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CUTTING FORCES IN DRY AND NEAR DRY CUTTING OFF MACHINING

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Abstract

The article presents research results on the effect of cooling and lubrication on the cutting force in cutting off process of A11and C45 steel rods using different rake face shapes and cutting parameters. The aim of the investigation was to determine outcomes of elimination (dry cutting) or reduction (minimum quantity lubrication – MQL) of a cooling and lubricating fluid in the cutting off process. It has been concluded that the minimum quantity lubrication allowed decreasing the cutting force compared to dry cutting. The impact of eliminating or reducing the quantity of the cooling and lubricating medium on the cutting force in the cutting off process of both types of steel depend on the applied feed rate and cutting speed. Taking into account environmental reasons, the dry and MQL cutting off is advisable and highly justifiable.
Keywords: *cutting off, dry cutting, MQL, cutting force*

1. Introduction

Lubricating and cooling liquids in cutting processes have a considerable impact on durability of cutting tools, dimensional accuracy and quality of machined surfaces. They also influence chip formation and all the phenomena in the cutting zone. As research has shown [1,7,9], machining without any cutting liquid (dry cutting) or with a minimal quantity of cooling and lubrication liquid is becoming more and more widespread in industrial environments. This can be attributed to more stringent environmental regulations, advancement in developing new tool materials and coatings, which increase tool durability as well as new solutions in machining equipment [2,5,6]. Eliminating cutting liquids from machining processes or their considerable reduction requires further investigation into the cutting process as well as determining optimal cutting conditions for different types of machined materials, which will lead to high quality surfaces obtained at reduced production costs [3,7,9].

The cutting forces are important features of the cutting process. One needs to know them to be able to determine the required power of a machine tool, tool life and ensure static and dynamic stability of the machining system. Their values depend on existing cutting conditions, including the cooling and lubrication mode of the cutting zone. Because of their importance for the cutting process, they should be taken into account while considering eliminating or reducing the application of cutting liquids [2,8].

The conducted research was aimed at determining cutting forces in cutting off machining of automatic A11 and construction C45 steel in dry and with minimum lubrication conditions in a wide range of cutting parameters.

2. Experimental procedure

The research was conducted on a TUD 50 lathe, equipped with an air-oil aerosol generator Accu-Lube Minibooster MBII. The steel samples were ø 30 mm rods made of both types of steel, whose composition and mechanical properties are presented in table 1 (according to PN-73/H-84026 and PN-93/H-84019).

Table 1. Chemical composition and properties of A11 and 45 steels

Steel grade	Chemical composition, %							
	C	Si	Mn	P	S	Cr	Mo	Ni
A11	0,07-0,13	0,15-0,40	0,50-0,90	≤0,06	0,15-0,25			
45	0,42-0,50	0,17-0,37	0,5-0,8	≤ 0,04	≤ 0,04	≤ 0,30	≤ 0,10	≤0,30

	Mechanical properties			
	R_e, MPa	R_m, MPa	A_5, %	HB
A11	400	500-750	8	159
45	340	620	16	207

The tool used in the research was a Mircona R-151S 2525x20x3 tool holder with interchangeable inserts made of TMC150 sintered carbide (P35 according to ISO) and CVD coated with TiC + Ti(C,N) + TiN, also produced by Mircona. The tool has been designed to be used with MQL equipment. The flat rake face (F) inserts had the following geometrical properties: κ_r=90° γ_o=10°, α_o=5°, α_o'=6° λ_s=0°, r_ε= 0,25 mm. In the case of the shaped rake face with a chip breaker (B) it was κ_r=90° and κ_r= 95° (Fig. 1).

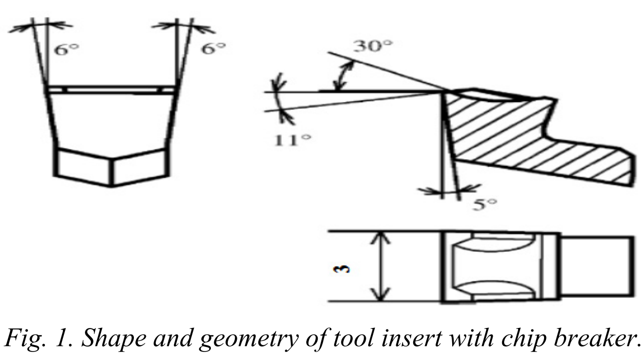


Fig. 1. Shape and geometry of tool insert with chip breaker.

