue to use cryogenic treatment of your perishable cutting tools?

- Have you expanded the use of cryogenically treated tools in your facility?
- Does your plant have a Cutting Tool Engineering Group and/or laboratory for tool testing?

The following questions were asked of other cutting tool laboratories at McDonnell-Douglas and General Dynamics.

- Have you evaluated cryogenically treated tools? If so, what were your results?
- Do you currently use any cryogenically treated perishable cutting tools?
- Have you ever compared tool life improvement of TiN coated tools to cryogenically treated tools?

Finally, cutting tool manufacturers were contacted. This industry is quite competitive. If one manufacturer could achieve an advantage over another, it would implement the technology. An example of this phenomenon is the availability of TiN coated cutting tools off the shelf from cutting tool manufacturers. Even Sears sells a line of TiN coated drills. A great number of cutting tool manufacturers have installed TiN coating equipment in their factories. A physical vapor deposition (PVD) chamber and associated cleaning equipment start at over \$200,000 each. If an advantage could be obtained with cryogenically treated tools at a cost for the treating facilities of less than \$25,000, surely some manufacturer would have installed the equipment. At this time, there are no cutting tool manufacturers claiming they are cryogenically treating their cutting tools.

The questions asked of the perishable cutting tool manufacturers were as follows.

- Have you every evaluated cryogenically treated cutting tools?
- If so, what were your results?
- Do you currently cryogenically treat any cutting tools?

Testing Results

Table 1 summarizes the results of the testing. Five of the seven perishable cutting tools tested show a decrease in tool life after being cryogenically treated. Both tools that showed an increase in their life were made from a high speed steel (probably an M-2 or M-7 tool steel). One of the tools was made by a foreign manufacturer known within KCD for making acceptable, but not high performance, cutting tools.

What the table also shows is that more of a change in tool life can be realized by changing perishable cutting tool manufacturers than by cryogenic treatment. Special design (Tc) perishable cutting tools are more closely controlled than standard tools. In this case, the cutting tools supplied by the two manufacturers were very different. One end mill was only to be used for profiling. There was no requirement for the axial face of the cutting tool to have cutting edges. The Regal-Beloit tools did not have axial cutting edges, while the Putnam did. Chipping of the corner was not a problem with this tool during the test, and this did not have an effect on the test.

In the case of the last tool, a number of the taps broke trying to tap 303 stainless steel. The material was changed to 6061-T6 aluminum. It was later found that all the tools broken in the stainless steel were from the untreated half-lot. Only two untreated samples were left for the test. The reliability of the improvement percentage is doubtful.

Survey Results

The customers contacted were the ones supplying testimonials
Seven of the 12
customers said the cutting tools used to make the comparisons were not from the same lot of tools. One customer was not sure. The same number verified that the tools were not inspected in-house. One user switched firms from one that cryogenically treated his cutting tools to one that uses the ACTOM process. He stated that the ACTOM longer cycle gives better and more consistent results.

A number of testimonials were from firms making punches and dies used with nonmetallic materials. Others treated knives used in paper processing equipment. These applications of cryogenic treatment are not being evaluated at this time and the results were not included.

Table 1. Test Data Summary

Cutting Tool Description	Tool Material	Workpiece Material	Untreated		Cryogenic Treatment		
			Average Width Wear Land (in.)	Standard Deviation	Average Width Wear Land (in.)	Standard Deviation	Increased Life With Cryogenic Treatment (percent)
Combo Drill Countersink # 3	HSS	Beryllium-Cu	0.00299	0.00022	0.00316	0.00015	5.40
			0.00419	0.00112	0.00477	0.00098	13.80
Drill Size L	Cobalt HSS	17-4Ph H1150M	0.00343	0.00195	0.00393	0.00171	-14.50
Drill Size #29	Cobalt HSS	6061-T6 Alum	0.00127	0.00002	0.00163	0.00077	-28.30
End Mill 0.0625	Carbide	416 Stainless	0.00129	0.00022	0.00134	0.00023	-3.90
End Mill, 0.156 dia., TiN Coated	Carbide	17-4Ph H1150M	0.00175	0.00014	0.00194	0.00014	-10.80
End Mill, 0.500 Dia.	T15 CPM	17-4Ph H1150M	0.00467	0.00112	0.00472	0.00084	-1.10
6-32 UNC Tap	HSS	6061-T6 Alum	0.00212		0.00143	0.00051	32.50
End Mill, 0.105 Dia., TiN Coated	Micro Grain Carbide	17-4Ph H1150M	0.00149*	0.00016*	0.00179**	0.00016**	-20.10

