Optimization of Turning Parameters of AISI 4340 Steel Using Parallel Textured Tool

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Abstract

The current work examines how input factors affect the surface quality of AISI 4340 steel while cutting the material with a parallel textured cutting tool. A copper electrode with a diameter of 500 m is used to create textures on the rake face of the tool that are parallel to the cutting edge. The distance between two consecutive lines is maintained at 100 m, while the line depth is maintained at 50 m. Cutting speed, feed rate, and depth of cut are taken into consideration as input parameters. The response parameter is chosen to be surface quality. The Taguchi L9 approach is used to optimize the parameters to enhance the quality of the surface. The contribution of each parameter to surface quality is determined using ANOVA. Results discovered that feed rate has maximum contribution on surface quality with 61.71% followed by depth of cut with 24.31% contribution, and cutting speed with 14.06% contribution. Confirmation experiment shows an improvement in surface roughness by 19.21% when it is compared with experiment number one of Taguchi L_9 OA.

Keywords. ANOVA; Parallel Texture; Surface Roughness; Taguchi

1. INTRODUCTION

Nowadays, demand for materials possessing rich surfaces is rapidly increasing in market because of their excellent performance characteristics. Turning is a metal cutting process in which material is removed from a rotating surface using single-point tool to get desired surface quality. Turning process is shown in Figure 1.

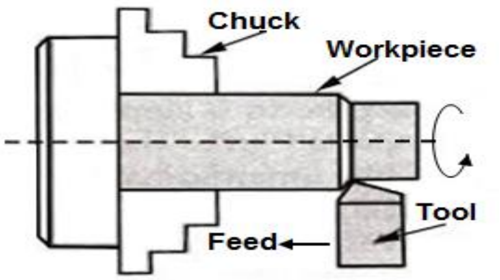


Figure 1. Turning process [1]

Cutting tools used for this purpose are generally made up of High-speed steel, ceramics, carbide, diamonds, cubic boron nitride, etc. Turning of alloy steel such as AISI 4340 steel is a challenging task since excess friction and adhesion at tool-chip interface increases the temperature of cutting area leading to high tool wear, reduction in tool life, and also reduces surface quality. Thus, cutting tool should be modified in such a way that it produces a better-turned surface. Surface texturing is relatively a new application that overcomes above-stated drawbacks by introducing different textures such as vertical, parallel, and dot at flank or rake face of tool inserts. Surface texturing reduces cutting forces, increases load-carrying capacity, and improves wear resistance and surface quality. Textured tools reduced tool chip contact thereby reducing cutting forces, cutting temperature, and coefficient of friction [2].

Gap provided between grooves in textured tools helped in reducing heat at surface of tool of titanium alloy, thus reducing cutting temperature [3]. Textures produced on rake face helped reduce friction on tool surface and also reduced cutting forces [4]. Turning was performed on annealed 1045 steel and 6061 aluminum workpieces using an isotropic parallel textured tool with a width and depth of 100µm produced on rake face and a significant decrease in feed rate and improvement in surface quality were found [5]. Effect of different textured tools on built-up edge formation and tool wear while machining carbon steel concluded that textured tools helped in destabilizing BUE resulting in a better surface quality [6]. Impact of built-up edge formation on surface quality with orthogonal cutting tests on titanium alloy was investigated. It was found that effect of BUE on surface roughness changes according to cutting speed and uncut chip thickness. Better surface values were also found at cutting speed = 62m/min [7]. Influence of rake angle of milling cutter on quality of TB17 was investigated. Researchers concluded that surface quality increases with rake angle [8]. Textures produced on rake face of tool reduced friction coefficient and improved lubrication of tool [9]. There are no certain guidelines made for producing surface textures and thus, input parameters can be optimized only by trial-and-error method [10].

Type of surface texturing greatly influences turning parameters and surface roughness of hard materials and alloys. Texturing of tools helped in improving wear resistance by reducing cutting zone temperature and also caused a reduction in machining forces [11]. Less BUE was found on tool edge having texture grooves 45º inclined to cutting edge [12]. Textured tools improved surface quality, tool wear, and cutting zone temperature as compared to conventional tools [13]. Therefore, demand for textured tools is rapidly increasing in market as it helps in reducing manufacturing costs, yields higher productivity, and also safeguard health of operators and environment. In present study, surface quality of AISI 4340 steel is evaluated with a parallel textured cutting tool. Taguchi L_9 OA is used with input parameters considered as cutting speed, feed rate, and depth of cut while surface roughness is considered as response parameter. Optimum results are verified by performing validation experiments.

