Research Article

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Experimental study on turning machine with permanent magnetic cutting tool

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Abstract: Implementing a magnetic field on the cutting area during the machining process is one of the ways to increase tool life, as a result, reducing the machining cost. Due to this, numerous researchers conducted various studies in that field. However, there was no study which used a permanent magnet tool has been found. In this study, the effects of a permanent magnet cutting tool on tool life have been investigated extensively with a designed experimental setup. Experiments were conducted on the CNC turning machine with a permanent magnet HSS cutting tool in this study at a cutting speed of 51 m/min, feed rate of 0.1125 mm/rev and with a depth of cut of 1 mm. Significant deduction was obtained in flank wear and cutting force. The wear of the permanent magnet HSS tool was 50% less than the HSS tool without a magnetic field. It has been determined that the cutting force in the cutting process with the tool without an applied magnetic field was approximately 10.4% more than the permanent magnet tool. It was also observed that higher temperature and longer comma shape chips occurred in the cutting process using a permanent magnet tool.

Keywords: cutting tools, magnetic field, tool life

1 Introduction

The cost of cutting tools is one of the major expenses in the machining industry, something which the companies looking for a reduction. As a result of this tendency, researchers studied this field extensively. One of the methods for increasing tool life and reducing machining cost is to apply magnetic field on the cutting region.

The first study to reduce tool wear by applying a magnetic field was made in the early 1970s by Bagchi and Ghosh [1]. Bagchi and Ghosh developed a theoretical model to show how adhesion affects wear on the tool. This model was verified with their experimental studies which demonstrated that adhesion-induced wear on the cutting tool is significantly reduced when the magnetic field is applied to the cutting region.

The study of Bagchi and Ghosh gained the attention of other researchers globally. El Mansoria et al. designed an experimental test setup to investigate the effect of magnetic field on cutting tools and machining both non-ferromagnetic (304 L stainless steel) and ferromagnetic (carbon steel) workpieces with ferromagnetic HSS tool. In their experimental setup, a magnetic field was created by a coil which is integrated around the tool holder [2]. El Mansoria et al. found out that, at different cutting speeds, tool life increased about 30–40% for each workpiece. They also observed an increase in the temperature where a magnetic field has been implemented.

These findings with regards to increasing tool life during the machining process encouraged El Mansoria et al. to conduct further research in this topic [3]. In the new experimental setup, El Mansoria et al. investigated the magnetic field effect of machining on ferromagnetic AISI 1045 steel by using a non-ferromagnetic carbide tool in a dry environment. As a result of the experimental studies, they stated that the tool life increased approximately 2–3 times.

Another study, Dehghani et al. also conducted a series of experimental studies [4]. They machined alloy steel workpieces for investigating the effect of magnetic field on HSS tool. They designed an L-shaped apparatus to implement the magnetic field on the workpiece and the tool and assembled the apparatus on a conventional turning machine. The magnetic field has been applied by a coil wrapped around the apparatus, which then created a magnetic effect on both the workpiece and the tool holder. They repeated their experiments by using different process parameters. Consequently, it has been

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found that the maximum reduction is 94% in flank wear after applying magnetic field at spindle speed of 115 rpm, feed rate of 0.052 mm/rev and depth of cut of 1 mm. Also, the cutting force demonstrated a maximum increase of 66% at spindle speed of 190 rpm, feed rate of 0.162 mm/rev and depth of cut of 1 mm.

They claimed that the magnetic field increased the dislocation movement speed and the plastic deformation rate in the workpiece. However, they did not carry out a study to prove this increase or investigate the reasons behind it.

Anayet et al. have designed another experimental setup to investigate machining performance under the effect of the magnetic field on mild steels [5]. The magnetic field has been implemented by mounting magnets on the tool holder in the turning process. It was observed that there was a significant improvement in the machinability of mild steel when cutting with the magnet placed on the tool holder. They claimed that tool wear was reduced by approximately 25% and the quality of the machined surface was markedly improved when a magnetic field was applied.

Anayet et al. conducted another study on this subject with different materials [6]. In addition to the previous study, they have investigated the effects of magnetic field on machining performance for heat-treated steel. They found a significant increase in tool life and also an improvement in surface roughness by approximately 20%. In the studies performed by applying both heat treatment and magnetic field, they have observed a decrease in continuous chip formation.

