Experimental Research and Mathematical Modeling of Parameters Effecting on Cutting Force and Surface Roughness in CNC Turning Process

Zeqiri F1, Alkan M2, Kaya B3, Toros S2
1Mitrovica University, Department of Mechanical Engineering, 40000 Mitrovica, Kosovo
2Nigde Omer Halisdemir University, Department of Mechanical Engineering, 51240 Nigde, Turkey
3Erciyes University, Department of Mechanical Engineering, 38039, Kayseri, Turkey
fitim.zeqiri@uni-pr.edu1, malkan@ohu.edu.tr2, bulentkaya@erciyes.edu.tr3, serkantoros@ohu.edu.tr2

Abstract: In this paper, the effects of cutting parameters on cutting forces and surface roughness based on Taguchi experimental design method are determined. Taguchi L9 orthogonal array is used to investigate the effects of machining parameters. Optimal cutting conditions are determined using the signal/noise (S/N) ratio which is calculated by average surface roughness and cutting force. Using results of analysis, effects of parameters on both average surface roughness and cutting forces are calculated on Minitab 17 using ANOVA method. The material that was investigated is Inconel 625 steel for two cases with heat treatment and without heat treatment. The predicted and calculated values with measurement are very close to each other. Confirmation test of results showed that the Taguchi method was very successful in the optimization of machining parameters for maximum surface roughness and cutting forces in the CNC turning process.

Keywords: Inconel 625, Taguchi design of experiments, Surface roughness, Cutting force, vibrations and temperature.

1. Introduction

Inconel-625 is one material that has high mechanical properties, and high resistance to oxidation and corrosion. This material is widely used in the gas turbine blades, aerospace components and nuclear plants. Mostly industrial and engineering applications include gas turbine components, space vehicles, submarines, steam power plants and rockets/missiles components may be used. Cutting forces and surface roughness are two important during the machining process of Super alloys materials. Therefore, experimental measurement of the cutting forces and surface roughness became unavoidable. According this in different laboratories are made research to understand the principles of chip formation, developing cutting force models, cutting process control, tool geometry optimization, tool condition monitoring and for detection and suppression of chatter vibrations.

According the values of cutting parameters, the experiment is designed by Taguchi L9 in Minitab 17 software. The regression model of surface roughness is done with ANOVA and was presented the optimization of parameter impact, [2, 4]. Nowadays a lot of works have been done to improve the capability of machine tools. The continuing development and trends in manufacturing and operations
engineering cannot be sustained using current methods and processes. Some set up parameters or machining processes are affected on main parameters such as tool life. One way to reduce work hardening effect on tool life is to conduct end-milling operations at high speed rates. The study of criteria for evaluating the surface roughness represents, today, one of the most important problem for the production of some specific and functional characteristics. For this reason many authors consider the roughness as the fourth dimension of the design. Increasing productivity, decreasing costs, and maintaining high product quality at the same time are the main challenges manufacturing face today. The importance of monitoring and controlling the cutting force in CNC turning process has been well recognized in machine tool communities, [4]. A considerable amount of investigations has been directed for the purpose of the prediction and measurement of cutting forces. That is because the cutting forces generated during metal cutting have a direct influence on the generation of heat because the experiment is taking without unleaded, tool wear, vibration, quality of machined surface and accuracy of the work piece. This research paper presents the use of coated tool for dry turning of Inconel 625 with heat treatment and without heat treatment investigating the cutting force and surface roughness. The specimens were annealed at 1350 °C for 1 hour and were cooled in room temperature, [5]

2. Experimental work - work piece material

Round bars with Ø62mm diameter and 180mm length were used as work piece materials. The work material used for the present investigation is Inconel 625. The chemical composition of the work piece materials is given in table 1.

| Table 1: Chemical composition of the Inconel 625 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Ni              | Cr              | Mo              | Nb              | Fe              | S               | Al              |
| 58.64           | 22.34           | 9.20            | 3.57            | 4.29            | 0.002           | 0.16            |
| Co              | Cu              | C               | Mn              | P               | Ta              | Si              |
| 0.032           | 0.091           | 0.020           | 0.057           | <0.005          | 0.014           | 0.28            |

*Calculated as the difference between 100% and the sum of the measured elements.

