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INFLUENCES OF THE MILLING DIRECTION ON SURFACE QUALITY ON MILLING X155CrVMo12-1 STEEL

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Abstract Surface quality is one of the main characteristics of a product and manufacturing process. In milling, there are two possible ways a tool moves relative to the movement of the workpiece – up and down milling. This paper investigates the effect of milling direction on surface quality and shows that the effect is independent of quality in terms of the arithmetic average of the roughness profile – Ra.

Keywords: Tool; quality; machining; metal cutting; direction.

1. INTRODUCTION

This paper investigates the influence of the tool movement direction on surface quality when milling steel using a carbide endmill, high-speed steel (HSS) endmill, and carbide insert endmill. The surface roughness is measured and displayed using the arithmetic average of the roughness profile – Ra as a surface quality indicator. The obtained results show that using the same parameters on climb milling gives significantly better surface quality than conventional milling.

2. RESEARCH OVERVIEW

For the past 20 years, there is a growing tendency to increase machining productivity and surface quality driven by the growing market competition which transformed machining steel towards more productive methods like High-speed machining (HSM), High-efficiency milling (HEM), dry cutting[1], hard milling and similar. These methods are grounded on high cutting speeds, fast feeds, using the whole flute length, and machining without coolant. These trends demand tools of greater quality that will stay stable even in high-stress conditions and will degrade in such a way as to have the least effect on surface quality, [1-4]. Jozić [5] researches the effect of milling direction on flank wear while milling hardened steel. Samsudeen et. al. 6] research cutting forces and tool wear when milling Ti-6A-4V titanium and give us the optimal cutting feeds and speeds for finish passes. Odedey et. al. [7] research tool wear when dry machining AISI 316 steel using carbide inserts with Physical vapor deposition (PVD) coatings, and establish the connection between cutting feeds and speeds and tool wear. Wojciechowskia et. al. [8] research the milling of X155CrVMo-12 steel using ball mill. They state that carbide tools have greater tool life when cutting with speeds up to 300 m/min compared with CBN tools. Bouzakis et. al. [9] analyze the effect of milling direction on tool life when using endmills with PVD coatings on AISI 304 steel. Hosni et. al. [10] research tool wear of carbide endmills with PVD coatings while milling hardened AISI D2 steel without using coolant. N.F. Kundor et. al. [11] also research tool wear and surface finish quality when dry milling hardened AISI D2 steel. J. A. Arsecularante et. al. [12] research the effect of different cutting parameters when turning hardened AISI D2 steel with PCBN tools. Vinayak et. al. [13] research the workability of hardened AISI D2 steel while dry cutting and establish a connection between different milling parameters and tool life and surface finish quality. For better transparency, the research overview and used parameters are grouped in table 1.

Table 1. Research overview.

Author, year	Work material	Hardened	Process, Milling parameters
Jozić (2015)	42CrMo4	Yes	Dry milling Cutting speed: 45-145 m/min Axial depth of cut (ADOC): – 5mm Radial depth of cut (RDOC): 0.5 – 2 mm Feed: 0.005-0.095 mm/tooth Tool coating: TiAlN
Samsudeen (2015)	Ti6Al4V	No	Titanium alloy milling. Cutting speed: 20-50 m/min ADOC: 1mm (slot milling) Feed: 0.02-0.08 mm/tooth
Odedey (2017)	AISI 316	No	Dry milling Cutting speed: 145 – 260 m/min ADOC: 1-2mm Feed: 58 – 520 mm/min Tool coating: TiAlN-PVD
Wojciechowskia (2012)	X155CrVMo12-1	No	Ball milling with WC i CBN tools. Cutting speed: 100 - 140 m/min Feed: 0.1 - 0.2 mm/tooth RDOC: 0.2 - 1.8 mm
Bouzakis (2014)	AISI 304L	No	Face milling with cemented carbide inserts. Cutting speed: 300 m/min ADOC: 0.12 mm Tool coating: TiAlN.
N A J Hosni (2014)	AISI D2	Yes	Dry milling Cutting speed: 80-120 m/min Feed: 0.05 mm/tooth ADOC: 0.5 mm RDOC: 3, 4, 5 mm Tool coating: TiAlN-PVD
Hik Faizu Kundor (2016)	AISI D2	Yes	Dry milling Cutting speed: 50-90 m/min Feed: 0.02-0.04 mm/tooth ADOC: 1mm RDOC: 20 mm Carbide inserts with CVD coating.
J.A. Arseculαratne (2005)	AISI D2	Yes	Turning Cutting speed: 70-120 m/min Feed: 0.08-0.2 mm/revolution Depth of cut: 0.5 mm
Vinayak H.G. (2016)	AISI D2	Yes	Dry milling Cutting speed: 90-180 m/min Feed: 0.1-0.4 mm/revolution Tungsten carbide tool.

