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RESEARCH ARTICLE - MECHANICAL ENGINEERING

Machinability of Stellite-6 Coatings with Ceramic Inserts and Tungsten Carbide Tools

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Abstract In this study, the machinability of Stellite-6 coating material was examined. For this purpose, Stellite-6 coating materials and two different types of cutting tool materials (ceramics and tungsten carbide) were used. The performance of the tool materials in the turning operation was analyzed. Two materials were compared in terms of surface roughness in different cutting speeds and feed rates. Taguchi method was used for the analysis of relationship between the surface quality and the cutting parameters. The estimated values were very close to the results of the experimental tests. Experimental and analysis results showed that whisker-reinforced ceramic insert was more suitable than tungsten carbide cutting tool for the machining of Stellite-6 coating material in terms of surface roughness. The objective of this study is to determine the ideal conditions and optimum machinability parameters for Stellite-6 coating material and to explore the appropriate cutting tool.

Keywords Stellite-6 · Coating · Ceramic · Surface roughness

الخلاصة

تم - في هذه الدراسة - فحص قابلية تصنيع مادة طلاء ستالايت-6. ولهذا الغرض تم استخدام مواد طلاء ستالايت-6 ونوعين مختلفين من أداة قطع المواد (السيراميك وكربيد التنجستن)، وتم تحليل أداء مواد الأداة في عملية التحول. وتمت مقارنة اثنتين من المواد من حيث خشونة السطح في سرعات قطع ومعدلات تغذية مختلفة. وتم كذلك استخدام أسلوب تاجوشي لتحليل العلاقة بين نوعية المياه السطحية ومعلمات القطع، وكانت القيم المقدرة قريبة جدا من نتائج الاختبارات التجريبية. وأظهرت النتائج التجريبية والتحليلات أن إدراج سيراميك ويسكر المعزز كان أكثر ملاءمة من أداة قطع كربيد التنجستن في تصنيع مادة طلاء ستالايت-6 من حيث خشونة السطح. إن الهدف من هذه الدراسة هو تحديد الظروف المثالية ومعلمات التصنيع المثلى لمادة طلاء ستالايت-6 واستكشاف أداة القطع المناسبة.

1 Introduction

Steel is the key driver of the world's economy. Iron and steel industry plays a critical role in economic and infrastructural development. Moreover, this industry is considered an indicator of economic growth. Iron and steel industry supplies input to almost all manufacturing sectors. Iron and steel production reached a peak of 34.1 million tons in Turkey last year which has led to an increase in spare parts demand and production. In production process of spare parts, specialists focused on how to carry out machining economically and quickly. Because new spare parts are expensive to manufacture, submerged arc welding is preferred for re-use. In molten process, the flux provides a path between the work and the electrode. This thick layer of flux completely covers the molten metal. Machining is the most common process associated with the production of spare parts, second to submerged arc welding. The machinability is also of interest due to its importance in possible spare part production. Coating produced by submerged arc welding technique is widely used for a range of production of spare parts to minimize the costs. Stellite-6 is generally performed for coating materials used

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in the industry. Machinability of this material is also of interest due to its importance in coating production. The major motive of the research is to discover the best cutting tool so that the machining costs can be minimized. Machinability is evaluated using various criteria including cutting forces, tool life, chip control, dimensional stability, metal removal rate, and surface roughness [1].