2.1 Material and method

The experiments were conducted under dry cutting conditions on champions made all geared CNC lathe machine. The cutting tool used was CNMG 120408NN with grade coating of TiN/TiCN PVD coated. Based on the research Inconel 625 is hard processed, for turning it is decided to use the tool holder PCLNR 2525 12A product of renowned company ISCAR.

2.2 Cutting force and surface roughness measurement.

For the experiment is used Force Measurement aperture Kistler Type 5070A. The cutting force Measurement, dynamometers which were mounted on the CNC lathe. The measurement equipment for the temperature measure was used Pyrometer Cella Temp PQ 38 which is specially designed for measuring the temperature. The measures of vibration are made with equipment Kistler Type 5134B, and for surface measurement is used machine for Surface Measurement Talsurf, Taylor Hobson. In this paper we will use two basic methods of determination of cutting forces and their characteristics:

- Analytical by Taguchi method and ANOVA:
- Experimental methods: direct measurement characteristics Fx, Fy and Fz, vibration, temperature and surface roughness.
Figure 1. Diagram of experimental setup.

3. Design of the experiment

In our study paper was use Taguchi standard orthogonal array L9 with 9 DOF as the experimental design. Taguchi’s orthogonal arrays are the most suitable techniques for conducting results with a less time and cost, [1, 3]. Compatible results can be achieved with these design of experiment as compare to full factorial design. Experiments were planned using 3 levels for each input parameter as shown in table 1.

| Cutting parameters | Exp. | Speed | Feed | Depth of cutting |
|--------------------|------|-------|------|------------------|
| Speed (v)          | 1    | 50    | 0.04 | 0.4              |
|                    | 2    | 65    | 0.06 | 0.7              |
|                    | 3    | 80    | 0.08 | 1.0              |
| Feed (f)           | 1    | 0.04  | 0.04 | 0.7              |
|                    | 2    | 0.06  | 0.06 | 1.0              |
|                    | 3    | 0.08  | 0.08 | 0.4              |
| Depth of cutting (d)| 1    | 0.4   | 0.04 | 1.0              |
|                    | 2    | 0.7   | 0.06 | 0.4              |
|                    | 3    | 1.0   | 0.08 | 1.0              |

Table 2: Experimental results using L9 orthogonal array.

| Exp. | T °C | Amplitude | Fx1 | Fy1 | Fz1 | T °C | Amplitude | Fx2 | Fy2 | Fz2 |
|------|------|-----------|-----|-----|-----|------|-----------|-----|-----|-----|
| 1    | 329.05 | 0.4930 | 134.98 | 260.14 | 399.63 | 0.5988 | 150.73 | 214.81 | 298.24 |
| 2    | 361.21 | 0.3999 | 276.04 | 478.31 | 407.81 | 0.4514 | 299.12 | 490.68 | 729.58 |
| 3    | 374.29 | 0.1083 | 442.98 | 687.93 | 467.70 | 0.1354 | 512.76 | 490.68 | 729.58 |
| 4    | 333.22 | 0.3108 | 262.06 | 383.37 | 404.28 | 0.3771 | 299.74 | 266.25 | 428.25 |
| 5    | 286.44 | 0.4281 | 282.97 | 622.56 | 343.72 | 0.5137 | 325.78 | 243.12 | 660.19 |
| 6    | 299.44 | 0.4617 | 174.01 | 236.20 | 419.92 | 0.3784 | 198.21 | 273.59 | 461.24 |
| 7    | 443.66 | 0.4322 | 262.1 | 164.92 | 460.55 | 0.5321 | 308.56 | 200.24 | 515.52 |
| 8    | 333.75 | 0.5217 | 145.71 | 342.28 | 416.19 | 0.6506 | 184.84 | 269.06 | 449.12 |
| 9    | 372.71 | 0.6544 | 371.15 | 642.74 | 438.30 | 0.7695 | 425.23 | 406.66 | 682.39 |

Table 3: Experimental results for cutting force.
### Table 4: Experimental results for surface roughness.