3. EXPERIMENTAL SETUP

The experimental part of the research is conducted in the laboratory for CNC machine tools on the Faculty of Mechanical Engineering, the University of Eastern Sarajevo., For those purposes, an EMCO Concept Mill 250 milling center was used. The arithmetic mean roughness Ra was measured using a Mitutoyo SURFTEST SJ-210 portable surface roughness measuring device. The following setting parameters have been used: λf = 2.5 µm, λc = 0.08mm, *ln* = 4 mm. Workpiece hardness was measured on a Mitutoyo HR-110MR Rockwell hardness testing machine in 3 layers and gave a mean hardness of 20HRC.

The workpiece material is X155CrVMo12-1 tool steel, also known as D2, in a normalized state. In this experiment 3 different endmills were used:

1. SUMITOMO Insert mill – WEZ 11016E Φ16x46 mm with carbide inserts AOM T11 T3 08 PEER-G.
2. Carbide endmill – EMCA ICE MILL 0300M 1000 Φ16x46 mm with AlCrN coating.
3. HSS endmill Φ10 manufactured by Jugoalat Trebinje.

Cutting parameters used for the given combination of the tool-workpiece-milling center are chosen as optimally recommended by the literature [14-20] and the tool manufacturer [20-22]. Milling with carbide inserts and carbide endmills has been performed with no coolant (dry cutting), while for milling with HSS endmills synthetic cutting fluid was used.

The experiments were grouped into 3 groups based on the tool and milling parameters. Experiment results are shown in Table 2.

Table 2. Experimental setup and results.

No:	Parameters	Surface quality, results
E.1	Vs = 120 m/min fz = 0.125 mm/tooth a_a = 5 mm a_r = 2.5 mm Dry cutting Carbide insert Climb milling	Ra roughness is inside the 0.250 – 0.650 micrometers range. After 85.5 minutes of cutting the measured Ra roughness is 0.290 micrometers. The measured roughness decreases even as the tool wear is increasing.
E.2	Vs = 120 m/min fz = 0.125 mm/tooth a_a = 5 mm	It was impossible to measure surface roughness because of bad surface quality and the danger of damaging measuring equipment.

	a_r = 2.5 mm Dry cutting Carbide insert Conventional milling.	
E.3	Vs = 105 m/min fz = 0.03 mm/tooth a_a = 10 mm a_r = 1 mm Dry cutting Carbide endmill Climb milling	The mean measured Ra roughness is 0,248 micrometers.
E.4	Vs = 105 m/min fz = 0.03 mm/tooth a_a = 10 mm a_r = 1 mm Dry cutting Carbide endmill Conventional milling	The mean measured Ra roughness is 0,709 micrometers. A significant visual difference in surface quality is visible between climb and conventional milling.
E.5	Vs = 20 m/min fz = 0.05 mm/tooth a_a = 10 mm a_r = 1 mm Synthetic cooling fluid HSS endmill Climb milling	The mean measured Ra roughness is 0,843 micrometers.

E.6	Vs = 20 m/min fz = 0.05 mm/tooth a_a = 10 mm a_r = 1 mm Synthetic cooling fluid HSS endmill Conventional milling.	It was impossible to measure surface roughness because of bad surface quality and the danger of damaging measuring equipment. A significant visual difference in surface quality is visible between climb and conventional milling.

Legend:
a_a *– axial depth of cut - ADOC*
a_r *– radial depth of cut - RDOC*
V_s *– cutting speed*
fz – feed.

