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Optimization of Surface Roughness in Turning of Wet & Dry Condition of Alloy Steel Using Taguchi Method

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1. Abstract

The present work is aimed at studying the performance in turning of alloy steel by using performance investigators on surface roughness. In alloy steel machining tool life is greatly affected by the following cutting parameters: Spindle speed peed, depth of cut and feed. Taguchi 's orthogonal array L9 is found to be the best suitable method for this experiment of both wet and dry turning. It is decided to use three levels for each factor. Also signal to noise ratio results and analysis are discussed. For each experimental value, three set of trials are performed and the average value is recorded as the final. Minitab software version 17 is used to optimization the experimental plan for Taguchi technique. The techniques are used to analyse optimum objective functions, minimum surface roughness. The experiments are conducted in dry and wet turning process using CNC machine. The work pieces used for the experiments were of diameter 45 mm and length 145 mm. In this study, the most effected parameters on surface roughness were feed rate. The experiments are planned in the design of experiments (DoE), which facilitates a smaller number of experiments to obtain the desired output.

Keywords: *Turning, Orthogonal array, roughness, spindle, Taguchi Method, Signal-to-noise*.

2. Introduction

Manufacturing is the procedure of turning raw resources into completed products in order to satisfy consumer demands. This involves employing diverse manufacturing techniques to modify the physical characteristics of the raw materials, such as their shape and dimensions.

2.1 Turning Process

In the process of turning, a machining method employed to manufacture rotational components by extracting material from the workpiece. In order to carry out turning, a workpiece, an arrangement, and a cutting tool are indispensable, along with one or more turning machines. The cutting tool, typically a single-point implement fastened to the machine, is affixed before securing the workpiece. Once in place, it engages with the rotating workpiece, eliminating material and creating tiny chips to achieve the desired shape

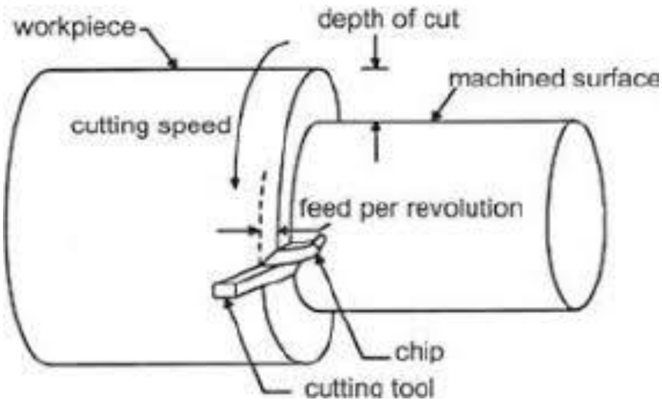

Figure 1: Turning Process

Rotational machining is primarily utilized for axi-symmetric components that exhibit a wide range of characteristics, including openings, passages, helical threads, slopes, different step intervals, and curved outer surfaces. This technique is commonly applied to manufacture intricately shaped parts like customized shafts and delicate fasteners, which are well-suited for prototype creation. Additionally, turning serves as a complementary method to enhance the qualities of workpieces previously shaped using alternative techniques. It particularly offers significant benefits in imparting precise rotational features to ringed workpieces, guaranteeing outstanding strength and smooth finishes.

3. Literature Review

Arafa S. Sobh et.al. (2023) This study focuses on investigating the machinability of TC21 Ti-alloy, a key trend in materials engineering. Utilizing the L9 Taguchi technique, the aim is to determine optimal cutting conditions with minimal experimental trials. Three cutting parameters, cutting speeds (V) at 80, 100, and 120 m/min, feed rates (f) at 0.05, 0.10, and 0.15 mm/rev, and cutting depth (a) at 0.2, 0.4, and 0.6 mm, will be varied to assess the alloy's machinability characteristics efficiently.[1]

Mulugundam Shiva Surya (2022) This research investigates the impact of cutting fluid and input factors (speed, feed, and depth of cut) on material removal rate and surface roughness during the turning of Ti-6Al-4V titanium alloy using a Micromatic CNC lathe. A Response Surface Methodology model is developed to predict the influence of these parameters, with depth of cut and speed being key factors for material removal rate, and feed and depth of cut crucial for surface roughness. Increasing depth of cut and speed enhances material removal rate, while decreasing feed and depth of cut reduces surface roughness. A confirmation test validates the model with less than a 5% error between predicted and experimental values.[2]