Manufacturers: *Putnam; **Regal-Beloit

The survey found that none of the firms have exclusively switched over to cryogenically treated perishable cutting tools. All stated that if faced with a difficult problem they would try a test group of tools before switching over to cryogenically treated tools.

Unlike a number of the manufacturers supplying testimonials, all KCD perishable cutting tool lots are sample inspected before being placed in stores. The test tools for this study were again inspected for chipping and flaking before testing. Chipping and flaking can lead to reduced cutting tool life. A number of the manufacturers questioned do not inspect incoming tools. To further mask the test results without prior inspection of the cutting tools can lead to false conclusions.

The writer does not doubt that some of the people surveyed saw an increase in life and that the increase seen by these people might be real; however, until a very controlled experiment is run, the magnitude of the improvement cannot be judged.

The cutting tool manufacturers were very helpful. Cleveland Twist Drill has had the most experience with cryogenically treated tools. They have evaluated them many times under controlled circumstances. They have never found an advantage in cryogenically treating their tools. Cleveland has a very closely controlled heat treatment facility. They control austenitizing temperatures, quenches, and tempering processes. The more complex tool steels require double and triple tempering, depending on the material. If heat treating and tempering are properly controlled, the amount of retained austenite is minimal (less than 1 percent). Cleveland currently produces one drill for one customer that is cryogenically treated. Cleveland stated that their tests show no improvement in tool life with cryogenic treatment. Others contacted either had no success or have not evaluated cryogenic treatment.

The easiest place to save costs in the competitive cutting tool industry is in the heat treating process. Either the process controls are not exercised, testing for proper heat treatment is deleted, and/or one of the tempering processes is deleted. If this is done, there will be retained austenite, and cryogenic treatment may be advantageous. If one is buying cutting tools from a manufacturer who is trying to skimp on his heat treating processes, will that manufacturer try to maintain exact cutting tool geometries? Will that manufacturer dress the grinding

wheels at set intervals to maintain consistency or wait until discrepant tools are produced?

The last six years have been very trying for the Cutting Tool Engineering group. Inspection of perishable cutting tools was initiated. Manufacturers have been called in and presented their inspection records with defect listings. The number of perishable cutting tool manufacturers that supply tools to this plant has been reduced. Today, only reliable, higher quality manufacturers are supplying tools. This project team believes that the manufacturers currently supplying tools to KCD are not the kind that are shortchanging their heat treatment processes.

McDonnell-Douglas and General Dynamic cutting tool laboratories were also surveyed. McDonnell-Douglas has tested cryogenically treated cutting tools four times in the last 15 years without finding any increase in cutting tool life. General Dynamics has tested and currently uses one cryogenically treated drill. They cannot offer any explanation why the process works. They tried it as a last resort and it proved successful. They will use it again in the future, when faced with similar circumstances.

All the customers, manufacturers, and laboratories were quizzed about comparison of cryogenic treatment to TiN coatings of perishable cutting tools. The biggest difference stated was the availability of TiN coated tools. Today, almost all cutting tool manufacturers have a line of TiN coated tools available off the shelf. Some stated that even though they do not get as good a result, especially after the tool has been reground, they are using the TiN coated tools. They are not required to purchase and ship the tools out to be treated. The larger companies state that their internal costs are high enough to make the TiN coated tools more cost effective than the cryogenically treated tools and procurement times are shorter.

Finally, Cleveland Twist Drill Co. sent KCD Cutting Tool Engineering a copy of an article³ which was a summary of Tool Steel Producers Committee of the American Iron and Steel Institute policy of processing tool steels in subzero temperatures. It states:

"The temperature chosen to transform any retained austenite depends on the type of steel; transformation is a phenomenon that occurs during cooling and it doesn't depend on reaching -320°F, specifically.

