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Investigation of the effect of the cutting fluid's flow rate on cutting parameters in turning AISI 1045

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The use of cutting fluids (CF) is regarded as one of the most efficient supplementary methods to lower production expenses and improve the quality of machined surfaces. In this study, the influence of CF's flow rate on machining performance of AISI 1045 was comparatively investigated in turning operations. The experimental design included different cutting velocities, feed rates, cutting depths and three flowing rates (2.5, 4, 6 l/min) of CF. 5% concentration of potassium dichromate ($K_2Cr_2O_7$) in water was used as a CF. The evaluation of machining performance was studied based on thermos-electromotive force (Thermo-EMF), chip shrinkage and formation, and tool wear characterization. The results indicated that high rates of fluid flow into cutting zone yielded better results in terms of reducing the thermo-EMF, minimizing tool wear and BUE, and improving chip morphology. It was then found that increasing the fluid flow rate during cutting leads to early fracture of the chip and the segmented chip formation. In addition, with an increase in the CF flow rate from 2.5 l/min to 6 l/min, the thermo-EMF generated during turning of AISI 1045 with titanium alloyed carbide tools decreased to 13%, and flange wear to 160%.

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1. Introduction

Cutting fluids (CF) play a vital role in machining operations by carrying out essential functions such as cooling, lubricating, and chip evacuation from the cutting area, thereby considerably enhancing overall machining performance. Several types of CF are widely used in mechanical processing of machine parts, including synthetic and semi-synthetic emulsions whose basis is water and oils [1–4]. Cooling and lubricating fluids reduce friction on the machined surface and increase the strength of the cutter. Lubricating and cooling fluids protect the workpiece and parts from rusting, preventing the formation of spots on the treated surfaces. The effectiveness of lubricating and cooling fluids depends on the chemical activity of the processed materials. CFs form an oxide film between the cutting tool and the workpiece, reducing tool wear, the formation of spots on the machined surface, and improving heat transfer. All types of CFs differ from each other in such specific properties as lubrication, cooling, cleaning of the cutting zone [5]. Water-based synthetic CFs are introduced into cutting processes due to their self-cooling properties, but their disadvantage lies in poor lubricating properties. Synthetic CFs are widely used in openwork processes, such as turning and milling [6].

To date, many scientists have conducted numerous studies on the development of new, modern varieties of CFs, improving their properties during the cutting process, etc. [7–9]. In particular, Ye Yang et al. [10] did research on developing new synthetic water-based cutting fluid for machining titanium alloys in the milling process. They studied the cutting force, tool wear, machined surface integrity and frictional torque in CF condition. They developed a novel composition of synthetic CF with some additives, and achieved the improvement of the tribological properties of the CF. Yousef Shokoohi et al. [11] investigated a combined cooling technique with adding thymus in a vegetable-based coolant. They turned an AISI 1045 steel part to study machining parameters including surface roughness and chip formation.

The flood cooling method in traditional cutting processes still retains its place as the most effective external cutting environment. CFs used in this method demonstrate very good lubricating and cooling properties, which contributes to a significant reduction in the production cost and improvement of the machining quality [12–14]. The pouring velocity of CF delivery into the cutting zone plays an important role in increasing its efficiency, as demonstrated by Changhe Li et al. [15] who experimentally studied the effect of fluid flow on grinding process. They conducted experiments under different fluid flow velocities and grinding wheel speeds, and confirmed that increasing the fluid flow one may heighten the efficiency. Toshiyuki Obikawa and his research team also studied the influence of cutting fluid flow on various parameters of machining processes [16, 17]. They mainly studied the high pressure coolant environment in machining difficult to cut materials. They investigated the improvement of the cutting fluid's pressure on fluid flow positively impact on the tool flank wear, and machined surface finish.

According to the literature review, despite the abundance of research on cutting fluids and their efficiency in metal cutting processes, comparative studies on the effect of CF's pouring rate on machining zone in flood cooling environment remain limited. The purpose of this research is to investigate the influence of the flowing rate of coolant on different machining parameters, including thermo-electromotive force (thermo-EMF) generated in the cutting zone, tool wear, and chip formation. Therefore, three different flowing speeds of water based synthetic CF and three types of different carbide tools were included in the experimental design. Details regarding the experimental conditions, setup configuration, and analytical findings are provided in the following sections.

2. Methods

Metal cutting, in particular, the turning process, is one of the most widely used traditional technological methods in mechanical engineering and the manufacturing industry. This is due to the fact that this process can provide high accuracy, surface finish, efficiency, and it has advantages in manufacturing parts made of various materials [18–20]. By in-depth study of the turning process under various conditions of application of lubricating and cooling fluids, it is possible to reduce energy consumption, improve surface quality, and improve the service life of the cutting tool [21–24]. The steel AISI 1045 was selected as the research object for the workpiece material for the experimental tests. It is characterized by a relatively high strength, good wear resistance, heat treatment suitability, and moderate welding properties. This steel is widely used in the machine-building, automotive, instrument-making industries, and the production of heat-treatable parts [25–27].

