Jurnal Kejuruteraan 34(6) 2022: 1169-1173
https://doi.org/10.17576/jkukm-2022-34(6)-16

Surface Roughness in High Speed Turning of Alloy Steel M303 Using Carbide Tools in Dry Cutting Condition

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Received 4 January 2022, Received in revised form 15 April 2022
Accepted 10 May 2022, Available online 30 November 2022

ABSTRACT

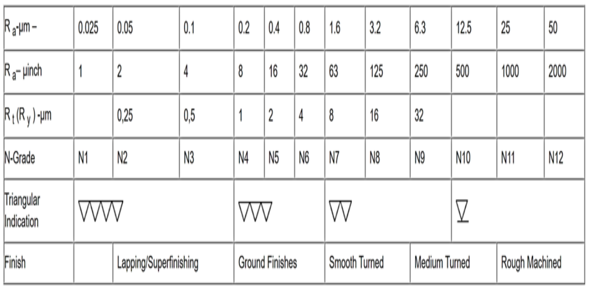
M303 is a corrosion resistant martensitic chromium steel offering excellent toughness, corrosion, and wear resistance, characterized by improved machinability and polish ability. It is widely utilized in industries such as in mould and die making, machinery and automotive equipment, bearing housing, and tooling. Recently, this material has also been used in locomotive bearing housing. This paper presents surface roughness achieved in the turning process of M303 in dry cutting condition using coated and uncoated carbide tools. The turning parameters included a high cutting speed regime (260-340 m/min) and feed rate at 0.1-0.2 mm/rev, suitable for the finishing process. The experiment was conducted according to the Taguchi method (L18). Average surface roughness (R_a) was in the range of 0.395-1.356 µm, in which a mirror finish was achieved for certain cutting conditions that could eliminate the grinding process. Results of surface roughness were analysed using Analysis of Variance (ANOVA) for linear models and revealed that feed rate is the main significant factor contributing to surface roughness, followed by type of cutting tool, and cutting speed. These findings show that good and acceptable R_a values for M303 turning are obtained in dry condition, therefore it is recommended to eliminate the use of flooding condition as normally practiced in the industry.

Keywords: Surface roughness; high speed turning; M303; dry cutting

INTRODUCTION

A surface finish is generally described as a measure of the texture of a surface and commonly characterized by the lay (direction) of the surface pattern such as roughness and waviness. According to Osborne (2020), standard surface finishes include characteristics frequently used in reference to machining finishes achieved using different production methods. The ISO standard commonly referred to for surface finishes is ISO 1302:2002 (2012). According to AN Engineering (2021), the Rules of Thumb for surface finishes equivalent of N grade and R_a values are as follows: Rough turned with visible toolmarks are N10 = 12.5 µm ; Smooth machined surfaces are N8 = 3.2 µm ; Static mating surfaces (or datums) are N7 = 1.6 µm ; Bearing Surfaces are N6 = 0.8 µm ; Fine lapped surfaces are N1 = 0.025 µm.

Guidance for R_a and R_t values, triangular indication, and type of finishes are shown in Figure 1.



R_a-µm –	0.025	0.05	0.1	0.2	0.4	0.8	1.6	3.2	6.3	12.5	25	50
R_a– µinch	1	2	4	8	16	32	63	125	250	500	1000	2000
R_t (R_y) -µm		0,25	0,5	1	2	4	8	16	32			
N-Grade	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
Triangular Indication	▽▽▽▽			▽▽▽			▽▽			▽̲		
Finish		Lapping/Superfinishing		Ground Finishes			Smooth Turned		Medium Turned		Rough Machined	

FIGURE 1. Guidance for Ra and Rt values (AN Engineering 2021).

Figure 2 shows different surface textures produced by various manufacturing processes (AN Engineering, 2021). Different surface textures can be produced using different processes even though the surface roughness measured is similar. Smoother surface roughness is produced using plain grinding and flat/external grinding. Therefore, these processes are commonly applied to obtain a mirror-like surface finish after machining processes such as milling and turning.

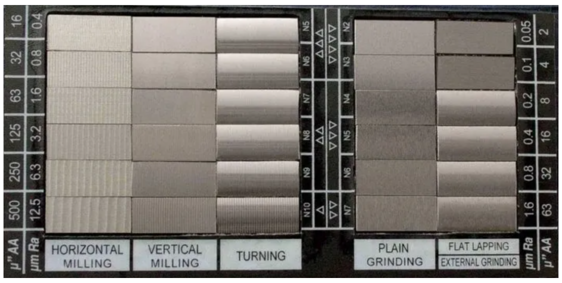


FIGURE 2. Different surface textures produced by various manufacturing processes (AN Engineering, 2021).

