

EXPERIMENTAL INVESTIGATION ON THE EFFECT OF COOLING AND LUBRICATION ON SURFACE ROUGHNESS IN HIGH SPEED MILLING

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Abstract: The article presents experimental investigations on the effect of cooling and lubrication conditions of the cutting zone on the surface texture after high speed milling of stainless steel 1.4301 and C45 steel in a wide range of cutting parameters. In the study three methods of cooling and lubrication were used: cooling with emulsion, minimal cooling and lubrication (MQL) and without emulsion – dry milling. The methodology and techniques of studies as well as their results and analysis of the effects of the investigated factors (conditions of cooling and lubrication and cutting parameters) on the geometric structure of the machined surface are presented. Conclusions regarding the impact of cooling and lubrication modes together with cutting parameters on the values of the analyzed surface parameters as well as their application recommendations are given too.

KEYWORDS: MILLING DRY, MQL, SURFACE TEXTURE, HSM

1. Introduction

The application of cooling and lubricating liquids in machining processes considerably influences the longevity of the cutting tool, machined surface quality, its dimensional accuracy as well as the physical phenomena in the cutting zone [1,2,4,11,13]. The phenomena such as the cutting temperature, cutting force and tool wear affect the results of a machining process, playing a crucial role in achieving the desired surface quality [2,7,8,9,10]. Apart from cooling, lubricating and chip removal functions, cooling and lubricating liquids negatively affect the natural environment and machining in which the oil usage is lower than 50 ml/h. How popular these methods become depends on the development of materials for tooling and their coatings which should be resistant to wear in high cutting temperatures, which are typical for high speed milling. Industrial application of dry and MQL machining for high speed machining calls for further research into the effects of eliminating or reduction of cooling and lubricating liquids on the quality of machined surfaces. This can be done by establishing a set of criteria to aid proper selection cutting parameters whose application will lead to the desired features of the surface layer. Milling soft and hardened materials with and without cooling and lubricating liquids has been the subject of numerous studies [3,10,11,12]. However hardly any covered the influence of MQL on the surface layer quality in high speed milling.

2. Research methodology

The research was conducted on a vertical milling machine FZ 22L made by CHIRON-WERKE GmbH, with 27 kW of main drive power, equipped in Minibooster MBII for minimal cooling and lubrication made by Acu-Lube Inc.. The 10x10x25 samples were made of 1.4301 austenitic stainless steel and C45 construction steel. The chemical composition and properties are shown in table 1.

Table 1. Chemical composition and mechanical properties

Steel	Chemical composition, %								
	C	Si	Mn	P	S	N	Cr	Mo	Ni
1.4301	<0,07	≤1,0	<2,0	≤0,045	≤0,03	≤0,11	17-19,5	-	8,0 -10,5
C45	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 _m , MPa		R _m , MPa		A ₅ , %		HB		
1.4301	205-310		515-620		40		215		
C45	340		620		16		207		

The top surface of the sample sized 10x25 mm was milled conventionally. The position of the MQL mist feeding nozzle to the machined workpiece helped to siphon the oil mist into the cutting zone by the turning tool teeth of the milling cutter when they cut

immediate work place surrounding. They also contribute to the overall cost of production. These environment related factors, increasingly higher costs of their application and stricter work safety regulations have led to numerous attempts to either eliminate or considerably reduce the amount of cooling and lubricating liquids used in the machining processes [5,6,7,8,9]. It is more and more common to use dry or minimum quantity lubrication (MQL)

The aim of this research is to define the influence of cooling and lubrication mode on the surface roughness in high speed milling of 1.4301 austenitic stainless steel and C45 construction steel.

into the machined material. The milling cutter used was SECO TOOLS R220.96-0063-08-6A with a diameter of 63 mm. The head was equipped with six universal cutting inserts SECO TOOLS XNEX 080608 TR-M13 with a MP 2500 (Ti(C,N) and Al₂O₃) coating. This coating is recommended for machining steels with and without cooling and lubricating liquid. In order to reduce the tool wear effect on the research results, new inserts were used for each cooling and lubricating mode.

