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Determination of Ceramic Cutting Tool Performance on Machining of Steel (PMD23) Produced by Powder

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Abstract

This study aimed to determine optimum cutting parameters for recovering the best surface roughness during PMD 23 powder metal machining with ceramic sharp cutting tool at CNC turning center. Experiments for this aim were carried out on 27 samples in 80 mm diameter and 200 mm length prepared at turning center by application of cutting parameters determined with Taguchi method. Three different cutting speeds (200, 350, 500 m/min.), three different feed rates (0,1–0,2–0,3 mm/rev) and three different tool nose radius (0,4-0,8-1,2 mm) were used and depth of cut was applied stable as 0,8 mm in the experiments. Later, surface roughness of experiment sample and the roughness change was evaluated with respect to cutting speed, feed rate and tool nose radius. Variant analysis (ANOVA) were used to investigate characteristics of the processes. As a result of the experimental study, it was found out that feed rate and tool radius of cutting parameters had an effect on surface roughness, but the effect of cutting speed was not significant.

Keywords: PMD 23 powder metal, surface roughness, cutting parameters

1. INTRODUCTION

Surface quality of machine parts produced with machining shows variability depending on a lot of factors. Surface roughness is an important factor taking in account not only conventional subjects of tribology such as only abrasion, rubbing and lubrication; both in different extent impermeability, hydrodynamic, electricity, heat transmission etc. Surface texture is affected by cutting parameters during material cutting. Surface roughness is a parameter determining surface quality. Surface roughness is depending on the parameters those are cutting speed, feed rate amount and depth of cut. In addition, it depends on use of cutting liquid and flowrate, tool nose radius and chip angle [1].

A. Devillez et al.[2], measured cutting forces and tool wear using dry experiments during turning with coated ceramic tools on Inconel 718 alloy. It was observed generation of adhesion force and welding contact by working material parts on chip surface and flank surface of tool during dry cutting of Inconel 718. M. Remadna and J. F. Rigal were measured tool wear and cutting forces generated during rough turning of CBN cutting tools. Finding of these studies revealed that direction changes occurred on cutting forces affect the tool life significantly [3].

D. A. Axinte et al. used two type round ceramic tools with 12 mm diameter those were 670 tools supported with good toughness and 6080 SiAlON having high level notch resistance in turning of developed alloy containing Ni base produced with powder metallurgy. They investigated the best tool life performance using different cutting speeds [4]. A. Y. L. Yong et al. investigated performance of tungsten carbide cutting tools tempered as cryogenic in turning. While other cutting parameters were kept stable various cutting speeds were used in a study of application of orthogonal cutting model. Cutting tools tempered with cryogenic gave better performance regarding to untampered cutting tips at short time or at intervals applications. But this result was not seen under heavy cutting conditions [5]. N. Çamuşcu investigated the effect of cutting speed to cutting tool performance during turning of nodular cast iron with ceramic cutting tool contained Al_2O_3. The findings showed that ceramic tool coated with TiN containing mixture of Al_2O_3 + TiCN is the best cutting tool during the nodular cast iron related to flank wear and surface roughness [6].

J. Rech investigated the effect of cutting tools coatings on friction between cutting tool and chip on orthogonal dry cut. Friction features of TiN and (Ti, Al) N + MoS_2 coating are better comparing to uncoated cutting tools in application of this method for various coatings [7]. T. Özel et al. investigated the effect of cutting speed, feed rate, work piece hardness and geometry of cutting edge on cutting forces and surface roughness during finish turning of AISI H13 hardened steel. Better surface roughness was yielded with arched cutting edge geometry and low work piece hardness.

