PARAMETRIC OPTIMIZATION OF TURNING PROCESS PARAMETERS DURING MACHINING OF AISI 304 MATERIAL

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Abstract— **The performance of the turning process is greatly impacted by turning process factors. In the current study, the Taguchi methodology was used to maximise turning process performance when AISI 304 material was being machined using a traditional cooling method. For the study, turning process characteristics such cutting speed, feed rate, and cut depth were taken into account. To conduct the tests, the Taguchi L9 orthogonal array (OA) experimental design plan was taken into consideration. Surface roughness, tool wear, and cutting temperature were taken into account as output process responses.**

The turning performance was found to be greatly enhanced by the Taguchi technique, which identified the optimal process parameters. It is advised that make use of these ideal cutting parameters to decrease material waste and increase the productivity while machining AISI 304 material.

Keywords— **Turning; Taguchi technique; Cutting Temperature; Tool Wear; Surface Roughness; AISI 304 material**

1. INTRODUCTION

Stainless steel is a type of steel alloy that contains a minimum of 10.5% chromium, which forms a protective oxide layer on the surface, preventing corrosion and providing enhanced durability. Among the various grades available, AISI 304 stainless steel stands out for its exceptional performance in numerous applications. AISI 304 stainless steel consists primarily of iron, chromium, and nickel, with small amounts of other elements such as carbon, manganese, and silicon. It offers excellent mechanical properties, including high tensile strength, good formability, and impressive impact resistance.

Turning is the most common lathe machining operation. During the turning process, a cutting tool removes material from the outer diameter of a rotating workpiece. The main objective of turning is to reduce the workpiece diameter to the desired dimension. In any machining process the tool is subjected to three distinct factors: cutting force, cutting temperature and sliding action, due to the relative motion between the tool and the workpiece. Due to these factors, the cutting tool will start giving unsatisfactory performance after some time.

In a given combination of work and tool material, the cutting temperature depends upon the cutting speed, feed, and depth of cut and to a limited extent cutting fluids. Among of these factors, cutting speed has a predominant effect. One of the important functions of the cutting fluid is to conduct the heat away from the tool and workpiece interface and avoid heat accumulation and temperature build-up in the vicinity of the active cutting edge. The fluid would be carried away by the outward flowing chip more rapidly than it could be forced between the tool and chip. The effectiveness of the fluid in lowering the tool temperature decreases with increase in cutting speeds and at higher speeds the fluids become completely ineffective in reducing the temperature.

In the turning process, higher cutting zone temperatures results in low productivity and high machining cost during machining of difficult to cut materials. For this reason, it is imperative to use cutting fluids at the machining zone to control the cutting zone temperatures during cutting of various types of difficult to cut materials. In the literature, various types of cooling techniques are available to supply the coolant at the machining zone (Chetan, Ghosh and Venkateswara Rao, 2015). Particularly, metal cutting industries focused more on environmental friendly cooling techniques like cryogenic, minimum quantity lubrication (MQL) and solid lubrication, etc. to meet the conscious environmental regulation. However, these techniques require costly experimental setups to supply the coolant at the machining zone (Chetan, Ghosh and Venkateswara Rao, 2015).

Vasumathy and Meena (2017) have made linear grooves on the rake face the tool and conducted dry turning experiments on AISI 316 material using textured and untextured tools respectively. From results they noticed low cutting force and tool wear in textured tools due rise in shear angle low too-chip contact area. Acayaba and Escalona (2015) conducted experiments on AISI 316 material with conventional tool under dry condition. In their work, predicted the surface roughness by using ANN and observed good agreement with experimental results. Leppert (2012) obtained low surface roughness and low cutting force in MQL condition with conventional cutting tool due to good lubrication over dry and wet condition respectively during machining of AISI 316 material.

Ukamanal and Mishra (2020) conducted experiments on AISI 316 material according to Taguchi L16 design with conventional tool and found optimum spray impingement cooling parameters by applying weighted PCA method. Bedi et al. (2020) compared the turning process performance with two different oils such as rice bran oil and coconut oil under MQL condition. Results from their study indicates that rice bran oil outperformed in process improvement due to low friction over MQL with MQL and dry cutting condition respectively. Kumar Mishra et al. (2020) Circular dimple single pattern textured tools were tested under MQL, nano-MQL condition, dry condition and results were compared with untextured tools in turning of Ti-6Al-4V alloy. It was observed improved machinability indices with textured tools under nano-MQL condition over MQL and dry cutting condition respectively. The reason for positive results with textured tools is accumulation of nano fluid in the texture design leads to low tool chip contact length.

The aim of this investigation is to optimize the cutting temperature, tool wear and surface roughness using Taguchi Technique during turning of AISI 304 material under wet cooling cutting conditions.