Ceramic cutting inserts are the most important tool material used in turning of hard materials due to their mechanical properties at high temperatures, compression strength and, high resistance against abrasive wear. Ceramic material has low thermal conductivity. Tungsten carbide has been widely used in industries because of its good combination of toughness and hot hardness. Carbides are cost-effective tools and owner of the low thermal expansion, high elastic modulus, toughness of the materials and wear resistances. Performance of the carbide and ceramic in the finishing milling of the fire face of the engine block made of cast iron was compared in terms of wear mechanisms and tool life in different cutting speeds by the researches [2]. Carbide is better than ceramic in terms of tool life in the milling cast iron. Stellite-6 is a cobalt-based superalloy and is widely used in applications requiring good wear, corrosion by the nuclear, aerospace, and biomedical industries [3–5]. Machining of hard superalloys is difficult, and machining of Stellite-6 will be more important with increasing use of the alloy for welding electrodes in the future [6]. Sharp cutting tools are not suitable for machining operations; because no tool is perfectly sharp, and generally available cutting tools have a tool edge radius varying from 5 to 250 μm [7–9]. In turning operations, cutting tool and geometry, cutting and tool condition, work piece materials, vibrations on the surface and stability of the turning machine determine the surface roughness [10–14]. Grzesik [10] used the minimum undeformed chip thickness and improved a model for predicting the roughness of the surface. A simulation model was improved with known vibration characteristics to simulate the surface finish profile after a cutting operation by Lin and Chang [11]. Surface topography model was developed and it was used in automated surface finishing processes by separating the surface finishing processes [12]. Ghani and Choudhury [13] conducted their experiment with ceramic tool and used vibration signals to monitor the tool wear. The effect of vibration on surface roughness and tool life was analyzed [15]. Prediction of the surface roughness was reviewed by Benardos and Vosniakos [16]. Surface roughness plays an important role in determining the quality of machined products [17,18].

Compared to ceramic tools, carbide tools are cheap. However, alumina-based ceramic tools are attractive cutting tool materials for the machining of ductile iron, because of their higher hot hardness and lower friction. Coating has been developed for an increasing number of engineering applications because of its combination of strength and toughness. Ceramic cutting tools are suitable for the machining of coating materials. However, their fracture toughness is much lower than that of the other widely used tool materials such as high-speed steel and carbides [19,20]. Dry machining has the advantage of reducing the health risks, the costs, the environment risks, and the problems involved with recycling chips [21]. Also producers want to reduce the costs of the life cycle of cutting fluids which have direct repercussions on manufacturing costs. Cutting fluids, workpiece material, tool geometry, built-up edge (BUE), and chatter are among the parameters that affect surface roughness [22]. Surface roughness was predicted based on cutting parameters using reliable models [23]. Surface roughness was predicted by used speed, feed rate, depth of cut, and tool holder [24]. Experimental observation that roughness depends on cutting parameters and tool vibrations is considered in the past studies [25,26].

The most used tool materials to cut Stellite-6 coatings are tungsten carbide and whisker-reinforced ceramic insert and both are tested in this study. The performance of this work was evaluated by estimating the turning conditions for Stellite-6 coatings. This work concentrates on experimental investigation of reflection of cutting speed and feed rate on surface roughness obtained in turning operations.

2 Experimental Procedures

Descalers are used in hot strip mills to obtain good surface quality of the hot rolled products. Therefore, descaling is a very important process of hot rolling. The fluid pressure can be increased up to 400 bar to remove any scale from the surface of the hot rolling product. The most important two descaling parameters are the descaling performance and the descaling condition. It is very important to obtain better descaling performance and condition to reach long operation times without making any maintenance. One way to optimize the performance is to improve the wear resistance of the rings which are installed on the descaling shaft to provide a bearing surface between the shaft and the housing. To improve the wear resistance, the surface is coated with Stellite-6 material by welding process.

Submerged arc welding is used as a welding process illustrated in Fig. 1. The arc area and the molten weld are protected from atmospheric contamination by being submerged under a flux. The flux can clean the weld metal zone and modify its chemical composition. This method can be applied economically over a very wide operating range like coating. Welds produced are uniform and have good impact value. This can lead to improving the surface features and boost the ring life.