In the turning process, one of the most common machine tools, the 1K62 lathe having a maximum rotational speed of 2000 rpm was used. During the process of the turning experiments "W-shape" type uncoated carbide tool inserts were used. Experiments were conducted using three types of carbide tool materials such as T15K6, T5K10, and VK8 [GOST 388274, ISO 513-75] which are the analogues of HS123, HS345, HG30 according to DIN standards (Table 1, Table 2, Table 3). Carbide tool insert properties are given in Table 4. Cutting parameters in the

Table 1. Chemical composition of T5K10 [HS345] in %

WC, %	TiC, %	Cobalt, %
85	5	10

Table 2. Chemical composition of T15K6 [HS123] in %

WC, %	TiC, %	Cobalt, %
79	15	6

Table 3. Chemical composition of VK [HG30] in %

WC, %	Cobalt, %	Carbon, %	Iron, %
91.7	7.4–8	0.6–0.66	< 0.3

Table 4. Tool insert properties

Thickness, mm	5
Inscribed circle, mm	13
Nose radius, mm	2
Relief angle	0
Rake angle	10

experiments were the following: cutting velocity 85 m/min, feed rate 0.13 mm/rev, cutting depth 1 mm.

To conduct machining tests, experimental setup shown in Fig. 1 is installed. In this figure, there is also shown the thermo-EMF measuring setup. Natural thermocouple method of measuring thermo-EMF in the metal cutting zone with a special digital oscilloscope is used to indicate the thermo-EMF generated in the experimental conditions.

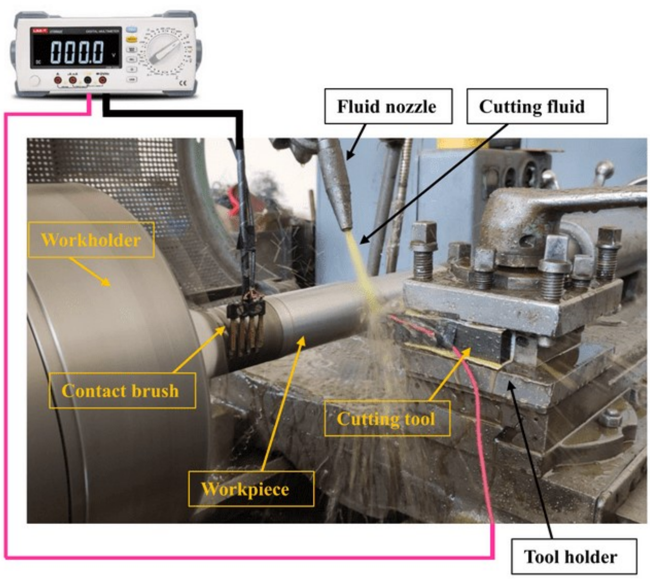

Fig. 1. Experimental setup

In this study, the flooding method of cooling with three different pouring speeds in the cutting zone was used as external environment. Synthetic type of water-based cutting fluid was selected as an effective and economically beneficial fluid in turning operations. During the initial preparation of the cutting fluid, references from existing studies, academic literature, and manufacturer's suggestions were carefully reviewed. Potassium dichromate ($K_2Cr_2O_7$) was used to prepare synthetic cutting fluid. Due to its strong oxidative properties, it is employed in numerous industrial and laboratory processes, notably in metal machining techniques. 5% mass concentration of potassium dichromate powder without any additives in distilled water was prepared as the cooling fluid in the turning tests. The selected cooling settings included a 2.5, 4, 6 l/min coolant flowing rate, a 60 mm spacing between the nozzle and the tool-chip interface, a 5.5 mm of nozzle hole, and a 15° spray angle of nozzle. The selection of cooling process parameters was based on a comprehensive literature review of previous experiments in similar studies.

3. Results

The primary objective of this study was to compare the influence of the cutting fluid flow rate on the turning process in the flood cooling method. The evaluation was carried out based on key performance indicators such as thermo-EMF generated in the cutting process, tool wear, types of chip shrinkage and formation characteristics. To ensure a robust comparison, three different flowing rates of coolant and the related cutting modes were employed, allowing for the analysis of cooling method performance under varying pouring conditions. In the experiments, carbide tool inserts made of three diverse types of grades were used. In total, 9 experimental tests were conducted to support the research.