In order to reduce tool wear on research results, for each cooling and lubrication mode a new insert was used.

The following cooling and lubrication modes were used:

MQL – minimal lubrication with oil aerosol,
D – dry cutting off, without cooling and lubrication liquid.
For MQL with Acu-Lube Minibooster MBII a LB8000 plant oil by Accu-Lube was used, which was designed for cutting steels, cast steels and non-ferrous metals. The aerosol generated by the Minibooster was fed into the cutting zone by means of channels in the tool holder, in the direction of the rake and flank face.
The cutting parameters used in the research are presented in table 2. Three different cutting speeds v_c and feed rates f were chosen. The cutting depth of cut was 3 mm, which equals to the width of the primary cutting edge.

Table 2. Cutting parameters

A11 steel					
κ_r=90°F , 90°B, 95°B					
$\boldsymbol{v_c}$ (m/min)	67	105			132
$\boldsymbol{f}$ (mm/rev)	0,08	0,08	0,19	0,24	0,24
45 steel					
κ_r=90°F					
$\boldsymbol{v_c}$ (m/min)	67	105			132
$\boldsymbol{f}$ (mm/rev)	0,08	0,19			0,24
$\boldsymbol{a_p}$ (mm)	3				

The cutting forces were measured with a Kistler 9247B force dynamometer connected to an amplifier and a computer with Dyno Ware software created by the manufacturer of the dynamometer.

3. Results and discussion

3.1. Cutting forces in cutting off A11 steel

The results of the research into an impact of the cooling and lubrication mode in the cutting zone on the total value of the cutting force in A11 steel cutting off machining are presented in fig 2. However the influence of the oil aerosol fed into the cutting zone depended on the used cutting parameters. For most cutting force values and feed rates employed in this research, the influence of the cooling and lubrication mode on the total force value proved negligible. The application of MQL in cutting off the A11 steel led to a decrease in the total cutting force in all the used cutting parameters. However, the influence of the MQL did not prove significant in each case. Apart from cooling and lubrication of the cutting zone, also the cutting edge angle and rake face shape proved to affect significantly the total force value.
For cutting off the A11 steel the greatest differences in this factor were observed for the following settings of the cutting speed and feed rate: 67/0,08; 105/0,19 for the insert with a chip breaker as well as 105/0,24 for the flat rake face. A comparison of cutting force values for cutting off with inserts with the flat rake face and with the chip breaker using the same angle κ_r=90° proved that shaping this surface for desired chip formation, which facilitates its movement in the groove, caused an increase in the cutting force, especially at higher cutting speeds and feed rates.