R. Thirumalai et. al. (2021) Optimizing manufacturing processes for precise, high-quality parts is vital across industries. This study applies Taguchi and Response Surface Methodology to optimize process parameters for turning titanium. Performance assessment, considering factors like cutting tool temperature and surface roughness, focuses on identifying optimal machining conditions for titanium with various cutting tools. Signal-to-noise ratio analysis reveals that cutting speed is the most influential parameter in titanium machining, followed by the depth of cut. Combined parameters, such as feed and depth of cut, significantly contribute to titanium machining efficiency. This research provides valuable insights for enhancing manufacturing processes.[3]

Emre altas et.al. (2020) This study optimizes machining parameters for minimal surface roughness (Ra) and flank wear (V_b) in dry milling of nickel-titanium shape memory alloy (NiTi) using uncoated cutting tools with varying nose radii (rε). Tungsten carbide tools (rε of 0.4 mm and 0.8 mm) are employed at different cutting speeds and feed rates. Taguchi L18 orthogonal sequence and Minitab 17 software analyze the effects of machining parameters. Results indicate that nose radius significantly impacts Ra, while feed rate is crucial for Vb. Validation tests confirm the accuracy of optimization, showing close agreement between predicted and measured values. [4]

Duy Trinh Nguyen et.al. (2019) Grinding wheel wear significantly impacts the quality and efficiency of the Ti-6Al-4V alloy grinding process. This study introduces a model that utilizes grinding force signals, adaptive neural fuzzy inference system - Gaussian process regression, and Taguchi analysis to predict abrasive wear and surface roughness during grinding. Experimental results demonstrate accurate predictions, with an average error of 0.31% and a reliability percentage of 98%. The proposed model offers potential for real-time forecasting of surface roughness and timely grinding wheel maintenance in industrial applications. [5]

M. J. Raghvendra et.al. (2018) In metal cutting and production industries, enhancing productivity and product quality during turning processes is crucial for market competitiveness. Taguchi's optimization method proves effective in improving manufacturing performance and quality. This study focuses on optimizing cutting parameters (cutting speed, depth of cut, and feed) in dry conditions for titanium grade-5 materials using a PVD carbide tool. Utilizing, Taguchi's L9 orthogonal array, the experiment identifies key factors affecting surface roughness and tool wear. Analysis reveals that lower speed and feed rate significantly minimize tool wear, with feed rate being the most influential parameter for surface roughness in turning titanium grade-5 materials.[6]

S.M. Ravi Kumar et. al. (2017) Machining hard titanium alloys poses challenges due to significant tool wear. Hard turning, a dry machining process with a single-point cutting tool, addresses this issue for materials with a Vickers hardness above 45. This method eliminates the need for grinding operations and is environmentally friendly. Investigating titanium alloy turning on a CNC machine using the L9 orthogonal array, this study optimizes cutting parameters through the Taguchi method. By analysing the response table, optimal surface roughness and tool wear conditions are identified, enhancing the longevity of machined components. Tool wear is assessed with a confocal microscope, while surface roughness is determined using Form Talysurf.[7]
S. Debnath et.al. (2016) This experimental study investigates the impact of cutting fluid levels and parameters on surface roughness and tool wear using Taguchi orthogonal array. Mild steel was machined with a TiCN + Al_2O_3 + TiN coated carbide tool insert in CNC turning. Feed rate predominantly influences surface roughness (34.3%), while cutting fluid flow rate significantly contributes (33.1%). Cutting speed (43.1%) and depth of cut (35.8%) are key factors for tool wear, with cutting fluid application (13.7%) also playing a substantial role. Optimal conditions for desired surface roughness and tool wear involve high cutting speed, medium depth of cut, low feed rate, and low-flow high-velocity cutting fluid. [8]
Kosaraju Satyanarayana et.al (2013) This study focuses on optimizing the turning of titanium (Grade 5) by investigating the impact of process parameters using the Taguchi-based Grey relational method. Cutting speed, feed, and depth of cut are varied, while cutting force, surface roughness, and tool life are evaluated as performance characteristics. Through L9 orthogonal array experiments, it is determined that cutting speed significantly influences cutting force and tool life, while feed has the most impact on surface roughness. The overall optimization identifies cutting speed as the most crucial parameter for the turning operation, considering cutting force, tool life, and surface roughness. [9]

4. Methodology

The objectives of the present work have just been mentioned in the foregoing section.
Accordingly, the present examination has been done through the following plan of experiment.

1. Checking and preparing the Lathe prepared for performing the machining operation.
2. Cutting steel bars by control saw and performing initial turning operation on Lathe to get desired dimension (of diameter 45mm and length 145 mm) of the work pieces.
3. Performing straight turning operation under dry and wet conditions on specimens in various combinations of procedure control parameters like: spindle speed, feed and depth of cut.
4. Length of cut was kept steady at 50 mm for both dry and wet turning.
5. Measuring surface roughness and surface profile with the assistance of a convenient stylustype profilometer, Tal surf (Taylor Hobson, Sturrock 3+, UK).