3.1. Thermo-EMF generated in cutting zone

Intense plastic deformation and high friction at the tool-chip interface generate considerable heat during metal cutting processes. This heat is distributed unevenly among the cutting tool, workpiece, and chip, creating steep temperature gradients. In such thermally dynamic environments, the contact of dissimilar metals – typically the tool and the workpiece – leads to the generation of thermo-EMF due to the Seebeck effect [28]. Thermo-EMF provides an effective means of measuring cutting temperature without interrupting the machining process. By calibrating the voltage readings, one can estimate the temperature at the chip-tool interface, which is critical in analyzing tool wear and chip formation behavior. As the cutting-edge wears, the shape of the tool-workpiece contact changes, potentially altering the thermo-EMF. Continuous monitoring of EMF can be an early indicator of tool degradation or failure, enabling predictive maintenance. Thus, the analysis of the thermo-EMF in the tool-workpiece contact zone is quite essential.

The influence of the cutting fluid flow rate on thermo-EMF is shown in Fig. 2. According to the figure, the increasing cutting fluid flow rate in the cutting zone causes that the thermo-EMF generated in tool-workpiece contact zone decreases.

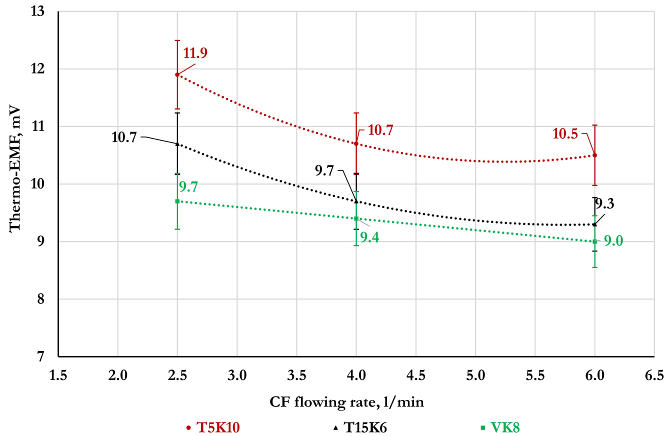

Fig. 2. Effect of cutting fluid flow rate on thermo-EMF

Moreover, the characteristics of the three types of carbide tools are different. Experiments conducted using a T5K10 brand carbide tool show that thermo-EMF reaches its maximum (11.9 mV) at the flowing rate of 2.5 l/min and starts to decrease when the cutting fluid flow rate increases. At the maximum flow rate in the experiment, the thermo-EMF decreased by 12% to 10.5 mV. In turning using a T15K6 brand carbide tool, the maximum value of thermo-EMF was 10.7 mV for the slowest flow rate, and it decreased by 13% when the flow rate reached 6 l/min. The results obtained for turning with VK8 brand carbide tool gave a similar decrease in EMF, however, the tool showed a much better strength. At the flowing speed of 2.5 l/min, the thermo-EMF was 9.7 mV, the lowest value compared to the other two cases.

3.2. Chip shrinkage

Chip shrinkage (chip compression ratio) is a critical parameter that reflects geometric transformation of the material under the shear exerted by the workpiece. Understanding this transformation provides valuable insight into the deformation behavior of the material under specific cutting conditions. The importance of chip shrinkage lies in its strong correlation with cutting mechanics. Analyzing chip shrinkage in machining is particularly important for optimizing cutting parameters. To study how shrinkage varies with the cutting ratio, feed rate, tool angles and lubricating-cooling methods, one needs to clearly understand the material removal process. This knowledge helps one to improve tool wear resistance, enhance work surface quality and reduce the cutting forces. Moreover, chip shrinkage directly affects chip morphology, which influences chip evacuation efficiency, surface roughness, and heat dissipation. Therefore, evaluating chip shrinkage is essential for both theoretical modeling of cutting mechanics and for practical decision-making in process planning.

Studying chip formation helps one to characterize material behavior during machining, and serves as a diagnostic indicator for tool performance, process stability and overall machinability. Fig. 3 presents a comparative illustration of chip morphology observed in AISI 1045 steel during turning operations using three types of tool inserts under varying CF flow speeds. The first column shows the pictures of the chip curls and types removed using three material types of tool inserts in the cooling condition with 2.5 l/min CF flowing rate, while the second and the third column present the results obtained in cooling conditions with 4 and 5 l/min CF flowing rates, respectively.