2. Literature Review

Many researchers have found that textured tools significantly help in reducing surface roughness. A comparative analysis between spot and dimple textured tools at different cutting speeds showed that spot-textured cutting tools produced better surface quality than dimple and conventional tools [14]. Authors found that parallel textured tools produced lesser wear than non-textured tools. It was also found that textured tools produced better surface quality and lower cutting temperature [15]. In another study, surface roughness of steel was compared and analyzed by three different types of textures that were vertical, parallel, and dot with a non-textured tool. It was concluded that surface quality improved at high values of cutting speed for all types of texturing [16].

When cutting AISI 420 steel, the effects of changing turning parameters such cutting speed, feed rate, and depth of cut were examined. Results showed that feed rate, which contributed 80.71% to surface quality, was the most important element [17]. Studying the impact of turning parameters on the surface roughness of AISI 4140 steel revealed that feed rate had the greatest influence on the quality, whilst cutting speed and depth of cut had the least. Additionally, it was found that increasing feed rate causes surface roughness to rise [18]. It was found that with cutting speed = 350m/min and feed rate = 0.15mm/rev, surface quality improved. It was also revealed that surface quality deteriorates at a higher feed rate [19]. Optimum condition for reducing surface quality of AISI 1045 steel was found as cutting speed = 116m/min, feed rate = 0.06mm/rev, and depth of cut = 0.25mm. Authors also inferred that surface roughness improves at a lower feed rate [20].

For obtaining high productivity and low manufacturing costs, industries need to operate in perfect conditions. Taguchi methodology is very useful for optimizing machining parameters and producing good quality and cheaper products. It is the most effective approach for solving complex problems as it makes use of an orthogonal array that studies parametric space with less experiments. Therefore, researchers utilized this approach in many research papers and optimal results provided by this approach showed a significant improvement in all types of responses. When Taguchi L_9 OA was utilized during turning of AISI D3 steel, it was found that feed rate had maximum contribution on surface roughness [21]. Taguchi L_9 OA was used on turning parameters like cutting speed, feed rate, and depth of cut during machining of SS-304 steel with carbide tools. After result analysis, best combination was found at cutting speed = 350m/min, feed rate = .12mm/rev, and depth of cut = .40mm [22]. Based on Taguchi optimization technique, at cutting speed = 90m/min, feed rate = .15mm/rev, and depth of cut = .5mm, improvement in surface roughness was seen to be 244% when compared with initial setting [23]. Minimum value of surface roughness of 52100 hardened alloy steel was achieved at optimum condition of cutting speed = 140m/min, feed rate = .08mm/rev, and depth of cut = .19mm [24].

3. EXPERIMENT DETAILS

3.1. Materials

AISI 4340 steel is selected as a workpiece for experiment. AISI 4340 steel is widely used in manufacturing industries as it possesses high hardness and can be machined by all conventional techniques. Dimensions of workpiece are taken as diameter = 25mm and length = 78mm. Composition of workpiece in terms of weight% is shown in Table 1.

Table 1. AISI 4340 steel composition

Component	C	Mn	P	S	Si	Ni	Cr	Mo	Fe
Weight (%)	.38-.43	.6-.8	.035	.035	.15-.35	1.65-2.00	.7-.9	.2-.3	Bal.

3.2. Machine tool and cutting tool

All experiments are performed on a lathe machine. Its specification is listed below:

Range of spindle speed: 45-800 rpm

Height of centers: 200mm

Diameter of a hole through spindle: 41mm

Required H.P.: 2 HP (1.5 KW)

Cutting tool inserts used for experimentation are carbide with ISO designation of E10-TH20. A ZNC 25 EDM machine with a capacity of 250L is used for making parallel textures on rake face of tool as shown in Figure 2. Copper electrode with a diameter of 500μm is used for making lines parallel to cutting edge. Distance between two successive lines is kept at 100μm and depth of lines is kept at 50μm. Parallel textures produced by EDM are depicted in Figure 3(a) and dimensions of parallel textures are depicted in Figure 3(b). These textured inserts are then brazed on a left-hand cutting tool holder. A TR200 surface roughness is used to measure the surface roughness of workpiece. To minimize variation in surface roughness, each experiment is performed three times and average surface roughness is considered.