The machining of Stellite-6 coating is difficult because of its abrasive characteristic and high hardness about 45 HRC. Another reason for machining difficulty is the wavy surface

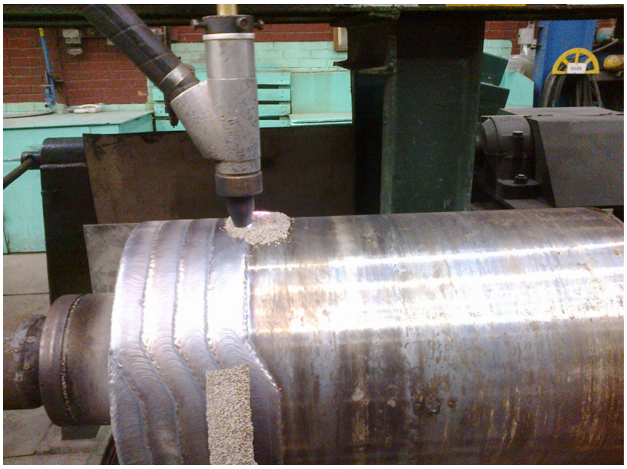

Fig. 1 Submerged arc welding operation

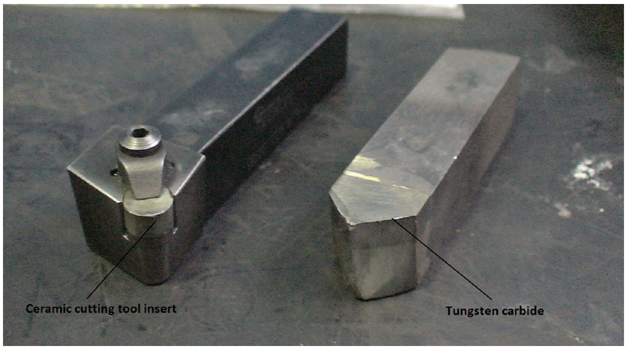

Fig. 2 Cutting tools and inserts used in the experiment

that is the result of the welding process. It produces an impact to the cutting edge of the insert during the turning operation. In this experiment, cutting tools were chosen as tungsten carbide and ceramic round types insert that are widely used in machining operations as shown in Fig. 2.

A universal turning machine (Type SN55) from Toss was used for the turning process. Cutting tests of the investigated tools were carried out as the continuous turning. The material type of the ring is AISI 304 austenitic stainless steel used for the substrate material; it contains 0.07 C, 0.7 Si, 1.2 Mn, 9 Ni, 20 Cr and Fe in balance (in wt.%). It has high ductility, forming and spinning properties. Because of its low carbon content, there is less carbide precipitation in the heat-affected zone during welding and a lower susceptibility to intergranular corrosion. The coating material is Stellite-6 cobalt base alloys consist of complex carbides dispersed in a CoCr alloy matrix and, is composed of (in percentage of weight) 1-C, 30-Cr, 5.5-W, and Co, remainder. They are resistant to wear and corrosion and retain these properties at high temperatures. It also has good resistance to impact and cavitation erosion and can be used at pump shafts and bearings. The hardness of the ring of base material was measured as 125 HB and the hardness of the coating was measured as 423 HB after machining. The outside diameter, the inner diameter and the length of the ring are 200, 170 and 300 mm, respectively. Workpiece, tool holder and cutting process can be seen in Fig. 3.