4.1 Material Used

The material selected was ALLOY STEEL bars (of diameter 45 mm and length 145 mm) on the basis that it was suitable for most engineering and construction application.

4.2 Alloy Steel

ALLOY STEEL is an economical medium-carbon steel that displays suitable strength and toughness properties, making it applicable for components requiring induction or flame hardening. The bar's hardness is gauged at 187 HB.
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Table 1: Chemical Composition of Alloy Steel in %

C	Si	Mn	P	I	Cu	Ni	Al
0.75	6.5	0.5	0.015	1.3	3.0	0.5	87.4

Figure 2: Picture of work piece before machining

4.3 PROCESS VARIABLES AND THEIR LIMITS

The software MINITAB 17 was employed to establish the experimental design, following Taguchi's L_9 Orthogonal Array (OA). In this current study incorporates essential process factors, specifically Spindle speed, feed, and depth of cut. Table 2 show a comprehensive overview of the process variables, their corresponding outcomes, and relevant explanations.

Table 2: shows the variables and their limits

Parameters		Level		
		1	2	3
A	SS (rpm)	150	300	600
B	Rate of feed (mm/rev)	0.20	0.30	0.40
C	DOC (mm)	0.70	0.80	0.90

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5. Result and Discussion:

TAGUCHI MAIN EFFECT PLOTS FOR SURFACE ROUGHNESS

Main effect plots for surface roughness for dry and wet turning are shown in the fig.5.1 and fig. 5.2 Main effect plot shows the variation of surface roughness with respect to Spindle speed, feed rate and depth of cut. X axis represents change in level of the variable and y axis represents the change in the resultant response.

