повышении температуры приращение слоя увеличивается. При температуре 1100°С для данных сталей достигает приращения линейных размеров в пределах 120-210 мкм. Это достаточно для восстановления одного из деталей прецизионных пар ремфонда. Все это явилось основанием считать температуру 1100°С оптимальной, при которой и велось поверхностное насыщение всех исследуемых образцов. Дальнейшее увеличение температуры скорость диффузии существенно увеличивает, и способствует прилипанию порошка.

Таким образом, газофазный метод хромосилицирования в течение 4-5 часов при температуре 1100 ℃, а парофазная диффузионная металлизация в течение 4 часов при температуре 1150 ℃ обеспечивает приращение линейных размеров. Изменение линейных размеров в значительной мере зависят от состава насыщающей смеси при хромосилицировании.

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THE SURFACE FINISH IN TURNING OF AISI 1050 STEEL BY DIFFERENT CUTTING TOOLS

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This report explains the effect of main cutting parameters including cutting tool materials and geometry on surface roughness in turning of AISI 1050 steel. The machining tests were carried out using coated carbide and cermet inserts having two different geometries without any cutting fluid. Based on Taguchi Technique, signal-to noise-ratios (S/N) for surface roughness was calculated to find out optimal cutting conditions. Analysis of variance (ANOVA) was also employed to investigate the cutting characteristics of steel bars. A first order linear regression equation presented and its theoretical values and experimental results compared. A better surface roughness in machining of AISI 1050 steel with square shaped coated carbide tool was obtained. According to the analysis of the results, the feed rate was the most powerful control factor of the process, which is followed by depth of cut and closely tool geometry.

Keywords: *Surface roughness, Coated carbide tools, Cermet tools, Taguchi method, multiple regression, Analysis of variance*

Introduction. Since turning is primary operation in the most of the production processes in the industry, surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate [1-14, 16, 17, 19, 21-27], cutting speed [1-14, 16, 19-22, 25-27], depth of cut [1-5, 7-11, 13, 14, 16, 19, 21, 22, 25-27], cutting tool materials [1, 3, 5, 6], cutting tool's nose radius [2, 8,17, 20, 26], workpiece hardness [4, 16, 17, 21], cutting tool length [8], tool wear and cutting forces [11], cutting fluid [11,14], tribological influences between tool-chip [15], cutting tool angles [18, 26], spindle speed and cutting time[16], and built up edge (BUE) [17].

Up to now, a little attention has been paid to gaining an understanding of the influence of the cutting tool geometry and materials on surface roughness. For example, Sentoku et. al.[28] discussed the machining performance of ceramics from the view point of the relation between the flank wear of a tool edge and roughness of the machined surface on the workpiece.

They found that a chamfer angle of -15 on the tool edge gives the best surface finish and longest tool life. Seah and Goh [29] performed a series cutting experiments to evaluate the performance of various coatings on different tool substrates. Results show that there is less difference in the surface roughness of the finished workpiece for the various coatings and substrates. Another work studied by Wang et.al.[30], based on regression analysis of tests, three comprehensive experimental models were presented in precision turning high-strength steel. The influence of tool geometry on machined surface integrity was analyzed systematically. The analytical results show that surface roughness increases with an increase of rake angle or clearance angle and decreases with an increase of cutting edge angle or minor cutting edge angle. The geometry of the cutting edge and its preparation can play a significant role on the insert performance, directly affecting tool life, surface finish and surface integrity. Coelho et. al.[31] study to evaluate the performance of some inserts subjected to modifications on the edge geometric form and preparation at high cutting speed on a nickel-based alloy. They found that some modifications caused significant improvements on the insert performance for all the tool materials tested. Thiele et. al.[32] an experimental investigation conducted to determine the effects of tool cutting edge geometry and workpiece hardness on the surface roughness in the finish turning of AISI 52100 steel. Their study show that the effect of edge geometry on the surface roughness did not statistically significant. Specifically, large edge hones resulted in higher average surface roughness values than small edge hones. Darwish [33] studied to assess the effect of the tool material and the cutting parameters on surface roughness of supermet 718 nickel-base superalloy, under dry cutting conditions. Their study show that the feed-rate has the dominant effect on surface roughness amongst the parameters studied, irrespective of the tool material used. The effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and resultant forces in the finish turning of AISI H13 steel experimentally were investigated by Özel et.al. [34]. Their studies show that the effects of workpiece hardness, cutting edge geometry, feed rate and cutting speed on surface roughness were statistically significant. Especially honed edge geometry and lower workpiece surface hardness resulted in better surface roughness. The Taguchi method, which is used in this work, is a relatively simple method that can be used for optimization different production stages with few experimental runs and minimum knowledge of statistical theory [36]. The machining tests were carried out using coated carbide and cermet inserts having two different geometries without any cutting fluid. Based on Taguchi Technique, signal-to noise-ratios (S/N) for surface roughness was calculated to find out optimal cutting conditions. Analysis of variance (ANOVA) was also employed to investigate the cutting characteristics of steel bars. A first order linear regression equation presented and its theoretical values and experimental results compared.