The following cooling and lubrication modes were used, marked:

- E – 5% emulsion with a 4 l/min flow rate,
- MQL – minimum cooling and lubrication oil mist,
- D – without cooling and lubricating liquid – dry.

The oil mist was generated by Minibooster MBII and made from the Acu-Lube – LB8000 plant oil. It was fed into the cutting zone by a nozzle of a 2,2 mm diameter at a pressure of 0,3 MPa. The oil consumption was 50 ml/h. The emulsion was made from the Emulex Synti RHS emulgating oil of 80 mm²/s viscosity in 40 degC, recommended for machining steels, cast iron and non-ferrous metals.

The milling was performed at the following cutting parameters: cutting speeds v_c : 800, 1200, 1600 m/min, feed rates per tooth f_z : 0,05; 0,1; 0,15 and constant cutting depth a_p of 0,5 mm.

The measurements of the roughness value R_a of the machined surface was done on a Hommel – Tester T2000 profilograph with a TK300 sensor and a M1 DIN-4777 filter. The measurement parameters: elementary length: 0,80 mm, measured length: 4,8 mm, feed rate: 0,50 mm/s. The values were measured 5 times, based on the measurements average values and standard deviations were calculated.

3. Research results and analysis

3.1. Surface roughness after milling 1.4301 steel

The research results shown in fig. 1 revealed a significant influence of the cooling and lubrication mode on the surface roughness of 1.4301 steel. The lowest values in the majority of the cutting speed and feed rates used were recorded for MQL milling, especially at a feed rate of 0,05 mm/tooth (0,31 μ m). The surface roughness after dry milling was higher than that after milling with

emulsion but their variation depended on the cutting parameters used and increased as the cutting speed increased.

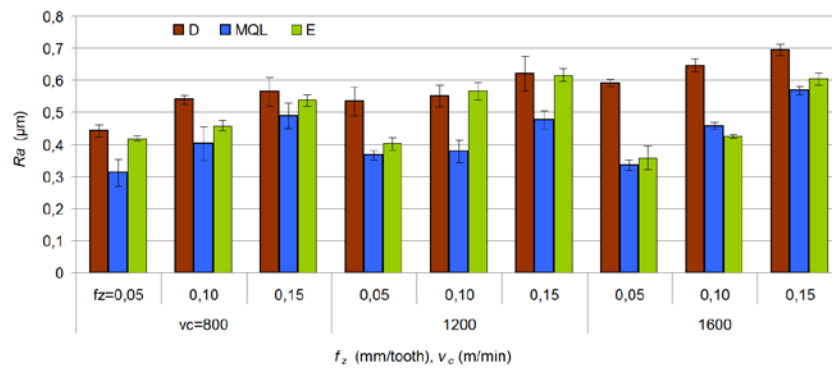


Fig. 1. The influence of the cooling and lubrication and cutting parameters on the surface roughness (1.4301 steel).

The influence of the cutting speed and feed rate in the used conditions of cooling and lubrication of the cutting zone is shown in fig. 2.

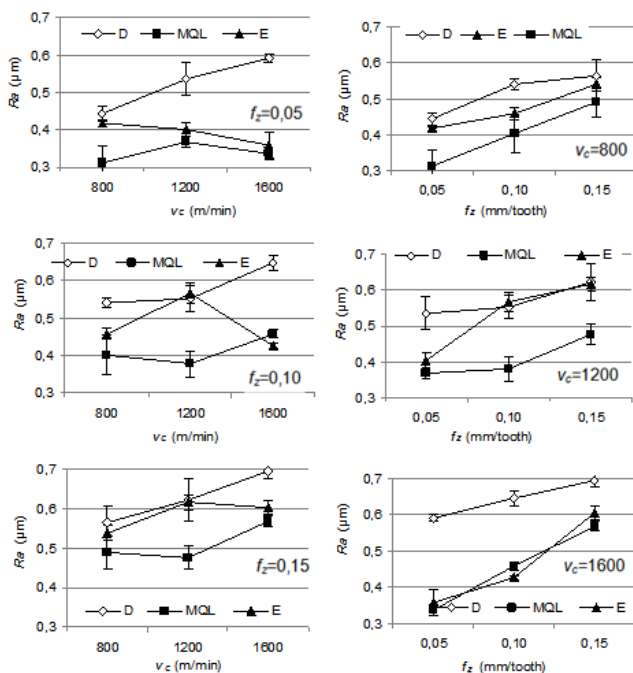


Fig. 2. The influence of the cutting speed and feed rate on the surface roughness in used modes of cooling and lubrication (1.4301 steel)