Nadia et al. stated that the magnetic field increases the radial force, feed force and cutting forces and improves the tool life by approximately 20% during machining AISI 1018 low-carbon steel with carbide tool in a dry environment [7].

Li et al. investigated the cutting force, rake wear, surface roughness, cutting chips and thermal conductivity in titanium alloy cutting process to reveal the effect of magnetic field treatment on titanium alloy machining tools. They found that the treated tools improved wear performance of WC-6Co. Because the thermal conductivity of WC-6Co is increased by 6.5% after pulse magnetic treatment, the increase in thermal conductivity is helpful to heat dissipation and enhances the wear performance of the tools [8].

In the literature review, it was seen that the magnetic field was applied to the cutting region; however, there was no study on machining by using the permanent magnet tool.

In this study, the machining performance of the permanent magnet tool during the mild steel cutting was investigated.

2 Materials and experiment

In this study, unlike many studies conducted in the literature, instead of the external magnetic field assembly integrated into the machine tool, a rectifier and coil assembly which are completely independent of the machine tool were used in order to provide permanent magnetic characteristics to the cutting tool. With the rectifier and coil, the permanent magnet characteristic was given to the HSS cutting tool. In the experimental setup as shown in Figure 1, force and temperature measurements were made during the process with the help of a dynamometer (Kistler piezoelectric dynamometer-type 9257B) and laser thermometer (Optris Laser Sight IR) connected to the turning machine, and the



Figure 1: Experimental setup.

wear on the free surface of the tool was measured by an optical microscope (SOIF model optical microscope having 1.0 µm precision OSM model ocular micrometer was used) after each 100 mm of cutting.

In experimental studies, the HSS turning cutting tool, and AISI 104 steel workpieces were used. The HSS tool was first used without applying a magnetic field and wear measurements were inspected.

Ferromagnetic materials like steel tend to stay magnetized after being subjected to an external magnetic field. In this study, the HSS tool was subjected to a magnetic field in the coil for 2 h and the tool was given permanent magnet characteristics. The initial value in the tool with a magnetic field applied for 2 h is 400 Gauss. Figure 2 shows schematic magnetic field setup.

As a result of preliminary experiments, it was decided to apply the cutting parameters, which are displayed in Table 1 [2].

During the experimental studies, the flank wear of the cutting tool and the magnetic field intensities at the tip of the cutting tool was measured after each 100 mm cutting operation.

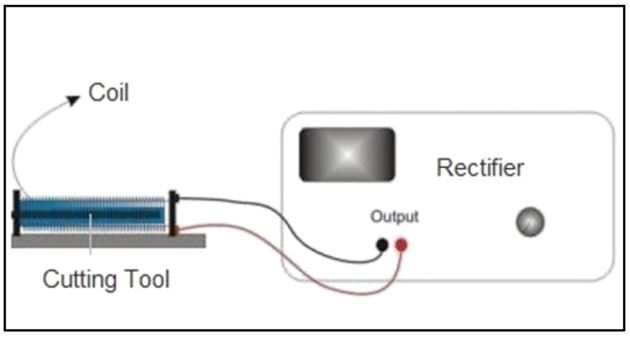


Figure 2: Magnetic field setup.

Table 1: Experimental conditions

Machine	CNC Goodway-GA-230
Cutting tool	HSS (DIN 4964/B)
Tool geometry	Rake angle γ: 10°, Flank angle α: 10°, and Wedge angle β: 70°
Workpiece	AISI 1040 steel
Workpiece geometry	D:80 mm and L:280 mm
Cutting speed	51 m/min
Cutting feed	0.1125 mm/rev
Cutting depth	1.0 mm
Environment	Dry

3 Results and discussion

The permanent magnet tool and the tool without an applied magnetic field was used during the cutting process by using the defined cutting parameters. It was observed that the permanent magnet tool wears less than the tool without an applied magnetic field. Figure 3 shows the flank wear values measured during the 100 mm cutting process. The parameters used in the study are given in Table 1. The flank wear observed on the tools after 500 mm cutting was measured as 252 µm in the HSS tool, while this value was measured as 126 µm by using a permanent magnet tool. The cutting process was continued with the permanent magnet tool and a total of 900 mm cutting was made. After 900 mm of cutting, the flank wear of the tool was measured as 241 µm.

