



TOOL WEAR IN MAGNETIZED DRILLING PROCESS

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ABSTRACT

This paper deals with the mechanisms governing influence of magnetic field on wear resistance of cutting tools in drilling process. The results show that the rate of crater wear of both HSS and carbide drills submitted to a high d.c magnetic field intensity, is drastically reduced compared to the one obtained without magnetisation. Moreover, opposite variations of thrust force have been recorded in the presence of magnetic field when 0.38% carbon steel work material were drilled with HSS and carbide tools. These results suggest that even the magnetic effect seems to be manifold, it can be basically grouped into two categories (i) a change in the cutting mechanics (ii) a material properties variation of workpiece and tool.

KEYWORDS: magnetic field, wear, dry drilling, HSS and carbide tools, drilling forces.

1. INTRODUCTION

Drilling, for lack of reliable managing drill wear and avoiding catastrophic failures, is still under extensive research and development. Much of the works to control drill wear follows two approaches [10, 18]. One is to develop a reliable real-time drill wear measurements as an automation issue of traditional drilling operations [10]. The second is to look for new alternative methods to cut difficult holes with adequate precision. Methods applied to real-tool wear monitoring and in spite of many attempts have not yet proven to be attractive economically nor technically. New holemaking alternative is a task amenable to in-shop research and development. Recently, two alternative methods include the Thriller tool from Emuge Corp (Northborough, MA), which enables hole drilling, thread milling, chamfering and spot facing all with a single tool, and the Novator AB (Spanga, Sweden) orbital drilling tool currently undergoing testing for aerospace and automotive applications [18].

This paper will attempt to present study regarding the "wearlessness" effects by application of external electromotive force (EMF) sources (e.g. magnetic field) with special emphasis in its illustrations and discussions on drilling process. Indeed, monitoring wear resistance of cutting tools by applying an external electrical current have been first studied by Bobrovskii [3], Kanji and Pal [11]. An increase of tool life time was observed. However no viable reasons for this improvement were given. Later, Bagchi and Ghosh [1, 2] reported that

residually magnetized HSS tools while machining mild steel exhibit increased wear-resistance when compared to no-magnetized tools. To provide some reasons explaining why a magnetized cutting tool has a greater life, Chakravarty proposed a qualitative model [4]. In his attempt of modelling, Chakravarty assume a physical reorientation of elementals magnets. Although the results of the modeling analysis were encouraging, the model itself was subject to question.

Two years later, Pal and Gupta [17] studied the effect of an alternating magnetic field on the wear behaviour of HSS drills. The authors observed that the presence of magnetic field considerably reduces the wear rate and possible reasons for this improvement have been suggested. More significant explanation of the "wearlessness" by application of magnetic field are given by Muju and Ghosh [13,15] when conducting tool wear experiments with magnetized HSS turning tools on mild steel and brass. The authors state that the magnetic field influences adhesive wear behaviour in such a way as to reduce the wear rate of the body with the lowest magnetic permeability. Moreover, they foresee that an increase of the temperature reduces the magnetic field effect. Following this reasoning, Muju and Radhakrishna [16] conclude that the application of a magnetic field to a contacting pair reduces the activation energy of wear and diffusion and is advantageous only when $H_1 / H_2 \geq 2$ where H_1 and H_2 are the harnesses of bodies with high and low magnetic permeability respectively. Even this criterion supports some of the



experimental data reported in preceding works, it seem to be only suitable for describing the improvement of wear behaviour in the presence of a magnetic field when an adhesive wear mechanism is a predominant. Thus the criterion which indicates the beneficial effect of the magnetic field may not be suitable for the selection of contacting pair.

Recently, we published some data on the magnetic field effects on HSS tools durability during machining [5, 6]. Cutting tests consisted on turning experiments. We observed high values of tool durability and significant reduction of wear rates at higher level of magneto-mechanical excitation, which is characterized by higher magnetic field and cutting speed.

In this study an attempt has been made to confirm this phenomenon in drilling process and to clarify the "wearlessness" mechanisms by application of external electromotive force (EMF) sources (e.g. magnetic field).