Experimental Procedure. Materials. In order the achieve the goal of this experimental work, i.e. to establish the correlation between control factors (cutting speed, feed rate, depth of cut, cutting tool's shape and cutting tool materials) and mean roughness parameter, machining issues were incorporated with different cutting conditions. The cutting tests were made on a Johnford TC35 Industrial type of CNC lathe machine with TNMG 160408 MF2-SNMG 120408 MF2 coated carbide tools (Grade TP100) and cermet cutting tools. The material used in the tests was an AISI 1050 steel. The chemical composition of AISI 1050 steel is shown in tab.1. The work pieces were in the form of cylinder of 60 mm in diameter and 240 mm length. These bars are machined under dry condition. The measurements were made over the turning surfaces using profilometer Perthometer Mahr-1 (five measurements).

Table1

The chemical composition of AISI 1050 steel

AISI 1050										
C	Si	Mn	P	Cu	Cr	Mo	Ni	Al	Co	Fe
0.47	0.176	0.658	0.0144	0.169	0.0540	0.0250	0.133	0.0201	0.0193	98.24

Experimental design. Taquchi method was used for the execution of the plan of experiments, for five factors at two levels, whereby the levels are the values by the factors. The factors to be studied and the attribution of the respective levels are indicated in tab. 2. L16 (2^{15}) orthogonal array was chosen. It has 16 rows corresponding to the number of tests with 15 columns at two levels. The answers to be studied are the mean roughness parameter, Ra. In order to allow the analysis of variance of results each test was repeated five times. To obtain optimal testing parametres, the-lower-the-better quality characteristic for surface roughness was taken. The S/N ratio for each level of testing parametres was computed based on the S/N analysis. Moreover, a statistical analysis of variance (ANOVA) was performed to see which test parameters are statistically significant. With S/N ratio and ANOVA analyses, the optimal combination of the testing parameters could be predicted for a 95 % confidence level.

Table 2

Control factors with their levels and cutting conditions

Control factors	Code	Level 1	Level 2	Degree of free-dom (DOF)
Cutting speed (m/min)	**A**	**300**	**400**	**1**
Feed rate (mm/rev)	**B**	**0.25**	**0.40**	**1**
Depth of cut (mm)	**C**	**1.0**	**2.0**	**1**
Tool's shapes	**D**	**TNMG**	**SNMG**	**1**
Cutting tool materials	**E**	**TP100**	**CM**	**1**

Experimental results. An orthogonal array with arranged control factors is shown tab.3. The right side of the table includes the results of the measured surface roughness and the calculated signal-to-noise (S/N) ratio. The S/N ratio is calculated [35, 36].

