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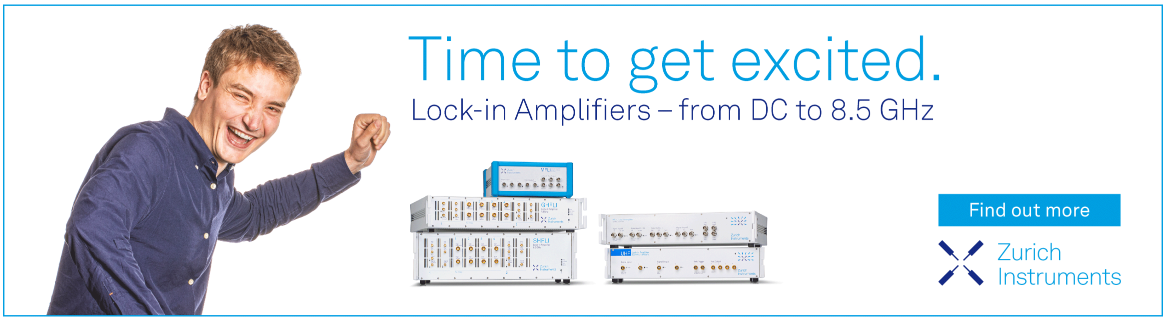

Optimization and Machining Characteristics of ST 60 Steel Material Due to the Annealing Process Using the Taguchi Method

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Abstract. This study looks at the effect of the ST 60 Annealing process on the turning results and analyzes the optimization of machining variables using the Taguchi method. The roughness (Ra) of the annealed lathe product is smaller than the standard material surface roughness or without annealing process; the spindle rotation speed affects the surface roughness of ST 60 steel material before undergoing the annealing process after undergoing the annealing process, which is getting bigger. The rotation speed used, the greater the surface roughness. Rotational speed affects the surface roughness value. The greater the rotational speed, the greater the roughness value obtained. Then the feed dramatically affects the surface roughness results. The greater the feeding speed used, the greater the surface roughness, and vice versa. The smaller the feeding speed, the surface roughness is also getting smaller or better. The depth of cut affects the surface roughness results where the higher the depth of feed, the higher the surface roughness value at the same material and cutting conditions and vice versa. Optimization using the Taguchi method, this study's most optimal roughness value occurred at an annealing temperature of 900^{o}C, the spindle speed of 1000 rpm with a feeding motion of 0.45 mm/rev with a depth of cut 0.5 mm.

INTRODUCTION

The machining process is one of the main processes in the metal manufacturing industry. The machining process plays an essential role in line with technological advances in the automotive industry, mainly in machinery construction and components. Machine tools used in machining include lathes, scraps, drilling, milling, and other machine tools [1]. Many factors influence the quality of the product, such as flat and smooth surfaces. The Cutting parameters are spindle speed, depth of cut, feed rate, angle and type of chisel, machine capability, type of cooling used, type of material, and operator skills. According to Altintas, several factors affect the roughness of the surface of the Turning process, including the feed rate, cooling medium, spindle speed, depth of cut, the material used, and chisel geometry [2-4]. In conventional turning processes, some of these factors are very important and need special attention. The desired quality of the product is usually done by increasing or reducing the spindle speed, feed rate, and cut depth [5-6].

The workpieces used in machining processes are very diverse, from soft workpieces to high hardness levels. Steel is a commonly used material in industries that require materials with good hardness, rigidity, and ductility. The high hardness of Steel makes it difficult to form or process by machine. In other words, the material has low machinability. In order to enhance the machinability of Steel, various ways can be done, including the annealing process. Annealing is a process that involves heating the Steel at a specific temperature and letting it cool inside the furnace, usually applied to produce a softer material. The annealing term also refers to treatments intended to alter mechanical or physical properties, produce definite microstructures, or eliminate gases. The annealing process's operating temperature and cooling rate depend on the material and the purposes[7].

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In this study, we aim to determine the ST-60 steel surface roughness before and after experiencing the annealing process and the influence of variable machining parameters on the roughness. Optimization of surface roughness analyzed with Analysis of Variance (ANOVA) with Taguchi method and Signal-to-Noise (S/N) ratio related to turning on ST60 Steel.