2. MAGNETIC-DRILLING SET-UP AND PROCEDURES

2.1. Materials

Workpiece and tool materials selection requires a specific approach to achieve better understanding of the magnetic field influence on the tool wear. In this connection, the effect of external magnetic field has been considered in respect to materials properties. Hence, all drilling tests were run on test specimens machined from block of ferromagnetic 0.38 percent carbon steel (see table 1).

Therefore, two kinds of twist drills were used as reported in Table 1. One is non-magnetic carbide twist drill. The other one is ferromagnetic HSS twist drill. The selection of HSS and carbide tools was motivated respectively by their magnetic reactivity and inertness with respect to the application of external electromotive force sources. The basic objective is to compare their wear response in order to appreciate whether the magnetic field effect is much concerned by a possible variation in materials properties rather than a probable change in the mechanisms of cutting.

2.2. Magnetic-drilling set-up

The drilling tests were carried out on vertical machining centre MIKRON VCE 500. The machine's rated maximum spindle speed is 7500 rpm with a maximum of 11kW power. To establish some effects of d.c. magnetic field on the growth of drill wear under dry cutting conditions, a special drilling-fixtured was built-up. An appropriate means of hole machining using an external magnetic field is through the work-piece holding device.

Table 1. Experimental conditions.

Cutting Tools	
Tivoly 8140101 , HSS E5 twist drill Tool geometry : Helix angle 35°, Point angle 130°, Φ 8, Tool hardness: 850 HV30	
Tivoly 8243921, solid carbide twist drill Tool geometry: Helix angle 25°, Point angle 130°, Φ 8, Tool Hardness:1500HV30	
Job material	
Low carbon steel (XC38) Composition: C 0.38%, Si 0.18%, S 0.03%, Mn 0.72%, P 0.3% Rod size : Diameter: 12 mm, length: 50 mm	
Machining conditions	
Carbide Twist Drill	Cutting speed: 80 m.min ⁻¹ Feed : 0.03 mm.rev ⁻¹ Magnetic field intensity: 0 – 3x 10 ⁴ A.m ⁻¹ Environment : dry
HSS Twist Drill	Cutting speed: 20 m.min ⁻¹ Feed : 0.2 mm.rev ⁻¹ Magnetic field intensity: 0 – 3x 10 ⁴ A.m ⁻¹ Environment : dry

Drilling is hence accomplished by feeding the magnetized rotating drill to the stationary work-piece already linked by magnetic flux. The external view of the used holding device is shown in figure 1. The last is designed to hold work solidly on the machining centre, to apply the magnetic field and to permit the associated drill forces to be gathered during a single test. Therefore, the drill jig consists of stiffened plate with three steel blocks of cylindrical shape, which serve as a fixed support of coil. Enclosed the body of the drill jig, the work-piece is held by a 3-jaw spur chuck.

A Kistler drill Dynamometer is mounted between the stiffened plate and spur chuck to monitor forces during hole making in order to follow the drill wear growth. To check the spindle head perpendicularity to the worktable and to make sure that coil and the work-piece are situated coaxially an positioning indicator was shop made. It consists of pipe whose its inside and outside diameters are respectively equal to the outer diameter of the work-piece and inner diameter of the coil.

The magnetic field which crosses both the drill and the work, in line with the drill axis, was created by an applied d.c. electric current in a coil fixed around the workpiece as shown in figure 1. The coil had an inside diameter, 6 mm, in excess of the tool diameter and the length of the coil was such that a considerable portion of the tool was linked by magnetic flux. The magnetic field strength was varied in the range of 0-3x10⁴ A.m⁻¹ according to the electric current intensity.

2.3. Procedures

The experiments consist of drilling a blind holes of 8mm in diameter and 20 mm in depth using 10 deburring cycles as shown in figure 2. This manner to drill under magnetic field has been taken for efficient chip and heat extraction. It seems to be an adequate approach to estimate the contribution of magnetization factor to the total drill wear compared to conventional drilling that build up a lot of friction and heat. Indeed, when considering wear of drill subjected to external magnetic field, it should be taking into account that it results from both mechanical and magnetic actions, which are closely interrelated. Thus, all dry drilling experiments have been performed using this procedure under the machining conditions given in Table 1. The cutting conditions chosen are the results of several initial tests under the used drilling configuration (see figure 2) in magnetic-free process. To get reliable results, each experiment was repeated five times under identical

conditions. For every single test, a new tool and a work-piece sample were used. Average thrust force and torque for each test are also estimated for further analysis.