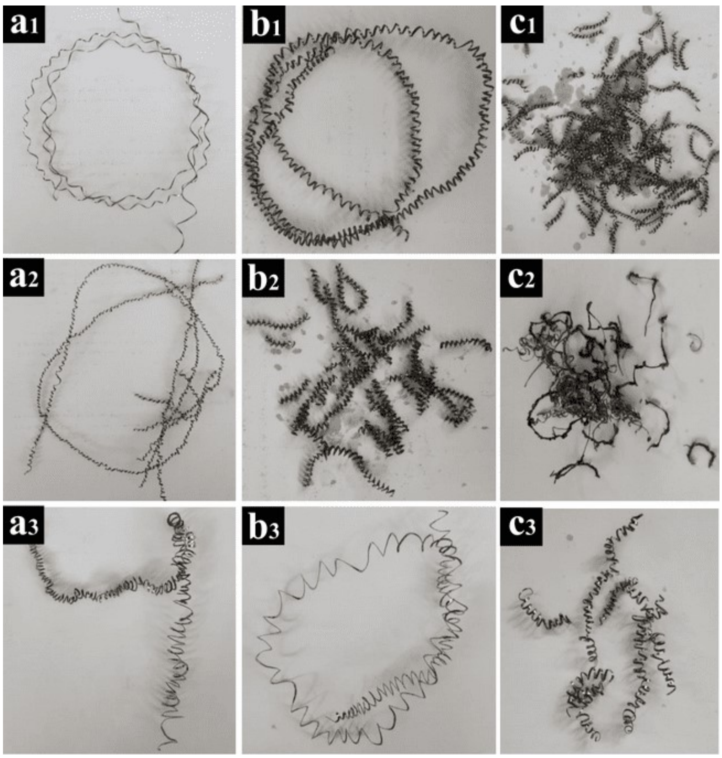

Fig. 3. Chip forms at 0.13 mm/rev feed, 85 m/min cutting speed; (a) CF flowing rate – 2.5 l/min, (b) CF flowing rate – 4 l/min, (c) CF flowing rate – 6 l/min

According to the figure, it is generally clear that all nine types of chips are different, and this diversity can be mainly connected with the cutting tool material. The experiments conducted in the same cutting modes using three different cutting tool materials indicate that a change in the cutting tool material causes a significant change of the shape of the resulting chip. This phenomenon can be associated with an increase in the temperature generated in the cutting zone and, as a consequence, with different wear of the cutting tool. If we pay attention to the diversity of the formed chip in different cooling media, we can see that an increase in the flow rate of CF into the cutting zone causes that the length of the chip decreases. In such a case, an increase in the CF flow velocity leads to a corresponding decrease in the temperature in the cutting zone, and as a result, the fracture of the chip accelerates. The high-speed inflow of CF into the cutting zone accelerates heat exchange in the zone and causes the CF to flow closer to the chip and the tool interface. In the experiments conducted using all cutting tools in the cooling condition with the pouring rate of 2.5 l/min (Fig. 3a_1, a_2, a_3), one can see the formation of continuous chips. In the following experiment with increasing flow velocity, the length and thickness of the chip decreased (Fig. 3b_1, b_2, b_3). In the last experiments, conducted at a flow rate of 6 l/min, segmented chips were formed (Fig. 3c_1, c_2, c_3). These results can be attributed to the deformation of the chip and the decrease in temperature in the cutting zone.

Fig. 4 shows the values of the chip shrinkage coefficient obtained during the turning process of steel AISI 1045 by pouring CF into the cutting zone at three different flow rates. The results presented in this graph are obtained in experiments using three different carbide tools. As can be seen from the results, an increase in the rate of CF inflow into the cutting zone leads to an increase in the chip shrinkage coefficient, which is different for the three experimented cutting tool inserts. The greatest increase was observed in the experiments with a carbide tool made of T15K6, i.e., at a CF flow rate of 2.5 l/min, where the chip shrinkage coefficient was 0.74, and in the experiments with a flow rate of 4 l/min and 6 l/min, where this indicator reached 0.96 and 1.56, respectively, which means a maximum increase by 50%. Also, in the experiments using carbide tools T5K10 and VK8, an increase in the fluid flow rate led to an increase in the chip shrinkage coefficient. In the

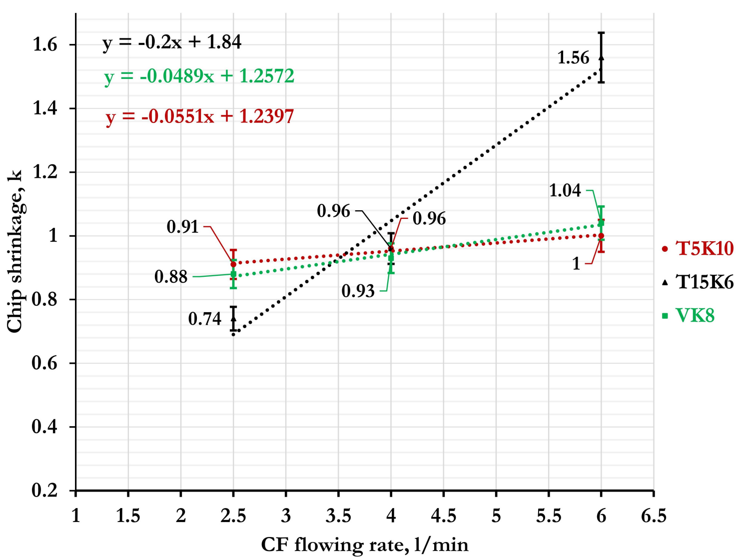

Fig. 4. Effect of cutting fluid's flowing rate on chip shrinkage

preliminary experiments with mechanical processing using T5K10 and VK8 in CF with a flow rate of 2.5 l/min, the chip shrinkage coefficient was 0.91 and 0.88, respectively, while in turning with a flow rate of 6 l/min, it was equal to 1 and 1.04, respectively. According to Fig. 4, the points obtained from the experiments conducted on each carbide tool follow a linear relationship.

