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Keywords : *drilling, cryogenic treatment, regression analysis, tool wear.*

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Performance Evaluation of Cryogenic Treated HSS Drill

P.V. Gopal Krishna [α], K. Kishore [σ], T. Srihari [ρ] & S. Venkataiah [ω]

Abstract - Tool wear is a worn portion over the flank and face of the tool. Tool wear is significant for determining tool life and hence it influences the machining economics. The wear measurements are carried by using a tool makers' microscope in the present investigations. All the investigations are carried in dry machining. Life enhancement by using cryogenic treatment on HSS drill (T1-type) is the objective of study. Investigations are carried on different work materials such as AA6041, AISI 1040 and EN36. Improvement in tool life up to 140% for AA6041, 90% for AISI 1040, 38% for EN36 is observed. These investigations are aimed at benefiting small industries that use aforementioned tool work combinations. Regressions models are constructed for wear for both untreated machining and cryogenic treated machining.

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I. Introduction

To understand the effects of cryogenic processing, it is essential to get acquainted with the heat treating of metals. The primary reason for heat treating steel is to improve its wear resistance through hardening. Gears, bearings and tooling for example are hardened because they need excellent wear resistance, improved fatigue life, stress relieving dimensional stability and corrosion resistance for extended reliability and performance. The steps in heat-treating are frequently explained in a simplistic manner but it takes significant skill and experience to execute heat treatments successfully. The steel tooling in practice would be immersed in liquid nitrogen for a period of time, allowed to warm up and then placed into service. It was also observed that the cryogenic treatment would convert the retained austenite into un-tempered martensite. The tools would experience a greatly enhanced service life. It was theorized that the increase in wear resistance was a direct result of the reduction in the amount of residual austenite. Liquid nitrogen systems have been the customary method for achieving cryogenic temperatures. Three types of systems have been developed viz heat exchanger systems, direct spray systems, and immersion systems. The last method i.e immersion system is used in present investigation.

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The tool wear can be measured directly by using a microscope. However several indirect methods depending on the measurement of a parameter that influence the tool wear. Some of the methods for indirect prediction are cutting force, vibrations, acoustics, radioactive isotopes, image processing etc. It should be noted that no method is accurate for indirect prediction. Studies by Penn State University researchers in 1996 showed that retained austenite was reduced from near 18% to roughly 8% in T15 tool steel upon cryogenic treatment. Hardness increased by 2 points (HRC) with cryogenic treatment and subsequently decreased (in some cases more than 2 points) after a temper cycle. Still there has not yet been enough investigation to precisely determine optimum processing parameters, even for tool steels. Some researchers suggest that tools should be sharpened after cryogenic treatment rather than before. However for present work cryogenic treatment was carried out after grinding the HSS drill to the standard nomenclature to the required angles. The tools are dipped in liquid nitrogen (-196^0 C) up to 24 hours and they are slowly brought down to room temperature.

The application of cryo-treated tools in metal cutting is a fascinating one and many investigators have shown keen interest in this area. Tool wear studies were carried out by Gill [1] et al on tungsten carbide cutting tools while turning AISI 1040. Wear studies on milling cutter treated by liquid nitrogen were performed by Young [2] et al. The influence of cryogenic treatment on the mechanical properties of tool steels were carried out by Molinari [3] et al. Structural changes in T-I type high speed steels when subjected to cryogenic treatment are reported by Popandopulo [4] et al. The lucid explanation by Carlson [5] about cold treatment of steels in his contribution for ASM hand book was a major inspiration for this work. Most of the modern investigators in the field of metal cutting preferred to use liquid nitrogen as a substitute coolant and they could obtain some improvements in cutting conditions. Yakup [6] et al was one of the investigators who tried to establish improvement of tool life due to a flood of liquid nitrogen. An overview on the performance of tool material after cryogenic treatment was presented as a review paper by Rupinder Singh [7] et al. Machining properties of titanium based alloy by cryogenic treated carbides and HSS tools was carried out by Aujla [8]. Improvement in cutting conditions using various means is a significant

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issue in the area of manufacturing as it cost effective. Gopalkrishna [9] et al reported cryogenic treatment for turning tools wear. Hence present studies attain significance in the context of extending the cryogenic treatment methods to small industries.

