AC 2007-437: EVALUATION OF THE COMPARATIVE PERFORMANCE OF CRYOGENICALLY TREATED CUTTING INSERTS AS A CAPSTONE DESIGN PROJECT

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Evaluation of the comparative performance of cryogenically treated cutting inserts as a capstone design project

Abstract

Cutting inserts are an integral part of machining operations. In the continual search for cost effectiveness in manufacturing we turn our focus to an attempt to reduce tooling cost by improving the life of cutting inserts. There has been continued research conducted to increase cutter tool life with various applications of cutting fluids, speed and feed rates, and the use of coated cutters. One newer approach, cryogenic processing, has been promoted as an effective method of extending the useful life of different cutting tools used in the manufacturing process. This research area provides an excellent opportunity to apply real life research into capstone design projects. The purpose of the project was to investigate the feasibility of the claim in conjunction with the industry partner, providing students an opportunity to do research in a relevant manufacturing topic in an industrial setting.

There are different applications of cryogenic processing, but all of them subject a substance to extremely cold temperatures for a certain length of time. The purpose of this freezing process is to refine the molecular structure of the material, creating a stronger, more durable product. The objective with this process is to minimize the amount of retained austenite in the structure, which tends to be brittle and can cause dimensional instability and loss of strength. There are many benefits touted to the cryogenic processing of metals, however, there is not a lot of application data available. Further, many manufacturing facilities have been reluctant to adopt this process without verification of appropriate research being conducted.

This paper deals with an experimental evaluation of the comparative performance of cryogenic treatment on TICN coated carbide inserts. Experiments have been conducted machining cast iron parts with non-treated inserts and inserts cryogenically treated by gas-infusion process. A group of non-treated and treated inserts were subjected to same machining conditions. The part selected for the experiment was a gray iron clutch drum machined in a 4-axis lathe with other operating parameters held constant. This work will present the results obtained from experimentation related to significant difference in tool life and predictability of the cutting inserts.

Introduction

The senior design project is a capstone course taken in the final year of the Manufacturing Technology program at the University of Northern Iowa (UNI). The purposes of a two semester research course, as highly suggested by both ABET and NAIT accrediting bodies is to provide an opportunity for students to work on a team to perform research and develop a project with an industrial sponsor.

Engineering technology and industrial technology programs must offer a relevant and validated curriculum that prepares students for post-graduation success. Courses that cover traditional subject matter in mathematics, sciences, materials, engineering economics, and related topics, provide the foundation of knowledge upon which specific skill sets are added depending on emphasis. However, it is critical for engineering/industrial technology to transition from theoretical work in the classroom to experiential learning. The main objective of senior projects or design courses in engineering technology curricula is to bridge the gap between academic theory and real world practice. The proposed senior projects should include elements of both credible analysis and experiential proofing such as design and implementation as discussed in ABET criteria [1]. Further, the senior design seminar can serve as an excellent culminating experience in the program of study when it focuses on research and design projects that have practical value to consumers or to industrial partners.

For the manufacturing technology majors at UNI, the senior design course is a year-long endeavor. During the first semester, the students focus on the conception phase of the project consisting of problem identification, product development and testing, cost analysis, process planning, and securing an industrial sponsor. The second semester includes the implementation phase of the design project focusing on research, testing, fabrication, documentation, and culminating with a classroom presentation. The presentation component brings students, faculty, and industrial sponsors together to evaluate the student teams' results by providing them additional experience of public presentation of their work. This course is an excellent capstone experience, which requires both teamwork and individual skills in solving industrial problems [2-4].

One of the senior design projects last academic year was to perform a preliminary investigation using cryogenically treated inserts to determine if the treatment prolongs tool life. The project, conducted at John Deere Waterloo Works, consisted of turning 28 pound nodular iron castings in a Motch twin spindle CNC vertical lathe. The inserts used during the tests for both treated and non-treated were Kennametal Grade KC 990. The inserts were cryogenically treated by Cryogenic Engineering, which is located in Iowa.

