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SPECIFICATION OF OPTIMUM PARAMETERS IN THE MACHINING OF AEROSPACE MATERIALS

ABDULLAH ALTIN

Yuzuncu Yil University, Van, Turkey, aaltin@yyu.edu.tr
E-mail: aaltin@gmail.com

Abstract - In this study, nickel based super alloy Rene 41 aerospace material was chosen as machining test material, the effects of cutting speed on cutting forces and surface roughness were investigated based on Taguchi experimental design. Tree different cemented carbide cutting tools were used in experiments as KCU10, K313 and KCU25. The effects of machining parameters were investigated using Taguchi L_{27} orthogonal array. Optimal cutting conditions were determined using the signal-to-noise (S/N) ratio which is calculated for average surface roughness and cutting force according to the "the smaller is better" approach. Using results of analysis of variance (ANOVA) and signal-to–noise (S/N) ratio, effects of parameters on both average surface roughness and cutting forces were statistically investigated. Main cutting force, Fz is considered to be cutting force as a criterion. It has seen that while cutting speed and feed rate has higher effect on the cutting force, the feed rate and cutting speed more effect on average surface roughness. At the machining of Rene 41, optimum parameters for the cutting forces was found 0,150 mm/rev. feed rate, 90 m/min. cutting speed and KCU 10 cutting tool. For the surfage roughnes 0,125 mm/rev. feed rate, 60 m/min cutting speed and KCU 25 cutting tool was found better parameters for Rene 41 material.

Keywords - Machinability, Taguchi method, Surface roughness, Cutting force, Rene 41

I. INTRODUCTİON

Nickel-based superalloys have attracted a great deal of interest from aircraft and nuclear industry with the heat treatment industry because of its resistance to heat, excellent mechanical properties, resistance to corrosion and high temperature operation [1,2]. Nickel-based alloys form the widest group of superalloys and are very difficult to process [3-6]. Generally, in the chemical content of a nickel-based superalloy, (Ni), more than 27% chromium (Cr) and 20% cobalt (Co) [38]. These materials are used in applications where high corrosion resistance or high strength is required at high temperatures [3, 4, 8-12]. Commercially available nickel based superalloys include Inconel (587, 597, 600, 601, 617, 625, 706, 718, X750, 901), Nimonic (75, 80A, 90, 105, 115, 263, 942, PE 11 , PE 16, PK 33, C-263), Rene 41,95, Udimet 400, 500, 520, 630, 700, 710, 720, Pyromet 860, Astroloy, M-252, Waspaloy, Unitemp AF2-IDA6, Cabot 214, and Haynes 230 [7, 13]. These alloys are used extensively in the chemical industry to produce heaters, condensers for the treatment of fatty acids, eveparator pipes for the production of sodium sulphate, pipe mirrors and other equipment. Due to its low thermal conductivity and high cutting strength, however, due to the intense heat generated at the cutting edge, processing is still very difficult. Hard abrasive carbides (eg MC, M23C6) present in the microstructure of nickel-base superalloys provide abrasive wear that causes tool wear. The austenitic matrix of nickel-based superalloys causes rapid curing during processing. This is the main reason for the wear of the depth of cut line [11].

Nickel-based superalloys are known to be the most difficult to process with a quality finish. These alloys are used in aircraft engines, industrial gas turbines, spacecraft, rocket engines, nuclear reactors, submarines, steam generators, petrochemical devices and other heat resistant applications. Due to its ability to operate at high temperatures, the amount of super alloys used has increased steadily to 60% of total aircraft engine weight in the 1990s [6]. These alloys have excellent oxidation resistance at temperatures exceeding 650 oC and excellent strength at the phase boundary. 45% of the amount of superalloy produced is forged and 25% is cast nickel based superalloy. Nickel-based superalloys contain at least 50% nickel. Nickel is the main compounding element. Super alloys are grouped into forging, casting and powder metallurgy alloys. Incoloy 907, Udimet 720 and Haynes 188 are widely used materials in commercial and super alloys in aircraft and space industries. Cobalt based Haynes 188; cobalt-nickel-chromium alloys is a super alloy with excellent high temperature resistance and wear oxidation resistance. [12-14]

II. MATERİAL AND METHOD

2.1. Material

In this study, the materials prepared in Ø50x300 mm were processed by subjecting to the chip removal processes in CNC turning experiments. The chemical and mechanical properties of these materials are given in Table 1 and Table 2.