HSS-M refers to the permanent magnet tool and HSS-N refers to the untreated cutting tool.

As a result of 500 mm cutting, it was observed that the wear occurred in the tool without the applied magnetic field was approximately 2 times more than the permanent magnet tool. The process was repeated until the wear observed in the permanent magnet tool reached the wear value obtained with the tool without an applied magnetic field and 400 mm more cutting was applied. Figure 4 shows the flank wear of the tools after 500 mm cutting, and Figure 5 shows the flank wear after 900 mm cutting with the permanent magnet tool.

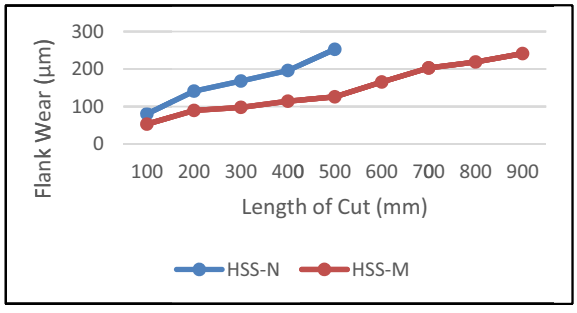
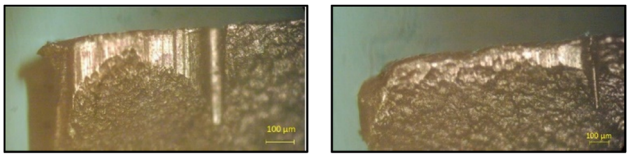


Figure 3: Flank wear graph according to experimental results.



(a) (b)

Figure 4: Flank wear after 500 mm cutting: (a) flank wear of the untreated cutting tool; (b) flank wear of the permanent magnet tool.

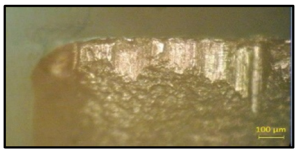


Figure 5: Flank wear after 900 mm cutting by using permanent magnet tool.

The magnetic field strength was also measured by taking a point on the tool as a reference while carrying out wear measurements. Before the cutting process, the initial value in the tool with an applied magnetic field for 2 h is 400 Gauss. As a result of 500 and 900 mm cutting operations, the magnetic field strength decreased to 362 and 337 Gauss, respectively. As a result of 500 and 900 mm cutting processes, the decrease in the magnetic field intensity of the permanent magnet tool was observed to be approximately 9 and 15%, respectively. This decrease in magnetic field strength was due to the heat and dynamic impact that occurred during the process. Figure 6 shows the magnetic field intensities measured from the reference point of the tool tip after every 100 mm cutting operation.

The force measurements were made during the cutting process by assembling a dynamometer on the machine tool. Figure 7 shows the forces acting on the tool which is without an applied magnetic field., while Figure 8 presents the forces acting on the permanent magnet cutting tool. While the average cutting force measured with the tool which is without an applied magnetic field was 393 N, the average cutting force measured in the permanent magnet tool was 352 N. It has been determined that the cutting force in the cutting process with the tool without an applied magnetic field was approximately 10.4% higher than the permanent magnet tool. The average feed force measured was, respectively, 256 and 224 N for the tool which is without an applied magnetic field and the permanent magnet tool. It was observed that the feed force was approximately 14.2% higher with the tool without an applied magnetic field.

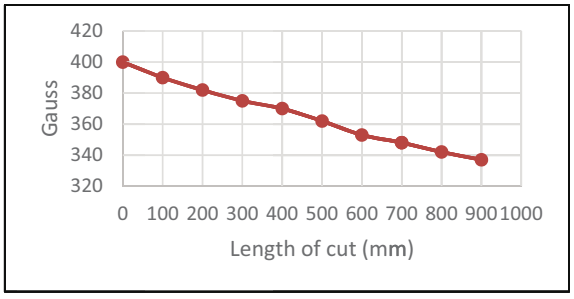


Figure 6: Magnetic field change on tool tip during cutting.