Tool wear features were investigated ex-situ by Optical Microscopy and quantified using a white light interferometry profilometer NT-3300 (Veeco device). A first important advantage of the white light interferometer is that the height (or 'Z') resolution is independent of objective. This allows to study wide areas -as often required on cutting tools- with low magnification objectives, while maintaining the high resolution. Secondly, due to its large Z range (up to 2 mm), the system can be used to measure both nanometer details and millimeter-sized steps, permitting to study the earlier stages of wear process as well as the more severe ones. Moreover, this technique allows the study of some supplementary criteria like the volume of the crater, the width of the crater and the roughness of the crater.

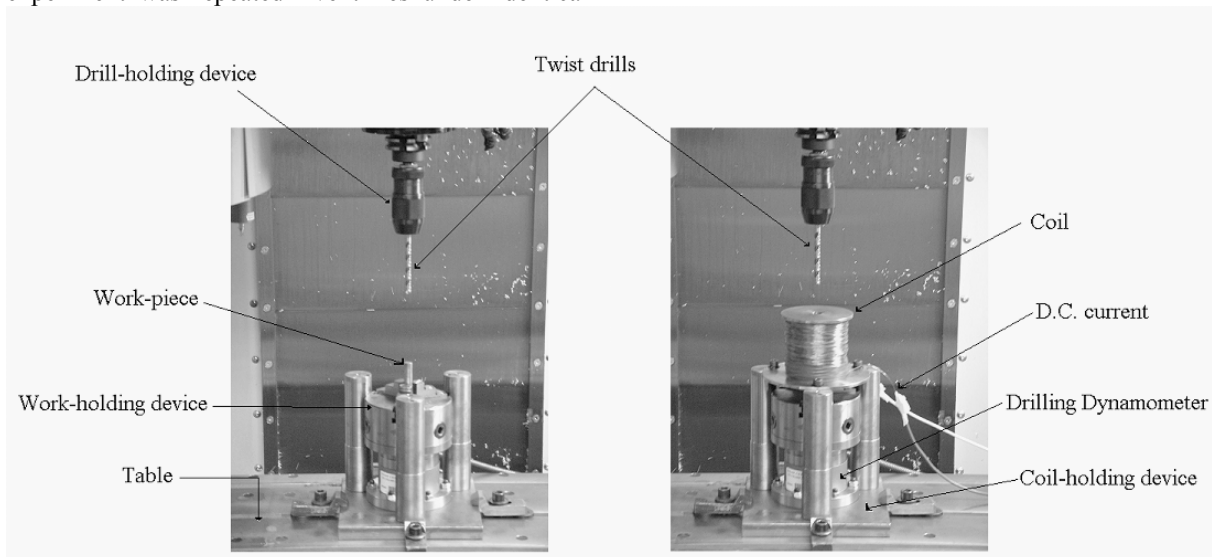


Fig. 1 Experimental set-up of hole making under magnetic field

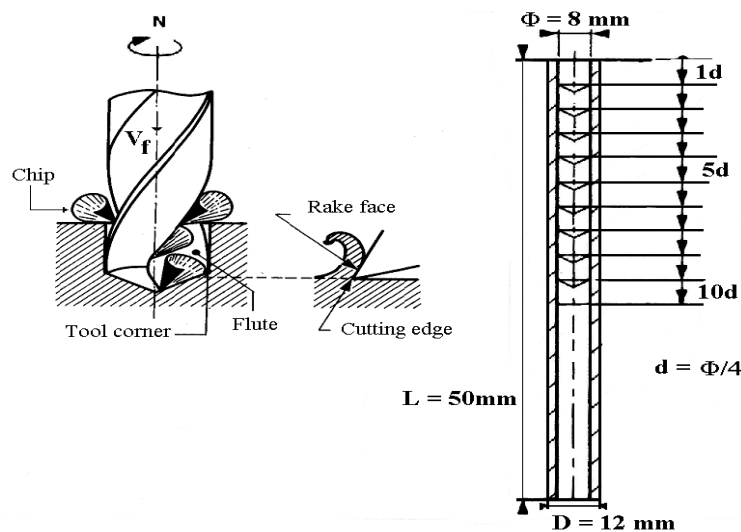


Fig. 2 Schematic diagram showing the deburring cycles for chip removal during a blind hole drilling.