"Properly heat treated tool steels ordinarily do not require refrigeration because they normally will contain little if any unstable retained austenite.

"Thus, the benefit of refrigeration to the group enters in when the steel is improperly heat treated, that is, heated too high in austenitizing and/or improperly quenched and ineffectively tempered.

"Even when highly alloyed tool steels such as Type D2 contain considerable amounts of retained austenite after quenching, multiple tempering at the appropriate tempering temperatures will normally transform most, if not all, of the unstable retained austenite."

ACCOMPLISHMENTS

Test conducted under this project showed that in two of seven cases, cryogenic treatment showed slight improvement in perishable cutting tool life. These were the tools made from the less sophisticated high speed steels.

These tests also showed that switching manufacturer of a cutting tool can lead to bigger changes in tool life than cryogenic treatment.

The project survey showed that firms using cryogenically treated tools use the process only when faced with difficult problems that could not be solved any other way. They test first before implementing the changeover.

The costs for cryogenically treated cutting tools will be higher than buying a TiN coated perishable cutting tool directly from the manufacturer. The procurement costs must include the in-plant handling costs and processing costs for the cryogenic treatment.

Future work on cryogenic treatment of perishable cutting tools is not recommended until a professionally run study, with documented test results on materials used at this facility, can be presented.

REFERENCES

¹Machining Data Handbook, 3rd Edition, Machining Data Center.

²ISO/DIS 86881/2 Tool Life Testing - Part 2: End Milling.

³Heat Treating, October 1979, p 49.

Appendix

TEST RESULTS

LTR 213733

Cryogenically Treated Tools

Tool: Tap 6-32UNC, 3 Flute, Bottoming

Speed: 955 rpm, 35 sfm

Feed: 30 in./min, 0.031 in./rev

Material: Samples 1 and 2 run in 303 Se Stainless Steel
Remainder of the samples were run in 6061-T6 Aluminum

Cut. Fl.: 50% 97022340 Vantrol 5487G
50% 97021270 Stuart's Threadcut 99

Test stopped after tapping 39 holes 6.5 to 7.0 threads deep or breakage.

Specimen Number	-----Wear-----			Average Wear (in.)	Treated Tools	
	Flute 1 (in.)	Flute 2 (in.)	Flute 3 (in.)			
1	*	*	*			*303 Se SS
2	*	*	*			*303 Se SS
3	0.00125	0.00100	0.00055	0.00093	X	
4	0.00175	0.00080	0.00080	0.00112	X	
5	**	**	**		X	**Broke on third hole
6	0.00425	0.00080	0.00115	0.00207		Tooth very narrow
7	0.00275	0.00260	0.00090	0.00208	X	
8	***	***	***			***Broke on 22 hole
9	0.00195	0.00155	0.00125	0.00475	X	
10	0.00345	0.00225	0.00080	0.00217		Tooth very narrow
Untreated Average Wear:			0.00212			
Standard Deviation:			-----			
Treated Average Wear:			0.00143			
Standard Deviation:			0.00051			

Wear measurements were taken on first crest at nose of tap. Wear measurements vary because width of crest varies at the beginning of tap camfer. Tapmatic tapping head used with Cortland Mill. Wear measurements taken on the ROI Microscope at 500 magnification.

March 1988

LTR 213733

Cryogenically Treated Tools

Tool: #29 (0.1360) Drill

Speed: 3500 rpm, 124 sfm

Feed: 10.5 in/min, 0.003 in./rev.

Material: 6061-T6 Aluminum

Cut. Fl.: Jon Cool 800 (20:1 Mixture)

Tool No.	---Wear (in.)---		Average Wear (in.)	Treated Tools
1	0.00120	0.00150	0.00135	
2	0.00200	0.00090	0.00145	X
3	0.00110	0.00080	0.00095	
4	0.00140	0.00120	0.00130	X
5	0.00140	0.00140	0.00140	
6	0.00300	0.00250	0.00275	X
7	0.00110	0.00180	0.00145	
8	0.00140	0.00100	0.00120	
9	*	*	*	X
10	0.00100	0.00100	0.00100	X
Untreated Average Wear:			0.00127	
Standard Deviation:			0.00020	
Treated Average Wear:			0.00163	
Standard Deviation:			0.00077	

Wear measurements were made after each drill drilled 392 holes three diameters deep. Measurement taken on lip 0.030 in. from chisel point.

