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Optimization of the Surface Roughness for Titanium Ti6A14V in Turning Process using Taguchi Method

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Abstract:

The purpose of this paper is to investigate the effect of cutting parameters on surface roughness, flank wear and chip formation using CBN tools under the conditions of turning of difficult-to-cut material, Ti6Al4V titanium alloy. Using the signal-to-noise (S / N) ratio, the Taguchi method is used to analyze the impact of cutting parameters on optimization to lower surface roughness values. The surface finish produced is very important in determining whether the quality of the machined part is within specification and permissible tolerance limits based on the flank wear and chip formation. The results shows that the cutting speed, the depth of cut and the feed rate had an impact on the surface roughness and the nose radius. It is observed that the feed rate and depth of cut values were the most significant parameters on surface roughness and cutting forces.

***Keywords:** CNC turning, surface roughness, titanium, Taguchi method*

I. INTRODUCTION

Nowadays, machining process involves optimizing and improving of the cutting parameters and processes especially for the difficult to cut materials of products. Titanium alloys are generally used in automobile, aerospace, marine, medical and chemical industries as a result of their unrivalled properties, for example, high corrosion resistance, biocompatibility and high strength-to-weight ratio. Thakur et al. (2012) stated that titanium and its alloys have high solidarity to weight proportions, great temperature and synthetic opposition, moderately low densities, which making them ideal for avionics applications [1]. These material characteristics have been accentuated by Wang et al. (2009) which can trigger elevated cutting temperatures in the cutting area and powerful hold between the device and workpiece material. In the processing of titanium amalgams, mechanical assembly wear is exceptional along these lines [2]. Regardless of how coolants can be used to lower the temperature and decrease the cutting power, dry cutting is attractive as it can give a decrease in costs and a non-tinting situation. The workpiece's surface roughness is a basic parameter that affects component quality. The roughness of the surface is a measure of the mechanical nature of the fragment and a marker for assessing the skills of machine components and machined tools. The surface roughness assessment of the product is desired and frequently defined in order to achieve the necessary quality of exhaustion, erosion obstruction, precision fits, tribological and stylish preconditions. As such, estimating and portraying the surface completion has been considered as the mediator of machining execution [3].

Kawin (2019), Selvaraj et al. (2014), Turgay (2014), Saravanakumar (2018) and Said et al. (2014) applied the optimization approach of cutting force, surface roughness and tool wear in machining processes using the Taguchi method [6, 7, 8, 9, 10]. A CNC machine is usually intended to use present day variants of carbide tooling and forms. Sarikaya et al. (2014) studied that the turning operation using a single point cutting tool has been one of the primitive and surely understood strategies for metal cutting [4]. It has even been restored crushing in specific applications with diminished lead time without influencing the surface quality. In this contact, two significant perspectives which are generally examined in turning tasks are cutting parameters and surface roughness of the work-piece. Process parameter streamlining is of incredible implication while investigating the procedure capacity of any machining operation. Therefore, the machining of difficult to-cut materials with the high strength like titanium alloys in turning process need to be considered the value of the cutting parameters with the material specification.

The main objective in this paper was to investigate the optimization of the cutting parameters on the difficult to-cut material using Taguchi method, which takes account to prevent the tool wear and the surface quality of the material during machining. Machining is a procedure of material removal from a work piece by applying cutting tools to decisively acquire the required product measurements with a decent surface finish. In practice, to get better result for surface roughness and tool wear, optimum cutting parameters have to be decided depending on the mechanical properties of the work piece [11].

II. PROCEDURE FOR PAPER SUBMISSION

In this paper, the turning process was used a Mazak 200MY CNC turning machine fitted with a maximum spindle speed of 4500 rpm. The workpiece material used was Ti-6Al-4V, titanium alloy with dimension, 170 mm length and 80 mm diameter in the form of a round bar. The mechanical properties of the workpiece is shown in Table I. The experimental set-up for the turning test is shown in Table II for experimental conditions and specifications. The level of factors and responses conducted in this study is shown in Table III.