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It was found that cutting force constituents were affected by cutting edge geometry, work piece hardness and cutting speed [8]. A. Kurt and U. Şeker investigated the effect of cutting edge angle of PCBN cutting tool on cutting forces and tool strain occurring during rough turning of AISI 52100 steel. A high effect of cutting edge angle on maximum strain was determined analysis carried on with method of finite element methods [9]. Aslan and colleagues examined effects of cutting speed, feed rate value and depth of cut on tool wear and surface roughness during machining of AISI 4140 steel with Al_2O_3 +TiCN mixed ceramic tool. They defined cutting parameters of minimum surface roughness and tool flank wear at the end of the study [10].

Moganapriya et al. [11], in their study; For the AISI 1015 soft steel; During the CNC turning, they investigated the effect of cutting parameters (coating material, depth of cut, feed rate and spindle speed) on the metal removal rate (MRR) and the effect of TiAlN / WC-C, TiAlN coated tools on surface roughness. To optimize the MRR and minimize surface roughness in the Jober XL CNC lathe, the Taguchi optimization method was used with the L9 vertical array. They observed that the coating material (TiAlN / WC-C) had a significant effect on the determination of the output parameters.

Mozammel Mia, et al.[12], MQL supported hard turning, using a coated cemented carbide tool, roughness parameters, tool wear parameters and the effects of material removal rate were investigated. They have identified optimization by Taguchi orthogonal array-based experiment design and signal-to noise ratio. Furthermore, they determined the effects of cutting speed, feed rate and depth of cut by analysis of variance. As a result of their study; the cutting speed affects the surface roughness; that the depth of cut affects tool wear; found that the feed rate effected the material removal rate.

Sujan Debnath et al. [13]; examined the effects of various cutting fluid and cutting parameters on surface roughness and tool wear. They used the Taguchi orthogonal sequence to minimize the number of experiments. The experiments were performed with TiCN + Al_2O_3 + TiN coated carbide inserts in CNC turning process. As a result of the experimental study; found that the rate of progress affected surface roughness by 34.3%. They also found that the flow rate of the coolant significantly improved the surface roughness.

Xiaobin Cui et al.[14]; In order to improve ceramic cutter tool life, researches on optimization of tool geometry parameters were carried out. As a result of the experimental study, the order of effect of the tool geometry parameters; corner radius, cutting edge angle and inclination angle.

In this study, the effect of 27 different variable cutting parameter sets on surface quality investigated during machining a steel produced with powder metallurgy with ceramic cutting tool. The effect of machining variables and interaction between variables on surface quality were determined by ANOVA of the results and evaluation. It resulted that flank wear value and tool nose radius are decisive factors on surface quality with respect to cutting speed.

2. METARIAL and METHOD

ISO 3685 standard was taken into consideration to implement machining experiments with which cutting performance were defined on the work piece sample produced by powder metallurgy using cutting tools having different cutting geometry [15]. A computer numerically controlled turning center, Good-way GLS-150, was used in the experiments. Cold work tool steel sized Ø80x200, a powder metallurgy metal, PMD 23 coded specifically in 260 HB hardness was used for experimental sample. Its wear resistance and toughness are more than known steels containing 12% Cr. It gives better results with cutting tools such as milling cutter, reamer and may work at high speed. Chemical composition of experimental sample is given in Table 1.

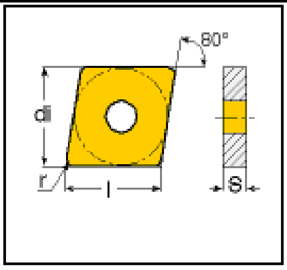
Table 1. Chemical composition of experimental sample, PMD 23

Chemical Component	C	Cr	W	Mo	V
	1,30	4,20	6,40	5,00	3,10

Rhombic cutting tool selected according to ISO 3685 standard and geometric features of it are shown in Table 2.