4. EXPERIMENT RESULTS

4.1. Experiments 1 and 2

Experiments 1 and 2 were done using a carbide insert endmill with a single insert. Experiment 1 uses climb milling and the surface roughness is inside the 0.270-0.610 Ra-micrometers range as shown in figure 1. Experiment 2 uses conventional milling with all the other parameters same as in experiment 1, and the surface quality is visually so bad that the surface roughness can not be safely measured because it would result in damage to the measuring equipment. The magnified surface after the second experiment is shown in Figure 2.

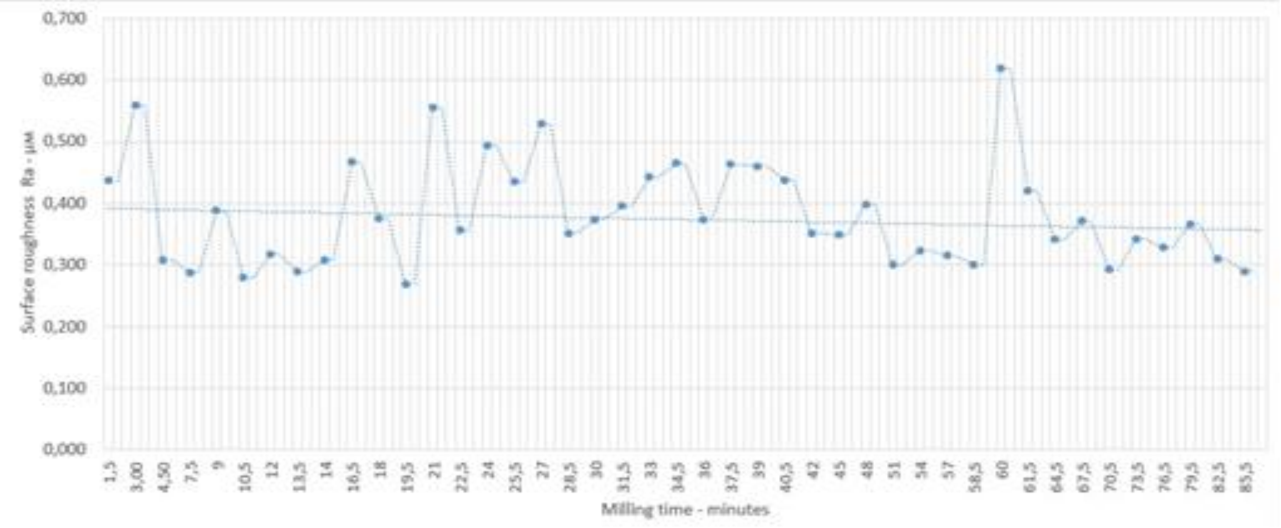

Figure 1. Surface roughness-milling time graph.

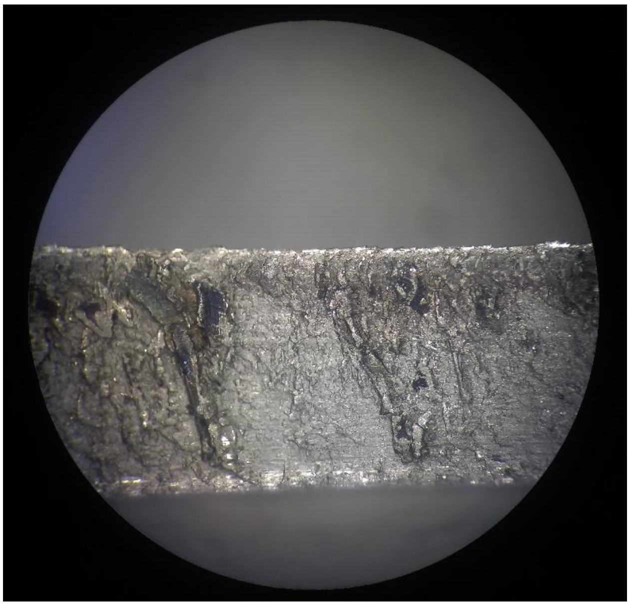

Figure 2. Magnified image of the surface after a conventional milling pass.