Table- I: The workpiece's material properties

Mechanical Properties	Metric
Hardness, Vickers	349
Hardness, Brinell	334
Modulus of Elasticity	114 GPa
Elongation at Break	10%
Modulus of Shear	44 GPa
Ultimate Tensile Strength	900 MPa
Fatigue Strength	510 MPa
Tensile Yield Strength	830 MPa
Shear Modulus	44 GPa

Table II: Experimental specification

Equipment/Parameters	Condition
Machine	Mazak 200MY CNC Turning Machine
Tool insert	Widia 0.4 CNMG120404-MS-WS25PT
Workpiece	Titanium Alloy Ti6Al4V, Grade 5, Length: 170 mm, Diameter: 80 mm
Surface texture analyser	Pocket MarSurf PS1
Cutting Force	Kistler 9129AA Dynamometer, 4-Charge Amplifier 5070A, Dynoware 2825D-02.
Tool wear	Digital Microscope Dino-Lite
Cutting parameters	Cutting speed (*Vs*): 45 – 160 m/min Depth of cut (*d*): 0.5 – 1.5 mm Feed rate (*f*): 0.05-0.35 m/rev
Coolant	Dry machining

Table- III: Cutting parameter and levels

Parameters	Unit	Levels		
		1	2	3
Vs	m/min	45	90	160
f	mm/rev	0.05	0.20	0.35
d	mm	0.50	1.00	1.50

Fig. 1 shows the Kistler Dynamometer type 9129AA and the multichannel charge amplifier type 5070A for turning operation. The cutting forces were measured using the Dynamometer, and the signals captured from the sensors and dynamometer, converted into readable information and outputs the results in a presentable format using Dynoware software

Fig. 1. The experimental setup for (A) CNC Turning Machine (B) Data Acquisition System (C) Multichannel Charge Amplifier (D) Laptop (E) Dino-Lite camera.

After finishing the first cutting parameter, the surface roughness was measured using MarSurf PS1 and acquired by measuring the surface roughness value at three locations around the workpiece circumference [14]. The tool insert was removed and put at the digital microscope to capture the tool wear. Then, the tool wear was observed by scanning of the digital microscope by Dino-Lite model.

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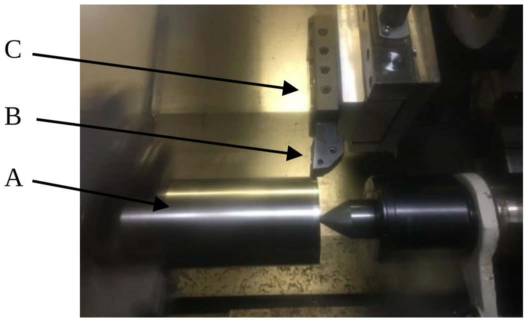

Fig. 2(a). The work piece (A), cutting tool (B) and dynamometer Setup (C)

Fig. 2(b). Surface roughness measurement

III. RESULTS AND DISCUSSION

Experimental values of surface roughness and nose radius were obtained at different cutting speed, feed rate and depth of cut combinations were in range from 0.440 to 2.907 µm with the carbide tool. Fig. 3 shows the cutting force acquired by varying the cutting depth and feed rate for different cutting speeds. The results of surface roughness was obtained by using MarSurf PS1 surface roughness measurement after turning process for each cutting parameter. Hence, the highest of the cutting force *Fy* was considered in optimization approach for this paper as shown in Fig. 3.

The measured nose radius before turning process is 0.4 mm by using Dino-Lite digital microscope, then, nose radius after turning process can be measured. Fig. 4 shows the tool wear with the nose radius after turning process for different parameters. Fig. 4 shows that most of them showed flank wear and crater wear. While changing the different cutting parameter for the next test, insert tool need to be changed especially when running test for depth of cut 1.5 mm.

