INFLUENCE OF A MAGNETIC FIELD ON HSS TOOL WEAR/LIFE AND THE INTENSITY OF EXTERNAL MACHINING ENVIRONMENTS IN TURNING

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Abstract - In this manuscript, the impact of a permanent magnetic field on the intensity of external lubricant/gaseous metal cutting environments in the turning process is studied. Tool life and wear resistance of solid High-Speed Steel (HSS) metal cutting tool was researched in diverse cutting modes and environments in turning steel 40X [analog: AISI 5135] and steel 25 [analog: AISI 1025] to study the effect of permanent magnetic field on the ferromagnetic tool. Experiments were conducted creating machine oil, oxygen, and argon conditions as an exterior machining environment in the process. The ferromagnetic HSS cutting tool is magnetically treated and used in diverse external machining conditions to analyze the intensity of affecting the lubricant/gaseous environment in the metal machining process. Furthermore, the influence of cutting speed and feed on the efficiency of magnetic field impact in lubricating and gaseous environment in the machining process is also researched. According to the experimental study, it is found that tool life and wear resistance of ferromagnetic HSS cutting tool is increased after the tool is magnetically treated with 10,000 ÷ 20,000 Oe of magnetic field strength in machining. However, the magnetic field effect on the HSS cutting tool showed subsidence while the cutting speed was increased in all external environments. Also, it is found that supplying oxygen and argon gases in metal cutting areas has a noticeably positive effect on tool wear and life, especially, since the influence of the gaseous environments has intensified results while the tool is used after magnetic treatment.

Keywords: Coolant, HSS tool, Lubrication, Machining, Magnetization, Tool wear, Tool life.

1. Introduction

The metal-cutting process is a complex of physical and chemical phenomena, which include process kinematics, stress state, plastic deformation, destruction in the cutting zone, friction, thermal phenomena, and chemical, electrical, and magnetic phenomena on contact surfaces [1-4].

S. Ravi et al. [5] analysed and reviewed the effect of cutting fluids on the metal cutting process. They summarise that reliable technique of application and selection of lubricants have a noticeable influence on life and machined surface quality. Moreover, they suggest that the method of application, selection, and disposal of cutting fluids remains an actual research direction in any metal cutting process. Mozammel Mia et al. [6] studied the frictional area in the metal-cutting process and the influence of various external environments on the process. They analysed many methods of creating lubricating, and cooling environments and their impact on the temperature generated in metal cutting. According to their work, the main factor affecting the metal cutting process including tool life, wear, and machined surface quality is the temperature generated in the process. They said that the machinability is improved by lubrication enhancement at the cutting zone. In conclusion, they inferred that studying the various technologies of using external cutting environments is a unique research area, and has an essential influence on developing any material removal process.

Based on an analysis of scientific researches performed in the scientific world, the research on the influence of the electromagnetic system on the metal-cutting process can be carried out in the following ways [7-11]:

a) cutting tool magnetization;
b) magnetization of the workpiece;
c) creation of a magnetic field in the cutting zone;
d) reversing the magnetization of the instrument;
e) pulse magnetic processing;
f) magnetization of cutting fluid.

One of the important advantages of these methods is their simplicity and the possibility of application in any manufacturing environment.

Furthermore, one of the promising directions for increasing machining productivity through tool life is the magnetization of the metal cutting tool. Numerous experiments have established a significant influence of the magnetic field on the durability of the cutting tool [12-15].

Omar Bataineh et al. [16] studied the wear mechanism of magnetic treatment of drilling tools. They used the pulsed magnetic field to magnetize the drills and found that the magnetic field treated drilling tool's wear resistance and life is increased noticeably. Moreover, they define that the effect of a pulsed magnetic field on drills depends on the treatment length. Sukhdev B. Waghmode et al. [17] conducted research on the influence of a magnetic field on the surface morphology of the workpiece and tool wear. They focused on the coated-carbide tool insert as an object of the study in turning, and analysed the chip morphology. They found that wear on the magnetically treated cutting tool is lower than the non-magnetized tool. They also proposed an effective cutting speed and magnetic field strength to reach high surface roughness. Moreover, in some researches, studying the metal-cutting process using magnetically, and electromagnetically treated lubricating-cooling fluids are considered as a novel approach of improving the material removal process [18, 19].