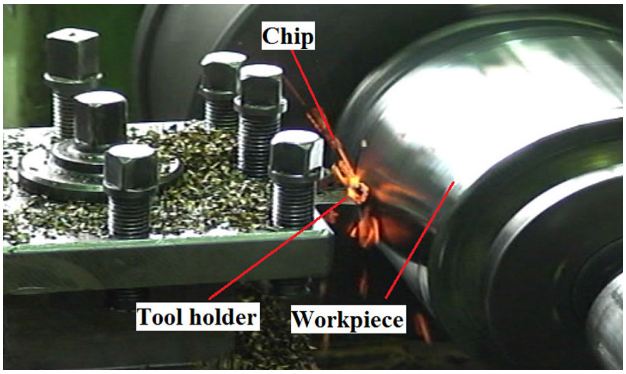

Fig. 3 Turning operations

In this experimental study, two types of cutting inserts were used. The first one is tungsten carbide tip which was brazed to the tool holder and the second one is the whisker-reinforced ceramic insert. The brazed tungsten carbide tip which has a positive rake angle was uncoated and its ISO grade was K20. The ISO designation code is not available. The grade of the ceramic insert is CC670. The ISO designation of the ceramic insert is RNGN 120700 T0 1020 670 and the manufacturer is Sandvik Inc. It is a silicon carbide "whisker" reinforced ceramic grade, where the whiskers are randomly orientated within the Al_2O_3-based material. It is particularly well suited for high-speed machining of heat resistant super alloys and hardened materials where demands are high for security or toughness. A right-hand tool holder (CRSNR2525M12S) which has a 6° negative rake angle is used for ceramic insert. All tests are performed under continuous turning conditions. Coolant is not used during the machining with ceramic insert. But soluble oil emulsion as a coolant was used during machining with tungsten carbide tip.

In this study, two rings are removed from the pump shaft and the outer surfaces are machined on a lathe to prepare the surfaces for welding operation. After machining, the ring surfaces are welded as two layers with Stellite-6 material which has a good wear resistance and 42–45 HRC hardness. Hardness values are measured after machining operations by Krautkramer ultrasonic hardness measurement device. One of the rings is then located on a lathe machine and adjusted by a comparator. The ring is machined using tungsten carbide tool. After finishing the first ring, the second ring is located on the lathe machine and adjusted. Ceramic insert is used for the machining of the second ring. The speeds and feeds given in the Table 1 are used for both and after each machining surface roughness is measured.

For tungsten carbide cutting tool, three cutting speeds $v = 30, 40, 50$ m/min have been selected. The feed rates and

Table 1 Variation of the surface roughness with the cutting speed and feed rate for ceramic insert and tungsten carbide tools

Insert type	Cutting speed (m/min)	Feed rate (mm/rev)	Average surface roughness (μm)	Tool type	Cutting speed (m/min)	Feed rate (mm/rev)	Average surface roughness (μm)
	V	f	Ra		V	f	Ra
Whisker-reinforced ceramic CC670	30	0.25	2.48	Tungsten carbide	30	0.1	2.6
		0.3	3.44			0.15	3.8
		0.35	4.74			0.20	5.1
	50	0.25	2.42		40	0.1	2.1
		0.3	3.29			0.15	3.1
		0.35	4.63			0.20	4.7
	70	0.25	2.30		50	0.1	1.8
		0.3	3.19			0.15	2.5
		0.35	4.54			0.20	4.0
	90	0.25	2.21				
		0.3	3.10				
		0.35	4.40				

depth of cut are $f = 0.1, 0.15, 0.20$ mm/rev and $a = 0.25$ mm, respectively.

The following cutting conditions were employed in this work for whisker-reinforced ceramic insert:

- Cutting speed (m/min): 30, 50, 70, 90.
- Feed rate (mm/rev): 0.25, 0.30, 0.35.
- Depth of cut (mm): 0.25.

A portable surface tester (SJ-301) from Mitutoyo was used to measure the surface roughness of machined surface. Cutting depth of 0.25 mm used in the finish turning operation was kept constant throughout the investigation.

3 Results and Discussion

The aim of the study was to assess the impact of the different tool materials in turning to choose the most suitable combination of parameters and materials. To achieve this objective, the performance of both ceramic insert and tungsten carbide tools was evaluated based on the workpiece surface roughness. In this section, results of surface roughness, Taguchi method and estimation of surface roughness values subsections will be presented.

3.1 Results of Surface Roughness

In this study, the surface parameter used to evaluate surface roughness is the arithmetic average roughness (Ra), which measures the average deviation of an irregular surface compared to a perfect cylinder or plane. Arithmetic Ra is recognized universally as the international parameter of roughness by ISO 4287, 1997 standard. Ra is determined using profilometers.

For the ceramic cutting inserts, four different cutting speeds and three different feed rates were used, under the constant depth of cut. In addition, cutting tests were performed on three different cutting speeds and feed rates with a constant depth of cut for the tungsten carbide tools. The surface roughness results obtained in this work are given in Table 1.