Table 3

Plan of experiments and the results

Trial No	A AB D ABCCBA AB * C* * * D* * * * * * E B CCE DDEDEE	Surface Roughness Measurements						S/N Ratios
		Ra_1	Ra_2	Ra_3	Ra_4	Ra_5	Ra_{ave}	
1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	2.303	2.199	2.292	2.179	2.256	2.2458	**-7.0295**
2	1 1 1 1 1 1 1 2 2 2 2 2 2 2 2	2.075	2.241	2.196	2.209	2.243	2.1928	**-6.8234**
3	1 1 1 2 2 2 2 1 1 1 1 2 2 2 2	2.447	2.530	2.491	2.513	2.496	2.4954	**-7.9433**
4	1 1 1 2 2 2 2 2 2 2 2 1 1 1 1	2.279	2.409	2.285	2.402	2.434	2.3618	**-7.4683**
5	1 2 2 1 1 2 2 1 1 2 2 1 1 2 2	5.936	6.184	6.112	6.300	6.324	6.1712	**-15.8096**
6	1 2 2 1 1 2 2 2 2 1 1 2 2 1 1	5.693	5.841	5.761	5.874	5.912	5.8162	**-15.2936**
7	1 2 2 2 2 1 1 1 1 2 2 2 2 1 1	5.880	5.963	5.875	5.942	5.596	5.8512	**-15.3471**
8	1 2 2 2 2 1 1 2 2 1 1 1 1 2 2	5.675	5.988	5.908	6.105	6.086	5.9524	**-15.4968**
9	2 1 2 1 2 1 2 1 2 1 2 1 2 1 2	2.378	2.522	2.453	2.573	2.534	2.4920	**-7.9343**
10	2 1 2 1 2 1 2 2 1 2 1 2 1 2 1	2.432	2.454	2.507	2.513	2.640	2.5092	**-7.9943**
11	2 1 2 2 1 2 1 1 2 1 2 2 1 2 1	2.410	2.348	2.412	2.344	2.400	2.3828	**-7.5425**
12	2 1 2 2 1 2 1 2 1 2 1 1 2 1 2	2.188	2.213	2.187	2.253	2.226	2.2134	**-6.9017**
13	2 2 1 1 2 2 1 1 2 2 1 1 2 2 1	5.667	5.768	5.776	5.897	5.883	5.7982	**-15.2668**
14	2 2 1 1 2 2 1 2 1 1 2 2 1 1 2	5.550	5.739	5.675	5.798	5.934	5.7392	**-15.1792**
15	2 2 1 2 1 1 2 1 2 2 1 2 1 1 2	6.120	6.041	6.188	6.232	6.159	6.1480	**-15.7752**
16	2 2 1 2 1 1 2 2 1 1 2 1 2 2 1	6.132	6.211	6.186	6.218	6.170	6.1834	**-15.8247**

Main effect and their interaction plots (S/N ratio plots). The main effects and their interaction plots for S/N ratios are shown in Fig.1. Optimal cutting conditions of these control factors can be very easily determined from this graph. A response graph showed the change of the S/N ratio when the setting of the control factor was changed from one level to the other. The best surface roughness value was at the higher S/N values in the response graphs. It could be seen in Fig.1 that the optimum condition for the tested samples becomes A1B1C1D2E1 for main control factors. Moreover, it is evident that feed rate had the greatest effect on influence the optimal testing condition. The surface roughness obviously decreased as feed rate decreased.

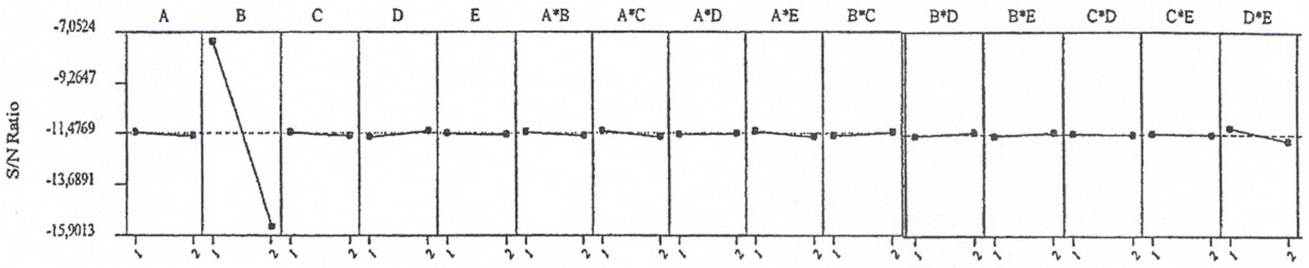


Fig. 1. Main effect and their interaction plots for S/N ratio plots

Optimal cutting conditions. The settings of control factors for achievement of the best value of the quality characteristic can be determined by the response graph[35]. The best value is at the higher value of the S/N ratio, so it can be concluded that the best surface roughness of a fine-turned surface will be achieved in the following conditions:

- A-Cutting speed : 300 m/min
- B-Feed rate : 0.25 mm/rev
- C-Depth of cut : 1.0 mm
- D-Tool's shape : SNMG 120408 MF2
- E-Cutting tool : TP100

Analysis of variance. The variance of the prediction error can be calculated on the basis of an analysis of variance (tab. 5). Examination of the calculated values F for all five control factors shows a very high influence of feed rate (B) and no influence of the other control factors on the surface roughness of turning process.