Table 1. Chemical composition of material Rene 41

C	Mn	Si	S	Cr	Ni	Co	Mo	Fe	Zr	Ti
0,062	0,01	0,05	0,001	18,53	53,86	10,52	9,53	2,37	0,03	3,24

Al	B	Pb	Bi	Se						
1,53	0,006	<0,0001	0,00001	<0,0001						

Tablo 2. Mechanical Properties of material Rene 41

Condition	Temprature(F)	UTS (ksi)	YS(.2%) (ksi)	Stress (ksi)	Life (Hrs)	%Elong.	%R.A.
M	Room Temprature (LONG)	208,0	150,0			26,0	31,0
M	1400(LONG)	152,5	128,5			14,0	15,5
M	1350(LONG)			97,5	35,2	34,0	

2.2. Method

Experiments were carried out under dry cutting conditions with a power of 10 kW and a speed of 50-3500 rpm. The JOHNFORD T35 is an industrial CNC lathe. Cutting tool properties and Levels of Cutting Parameters are given in Table 3 and Table 4. (Fx, Fy, Fz) were measured using a 9257 B-type dynamometer with a three-piece piezo electric Kistler brand. The device is mounted on a holder with a suitable load amplifer. The device visually shows the direct and continuous graphical record of each of the three forces. Tools were used in the specifications given in Table 3 for the cemented carpide tools in the machining process. The depth of cut (1.6 mm) and the feed rate (0,10-0,125 and 0,15 mm / rev.), Taking into account the ISO 3685 standard and the manufacturer's recommendations, fixed selected. Surtrasonic 3-P measuring device and cutting tools and 40 ° approach angle PCLNR 2525 M12 type tool holder were used for surface roughness measurement.