As can be seen from Table 1, the obtained surface roughness values for whisker-reinforced ceramic insert were between 2.21 and 4.74 μm. Surface roughness decreases by 10.9 % with the increase of cutting speed from 30 to 90 m/min at a feed rate of 0.25 mm/rev. At a feed rate of 0.35 mm/rev, surface roughness decreases by 7.17 % with the increase of cutting speed from 30 to 90 m/min. 2.4 pct. decrease in surface roughness with the increase of cutting speed from 30 to 50 m/min at a feed rate of 0.25 mm/rev is observed. On the other hand, surface roughness decreases by 21.5 % with the increase of cutting speed from 30 to 50 mm/min at feed rate of 0.2 mm/rev for tungsten carbide cutting tool. Although the feed rate of the whisker-reinforced ceramic insert is higher than the other cutting tool at the same cutting speed, surface roughness of workpiece material of tungsten carbide cutting tool is higher than of whisker-reinforced ceramic insert. In other word, the surface quality of whisker-reinforced ceramic insert is much better than of the other tool.

Whisker-reinforced ceramic cutting inserts are suitable for faster machining than tungsten carbide tools. Therefore, at the same cutting speeds higher feed rate values can be used. It is observed that at feed rate of 0.25 mm/rev, both inserts result in different surface roughness, because of the mechanical properties of the tools and different cutting speeds. At the same cutting speed of 30 m/min, feed rates can be selected 0.1, 0.15, 0.20 mm/rev for tungsten carbide tools, while selected feed rates values are 0.25, 0.30 and 0.35, respectively, for whisker-reinforced ceramic inserts. According to these results, as the cutting speed increases, average surface roughness decreases. It is obvious from Table 1 that as feed rate increases and the surface roughness also increases as well. Due to the different values of feed rates used, we analyze both carbide cutting tool and ceramic insert, separately.

Improved surface roughness values were obtained when machining with the whisker-reinforced ceramic tools under the cutting conditions mentioned above. Surface quality is due to the round shape (RNGN 120700) of the ceramic insert with a large contact radius (6 mm) with the workpiece material and feed rate to a greater extent. Lower feed rate is the ability to produce high-quality surface finish.

The surface quality gets better with increasing the cutting speed in the tungsten carbide tool and ceramic cutting insert. For the ceramic cutting insert at the same cutting speeds, the surface roughness values of the materials are lower than those obtained in the tungsten carbide tool. This is due to the high feed rate values and the BUE formation. Surface quality increases parallel to increasing feed rate. Interaction between the tungsten carbide tool, the low cutting speed and workpiece material increases the BUE formation. The surface roughness is deteriorated by the BUE formation. As cutting speed decreases, the cutting temperature decreases. The reason for increasing surface quality may be explained with decreased BUE on the cutting tool as cutting temperature decreases.

At low cutting speeds, the built-up edge is formed and both chip fracture also built-up edge produce the rough surface. Due to the better performance of the ceramic insert at higher cutting speeds, low Ra values were observed. This was attributed to high temperature in the plastic deformation zone, and as a result bonding effect decreases.

3.2 Taguchi Method

Taguchi method is based on statistical design of experiments and is used for the design of tests and selection of the optimal cutting conditions. The main purpose of the method is reducing the cost of the experiments.

Taguchi method offers a systematic and simple approach to optimize design for cost and performance. This method uses a special design of orthogonal arrays and combines the experiment design theory and the quality loss function concept. Also, it has solved some confusing problems in manufacturing. Available past studies regarding the optimization, the optimal setting of parameters was determined through experiments planned, conducted and analyzed with the help of the Taguchi method [27–30].

Turning tests were performed to assess the influence of cutting parameters on surface quality. Taguchi method was performed separately for the two different cutting tool materials and both of them were compared.

3.2.1 Analysis for Whisker-Reinforced Ceramic Cutting Insert

In this part of the experiment for the ceramic inserts, the fractional factorial design used is L12 orthogonal array. L12 orthogonal array and level of experiment factors are shown in Table 2.