Table 5

The analysis of variance for machining mild steel

Control factor	Degree of free-dom (DoF)	Sum of squares(SS)	Mean square (MS)	F Characteristics	Contributions P (%)
A	1	0.04498	0.04498	0.35151	0.0173
B	1	258.59915	258.59915	2020.75886	**99.3120**
A*B	1	0.01565	0.01565	0.12231	0.0060
C	1	0.12160	0.12160	0.95023	0.0467
A*C	1	0.00743	0.00743	0.05806	0.0029
B*C	1	0.11123	0.11123	0.86917	0.0427
D*E	1	1.01408	1.01408	7.92424	0.3894
D	1	0.11866	0.11866	0.92722	0.0456
A*D	1	0.02188	0.02188	0.17097	0.0084
B*D	1	0.00118	0.00118	0.00921	0.0005
C*E	1	0.01198	0.01198	0.09362	0.0046
C*D	1	0.02510	0.02510	0.19613	0.0096
B*E	1	0.06839	0.06839	0.53439	0.0263
A*E	1	0.20900	0.20900	1.63317	0.0803
E	1	0.02045	0.02045	0.15979	0.0079
Error	14	1.79160			
Total	15	260.39075			

Regression analysis (First order model for surface roughness). The postulated model for surface roughness based on multiple linear regression is;

$$Ra_{ave} = -1.35 + 0.0474A + 3.60B + 0.0780C - 0.0770D + 0.0320E \quad (2)$$

This equation indicates that surface roughness improves with decreasing the cutting speed, feed rate and depth of cut. But, the feed rate has the most significant effect on the surface

roughness, which is followed by depth of cut and tool geometry. The model has an adjusted R^2 value of 99.4%. This shows that the first order model can be explained the variation to the extent of 99.4%.

The experimental results and their theoretical values with residuals. The experimental results and their theoretical values with residuals for first model are shown in tab.6. As shown in this table, some differences between the calculated and the actual values of the surface roughness can be seen, but both values are within a reasonable limit.

Table 6

Experimental results and their theoretical values with residuals for models

Trial number	Mean surface roughness, μm (Experimental value)	First order model	
		Mean surface roughness, μm (Theoretical)	Residual
1	2.2458	2.32148	-0.075675
2	2.1928	2.27643	-0.083625
3	2.4954	2.43143	0.063975
4	2.3618	2.32243	0.039375
5	6.1712	5.94928	0.221925
6	5.8162	5.84028	-0.024075
7	5.8512	5.99528	-0.144075
8	5.9524	5.95023	0.002175
9	2.4920	2.40088	0.091125
10	2.5092	2.29187	0.217325
11	2.3828	2.44687	-0.064075
12	2.2134	2.40182	-0.188425
13	5.7982	5.96473	-0.166525
14	5.7392	5.91968	-0.180475
15	6.1480	6.07468	0.073325
16	6.1834	5.96568	0.217725

Conclusions:

- The achievement of a surface quality characteristic in machining of AISI 1050 steel has been presented with the Taguchi method. Optimal cutting conditions for achievement of the desired surface roughness with a minimal number of experimental runs have been determined.
- First order surface roughness prediction have been developed using multiple linear regression techniques.
- A better surface roughness in machining of AISI 1050 steel with square shaped coated carbide tool was obtained.
- According to the analysis of the results, the feed rate was the most powerful control factor of the process, which is followed by depth of cut and closely tool geometry.

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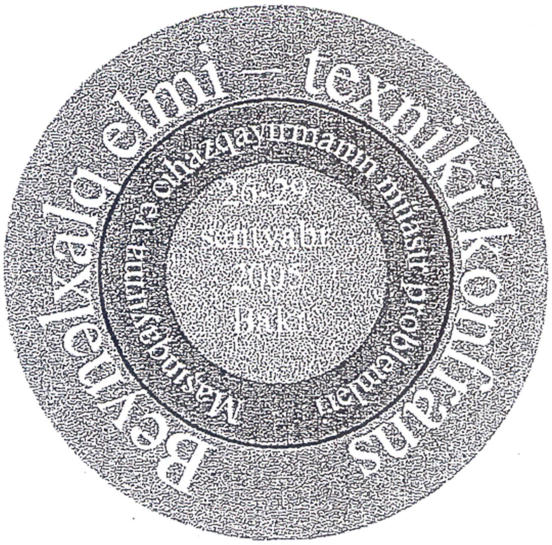
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