RESEARCH METHOD

Tools and materials

In conducting the research, we utilize tools and materials in the form of 1) Lathe machine, 2) Holder (MTENN2020K16) with Carbide Chisel, 3) Heat treatment Furnace, 4) Surface Roughness Test with Laser-assisted microscope (LEXT OLYMPUS-OLS4100), 5) ST-60 Steel with diameter of 30.5 mm and length of 200 mm. The chemical composition and mechanical properties of the standard ST-60 steel material (No Treatment, NT) used can be found in table 1. The standard ST-60 Steel the annealed with the heating temperature at 900ºC and holding time of 30 minutes and then kept in the furnace for 24 hours for the cooling process.

TABLE 1. Chemical composition of ST60 carbon steel

Element	Content (%)
C (carbon)	0.476
Al (aluminum)	0.0208
Cr (chromium)	0.0444
Cu (copper)	0.0184
Fe (iron)	0.98
Mn (manganese)	0.887
Si (silicon)	0.292
Ti (titanium)	0.146
Zn (zinc)	0.0009

TABLE 2. Mechanical properties ST60 carbon steel

Mechanical Properties	Value
Yield Strength (MPa)	598
Hardness, Rockwell B	91.63

Two sets of materials were prepared before (Normal ST-60 Steel and Annealed ST-60 Steel) then continued in the turning process. The turning process was conducted with the variation of spindle speed, feed rate, and depth of cut. The spindle speed (n) was variated at 800 rpm, 900 rpm, and 1000 rpm. The feed rate (f) variated at 0.45 mm/rev, 0.54 mm/rev and 0.63 mm/rev. Depth of cut (a) variated at 0.5 mm, 1 mm, and 1.5 mm with a turning feeding length of 10 mm. After that, The workpiece was cleaned from the remaining chip and then conducting roughness testing by recording the roughness value (Ra).

First, we put the workpiece into the furnace, then heat the workpiece for 105 minutes to reach the specified temperature. The holding time for the workpiece was 30 minutes. Let it cool in the furnace for ± 24 hours until the workpiece is reached room temperature. Then for the lathe machining process, the spindle speed settings (800, 900, and 1000 rpm) of feed are carried out with variations speed (0.45, 0.54 and 0.63 mm / turn) on lathes with feed rate

(0.5, 1, and 1.5 mm) length of 10 mm. Next, Prepare a surface roughness measuring device, clean the work piece from the sticking chip, then carry out a roughness test on the workpiece and record the roughness value Ra.

Flowcharts

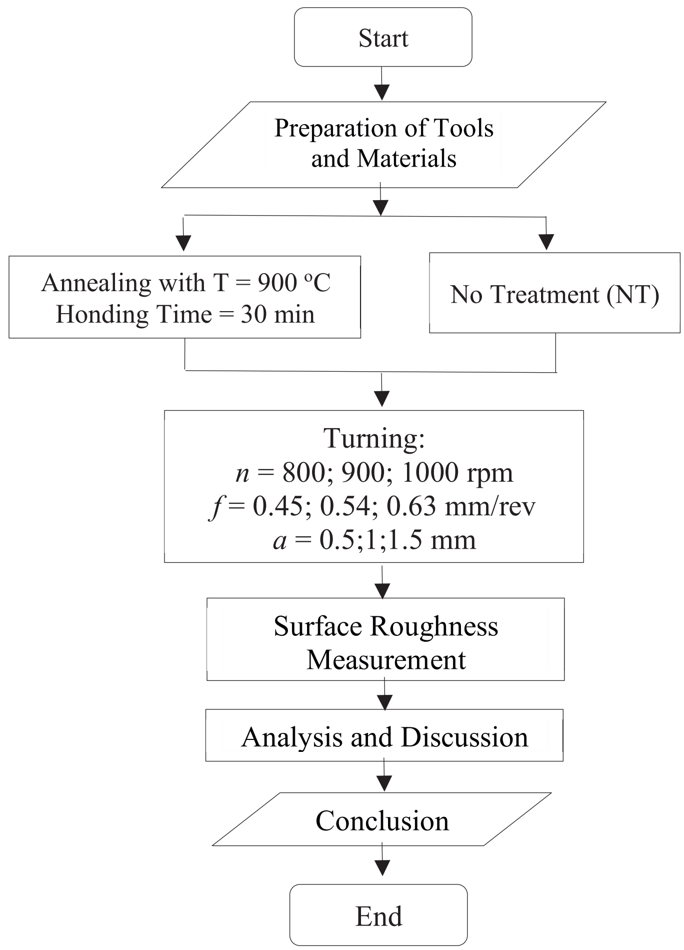


FIGURE 1. Research Flowchart

RESULTS AND DISCUSSION

The following graphs show a rough comparison of ST 60 steel wihout and after undergoing the annealing process.