| Exp. | T°C | Amplitude | Ra1 | Rz1 | Rt1 | T°C | Amplitude | Ra2 | Rz2 | Rt2 |
|------|-----|-----------|-----|-----|-----|-----|-----------|-----|-----|-----|
| 1    | 329.05 | 0.4930 | 0.9111 | 7.7501 | 5.1382 | 399.63 | 0.5988 | 0.9974 | 8.4336 | 5.5721 |
| 2    | 361.21 | 0.3999 | 1.5957 | 16.4656 | 7.7612 | 407.81 | 0.4514 | 1.6015 | 11.6238 | 8.4998 |
| 3    | 374.29 | 0.1083 | 1.5733 | 14.5312 | 8.7791 | 467.70 | 0.1354 | 1.6281 | 10.4363 | 8.3969 |
| 4    | 333.22 | 0.3108 | 1.1743 | 10.3691 | 6.4573 | 404.28 | 0.3771 | 1.2317 | 8.6635 | 6.8242 |
| 5    | 286.44 | 0.4617 | 2.0923 | 15.9306 | 10.3342 | 376.24 | 0.5800 | 2.2018 | 19.3488 | 10.6679 |
| 6    | 299.44 | 0.4322 | 0.8837 | 6.8065 | 5.1143 | 376.24 | 0.5800 | 2.2018 | 19.3488 | 10.6679 |
| 7    | 443.66 | 0.4322 | 0.8837 | 6.8065 | 5.1143 | 376.24 | 0.5800 | 2.2018 | 19.3488 | 10.6679 |

#### 3.1 Main effect plots of S/N ratio for output responses

S/N ratio is the Signal-to-noise ratio, measuring the variation of the observation in a run. It is generally calculated to select the optimal conditions of input parameters for getting the best output results under a particular working conditions, [2-4]. The value of S/N ratio should be always maximum to reduce the effect of noise. There are three different formulae for calculating the S/N ratio depending on the type of responses. Here, smaller-is-better methodology has been implemented for each output responses which can be calculated as below: \[ S/N_i = -10 \cdot \log \left( \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right) \]

#### 3.2 Analysis of Variance (ANOVA)

ANOVA table is generally prepared to find the significant input parameters which will mostly effect the output responses. Analysis of variance table was prepared for each output response with a significant level of \( \alpha = 0.05 \) and confidence level of 95%. The sources present in the ANOVA table having P-Value less than 0.05 had been treated as the significant parameter for the respective output response. In the table given the analysis with ANOVA, for cutting force and surface roughness without heat treatment.

### Table 5: Analysis of Variance for cutting force \( F_{x1} \).

| df | SS | MS | F  | Significance F |
|----|----|----|----|----------------|
| Regression | 5 | 90751.12 | 18150.22 | 3.23 | 0.181 |
| Residual | 3 | 16852.82 | 5617.60 | | |
| Total | 8 | 107603.95 | | | |

### Table 6: Analysis of Variance for cutting force \( F_{y1} \).

| df | SS | MS | F  | Significance F |
|----|----|----|----|----------------|
| Regression | 5 | 44988.729 | 8997.746 | 2.082 | 0.290 |
| Residual | 3 | 12964.480 | 4321.493 | | |
| Total | 8 | 57953.209 | | | |

9th International Conference on Tribology (Balkantrib’17) IOP Publishing
IOP Conf. Series: Materials Science and Engineering 295 (2018) 012011 doi:10.1088/1757-899X/295/1/012011
### Table 7: Analysis of Variance for cutting force $F_{z1}$.

| df  | SS             | MS     | F    | Significance F |
|-----|----------------|--------|------|----------------|
| Regression | 5       | 166360.228 | 33272.046 | 23.426 | 0.013 |
| Residual | 3       | 4260.898   | 1420.299  |       |      |
| Total      | 8       | 170621.126 | 21327.64 |      |      |

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | -146.115       | 0.342   | Multiple R            | 0.987 |
| Speed        | -0.920         | 0.564   | R Square              | 0.975 |
| Feed         | 5329.360       | 0.007   | Adj R Square          | 0.933 |
| Depth of cutting | 481.723 | 68.422  | 0.006 | Standard Error | 37.687 |
| Temperature  | -0.155         | 0.679   | Observations          | 9.000 |
| Amplitude    | 189.862        | 0.256   |                       |      |