*Incorrect material, drill broke

January 1988

LTR 213733
 Cryogenically Treated Tools
 Tool: "L" Cobalt HS Drill

Speed: 711 rpm, 54 sfm
 Feed: 2.8 in./min, 0.0039 in./rev
 Material: 17-4 PH Stainless Steel
 Condition: H1150 Mod
 Cut. Fl.: 50% 97022340 Vantrol 5487G
 50% 97021270 Stuart's Threadcut 99

Tool No.	---Wear (in.)---		Average Wear (in.)	Flutes Rusted	BUE Observed	Tools Treated
1	0.00290	0.00650	0.00470	X	X	X
2	0.00220	0.00250	0.00235			
3	0.00140	0.00250	0.00195	X		X
4	*	*	*	X		
5	0.01000	0.00170	0.00585		X	
6	0.00210	0.00220	0.00215			X
7	0.01000	0.00170	0.00585		X	X
8	0.00290	0.00350	0.00320	X	X	
9	0.00260	0.00780	0.00520	X	X	
10	0.00190	0.00130	0.00160	X		

Untreated Average Wear: 0.00343
 Standard Deviations: 0.00195
 Treated Average Wear: 0.00393
 Standard Deviation: 0.00171

Wear measurements were made after each drill drilled 50 holes three diameters deep. Measurement taken on lip 0.060 in. from chisel point.

* Drill broken during test due to operator error.

November 1987

LTR 213733

Cryogenically Treated Tools

Tool: Carbide End Mill (0.500 in. dia., 4 flute, TiN coated)

Speed: 2025 rpm 265 sfm Runs 1 and 2

Feed: 16.2 in./min, 0.008 in./rev

Speed: 764 rpm, 100 sfm, Runs 3 to 10

Feed: 3.1 in./min, 0.004 in./rev

Material: 17-4 Ph Stainless Steel

Condition: H1150 Mod.

Cut. Fl.: Jon Cool 800 (20:1 Mixture)

Tool No.	----- Wear -----				Average Wear (in.)	Treated Tool
	Flute 1 (in.)	Flute 2 (in.)	Flute 3 (in.)	Flute 4 (in.)		
1	*	*	*	*	*	X
2	*	*	*	*	*	
3	0.00575	0.00515	0.00480	0.00515	0.00521	X
4	0.00605	0.00515	0.00370	0.00565	0.00514	
5	0.00570	0.00520	0.00590	0.00490	0.00543	
6	0.00465	0.00670	0.00635	0.00530	0.00575	
7	0.00285	0.00295	0.00360	0.00300	0.00310	
8	0.00370	0.00385	0.00370	0.00375	0.00375	X
9	0.00405	0.00400	0.00455	0.00310	0.00393	
10	0.00530	0.00470	0.00510	0.00570	0.00520	X
Untreated Average Wear:					0.00467	
Standard Deviation:					0.00112	
Treated Average Wear:					0.00472	
Standard Deviation:					0.00084	

End mill removed 90.0 linear inches of material while making an axial and radial depth of cut of 0.125 inch. Wear measurements comply with ISO 8688/2. Uniform flank wear was found.

* End mills were made from T-15 Tool Steel. Store description of tool material is C-2 carbide. Initial speeds and feeds for specimens 1 and 2, 2 were for end mills made from carbide. End mills run at this speed broke. Speeds and feeds were adjusted downward so the high speed steel tool would live through the test. Remaining eight specimens were run at these lower machining parameters.

March 1988

LTR 213733

Cryogenically Treated Tools

Tool: Carbide End Mill (0.156 in. dia., 4 flute, TiN coated)

Speed: 1930 rpm, 80 sfm

Feed: 4.83 in./min, 0.0025 in./rev

Material: 17-4 Ph Stainless Steel

Condition: H1150 Mod.