II. Experimentation

Although a lot of choices are available for the industry, so far as tool materials are concerned, it is to be noted that most of the presently used multipoint cutting tools are made of HSS. This tool material has high toughness and is capable of taking impact loads. On the other hand still single point cutting tools made of HSS are routinely used in small and medium machine shops, which cannot effort expensive tools made of carbides or ceramics. An attempt is made in the present work to improve the tool life of single point cutting tools made of HSS, by exposing them to liquid nitrogen (-196^{0}C). This cryogenic liquid is commercially available at very low cost, as nitrogen is abendently available in atmos[heric air.

The machining parameters considered during the current investigations to evaluate the tool life are the cutting speed, feed and depth of cut. Experiments are conducted using an L_8 orthogonal array designed by Taguchi and the response is measured. All the experiments are conducted on work pieces 20mm thickness and 20 holes are taken over them before measuring the tool wear. The wear is measured by using a Tool makers' microscope. All the experiments are conducted at random to avoid error and bias, each condition is repeated for confirmation of tool wear. The work materials selected in the present investigations are AA6041, AISI 1040 and EN36. The reason for selecting these materials is that most of the small and medium scale industries fabricate components made of these materials only. The present studies are targeted to benefit only these industries which cannot afford expensive tool materials, machines and necessary equipment for measurement of tool wear, torque and thrust.

The tool material used in the present investigations is T-1type HSS with 5% cobalt. The tools are ground to ASA standard 11^0-12^0–7^0-7^0–15^0–20^0–0.5mm, on a tool and cutter grinder. A set of these tools are subjected to liquid nitrogen treatment for a period of 24hrs and are slowly brought to room temperature.

III. Results and Discussions

Tool wear and tool life are in separable in metal cutting industry. The machining parameters are set based on the final constraints such as quality of surface finish and productivity. The tool life will come to an end due to progressive wear or due to premature failure of the tool. The former is the main reason for most of the tools used in industry. An attempt is made in the present work to improve the tool life by performing cold (cryogenic) treatment. This treatment brings about structural changes in cutting tools made of steel. Figures 1 and 2 respectively show microscope images of the tool before and after cryogenic treatment.

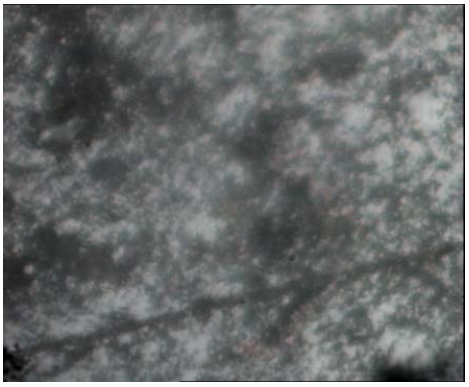

Figure 1 : Image of cutting tool before cryogenic treatment (magnification X600)

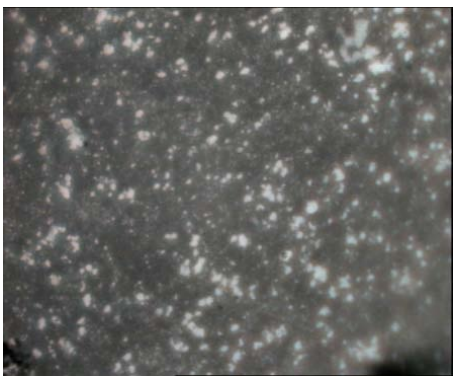

Figure 2 : Image of cutting tool after 24 hours cryogenic treatment (magnification X600)

The levels selected for the machining parameters and experimental matrix used for different work materials are shown in tables 1 to 4. All experiments are carried out for dry condition only.

