OPTIMIZATION OF TURNING HAYNES 188 COBALT BASED AEROSPACE MATERIAL WITH CEMENTED CARBIDE CUTTING TOOL BASED ON TAGUCHI EXPERIMENTAL DESIGN

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Abstract

In this paper were determined the effects of cutting speed, cutting tool and feed rate on cutting forces and surface roughness based on Taguchi experimental design. The effects of machining parameters were investigated using Taguchi L_{18} orthogonal array. Three different cutting cemented carbide tools were used in experiments as K313, KCU10 and KCU25. Main cutting force *Fz* was considered to be cutting force as a criterion. The experimental design described herein was used to develop a main cutting force and surface roughness prediction model using analysis of Taguchi. Optimal cutting conditions were determined using the signal-to-noise (SN) ratio which was calculated for average surface roughness and cutting force according to the "the smaller is better" approach. Using results of analysis of variance (ANOVA) and SN ratio, effects of parameters on both average surface roughness and cutting forces were statistically investigated. In the experiments, depending on the tool material, lowest main cutting force 370 N at 75 m/min with KCU 25 and lowest average surface roughness (0.424 µm) at 60 m/min with KCU 25 cemented carbide tool was found. It was found the effect of feed rate 0.198%) and cutting tool (0.06%) has higher effect on the cutting force and the feed rate (18.82%). The cutting speed (17.31%) has shown higher effect on average surface roughness. In the cutting force turning tests KCU25 and in the surface roughness turning tests, K313 cutting tool has shown better performance than the other cutting tools.

Keywords: Machinability, Taguchi design, Haynes 188, surface roughness, cutting force

1. INTRODUCTION

A superalloy is a metallic alloy which can be used at high temperatures, often in excess of 0.7 of the absolute melting temperature. Creep and oxidation resistance are the prime design criteria. Superalloys can be based on iron, cobalt or nickel, the latter being best suited for aeroengine applications. Co-based superalloys are employed widely in practices because of wear, corrosion, and heat resistance properties. In the structure of Co-based superalloys, there are significant amounts of cobalt, nickel, chrome and tungsten. For example, Stellite, Haynes 188 and Haynes 25 are the most commonly used Co-based super alloys [1]. Superalloys have been developed to obtain the better strength-to-weight ratio and they provide higher heat and corrosion resistance compared to conventional alloys. The alloys are extensively used in applications such as turbine and furnace parts, aerospace, dental, orthopedic, heat-treating and chemical handling equipment and petroleum refining components where low thermal conductivity, wear resistance, heat resistance, corrosion resistance and high strength in working conditions under high temperature is required [2]. Haynes 188 superalloy has many favourable properties, including good strength at high temperatures, excellent ductility, fabricability and weldability and good resistance to hostile environments (e.g., corrosion, extreme heat, extreme cold, and so on). It is widely used for fabricating the combustor liners in aircraft turbine engines and is also used to produce the liquid oxygen posts in the main injectors of the space shuttle engines [3, 4]. In such applications, the components are subjected to extremely high temperatures and strain rates. Machining process of the superalloy brings two main problems. The first is a short tool life or rapid tool wear due to the work hardening and attrition properties of the superalloy. The second is poor surface quality of the machined surface due to heat generation and plastic deformation [5]. The simultaneous improvement or optimization of these two criteria is very important for high efficiency in the machining of superalloy. Cutting forces and surface roughness are two important issues in the machining of superalloys. In the last decades, different types of dynamometers have been used in industry and research laboratories for understanding the principles of chip formation [6], for developing cutting force models [7], as well as for cutting process control [8], tool geometry optimization [9], tool condition monitoring [10-13] and for detection and suppression of chatter vibrations [14, 15]. Cutting forces have a direct influence on specific cutting pressure and power consumption, For this reason, a commercially available Kistler piezoelectric dynamometer have been used for cutting force monitoring during machining [16]. Parameter design experiments identify settings of product design characteristics that minimize the estimated expected loss. A performance statistic is a criterion for comparing different settings of product and the loss function. Taguchi recommends the use of orthogonal arrays for planning parameter design experiments. Parameter design experiments can also be used to identify settings of the process variables that minimize the effect of manufacturing variations on the process's performance [17]. Cutting forces have a direct influence on specific cutting pressure and power consumption, For this reason, a commercially available Kistler piezoelectric dynamometer have been used for cutting force monitoring during machining [18]. With the increasing demand for reduced product tool wear and heat generation. Surface roughness is an important characteristic that describes the quality of the machined surface being, in most cases, a technical requirement for machined products. In addition, the surface roughness affects several attributes of machined parts like friction, wear, and heat transmission [19].