Based on these results, one can say that a lower shrinkage ratio typically leads to a higher plastic deformation, which in turn is associated with increased cutting forces, elevated temperatures, and accelerated tool wear. Conversely, higher shrinkage values may suggest more favorable cutting conditions with smoother chip flow and reduced energy consumption.

3.3. Tool wear

Tool wear has a direct influence on various quality parameters that critically determine machinability, including tool wear resistance, energy consumption, cutting forces, thermal conditions in the process of metal cutting, and roughness of the machined surface. Therefore, comprehensive analysis of tool wear and providing appropriate recommendations is of great importance. In this study, the effect of three flow rates of synthetic CF on wear of three types of tool inserts was examined. To accurately evaluate the influence of cooling conditions on the experimental outcomes, machining parameters such as feed rate (0.13 mm/rev), depth of cut (1 mm), cutting speed (85 m/min), and tool nose radius were maintained at constant levels throughout the process. Microphotographs showing wear mechanisms of T5K10, T15K6, and VK8 carbide tool inserts in different cooling conditions of are given in Figs. 5–7.

Generally, in all experiments, the tool inserts were worn mainly along the flank surface and through the nose. Moreover, when turning was performed using cutting tools made of T5K10 and T15K6 carbides (Figs. 5, 6), one could observe the formation of BUE at low CF flow rates. Analyzing the wear mechanism of the carbide tool T5K10, showed in Fig. 5, we can find that the nose wear is the main wear type causing the cutting tool failure. In addition, with an increase in the flow rate of CF into the cutting zone, a decrease in nose wear and the BUE was observed. When the CF flow rate reached its maximum value in the experiment (6 l/min), no BUE was formed at the tip of the cutter, and the nose wear and the flank wear decreased. In the experiments conducted at low flow rates (2.5 l/min and 4 l/min), friction marks, adhesion, and slight plastic deformation were observed on the rake face of the tool insert. The traces of plastic deformation and chip abrasion can be attributed to the high temperature at the chip-tool interface. If CF is poured into the cutting zone at a low flow rate, it cannot prevent the increase in generated temperature, and as a result of heat, the wear and plastic deformation of the cutter increase.

Similarly, when conducting experiments using a cutting tool made of T15K6 carbide in 3 different cooling media, the formation of BUE at the tip of the cutting

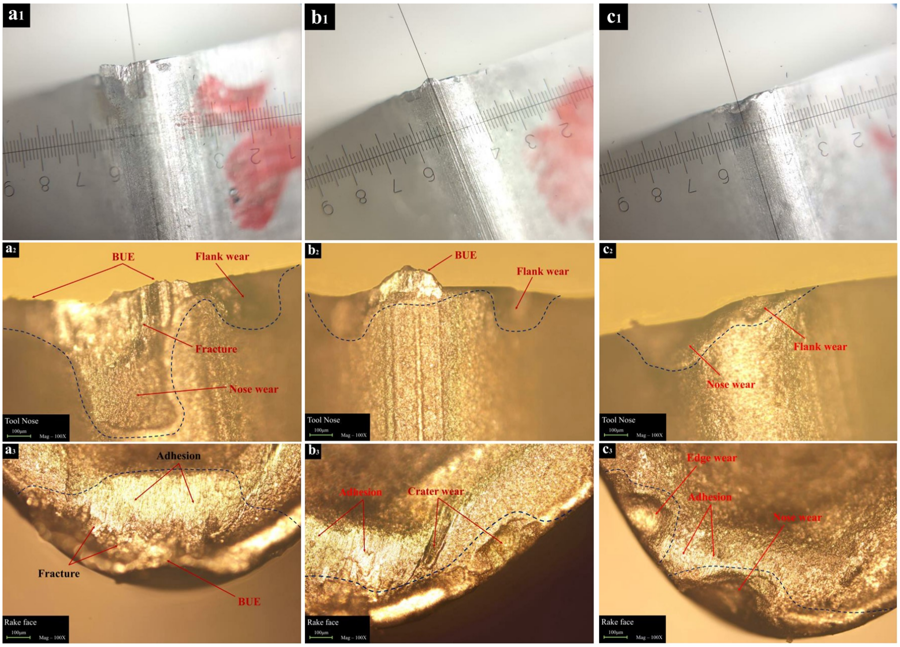

Fig. 5. Microscopic spectrum of tool wear mechanism. Tool material was T5K10. CF flowing rate in row a, b and c columns were 2.5 l/min, 4 l/min, 6 l/min, respectively