2. EXPERIMENTAL WORK

Austenitic stainless steel materials, i.e. AISI 304, have been widely used in many areas such as automotive and aerospace industries. AISI 304 austenitic stainless steel is categorized under a group of materials that are very hard to machine.

Turning experiments were conducted on AISI 304 using CNC lathe machine as shown in Figure 1 under wet cooling conditions. The machining zones of conventional (wet) cutting conditions are shown in Figure 2. After machining, workpiece can be seen as depicted in Figure 3. Cutting tools were selected inserted in the tool holder and performed each experiment for 200 mm length of the workpiece. Each experiment was conducted with a new cutting edge for tool wear analysis purposes. The cutting conditions used to perform the experiments are shown in Table 1. Every experiment was conducted three times and the average was considered in each response to provide the accuracy in the data. Experiments were conducted based on Taguchi L9 orthogonal array. The selected process variables were selected based on the trial experiments. ISO 4287-1997 standards were followed to measure the average surface roughness (Ra) using Talysurf tester. Tool wear analysis and measurement were done by using a Metallurgical microscope. Thermal image camera was used to measure the cutting zone temperature during machining. Factors like obstruction of Infrared rays by chip particles and cutting fluid were taken into consideration while measuring cutting zone temperature. The process variables and their levels are shown in Table 2.Final obtained results were shown in Table 3.

Figure 1 CNC machine

Figure 2 Wet cooling condition

Figure 3 Machining zone images at the wet cooling

Table 1 Details of experimental conditions

Workpiece material and dimensions	AISI 304 SS round bar (⌀30 mm x 150 mm)
Cutting inserts	AlTiN PVD coated tungsten carbide inserts (An ISO designation of SNMG432 KC 910)
Tool holder	ISO specification of PSBNL 2020 K12, WIDIA make
Working insert tool geometry	Inclination angle: - 6°, rake angle: - 6°, clearance angle: 6°, Nose radius: 0.8 mm, major cutting edge angle: 75°
Turning Process parameters	Cutting speed (*v*): 800,1250and 1700RPM Feed rate (*f*): 0.06,0.09 and 0.12mm/rev Depth of cut (a_p): 0.6,0.4, and 0.2mm
Environmental conditions and coolants used	Conventional cooling (emulsion based flood cooling 1:20 soluble oil)- flow rate: 5 l/hr (through external nozzle); Nozzle diameter- ⌀ 10 mm

Table 2 Process variables and their levels

Parameters	Levels		
	-1	0	1
Spindle Speed (rpm)	800	1250	1700
Feed Rate (mm/rev)	0.06	0.09	0.12
Depth of Cut (mm)	0.2	0.4	0.6

Table 3 Experimental results

S. No.	Spindle Speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)	Temp (°C)	Surface roughness (µm)	Tool flank wear (µm)
1	800	0.06	0.6	103	0.361	41.085
2	800	0.09	0.4	52	0.324	66.8067
3	800	0.12	0.2	70	1.009	114.3284
4	1250	0.06	0.6	61	0.763	61.54035
5	1250	0.09	0.4	133	0.354	78.0615
6	1250	0.12	0.2	75	0.420	108.3275
7	1700	0.06	0.6	80	1.347	118.7108
8	1700	0.09	0.4	69	0.538	131.7708
9	1700	0.12	0.2	52	0.759	138.9171

3. RESULTS AND DISCUSSION

The objective of this work is to understand the creation of a product or process design that is insensitive to all possible combinations of uncontrollable noise factors and is at the same time effective and cost-efficient as a result of setting the key controllable factors at certain levels. The central purpose of this study is to understand and evaluate the impact of Taguchi methods in quality engineering and management for product or process parameters optimization both in the manufacturing industry and service industry.

Any process is the combination of one or more factors and will give the best possible output when all these factors operate at the optimum values. If total number of factors and levels involved is more, then the number of experiments will become very large because of this Taguchi design of experiments is used which uses Orthogonal Array (OA) which is the shortest possible matrix of combinations.

Taguchi used the term signal and noise which represents wanted value (mean) for the response and unwanted value (standard deviation) for the response respectively. Based on the requirements of response, Taguchi has divided the S/N ratio into to three categories namely medium-the-better, higher-the-better and lower-the-better. In the present study, the quality characteristics like R_a and V_b are the lower-the-better to enhance the machinability. Hence, Eqn. (1) has been used to calculate the S/N ratio and results have been shown in Table 4. Taguchi analysis was done using Minitab 17.0 software tool and the means of mean plot, means of S/N ratio plots.