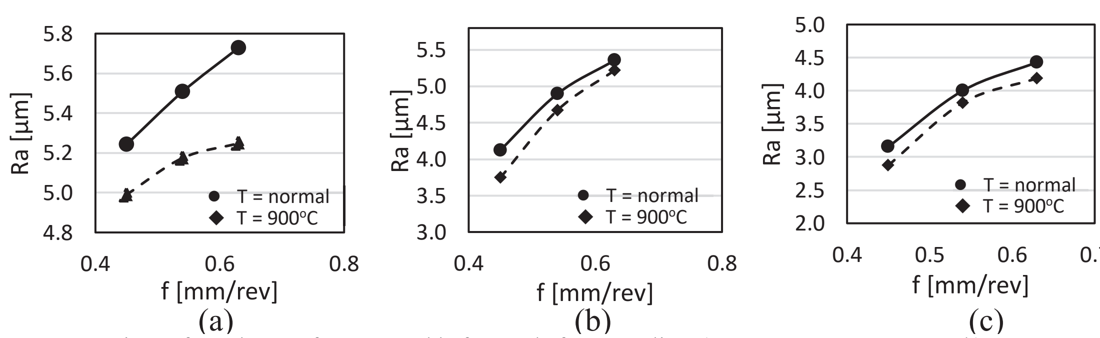
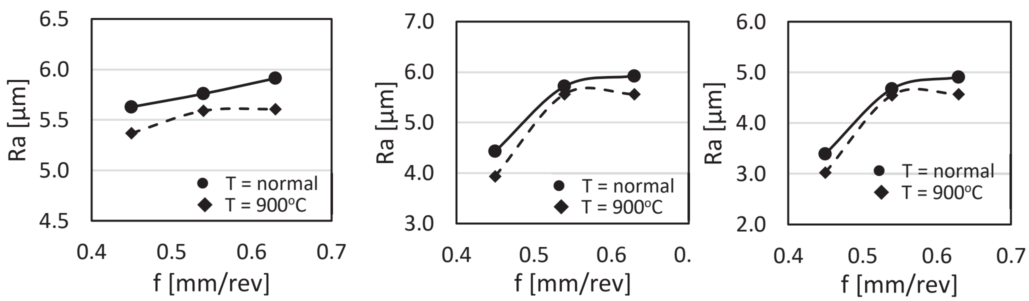
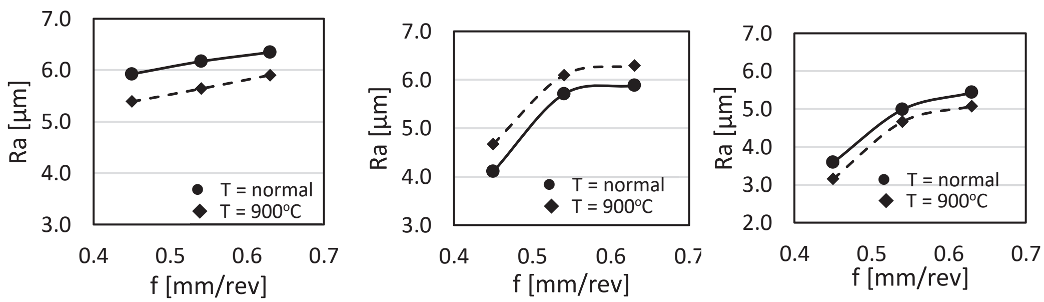


FIGURE 2. Comparison of roughness of ST 60 steel before and after annealing a). n= 800 rpm, a = 0.5 mm. b). n= 900 rpm, a = 0.5 mm c). n= 1000 rpm, a = 0.5 mm



(a) (b) (c)

FIGURE 3. Comparison of roughness of ST 60 steel before and after annealing. a). n= 800 rpm, a = 1 mm. b). n= 900 rpm, a = 1 mm c). n= 1000 rpm, a = 1 mm