### Table 8: Analysis of Variance for cutting force $R_{a1}$.

| df  | SS     | MS     | F    | Significance F |
|-----|--------|--------|------|----------------|
| Regression | 5       | 1.728  | 0.346 | 5.030 | 0.107 |
| Residual | 3       | 0.206  | 0.069 |       |      |
| Total      | 8       | 1.934  |       |      |      |

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | -0.203         | 0.836   | Multiple R            | 0.945 |
| Speed        | -0.001         | 0.911   | R Square              | 0.893 |
| Feed         | 24.979         | 5.479   | Adj R Square          | 0.716 |
| Depth of cutting | 0.185  | 0.723   | Standard Error | 0.262 |
| Temperature  | -0.001         | 0.002   | Observations          | 9     |
| Amplitude    | 1.147          | 0.311   |                       |      |

### Table 9: Analysis of Variance for cutting force $R_{z1}$.

| df  | SS     | MS     | F    | Significance F |
|-----|--------|--------|------|----------------|
| Regression | 4       | 72.336 | 18.084 | 2.495 | 0.199 |
| Residual | 4       | 28.995 | 7.249 |       |      |
| Total      | 8       | 101.331|       |      |      |

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | 9.905          | 0.322   | Multiple R            | 0.845 |
| Speed        | -0.136         | 0.152   | R Square              | 0.714 |
| Feed         | 146.165        | 0.060   | Adj R Square          | 0.428 |
| Depth of cutting | -1.224 | 0.782   | Standard Error | 2.692 |
| Temperature  | 0.097          | 0.079   | Observations          | 9     |
| Amplitude    | 9.905          | 0.332   |                       |      |

### Table 10: Analysis of Variance for cutting force $R_{t1}$.

| df  | SS     | MS     | F    | Significance F |
|-----|--------|--------|------|----------------|
| Regression | 5       | 26.181 | 5.236 | 7.341 | 0.066 |
| Residual | 3       | 2.140  | 0.713 |       |      |
| Total      | 8       | 28.321 |       |      |      |

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | 2.092          | 0.523   | Multiple R            | 0.961 |
| Speed        | 0.010          | 0.784   | R Square              | 0.924 |
| Feed         | 100.458        | 0.011   | Adj R Square          | 0.799 |
| Depth of cutting | 0.434   | 0.796   | Standard Error | 0.845 |
| Temperature  | -0.005         | 0.535   | Observations          | 9     |
| Amplitude    | 1.143          | 0.732   |                       |      |
In the table: 11-16 given the analysis with ANOVA, for cutting force and surface roughness after heat treatment (annealed).

**Table 11: Analysis of Variance for cutting force Fx2.**

| df  | SS       | MS   | F     | Significance F |
|-----|----------|------|-------|----------------|
| Regression | 5       | 69713.56 | 13942.71 | 3.220 | 0.182 |
| Residual    | 3       | 12986.47 | 4328.82  |       |       |
| Total       | 8       | 82700.04 |          |       |       |

**Coefficients**

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | -187.274       | 226.316 | Multiple R            |
| Speed        | -1.209         | 2.488   | 0.660                 | R Square            |
| Feed         | 2994.792       | 1375.271| 0.118                 | Adj R Square        |
| Depth of cutting | 250.989 | 119.450 | 0.126                 | Standard Error      |
| Temperature  | 0.514          | 0.393   | 0.450                 | Observations        |
| Amplitude    | -16.785        | 236.838 | 0.948                 |                      |

**Table 12: Analysis of Variance for cutting force Fy2.**

| df  | SS       | MS   | F     | Significance F |
|-----|----------|------|-------|----------------|
| Regression | 5       | 51805.03 | 10361 | 1.38 | 0.420 |
| Residual    | 3       | 22533.07 | 7511  |       |       |
| Total       | 8       | 57953.20 |          |       |       |

**Coefficients**

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | -24.284        | 317.850 | Multiple R            |
| Speed        | 1.108          | 3.71476 | 0.784                 | R Square            |
| Feed         | 4253.220       | 1797.85 | 0.098                 | Adj R Square        |
| Depth of cutting | -79.192 | 159.136 | 0.652                 | Standard Error      |
| Temperature  | 0.4250         | 0.6899  | 0.581                 | Observations        |
| Amplitude    | -233.652       | 297.184 | 0.489                 |                      |