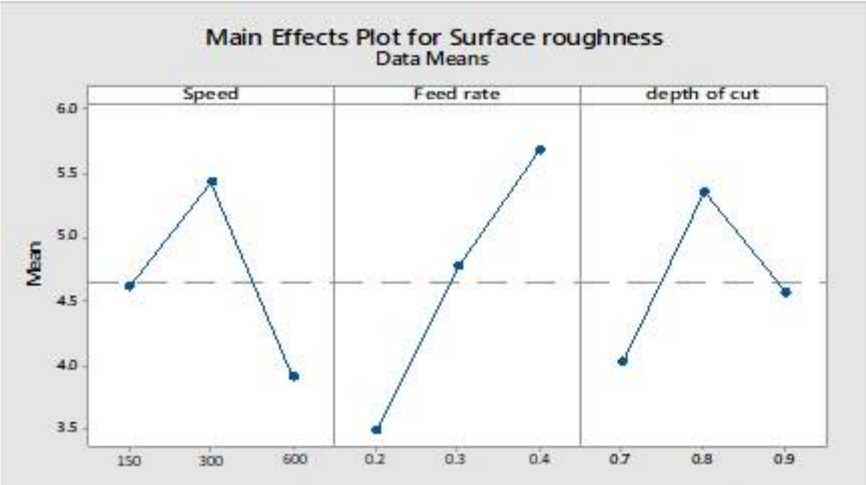

Figure 3: Main effects plot for means for surface roughness for dry turning

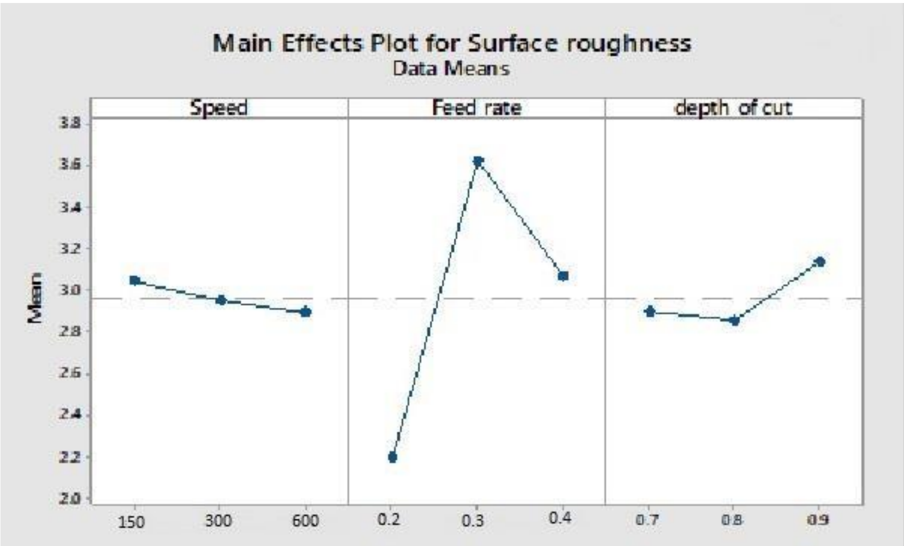

Figure 4: Main effects plot for means for surface roughness for wet turning

ANALYSIS OF S/N RATIO FOR SURFACE ROUGHNESS FOR DRY AND WET TURNING

The signal to noise ratios tells us about the variations present in the process. The values of all the results according to Taguchi array parameter design layout are presented in this section. The S/N ratios have been calculated to identify the major contributing factors for variation of force values. In this design situation, lower-the-better is used.

Table 3 Analysis of variance for S/N ratios for surface roughness (Ra) in Dry Turning

Source	DF	Adj SS	Adj MS	F	P	Percentage Contribution %
Spindle speed (rpm), N	2	14.561	7.28	1.75	0.363	19.67 %
Feed rate (mm/rev), f	2	35.606	17.803	4.29	0.189	48.44 %
Depth of cut (mm), d	2	15.025	7.513	1.81	0.356	20.44 %
Error	**2**	**8.307**	**4.154**			**11.3 %**
Total	**8**	**73.5**				**100 %**

Table 4: Response table for S/N Ratios of surface roughness (Ra) in Dry Turning

Level	Spindle Speed (rpm), N	Feed rate (mm/rev), f	Depth of Cut (mm), d
1	-12.51	-10.28	-11.41
2	-14.66	-13.46	-14.56
3	-11.63	-15.06	-12.83
Delta	**3.02**	**4.79**	**3.16**
Rank	**3**	**1**	**2**

Table 5: Analysis of variance for S/N ratios for surface roughness (Ra) in Wet Turning

Source	DF	Adj SS	AdjMS	F	P	Percentage Contribution %
Spindle speed (rpm), N	2	5.3878	0.01539	0.09	0.914	16.34 %
Feed rate (mm/rev), f	2	29.148	14.574	8.91	0.101	66.84 %
Depth of cut (mm), d	2	4.5985	0.4292	0.26	0.792	13.68 %
Error	**2**	**3.2715**	**1.6357**			**3.14 %**
Total	**8**	**33.586**				**100 %**

Table 6: Response table for S/N Ratios of surface roughness (Ra)in Wet Turning

Level	**Spindle Speed (rpm), N**	**Feed rate (mm/rev), f**	**Depth of Cut (mm), d**
1	-9.443	-6.836	-9.007
2	-9.260	-11.173	-9.023
3	-8.993	-9687	-9.667
Delta	0.451	4.338	0.66
Rank	3	1	2

