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Research Paper

EFFECT OF CRYOGENIC TREATMENT ON CUTTING TORQUE AND SURFACE FINISH IN DRILLING OPERATION WITH AISI M2 HIGH SPEED STEEL

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Cryogenic treatment is considered as a recognized treatment to improve the wear resistance of HSS tools. Different researchers have explained the exact mechanism behind this improvement. However, the impact of cryogenic treatment on cutting forces and surface finish has not yet considered by the researchers. The purpose of present work is to study the impact of two variables in cryogenic treatment, viz., soaking temperature and soaking period on the performance of drills in terms of cutting torque and surface finish of work piece in drilling operation. The various drills were given different cryogenic treatment and their performance in drilling operation was tested. After rigorous experimentation it was found that the soak temperature and soak period has great impact on the performance of drilling operation in terms of the selected response variables like roughness value, torque, etc. This cryogenic treatment was carried out for a AISI M2 grade of HSS tools only and hence further research is required to be carried out to study such impact on other grades of HSS or other tools. The use of this treatment has got great impact on industrial productivity in terms of improved tool life of drills or other such cutting tools made of same material.

Keywords: Cryogenic treatment, Tool life, Surface finish, Cutting torque, Thrust force

INTRODUCTION

Tool life is a cause of great concern particularly in manufacturing industries in today's competitive environment. Several methods are available for improvement in tool life. Cryogenic Treatment (CT) is one of them. While comparing various tool life improvement techniques it was found that CT is superior in terms of performance as well as cost cutting.

In manufacturing industries, CT is not yet to be considered as a regular post heat treatment

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cycle. The main reason behind this, that there can be the treatment provided for improvement of wear resistance from metal to metal. Here, the cost and mechanism involved is noteworthy.

CT is a treatment used for the variety of reasons. It is mainly used for improvement in wear resistance. Research shows, there is definite improvement in wear resistance after CT. This improvement varies from material to material dealing with the treatment parameters.

The subzero treatment, normally called as cold treatment (between –90 °C to –185 °C) of steel is a supplementary treatment to a conventional heat treatment. Conventional heat treatment is unable to transform full austenite into martensite. The subzero treatment followed by conventional heat treatment, enhances the transformation of retained austenite into martensite thereby improving the wear resistance.

Many researchers (Huang *et al.*, 2003; and Flavio *et al.*, 2006) have shown that, the cryogenic treatment, in which a metal is cooled to a temperature of –190 °C, improved certain properties beyond complete conversion of retained austenite into martensite. The presence of fine K-phase carbide precipitates has been identified as another cause for the enhancement in various properties including wear resistance, corrosion resistance and toughness.

Looking at the literature it is seen that much work in specific areas for a particular grade of material has been carried out, further different researchers have only shown the performance in terms of specific response variables like wear resistance (Mohan *et al.*, 2001; Kalin *et al.*, 2006; Firouzdor *et al.*, 2008; and Das *et al.*, 2009), microstructure changes (Huang *et al.*, 2003; and Gogte *et al.*, 2009), change in mechanical properties (FranjoCajner *et al.*, 2009; and Paolo *et al.*, 2009).

Tsao and Hocheng (2008) have studied experimentally the evolution of thrust force and surface roughness produced by candle stick drills. They found that the feed rate and drill diameter are significant factors that affect the cutting torque, while spindle speed and feed rate are influencing factors in surface finish. Similar studies also carried by Vimal *et al.* (2009).

However, it has been seen that the measurements of cutting torque and surface finish of cryo treated drills in drilling operation is not considered as the response variable during such studies.

Considering this important aspect of CT, the experimental investigations are carried out on widely used HSS tools considering the two most important machining parameters, viz., cutting torque and surface finish in drilling operation. The result of experimentation are presented in this paper.

Cutting torque has a direct relation with tool life. Higher cutting torque means higher cutting forces which in turn reduces the tool life. In this experimentation, cutting torque in drilling operation is measured for different CT conditions and therefore an attempt has been made to identify the critical parameters of the CT which affect cutting torque and thereby tool life.