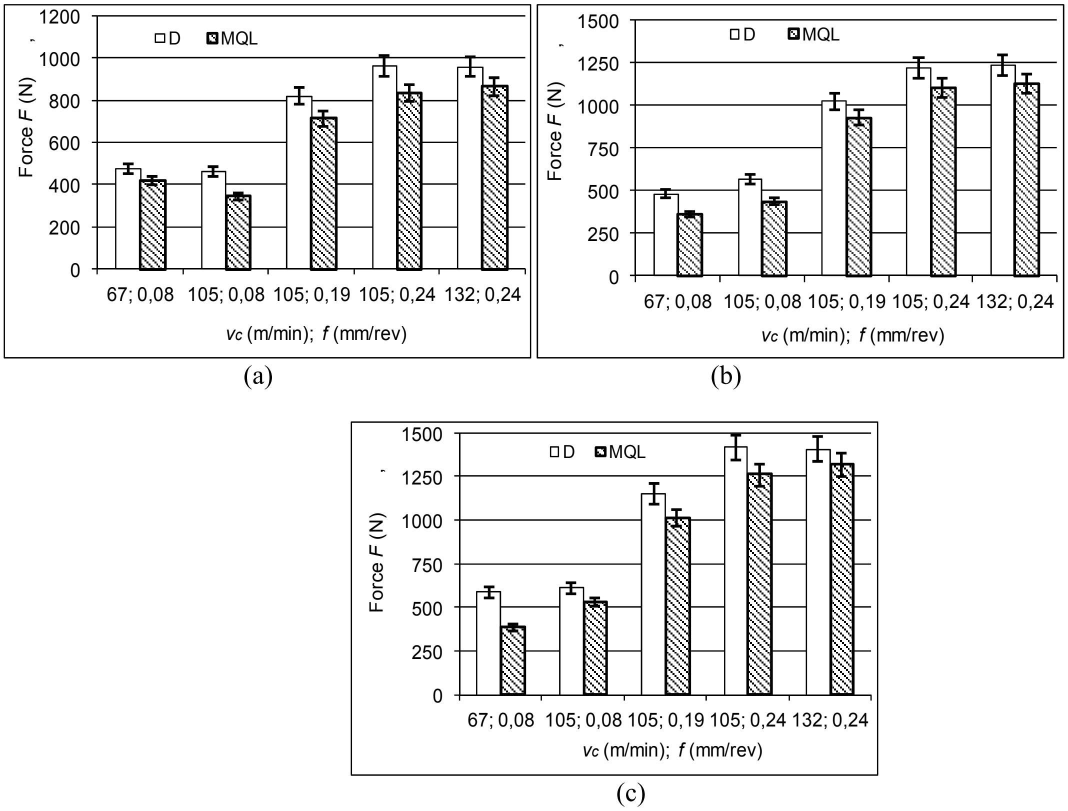


Fig. 2. Impact of cooling and lubrication mode on the total force F: a) κ_r=90oF, b) κ_r=90^{o}B, c) κ_r=95^{o}B

An analysis of the total force dependent on cooling and lubrication points to a positive influence of oil aerosol in the cutting off the A11 steel (fig. 3). In the range of used cutting parameters, the greatest impact on the total cutting force was exerted by the feed rate. Its increase always caused a significant increase in the cutting force and this holds for all cutting speeds set during the research. The impact of the cutting speed depends on the applied feed rate and increases as the feed rate increases. This contributes to a slight decrease in the cutting force resulting from a higher cutting temperature and a lower cutting resistance of the machined material. The impact of the cooling and lubrication mode is greater in the range of the increased feed rates (fig. 3b).

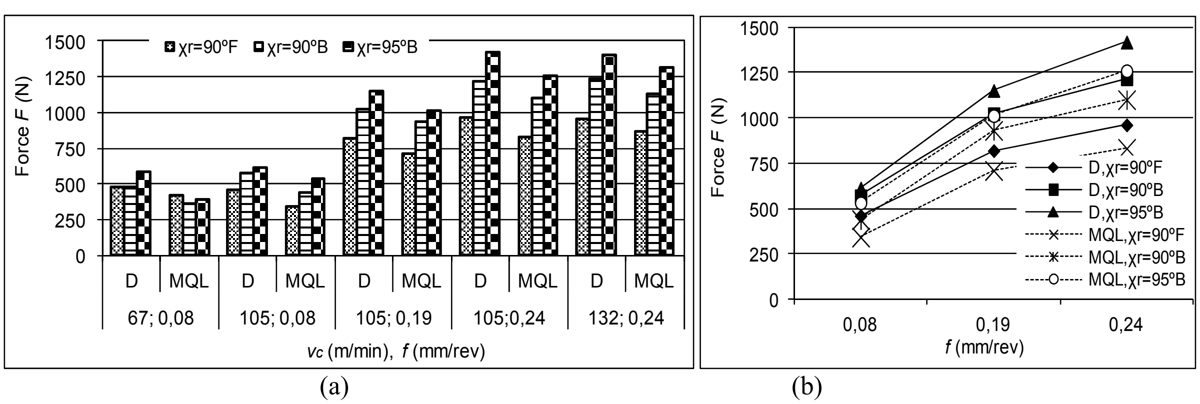
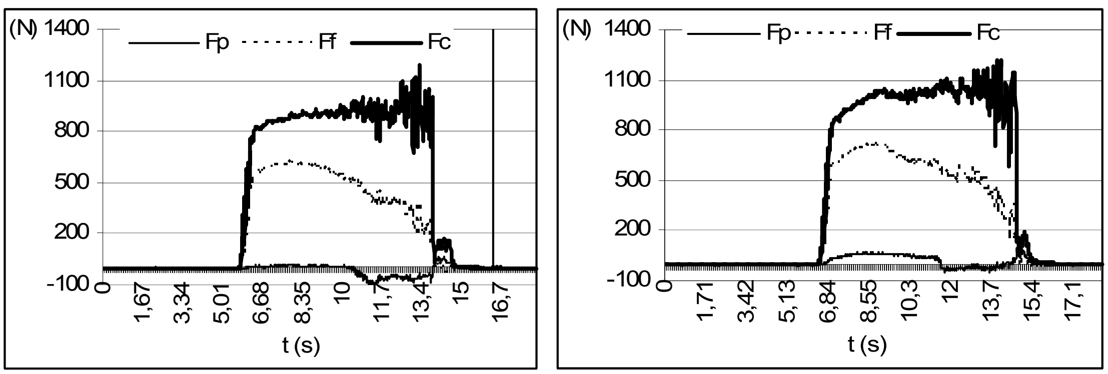