It is also known that the gaseous environment significantly influences the characteristics of the cutting process, and this effect is explained by their chemical interaction with contact surfaces [20-22]. Yue Zhang et al. [23] studied the machined surface roughness, and micrograph to determine the influence of gaseous environment on machining. They summarise that nitrogen gas has a lower effect on decreasing surface roughness, while other gases, only to a certain extent, can restrain nubs adhibiting and lower roughness value. Murat Sarikaya et al. [24] reviewed the effect of different factors on the material removal process including external cutting environments. They analysed the many wear types of cutting tools and suggested that the utilization of cooling/lubrication methods has become inevitable in recent years to reduce the high temperature generated in metal cutting, and to escalate the wear resistance, and life of metal cutting tools.

Numerous experiments have established that when chemically active oxygen is introduced into the cutting zone, special films are formed on the tool-chip contact area that differs in their properties from films formed during machining in air [25, 26]. The existence of surface films will depend on the rate of destruction and on the rate of recovery of these films. For their continuous existence, it is necessary that the recovery rate must be higher than the rate of their destruction [27, 28].

All of the above-mentioned studies conclude that the use of external cutting environments including lubricants/coolants/gases has a noticeable effect on improving any material removal processes. Mainly, the influence of an artificially generated environment in the metal cutting zone has the advantages of increasing tool life, and machined surface quality. However, some works and environment.

Thus, it can be expected that under cutting conditions where oxygen increases tool wear resistance, the magnetization will promote oxide film recovery. On the contrary, under cutting conditions, when oxygen reduces tool life due to the formation of weak oxide films (film strength decreases under unfavorable temperatures and high cutting speeds), intensification of the oxidation process due to magnetization should lead to a decrease in durability.

It is clear from the analyses of the works that almost all research works focus on the effect of magnetic field on various parameters in metal machining process including cutting environments. However, there are lack of experiments and studies about how the magnetic field influences the intensity of external cutting environments. Because of the fact that this research focuses on how magnetically treated tools reacted to lubricant/gaseous environments created in machining conditions.

2. Methods

One of the main objectives of this work was to study the conditions for the effective use of a magnetic field when cutting metals. Currently, one of the most widely used tool materials is high-speed steels (HSS) [29]. Therefore, given its widespread use in production and its ferromagnetic properties, solid HSS cutting tools were used in all experiments.

The choice of this material is also justified by the fact that when magnetizing the tool, it is not essential to use strong magnetic fields, because it is known that a field of several tens of oersteds (Oe) is sufficient for the magnetization of HSS tools to reach the saturation limit. Mainly, for most ferromagnets 10,000 ÷ 20,000 Oe of magnetic field strength is sufficient.

Cutting experiments were carried out using the longitudinal turning method on a screw-cutting lathe model 1A62. The machine was equipped with a G.M. (Generator-Motor) system, which provided smooth control of the spindle speed with an accuracy of ± 1 rpm. Wear measurements were carried out using a Brinell magnifying glass with 24x magnification and a division value of 0.05 mm. The magnetic treatment direction of the cutters and the workpiece was controlled using a compass. To assess the precision of the resistance experiments, calculations of variation coefficients were carried out. For this purpose, the results of experiments were selected, which were repeated 3 ÷ 4 times.

The magnetization of the cutters was carried out using a coil powered by a rectifier assembled from diodes; the internal diameter of the winding wire is d=0.8 mm (Fig. 1).