2. MATERIALS AND METHOD

2.1. Experiment specimens

Specimens of Haynes 188, which has an industrial usage, were prepared as the dimension of diameter Ø 50 × 400 mm and then used for the experiments. The chemical composition and mechanical properties of alloy Haynes 188 are given in **Tables 1 and 2**. These material is hard to machine which make them suitable for high temperature applications.

Table 1 Chemical composition of Haynes 188 workpiece material (wt.%) [20]

	Co	Ni	Cr	W	Fe	C	Mn	Si	P	S	La	B
Min.	balance	20.0	20.0	13.0		0.05		0.20			0.02	
Max.		24.0	24.0	16.0	3.0	0.15	1.25	0.50	0.020	0.015	0.12	0.015

Table 2 Mechanical properties of Haynes 188 [20]

Density	8.98 g/cm³
Melting range	1315 - 1410 °C
Yield strength	446 MPa
Tensile strength	963 MPa
Elongation	55%

2.2. Machine tool and measuring instrument of cutting forces

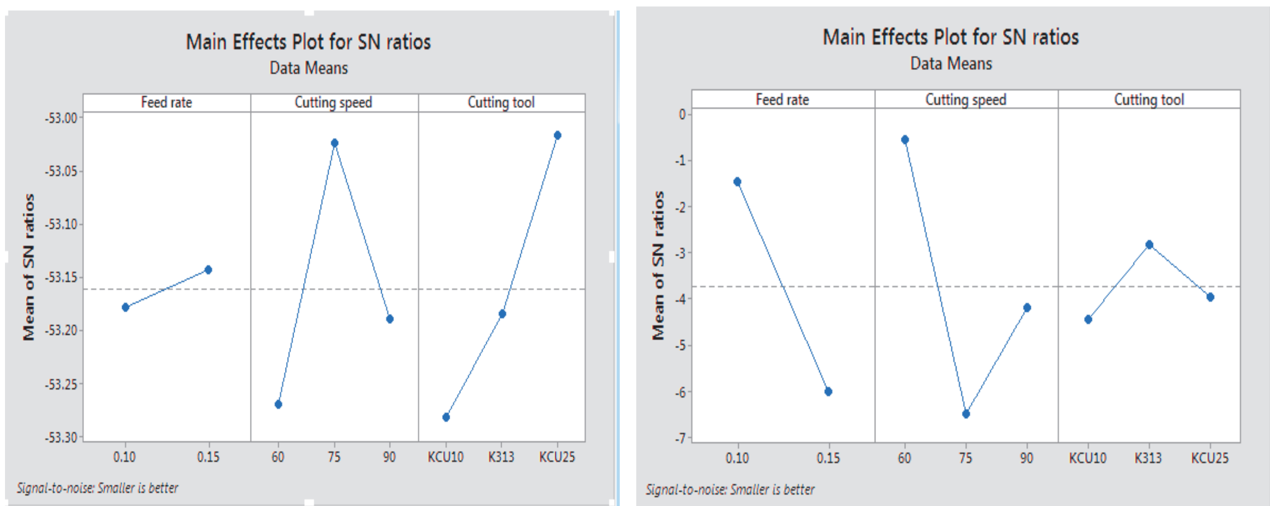
Machining tests were carried out on JOHNFORD T35 industrial type CNC lathe maximum power of which is 10 kW and has revolution number between 50 and 3500 rev/min. During dry cutting process, Kistler brand 9257 B-type three-component piezoelectric dynamometer under tool holder with the appropriate load amplifier was used for measuring three orthogonal cutting forces (*Fx*, *Fy*, *Fz*). This allows direct and continuous recording and simultaneous graphical visualization of the three cutting forces.

2.3. Cutting parameters, cutting tool and tool holder

The cutting speeds 60, 75 and 90 m/min, depth of cut constant 1 mm and feed rate 0.10-0.15 mm/rev. were chosen by taking into consideration ISO 3685 standard as recommended by manufacturing companies. During cutting process, the machining tests were conducted with three different cemented carbide tools namely TiAlN PVD coating KCU10 and KCU25 and K313 Wo/Co uncovered cutting tool. The test specimens were chosen Ø 50 × 400 mm. for turning operations. Surtrasonic 3-P measuring equipment was used for the measurement of surface roughness. Measurement processes were carried out with three replications. For surface roughness on work-piece during machining, cut-off and sampling length were considered as 0.8 and 2.5 mm, respectively. Ambient temperature was 20 ± 1 °C. The following details tool geometry CNGN inserts were mounted on the CCKNL 2525 M 12 type tool holder.