Fig. 3. Impact of κ_r angle, chip breaker and the cooling and lubrication mode (a) and feed rate (b) on the total force F

The progression of total cutting force components in the function of the cutting off diameter is shown in fig. 4. The greatest changeability especially at the end of the cutting off process was recorded for the cutting force component F_c, whose values increase or decrease in the final phase of the cutting off process as the cutting speed changes proportionally to the decreasing diameter of the machined sample. This is caused by unstable cutting conditions resulting from changes in tool edge angles during the cutting off process and its smaller cutting efficiency as well as from the loss of material continuity between the cut off object and the rod, which takes a form of a small pin on the rear surface of the cut off object. The diameter of the pin depends to a large extent on the tool cutting edge angle and for the angle κ_r=90° it reaches the highest values. The value of the F_f force ranges from 40 to 60% of the value of the F_c force and is characterized by greater stability during cutting. In the case of the angle κ_r=90° the force F_p takes minimum values around zero, which are negligible from the point of view of their impact on the other component forces as well as on the total force. An increase in the tool cutting edge angle up to κ_r=95° causes greater stability of the F_p force, but its value still remains low compared to those of the other component forces. Lubricating by means of oil aerosol did not reveal any significant impact on the component forces of the total force.



(a) (b)

Fig. 4. Component forces F_c, F_f, F_p of the total force: a) κ_r=90°B, cutting dry, b) κ_r=95°B, MQL

The cooling and lubrication mode in the cutting zone as well as cutting parameters have a considerable influence on the component forces. The dependence of the component forces F_c and F_f in the function of tool cutting edge angle and the shape of the rake face is presented in fig. 5.

For cutting speeds of 67 and 105 m/min and a feed rate of 0,08 mm/rev, the values of the component forces did not differ significantly although an increasing tendency was observed, which resulted from using a chip breaker and an increased tool edge angle. Clear differences between the values of the component forces appear at feed rates of 0,19 and 0,24 mm/rev. The highest values were recorded for an insert with a chip breaker and an angle κ_r=95°, the lowest for flat rake face. The dependence of the component forces in dry machining and machining with MQL are similar.