In Taguchi method, the magnitude of signal-to-noise (S/N) ratio indicates the robustness of the system against noise and the aim is to minimize the number of experiments. In this analysis, a smaller S/N ratio corresponds to a better performance. In other words, "the smaller the better" quality characteristic was selected in this method. Based on the experimental and S/N ratio results, the best levels for each control factors were found with cutting speed at level 4 and feed rate at level 1.

The mean effect for each levels of S/N ratio was illustrated in Table 3. Whereas Table 4 shows the average effect response value calculated for surface roughness. The highest difference value was 3.257 for the cutting speed, which means it was the most effective factor on surface roughness. The lowest difference value giving the least effective parameter on the surface roughness was found as cutting speed with the difference value of 2.353 from Table 4. The ceramic cutting insert exhibits good performance in machining of Stellite-6 material in view of surface quality with more feed rate and cutting speed values than observed with tungsten carbide cutting tools.

Table 2 Level of test factors used in the tests

Sample	Cutting conditions	Level 1	Level 2	Level 3	Level 4
A	Cutting speed (m/min)	30	50	70	90
B	Feed rate (mm/rpm)	0.25	0.30	0.35	–

Table 3 Main effect for S/N ratio

Level	*A*	*B*
1	−10.712	−7.422
2	−10.444	−10.245
3	−10.150	−13.239
4	−9.901	–
Difference	0.811	5.817
Rank	2	1

Table 4 Main effect for surface roughness means

Level	*A*	*B*
1	3.553	2.353
2	3.447	3.255
3	3.343	4.593
4	3.257	–
Difference	0.297	2.240
Rank	2	1

The main objective of employing Taguchi method is to understand the influence of factors. Table 4 shows the influence of selected factors on both the surface roughness means. Results with the designed experimental set showed process efficiency was found to be very much dependent on the test conditions. The difference between the values at levels of each factor indicated the relative influence of each factor as shown in Table 4. Among the factors studied, feed rate showed stronger influence followed by cutting speed. The decreasing feed rate reduces the surface roughness due to the decrease in friction between tool interface and work piece material and decreases the temperature in the cutting zone.

Test of normality was conducted for DOE model adequacy checking with Minitab 16 for whisker-reinforced ceramic cutting insert. It was found that the distribution of the Ra value is normal. A hypothesis test can be performed in which the null hypothesis is that the errors have a normal distribution. *P* value (probability of obtaining a test statistic) is acceptable. Test of homogeneity was conducted with Minitab 16 for whisker-reinforced ceramic cutting insert. From all the results, *P* value of Levene's test is bigger than critical value (0.05). There is no evidence to support that the variances are different. As part of the analysis of variance (ANOVA) analysis, separate tests (Bartlett's and Levene's tests) were applied to determine whether the variances of the two groups really comparable. The basic assumption for these tests is that the variance is comparable. All *P* value results of the tests are bigger than 0.05. This means that all variances are similar, and the author can use the results of the ANOVA. There is no significant difference between the groups. Data analysis for the Taguchi method was carried out by the ANOVA to determine the degree of importance of cutting parameters. The analysis indicates that the % of contribution by feed rate is 98.51 % and cutting speed 1.49 % on the surface roughness.

3.2.2 Analysis for Tungsten Carbide Cutting Tool

In this work, the fractional factorial design used is L9 orthogonal array. This orthogonal array is chosen due to its capability to check the interactions among the surface roughness and the cutting condition. L9 orthogonal array and level of test factors are summarized in Table 5.

Table 5 Level of test factors used in the tests

Sample	Cutting conditions	Level 1	Level 2	Level 3
A	Cutting speed (m/min)	30	40	50
B	Feed rate (mm/rpm)	0.1	0.15	0.20

Table 6 *S*/*N* ratio values and experimental results of Ra

Exp. no	Level of factors		Experiment result Ra (μm)	*S*/*N* ratio
	A	B		
1	1	1	2.6	−8.3
2	1	2	3.8	−11.6
3	1	3	5.1	−14.15
4	2	1	2.1	−6.44
5	2	2	3.1	−9.82
6	2	3	4.7	−13.44
7	3	1	1.8	−5.10
8	3	2	2.5	−7.96
9	3	3	4.0	−12.04

S/*N* ratio values and experimental results of Ra were listed in Table 6. The obtained surface roughness values were between 1.8 and 5.1 μm. Based on the *S*/*N* ratio analysis, the smallest *S*/*N* ratio was found with feed rate at level 1 and cutting speed at level 3. This value is corresponded to seventh line of the Table 6.

