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# PARAMETRIC ANALYSIS OF TURNING PROCESS CHARACTERISTICS IN INCONEL 625 ALLOY USING TRADITIONAL TECHNIQUES

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**ABSTRACT**

*This research works aims on optimizing the turning process variables by employing Taguchi techniques to inherit the best quality for the products machined using traditional machining processes. Taguchi techniques has been utilized to optimize the machining variables while turning Inconel 625 alloy with coated cemented carbide tool in dry condition. CNC machine has been employed to conduct various trials based on the design of experiments with a predetermined orthogonal array. Signal to noise ratio and analysis of variance have been used to determine the minimum surface roughness. The trials have showed that that the optimal parameters for surface roughness occurs while the parameters have been kept at spindle speed as 500 m/min, feed rate as 0.2 mm/rev and the depth of cut as 1.2 mm. The optimum value of the surface roughness turns out to be 0.85µm. The results have been validated by confirmatory experiments.*

**Keywords:** Turning process; Optimization; Inconel 625 alloy; Taguchi techniques; Surface roughness

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## 1. INTRODUCTION

The machining industries mainly targets on the achievement of high quality products, relating to the, surface finish, workpiece dimensional accuracy, less wear on the cutting tools, economy etc. Machining operations have been the core of the manufacturing industry and this research work deals with the optimization of process parameters in turning process in Inconel 625 alloys for minimizing the surface roughness ($R_a$). These conditions or manufacturing circumstances are regarded as computing simulations and their applicability to real world industry is still uncertain and therefore, a general optimization scheme without equipment operations is deemed to be necessarily developed. Surface roughness is commonly considered as a major manufacturing goal for turning operations in many of the existing researches. The machining process on a CNC lathe has been pre-programmed. Although $R_a$ prediction systems were designed using a variety of sensors including dynamometers for force and torque. Taguchi and analysis of variance (ANOVA) table have been employed to determine the percentage contribution of each parameter on $R_a$. Tzeng et al [1] have used grey relational analysis (GRA) for optimizing the process parameters in turning process of tool steels. They have performed the trials based on Taguchi techniques design of experiments (DOE) and the optimum machining parameters have been determined and validated using GRA in order to minimize the $R_a$ obtained. Sahoo et al [2] have also used GRA to optimize the parameters of turning process in AA 1040 steel and determined the output parameters such as materials removal rate (MRR) and $R_a$ and have concluded that speed of the cutting tool plays a significant role in affecting the responses. Tosun [3] have done trials on drilling process in minimizing the $R_a$ by varying the parameters and Chang et al [4] have investigated cutting parameters in side milling operations and have found the best parameters by varying it using optimization techniques. Datta et al [5] investigated optimization of bead geometry in submerged arc welding process. Chakradhar et al [6] have done experiments in electrochemical machining (ECM) of EN31 steel and have optimized the input parameters of ECM using GRA. Jeykrishnan et al [7-10] have done several experiments on electro-discharge machining (EDM) and ECM to optimize the parameters on different materials using Taguchi techniques to find to best responses such as MRR, $R_a$, tool wear rate (TWR) etc. Ramnath et al [13-15] have done experiments on drilling and Electro-chemical Machining (ECM) using the materials such as fibre hybrid composites, SKD-12 tool steels and have optimized the process variables using Taguchi and Grey-Relational Analysis. From the literature review, very less works have been done on turning operations to optimize the process parameters in Inconel 625 alloy. This research work deals with optimizing the input parameters such as speed, feed and depth of cut (DoC) in minimizing the $R_a$.

## 2. EXPERIMENTAL PROCEDURE

The experimental trials have been performed on lathe machine "Georg Fisher NDM-16". The workpiece selected were Inconel 625 alloy with 100 mm in diameter and 200 mm in length. Chemical composition and mechanical properties of Inconel 625 alloy have been given in table 1 and 2 respectively. Surface roughness measurements were performed with Surftest Mitutoyo SJ-201P. The surface roughness measured in the paper is the arithmetic mean deviation of surface roughness of profile $R_a$ [11-12].

**Table 1** Chemical composition of Inconel 625 alloy in %

| Ni | Cr | Fe | Mo | C | Mn | Si |
|---|---|---|---|---|---|---|
| 60 | 22 | 5 | 9 | 0.1 | 0.5 | 0.5 |

**Table 2** Mechanical properties of Inconel 625 alloy

| Material | Tensile Strength (MPa) | Yield Strength (MPa) | % of Elongation | Hardness (BHN) |
|---|---|---|---|---|
| Inconel 625 alloy | 850 | 450 | 30-55 | 145-240 |

## 3. DESIGN OF EXPERIMENTS

The Taguchi technique uses orthogonal array (OA) to study the parameters with a limited number of experiments and the experiments have been carried out by using $L_9$ OA with three main cutting parameters, namely, cutting speed, feed rate and depth of cut and have been given in table 3 along with their values. The process parameters have to be optimized in efficient manner to obtain the optimal outputs. From the literature review, it has been understood that the speed of the spindle, feed rate of the tool and the depth of cut to the workpiece stands top to obtain the desired results.