In the range of used feed rates per tooth, an increase in the cutting speed caused a considerable increase in the R_a value in milling dry. For the feed rate of 0,05 mm/tooth, increasing the cutting speed from 800 to 1600 m/min caused lower roughness in milling with emulsion. For MQL milling, lower roughness was observed at cuttings speeds between 1200 and 1600 m/min. Increasing the feed rate to 0,10 and 0,15 mm/tooth in milling with emulsion, the increase of the cutting speed from 800 to 1200 m/min led to a higher surface roughness, whose values along with the increased cutting speed (from 1200 to 1600 m/min) became lower or remained at a similar level. Applying MQL for milling at these feed rates with the speed increased from 1200 to 1600 m/min caused an increase in the roughness value, which may have resulted from hindered access of the oil mist into the cutting zone. The greatest value variation of the R_a parameter between dry and MQL milling

was recorded at the maximum cutting speed of 1600 m/min and a feed rate of 0,05 mm/tooth, and became lower as the feed rate increased. The low roughness of the machined surface (0,33 μm) at these parameters points to a positive impact of MQL to decrease the surface roughness in milling 1.4301 steel at high cutting speeds.

An increase in the feed rate caused a considerable increase in the surface roughness in the used range of cutting speeds and cooling and lubrication modes in the cutting zone. In the used range of feed rates, the greatest roughness – 0,69 μm was observed in dry milling at a speed rate of 1600 m/min and a feed rate of 0,15 mm/tooth. As the cutting speed increased the variation of the R_a parameter in milling dry and with MQL increased. The influence of the feed rate on this variation in milling with emulsion and with MQL was insignificant.

3.2. Surface roughness in milling c45 steel

The results of the research into the surface roughness R_a , depending on the cooling and lubrication mode of the cutting zone and cutting parameters in milling C45 steel are shown in fig. 3. They suggest a considerable influence of the cooling and lubricating medium on the surface roughness. The observed differences in the R_a parameter for various cooling and lubrication modes largely depended on the used cutting parameters. For most of the used cutting parameters the application of minimal cooling and lubrication resulted in a reduced surface roughness compared to milling dry and with emulsion. Eliminating cooling and lubrication liquid – milling dry, caused a lower surface roughness compared to milling with emulsion or the R_a values were comparable. The greatest reduction of the surface roughness compared to milling with emulsion was recorded for milling dry and with MQL at a high cutting speed of 1600 m/min and a low feed rate of 0,05 mm/tooth. A decreased surface roughness in MQL milling compared to machining with and without emulsion was recorded for higher feed rates (0,10 and 0,15 mm/tooth).

The influence of the cutting speed and feed rate on the surface roughness in milling C45 steel with the used cooling and lubrication modes is shown in fig. 4. An increase in the cutting speed from 800 to 1200 m/min in the range of the used cutting conditions caused an increase in the surface roughness. A further increase in the cutting speed to 1600 m/min at feed rates between 0,05 and 0,1 mm/tooth did not affect the surface roughness in milling dry and with MQL. However, as the feed rate increased to 0,15 mm/tooth a noticeable increase in the R_a value was observed for all the used cooling and lubrication modes, the variation in the R_a value for different cooling and lubrication conditions being insignificant.

