ASSESSING THE EFFECT OF MINERAL OIL-BASED CUTTING FLUID ON THE TOOL WEAR IN FACE TURNING

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Abstract

This paper discusses the wear of the turning tool bit in face turning under lubricated friction conditions. The test results obtained after wet turning, i.e. turning in the presence of mineral oil-based cutting fluid, were compared with the data registered under dry friction conditions. The experiments were performed on a CTX 310 ECO CNC machine tool. The tool wear after face turning was analysed using an SX80 stereo zoom microscope. The workpiece surface texture was studied with a Talysurf CCI Lite non-contact 3D profiler. A JSM 7100F scanning electron microscope equipped with an EDS microanalysis system was employed to identify the elements on the surface of the tool tips. The tribological tests were carried out with a T-01 M tribometer for a ball-on-disc configuration in the sliding contact. The use of the cutting fluid resulted in lower wear of the tool, as concluded from smaller depths of the wear tracks.

Keywords: Cutting fluid, turning, friction, wear

1. INTRODUCTION

Machining is a process that is crucial to the manufacturing sector [1, 2]. During machining operations, energy is used to produce deformation of the workpiece material and friction between the tool and the chip [3]. Friction then generates heat, which is responsible for lower dimensional accuracy, lower surface quality and higher surface roughness of the workpiece and a shorter service life of the tool [4]. It is thus essential that machining operations should be performed using cutting fluids with cooling and lubrication properties [5]. The two functions of the fluid contribute to a longer service life of the tool, smaller thermal deformation of the workpiece and its higher surface quality. The use of cutting fluids results in more efficient removal of chips from the cutting zone, higher effectiveness of the machining process and smaller cutting forces [6]; they also protect the workpiece against corrosion [7].

Cutting fluids have a significant impact on human health and the natural environment over the whole period of use. When cutting fluids containing mineral oil come into contact with human skin, they may cause various skin complaints such as dermatitis, folliculitis or discolouration. All skin disorders result from the use of additives, whose role is to alter the properties of cutting fluids and remove impurities [8].

The 2004 Health and Safety Executive (HSE) report shows that about 80% of all the occupational diseases associated with metal cutting are due to skin exposures to cutting fluids. Extensive research by chemists and tribologists on mineral oil-based cutting fluids is thus important to eliminate or control the above mentioned occupational health hazards [9].

2. MATERIALS

2.1. Cutting fluid

The tests were performed using Bechem Avantin 361 cutting fluid in the form of water-oil emulsion. The fluid is designed for general-purpose and heavy-duty machining of steel, cast iron, non-ferrous metals as well as aluminium alloys, brass and copper. Bechem Avantin 361 does not cause skin irritation to machine-tool operators. The basic parameters of the cutting fluid tested are provided in **Table 1**.

Table 1 Main parameters of Bechem Avantim 361 cutting fluid

Mineral oil content	pH value (5 %)	Corrosion protection (DIN 51360\2)	Refractometer factor
56 %	9.1	5.00 %	1.0

2.2. Tool and the workpiece

The tool used in the experiments consisted of a holder and replaceable 10 x 10 mm square tool bits made of high-speed steel (HSS). The material exhibits very good ductility, high impact resistance and high abrasive wear resistance. Its composition is shown in **Table 2**.

Table 2 Composition of HS6-5-2C steel

Elem.	C	Mn	Si	P	S	Cr	Ni	Mo	W	V	Co	Cu
wt. %	0.82 - 0.92	≥ 0.4	≥ 0.5	≥ 0.03	≥ 0.03	3.5 - 4.5	≥ 0.4	4.5 - 5.5	6-7	1.7 - 2.1	≥ 0.5	≥ 0.3

The workpieces were cylindrical in shape with a diameter of 38 mm. They were made of C45 steel, which is a non-alloy quality steel that can be hardened by heat treatment. Its chemical composition is presented in **Table 3.**

Table 3 Composition of C45 steel

Elem.	C	Mn	Si	P	S	Cu	Cr	Ni	Mo	W	V	Cu
wt. %	0.42 - 0.5	0.5 - 0.8	0.1 - 0.4	max 0.4	max 0.4	max 0.3	max 0.3	max 0.3	max 0.1	-	-	max 0.3

3. METHODS

3.1. Surface texture

A Talysurf CCI Lite optical profiler was used to analyse the surface texture of the workpieces after turning. The wear intensity was determined by means of an SX80 stereoscopic microscope.

3.2. Surface topography

A JSM 7100F scanning electron microscope equipped with an EDS micro-analyser was employed to identify the elements on the built-up edge after turning.