**Table 13: Analysis of Variance for cutting force Fz2.**

| df  | SS       | MS   | F     | Significance F |
|-----|----------|------|-------|----------------|
| Regression | 5       | 149968.07 | 29993.62 | 15.94 | 0.022 |
| Residual    | 3       | 5643.14  | 1881.04 |       |       |
| Total       | 8       | 155611.22 |          |       |       |

**Coefficients**

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | -103.352       | 159.064 | Multiple R            |
| Speed        | 0.771          | 1.859   | 0.706                 | R Square            |
| Feed         | 520.68         | 899.717 | 0.010                 | Adj R Square        |
| Depth of cutting | 422.454 | 79.638  | 0.013                 | Standard Error      |
| Temperature  | -0.1427        | 0.345   | 0.707                 | Observations        |
| Amplitude    | 63.558         | 148.722 | 0.697                 |                      |

**Table 14: Analysis of Variance for cutting force Ra2.**

| df  | SS       | MS   | F     | Significance F |
|-----|----------|------|-------|----------------|
| Regression | 5       | 62700.04 | 12540.00 | 5.120 | 0.132 |
| Residual    | 3       | 2386.47  | 795.52  |       |       |
| Total       | 8       | 65086.51 |          |       |       |

**Coefficients**

| Coefficients | Standard Error | P-value | Regression Statistics |
|--------------|----------------|---------|-----------------------|
| Intercept    | 0.229          | 0.3156  | Multiple R            |
| Speed        | -0.001         | 0.012   | 0.919                 | R Square            |
| Feed         | 24.022         | 5.750   | 0.025                 | Adj R Square        |
| Depth of cutting | 0.295  | 0.509    | 0.603                 | Standard Error      |
| Temperature  | -0.002         | 0.002   | 0.519                 | Observations        |
| Amplitude    | 0.829          | 0.950   | 0.447                 |                      |
Table 15: Analysis of Variance for cutting force $R_z^2$. 

|            | df | SS    | MS    | F    | Significance F |
|------------|----|-------|-------|------|----------------|
| Regression | 5  | 107.674 | 21.535 | 2.877 | 0.207          |
| Residual   | 3  | 22.454 | 7.485 |      |                |
| Total      | 8  | 130.128 |       |      |                |

Table 16: Analysis of Variance for cutting force $R_t^2$. 

|            | df | SS    | MS    | F    | Significance F |
|------------|----|-------|-------|------|----------------|
| Regression | 5  | 25.665 | 5.133 | 11.084 | 0.038        |
| Residual   | 3  | 1.389 | 0.463 |      |                |
| Total      | 8  | 27.055 |       |      |                |

4. Regression analysis equations

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modelling and analysing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. Regression analysis was employed to derive the predictive equations of the cutting forces, and roundness error. The predictive equations generated for cutting force and surface roughness in Minitab 17 by ANOVA analysis.

Regression analysis equations for cutting force:

\[
F_{x1} = -187-1.21v + 2995f + 251d + 0.514t - 17a, \quad R^2 = 84\%
\]
\[
F_{y1} = -42 -0.66v + 3955f - 18d + 0.555t - 178a, \quad R^2 = 77\%
\]
\[
F_{z1} = -146 -0.92v + 5329f + 481.7d - 0.155t + 190a, \quad R^2 = 97\%
\]
\[
F_{x2} = -187-1.21v + 2995f + 251d + 0.514t - 17a, \quad R^2 = 84\%
\]
\[
F_{y2} = -42 -0.66v + 3955f - 18d + 0.555t - 178a, \quad R^2 = 77\%
\]
\[
F_{z2} = -146 -0.92v + 5329f + 481.7d - 0.155t + 190a, \quad R^2 = 97\%
\]

Regression analysis equations for surface roughness:

\[
R_{a1} = -0.203 -0.00121v + 24.98f + 0.185d - 0.00097t + 1.147a, \quad R^2 = 89\%
\]
\[
R_{t1} = -10.6 -0.116v + 145.7f - 1.99d + 0.0062t + 2.8a, \quad R^2 = 71\%
\]
\[
R_z = 2.09 + 0.0095v + 100.5f + 0.43d - 0.00532t + 1.14a, \quad R^2 = 92\%
\]
\[
R_{a2} = -0.23 -0.0013v + 24.02f + 0.295d - 0.00161t + 0.829a, \quad R^2 = 87\%
\]
\[
R_{t2} = 4.98 + 0.0359v + 91.0f - 0.05d - 0.01167t + 0.06a, \quad R^2 = 97\%
\]
\[
R_{z2} = 12.6 + 0.189v + 126.4f + 11.11d - 0.0183t - 9.92a, \quad R^2 = 82\%
\]
4.1 Normal probability plots