Table 2. Cutting tool geometries selected according to ISO 3685 standard

CNMG 120404 – TF IC 907			
l	di	s	r
12,90	12,70	4,76	0,40
CNMG 120408 – TF IC 907			
l	di	s	r
12,90	12,70	4,76	0,80
CNMG 120412 – TF IC 907			
l	di	s	r
12,90	12,70	4,76	1,20



Tool holder coded TCLNR 2020 K 12, Hommel Tester T1000 roughness measurement device and tool microscope were used as tool holder, measurement of surface quality of samples at the end of experiments and measurement of tool flank wear, respectively. Values given in Table 3 were used to produce experiment pattern according to ISO 3685 standard [15].

Table 3. Cutting parameters used in the experiments

Cutting speed V_c (m /min.)	Feed Rate f_a (mm/rev)	Tool Nose Radius r (mm)	Depth of Cut a_p (mm)
500	0,1	0,4	0,8
350	0,2	0,8	
200	0,3	1,2	

Tool target combined with tool holding according to tolerance of measurement of ISO 3685 was unclamped until complementing experiment group. Sample prepared previously was clamped between chuck and tailstock and the cut was obtained by a separate cutter until elimination of secretion. Experiments were carried out with a new tool after pre-machining. Flank wear was recognized with VBmax = 0,3 mm suggested by ISO 3685 standard (figure 1).

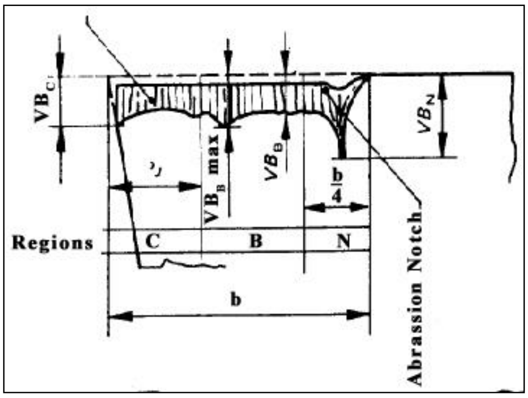


Figure 1. Tool wear with respect to ISO 3685 standard

Surface roughness values were measured by taking 3 measurements value per surface by rolling 120◦ work piece around its axis and parallel to axis of work piece.

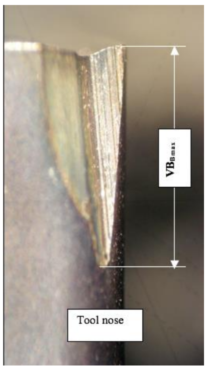


Figure 2. Tool flank wear (Vc3=200m/min, f1=0.1mm/rev,r3=1.2mm)

3. EXPERIMENTAL RESULTS and DATA ANALYSIS

Effect of three different levels of cutting speed (Vc), feed rate value (f) and tool rose radius (r) to surface roughness (Ra) were searched in the experiment plan. 27 experiments carried out in this study were divided 3 groups according to different cutting parameters and measured surface roughness values are given in Table 4, Table 5 and Table 6.

Cutting speed (Vc), was determined Vc1= 500 m/min for 1st group, Vc2=350 m/min for 2nd group and Vc3= 200 m/min for 3rd group.

Feed rate (f) was defined f1= 0.1 mm/rev, f2= 0.2 mm/rev, f3= 0.3 mm/rev for each group.

Tool rose radius (r) was determined as r1= 0.4 mm, r2= 0.8 mm, r3= 1.2 mm for each group.

Effects of cutting parameters and interaction to surface roughness were determined by statistical analysis of measured roughness values. The results of variant analysis (ANOVA) are shown on Table 7. 95% reliable space and 5% mean level were taken into account.

As it seen on ANOVA table (Table 7) feed rate (f) and tool nose radius (r) were found significant at 5% mean level. Even feed rate (f) was decisive in the experiment conditions. Because rate of feed rate to surface roughness was 41,11%. Effect of tool nose radius, another influential parameter, was 10,38%. Cutting speed, 5.3%, was the most ineffective parameter.