The influence of tool wear on various machining parameters is analyzed on AA6041, AISI 1040 and EN36 working materials. A few more experiments are conducted to obtain the relation between cutting speed and flank wear for all the work materials.

The flank wear in the tool materials selected for the present study with the speed for untreated and cryo-treated samples are shown in figure 3. It was observed that for the materials like AA6041, AISI 1040 and EN36 cutting speed has significant influence on tool life when compared to feed and depth of cut for both untreated and cryogenic treated HSS drill. It was also found that the interaction of speed, feed and depth of cut is more for untreated tool than cryogenic treated tool. The interaction of speed and feed is more on AA6041 when compared to AISI 1040 and EN36 on both untreated and cryogenic treated tool.

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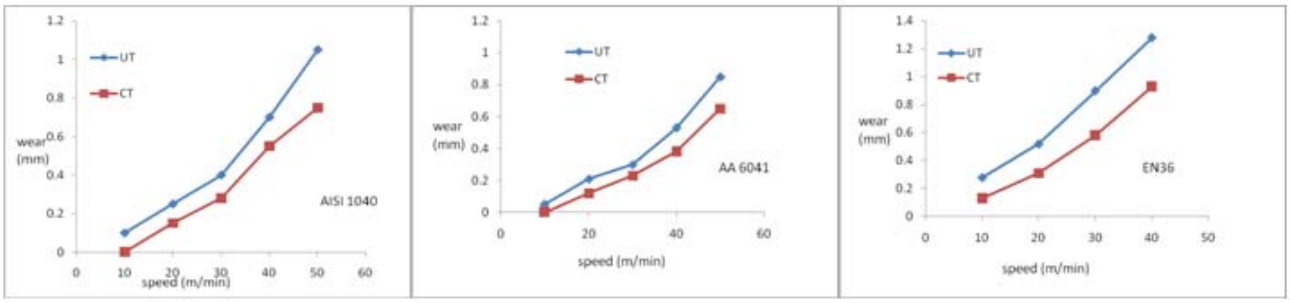

Figure 3 : Variation of flank wear with speed in untreated and cryo-treated tools AA6041, AISI 1040 and EN36

It is evident from figure 3 that the flank wear is less in all the cryo-treated sample tools i.e. AA604, AISI 1040, and EN36 compared to untreated tools at various speeds. So the low wear in the cryo-treated tools can be attributed to micro-hardening of the tools due to immersion in liquid nitrogen. The grain size on surface of the tool might have changed due to the cryogenic treated and hardened the tool.

A negative influence has been observed in the interaction of speed and depth of cut on both the tools. However, the interaction of feed and depth of cut has little influence on both treated and untreated material.

The regression analysis has been conducted on the data and the results are presented in table 5. The parameters in the regression analysis are speed (x_1), feed (x_2) and depth of cut (x_3). From the regression analysis it can be concluded that the life of the tool increases by cryogenic treatment for both soft and hard materials. Hence cryogenic treated tools are found to be most effective at high speeds and feeds.

IV. Conclusions

The cold treatment on HSS drill tools in the present study has shown significant influence on the tool life. The tool life improvement up to 140%, 90% and 38% respectively are observed while machining AA6041, AISI 1040 and EN36 during the experiments. The interaction of speed, feed and depth of cut is more for untreated tool than cryogenic treated tool. This is evident from the regression analysis. The interaction of speed and feed is more on EN36 when compared to AISI 1040 and AA6041 on both untreated and cryogenic treated tool. It can be concluded that the life of the tools has increased due to cryogenic treatment while machining both soft and hard materials. The cryogenic treated tools are found to be most productive at high speeds and feeds. These findings will benefit small and medium machining shops.