Surface finish of the work-part is another cause of concern. Here again an attempt has been made to identify the parameters of CT which affects surface finish.

In this paper, therefore, an effort is made to study the performance of drills in the drilling operation in terms of cutting forces and surface finish experimentally. What follows in the further section are the experimentation details of the study carried out.

MATERIALS AND METHODS

The AISI M2 grade HSS drills of size 12 mm diameters were selected for experimentation. These drills belong to same lot with identical process parameters. Chemical composition and relevant properties of the used M2 HSS drills are presented in Tables 1 and 2 respectively.

Table 1: Chemical Composition of the Used M2 HSS Drills (wt %)

C	0.86
W	6.00
Mo	4.90
Cr	4.00
V	1.90
Si	0.40
Ni	0.20
Cu	0.10

Table 2: The Relevant Properties of the Used Drills

Tool Material	M2 HSS
Tool Reference	1055 (DIN 1897)
Coating	None
Helix Angle	30°
Point Angle	120°
Diameter	12 mm

The two most significant factors in CT, i.e., soak period and soak temperature was only considered for variation where, as all other factors were kept constant. Details of treatment carried out are as under (Table 3).

Table 3: Process Sheet

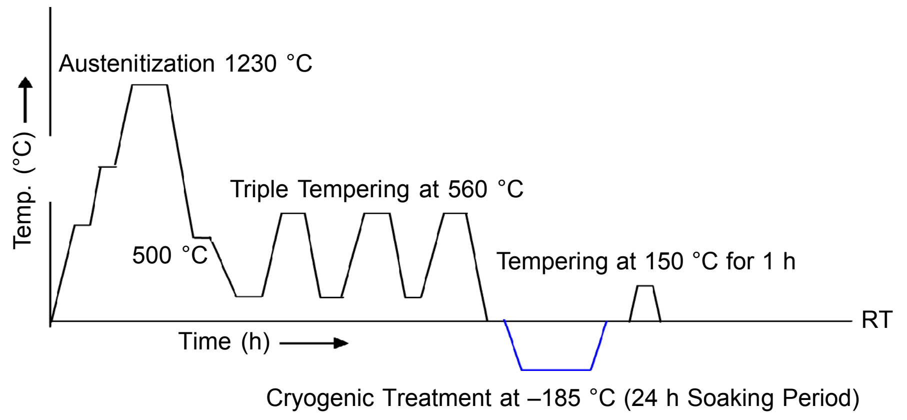
Process	Soak Period	Soak Temp.
A	Non Cryo Treated Tools	
B	8 h	–90 °C
C	16 h	–90 °C
D	24 h	–90 °C
E	8 h	–185 °C
F	16 h	–185 °C
G	24 h	–185 °C

The CT was carried out in a fully computer controlled cryo chamber SC-50. For process B to F the following factors and their level were kept constant for CT.

- Cooling rate – 1°C/min
- Tempering temp. – 150°C
- Tempering cycle – 1
- Tempering period – 1 h

CT consisted of slowly cooling drills to approximately –90 °C and –180 °C and holding at this low temperature for various soak periods (8, 16, 24 h) and gradually bringing the drills back to room temp. To avoid thermal shocks from rapid cooling and heating, the drills were cooled down and heated up slowly, to and from low temperature at a rate of 1 °C/min. Further, for the stabilization of transformed martensite, one hour tempering at a temperature of 150 °C was given to drills. Before CT conventional heat treatment followed by CT and then tempering on these tools were performed. Figure 1 illustrates the standard CT cycle.

Figure 1: Sequence of Conventional and Cryogenic Treatment for AISI M2



A standard 150 mm × 150 mm M.S. plate of 12 mm thickness was used as a work piece. All these plates were cut from a single plate to avoid any variation because of work piece material.

Drilling operation was performed on state of the art CNC VMC AGNI (BMV45/T20/TC20/TC24) using a simple CNC part program. No coolant used during the drilling operation. A series of holes were drilled by these drills on plates. Total 40 holes were drilled by each drill.. The position of every hole and its drilling sequence was same for each plate. The typical cutting conditions were as under.