**Table 3** Input Parameters with their values

| Parameters/Values | Value 1 | Value 2 | Value 3 |
|---|---|---|---|
| Speed (m/min) | 400 | 500 | 600 |
| Feed rate (mm/rev) | 0.10 | 0.15 | 0.20 |
| Depth of cut (mm) | 0.4 | 0.8 | 1.2 |

## 4. RESULTS & DISCUSSION

The results for the surface roughness ($R_a$) along with the S/N ratio have been given in table 4.

**Table 4** Results of the experiment

| Exp. | Input parameters | | | Responses | |
|---|---|---|---|---|---|
| No | Speed (m/min) | Feed rate (mm/rev) | Depth of cut (mm) | Surface roughness ($R_a$) (µm) | S/N ratio for $R_a$ |
| 1 | 400 | 0.10 | 0.4 | 0.88 | 1.1103 |
| 2 | 400 | 0.15 | 0.8 | 1.45 | -3.2274 |
| 3 | 400 | 0.20 | 1.2 | 2.23 | -6.9661 |
| 4 | 500 | 0.10 | 0.8 | 1.16 | -1.2892 |
| 5 | 500 | 0.15 | 1.2 | 1.27 | -2.0761 |
| 6 | 500 | 0.20 | 0.4 | 2.05 | -6.2351 |
| 7 | 600 | 0.10 | 1.2 | 1.24 | -1.8684 |
| 8 | 600 | 0.15 | 0.4 | 1.09 | -0.7485 |
| 9 | 600 | 0.20 | 0.8 | 1.86 | -5.3903 |

### 4.1. Effect of input parameters on surface roughness ($R_a$)

The signal to noise (S/N) ratio for the response $R_a$ has been shown in figure 1. The feed rate of the machining process plays an important role in obtaining the optimal response. When the speed increases, strain energy produced will be higher but the $R_a$ becomes coarse as the wobbling factor which occurs because of the speed rate worsens the surface integrity. Therefore, the best $R_a$ occurs when the speed rate is lesser. When the feed rate and depth of cut increases the surface characteristic increases as the more material gets removed because the plastic flow of the materials increases at higher feed rate and depth of cut. From the S/N ratio table which has been given in table 5, feed rate plays an important role which is followed by the depth of cut as well as the speed rate of the tool.

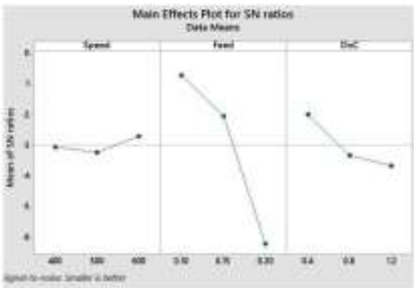

**Table 5** Response table

| Levels | Speed (m/min) | Feed rate (mm/rev) | Depth of Cut (mm) |
|---|---|---|---|
| Level 1 | -3.0277 | -0.6824 | -1.9578 |
| Level 2 | -3.2001 | -2.0173 | -3.3023 |
| Level 3 | -2.6691 | -6.1971 | -3.6369 |
| Max - Min | 0.5310 | 5.5147 | 1.6791 |
| Rank | 3 | 1 | 2 |

## 4.2. Analysis of variance (ANOVA)

The experimental results analyzed with ANOVA are shown in the Table 6. The F value calculated through MINITAB 16 software has been shown ANOVA table which suggests the significance of the factors on the desired characteristics. Larger the Fisher value (F-value) higher is the significance (considering confidence level of 95%). The results show that only feed rate is the most significant factor followed by the depth of cut as well as the speed rate of the tool. From the ANOVA table, the feed rate has the most contributing factor with 88.29% followed by depth of cut and the speed rate with 5.05% and 1.45%, respectively. The optimal parameters have been given in table 7, which has been found by Taguchi techniques to obtain the best surface roughness output parameter from figure 1. The confirmatory test has been done according to the obtained results and the $R_a$ attained has also been given in table 7.

**Table 6** ANOVA table for $R_a$

| Source | DOF | Sum of squares | Variance | F-ratio | Percent (%) |
|---|---|---|---|---|---|
| Speed (m/min) | 3 | 0.02527 | 0.01263 | 0.28 | 1.45 |
| Feed rate (mm/rev) | 3 | 1.54327 | 0.77163 | 16.91 | 88.29 |
| Depth of cut (mm) | 3 | 0.08820 | 0.04410 | 0.97 | 5.05 |
| Error | 6 | 0.09127 | 0.04563 | ----- | 5.22 |
| Total | 15 | 1.74800 | ----- | ----- | 100.00 |

**Table 7** Optimal parameters

| Parameters | | | | Optimum Value |
|---|---|---|---|---|
| Speed | Feed rate | | Depth of cut | Surface roughness ($R_a$) |
| (m/min) | (mm/rev) | | (mm) | (µm) |
| | | | | |
| 500 | 0.2 | | 1.2 | 0.85 |

# 5. CONCLUSION

It has been found that feed rate is found to be the most significant factor & its contribution to surface roughness is 88.29% that has been revealed by ANOVA table. The optimal results for surface roughness (lower is better) can be achieved when Inconel 625 alloy is machined at spindle speed as 500 m/min, feed rate as 0.2 mm/rev, depth of cut as 1.2 mm and the optimal surface roughness obtained is 0.85µm. The $R_a$ is mainly affected by feed rate, depth of cut and spindle speed. With the increase in feed rate and the depth of cut, surface roughness increases. The $R_a$ decreases first and then increases as the speed increases.

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