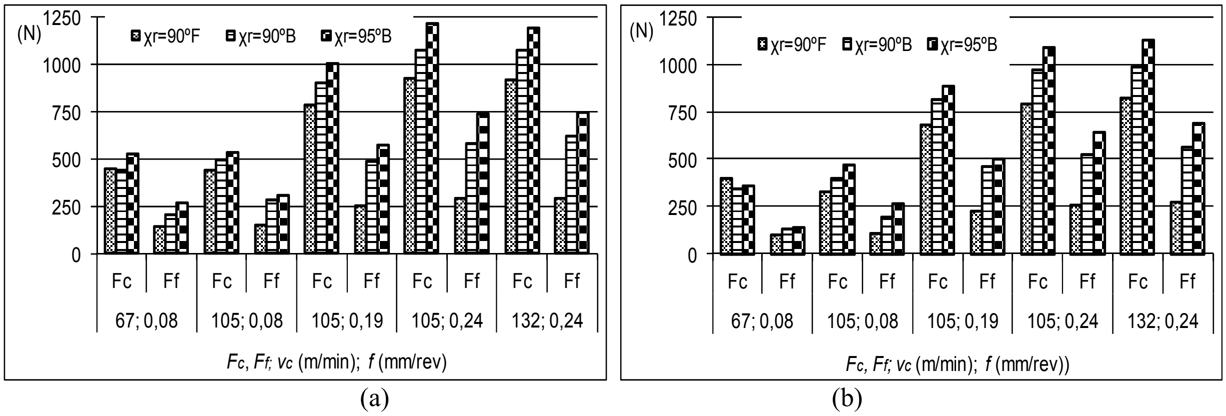


Fig. 5. Impact of κ_r angle, chip breaker and cooling and lubrication mode on component forces F_c and F_f in the range of used cutting parameters: a) machining dry, b) MQL

3.2. Cutting forces in cutting off C45 steel

The cooling and lubrication mode applied in the research into cutting off the C45 steel proved insignificant (fig. 6). In the range of used cutting parameters slightly lower values of the total force were observed in dry cutting off than in cutting off with oil aerosol. This considerably smaller impact resulted from worse access of the oil aerosol to the rubbing surfaces of the chip and tool point. A higher temperature in dry cutting of C45 steel may have caused lower material strength and thus a decreased cutting force. Minimal cooling and lubrication did not cause any significant differentiation of the component forces of the total force either. Depending on the cutting parameters, they had lower or higher values compared to dry cutting. The recorded cutting force for the same cutting parameters and tool point geometry was considerably higher for C45 steel than for A11 steel. For v_c=132 m/min and f=0,24 mm/rev the difference in the total force value as compared to A11 steel reached 25%, which means that the cutting conditions are much more difficult.

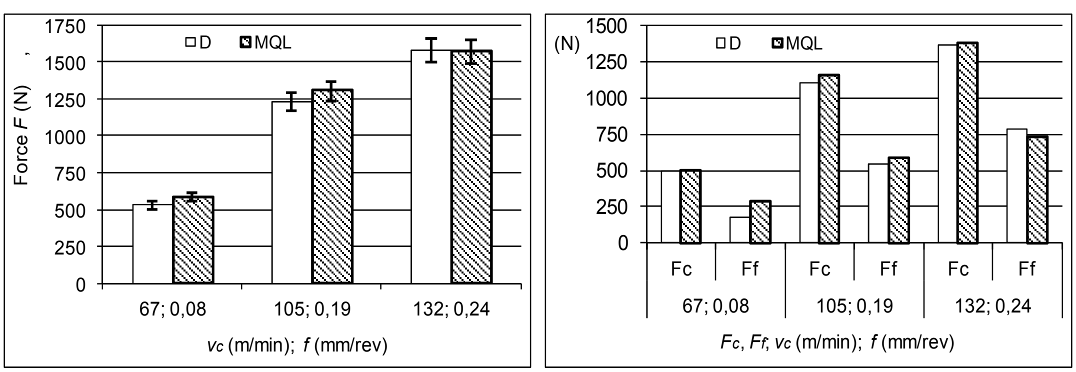


Fig. 6. Impact of cooling and lubrication mode on the total force F (a) and its components F_c and F_f (b), $\kappa_r=90^0F$

4. Conclusions

The conducted research has revealed a limited influence of minimal quantity cooling and lubrication in the cutting zone on reducing the cutting force as compared to dry machining in cutting off the A11 steel.

For the used cutting parameters minimal quantity lubrication allowed decreasing the cutting force compared to dry cutting. The action of the cooling and lubricating medium largely depended on the chosen cutting parameters.

In cutting off C45 steel the influence of minimal cooling and lubrication on the cutting force proved insignificant. The forces observed for the used cutting parameters were slightly lower in dry cutting off than in cutting off with MQL.

The research showed a significant impact of the cutting parameters on component forces and the total force in machining of both types of steel. The greatest impact was exerted by the feed rate and at a fixed feed rate the increase in the cutting speed caused the component forces and total force to decrease, especially at higher feed rates.

The research showed that with carefully chosen parameters it is possible to decrease the value of the cutting force in cutting off A11 steel. Replacing the conventional and generous application of machining liquid to the cutting zone with minimal cooling and lubrication helps reduce the negative impact of the machining liquid on the working environment.

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