Feed rate – 0.03 mm/rev

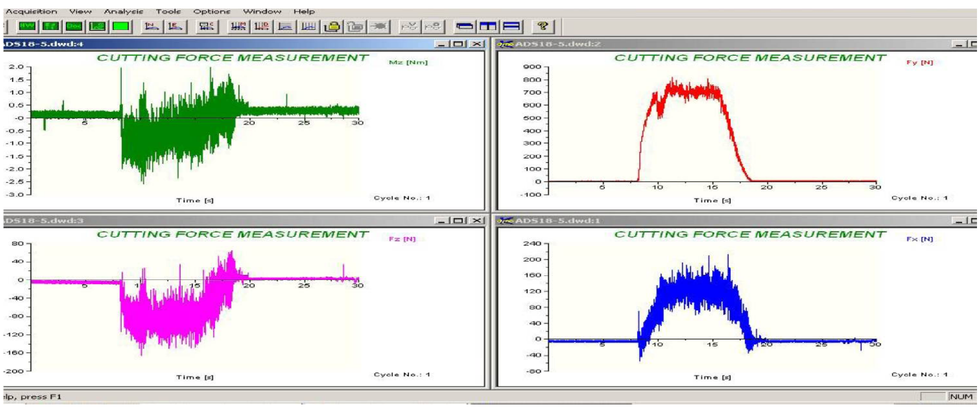
Spindle speed – 1000 rpm

The cutting force was measured using KISTLER drill Dynamometer with multichannel amplifier type 9257B and the appropriate hardware. The parameters that can be measured on this dynamometer are.

- Resultant force components Fx, Fy and Fz in X, Y and Z directions respectively in Newton
- Moment (Torque) Mz in Nm

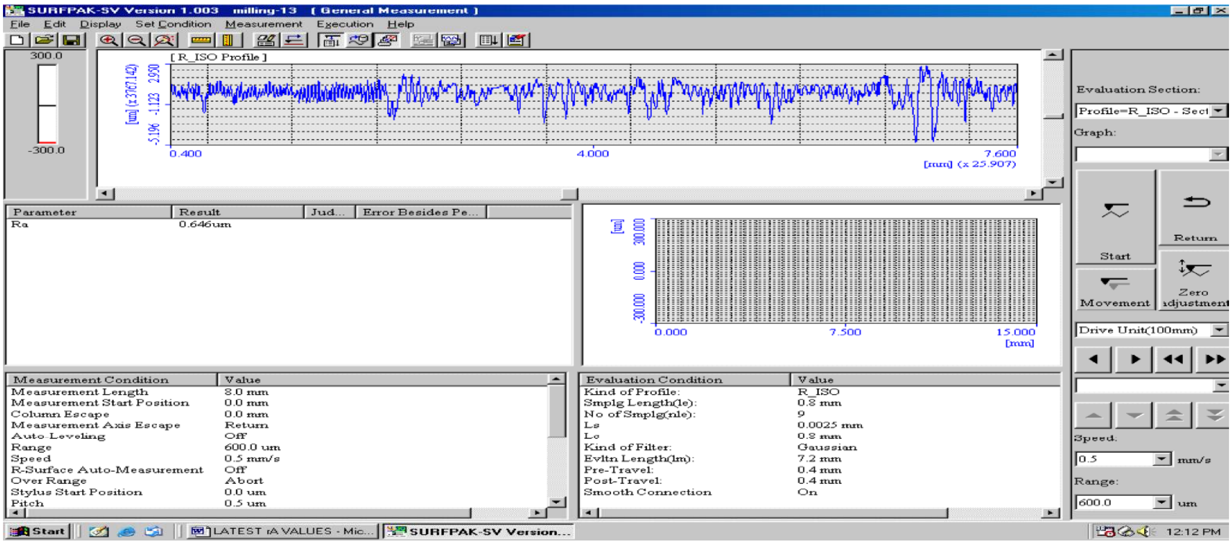
Figure 2 indicates the sample screen of measurement of cutting forces:

Figure 2: Sample Screen for the Measurement of Cutting Forces on the KISTLER Drill Dynamometer