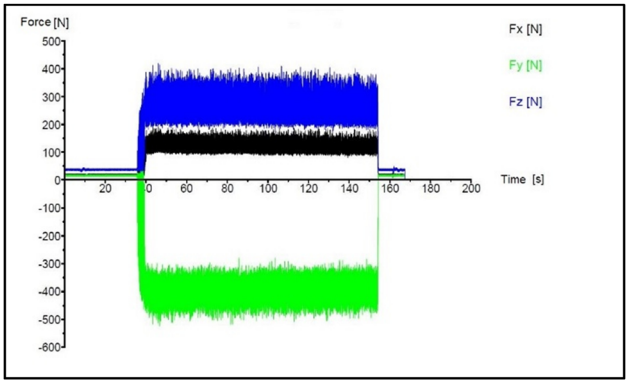


Figure 7: Forces on the tool without an applied magnetic field (HSS-N): F_x: radial force, F_y: shear force and F_z: advance force.

There was no significant difference between the radial forces. The average radial force measured was, respectively, 119 and 117 N for the tool without an applied magnetic field and the permanent magnet tool.

The temperature of the extreme point on the rake surface where the tool comes in contact with the workpiece was measured by using a laser thermometer. Figure 9 shows the graphs of the temperature values measured during the process. It has been observed that higher temperatures are reached during the cutting process with the permanent magnet tool. While the highest temperature measurement obtained was 156.4°C with the permanent magnet tool, it was observed that this value was 145°C for the tool without an applied magnetic field. It is thought that the difference in the temperature value measured at the tip of the tool arises due to the eddy currents caused by the permanent magnet tool [9].

Chip morphology during cutting operations was also investigated. Figure 10 shows the comparison of the chip forms obtained from the cutting process with the

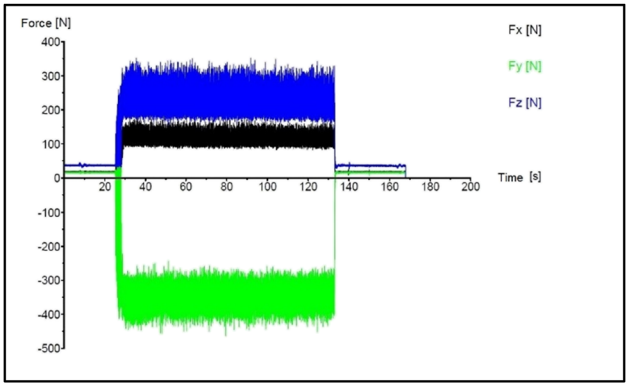


Figure 8: Forces on the permanent magnet tool (HSS-M): F_x: radial force, F_y: shear force and F_z: advance force.

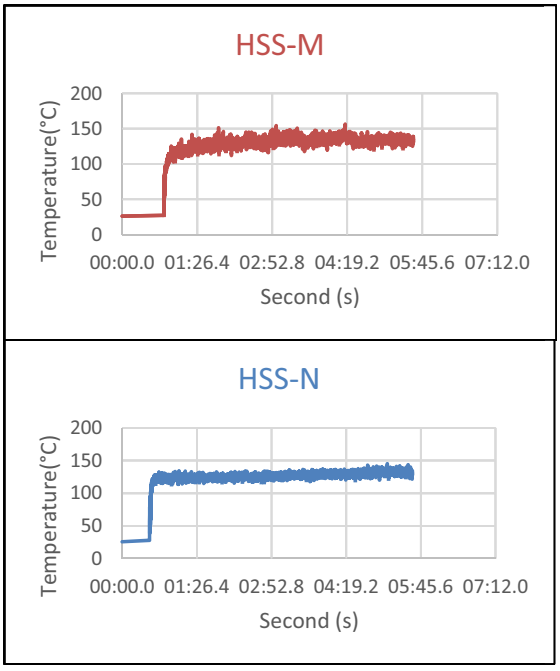


Figure 9: Temperature measurements during process.