The optimum case for finding three cutting parameters were used the Taguchi method which is known as one of the statistical methods that reduces the number of simulations or experiments. The Taguchi method utilizes S/N ratio to assess the trait of quality that deviates from the required value. Depending on the type of features such as higher-the-better, lower-the-better and nominal-the-better, there are several S/N ratios available. In this paper, Minitab software analysis, nominal-the-better is chosen as the categories of quality characteristic. So, orthogonal arrays L27 were used to extract the appropriate response experiments, such as cutting forces, surface roughness, nose radius and corresponding S/N ratios as shown in Table IV.

Cutting forces correlated well with the mechanical properties of the material. As the cutting parameter increases the cutting force increases [12]. This may be due to the higher yield strength and hardness of Ti6Al4V. The probable reason can be explained as the cutting speeds increase, the heat generated at the deformation zone increases as a result of adiabatic heating due to high strain rate deformation and friction between the tool and work piece. For cutting speed of 90 m/min and feed rate of 0.05 mm/rev, the cutting force recorded was 0.02167×10^{-3} kN, whereas 160 m/min for cutting speed and 1.5 mm for depth of cut, the cutting force recorded was 0.1313×10^{-3} kN. Increased cutting force also occurred at higher depth of cut with varying cutting speeds by keeping the feed rate constant.

It is noted that the effect of changing the depth of the cut from one stage to another is less a change in surface roughness due to the heat softening effect. The interaction between feed rate and depth of cut are shown in Fig. 5, Fig. 6 and Fig. 7. However, the surface roughness improves as the feed rate increases due to the increased duration of contact between the workpiece and the tool resulting in increased friction.

The tool insert was investigated for general types of wear patterns such as flank, crater, and nose wear using a Dino-Lite digital microscope. The hardness of the surface of the titanium alloy was increased when machined with a carbide insert. The hardness may also be expected to increase adhesive wear. Fig. 8 shows the images of carbide insert after machining the titanium alloy material. Due to the high temperature and strong attachment of the tool and parts of the workpiece, the tool's wear is making rapid progress in converting the operation of the titanium alloy. When the cutting depth increases by varying the cutting speed at a constant feed rate, the chips are attached to the carbide rake face when the

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cutting speed changes from 90 to 160 m/min at the end of the Ti6Al4V alloy turn. When the cutting speed increase at 160 m/min with the depth of cut 1.5 mm, the wear at the carbide insert seen clearly as flank wear. The carbide insert need to be changed the insert for the next experimental run. It is concluded that when the cutting parameter increases the tool wear may occur rapidly.

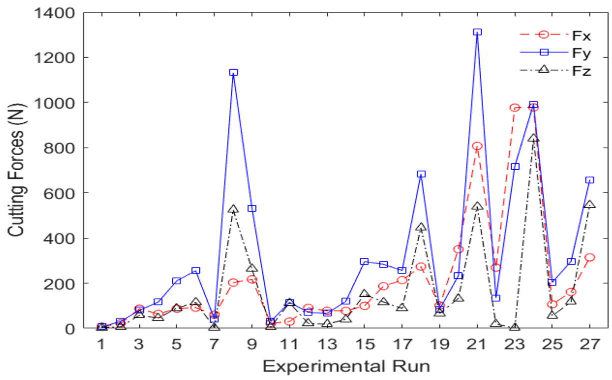

Fig. 3. Experimental run for cutting force.