Cut. Fl.: Jon Cool 800 (20:1 Mixture)

Tool No.	----- Wear -----				Average Wear (in.)	Treated Tools
	Flute 1 (in.)	Flute 2 (in.)	Flute 3 (in.)	Flute 4 (in.)		
1	0.00200	0.00170	0.00220	0.00200	0.00198	X
2	0.00140	0.00170	0.00180	0.00140	0.00158	
3	0.00170	0.00230	0.00170	0.00160	0.00183	
4	0.00150	0.00150	0.00250	0.00160	0.00178	X
5	0.00210	0.00220	0.00160	0.00140	0.00183	
6	0.00230	0.00190	0.00220	0.00180	0.00205	X

Untreated Average Wear: 0.00175

Standard Deviation: 0.00014

Treated Average Wear: 0.00194

Standard Deviation: 0.00014

End mill removed 93.8 linear inches of material while making an axial and radial depth of cut of 0.0390 inch. Wear measurements comply with ISO 8688/2. Uniform flank wear was found.

March 1988

LTR 213733

Cryogenically Treated Tools

Tool: Carbide End Mill (0.105 in. dia., 4 flute, TiN coated)

Speed: 3500 rpm, 96 sfm
Feed: 5.25 in./min, 0.0015 in./rev
Material: 17-4 Ph Stainless Steel
Condition: H1150 Mod.
Cut. Fl.: Jon Cool 800 (20:1 Mixture)

Tool No.	Wear				Average Wear (in.)	Treated Tools
	Flute 1 (in.)	Flute 2 (in.)	Flute 3 (in.)	Flute 4 (in.)		
1	0.00200	0.00100	0.00180	0.00260	0.00185	X
2	0.00100	0.00190	0.00140	0.00170	0.00150	
3	0.00140	0.00280	0.00210	0.00290	0.00230	X
4	0.00100	0.00100	0.00180	0.00280	0.00165	
5	0.00100	0.00160	0.00150	0.00120	0.00133	
6	0.00150	0.00100	0.00090	0.00150	0.00123	X

Untreated Average Wear: 0.00149
Standard Deviation: 0.00016
Treated Average Wear: 0.00179
Standard Deviation: 0.00054

Man'f Putnam: Average Wear: 0.00149
Standard Deviation: 0.00016
Man'f R-B: Average Wear: 0.00179
Standard Deviation: 0.00016

End mill removed 90 linear inches of material while making an axial and radial depth of 0.0262 inch. Wear measurements comply with ISO 8688/2. Uniform flank wear was found.

Note: Tools number 1, 3 and 6 had a rust colored material on the flutes, had a cupped end and was manufactured by Regal-Beloit Corp.

Tools number 2, 4 and 5 were 4 flute 2 flute cutting to center and were manufactured by Putnam (now Greenfield Industries Inc.).

All tools were marked with the same tool and issue numbers.

February 1988

LTR 213733

Cryogenically Treated Tools

Tool: Carbide End Mill (0.0625 dia., 2 flute)

Speed: 3500 rpm, 147 sfm

Feed: 1.75 in./min, 0.0005 in./rev

Material: 416 Stainless Steel

Hardness: 90 Rb

Cut. Fl.: Jon Cool 800 (20:1 Mixture)

Tool No.	---Wear (in.)---		Average Wear (in.)	Chipped Corner Height (in.)		Average Chip Height (in.)	Treated Tools
				Corner 1	Corner 2		
1	0.00110	0.00090	0.00100				
2	0.00140	0.00150	0.00145				X
3	0.00150	0.00160	0.00155	0.00270	0.00350	0.00310	X
4	0.00140	0.00170	0.00155	0.00800			
5	0.00110	0.00080	0.00095				X
6	0.00130	0.00110	0.00120	0.00220			
7	0.00140	0.00110	0.00125	0.00750			
8	0.00150	0.00130	0.00140				X
9	0.00130	0.00140	0.00135	0.00850			X
10	0.00130	0.00160	0.00145	0.00700	0.01000	0.00850	
Untreated Average Wear:			0.00129				
Standard Deviation:			0.00022				
Treated Average Wear:			0.00134				
Standard Deviation:			0.00023				

End mill removed 97.5 linear inches of material while making an axial and radial depth of cut of 0.0156 inch. Wear measurements comply with ISO 8688/2. Uniform flank was found. In cases of localized chipping the length of the chip along margin above corner is noted.

February 1988