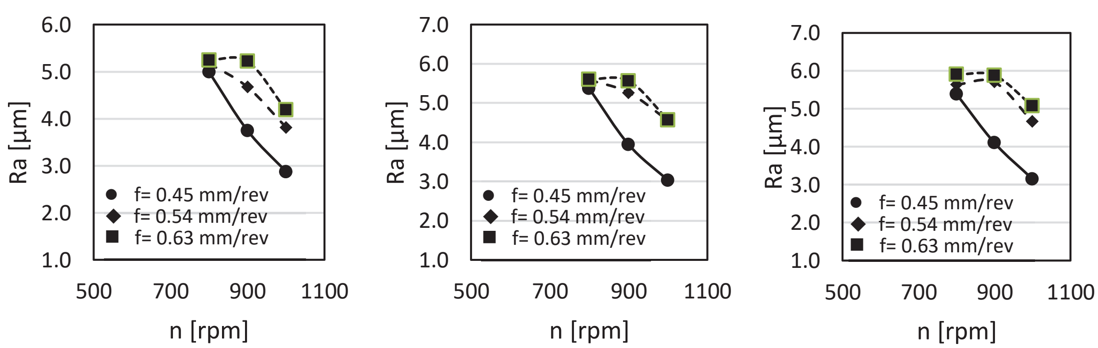


(a) (b) (c)

FIGURE 4. Comparison of roughness of ST 60 steel before and after annealing. a). n= 800 rpm, a = 1.5 mm. b). n= 900 rpm, a = 1.5 mm c). n= 1000 rpm, a = 1.5 mm

From Fig. 2-4, it can be seen that the overall average value of each workpiece surface roughness test for normal ST-60 steel and after undergoing the annealing process. It was found that the small value of this roughness causes the machinability of the material to increase due to reduced friction between cutting chisel with the surface of the workpiece material. According to Chao, the annealing (softening) heat-treatment process will produce a smaller (more refined) roughness value compared to standard specimens[8]. So it can be concluded that the surface roughness of the turning material that has undergone the annealing process is smoother than the surface roughness of the turning results on standard ST60 material or without the annealing process.

The effect of machining variables on the roughness of ST 60 steel material after undergoing the annealing process can be seen in graph below.



(a) (b) (c)

FIGURE 5. Effect of Spindle Speed n (rpm) on Surface Roughness. a). a = 1.5 mm. b).a = 1.5 mm c). a = 1.5 mm

From the results of the roughness test seen in Fig. 5, it can be seen that the value of the surface roughness of the ST60 annealing results in the higher the spindle rotation speed, the lower the surface roughness value obtained at the same material and cutting conditions. The lowest or smoothest roughness value in this study occurred at a spindle rotation speed of 1000 rpm. It can also be seen that the spindle rotation speed affects the surface roughness of the ST60 steel material undergoing the annealing process, where the spindle rotation speed affects the surface roughness value. The greater the rotational speed, the smaller the roughness value (Ra) obtained and vice versa. The increase in cutting speed affects to decreases the surface roughness value. The chisel starts to scratch on the surface of the workpiece, the resulting debris quickly shifts so that it does not scratch the surface of the workpiece that has been cut, the increase in cutting speed also causes the temperature in the contact area and the splinters become more and more, along with that the splinter becomes weaker and then breaks so that there are no elongated flakes that can scratch the surface of the workpiece [9].

From the results of the roughness test seen in Figure 6, it can be seen that the surface roughness value of the ST 60 turning after the annealing process is directly proportional to the value of the feed on turning. The higher the feed motion on the turning, the higher the surface roughness value obtained at the same material and cutting conditions. The lowest roughness value or the smoothest in this study occurred at 0.45 mm/rev feed and the highest at 0.63 mm/rev feed.