Table- IV: Results of the experimental runs

Runs No.	*Vs* (m/min)	*f* (mm/rev)	*d* (mm)	*Fx* (N)	*Fy* (N)	*Fz* (N)	*Ra* (µm)	*VB* (mm)	S/N Ratio (dB)
1	45	0.05	0.5	7.50	6.73	3.92	0.700	0.440	3.67616
2	45	0.05	1.0	22.15	31.07	7.29	0.773	0.456	0.91324
3	45	0.05	1.5	87.07	79.89	58.13	0.792	0.462	3.19174
4	45	0.20	0.5	63.67	116.20	45.26	1.870	0.468	1.57295
5	45	0.20	1.0	87.31	211.10	89.90	1.781	0.474	1.08419
6	45	0.20	1.5	91.65	255.00	114.90	1.604	0.532	0.85920
7	45	0.35	0.5	60.50	41.44	3.99	5.510	0.448	0.01733
8	45	0.35	1.0	202.80	1132.00	524.20	2.830	1.726	0.50883
9	45	0.35	1.5	217.00	531.60	262.70	1.430	2.192	1.30798
10	90	0.05	0.5	22.15	31.07	7.29	0.696	0.454	0.88527
11	90	0.05	1.0	30.20	115.20	113.30	0.722	0.471	0.92604
12	90	0.05	1.5	90.53	70.79	21.67	0.488	0.473	0.79127
13	90	0.20	0.5	77.75	66.46	18.97	1.871	0.474	1.04563
14	90	0.20	1.0	77.36	119.50	40.23	1.200	0.479	1.41333
15	90	0.20	1.5	99.58	295.70	151.00	1.623	0.558	0.96147
16	90	0.35	0.5	186.80	283.60	116.80	2.161	0.524	1.89136
17	90	0.35	1.0	213.70	256.20	87.78	0.815	0.795	1.53907
18	90	0.35	1.5	273.40	683.10	445.00	1.041	2.907	1.73049
19	160	0.05	0.5	101.00	84.94	65.80	0.520	0.441	3.10513
20	160	0.05	1.0	350.10	233.40	133.30	0.774	0.471	1.64619
21	160	0.05	1.5	807.70	540.00	1313.00	1.915	0.478	1.71517
22	160	0.20	0.5	269.10	134.90	19.26	0.908	0490	1.34728
23	160	0.20	1.0	977.30	717.00	1.30	0.935	0.491	1.42731
24	160	0.20	1.5	978.00	992.60	840.00	1.125	0.509	1.82492
25	160	0.35	0.5	106.60	203.90	54.92	2.888	0.469	0.62003
26	160	0.35	1.0	161.30	296.90	117.90	1.373	0.479	1.45749
27	160	0.35	1.5	314.20	657.70	546.70	3.665	1.226	2.38546

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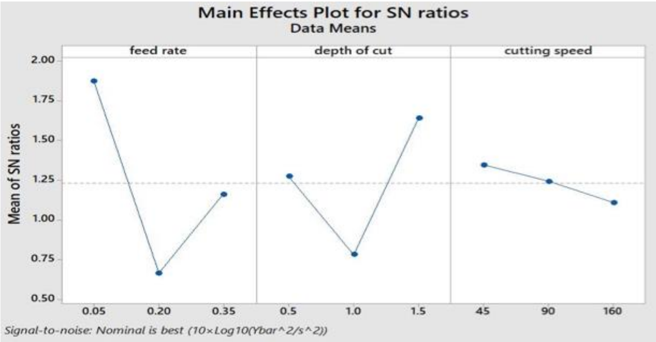

Fig. 4. Responses of main effect graph for S/N ratios.

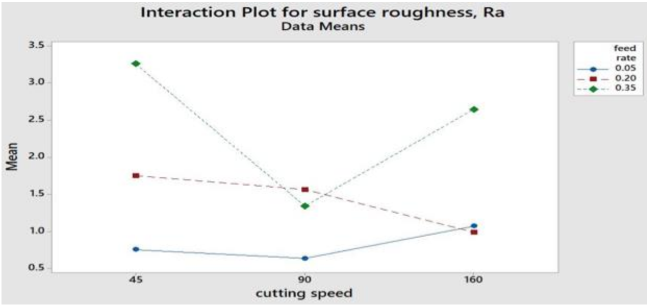

Fig. 5. Interaction graph for *Vs* between *d* and *f*.

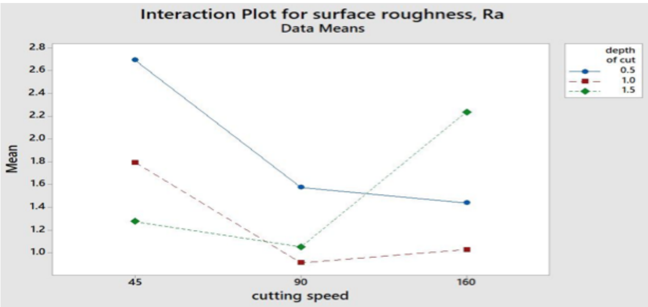

Fig. 6. Interaction graph for *Vs* between *Ra* and *d*.