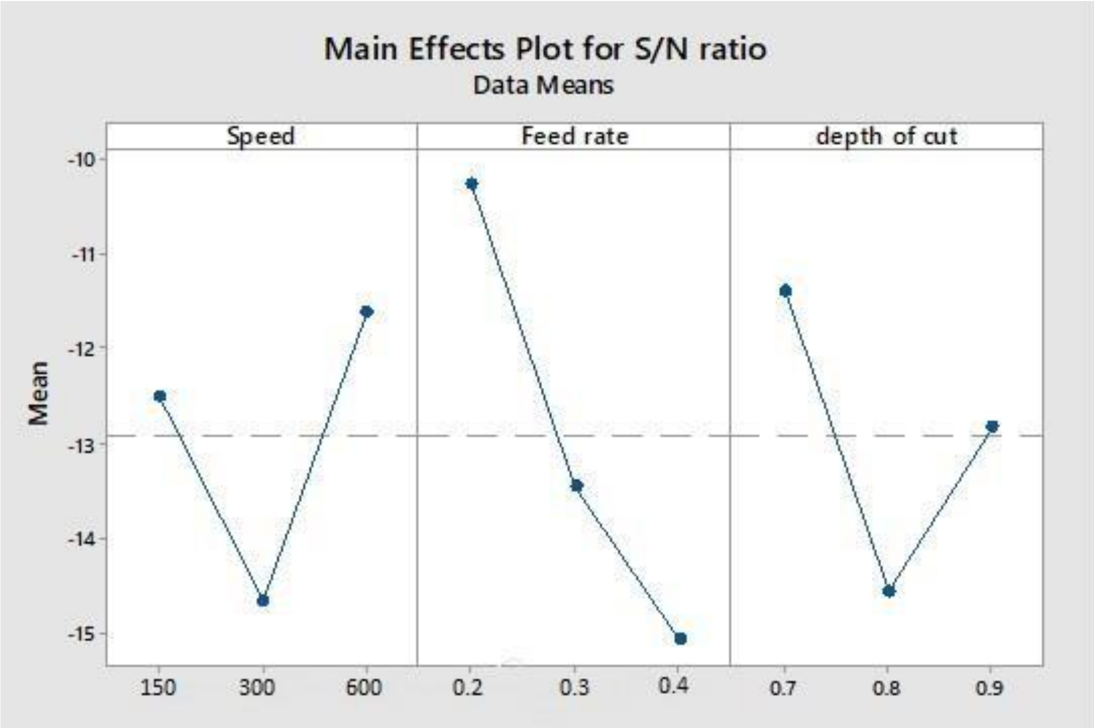

Figure 5: Main effects plot for S/N ratios for surface roughness in Dry Turning

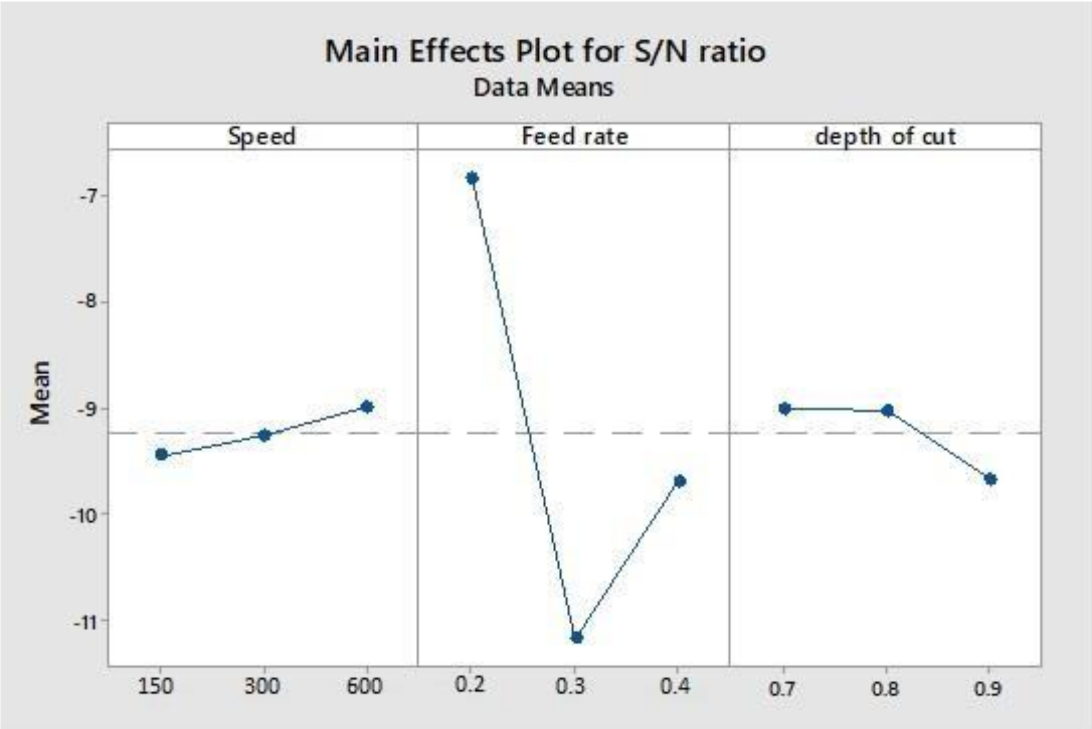

Figure 6: Main effects plot for S/N ratios for surface roughness in Wet Turning

6. Conclusion:

Conclusion from surface roughness in dry turning

The Surface roughness is mainly affected by feed rate, depth of cut and spindle speed. With the increase in feed rate the surface roughness also increases, as the depth of cut increases the surface roughness first increase and decrease and as the spindle speed increase surface roughness decreases. Also, it is observed from the S/N ratio graph that surface roughness minimizes at a combination of spindle speed = 150 rpm, feed = 0.2 mm/rev. and Depth of cut = 0.7 mm which gives a surface roughness of 2.52.

Conclusion from surface roughness in wet turning

The Surface roughness is mainly affected by depth of cut, feed rate and spindle speed. With the increase in depth of cut the surface roughness also increases, as the feed rate decreases and as the spindle speed increase surface roughness decreases. Also, it is observed from the S/N ratio graph that surface roughness minimizes at a combination of spindle speed = 600 rpm, feed = 0.2 mm/rev. and Depth of cut = 0.9 mm which gives a surface roughness of 2.11.

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