The lowest difference value was 2.167 for the cutting speed from Table 7, which means it was the least effective factor on surface roughness. The highest difference value giving the most effective parameter on the surface roughness was found as feed rate with the difference value of 2.767. The main effect for *S*/*N* ratio was given in Table 8. From the experimental result, the best combination to get high surface quality is $A3B1$ within the tested range. The role of the feed rate is maximum in obtaining good surface quality, it is indicated that to achieve good surface quality, always prefer low feed rate with high cutting speed values. This result is in agreement with other studies in the literature [31,32]. Tungsten carbide cutting tools are only suitable for machining of the Stellite-6 material at lower cutting speeds in view of surface roughness. The tool-chip contact area exhibited a decreasing tendency with increasing cutting speed and this also decreased the friction providing a decrease in the surface roughness value. An increase of cutting speed increased the surface quality and this also decreased the friction providing an increase in the surface quality.

Test of normality was carried out for tungsten carbide tool. The test of normality results indicates that Ra value is suitable and *P* value is acceptable for normal distribution. Further-

Table 7 Main effect for surface roughness means

Level	A	B
1	3.833	2.167
2	3.300	3.133
3	2.767	4.6
Difference	1.067	2.433
Rank	2	1

Table 8 Main effect for S/N ratio

Level	A	B
1	−11.349	−6.616
2	−9.905	−9.794
3	−8.368	−13.212
Difference	2.980	6.595
Rank	2	1

more, homogeneity test for tungsten carbide tool was done. The results show that P value is bigger than 0.05 and the basic assumption is that the variance is comparable for the test. The results of the ANOVA can be used for the analysis. ANOVA values were calculated using the test results for tungsten carbide cutting tool. Feed rate (f) is the most important parameter with a contribution ratio of 99.10 %, cutting speed (v) is the second important parameter with a contribution ratio of 0.90 %. The most effective variable found was feed rate which confirms the results obtained by the Taguchi method and ANOVA.

3.3 Estimation of Surface Roughness Values

In this part of the study, the objective function is to minimize the surface roughness value. Taguchi method used to obtain the optimal machining parameters to minimize the surface roughness values will be briefly discussed for whisker-reinforced ceramic cutting insert and tungsten carbide cutting tool. Later, estimated values will be compared with the experimental results. The parameters to be optimized are cutting speed and feed rate.

Taguchi results listed in Tables 4 and 7 were used for minimization of the surface roughness with the optimum machining parameters.

Predicted mean (minimum surface roughness):

$$\mathrm{Ra_W} = A4 + B1 - (n) = 3.257 + 2.353 - (3.395) = 2.215 \quad (1)$$

$$\mathrm{Ra_C} = A3 + B1 - (n) = 2.767 + 2.167 - (3.3) = 1.634 \quad (2)$$

where n is the average value of surface roughness. $\mathrm{Ra_W}$ and $\mathrm{Ra_C}$ correspond to the predicted surface roughness value with Taguchi method for whisker-reinforced ceramic cutting insert and tungsten carbide cutting tool, respectively. $\mathrm{Ra_W}$ and $\mathrm{Ra_C}$ were calculated by Eqs. (1) and (2), respectively.

The experimental optimum surface roughness was Ra = 2.21 µm as mentioned this section for whisker-reinforced ceramic cutting insert. This method estimated the surface roughness as 2.215 µm at this optimal condition. The estimated surface roughness value for tungsten carbide cutting tool was Ra = 1.634 µm as calculated from Eq. (2). The measured value for surface roughness was Ra = 1.80 µm as read from Table 1. Test results agreed with the values estimated by the Taguchi Method and measured with experiments. The predicted surface roughness largely is in line with the test results.