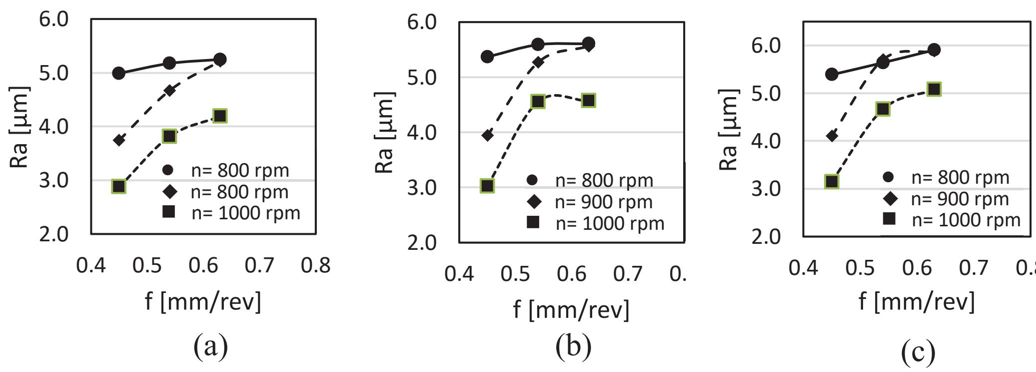


FIGURE 6. Comparison between feed to the roughness after annealing. a). a = 0.5 mm. b). a = 1 mm c). a = 1.5 mm

The results of the roughness test seen in Figure 7 show that the surface roughness value of the ST 60 turning after the annealing process is directly proportional to the value of the depth of cut in turning. The higher the feed motion of the dept of cut on the turning, the higher the surface roughness value obtained at the same material and cutting conditions.

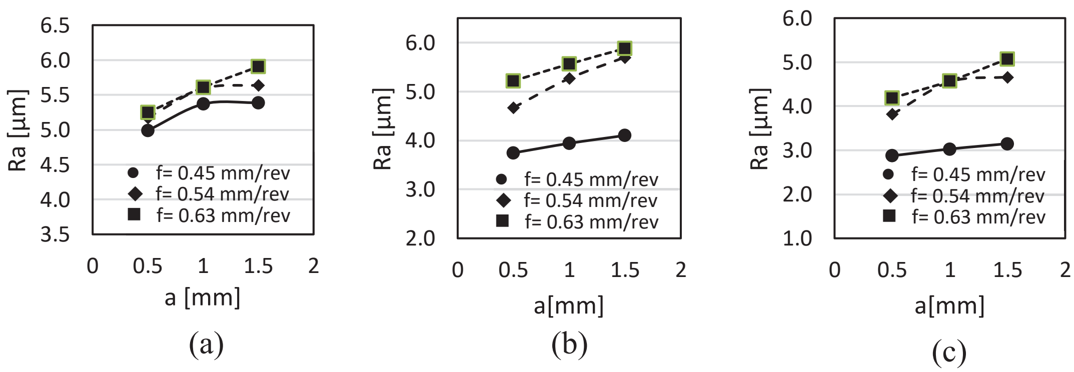


FIGURE 7. Comparison between Depth of Cut ST 60 steel and surface roughness after annealing. a). n = 800 rpm. b). n = 900 rpm, c) n = 1000 rpm

Taguchi Method

Optimization of the surface roughness of the ST 60 steel turning process using the Taguchi method to determine the Optimum roughness value. Research Independent Variables are shown in Table 3.

TABLE. 3 Independent Research Variables

Factor	Independent variable	Level	Level Value		
			1	2	3
A	Spindle speed (rpm)	3	800	900	1000
B	Feeding (mm/rev)	3	0.45	0.54	0.63
C	Depth of cut (mm)	3	0.5	1	1.5
D	Heat treatment	2	NT	900	-

Determine the orthogonal matrix used, namely four factors and three levels. So the orthogonal matrix used is L9. The L9 type orthogonal matrix has three columns and nine rows which can be used for four independent variables, each of which has three levels. Furthermore, the calculation of the S/N ratio (signal to noise ratio) depends on the type of response. The surface roughness response has a roughness quality characteristic where the smaller, the better or (small is better). The roughness response was calculated using the equation (1)

$$\frac{S}{N} = -10\ log\left[\sum_{i=1}^{n} \frac{yi^2}{n}\right] \quad (1)$$

According to the calculations that have been done, the value of the S/N ratio was obtained using the Minitab 17 application for each response observed in each combination of factors.