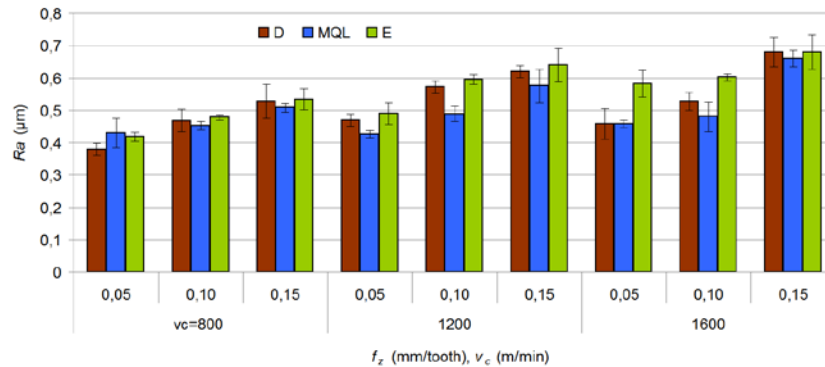


Fig. 3. The influence of cooling and lubrication mode and cutting parameters on the surface roughness (C45 steel)

The results of the roughness measurements revealed a considerable influence of the feed rate on the surface roughness of the milled surfaces in the range of the used cooling and lubrication modes of the cutting zone, confirming the kinematic-sterometric influence of the tool insert geometry and feed rate on the surface texture. At high cutting speeds (1600 m/min) an increase in the feed rate from 0,10 to 0,15 mm/tooth caused reduction of the positive influence of MQL on the surface roughness as a result of hindered access of the oil mist between the moving surfaces of the chips, tool insert and the machined workpiece.

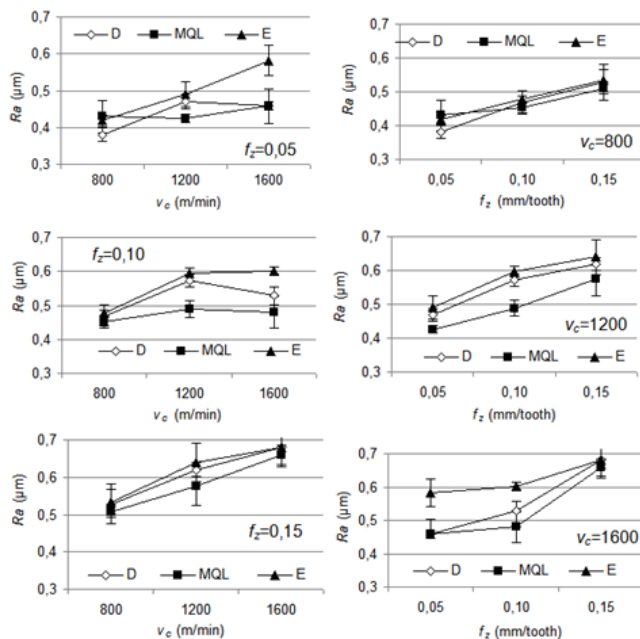


Fig. 4. The influence of the cutting speed and feed rate on the surface roughness in used modes of cooling and lubrication (C45 steel)

4. Conclusion

The conducted research revealed a significant influence of the cooling and lubrication mode of the cutting zone on the surface roughness in milling 1.4301 austenitic stainless steel and C45 steel. The action of the cooling and lubrication liquid depended on the used cutting speed and feed rates.

In the applied cooling and lubrication conditions and milling parameters, the application of the MQL mode brings clear advantages for machining the chosen materials.

Applying MQL in milling 1.4301 steel caused a considerable reduction of the surface roughness compared to milling with and without emulsion, especially in milling at a low feed rate (0,05 mm/tooth). The roughness parameter achieved in these conditions was below 0,40 μm . Eliminating the emulsion completely from

the machining process led to a significant increase in the surface roughness compared to the other modes of cooling and lubrication.

Applying MQL in milling C45 steel resulted in a lower surface roughness compared to milling dry and with emulsion. The values of the Ra parameter after milling with and without emulsion in the range of the used cutting parameters were comparable, which means that milling this material without emulsion is recommended.

Of all the cutting parameters, the greatest impact on the surface roughness of 1.4301 and C45 steels was exerted by the feed rate. Its increase caused the surface roughness to increase and the action of the cooling and lubrication became less effective. The influence of the cutting speed on the surface roughness in milling depended on the cooling and lubrication mode. As it increased, the value of the Ra parameter either decreased or increased.

5. Literature

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