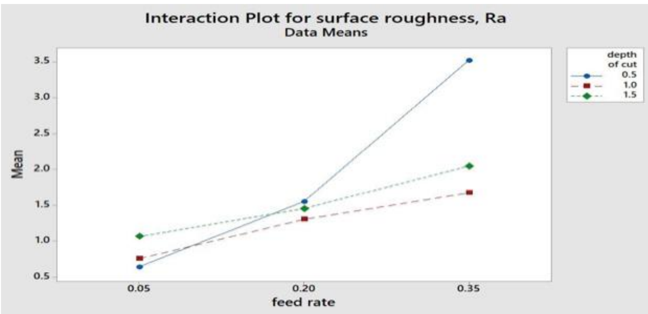

Fig. 7. Interaction graph for *Ra* between *f* and *d*.

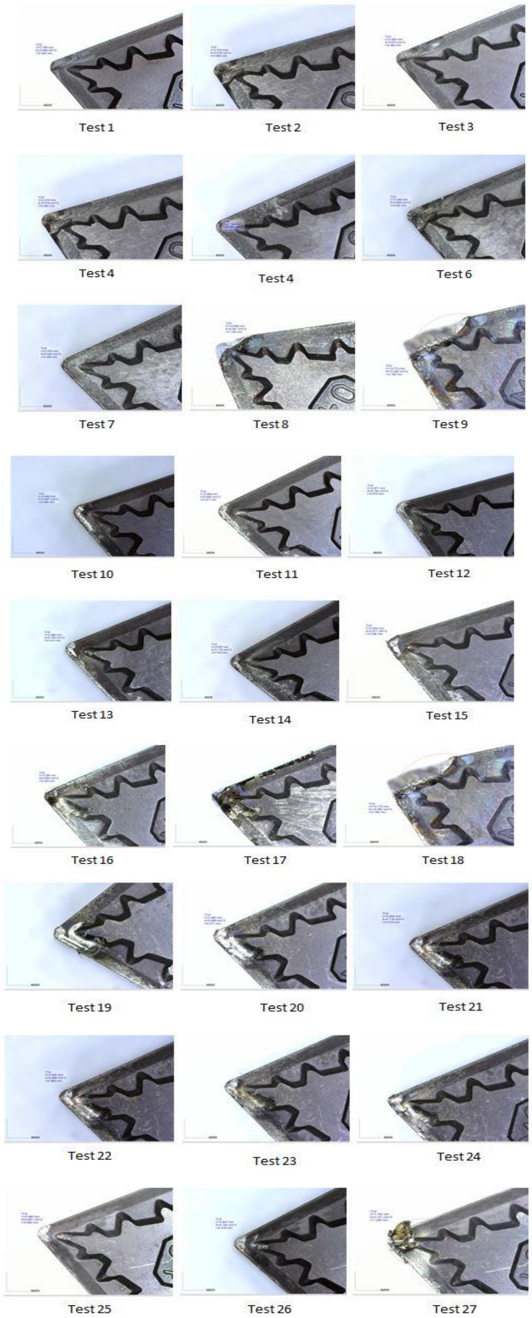

Fig. 8. The tool wear with measured nose radius after turning process for experimental tests 1 to 27.

Chips are formed due to a shear between the work piece and the cutting edge. During machining of the end cut, it can be seen that chips were formed after the cutting of the Ti6Al4V to various cutting parameters. Fig. 8 and Fig. 9 show that different types of chips are formed in the turning process of the titanium alloy. The advancement of different kinds of chips usually relies on different parameters such as cutting variables, angle of orthogonal rake, features of inherent material, friction among rake face and chip contact region [5].