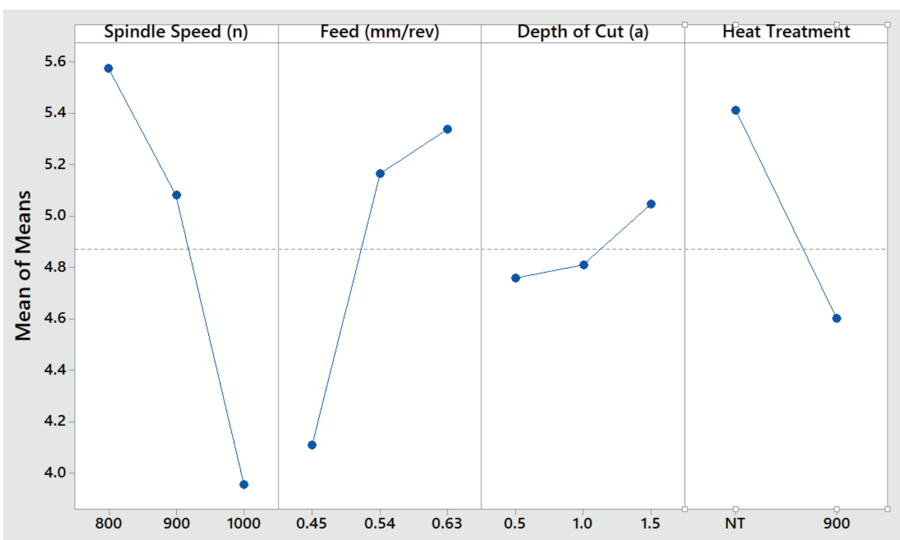


FIGURE 8. S/N ratio calculation results (signal to noise ratio) small is better in Minitab 17

It can see that factor A (spindle speed) has the most significant influence on the surface roughness of turning results with a rating of 1. From the average of each factor, the smallest rating value is chosen as the proposed design because the quality characteristic, in this case, small, is better. From all the above analyses, the proposed designs A1, B2, C4, and D3 were obtained. Then from the calculation above, the most optimal roughness value in this study occurred at an annealing temperature of 900ºC with a spindle rotation speed of 1000 rpm with a feeding motion of 0.45 mm/rev with a feeding depth of 0.5 mm.

Analysis of variance (ANOVA)

To determine the most influential machining variables between 4 factors on the surface roughness of lathe machining results using the Taguchi method by analyzing variance. Analysis of variance was used to analyze the data that has been compiled in the design statistically. This analysis was carried out by describing all the variances of the parts studied. Analysis of variance was used to analyze experimental data consisting of two or more factors with two or more levels.

TABLE 4. Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Spindle Speed (n)	2	4.14599	50.07%	4.14599	2.07299	142.92	0.059
Feed (mm/rev)	2	2.66128	32.14%	2.66128	1.33064	91.74	0.074
Depth of Cut (a)	2	0.14328	1.73%	0.14328	0.07164	4.94	0.303
Heat Treatment	1	1.31454	15.88%	1.31454	1.31454	90.63	0.067
Error	1	0.0145	0.18%	0	0.0145	0.0145	
Total	8	8.27959	100%				

The results of the calculation of the analysis of variance above (Table 4) shows P-value $\leq \alpha$ where α is obtained in the Distribution for Probability = 0.05, so it can say that it has a significant effect on the surface roughness of the turning results on each machining variable[10]. Moreover, the most influential machining variable is the spindle speed (rpm), with the highest percentage contribution of 50.07%.

CONCLUSIONS

The roughness value of ST 60 annealed has a low value compared to the surface roughness of the ST 60 turning without annealing heat treatment. In other words, the surface of ST 60, which has annealed process, is smoother than the non-treated one. The effect of machining variables on the roughness of ST 60 steel material after undergoing the annealing process. Spindle rotation speed dramatically affects the surface roughness of ST 60 Steel Materials before undergoing the annealing process. After undergoing the annealing process, the more significant the rotation speed used, the greater the obtained surface roughness. The rotating speed affects the surface roughness value, the greater the spindle rotates, the greater the roughness value (Ra) obtained. Feed motion (feed) affects the surface roughness results. The greater the feed speed used, the higher the surface roughness result, and vice versa, the smaller the feed speed used, the smaller or better surface roughness results. The depth of cut affects the surface roughness results where the higher the depth of feed, the higher the surface roughness obtained at the same material and cutting conditions and vice versa. Optimization of the surface roughness of the ST60 steel turning process using the Taguchi method using the minitab 17 application, showing that the most influential machining variable is the spindle rotation speed (rpm) with the highest percentage contribution of 50.07% or half of the total percentage contribution from several test factors.

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