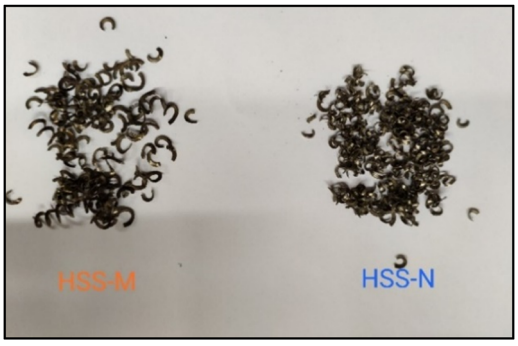


Figure 10: Chip forms obtained during cutting with magnet and non-magnetic tool.

permanent magnet tool and the chip forms obtained from the cutting process using the non-magnetic tool. It was observed that longer comma shape chips were formed in the cutting process using a permanent magnet tool.

4 Conclusion

This article discusses the influence of using the permanent magnet HSS cutting tool. The main conclusions of this research can be summarized as follows:

- The wear of the permanent magnet HSS tool was 50% less than the HSS tool without an applied magnetic field.
- While the average cutting force was measured as 393 N with the tool without an applied magnetic field, the average cutting force was measured as 352 N in the permanent magnet tool.
- The average feed force was, respectively, measured as 256 and 224 N in the tool without an applied magnetic field and the permanent magnet tool.
- There was no significant difference between the radial forces, the average radial forces were, respectively, measured as 119 and 117 N for the tool without an applied magnetic field and the permanent magnet tool.
- 8% higher temperature occurred during the process with the permanent magnet HSS tool.
- It was observed that chips in longer comma shapes were formed during the cutting process, which used a permanent magnet tool.
- The magnetic field strength, which decreases during the process, can be brought back to the initial value by applying an additional magnetic field to the tool.

This study delves into the application of gaining permanent magnetic properties to the cutting tool. It has been observed that tool life increases by using a permanent magnet HSS tool in the machining process. This also affects the tool change time positively. This method can be applied to all HSS tools, which are used in the machining industry. The study therefore concludes that using permanent magnet cutting tools can reduce the cost of machining.

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Conflict of interest: Author declares no conflict of interest.

Data availability statement: All data generated or analyzed during this study are included in this published article.

Ethical approval: The conducted research is not related to either human or animal use.

References

[1] Bagchi PK, Ghosh A. Mechanisms of cutting tool in the presence of a magnetic field. Indian J Technol. 1971;9:165–8.
[2] El Mansoria M, Pierrona F, Paulmierb D. Reduction of tool wear in metal cutting using external electromotive sources. Surf Coat Technol. 2003;163–164:472–7.
[3] El Mansoria M, Iordachea V, Seitiera P, Paulmierb D. Improving surface wearing of tools by magnetization when cutting dry. Surf Coat Technol. 2004;188–189:566–71.
[4] Dehghani A, Khalaj Amnieh S, Fadaei Tehrani A, Mohammadi A. Effects of magnetic assistance on improving tool wear resistance and cutting mechanisms during steel turning. Wear. 2017;384–385:1–7.
[5] Anayet UP, Mahmood MN, Arif MD. Improvement of machinability of mild steel during turning operation by magnetic cutting. Int J Adv Sci Eng Inf Technol. 2012;2(3):9–12.
[6] Anayet UP, Mahmood MN, Noor S, Shovon ZH. Investigation of machinability responses during magnetic field assisted turning process of preheated mild steel. Procedia Eng. 2013;56:713–8.
[7] Nadia JN, Aaron F, Azuddin M. Influence of electromagnetic field on metal cutting in turning operation of AISI 1018 low carbon steel. International Technical Postgraduate Conference in Materials Science and Engineering. Vol. 210; 2017. p. 012066. doi: 10.1088/1757-899X/210/1/012066.
[8] Li Q, Yang Y, Yang Y, Li P, Yang G, Liu J, et al. Enhancing the wear performance of WC-6Co tool by pulsed magnetic field in Ti-6Al-4V machining. J Manuf Process. 2022;80:898–908.
[9] Pal DK, Gupta NC. Some experimental studies on drill wear in the presence of an alternating magnetic field. J Inst Eng India. 1975;53:195–200.