Signal to noise ratio for the smaller the better

$= -10 \log \frac{1}{n}\sum(R)^2$ ……… (1)

Where, n = No. of observations

R = Observed data for each response

Table 4 Experimental results and respective calculated S/N ratios

S. No.	Spindle Speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)	Temp (°C)	Surface roughness (µm)	Tool flank wear (µm)
1	800	0.06	0.6	-40.2567	8.84986	-32.2737
2	800	0.09	0.4	-34.3201	9.78910	-36.4964
3	800	0.12	0.2	-36.9020	-0.07782	-41.1631
4	1250	0.06	0.6	-35.7066	2.34951	-35.7832
5	1250	0.09	0.4	-42.4770	9.01993	-37.8487
6	1250	0.12	0.2	-37.5012	7.53501	-40.6948
7	1700	0.06	0.6	-38.0618	-2.58735	-41.4898
8	1700	0.09	0.4	-36.7770	5.38435	-42.3964
9	1700	0.12	0.2	-34.3201	2.39516	-42.8551

3.1 Determination of optimum cutting conditions for cutting temperature

The obtained S/N ratio response table for the cutting temperature is shown in Table 5. Figure 4 represents the mean S/N ratio graph obtained in Minitab software tool. Higher S/N ratio represents the minimum variation difference between the desirable output and measured output. From Figure 4, it was noticed that the highest mean S/N ratio obtained for cutting temperature are cutting speed at 1700rpm, feed rate at 0.12 mm/rev, depth of cut 0.4 mm respectively. Therefore, the predicted optimum process parameters for obtaining the low cutting temperature using Taguchi method were found as cutting speed at 1700rpm, feed rate at 0.12 mm/rev, depth of cut 0.4 mm respectively. Figure 5 shows the impact of individual process variables on cutting temperature.

Table 5 Mean S/N ratio response table for cutting temperature

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed (RPM)	-37.16	-38.56	**-36.39**	2.18	2
f	Feed rate (mm/rev)	-38.01	-37.86	**-36.24**	1.77	3
d	Depth of cut (mm)	-39.15	**-34.78**	-38.18	4.36	1

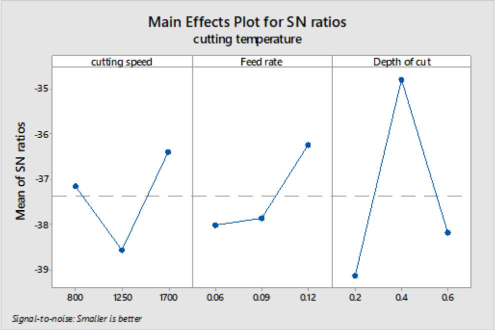

Figure 4 Mean S/N ratio of cutting temperature

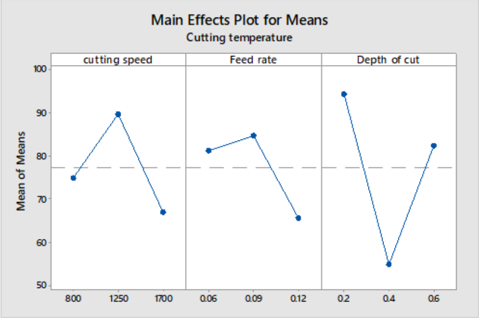

Figure 5 Effect of individual process variables on cutting temperature

3.2 Determination of optimum cutting conditions for surface roughness

The obtained S/N ratio response table for the surface roughness is shown in Table 6. Figure 6 represents the mean S/N ratio graph obtained in Minitab software tool. Higher S/N ratio represents the minimum variation difference between the desirable output and measured output. From Figure 6, it was noticed that the highest mean S/N ratio obtained for surface roughness are cutting speed at 1250RPM, feed rate at 0.09 mm/rev, depth of cut 0.6mm respectively. Therefore, the predicted optimum process parameters for obtaining the low surface roughness using Taguchi method were found as cutting speed at 1250RPM, feed rate at 0.09 mm/rev, depth of cut 0.6 mm respectively. Figure 7 shows the impact of individual process variables on surface roughness.

Table 6 Mean S/N ratio response table for surface roughness

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed (RPM)	6.187	**6.301**	1.731	4.571	3
f	Feed rate (mm/rev)	2.871	**8.064**	3.284	5.194	1
d	Depth of cut (mm)	2.118	4.845	**7.256**	5.138	2