The design team decided to measure tool performance in two ways. The first procedure consisted of turning twelve (12) parts and then indexing the insert to machine on all four sides of the insert. This is the procedure currently followed by the industrial sponsor. If more than 12 castings are machined without indexing the insert, the part features will not conform to part specifications. A 134 mm inside diameter (ID) and a 280 mm outside diameter (OD) part feature was measured using a 12" Mitutoyo digital caliper, and then compared to part specifications for each machined casting. This procedure was followed for both treated and non-treated inserts. The parts were machined without the operator knowing which insert was being used. The second evaluation consisted of using an insert without indexing it to turn as many castings as possible before either the insert broke or the part features (ID and OD) were no longer within print specifications. This procedure was followed for both treated and non-treated inserts. To minimize variation, the machining parameters were consistent including using one operator, turning the castings on the same lathe, and using the same part number. The initial results, as determined by the design team, indicate an increase of three additional turned castings per insert corner which is equivalent to 12 additional castings per insert. Using untreated inserts 12 castings could be machined without indexing the insert before the part no longer conformed to part specifications. When the treated insert were tested, 15 castings could be machined before the part no longer conformed to part specifications. This increase in machined castings resulted in a 25% improvement in tool life. As the results found by the capstone project look promising, additional research would need to be conducted to further study the effectiveness of cryogenically treated inserts. The material reported in this paper is an extension of the research from the capstone design project.

Cryogenics

In the continual search for cost effectiveness in manufacturing, and in particular machining operations, there is a continuous need to reduce tooling costs to meet budget requirements. Traditional approaches to reduce cost have included developing more resistant tool materials to increase productivity and reduce tool costs [5]. In addition, other machining parameters have been studied in an attempt to improve productivity and lower costs. Several examples in an effort to increase cutter tool life include various applications of cutting fluids, speed and feed rates, and the development of coated cutters.

A more recent approach to address these issues is the application of cryogenic treatment. Over the past few years, there has been an interest in the application of cryogenic treatment of cutting tools [6]. Cryogenics has been promoted as an effective method of extending the useful life of different cutting tools used in machining processes. There are many reports in the literature publicizing significant increases in tool life after being subjected to below 0° C temperatures. Deep cryogenic treatment in the range of -125 to -196° C has been reported to increase tool life 90—400 % [7].

There are many benefits touted to the cryogenic processing of metals, however, there is not a lot of application data available. There are several theories concerning reasons for changes in the metallurgical aspects as a result of cryogenic treatment. The articles found in the literature report increased wear resistance and longer tool life, however, cryogenics is not a panacea and there are articles contradicting these findings [8-9]. Most of the research on cryogenic treatment of cutting tool materials has been conducted on tool steels and HSS [5]. There has not been a lot of research conducted on other cutting tool materials such as the coated carbides.

Cryogenic treatment

Cryogenic processing has been around for approximately 40 years and has been applied to a wide range of materials from golf balls to race car components. There are several different cryogenic processes, which have been used tested by researchers. The first cryogenic process applied temperatures in the range of -78°C to -85 °C to the material and held at the temperature for several hours [10]. This treatment does improve wear resistance as a result of converting some retained austenite to martensite and creating a more uniform and refined structure. The more recent application, known as deep cryogenic processing, subjects a material to a controlled lowering of the temperature to -196 °C and held for approximately twenty four hours. After holding the material for twenty four hours, the material is then slowly raised to +196 °C before slowly returning to room temperature. The benefits obtained by this deep cryogenic process are many. Austenite is significantly decreased through a transformation which increases the martensite in the structure. In addition, carbides are increased as a result of the formation of micro-fine carbide fillers. These changes lead to an increase in durability and enhancing cutting tool life.

In this study, the cutting tools were cryogenically treated at Cryogenic Engineering. The process used at Cryogenic Engineering is a dry process where the materials being treated are not exposed to the liquid nitrogen. This eliminates the risk and damage of thermal shock [11]. A recommended thermal cycle was used for this study, which in general consisted of cooling to a temperature of -196 °C followed by raising the temperature to room temperature. The procedure used for the treatment in this study is outlined in the following steps. Inserts are placed in a container. The computer controlled temperature is reduced to -196 °C in intervals. At each interval, the material is allowed to stabilize in two hour increments. The temperature is held constant for twenty fours before the process is reversed. The material is slowly brought to room temperature allowing the material to stabilize. Then the material is subjected to two heat treatment processes to temper the material. This is accomplished by increasing the temperature to +196 °C and then a slowly reducing the temperature back to room temperature.