3.3. Turning process

Table 5 Parameters of the turning process

Workpiece speed n, m / min	Working diameter d, mm	Cutting speed v_c, m/min	Feed rate f, mm/rev	Depth of cut a_p, mm
400	38÷0	47.5÷0	0.098	0.5

The aim of the experiments was to determine the effect of the cutting fluid on the tool wear in the turning of C45 steel. The influence of the water-oil emulsion on the tool wear and the workpiece surface quality was assessed by comparing the results with those obtained under dry friction conditions.

Table 5 shows the basic parameters of the turning process.

3.4. Tribological tests

The tribological tests were performed according to the requirements of the ASTM G 99 standard using a T-01M ball-on-disc system. The test parameters were as follows:

- friction configuration: 100Cr6 steel ball-on-HS6-5-2C steel disc;
- load P = 50 N;
- sliding rate v = 0.1 m / s;
- sliding distance S = 1 000 m;
- relative moisture 50 ± 5 %;
- ambient temperature T_0 = 23 ± 1˚C;
- friction: dry friction conditions and lubricated friction conditions with the use of Bechem Avantin 361 cutting fluid.

4. RESULTS AND DISCUSSION

4.1. Surface texture

After turning, images of the tool bit surfaces were taken with an SX80 stereoscopic microscope. The microscope software was used to measure the tool wear. The results are shown in **Figure 2**.

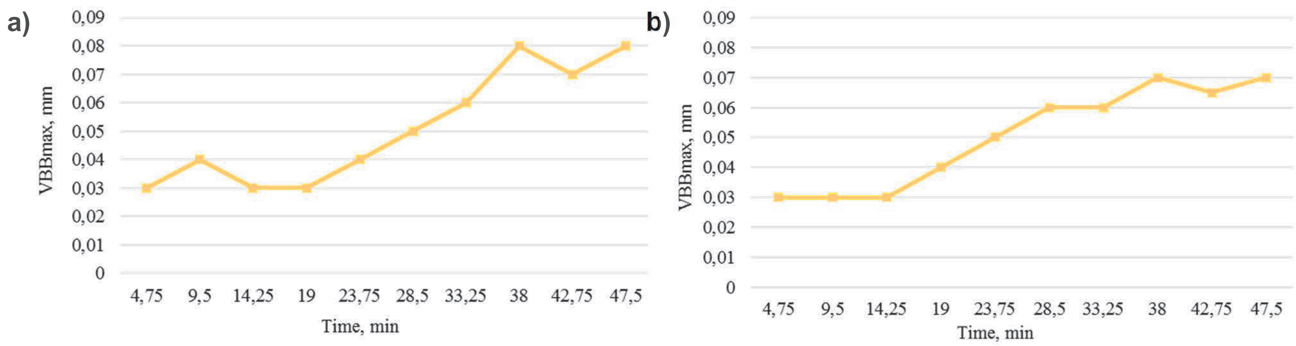


Figure 2 Tool wear after turning under a) dry friction conditions
b) lubricated friction conditions

From the comparative analysis it is evident that the maximum wear bandwidth, VB_Bmax, was lower in turning under lubricated friction conditions; after the 10th cycle it was 0.07 mm. By contrast, after turning under dry friction conditions, VB_Bmax was 0.08 mm. The VB_Bmax curves plotted for turning in the presence of the cutting fluid were more stable than those recorded for turning under dry friction conditions.

Figures 4 and **5** show surface topographies and surface roughness profiles obtained for the workpieces after turning under dry friction and lubricated friction conditions, respectively.

The surface topographies and roughness profiles reveal that lower peak heights and greater valley depths were recorded for C45 steel after turning in the presence of the water-oil emulsion. The average peak height was approx. 14 µm, while the average valley depth was about 10 µm. After turning under dry friction conditions, the average peak height was about 13 µm, whereas the average valley depth was approx. 10 µm.