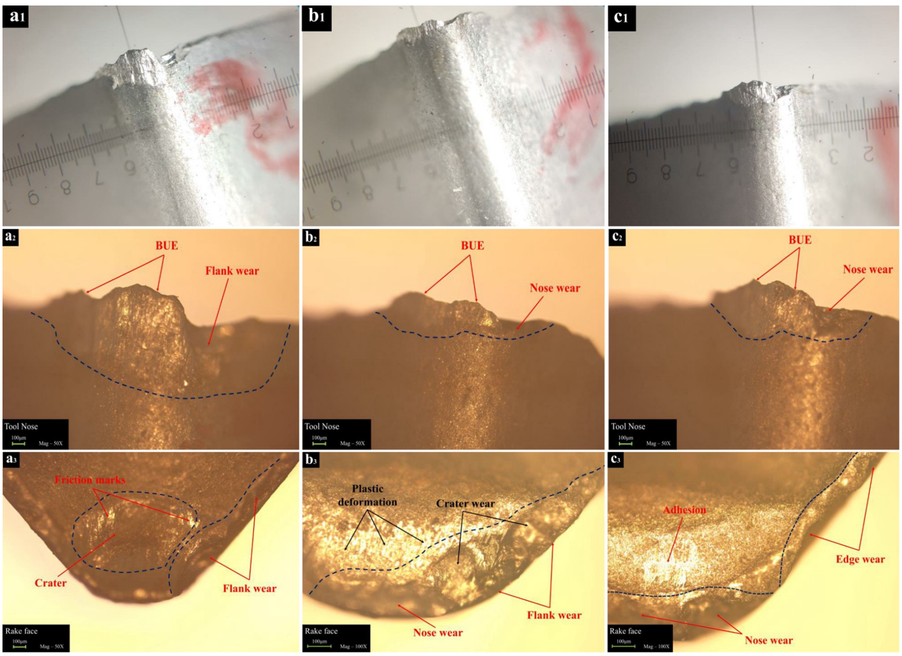

Fig. 6. Microscopic spectrum of tool wear mechanism. Tool material was T15K6. CF flowing rate in row a, b and c columns were 2.5 l/min, 4 l/min, 6 l/min, respectively

tool was observed (Fig. 6). BUE was also observed in three different flow velocity media in cutting with this tool insert. Similarly as in the previous experiment, the volume of BUE decreased with increasing CF flow velocity. In this experiment, the nose wear was also observed as the main wear criterion. Moreover, at low velocities of the CF flow, significant crater wear and plastic deformations from heat were observed on the rake surface of the tool. Flank wear of the cutting tool was also observed at low flow rates (2.5 l/min and 4 l/min).

The wear properties of the tool insert made of VK8 carbide material, showed in Fig. 7, indicate that the strength of this insert is higher than that of the other ones. Even in the experiments conducted at three flow speeds of CF, it can be seen that the tool wear was much smaller compared to the previous two tool wears. It is assumed that the main criterion of wear on this type of carbide is chipping and abrasive wear along the nose. At low CF flow rates (2.5 l/min, 4 l/min), fracture and wear occurred on the cutting edge of the tool. As in previous cases, this experiment shows that that there was slight friction of the chip at low flow velocities. The hardness of the tool material can be assumed as the main factor causing these types of wear. High hardness of the tool material prevents its plastic deformation. At the same time, in the result of friction at the chip-tool interface and intensive heat generation, the soft material of the chip adheres to the rake surface of the hard insert. However, as the CF flow rate increases to 6 l/min, the heat in the contact