4.2. Experiments 3 and 4

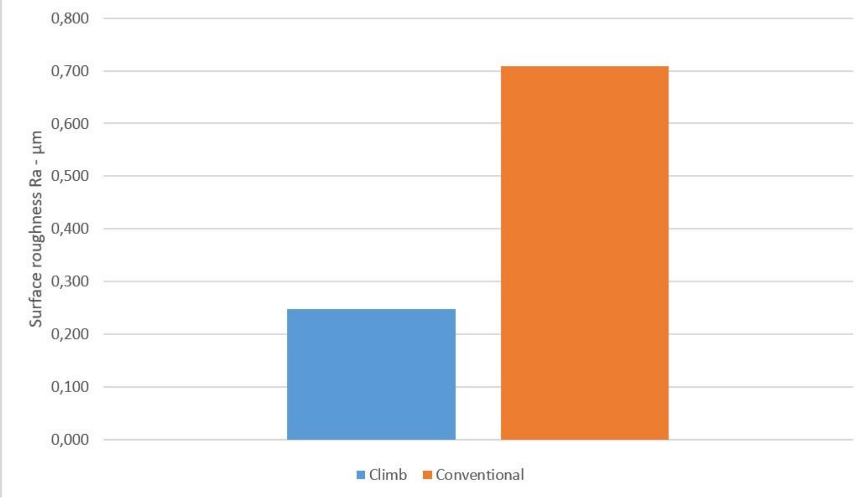

Figure 3. Mean surface roughness for Experiment 3 (Climb) and Experiment 4 (Conventional).

Experiments 3 and 4 were done using a carbide endmill with identical parameters, only the milling direction was varied. Experiment 3 uses climb milling and the mean surface roughness measure 0.248 Ra-micrometers, while experiment 4 uses conventional milling, and the mean surface roughness measures 0.709 Ra-micrometers.

5. EXPERIMENTS 5 AND 6

Experiments 5 and 6 were done with an HSS endmill, the only difference being that experiment 5 was done using climb milling and experiment 6 was done using conventional. The mean surface roughness measures 0.843 Ra-micrometers for experiment 5, while the surface roughness could not be measured for experiment 6 because it would result in damage to the measuring equipment. The magnified milled surface is shown side by side in figure 5.

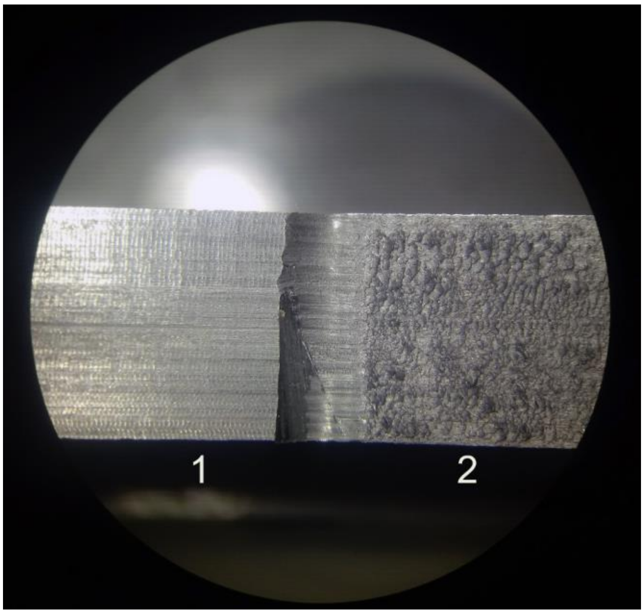

Figure 5. Visual comparison of the milled surfaces for 1) Climb milling (Experiment 5), 2) Conventional milling (Experiment 6.)

6. CONCLUSIONS

1. Surface roughness can be viewed as a function of the milling direction.
2. Regardless of endmill type and material used climb milling gives visually better surface quality compared to conventional milling, also the measured surface roughness is smaller for climb milling.
3. It can be seen that a bigger influence on surface roughness has the milling direction compared to cutting speed and feeds.
4. Surface quality after conventional milling can be so bad that it can not be safely measured using contact methods.
5. There is no justification for using conventional milling over climb milling in modern machining from the standpoint of surface quality.

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