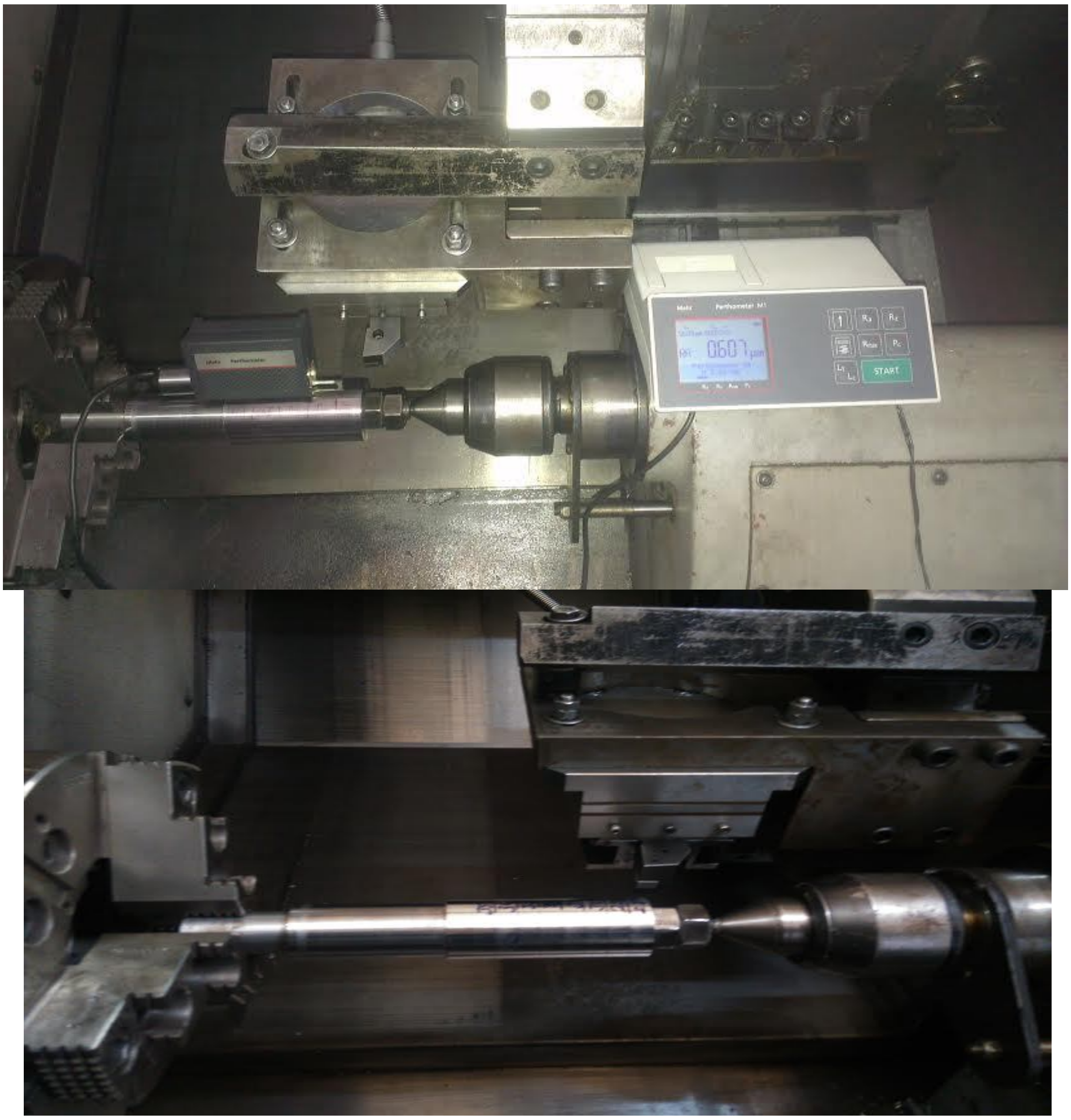

Figure 1: Kistler 9257B (1997) dynamometer (10 KW), cutting force measuring unit with JOHNFORD T35 CNC lathe.

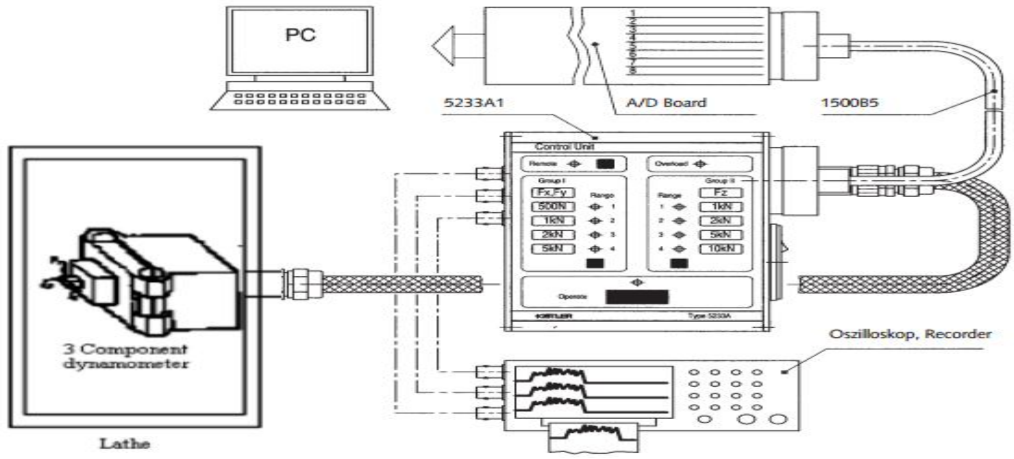

Figure 2. Measuring system and schematically figure of dynamometer unit

Tablo 3. Cutting tool specifications

Manufacturer and code	Coating type and layers	Coating method	ISO quality of material	Geometric shape code
Kennametal K313	WC/Co kaplamasız	WC/Co kaplamasız	M10-30 , K05-20	CNMG120404MS
Kennametal KCU10	TiAlN	PVD kaplama	P10-20, M10-20, K10-20	CNMG120404MS
Kennametal KCU25	TiAlN	PVD kaplama	P20-30, M20-30, K20-30	CNMG120404MS

Tablo 4. Levels of Cutting Parameters

Cutting Parameters		Unit	Levels		
			1	2	3
Cutting speed, v (m / min)	(A)	m/min.	60	75	90
Feed rate, f (mm / dev)	(B)	(mm/rev)	0.1	0.125	0,150
Cutting tool (cemented carbide)	(C)		KCU 10	K 313	KCU 25