Experimental setup in actual condition is shown in Figure 3(c). A minimum of three experiments at each level are performed to minimize variability. Pilot experiments are performed and a range of machining parameters is identified. Factors and their levels (Table 2) are selected and Taguchi L_9 OA is used (Table 3). Degree of freedom (DF) is calculated by equation (3.2) [25]

$$DF = [(\text{level} - 1) + (\text{level} - 1) \times (\text{level} - 1) + 1] \quad (3.2)$$

Surface roughness values obtained for all nine experiments are then converted into S/N ratio which is further utilized for obtaining optimum level as well as to perform ANOVA analysis. Taguchi L_9 OA and surface roughness values are provided in Table 3. S/N ratio (Table 3) is solved by equation (4.1).

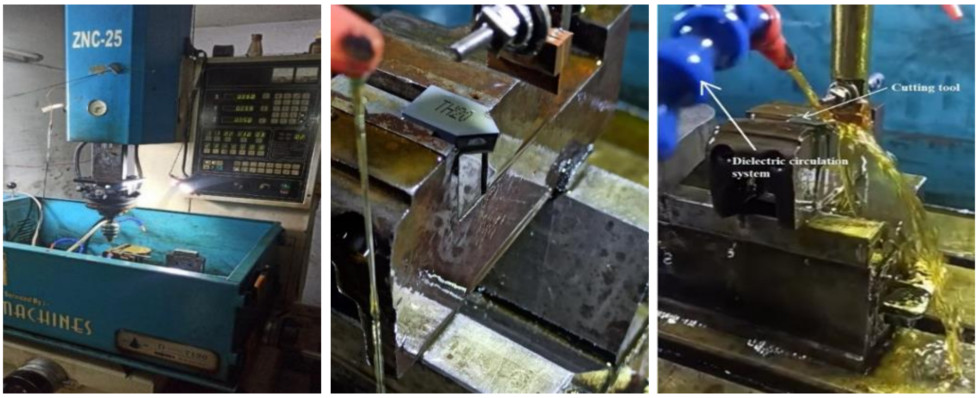
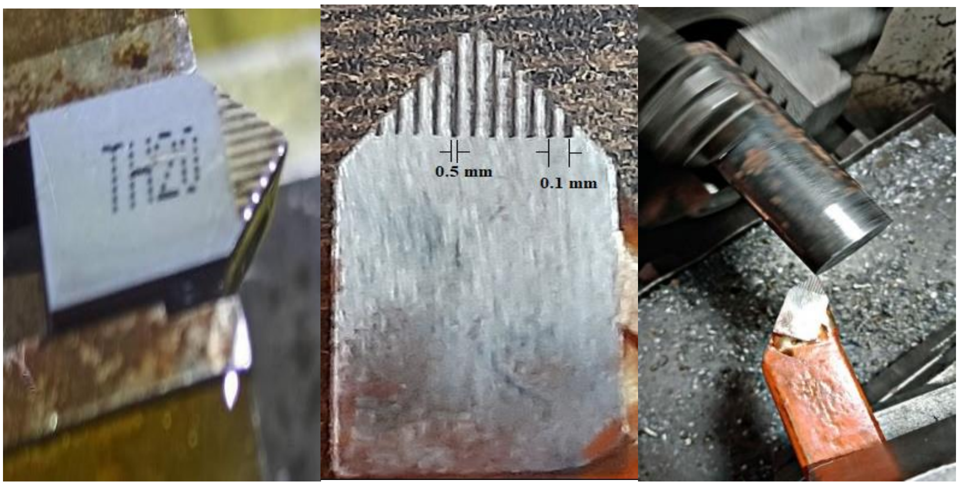


Figure 2. Texturing performed on EDM



(a) (b) (c)

Figure 3: (a) Parallel textures produced by EDM; (b) Dimensions of parallel texture (c) Turning performed on AISI 4340 by parallel textured cutting tool

Table 2. Factors and levels

Factors	Symbols	1	2	3
Cutting speed (m/min)	V	80	100	120
Feed rate (mm/rev)	f	.16	.20	.24
Depth of cut (mm)	t	.25	.50	.75

Table 3. Experimental results for L_9 OA on parallel-texture

Trial No.	Input Conditions			Parallel-textured	S/N ratio
	V (m/min)	f (mm/rev)	t (mm)	Ra(μm)	
1	1	1	1	2.732	-8.7296
2	1	2	2	1.784	-5.0278
3	1	3	3	3.997	-12.0346
4	2	1	2	1.213	-1.6772
5	2	2	3	2.468	-7.8469
6	2	3	1	3.784	-11.5590
7	3	1	3	1.171	-1.3711
8	3	2	1	2.214	-6.9035
9	3	3	2	2.512	-8.0003

4. RESULT AND DISCUSSION

In this section, results obtained from Taguchi L_9 OA are analyzed in form of ANOVA and average value of S/N ratio. Confirmation experiments are performed to verify feasibility of the experiments.