Surface finishes vary tremendously according to manufacturing process as shown in Figure 2 and Figure 3. For example, a flame cut plate edge has a totally different surface finish than a ground surface. Commonly, there is more than one manufacturing processes that will achieve a desired surface finish, hence, one should choose the process in accordance with their suitability and cost effectiveness. Figure 3 shows relative surface finish roughness of various manufacturing processes (Grzesik et al. 2010).

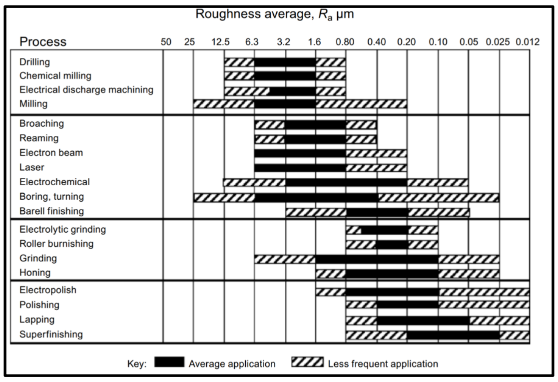
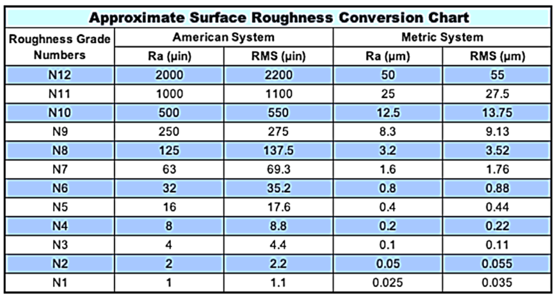


FIGURE 3. Relative surface finish roughness of various manufacturing processes (Grzesik et al. 2010)

Average surface roughness (R_a) is a calculation of the average length between all peaks and valleys (or the average height) from the mean line of the surface (Osborne, 2020). Because this neutralizes any significantly outlying points, R_a is not sensitive to occasional spikes and gouges. Figure 4 shows conversions of surface roughness units between R_a and Root Mean Square (RMS).



Approximate Surface Roughness Conversion Chart

Roughness Grade Numbers	American System		Metric System	
	Ra (µin)	RMS (µin)	Ra (µm)	RMS (µm)
N12	2000	2200	50	55
N11	1000	1100	25	27.5
N10	500	550	12.5	13.75
N9	250	275	8.3	9.13
N8	125	137.5	3.2	3.52
N7	63	69.3	1.6	1.76
N6	32	35.2	0.8	0.88
N5	16	17.6	0.4	0.44
N4	8	8.8	0.2	0.22
N3	4	4.4	0.1	0.11
N2	2	2.2	0.05	0.055
N1	1	1.1	0.025	0.035

FIGURE 4. Relative surface finish roughness of various manufacturing processes (Grzesik et al. 2010)

In this study, the surface roughness in turning M303 at high cutting speed regime is investigated in dry cutting condition. Dry cutting is a sustainable and environmentally friendly process as compared with flood condition as usually practiced in the manufacturing industry.

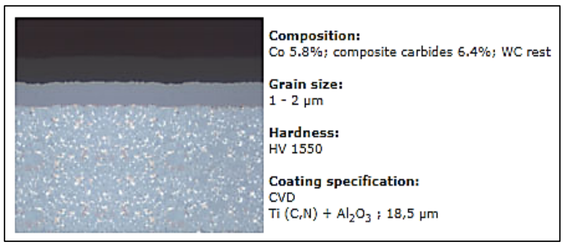
METHODOLOGY

In this study, the turning process is carried out to investigate surface roughness produced in dry cutting of M303. This material is a corrosion resistant martensitic chromium steel offering excellent toughness, corrosion, and wear resistance. It is characterized by improved machinability and polishability. M303 is widely used in mould making processes, automotive components, and recently in locomotive bearing housing. This study focuses on producing a locomotive bearing housing, and due to the shape of the component, turning process has been chosen. Chemical composition of materials is shown in Table 1.

TABLE 1. Chemical composition of M303 (KG, 2021).

Chemical composition (%)					
C	Si	Mn	Cr	Ni	Mo
0.27	0.30	0.65	14.50	0.85	1.00

The size of the rod prepared was Ø50 mm x 100 mm. The rhombus shaped carbide cutting tool used was VCGT 110302EN-SF CTCP115 CERATIZIT with composition as shown in Figure 5. It has the geometry of insert thickness of 3.18 mm, nose radius of 0.2 mm, clearance angle of 6-8°, and rake angle of 12-15°.