The surface roughness of drilled holes was measured using a surface roughness testing machine 'SURFTEST' model SV614 (Mitutoyo, Japan) using the software SURFPAK (Vol. 3). The center line average or Ra was chosen as the surface roughness parameter which is widely agreed to that effect. Figure 3 indicates Sample screen for the measurement of surface roughness on the 'SURFTEST'

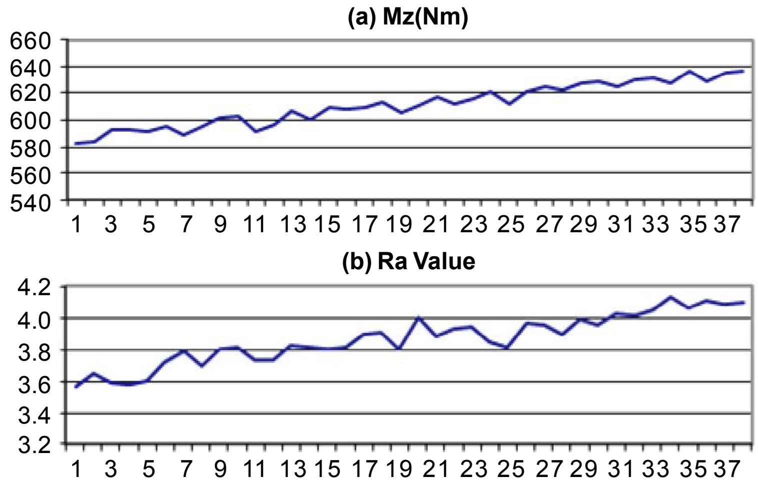
Figure 3: Sample Screen for the Measurement of Surface Roughness on the 'SURFTEST'



RESULTS

Following are the results of experimentation in an abstract form. Figure 4 shows a sample readings of cutting torque and surface roughness.The most significant factor in drilling operation is cutting torque, i.e., moment (Mz) is only taken into consideration for comparative study. The

Figure 4: Sample Reading of the Mz and Ra (a and b)



results obtained are summarized in Table 4. Figures 5 and 6 represents bar charts of cutting torque and surface roughness respectively.

Table 4: Summary of Results

Process	Av. Mz(Ncm)	Av. Ra (µm)
A	634.199963	4.5461
B	631.639543	4.2386
C	617.498983	4.3267
D	583.177968	3.8923
E	611.599797	3.8641
F	585.527316	3.8923
G	576.990868	2.9926

DISCUSSION

The experimentally observed impact of two significant factors in cryogenic treatment viz. soak temperature and soak period in term of cutting force and surface roughness in performance of drills of AISI M2HSS grade may be summarized as follow.