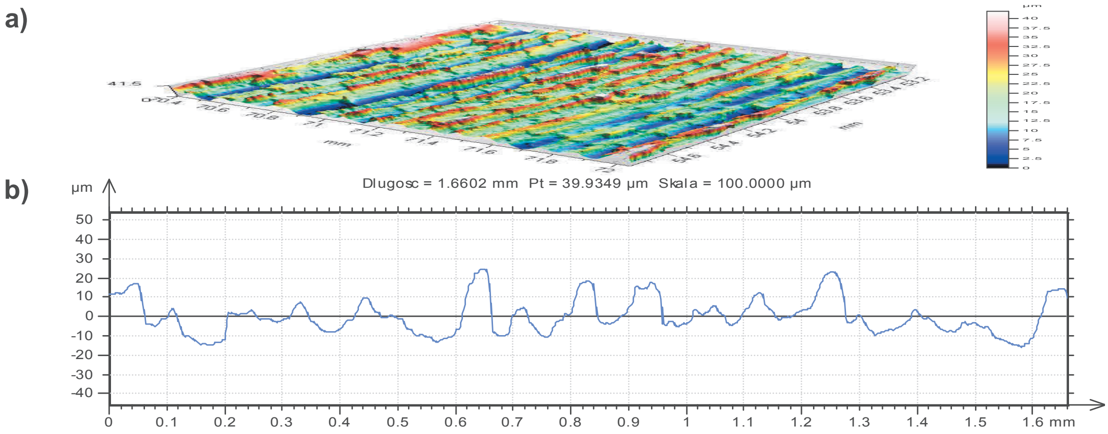


Figure 4 Workpiece surface after dry turning: a) 3D surface texture and b) roughness profile

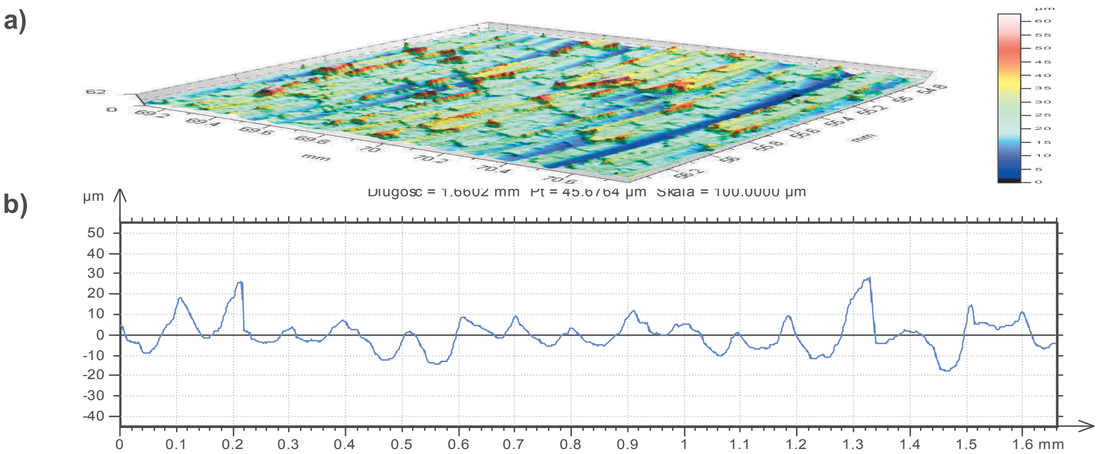
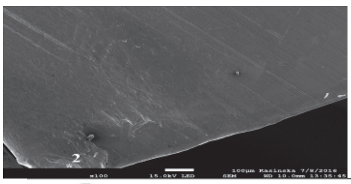


Figure 5 Workpiece surface after turning with cutting fluid: a) 3D surface texture and b) roughness profile

4.2. Surface topography

Figures 5 and **6** show SEM images of the wear track and X-ray energy spectra for the tool bits after turning under dry friction and lubricated friction conditions.

a)



b)

Result Type				Weight %				
Spectrum Label	Si	Cr	Mn	Fe	Ni	Cu	Mo	Total
2	0.50	0.27	0.77	96.43	0.34		0.01	98.33

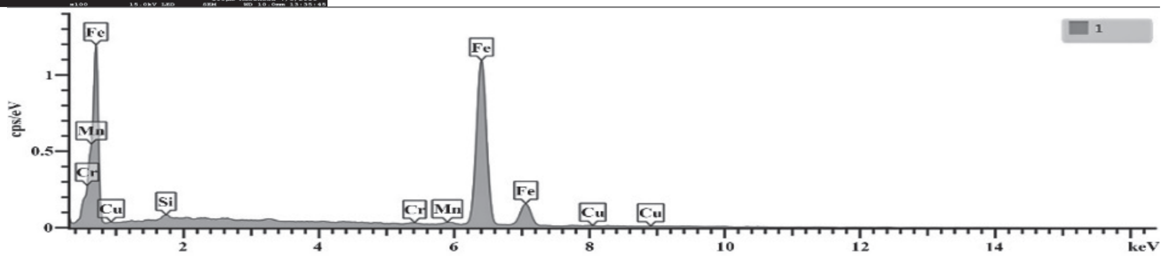
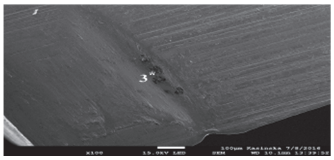


Figure 6 SEM analysis of the tool wear after dry turning: a) image of the wear track and b) X-ray energy spectrum

a) 

b)