3. RESULTS

3.1. Torque and thrust force

The dependence of drilling forces (torque and thrust force) on the magnetic field intensity across the cutting contact revealed by experiments, appears to be different when cutting with HSS or carbide drills. In HSS/XC38 carbon steel drilling experiments, where both materials are ferromagnetic, the average thrust force drastically increased when the applied magnetic field reaches sufficient intensities (see figure 3).

At intensities above 7.10^3 A.m^{-1} , average thrust force is close or even equal to that measured without magnetic field. The average torque trend with applied magnetic field seems to fall as intensity rises (see figure 3). However, when examining this variation by taking into account the scatter of the torque values, no significant effect of magnetic field can be noted.

Concerning the case where drilling operations of ferromagnetic XC38 carbon steel were performed with non-ferromagnetic carbide drill, an opposite effect was observed (see figure 4).

Results obtained show that as magnetic field strength increases, the average feed force decreases even in intensities above 7.10^3 A.m^{-1} . At high level of magnetic strengths (about $2.8 \cdot 10^4 \text{ A.m}^{-1}$) this reduction is more prominent. However, for average torque values, a scatter similar to that observed on HSS/XC38 carbon steel experiments is noticed. The presence of magnetic field does not have any effect on torque values.

3.2. Tool wear

Drill wear is a progressive process which takes place at the outer margin of the flutes of the drill due to the intimate contact and high temperatures at the

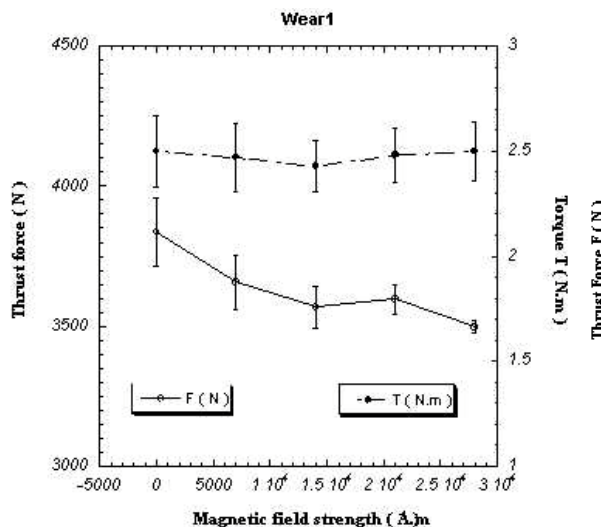


Fig. 3 Magnetic field effect on cutting forces when drilling X38 carbon steel using HSS twist drill

tool-workpiece contact. However, under constant cutting conditions drill failure is a stochastic process. Since the objective of drilling test was to study the effect of the intensity of magnetic field strength on the total cumulative tool wear, only wear measurements at the ending cutting test were made. Figure 5 shows typical optical photographs of wear pattern of cutting edges and their corresponding White Light Interferometry 3D image.

Each wear measurement consists in estimating the maximal depth of the crater KT using both a tool makers microscope to $1\mu\text{m}$ accuracy and white light interferometry profilometer. Good correlation was observed between the two techniques as can be attested in figure 5.

Depending on its intensity and tool materials, the magnetic field modifies the tool wear during a cutting operation. Figure 6 shows these modifications in terms of maximal depth (KT) values of crater at the edge face. As shown in this figure, the parameter KT gradually decreased at identical cutting conditions when the applied magnetic field intensity increased. We observe that a clear drop of the KT values occurs at higher level of magnetic excitation confirming the increase of wear resistance of tool. The level of this drop is more perceptible in the case of carbide drill compared to HSS drill.

4. DISCUSSION

Metal cutting is an extremely complex process that cannot be described by a single mechanism. While a single mechanism may be predominant over a limited range of operation conditions, experience teaches that no single mechanism hold in general. This counts the complexity of the task when suggesting mechanism to explain cutting results obtained under the effect of magnetic field.