Figure 5: Bar Chart of Mz

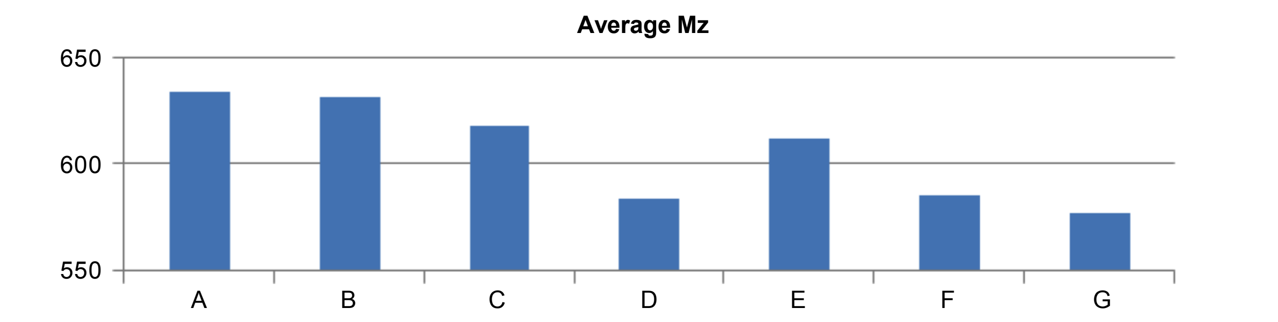
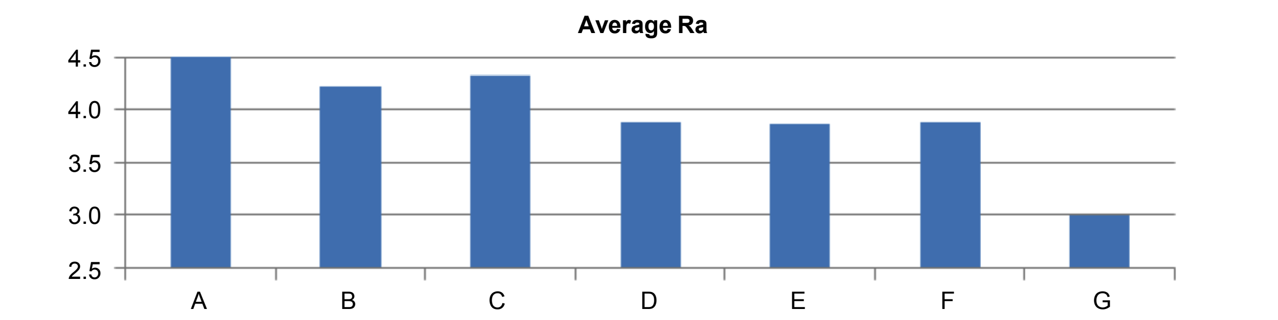


Figure 6: Bar Chart of Ra



- Cutting force has a direct inverse relationship with the tool life. While comparing the performance of non cryotreated drills (process A) against cryotreated drills (process B to G) in terms of cutting torque and surface finish, it is clearly observed that cryotreated drills perform better as that of non cryotreated drills. This performance improvement in terms of tool life, mechanical properties, metallurgical properties has been tested and proved by the earlier researchers (1 to 11).
- The result of cutting torque clearly show the pronounced effect of soaking period at both the soaking temperatures. It is

clearly observed that the cutting torque for –185 °C and 24 h treatment condition is lowest (576.99 Nm) when compared with other treatment conditions. Further the cutting torque for –90 °C and 24 h treatment condition is the second lowest (583.177 Nm).

- The values of surface roughness show that the surface quality of the machined component is best (2.99 μm) for –185 °C and 24 h treatment condition. At the same time, it is also observed that soak temperature plays vital role in determining the surface roughness of the machined component as its values for –185 °C soak temperature are minimum in the whole experimentation.
- The coefficient of determination, R^2 in a moment comparison graph (Figure 7) for both the soak temperature is around 0.92,