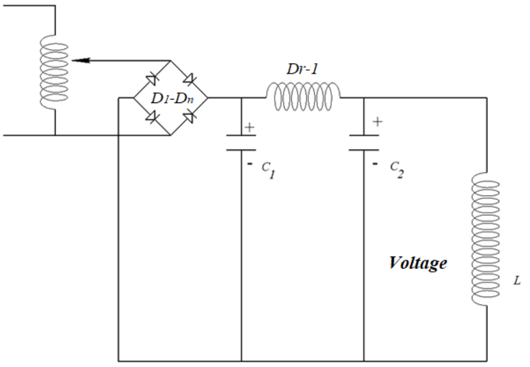

Figure 1: Scheme of a rectifier assembled from 4 D245A diodes to the magnetization of cutters

During the magnetic treatment process of cutters, a voltage was applied to the coil through the autotransformer equal to U = 220 volts (V), and the current strength was I = 3.75 Amperes (A). In all experiments, the cutter was magnetized for 3 minutes before it was installed in the tool holder. The residual magnetic induction on the cutters was determined using the ballistic method. In order to test this assumption, all experiments were carried out during the longitudinal turning of steel 40X [analog: AISI 5135] with a P18 [analog: AISI T1] HSS cutter. The cutting tools had a length of 250mm, and a cross-section of 20×20mm. These cutters were cut in the middle into two equal parts. Preliminarily, control resistance tests were carried out with these two cutters. After testing that the cutters provided the same durability, the main experiments were conducted. One of these cutters remained in its original position, and the second was magnetized. The cutter geometry was as follows: $\alpha = \alpha_1 = 8°$, $\gamma = 15°$, $\lambda = 0°$, $\varphi = \varphi_1 = 45°$. In these experiments, the cutting depth was t = 2mm, feed was s = 0.11mm/rev (table 1).

Table 1. Experimented HSS cutter's main geometric parameters and cutting modes

Tool geometric parameters	
Clearance angle – $\boldsymbol{\alpha = \alpha_1}$	8^0
Rake angle - $\boldsymbol{\gamma}$	15^0
Lead angles - $\boldsymbol{\varphi = \varphi_1}$	45^0
Feed - $\boldsymbol{s}$	0.11mm/rev
Cutting depth - $\boldsymbol{a_p}$	2mm

After completing each cutting movement in the experiments, the cutter was grinded to provide the same geometrical angles for the following experiment. The sharpening (grinding) of the cutting tools was conducted by using a semi-automatic grinding machine tool marked 3B625 [GOST] which was installed to provide similar tool angles shown in Table 1. In order to minimize the influence of the sharpening mode on the results of durability experiments, regrinding was carried out only on the flank surface of the HSS tool, and maximum attention was paid to the operation of sharpening the cutters in order to avoid burns during sharpening.

In the experimental tests to study the effect of the magnetic field on the intensity of the external environment's impact on the cutting process, lubricant, oxygen, and argon environments were created in the machining area. Dry cutting was also processed to compare the obtained results in diverse cutting environments.

In the gaseous environment, oxygen (O_2), and argon (Ar) were supplied into the chip-tool friction area along the rake face of the tool using a copper tube with an internal diameter of 6mm installed in the tool holder. Gases (O_2, and Ar) were delivered to the tube from a cylinder through a reducer, an adjustment valve, and a rotameter, connected by a rubber hose. The flow rate was set using a gearbox and an adjusting valve according to the indications of the RS-5 rotameter and amounted to 12÷16 l/min. As a lubricating fluid, machine oil was used in the tests, and the oil consumption was 10÷12 l/min.

3. Results and Discussions

According to the obtained results shown in Fig. 2. it can be seen that the simultaneous supply of oxygen to the cutting zone increases the durability of the cutter (tool life) compared to traditional dry cutting in air. Moreover, when a magnetically treated cutter is used in the incessant spray of oxygen environment created in the cutting zone, the tool life is increased by a greater amount. Creating an oxygen environment in the metal machining process improved the tool life by about 26 percent compared to traditional dry cutting. However, a magnetized cutting tool showed a better result (average 13%) in tool life rather than a non-magnetized cutter used in an oxygen environment. The best results were obtained when a magnetically treated cutter was used in an oxygen environment in machining. However, in all of the experimental conditions, tool life was decreased when the cutting speed was improved. It is also noticeable that at higher cutting speeds, the effect of the external environment is reduced (Fig. 2).