Composition:
Co 5.8%; composite carbides 6.4%; WC rest

Grain size:
1 - 2 µm

Hardness:
HV 1550

Coating specification:
CVD
Ti (C,N) + Al_2O_3 ; 18,5 µm

FIGURE 5. Properties and composition of the cutting tool used (E-techstore, 2021)

Machining experiments were carried out using CNC turning machine model DMG Mori Seiki Alpha 500 at high cutting speed regime for M303 in dry cutting condition. The factors and levels used for the experiments are shown in Table 2. Taguchi method L18 (21×37) was utilized for factor and level combinations in the experiments.

TABLE 2. Factors and levels used in the turning process

Factor / Level	1	2	3
Tool type	Coated carbide tool	Uncoated carbide tool	-
Cutting Speed (m/min)	200	300	340
Feed rate (mm/rev)	0.1	0.15	0.2
Depth of cut (mm)	0.2	0.4	0.6

Average surface roughness (R_a) was measured at the beginning of each cut for all the factor and level combinations using portable surface roughness tester model SJ-210 Mitutoyo.

RESULTS AND DISCUSSION

Table 3 shows that R_a values measured in this study are in the range of 0.395-1.356 µm. According to ISO 1302:2002 (2012), this range of surface roughness value is within N5-N7. Referring to the chart of relative surface finish roughness due to various manufacturing processes (Cookbook, 2020), this range of R_a obtained is similarly obtained using grinding process. Furthermore, it is stated that R_a value of 0.2-0.4 µm is similar to R_a values that can be obtained from processes such as polishing and lapping in abrasive processes to produce mirror-like surfaces and roller burnishing in forming processes.

TABLE 3. Factors and levels used in the turning process

Experiment no.	Factors				R_a (µm)
	A: Type of tool	B: Cutting speed, Vc (m/min)	C: Feed rate, f (mm/rev)	D: Depth of cut (mm)	
1	Coated	260	0.1	0.2	0.741
2	Coated	260	0.15	0.4	0.876
3	Coated	260	0.2	0.6	1.225
4	Coated	300	0.1	0.2	0.395
5	Coated	300	0.15	0.4	0.754
6	Coated	300	0.2	0.6	0.962
7	Coated	340	0.1	0.2	0.668
8	Coated	340	0.15	0.4	0.649
9	Coated	340	0.2	0.6	0.972
10	Uncoated	260	0.1	0.2	0.891
11	Uncoated	260	0.15	0.4	0.965
12	Uncoated	260	0.2	0.6	1.356
13	Uncoated	300	0.1	0.2	0.867
14	Uncoated	300	0.15	0.4	0.847
15	Uncoated	300	0.2	0.6	1.345
16	Uncoated	340	0.1	0.2	0.754
17	Uncoated	340	0.15	0.4	0.732
18	Uncoated	340	0.2	0.6	1.1

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Figure 6 shows the surface roughness obtained against the various combinations of factors and levels. The figure shows that turning using coated carbide tools resulted in lower values of surface roughness.

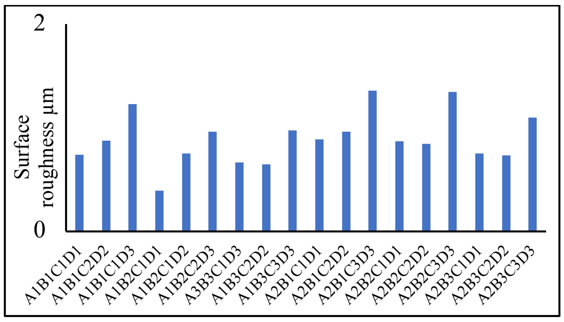

FIGURE 6. Surface roughness against combinations of factors and levels

SN-graph using smaller-the-better criteria was plotted to identify significant factors affecting R_a values as shown in Figure 7. From the slope of the plotted graph, feed rate has the stiffest slope followed by the type of tool, depth of cut, and cutting speed. These findings suggest that the optimum turning process to obtain a small value of R_a is by using a coated tool, high cutting speed of 340 m/min, low feed rate of 0.1 mm/rev, and low depth of cut of 0.2 mm – in agreement with previous findings (Othman et al. 2020; Ruslan et al. 2016).

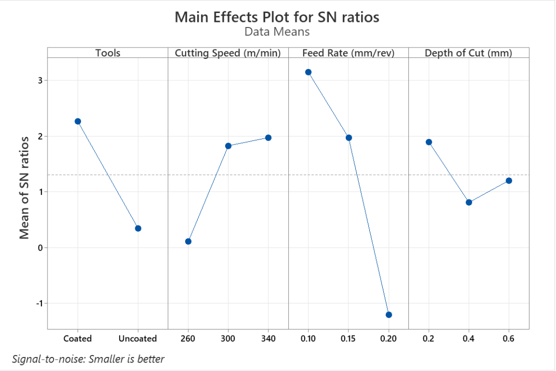

FIGURE 7. SN graph using smaller-the-better criteria for R_a

Analysis of variance (ANOVA) for linear models using Minitab 20 commercial statistical package was carried out to identify significant factors affecting values of surface roughness as shown in Table 4. Table 5 shows the model summary. From the ANOVA conducted, R-Squared is equal to 76.48%, indicating a strong relationship between the R_a and the factors.