4.1. *Taguchi Method*

Taguchi is a method of optimization in which parameters are optimized by using S/N ratio. It is calculated by using equation (4.1) [13] and values obtained are presented in Table 3.

$$\mathbf{S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]} \tag{4.1}$$

Here, yi = observed response, n = number of trials.

4.2. *ANOVA analysis*

S/N ratio (Table 3) is used for calculating ANOVA in sum of squares (SS), their adjusted values, F-ratio, and percentage contribution. ANOVA results are shown in Table 4. Graphical representation of percentage contribution is shown in Figure 4. Variation of S/N ratio for each level is shown graphically in Figure 5.

Table 4. ANOVA analysis

Parameters	DF	Adj SS	Adj MS	F-ratio	PC (%)
V	2	15.10	7.548	1	14.06
f	2	66.25	33.127	4.387	61.71
t	2	26.01	13.00	1.722	24.31
Pooled error#	--	15.10#	7.548	--	--
Total	6	107.36	--	--	--

Table 5. Average S/N ratio at each level

Mean	V	f	t
Level 1	-8.5973	-3.9259*	-9.0640
Level 2	-7.0277	-6.5927	-4.9017*
Level 3	-5.4249*	-10.5313	-7.0842

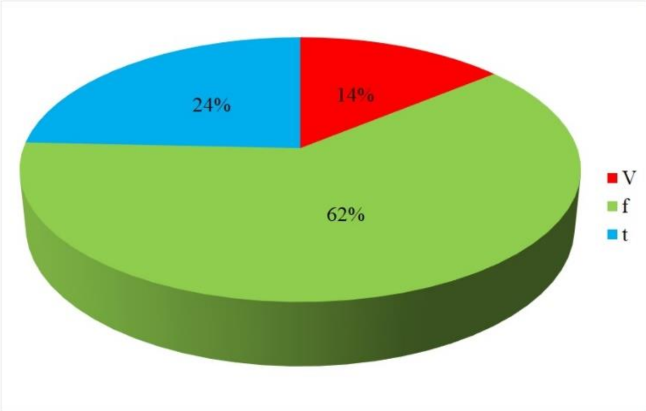


Figure 4. Percentage contribution of each factor

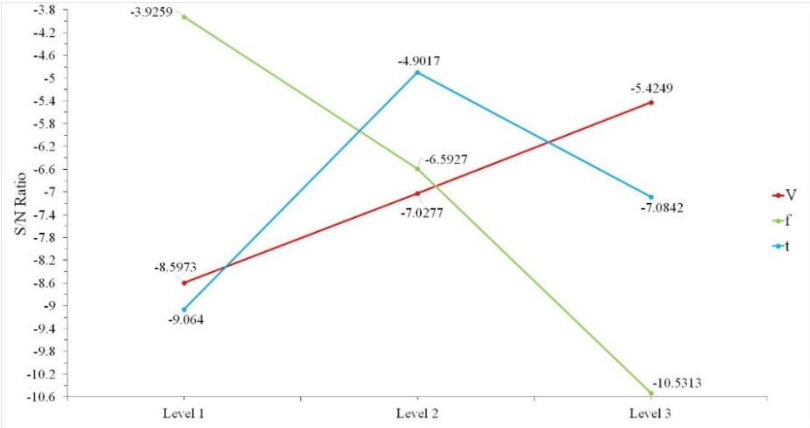


Figure 5. Variation of S/N ratio for each level

4.3. Validation of optimal level

Optimal level obtained after the analysis is V_3-f_1-t_2 (V = 120m/min, f = .16mm/rev, and t = .50mm). Experiments are conducted at optimal condition and then compared with initial setting. From analysis of Table 6, it is observed that surface roughness, Ra improves by 19.21% from initial setting parameters.

Table 6. Confirmation experiment

Response	Initial Setting V_1-f_1-t_1	Optimum results		
		Predication V_3-f_1-t_2	Experiment V_3-f_1-t_2	%Improvement
Ra	2.732	–	2.207	19.21%

5. CONCLUSION

In present work, optimum level of textured tool is experimentally tested and verified. It is concluded that:

1. Percentage contribution of each factor on response is, cutting speed = 14.06%, feed rate = 61.71%, and depth of cut = 24.31%.
2. Optimal level of input parameter using Taguchi L_9 technique is, cutting speed = 120m/min, feed rate = .16mm/rev, and depth of cut = .50mm.
3. ANOVA analysis indicates that feed rate has maximum contribution on surface quality.
4. Improvement in response obtained during confirmation experiment is, Ra = 19.21%.

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