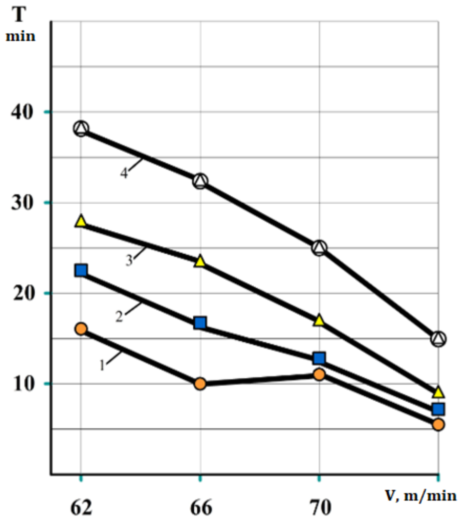

Figure 2: The influence of cutter magnetization and oxygen environment on the durability of cutting tools when machining steel 40X, s = 0.11 mm/rev. 1 - non-magnetized tool; 2 – oxygen environment; 3 - magnetized tool; 4 - magnetized tool + oxygen environment

The next series of resistance tests were carried out with a feed of s=0.18 mm/rev, and cutting speed was installed at V=52, 55, 58, 61, and 64 m/min, respectively. Further experiments were carried out at these cutting modes (Fig. 3). Positive and negative effects of oxygen on the wear resistance of the cutter were preliminarily determined.

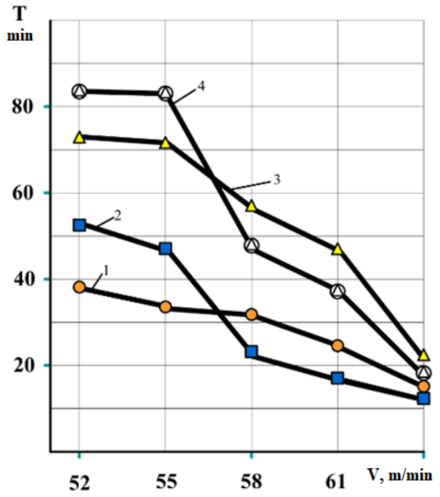

Figure 3: The influence of cutter magnetization and oxygen on the tool life when machining steel 40X, s = 0.18 mm/rev. 1 - non-magnetized tool; 2 – oxygen environment; 3 - magnetized tool; 4-magnetized instrument + oxygen environment

Analysis of the data obtained from the experiment shows that at cutting speeds V = 52, 55 m/min, an oxygen environment increases the durability of the cutter, and magnetic treatment of the cutting tool intensifies this increase. These results clarify an improvement in the positive effect of the oxygen environment on the durability of the cutter when the experimented tool is used after magnetically treated. From Fig. 3., it is also clear that the effect of the oxygen environment created in the metal cutting zone is negative at higher cutting speeds including V = 58 m/min, 61 m/min, 64 m/min, i.e. when oxygen is sprayed to the cutting zone, tool life is decreased, and the magnetization of the tool and the simultaneous supply of oxygen to the cutting zone lead to even lower tool life indications at high cutting speeds.

Further experiments were carried out on the same workpiece with another cutter with neutral gases of argon and oxygen supplied to the cutting zone. The experimental results are shown in Fig. 4. show that when argon is sprayed to the cutting zone, the wear of the cutter increases compared to dry cutting in air, and when oxygen is supplied, on the contrary, tool flank wear decreases.