III. RESULTS

3.1 Taguchi Method

The Taguchi method is used to determine optimum ranges of process parameters commonly used in the production area and engineering analysis. It is an experimental technique developed by Genichi Taguchi. " Taguchi method is very important in today's industrial world where time and economy are very important. This method is an important tool for designing and developing high quality systems. For these reasons, using the Taguchi method, industry can dramatically reduce product development time without sacrificing cost " [15-19]. Taguchi method; system design, parameter design and tolerance design. System design consists of the use of engineering and scientific knowledge necessary to form a product. Parameter design finds optimal ranges of process parameters to determine parameter values of a product under optimum process parameters and to improve performance characteristics. Tolerance design allows for the analysis and determination of tolerances around the optimal limits recommended by the parameter design. Among these designs, parameter design is a very important and most commonly used step because it plays a functional role in achieving high quality without increasing cost [20-24]. On the other hand; classical experimental design techniques are very complex, time-consuming and reduce their use. In addition, if the number of process parameters increases in classical experimental design techniques, the number of experiments to be done must also increase. To solve these problems, the Taguchi method concludes by combining three important tools: orthogonal experimental design, signal / noise ratio (S / N) and variance analysis (ANOVA). " Orthogonal experimental design is used to make a special design that scans the entire parameter space with very few experiments. The results from the experiments planned according to the orthogonal experimental design are analyzed by carrying them into the S / N ratio. The S / N ratio is used to measure the performance characteristics that are subtracted from the desired values. The S / N ratio is based on three bases such as "(S / N) SB, smaller-better", "(S /

N) LB, larger-better" and "S / N) NB, nominal- better depend on performance characteristics. ANOVA analysis is used to statistically determine the degree of significance of the process parameters that affect performance characteristics. Apart from these three important tools, the Taguchi method performs a final validation test to check the reliability of the best results obtained [25-27]. These three basic performance characteristics are indicated by the following formulas (1, 2, 3). Here; yi; the result measured from the experiments; the average of the results measured from the experiments, n; experiment number and s²y; The steps necessary to implement the Taguchi optimization method are expressed below respectively.

$$S/N_{LB}=\eta = -10 \log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (1)$$

$$S/N_{SB}=\eta= -10 \log\left[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right] \quad (2)$$

$$S/N_{NB}=\eta = 10 \log\left[\frac{\bar{y}}{s^2 y}\right] \quad (3)$$

Here,
$\bar{y}$: average of the data obtained from experiments
yi: experimental data (surface roughness or cutting force)
n: number of experiments
A total of 27 experiments were carried out based on the L27 orthogonal experimental design.
The Taguchi method combines three important tools to analyze and evaluate numerical results, such as orthogonal experimental design, S / N ratio and ANOVA [21-22]. In this study, numerical results are obtained by using three tools expressed in Taguchi method in order.

3.2 ANOVA (Variance) Analysis

In determining the total variance of the variance rates, each of the processing parameters is separated from the variability resulting from the error. To this end, the effect of each factor emerged for both materials used in the experiments was determined. The L27 orthogonal design is composed of 27 columns (26 degrees of freedom), corresponding to 9 columns and turning experiments at 3 levels. The S / N ratio is a statistical measure of the performance characteristics of the Taguchi method and is a logarithmic function of the desired response. In this study, as a performance characteristic, the cutting force and surface roughness of the part were selected after the turning operation. The smaller the cutting force and surface roughness, the "(S / N) SB is smaller-better" as the quality characteristic [23-24]. The average surface roughness and the main cutting force for each experiments and the S / N ratios are given in Tables 5. For the determination of the smallest average surface roughness value, the maximum S / N ratio for each level of the parameters was determined and the verification experiment was performed according to the new combination of experiments. In this study, the optimal cutting conditions that gave the smallest roughness and cutting force values for all three materials were determined by selecting the largest S / N ratio for each cutting condition. In addition, final verification tests have been performed with optimal cutting conditions that give the lowest surface roughness and cutting force for Rene 41 material. Development rates were calculated by comparing the results obtained from the verification test with the results obtained from the initial values. Thus, by Taguchi analysis, a small number of turning experiments were carried out to determine the optimum cutting conditions for all three materials.