3. RESULTS AND DISCUSSION

Figure 1 shows mean of SN (signal/noise) response graphs of the cutting forces (a) and surface roughness (b) respectively. Level of independent variables is shown in **Table 3.** In the experiments, obtained results of average surface roughness, main cutting force and signal to noise ratios was found according to ‘’smaller is better’’. In the experiments, depending on the tool material, lowest main cutting force was found 370 N at 90 m/min with K313 and in the lowest average surface roughness 0.424 µm at 60 m/min with KCU25 cemented carbide tool. According to ANOVA analysis in **Table 4**, feed rate (0.198%) and cutting tool (0.06%) has higher effect on the cutting force. In the **Table 5** feed rate (18.82%) and cutting speed (17.31%) has higher effect on average surface roughness. In the cutting force turning tests KCU 25 and in the surface roughness tests, K313 cutting tool has shown better performance than the other cutting tools.



(a) (b)

Figure 1 Mean of SN (signal/noise) response graphs of the (a) cutting forces, (b) surfage roughness

According to **Table 6,** results of confirmation tests for cutting force were found as better parameters 0.15 mm/rev. feed rate, KCU25 cutting tool and 75 m/min, cutting speed. According to **Table 7,** for the surface roughness as better parameters was found as 0.1 mm/rev. feed rate, K313 cutting tool with 60 m/min cutting speed for turning Haynes 188.

Table 3 Level of independent variables

Variables	**Level of variables**		
Feed rate (mm/rev.)	0.100	0.150	
Cutting speed (m/min)	60	75	90
Cutting tool	KCU10	K313	KCU25

Table 4 Analysis of variance for SN (signal to noise) ratios of cutting force

Source	Degrees of freedom	Sequential sum of squares	Mean sum of squares	F-test	P-coefficient (%)	Distribution (%)
Feed rate	1	19.20	19.18	0.00	0.962	0.198
Cutting speed	2	547.6	273.80	0.03	0.966	0.05
Cutting tool	2	623.2	311.59	0.04	0.962	0.06
Residual error	12	95518.5	7959.88			98.76
Total	17	96708.5				

Table 5 Analysis of variance for SN (signal to noise) ratios of surface roughness

Source	Degrees of freedom	Sequential sum of squares	Mean sum of squares	F-test	P-coefficient (%)	Distribution (%)
Feed rate	1	42.354	42.354	3.63	0.081	18.82
Cutting speed	2	38.904	19.452	1.67	0.229	17.31
Cutting tool	2	0.3675	0.1838	0.16	0.856	1.60
Residual error	12	139.824	11.652			62.21
Total	17	224.757				

Table 6 Results of confirmation tests for cutting force *Fz*

Cutting force *Fz* (N)			
		Optimal cutting parameters	
	Starting cutting parameters	Prediction	Experimental
Parameters	0.10-90-K313	0.15-75-KCU25	0.15-75-KCU25
Cutting force (N)	573.05	371.14	375.2
SN ratio (dB)	-55.1639	-51.3908	-51.485
Improvement of SN ratio	3.6789		
Prediction error (dB)	3.7731		

Table 7 Results of confirmation tests for surface roughness *Ra*

Surface roughness *Ra* (µm)			
		Optimal cutting parameters	
	Starting cutting parameters	Prediction	Experimental
Parameters	0.10-90-KCU25	0.10-60-K313	0.10-60-K313
Surface roughness (µm)	0.879	1.819	1.832
SN ratio (dB)	1.12352	-5.19825	-5.2585
Improvement of SN ratio	6.4937		
Prediction error (dB)	6.3217		

4. CONCLUSIONS

The experimental design described herein was used to develop a main cutting force and surface roughness prediction model roughness using analysis of Taguchi for turning Haynes 188.

Results of this experimental study can be summarized as follows:

- According to experimental results of confirmation tests for cutting force *Fz,* was found as better parameters 0.15 mm/rev. with KCU25 cutting tool and cutting speed 75 m/min.
- For the surface roughness *Ra,* was found as better parameters 0.10 mm/rev. K313 cutting tool and 60 m/min for turning Haynes 188 with cemented carbide tools.
- While feed rate 0.198 % and cutting tool 0.06 % had higher effect on the cutting force, the feed rate 18.82 % and cutting speed 17.31% had shown higher effect on average surface roughness. In the cutting force KCU 25 and in the surface roughness turning tests, K313 cutting tool had shown better performance than the other cutting tools.
- In the experiments, depending on the tool material, lowest main cutting force 370 N at 75 m/min with KCU25 cutting tool and lowest average surface roughness 0.424 µm at 60 m/min with KCU25 cemented carbide tool was found.
- Taguchi orthogonal array arrangement - it has seen appropriate to analyzed the cutting force and average surface roughness defined in this article.
- According to turning test results, the depth of cut and feed rate are two main parameters between four can be controlled factor (cutting tool, cutting speed, feed rate, and depth of cut) affecting average surface roughness and cutting forces.

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