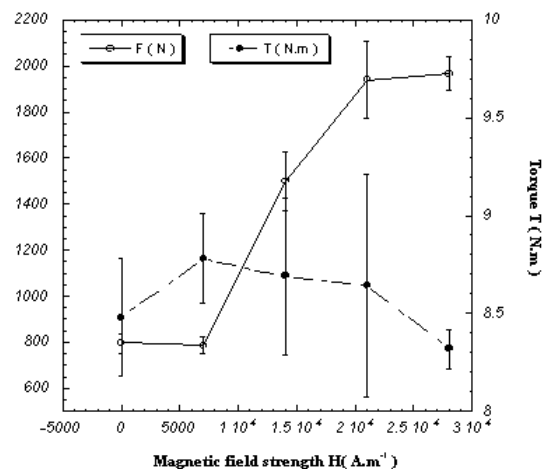


Fig. 4 Magnetic field effect on cutting forces when drilling X38 carbon steel using carbide twist drill

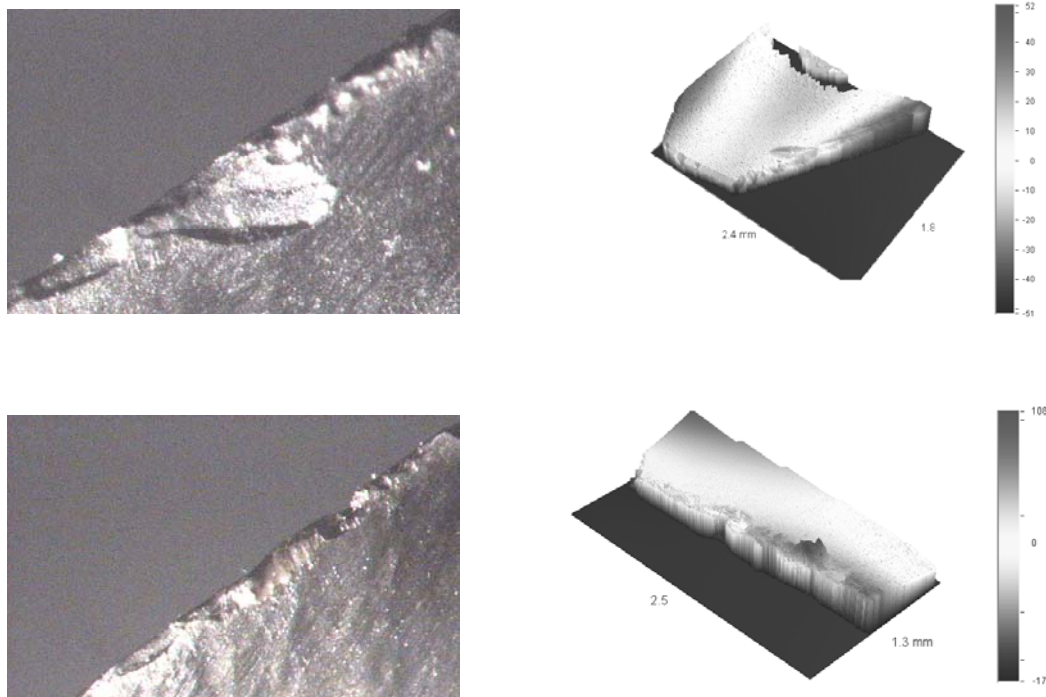


Fig. 5 Typical optical photographs showing wear pattern of cutting edges and their corresponding White Light Interferometry 3D image.

Taking into account the all above results, we can therefore outline the most important points in understanding magnetic field influence on metal cutting process. Indeed, in HSS/XC38 carbon steel cutting contacts, the experiments show that the magnetic field enhances the thrust force and reduces the tool wear. These phenomena are in first viewpoint controversial. Logically cutting forces expand as tool wear increases. This is due to the friction growth between tool and workpiece.

However, the observed change of feed force under magnetization is not only related to the wear modification but also to the attractive magnetic force, to the temperature rise and an expected change in cutting mechanics [5-6]. The presence of coaxial magnetic field amounting to an external force being superimposed on the equilibrium force diagram may modify the shear angle.

Indeed, the processes of domain wall motion and domain rotation are central to the study of magnetic materials behaviour in magnetic field [6, 8].