As shown in Table 5 for Rene 41, the lowest main cutting force of F 395,45 N was obtained at 90 m/min. with 0,150 mm/rev. and the greatest cutting force of F685,79 N at 60 m/min. cutting speed, 0,125 mm/rev. Feed rate both with K313 cutting tool. The lowest surface roughness value was obtained 0,701µm at 90 m/min. cutting speed, 0,150 mm/rev feed rate with K313 cutting tool.According to ANOVA results ofcutting force (Fz),the most effect cutting speed was found % 93,30 and for the surface roughness the most effect of feed rate was found as % 43,36 for Rene 41 in cemented carbide cutting toolsare given in Table 6 and Table 7 respectively. The mean surface roughness value as a result of the turning for the verification experiment was measured as 1,042µm at Rene 41, smaller than this value was not obtained during the experiment. and verification tests for cutting force (Fz) and surface roughness at Rene 41 are given in Table 8 and Table 9.
Average response graphs of cutting forces and surface roughness according to feed rate, cutting speed and cutting tool are given at Figure 2.

Table 5. S / N ratios for Ra and Fz in Rene 41 with cemented carbide cutting tools

Feedrate	Cutting speed	Cutting tool	Average surface roughness Ra, (µm)	S/N ratio For Ra	Main cutting force Fz (N)	S/N ratio For Fz
0.100	60	KCU10	1,033	-3,32564	502,66	-55,2581
0.100	60	KCU10	1,366	*	597,31	*
0.100	60	KCU10	1,876	*	630,34	*

0.100	75	K313	1,042	-3,09752	464,98	-54,4714
0.100	75	K313	1,393	*	539,13	*
0.100	75	K313	1,760	*	577,14	*
0.100	90	KCU25	1,309	-5,32999	405,31	-53,9814
0.100	90	KCU25	1,797	*	498,61	*
0.100	90	KCU25	2,301	*	580,91	*
0.125	60	K313	1,094	-3,10077	480,14	-55,3524
0.125	60	K313	1,396	*	572,73	*
0.125	60	K313	1,727	*	685,79	*
0.125	75	KCU25	0,941	-2,18073	462,79	-54,3134
0.125	75	KCU25	1,254	*	514,40	*
0.125	75	KCU25	1,581	*	575,48	*
0.125	90	KCU10	0,870	-2,28916	398,59	-53,2949
0.125	90	KCU10	1,214	*	454,12	*
0.125	90	KCU10	1,689	*	524,91	*
0.150	60	KCU25	0,897	-2,91063	468,71	-55,1212
0.150	60	KCU25	1,156	*	567,11	*
0.150	60	KCU25	1,929	*	658,96	*
0.150	75	KCU10	1,174	-6,27235	442,32	-54,2211
0.150	75	KCU10	2,636	*	487,51	*
0.150	75	KCU10	2,095	*	599,68	*
0.150	90	K313	0,701	-8,54198	395,45	-53,2916
0.150	90	K313	2,849	*	444,64	*
0.150	90	K313	3,583	*	534,85	*
0.100	60	KCU10	1,033	-3,32564	502,66	-55,2581
0.100	60	KCU10	1,366	*	597,31	*
0.100	60	KCU10	1,876	*	630,34	*
0.100	75	K313	1,042	-3,09752	464,98	-54,4714
0.100	75	K313	1,393	*	539,13	*
0.100	75	K313	1,760	*	577,14	*
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0.100	90	KCU25	1,797	*	498,61	*
0.100	90	KCU25	2,301	*	580,91	*
0.125	60	K313	1,094	-3,10077	480,14	-55,3524

Tablo 6. ANOVA results for cutting force (Fz) at Rene 41 in cemented carbide cutting tools