Result Type	Weight %								
Spectrum Label	Si	V	Cr	Mn	Fe	Ni	Mo	W	Total
3	0.82	0.51	4.25	0.21	92.50	0.25	0.36	1.05	99.95

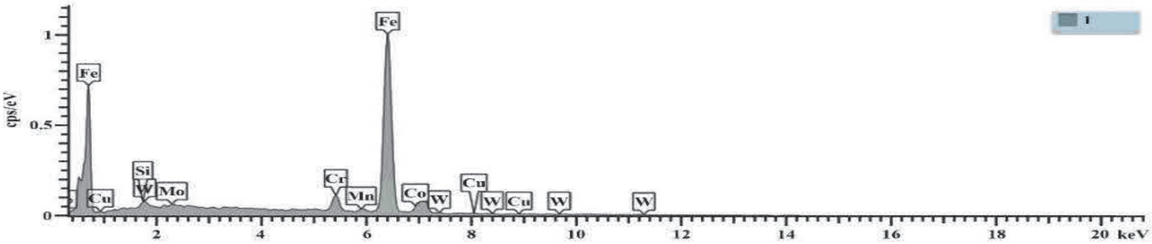


Figure 7 SEM analysis of the tool wear after wet turning: a) image of the wear track and b) X-ray energy spectrum

After dry and wet turning, a built-up edge was observed on the steel tool bits. When the process was performed with the cutting fluid supplied to the cutting zone, constituent elements of the tool material (tungsten W and vanadium V) were found on the built-up edge. By contrast, no such elements were observed after dry turning. This suggests that some workpiece material was locally transported.

4.3. Tribological tests

The results of the tribological tests were represented graphically to show the relationship between the coefficient of friction and the intensity of linear wear under dry friction and lubricated friction conditions for the HS6-5-2C steel ball and 100Cr6 steel disc configuration. The results registered under dry friction conditions were the reference data.

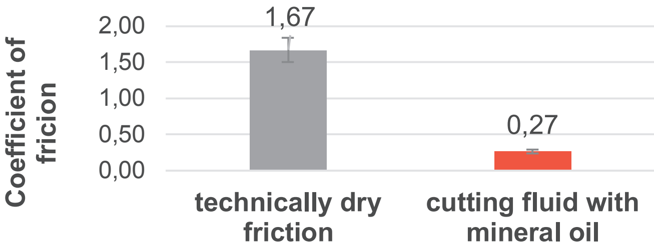


Figure 9 Coefficient of friction for dry and wet turning

Figure 9 presents the average values of the coefficient of friction for the ball-on-disc configuration operating under dry friction and lubricated friction conditions. The value of the coefficient of friction reported after wet turning was lower ($\mu \cong 0.27$) than that obtained after dry turning ($\mu \cong 0.67$). There is a clear difference in the coefficient of friction between dry turning and wet turning.

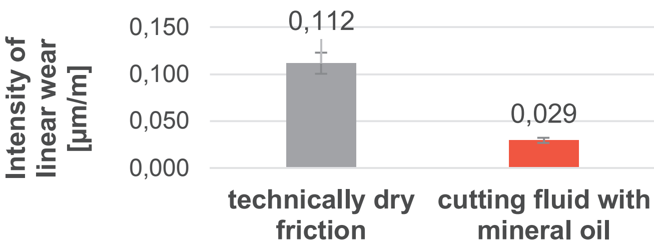


Figure 10 Intensity of linear wear for dry and wet turning

Figure 10 compares the tool wear under dry friction conditions with that under lubricated friction conditions. The intensity of linear wear obtained after wet turning (w ≅ 0.029 μm) was lower than that reported after dry turning (w ≅ 0.112 μm).

5. CONCLUSION

The increased demand for cutting fluids that do not cause allergy in humans and can be used safely during production is a result of higher workplace health and safety requirements. This article has looked at the latest trends in cutting fluids that are safe for machine-tool operators.

The test results reveal that after the turning process conducted in the presence of the selected cutting fluid, the analysed coefficients describing the tool wear at the flank face, i.e. the maximum and average wear bandwidths (VB_Bmax and VB_B, respectively), were higher than those obtained under dry friction conditions.

The SEM analysis of the tool bits indicates that during dry turning there was a local transport of material from the workpiece.

From the surface topographies and roughness profiles obtained with an optical profiler it is evident that after wet turning the workpiece surface was smoother with lower peak heights and smaller valley depths.

The tribological data suggest that the use of the cutting fluid resulted in lower tool wear. The coefficient of friction was more than 80 % lower and the intensity of linear wear was about 74 % lower when compared with the values recorded after dry turning.

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