As is well known, crystals within ferromagnetic materials are usually divided into magnetic Weiss domains. The application of an external magnetic field on ferromagnetic materials increases their overall magnetization by the following processes. The Weiss domains among which magnetization is oriented to a direction close to that of the applied field grow by reversible motion of Bloch walls to the detriment of the others. Under high magnetic field intensities, the magnetization aligns itself according to the applied field by irreversible rotation and all the Bloch walls are irreversibly removed as saturation takes place. Thus when the crystals orient, there is a

possibility of getting different cutting properties according to the degree of the boundaries motion and rotation depending on the direction and intensity of magnetic field.

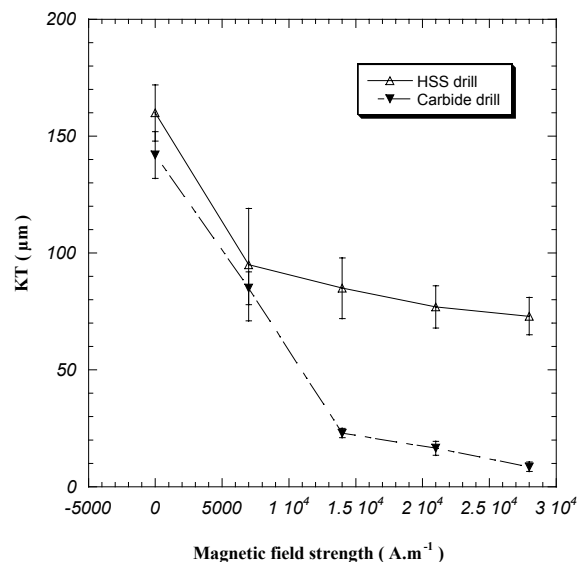


Fig. 6 Maximal depth (KT) values of crater wear vs. magnetic field intensity

Moreover, we have previously investigated the surface modifications of numerous materials in sliding magnetized contact [7, 9]. We observed that micro-hardness of the sliding surfaces of both ferromagnetic and non-ferromagnetic materials increased when a critical magnetic field was applied. To highlight these modifications, we have developed



a theoretical model based on the dynamics of dislocations in the junctions of asperities [7]. Predictions of this theoretical model have shown that magnetic field significantly modifies the plastic properties of materials. Furthermore, depending on the magnetic properties of these materials, positive or negative effects can be observed. Both effects can influence wear resistance.

In this study, all wear experimental results (section 3) shows that the magnetization during drilling process enhances a wear resistance of tool materials. The mechanism behind such improvement resides in surface hardening, cutting mechanics change and modification of wear mechanisms induced by magnetization [5, 6].

Concerning the feed forces results and from an energetical approach point of view, it is believed that in cutting ferromagnetic material under magnetization, the specific cutting energy is almost expended on plastic deformation. Nonetheless, this energy in magnetic-free cutting process is expanded on plastic deformation and rearrangement of the magnetic structure of the materials. This behaviour was established by Levin and his colleagues when investigating the indentation energy of ferromagnetic materials under external magnetic field [12]. The authors examined the effect of various processes of change in the magnetic structure on the microhardness of the ferromagnetic materials. A relationship was established between the effect and the change in magnetic energy due to external stress. Thus, when drilling with inert carbide tool under external magnetic field, the cutting energy is nearly expended on plastic deformation which leads to a reducing of feed force especially at high level of magnetic excitation. However, with ferromagnetic HSS tool, the simultaneous start-up and activation of magnetisation process both on tool and workpiece materials lead to an increase on feed force.

5. CONCLUSION

Although the results presented in this paper are partial, their discussion has attempted to provide information relative to the importance of EMF sources as an integral part of non-wear conditions.

Thus, from established favorable effect achieved by applying d.c. magnetic field in tools wear, the following concluding points can be drawn:

1. When a carbide and HSS drills were magnetized, a distinguishable reduction of wear was observed. This reduction is more pronounced at higher level of magnetic excitation.
2. Presence of coaxial magnetic field amounting to an external force being superimposed on the magnetization process may have affected the

shear angle causing the observed change of thrust forces.

3. No explicit relationship between the presence of magnetic field and the measured torque values was observed. In all the experimental results, the effect of the magnetic field on the torque do not exceeds the error of measurement and is insignificant statistically.
4. In metal cutting processes the effect of magnetic field seems to be manifold but it can be basically grouped into two categories (i) a probable change in the mechanism of cutting and (ii) a material property variation in the presence of magnetic field.

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