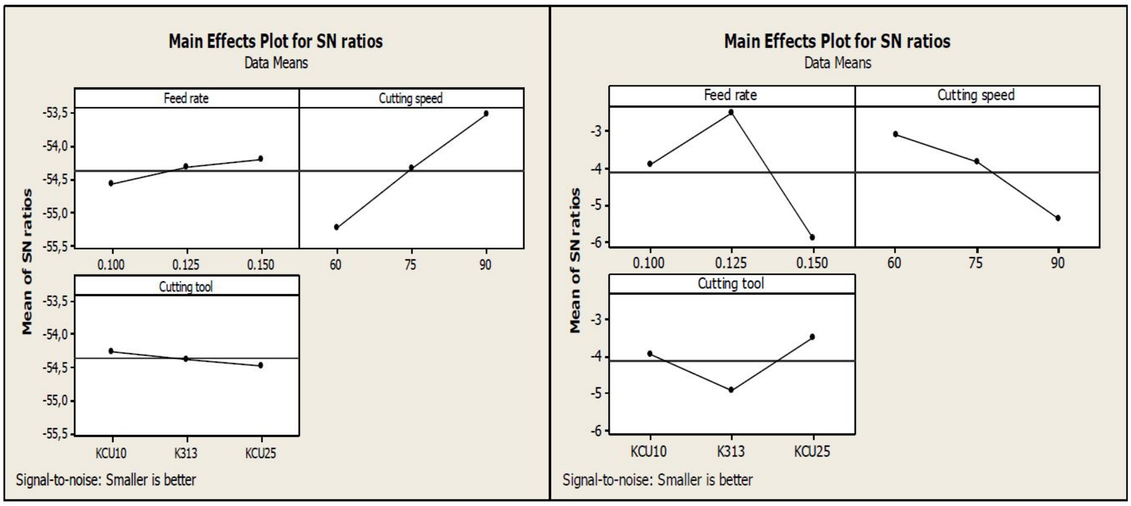
Parameters	Degree of freedom (Dof)	Sum of squares	Average of squares	F	P ($p<0.05$)	Parameter effect (%)
Feed rate	2	740,4	370,21	3,17	0,240	4,33
Cutting speed	2	15925,6	7962,80	68,15	0,014	93,30
Cutting tool	2	169,0	84,52	0,72	0,580	0,09
Error	2	233,7	116,84			1,36
Total	8	17068,7				100

Tablo 7. ANOVA results for surface roughness (Ra) at Rene 41 in cemented carbide cutting tools

Parameters	Degree of freedom (Dof)	Sum of squares	Average of squares	F	P ($p<0.05$)	Parameter effect (%)
Feed rate	2	0,5182	0,25912	1,79	0,358	43,36
Cutting speed	2	0,2794	0,13970	0,97	0,508	23,37

Cutting tool	2	0,1088	0,05438	0,38	0,726	9,10
Error	2	0,2887	0,14436			24,15
Total	8	1,1951				100

Average response graphs of cutting forces and surface roughness according to feed rate, cutting speed and cutting tool are given at Figure 2. According to Figure 3, the cutting forces decrease as the cutting speed increases. According to Figure 4. it has seen the change of surface roughness according to cutting speed is variable.



(a) (b)

Figure 2. Average response graphs of (a) cutting forces (b) surface roughness according to feedrate, cutting speed and cutter attachment at Rene 41

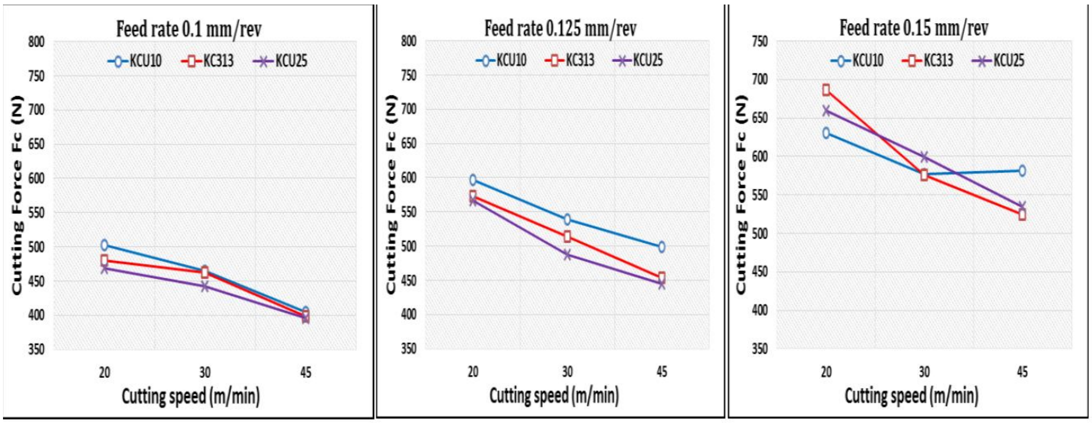
Tablo 8. The optimum result and verification test Fz (N) for cutting force at Rene 41