Experimental procedure

In this section, we focus on describing the experimental procedure followed to perform the comparison of the treated vs. non-treated coated cutting inserts. In order to close the gap between academic and real work experience, this experiment was conducted in conjunction with an industry partner using a real life application. All treated inserts were treated at Cryogenic Engineering in Cedar Rapids, Iowa, and all machining of parts for testing were done at John Deere Waterloo Works.

Experiments were conducted machining cast iron parts at the onsite location. All parts were machined using a Warner & Swasey 4 axis, 15” lathe, Titan model M-6167 and with a Fanuc control 15TTA. The parts machined during the experiment were used in production.

The following data described all parameters and basic information.

PART & LOCATION INFORMATION	
Department #	310 – John Deere Small Cast Iron Machining
Machine #	3660
Part #	R219746
Part Description	Drum, Clutch
Operation #	0015 (after stress relief & tumblast)
Sequence #	10525
Start Block #	N10

HOLDER INFORMATION	
Description	Holder, Valentine, 1-1/4 x 1-1/4
Nomenclature	MCLNL 20-5D
INSERT INFORMATION	
Description	Insert, Mitsubishi, TICN Coated Carbide
Nomenclature	CNMG543 UC5105

EDP Part #	160612
Quantity	20 Treated/20 Non-Treated

SPEEDS & FEEDS	
Speed	350 ft/min
Feed	0.016 in/rev
Depth of Cut	0.001-0.003 in (depending on casting)

All 4 corners of the inserts were used on exactly 20 pieces of the drum, clutch (R219746), thus giving a tool life of 80 pieces per insert. All machining was conducted during a first shift operation and utilizing the same machining operator to minimize variability. This process was held constant for all inserts tested to provide a valid comparison.

After obtaining all data, the inserts were transferred to the University to obtain a measure of analysis and comparison.

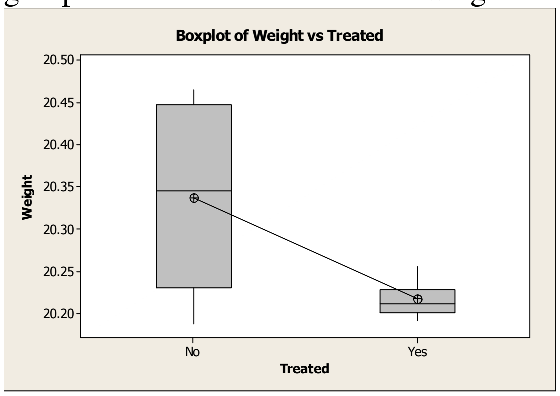
Analysis

The analysis of the cutting inserts was performed in conjunction with the University of Northern Iowa and the University of San Diego. Initially, the inserts were weighed to determine the potential tool life of each part. The weights are used to determine if cryogenically treated and untreated inserts perform differently when exposed to similar experimental conditions. The experimental data for the inserts are shown in Figure 1.

Cryogenically Treated Inserts				**Untreated Inserts**		
Run	**Weight**	**Group**		**Run**	**Weight**	**Group**
1	20.2088	1		1	20.2246	1
2	20.2543	1		2	20.2843	1
3	20.2434	1		3	20.4515	1
4	20.2488	1		4	20.2399	1
5	20.2227	1		5	20.4596	1
6	20.2071	1		6	20.4647	1
7	20.2238	1		7	20.4413	1
8	20.2072	1		8	20.4095	1
9	20.2082	1		9	20.2546	1
10	20.2550	1		10	20.2730	1
1	20.1962	2		1	20.4502	2
2	20.1935	2		2	20.2527	2
3	20.1910	2		3	20.1951	2
4	20.2288	2		4	20.2011	2
5	20.2147	2		5	20.4383	2
6	20.1989	2		6	20.4063	2
7	20.2272	2		7	20.1879	2
8	20.2187	2		8	20.4516	2
9	20.2078	2		9	20.4243	2
10	20.1960	2		10	20.2273	2

Figure 1: Tool Life Data for Inserts

Patterns or trends are difficult to discern when looking at a table, but are easy to discover when utilizing graphing techniques. There are several graphical methods, but we found boxplots to be most revealing. The left boxplot in Figure 2 shows that untreated inserts result in a higher residual weight with significantly more variation. The treated inserts have a lower residual weight, but provide a more repeatable result. The statistical significance of the treated verses untreated inserts will be addressed later. The right boxplot in Figure 2 supports the notion that group has no effect on the insert weight or tool life.