Table 4. Experimental results for Ra (Group I)

Test no	Factors			Performance measure
	Cutting Speed V_c (m/min)	**Feed Rate** f(mm/rev)	**Tool Nose Radius** r(mm)	**Surface Roughness** R_a(µm)
1	V_{c1}	f_1	r_1	1,026
2			r_2	1,022
3			r_3	0,937
4		f_2	r_1	1,635
5			r_2	1,245
6			r_3	1,322
7		f_3	r_1	1,026
8			r_2	1,284
9			r_3	0,922

Table 5. Experimental results for *Ra* (Group II)

Test no	Factors			Performance measure
	Cutting Speed V_c (m/min)	**Feed Rate** f(mm/rev)	**Tool Nose Radius** r(mm)	**Surface Roughness** R_a(µm)
1	V_{c2}	f_1	r_1	1,223
2			r_2	1,231
3			r_3	0,999
4		f_2	r_1	1,657
5			r_2	1,331
6			r_3	1,68
7		f_3	r_1	1,002
8			r_2	1,24
9			r_3	1,182

When main factors taken into account, third level (200 mm/min) of cutting speed, first level of ((0.1 mm/dev) of feed rate (f) and third level (1,2 mm) of tool nose radius (r) were optimum values to minimize surface roughness. But there were no significant differences between first and third level of cutting speed. Main effects of cutting parameters to surface roughness are shown on Figure 3.

Table 6. Experimental results for Ra (Group III)

Test no	Factors			Performance measure
	Cutting Speed V_c (m/min)	**Feed Rate** f(mm/rev)	**Tool Nose Radius** r(mm)	**Surface Roughness** R_a(µm)
1	V_{c3}	f_1	r_1	1,159
2			r_2	1,299
3			r_3	0,649
4		f_2	r_1	1,393
5			r_2	1,387
			r_3	1,012
7		f_3	r_1	1,002
8			r_2	1,336
9			r_3	1,1235

Interactions between cutting parameters are shown on ANOVA table (Table 7) and Figure 4. Interaction between feed rate and tool nose radius (f-r) are significant according to these results. P-value was 0.036 and this interaction is affective on surface roughness at 5% significant level. Beside, interaction between Vc-f and Vc-r are meaningless statistically at 5% significant level. Parallel of lines to each other on interaction graphs is indication poor interactions. Divergence of parallels of lines and interception each other make interaction of power increase. As it is seen from inter-action graph and ANOVA table, feed rate and tool nose radius parameters all together are affective on surface roughness. 1st level of feed rate and 3rd level of tool nose radius minimizes the surface roughness according to the results. On the other hand, it may said that cutting speed and tool nose radius are interspace of interaction, even these parameters are weak. 3rd levels of cutting speed and nose radius parameters are effective decreasing surface roughness more or less with regard to position. Interactions of cutting parameters are shown in Figure 4.

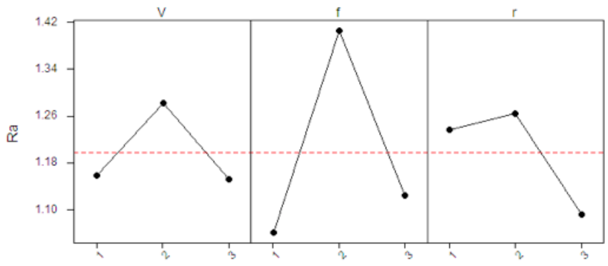


Figure 3. Main Effects Plot - LS Means for Ra

Table 7. ANOVA table for the surface roughness (Ra)*

Source of Variance	df	SS	Variance	*F*-value	*P*-value	C (%)
A (*Vc*, m/min)	2	0.09905	0.04952	3.32	0.089	6.7
B (*f*, mm/rev)	2	0.61178	0.30589	20.51	0.001	41.41
C (r, mm)	2	0.15342	0.07671	5.14	0.037	10.38
AB	4	0.07842	0.01960	1.31	0.343	5.3
AC	4	0.15373	0.03843	2.58	0.119	10.4
BC	4	0.26161	0.06540	4.39	0.036	17.7
Error	8	0.11930	0.01491			8.07
Total	26	1.47729				100

*df: degree of freedom; SS: sum of squares; C : percent contribution.