V. Acknowledgement

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Table 1 : Selection of process parameters

Level	Cuttingspeed V (m/min) x_1	FeedS (mm/rev) x_2	Depth of cut t (mm) x_3
Level-1	21.35	0.3	5.0
Level-2	11.30	0.1	2.5

Table 2 : Tool Wear for Machining of AISI 1040

S. No.	Cutting speed (V) (m/min) x_1	Feed (S) (mm/rev) x_2	Depth of cut (t) (mm) x_3	Tool wear Without cryogenic treatment (mm)	Tool wear with 24 hour cryogenic treatment (mm)	% Increase in Tool life.
1.	1	1	1	0.6	0.306	49.00
2.	1	1	2	0.49	0.248	49.38
3.	1	2	1	0.37	0.168	54.59
4.	1	2	2	0.315	0.185	41.26
5.	2	1	1	0.29	0.136	53.10
6.	2	1	2	0.28	0.127	54.64
7.	2	2	1	0.185	0.125	70.27
8.	2	2	2	0.12	0.112	90.00

Table 3 : Tool Wear for Machining of AA6041

S. No.	Cutting speed (V) (m/min) x_1	Feed (S) (mm/rev) x_2	Depth of cut (t) (mm) x_3	Tool wear Without cryogenic treatment (mm)	Tool wear with 24 hour cryogenic treatment (mm)	% Increase in Tool life.
1.	1	1	1	1.05	0.895	85.71
2.	1	1	2	0.88	0.665	75.56
3.	1	2	1	0.61	0.562	92.78
4.	1	2	2	0.56	0.551	91.25
5.	2	1	1	0.48	0.422	88.12
6.	2	1	2	0.45	0.315	90.00
7.	2	2	1	0.15	0.079	123.96
8.	2	2	2	0.12	0.051	140.0

Table 4 : Tool Wear for Machining of EN36

S. No.	Cutting speed (V) (m/min) x_1	Feed (S) (mm/rev) x_2	Depth of cut (t) (mm) x_3	Tool wear Without cryogenic treatment (mm)	Tool wear with 24 hour cryogenic treatment (mm)	% Increase in Tool life.
1.	1	1	1	1.060	0.650	38.69
2.	1	1	2	1.380	0.930	32.60
3.	1	2	1	1.100	0.830	24.45
4.	1	2	2	0.875	0.770	12.00
5.	2	1	1	0.685	0.505	26.27
6.	2	1	2	0.635	0.440	30.70
7.	2	2	1	0.510	0.350	31.37
8.	2	2	2	0.450	0.320	28.88

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Table 5 : Regression equations for various working materials

Working Material	Tool wear (mm) for Untreated HSS	Tool wear (mm) for Cryogenic treated HSS for 24 hours
AISI 1040	$y = 0.2312 + 0.112x_1 + 0.0837\ x_2 + 0.03\ x_3 + 0.28\ x_1\ x_2 - 0.2\ x_3\ x_1 + 0.22\ x_1\ x_2\ x_3.$	$y=0.1236+0.0608x_1+0.0381x_2+0.00031x_3-0.171x_1x_2-0.099x_2x_3-0.48x_3x_1+0.03x_1\ x_2\ x_3$
AA 6041	$y = 0.3756 + 0.1018\ x_1 + 0.0940\ x_2 + 0.0393\ x_3 + 0.75\ x_1\ x_2 + 0.15\ x_2\ x_3 - 0.31\ x_3\ x_1 + 0.33\ x_1\ x_2\ x_3.$	$y = 0.1793 + 0.1118\ x_1 + 0.1081\ x_2 + 0.0143\ x_3 + 0.25\ x_1\ x_2 - 0.03\ x_2\ x_3 - 0.73\ x_3\ x_1 + 0.01\ x_1\ x_2\ x_3.$
EN36	$y = 0.9993 + 0.4293\ x_1 + 0.2656\ x_2 + 0.0543\ x_3 + 1.21\ x_1x_2 - 0.11x_2x_3 + 0.09\ x_3\ x_1 - 0.07\ x_1\ x_2\ x_3$	$y = 0.7518 + 0.3443\ x_1 + 0.0843\ x_2 - 0.0143\ x_3 + 0.15\ x_1x_2 + 1.05\ x_2x_3 - 0.25\ x_3\ x_1 - 0.79\ x_1\ x_2\ x_3$

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