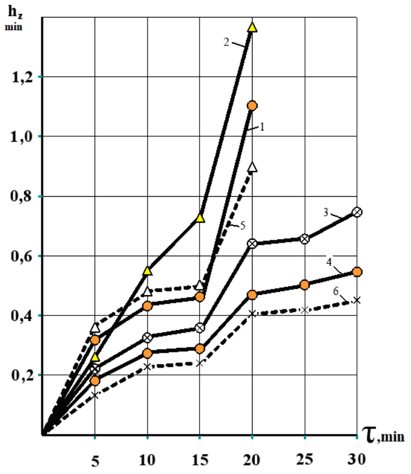

Figure 4: The influence of magnetization of the cutter and argon on the wear of the cutting tool when machining steel 40X, s = 0.11 mm/rev. 1 - non-magnetized tool; 2 - argon; 3 - oxygen; 4 - magnetized tool; 5 - magnetized tool + argon; 6 - magnetized instrument + oxygen environment

Magnetization of the cutter and the ceaseless supply of oxygen to the metal cutting zone leads to even lower values of wear on the flank surface of the cutter. These experimental data indicate that when neutral argon gas is supplied to the metal cutting zone, the formation of surface films on the rubbing surfaces between the tool rake face and chip is hampered due to the impossibility of air oxygen penetrating the cutting zone. When oxygen is supplied to the cutting zone, a favorable condition is created for the appearance of oxide films, which is ultimately intensified due to the magnetization of the HSS cutter.

Therefore, it can be assumed that the magnetization of cutters not only intensifies the process of interaction of the contact surface with the external environment but also changes the properties of the surface films. The oxidation process is intensified due to changes in the surface layers of the contact surfaces under the influence of magnetization. Therefore, the properties of the final film product will be different from the properties of films formed on non-magnetized cutters.

Currently, there are also several known ways for coolant to flow the cutting zone onto contact surfaces in the machining process. According to some authors, along with the well-known methods of coolant getting onto contact surfaces, its penetration is facilitated by such factors as chemical interaction forces, adsorption phenomena, and external electric and magnetic fields. The penetrating properties of the coolant are improved with a decrease in its viscosity and surface tension, a tendency to cavitation, and an increase in its heating temperature in a certain range [7, 30].

To clarify the effect of magnetic treatment of an HSS cutting tool on the effectiveness of the lubricant oil as a cutting fluid, experiments were carried out when machining stal 25 [analog: AISI 1025] with a P18 HSS cutter when supplying machine oil to the cutting zone by free-flowing method. The oil consumption was 10÷12 l/min. Moreover, oil consumption was checked before each experiment to ensure constant consumption.

Previous experiments have shown that when machining stal 25, the optimal rake angle of a magnetized cutter is γ = 15°. Therefore, in these experiments, a cutter with a rake angle of γ = 15° was used.

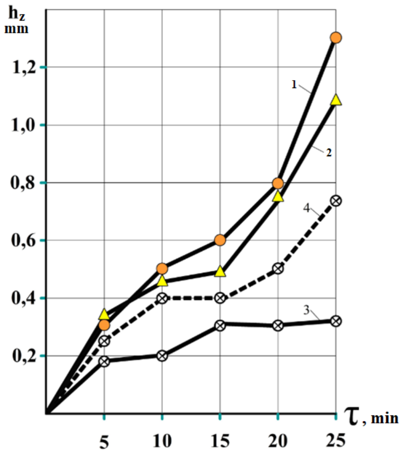

Figure 5: The influence of coolant and magnetization of the cutter on its wear when machining steel 25, V=146m/min, s=0.11 mm/rev, γ=15°. 1 - non-magnetized tool; 2 - magnetized tool; 3 – oil (coolant); 4 - magnetized tool + oil (coolant)

Fig. 5 shows that magnetization of the cutter to a certain extent reduces the flank wear of the cutting tool by an average of 8% compared to non-magnetized tool in the dry cutting environment, while magnetization of the cutter and the simultaneous supply of lubricating oil to the cutting zone at the same time reduces tool flank wear about 30% compared to a magnetized cutter. However, tool flank wear showed a noticeable decrease when using a non-magnetized tool in an oil environment compared to other experimented conditions.

Similar experiments were carried out when cutting the steel 25 with other cutting modes (V=90m/min, s=0.2mm/rev). The experimental results shown in Fig. 5. give information that under these cutting conditions, the magnetization of the cutter with the use of oil sharply reduces tool wear.