Figure 7: Moment Comparison Graph

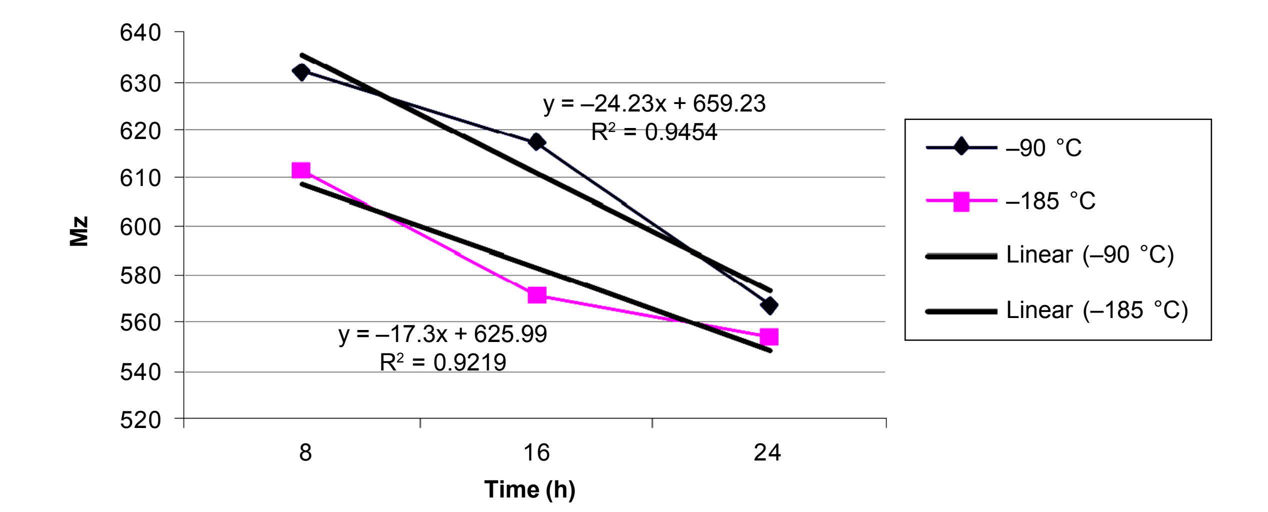
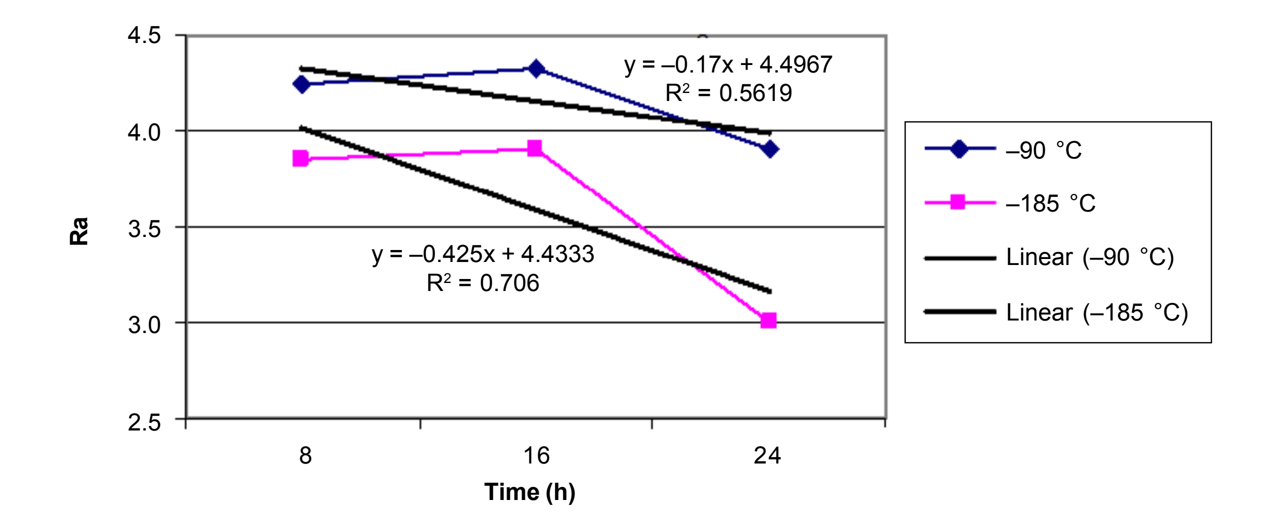


Figure 8: Ra Comparison Graph



which show that there is a strong correlation between soak period and moment.

- The coefficient of determination, R^2 in a Ra comparison graph (Figure 8) for both soak temperature are 0.5 and 0.7, which show that there is a moderate correlation between soak period and Ra.

CONCLUSION

The following conclusions can be drawn for CT of AISI M2 HSS in measurement of cutting torque and surface roughness in drilling operation

- Soak temperature in the CT is the most influencing factor in the whole process as the values of cutting torque and surface roughness are lowest at –185 °C soak temperature.
- Soak period is the second most influencing factor in the experimentation.
- About 10% reduction in cutting torque is observed while comparing non CT dills with CT drills (–185 °C, 24 h), which clearly indicate improvement in wear resistance and thereby in tool life.
- About 35% reduction in Ra value is observed while comparing non CT dills with CT drills (–185 °C, 24 h), which clearly indicate improvement in surface quality of the work piece.

This change is a clear indication of reduction in the anisotropy of the tool due to cryogenic treatment.

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