	Initial cutting Parameters	Optimum cutting parameters	
		Predicted Verification	Verification experiment
Level	0,125-75-K313	0,150-90-KCU 10	0,150-90-KCU 10
Cutting force	472,55	527,3	520,2
S / N ratio (dB)	-53,488	-54,441	-54,323
S / N ratio	0,835		
Error (dB)	0,953		

Tablo 9. The optimum result and verification test (Ra (µm) for surface roughness (Ra) at Rene 41

	Initial cutting Parameters	Optimum cutting parameters	
		Predicted Verification	Verification experiment
Level	0,10-75-KCU 10	0,125-60-KCU 25	0,125-60-KCU 25
Surface roughness	1,042	1,366	1,340
S / N ratio (dB)	-0,357	-2,709	-2,54
S / N ratio	2,183		

Error (dB)	2,352		



(a) (b) (c)

Figure 3. The change of the main cutting force according to cutting speed (a) Rene 41 a = 0.1 mm / rev, (b) Rene 41 a = 0.125 mm / rev. (c) Rene 41 a = 0.15 mm / rev.

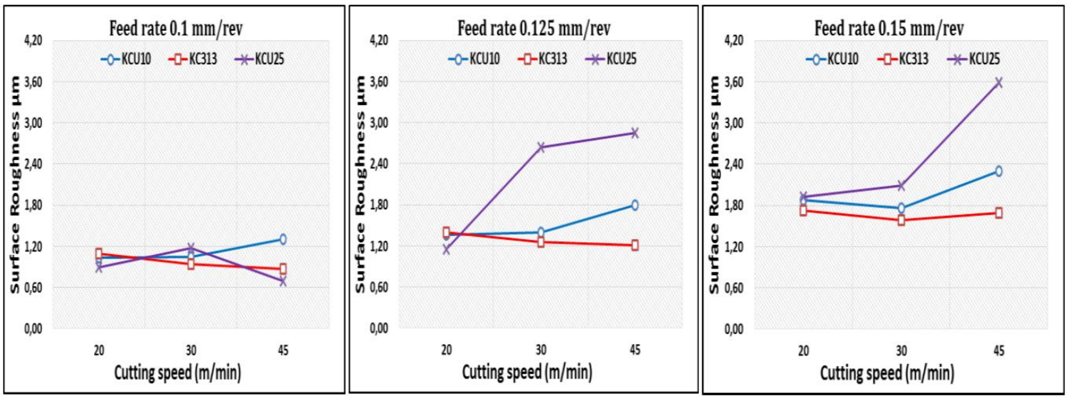


Figure 4. The change of surface roughness according to cutting speed (a) Rene 41 a = 0.1 mm / rev. (b) Rene 41 a = 0.125 mm / rev. (c) Rene 41 a = 0.15 mm / rev.

CONCLUCİONS

In this study, optimum machining parameters were tried to be obtained by taking the Taguchi experimental design as the basis for the Rene 41 turning. Based on the experimental results of this study, the following conclusions can be drawn:

• It has been seen that parameterization by Taguchi method, provides a simple, systematic and efficient method of optimizing the cutting parameters.

• It has been seen that while cutting speed and feed rate has higher effect on cutting force, the feed rate and cutting speed has higher effect on average surface roughness. Optimum parameters for the cutting forces was found 0,150 mm/rev., 90 m/min. and KCU 10 cemented carpide cutting tool. For the surfage roughnes 0,125 mm/rev. 60 m/min and KCU 25 cutting tool was found better parameters.

• Turning test results are the main parameters between the three controllable factors (cutting tool, cutting speed and feed rate) that affect average surface roughness and cutting force. As a result of the experiments, the effect of the cutting speed on the cutting force were seen more in the machining of the Rene 41 with the cemented carbide tools. The effect of feed rate and the cutting speed on the surface roughness was observed more effective.

• Achieving better average surface roughness and cutting force on the Rene 41 is achieved at nearly the same test range as the specified parameters.

• The Taguchi orthogonal array set is considered suitable for analyzing the cutting force and mean surface roughness defined in this article.

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