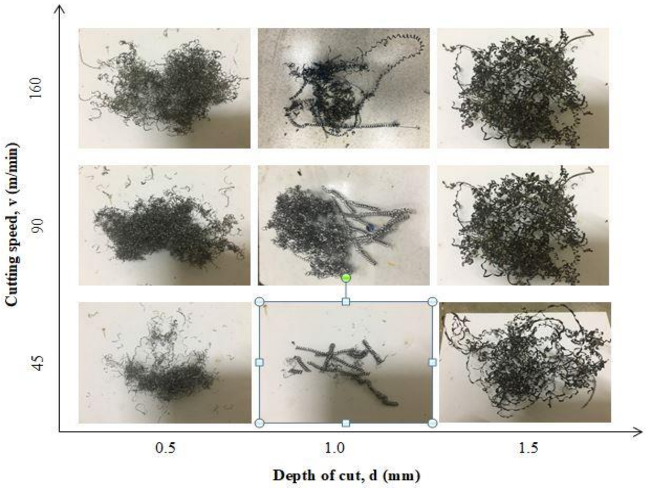

Fig. 9. The chips formed after turning process cutting speed against depth of cut.

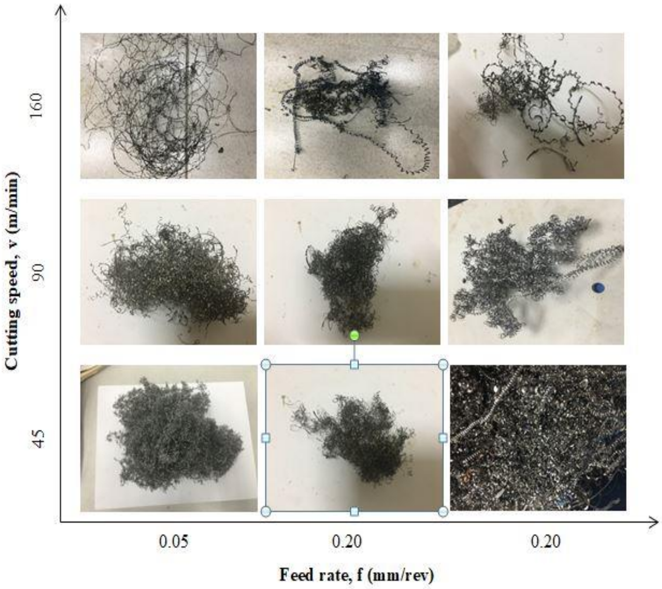

Fig. 10. The chips formed after turning process cutting speed against feed rate

The tubular type and helical shape of chips are regularly a big part of the chip frames. By raising cutting velocity in range 90-160 m/min and cutting depth in range 0.20-0.35 mm, lengthy helical chip type modifications to long tubular chip type. Increased cutting depth at low cutting speed and consistent feed of long helical chips. A long tubular form of chips is created at high cutting speed and steady feed.

IV. CONCLUSION

In this paper, comparative study on cutting forces, surface roughness, insert wear and chip formation in turning process of Titanium alloy has been conducted. It can be concluded as follows:

1. The optimum cutting parameters obtained for carbide insert and titanium alloy material are 90 m/min for cutting speed at medium level, 0.05 mm/rev for feed rate and 0.5 mm for depth of cut at low levels to get good surface roughness and cutting forces. The findings also demonstrate that the cutting parameters are very closely related to surface roughness and cutting forces, especially during the machining process of difficult-to-cut material.
2. The surface roughness increases with increasing of feed rate and cutting speed during turning of Titanium alloy using coated carbide tool. Low surface roughness is observed at lower cutting speed, depth of cut and feed rate of the cutting parameters. Generally, at high feed rate and cutting speed parameters, larger chip load are produced, might give rise to high surface roughness values. The low surface roughness values can be maintained with changing one of the parameters (feed rate, cutting speed) at the lower values.
3. The chip form produced in turning of Titanium alloy was found continuous chip forms. Long size of chip formed when machining at higher cutting speed and produced better surface finish.

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