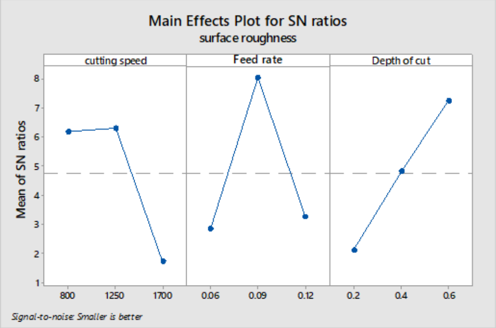

Figure 6 Mean S/N ratio of surface roughness

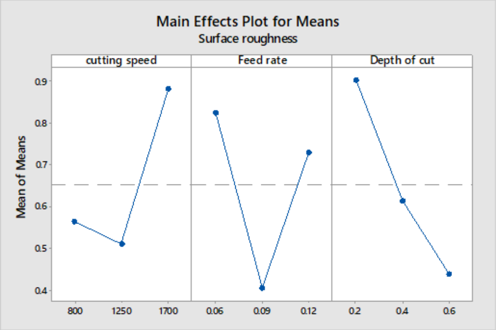

Figure 7 Effect of individual process variables on surface roughness

3.3 Determination of optimum cutting conditions for tool flank wear

The obtained S/N ratio response table for the tool flank wear is shown in Table 7. Figure 8 represents the mean S/N ratio graph obtained in Minitab software tool. Higher S/N ratio represents the minimum variation difference between the desirable output and measured output. From Figure 8, it was noticed that the highest mean S/N ratio obtained for tool flank wear are cutting speed at 800RPM, feed rate at 0.06 mm/rev, depth of cut 0.4 mm respectively. Therefore, the predicted optimum process parameters for obtaining the maximum tool flank wear using Taguchi method were found as cutting speed at 800RPM, feed rate at 0.06 mm/rev, depth of cut 0.4 mm respectively. Figure 9 shows the impact of individual process variables on surface roughness.

Table 7 Mean S/N ratio response table for tool flank wear

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed (RPM)	**-36.64**	-38.11	-42.25	5.60	1
f	Feed rate (mm/rev)	**-36.52**	-38.91	-41.57	5.06	2
d	Depth of cut (mm)	-40.17	**-38.38**	-38.45	1.79	3

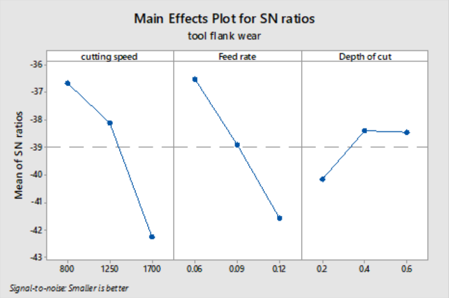

Figure 8 Mean S/N ratio of tool flank wear

Figure 9 Effect of individual process variables on tool flank wear

3.4 Confirmation Test

For validating the Taguchi predicted optimum conditions, confirmation tests need to be performed. At the Taguchi predicted optimum cutting conditions, the confirmation experiments were performed at the required positions and results were shown in Table 8 for all outputs respectively. The predicted optimum cutting conditions for all outputs gives an improvement in the performance characteristic results.

From the confirmation experiments, it was found that the Taguchi predicted optimum cutting conditions gives favourable results over the initial parameter conditions. Therefore, the Taguchi predicted optimum cutting conditions were taken as the optimum cutting conditions for obtaining the high machining performance during turning of AISI304 material under the given conditions. From results, it was observed that Taguchi optimization method significantly improved the machinability characteristics of AISI 304 material under the given process parameters.

Table 8 Conformation test results for Cutting temperature, surface roughness and tool flank wear.

	Initial process parameter	Predicted optimal process parameters
Cutting temperature (^oC)		
Level	N=800RPM, f=0.06 mm/rev, depth of cut = 0.6 mm	N=1700RPM, f=0.12 mm/rev, depth of cut 0.4 mm
Cutting temperature (^oC)	*103*	*85*
Surface roughness (µm)		
Level	N=800RPM, f=0.06 mm/rev, depth of cut = 0.6 mm	N=1250RPM, f=0.09 mm/rev, depth of cut 0.6 mm
Surface roughness(µm)	*0.361*	*0.321*
Tool flank wear(µm)		

Level	N=800RPM, f=0.06 mm/rev, depth of cut = 0.6 mm	N=800RPM, f=0.06 mm/rev, depth of cut 0.4 mm
Tool flank wear (μm)	41.08	38.42

4. CONCLUSIONS

From the present work, following conclusions were drawn.

- The selected optimum set of control parameters for low cutting temperature are cutting speed at 800RPM, feed rate at 0.12 mm/rev, depth of cut 0.4 mm respectively using Taguchi technique.
- The determined optimum set of control parameters for low surface roughness are cutting speed at 1250RPM, feed rate at 0.09 mm/rev, depth of cut 0.6 mm respectively using Taguchi technique.
- The identified optimum conditions for low tool flank wear cutting speed at 800RPM, feed rate at 0.06 mm/rev, depth of cut 0.4 mm respectively using Taguchi technique.
- Manufacturing cost and wastage of material could be reduced by conducting experiments at the Taguchi technique identified optimum cutting conditions during turning of AISI 304 in the production line consists of turning operation.

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