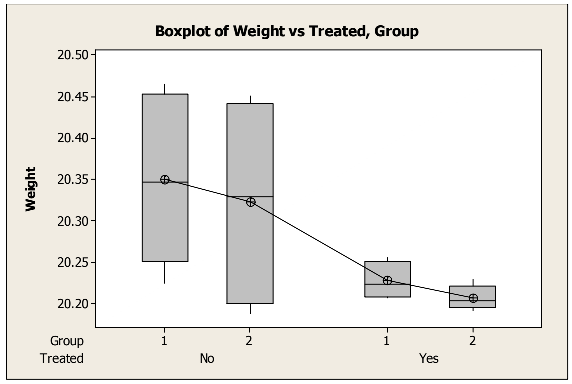


Figure 2: Boxplots of Weight verses Experimental Factors

The ANOVA or Analysis of Variance procedure is used to determine if experimental factors have an effect on a measured response. In our experiment, the hypothesis was whether the experimental factors, treated inserts and group, have a statistical effect on insert weight. Based on the ANOVA table in Figure 3, the factor, Treated, is statistically significant based on an alpha value equal to 0.05. The interaction and group effect prove to be insignificant on explaining the variability on overall insert weight. The conclusions are consistent with our preliminary insights in the boxplots.

Analysis of Variance for Weight					
Source	DF	SS	MS	F	P
Group	1	0.006	0.006	0.890	0.351
Treated	1	0.142	0.142	22.570	0.000
Interaction	1	0.000	0.000	0.020	0.903
Error	36	0.227	0.006		
Total	39	0.375			

Figure 3: ANOVA of Weight Inserts.

Summary and Conclusions

In this paper, the experiment resulted in valuable information. When comparing the treated vs. untreated inserts the analysis shows that untreated inserts actually have a larger average residual weight than the cryogenically treated inserts implying a longer tool life for the inserts, however, actual machining proves differently. Although, the untreated inserts do display some concern with a large amount of variability. This evidence provides an excellent opportunity to continue research in the area and involve the students in future design projects in the topic.

The benefit of this research is invaluable as to the interaction of students with industry in real life application. Student outcomes and project evaluations by other students and industrial members have shown that the project provided an excellent opportunity for student's development. The capstone design team members grew personally and professionally throughout this year-long capstone experience. The students developed presentation and research skills utilizing a variety of research journals, flow charts, and other project management tools. Additionally, the students refined their technical skills and experienced working on a team with an industrial sponsor. The senior design team was required to meet their faculty advisor numerous times throughout the year-long course. The meetings were established for the three-member design team to provide updates on the project status, costs, and tasks on which each member was working. There is no substitute for time on task and learning to use one's time well is critical for students. Students and professionals need help with time management skills and in learning to allocate realistic amounts of time for tasks. The design team learned first hand how some aspects of the project took longer than estimated, but to also finish the project on time. Both a final paper and a presentation were prepared at the conclusion of the course.

It has been said that much learning takes place outside of the classroom, which is why senior design projects are an excellent way to bridge the gap between theory and real-world application. In addition, the students in the design team experienced an educational paradigm shift. The traditional educational paradigm is focused on instruction or teaching. This consists of a transfer of knowledge from faculty to students in a traditional lecture format. In contrast, the student design team experienced a learning paradigm, which encourage proactive learning and elicits student discovery and construction of knowledge. While the theories in the books sometimes lag behind, the interaction with industry keep the students with current issues that they will face in their immediate future upon graduation.

Based on the preliminary findings by the capstone project, additional research will be conducted to measure the impact of cryogenic treatment in cutting tools. Using the inserts from the design capstone project, both the treated and non-treated inserts will be examined using a Mitutoyo toolmaker's microscope to measure the maximum flank wear. This will provide additional information on tool wear analysis and chipping of the tool, which is of importance when using coated carbide cutters. This research will be conducted assisted by students in both academic institutions on parallel to provide a better foundation for comparison, and conclusive results.

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