Best combination of parameters leading to minimum surface roughness is determined. The surface roughness obtained by Taguchi method and confirmation tests was very close. Taguchi method was found very effective for the estimation of the operating conditions for minimum surface roughness.

Among the works, the studies of Kohli and Dixit [24] and Cakıroglu and Acir [30] appear to be most reliable according to this analysis. Taguchi experimental design method was an efficient and effective way of determining the optimal cutting parameters for surface finish, which is in accordance with the findings of Zhang et al. [33] and Cakıroglu and Acir [30]. Some useful works were documented by Kohli and Dixit [24]. They predicted surface roughness using feed rate, speed, depth of cut, and tool holder. However, in the present study, the value of surface roughness was minimized by Taguchi method.

4 Conclusions

This paper concentrates on theoretical and experimental investigation of the effect of different tool and inserts materials on surface roughness obtained in turning operations of Stellite-6. Performance of the whisker-reinforced ceramic cutting insert and tungsten carbide cutting tool was studied. Taguchi method was used to analyze problems and suitable cutting inserts were tested as described in this study.

The conclusions drawn from the turning of Stellite-6 with whisker-reinforced ceramic cutting insert and tungsten carbide cutting tool are as follows:

- Optimum machinability parameters have been determined and appropriate cutting tool for cutting is selected. Based on the signal-to-noise ratio results, it can be concluded that the $A4B1$ (v = 90 m/min, f = 0.25 mm/rpm) and $A3B1$ (v = 50 m/min, f = 0.10

mm/rpm) settings are the optimal machining parameters for whisker-reinforced ceramic cutting insert and tungsten carbide cutting tool, respectively.

- It has been shown that surface roughness can be improved significantly for turning operations.
- Generally good agreement is observed between these experimental results and the Taguchi method. Higher speeds and slower feeds lead to better surface finish.
- The feed is the most effective parameter on the surface roughness; the cutting speed has less effect.
- In addition to this, the ceramic cutting insert exhibits good performance in machining of Stellite-6 material in view of surface quality with more feed rate and cutting speed values than observed with tungsten carbide cutting tools.
- Ceramic cutting tool can produce a very fine surface finish; depending on the high cutting speed and feed rates.
- Although using cutting tools several times with grinding can be seen advantage, labor costs increase directly. Cutting inserts reduce labor costs and cutting is made symmetrically so that when the first cutting edge is dull than inserts can be rotated. Therefore, we can improve productivity and reduce costs.
- Taguchi method results showed that the feed rate is the most important cutting parameter for determining the machined surface roughness and followed by the cutting speed. This method is a useful computational tool to help analysis of relationship between the surface quality and the cutting parameters. Estimation result obtained by Taguchi method was verified by experimental study. The percentage deviation between analytical method and experimental result is $<10\,\%$. Furthermore, the average error of the Taguchi method was found as 0.2 % for cutting with whisker-reinforced ceramic cutting insert. This application of the model can be used in predicting the optimal cutting condition of the Stellite-6 material.
- Instead of manufacturing a new bushing, coating and turning operation of the used bushing is useful and more economical for the spare parts in iron and steel company.
- The research finally reveals the whisker-reinforced ceramic cutting insert for the best possible output in machining Stellite-6 on the basis of surface quality.
- The method produced by Taguchi suggested high predictive performance and largely agreed with the test results.
- Taguchi method was an effective tool to predict the degree of importance of the cutting parameters in the turning operation. Deviations occurred when Taguchi method used were very small.
- Experimental results showed that whisker-reinforced ceramic insert with ISO tool designations RNGN 120700 T0 1020 670 is more suitable than tungsten carbide cutting tool for the machining of Stellite-6 coating material in terms of surface roughness.
- Turning operation can be accorded faster, with a short time and carried out economically with whisker-reinforced ceramic insert.

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