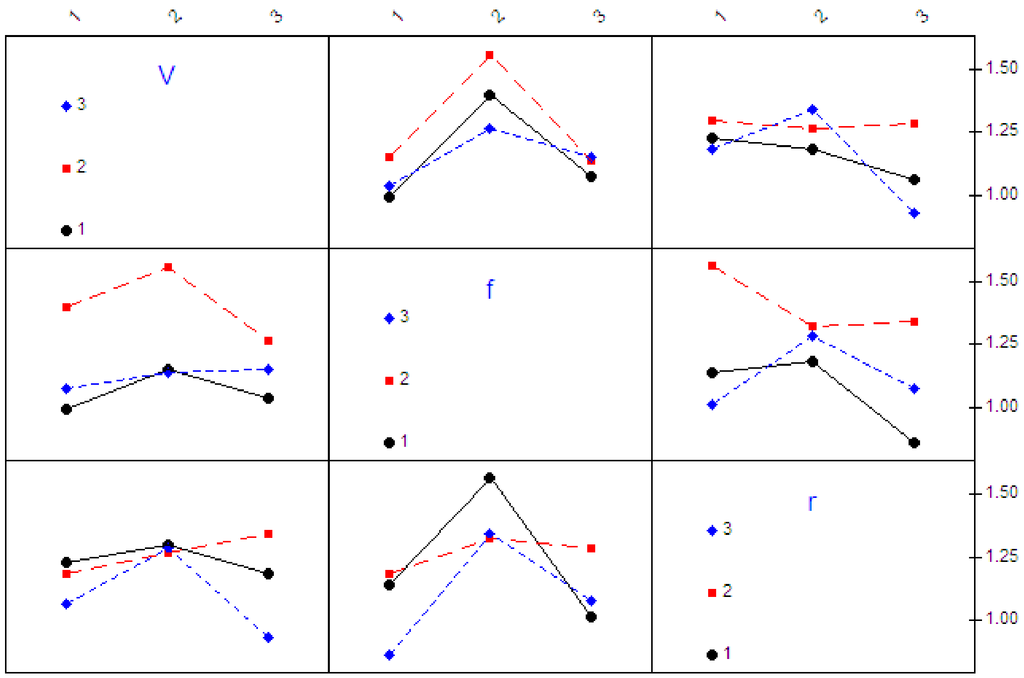


Figure 4. Interaction Plot-LS Means for Ra

3. CONCLUSIONS

In this study, optimum parameters of machining of PMD 23 material on ceramic cutting tool were determined.

•Statistical analysis of experimental results shows that feed rate (f) of cutting parameters is the most important factor effecting surface roughness. Minimum surface roughness was obtained at the 1st level of feed rate of 0.1 mm/rev. The highest level of surface roughness was acquired on the 2nd level of 0.2 mm/rev feed rate values and must not preferred. The 3rd level of 0.3 mm/rev feed rate is preferable level.

•Tool nose radius (r) is one of the effective factor on surface roughness. Minimum surface roughness was obtained at the 3rd level of 1.2 mm tool nose radius. 1st and 2nd levels of tool nose radius were similar each other and should not prefer.

•In this study, cutting speed was the least effective factor on surface roughness. This effect is meaningless effect statistically.

•The best surface quality was achieved when the third level of cutting speed (Vc= 200 m/min), first level (f=0.1 mm/rev) of feed rate and third level (r=1.2 mm) of tool nose radius were used.

•The worse surface quality was obtained in case of using second level (Vc=350 m/min) of cutting speed, second level (f=0.2 mm/rev) of feed rate and second level (r=0.8 mm) of tool nose radius.

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