To check the validation or the authenticity of the above statistical model normal probability plot. There will be no inadequacy in the model and there will no unusual structure in the model. It will predict better result in future. So from the graphs as shown in figure 2 and 3, it has been cleared that our statistical model is an authenticate model.

![Figure 2. Normal Probability plots for cutting force.](image-url)
**Figure 3.** Normal Probability plots for surface roughness.

**Figure 4.** Multi objective optimization plot for cutting force.
From the analysis of the obtained values in table 3, and from the analysis of figure 4 we can see that after heat treatment (annealed) the values of cutting forces increase. But optimization of maximal cutting forces must be done with: \( v_{\text{min}}, f_{\text{max}}, d_{\text{max}} \) and with \( t_{\text{max}}, a_{\text{max}} \).

In other hand from the analysis of experimental values on table 4 and analysis of diagrams in figure 5 we cannot see big difference between values of surface roughness. But the optimization of maximal values of surface roughness must be done with: \( v_{\text{min}}, f_{\text{max}}, d_{\text{min}} \) and with \( t_{\text{min}}, a_{\text{max}} \).

Heat treatment more influence has in the cutting forces, which influence in the increase of the tool wear. While in the surface roughness make the structure adjustment so we can reach better surface roughness.

5. Conclusion

The realization of the experiment and analytical researches, as well as complete analysis of so far literature, enables us to come up with conclusions that due the complexity and the conditions under which the cutting occurs, cutting force, temperature, vibration and surface roughness defining is necessary to be presented by mathematical model, by which physical phenomenon changes and technological effects of the treated surface roughness is possible to be foreseen. From results of mathematical models for cutting forces and from their graphic shows we can conclude:

- With the increase of cutting speed, cutting forces decrease,
- With the increase of cutting feed, cutting forces increase,
- With the increase of depth of cutting, cutting force increase,
- With the increase of temperature and vibration, cutting force increase.

From the obtained results in experimental way, mathematical models and graphics interpretation we can see that with the increase of cutting speed, the roughness parameters \( R_a, R_t \) and \( R_z \) decrease. While with the increase of cutting depth also increase the roughness parameters. The temperature has a small influence in the surface roughness parameters, while the vibrations have much more influence on the surface roughness parameters.

6. References

1. Kaya B, Oysu C, Ertunc M. H, Force – torque based on-line wear estimation system for CNC milling of Inconel 718 using neural networks, Advances in engineering softw.42, 76-84, 2011.
2. Rao C. J, Nageswara Rao D, Srihari P, Influence of cutting parameters on cutting force and surface finish in turning operation, Procedia Engineering 64, 1405-1415, 2013.

3. Deep D. Vadalia, Alpesh H. Makwana, Investigation of cutting and tool wear in dry turning of Inconel 625, International Journal of advance engineering and research development, V.2, Issue 5, May 2015.

4. M. Nalbant, H Gökkaya, G. Sur, Application of taguchi method in the optimization of cutting parameters for surface roughness in turning, Materials and Design 28,1379-1385, 2008.

5. Hemant J, Jaya T, Ravindra B, Sanjay J, Avinash K, Optimization and evaluation of machining parameters for turning operation of Inconel 625, Materials Today: Proceedings 2, 2306-2313, 2015.

6. FujiaXu, YaohuiLv, Yuxin Liu, BinishiXu, Penge He, Effect of heat treatment on microstructure and mechanical properties of Inconel 625 alloy fabricated by pulsed plasma arc deposition, PhysicsProcedia 50, 48-54, 2013.

7. Venkatesan K, Ramanujam R, Saxena V, Chawdhury N, Choudhary V, Influence of cutting parameters on dry machining of Inconel 625 alloy with coated carbide insert- a statical approach, Journal of engineering and applied sciences, vol.9, no 3 , march 2014.