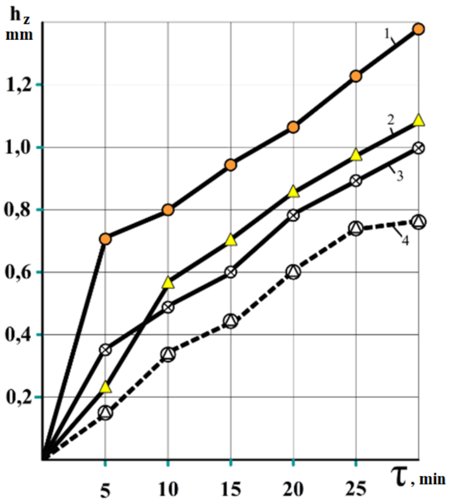

Figure 6: The influence of coolant and magnetization of the cutter on its wear when machining steel 25, V=90m/min, s=0.2 mm/rev, γ=15°. 1 - non-magnetized tool; 2 - magnetized tool; 3 – oil (coolant); 4- magnetized tool + oil

According to the results given in Fig. 5 and Fig. 6, it can be seen that when cutting in a coolant (oil) environment and simultaneous magnetization of the cutters, the wear resistance of HSS cutting tools changes, and this change depends on the cutting conditions.

The results of experiments conducted under production conditions also showed that when cutting with a magnetized cutter using oil as a coolant, an increase in the durability of the cutter was observed, as well as a doubling of the number of processed parts compared to cutting with a non-magnetized cutter. Considering similar phenomena during the friction of metals, some researchers believe that the oil acts as a screen that prevents the flow of oxygen into the friction zone since the oxygen content in lubricating oils is much lower than in the air [31]. However, this amount of oxygen may also be excessive under conditions with a relatively low level of structural-thermal activation, and under severe friction conditions with a high level of activation of friction surfaces, the amount of natural additive may be insufficient to regenerate films of secondary structures. This is explained by the fact that external environments, penetrating into the cutting zone, can influence the diffusion of atoms of C, W, and other alloying elements. Oxygen entering the zone can enhance the diffusion process.

When coolant is poured into the cutting zone, it can limit the flow of oxygen to the contacting surfaces, playing a kind of screen role. Therefore, under cutting conditions where oxygen reduces tool life, oil can reduce it. However, literature data indicate that oil, by creating surface films on the contact, can significantly increase resistance [32].

4. Conclusions

It can be assumed that the magnetization of cutters affects the properties of surface films formed in contact zones when cutting in a lubricant/gaseous environment. If magnetization led to an increase in the intensity of the formation of surface films, as was the case when cutting in an oxygen environment, the wear of cutters when cutting in coolant condition with magnetized cutters would be reduced compared to cutting in an oil environment with non-magnetized cutters.

Magnetic treatment of the HSS cutting tool before using machining Steel 40X improves the tool life by an average 58 and 70 percent in both dry and oxygen environments respectively. However, the intensity of the effect of all external environments showed a decrease when the cutting speed was increased. At the speed of 64 m/min, the difference among the tool life indications in all experimental conditions was not great at all.

Studies conducted on the tool flank wear proved that the magnetization of the HSS cutting tool improved the wear resistance of the cutter noticeably in all experimented gaseous environments. However, using argon gas as an external environment when cutting Steel 40X had a negative impact on the tool wear resistance. Magnetically treated HSS cutting tool used in an oxygen environment showed the best wear resistance in all experimented conditions indicating h_z=0.4mm wear after 20min of cutting while the non-magnetized HSS tool wear indications were above 0.6mm in all experimented gaseous environments.

Analysis of the data obtained in an oxygen and oil (coolant) environment leads to the opinion that changes in the efficiency of these environments depend on the magnetization of the tool. When using oxygen with magnetized cutters, the maximum effect occurs at relatively average cutting speeds (V=50 ÷ 60m/min). However, the efficiency of using an oil environment as a cutting fluid with a magnetized HSS tool has better results at high cutting speeds (V>150m/min).

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