TABLE 4. ANOVA for surface roughness

Source	DF	Adj SS	Adj MS	F-value	P-value
Type of tool	1	0.1449	0.144901	15.88	0.00258
Vc	2	0.12547	0.062737	6.88	0.01322
Feed	2	0.65636	0.328182	35.98	0.00003
Depth cut (mm)	2	0.01885	0.009427	1.03	0.39087
Error	12	0.2438	0.02032		
Total	17	1.0368			

TABLE 5. Model summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.142542	76.48%	66.69%	47.09%

From Table 4, it is shown that feed rate (factor C from Table 3) is the most significant factor affecting the values of R_a, followed by the type of cutting tool, and cutting speed, however, cutting speed is not highly significant. This finding is based on the theory that R_a = f2 /32R (Groover, 2019) where f is feed rate and R is nose radius. According to Grzesik et al. (2010), the minimum height of irregularities on the machined surface in the turning process can be achieved by minimizing feed rate and maximizing tool nose radius.

Feed rate is very significant compared to other factors in determining R_a value. Similar findings were also observed by Carou et al. (2014) reporting that feed rate was the main contributing factor affecting all machining tests in intermittent turning of UNS M11917 magnesium alloy. They also proposed that more dispersion of surface roughness values, in terms of R_a, was identified when machining at low feed rates. Othman et al. (2020) also found that feed rate is the most significant factor in turning Al-Si alloy. ANOVA carried out by Halim et al. (2021), in regards to machining Inconel 718 at high speed using PVD carbide coated ball nose inserts, revealed that the dominant factor affecting R_a was cutting speed, followed by axial DOC and interaction between cutting speed and feed rate. This experimental work was conducted under cryogenic conditions using a novel cryogenic CO2 cooling system.

Another work utilizing cryogenic cooling was conducted by Musfirah et al. (2017) and found that in comparison to dry machining, cutting force in cryogenic cooling was reduced to 23% and improved surface roughness to a maximum of 88%. The team contributed these findings to LN2 allowing for better cooling and lubrication through the reduction of heat generation at the cutting zone. Hence, findings from Halim et al. (2021) and Musfirah et al. (2017) show that cutting environment also plays a significant role in determining surface roughness and other machining outputs such as cutting force and tool life, in addition to machining parameters.

Bubble plot of R_a against cutting speed utilizing feed rate as bubble size is shown in Figure 8. In general, Figure 8 shows that turning using uncoated tools resulted in higher R_a values; therefore, coated cutting tools are believed to produce smoother machined surfaces. Furthermore, different coatings with different coefficients of friction will also influence the surface roughness produced. A study done by Ucun et al. (2014) utilizing micro end mills with a diameter of 768 μm, coated with five separate coating materials (AlTiN, AlCrN, TiAlN + AlCrN, TiAlN + WC/C, and diamond-like carbon) found that the mean surface roughness values of machined surfaces with a diamond-like carbon-coated and AlTiN-coated cutting tool were lower when compared to other coating materials.

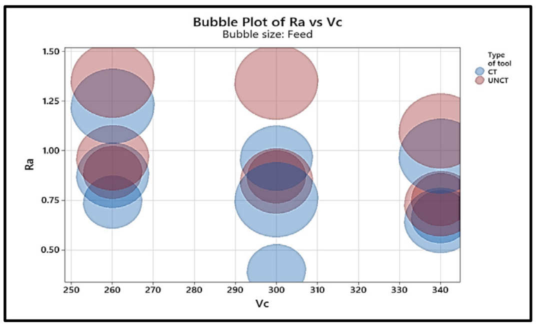

FIGURE 8. Bubble plot of R_a vs cutting speed

CONCLUSION

From the analyses of the results, it can be concluded that turning in dry condition at high cutting speed regime is able to produce a mirror-like finish. Therefore, it could eliminate other processes such as grinding. ANOVA analysis revealed that feed rate is the most significant factor affecting surface roughness of machining, followed by type of cutting tool, and cutting speed. Coated cutting tools will produce smoother surfaces due to their low coefficient of friction as compared with uncoated tools.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Kebangsaan Malaysia for their financial support under grant FRGS/1/2019/TK03/UKM/01/2.

DECLARATION OF COMPETING INTEREST

None

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