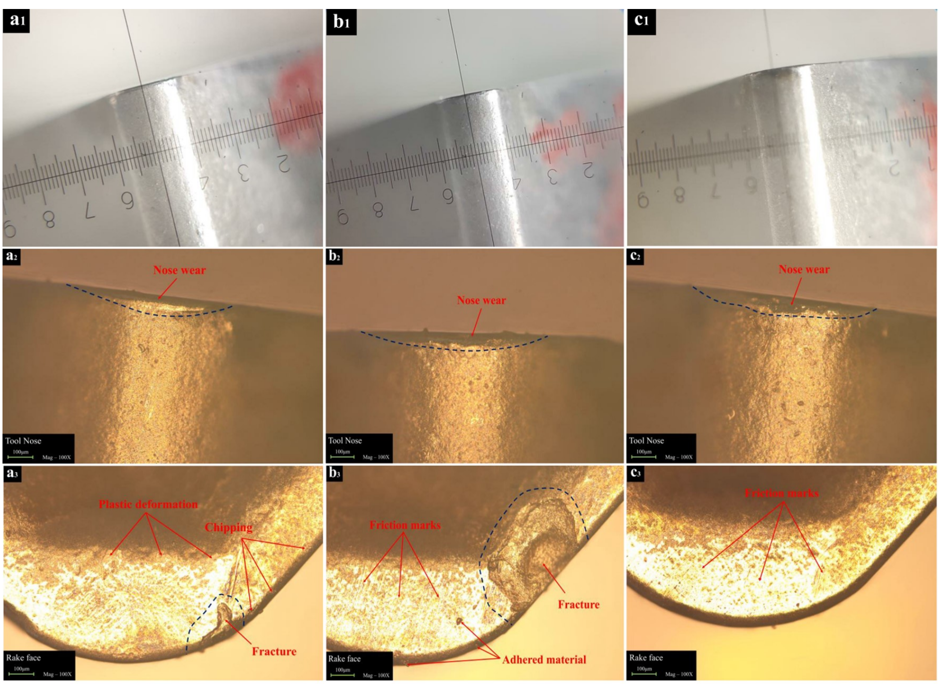

Fig. 7. Microscopic spectrum of tool wear mechanism. Tool material was VK8. CF flowing rate in row a, b and c columns were 2.5 l/min, 4 l/min, 6 l/min, respectively

friction zone is reduced, the high-speed fluid washes off the chip from the cutting zone faster, which prevents the adhesion of the chip material to the rake surface of the cutting tool.

The results of the above wear tests are presented in a line graph of tool flank wear developed on the cutting tool at different CF flow rates (Fig. 8). As can be seen from Fig. 8, with an increase in the flow rate of CF into the cutting zone, the wear of the cutting tool along the flank surface decreases. Fig. 8 shows that enhanced CF flow velocity decreases the tool flank wear in all cases of the investigated tool grades.

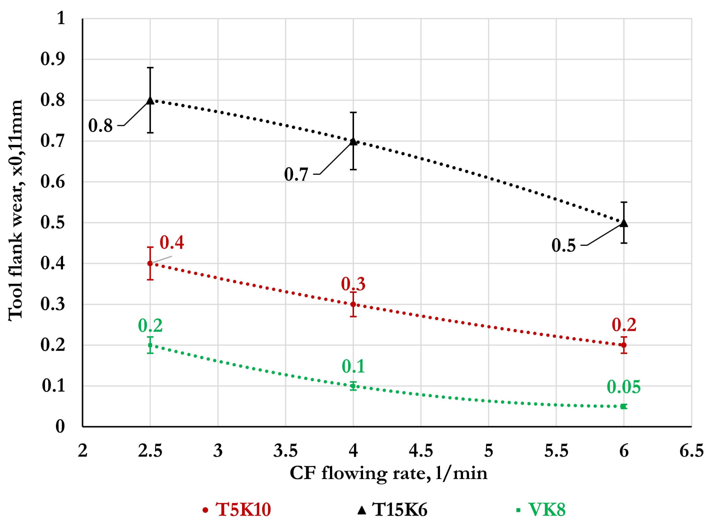

Fig. 8. Effect of cutting fluid flow rate on tool flank wear

4. Discussions

CFs play a special role in improving the mechanical processing of metals. It is easy to reduce cutting temperature, tool wear, increase tool life, and improve the surface quality of the machined part by using CF in the machining process [4]. To date, this has led to the development of many methods for using CFs in mechanical processing, including flood cooling, MQL, NMQL and cryogenic cooling [30, 31]. Each of these methods has its own area of application, advantages and disadvantages. Flood cooling technology is one of the oldest and most traditional methods [4]. Numerous studies have been conducted on the effectiveness of this method [32]. Mendes et al. [33] studied the performance of CFs in machining aluminum alloys. They found that the CF's flow rate noticeably improves the machining parameters. Fang and Obiwaka [16] studied the effect of CF's flow rate on tool wear using internally cooled inserts. They found that increased CF pressure improve the tool life. Moganapriya et al. [34] studied the influence of CF flow rate on the machining performance of AISI 1015. However, in most of the works carried out in this field, only the cutting tool wear and roughness of the machined surface were taken into account. However, few works investigated the influence of the CF flow rate on the machining performance during the machining of high-alloyed steels.

Table 5. Obtained results of the experimental study

CF flow rate, l/min	Thermo-EMF, mV			Flank wear, x0.11 mm			Chip shrinkage		
	T15K6	T5K10	VK8	T15K6	T5K10	VK8	T15K6	T5K10	VK8
2.5	10.7	11.9	9.7	0.8	0.4	0.2	0.74	0.91	0.88
4	9.7	10.7	9.4	0.7	0.3	0.1	0.96	0.96	0.93
6	9.3	10.5	9	0.5	0.25	0.05	1.56	1.00	1.01

Thus, this study was aimed at a comprehensive evaluation of the effect of cutting fluid flow rate on the turning performance of AISI 1045 steel, highlighting both practical and scientific contributions. The main contributions of the work can be summarized as follows:

- Tool life enhancement. In previous works, more attention was paid to the influence of CF flow velocity on the tool flank wear [34–36]. However, the influence of the cutting tool on the wear mechanism has not been studied comprehensively. Detailed analysis of wear mechanisms across multiple carbide tools (T15K6, T5K10, VK8) conducted in this study shows that the increased CF flow mitigates flank, edge and nose wear, as well as adhesion and crater wear, thereby extending tool life and reducing downtime. With an increase in the CF flow rate from 2.5 l/min to 6 l/min, T15K6, T5K10, VK8 tools' flank wear decreased by 160%, 160%, 400%, respectively.
- Improved chip control and machining efficiency. In previous works, the influence of CF flow rate on chip formation, the chip shrinkage coefficient in turning process were not studied [33–38]. However, by controlling chip formation during the cutting process, it is possible to control the process in a real working environment. Therefore, the study of chip formation at different CF flow rates is of great importance. In this study, the influence of CF flow rate on chip formation and chip shrinkage was also investigated. The results confirmed that faster CF flow facilitates segmented chip formation, minimizes long chip entanglement and improves machining stability, surface quality, and operational safety. In addition, the increase of the CF flow rate causes a linear increase of the chip coefficient. Specifically, with an increase in the CF flow rate from 2.5 l/min to 6 l/min, the chip coefficients generated by the cutting tools T15K6, T5K10, VK8 increased by 53%, 9%, and 15%, respectively.
- Optimization of heat transfer. This research demonstrates that higher CF flow rates (up to 6 l/min) significantly improve tool-chip interface thermal behavior. This result provides clear guidance for process optimization. In turning AISI

1045 blanks with T15K6, T5K10, VK8 cutters, increasing the CF flow rate to 6 l/min caused that the thermo-EMF generated in the cutting zone decreased by 13%, 12%, and 7%, respectively. This indicates a decrease in the cutting temperature.
- Comprehensive experimental insight. By combining multiple tool grades, flow rates, and machining responses, the study provides a robust dataset that can be useful for both industrial applications and future research on thermal and tribological effects in turning operations. Experimental studies have confirmed that the high CF flow rate improves heat exchange in the cutting zone and reduces friction in the chip-tool interface. This increases machinability of the workpiece.

Overall, the study confirms that careful management of CF flow rate is the key strategy for enhancing thermal control, tool longevity, and chip breakability, contributing to more efficient and reliable machining of AISI 1045 steel.

However, since the above experimental research work was carried out on synthetic water-based CF, the application of the results of this study in operations performed with other types of CF may not yield the same results. For example, when using oils as CF, the main function of CF is lubrication, while in synthetic CF, cooling is the main factor. Therefore, in the future, research on applying various flow rates of oils, semi-synthetic liquids, and emulsions using the flood cooling method can be considered a relevant area. In addition, a research on the influence of CF flow velocity on the surface microstructure of various metal alloys during machining is planned as a potential future study.

5. Conclusions

The effects of CF flow velocity on thermo-EMF, tool wear, and chip shrinkage were investigated during the turning of AISI 1045. Three types of carbide cutting tool grades (T15K6, T5K10, and VK8) were used in the experimental tests. The results of the experimental tests can be summarized as follows:

CF flowing into the cutting zone with the velocity of 6 l/min significantly reduced the thermo-EMF generated in turning AISI 1045. In the experiments conducted at 6 l/min flow velocity, the thermo-EMF decreased by 13% (T15K6), 12% (T5K10) and 7% (VK8) compared to the EMFs obtained at 2.5 l/min of CF flow rate in 85 m/min of cutting speed, 0.13 mm/rev of feed rate, and 1 mm of cutting depth.

It was found that the increase in the CF flow rate caused a linear increase in the chip coefficient. At the flow velocity of 6 l/min, the chip coefficient increased by 53% for T15K6, 9% for T5K10, and 15% for VK8 in comparison with the lowest flow condition. Chip formation improved noticeably with the increase of CF flow rate. Enhanced CF delivery promoted a transition from continuous to segmented chip formation, thereby reducing chip entanglement and contributing to improved machining stability, surface integrity and operational safety. Continuous chips predominated at flow rates of 2.5 and 4 l/min, whereas well-defined segmented chips with improved morphology and coloration were obtained at 6 l/min.

Moreover, increased CF flow velocity mitigates flank, edge, and nose wear, as well as adhesion and crater wear, thereby extending tool life and reducing downtime. Additional wear mechanisms such as adhesion, crater wear, and chipping were also observed. Across all tool materials, the application of a higher CF flow rate resulted in a significantly lower tool wear compared to the lower flow conditions. Notably, under low coolant flow rates, one observes increased occurrence of chip adhesion and welding on the rake face, which leads to the formation of BUE and pronounced plastic deformation. Experimental studies have confirmed that a high CF flow rate improves heat exchange in the cutting zone and lowers friction in the chip-tool interface. This improves machinability of the workpiece.

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