Optimization on end milling operating parameters for super alloy of Inconel 617 by Taguchi’s L27 orthogonal array

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Abstract: In recent days super alloys contributions were created more impact on the current industrial growth with various researches and developments. Among these super alloys in this experimental study considered on the subject of the by CNC milling machine used end milling operation parameters optimization on Inconel 617. The famous Taguchi method in the company of L27 orthogonal array is used here for the greatest results on the optimization consequences. There are the three considerations focused for the end milling operation such as rate of feed (FR), velocity of the cutting (CV) and depth of cutting (CD) with 27 combination of experiment testing. These considerations were optimizing based on the end product roughness on machined surface (ROMS) and rate of the material removal (RMR). These two responses associated parameters were separately and mutually optimized and corresponding consequences were evidently point out with a variety of plots and response diagrams. The greatest consequences of ROMS (0.208795 microns) and RMR (8.20895 mm3/sec) obtained at the testing number of 7 and testing number of 25 respectively.

Keywords. optimization, end milling, Inconel 617, roughness on machined surface, rate of the material removal.

1. Introduction
Now the world need updated version of alloys for the recent days requirements and various application based on the various places so the super alloys give their contribution to solve these criteria. Here most hard Inconel alloy 617 considered for the investigation. Anish Nair et al [1], give the full details about the chemical compositions and basic properties and application of the Inconel 617 super alloys. They also optimized the parameters of the machining by abrasive particles used water jet in the production process.[2] Lohithaksha M Maiyaret al, focused on the end milling operation conditions with some factors and response mainly verities of roughness on surface such as mathematics mean roughness, RMS mean roughness and etc,. They also provide the clear view on the parametric optimization on milling operation.
Yusuf Fedai [3], et al completely explained about the process parameters of face milling through the technique of Taguchi with verities of the desired responses. The essential possessions on method of optimization for diverse composites of reinforcement like reinforcement of aluminium with various materials like ZnC [4], SiC [5] and some nano particles [6] for the matching were provide the method of the optimization technique with the help of Taguchi orthogonal arrays. There are number of machining parameters of end milling [2], face milling [3], electrochemical machining [7], Laser welding [8], diffusion bonding welding [9] and materials turning [10]. In these all machining have the different parameters optimization with respect to the different desired responses based on the corresponding operations. In this investigation mainly focused on milling especially end milling constraint participation based on the two reactions in machining.

Yung-Kuang Yang et al. [11] mentioned that the industries were mostly give preference for the end milling process when compared to different machining technique for the metal removal processes. Particularly face milling is the easy way to complete this cutting work on the materials. Choudhury et al. [12] and Babur Ozcelik et al. [13] mentioned the various applications of super alloys based on nickel. These super alloys can be used in maximum heat applicable places like the nuclear and thermal plants, vehicles of aerospace, parts of submarines and etc., Mohammadreza Shabgard et al. [14] focused about the Inconel 617 machining in wire electrical discharge machining based integrity on surface. The micro hardness of the specimens get reduced with the increase of the gap of the top surface. Duration pulse increase directly proportional to the micro hardness of the subsurface and inversely proportional to the surface hardness. Rahul et al. [15] also investigate about the supper alloy Inconel 718 machining in EDM with basic mechanical properties. They have taken the voltage, current, pulse on time, duty factor, flushing pressure are the parameters for the responses of metal removal rate, electrode wear rate, surface crack density, surface roughness.

Rahman et al. [16] mentioned the important problem of the super alloys such as the life of the tool used for machining and high cutting force lead to the metallurgical damage. These can be solved by the special tools which is greater hardness than work piece can be used. Optimum cutting force usage on the work piece leads to avoid the metallurgical problems. Skrabalak et al. [17] explained about the end milling process parameters optimization on the super alloy of Inconel 617. This Inconel 617 specimen was hardened for avoiding the corrosion on the surface.

Skrabalak et al. [18] clearly explained that the Dry milling process leads to enhanced performance properties, structure of the machine tool can be easy to understand, reduced expenses of the electric medium and eco-friendly machining. These all are produced the production rate in the economic way.

Leao F.N et al. [19] reviewed about the various dielectric fluids in the EDM machining process. They recommended that the various organic and chemical dielectric fluids can be replaced by the water in the pure form or minimum concentration solutions of water. Aspinwall DK et al. [20], investigate about the surface roughness comparison on alloy and super alloy-based machining in the WEDM process [21]. They focused the integrity damage reduction on the work pieces by using the numerous roughing and repeated finishing methods [22-32].

In this investigation focused about the CNC milling machine-based parameter (like feed rate, cutting velocity, cutting depth) optimization with respect to the two outputs like roughness on machined surface (ROMS) and rate of the material removal (RMR). L27 orthogonal array-based Taguchi method is used for the optimization with the help of the Minitab 2017 software.

2. Experimental procedure

For this investigation on end milling operation is carried with the machine of CNC milling mentioned in figure 1 with the following specifications like twenty-kilowatt capacity of motor, ten thousand revolutions per minute of maximum spindle speed with ten meter per minute of maximum feed rate. The part programming for these operations was created. Similarly, the specification of the work pieces were considers as 250 mm of length, 40 mm of the breadth and 9 mm thickness specimens of the super
alloy of Inconel 617. The Sandvik created Tungsten carbide tool have diameter of ten millimetres with four flutes was chosen as the working toll for this CNC milling operation.

| Testing Number | FR – Feed rate mm / teeth | CV – Cutting velocity m/ min | CD – Cutting depth mm |
|----------------|---------------------------|----------------------------|----------------------|
| TN 1           | 0.075                     | 30                         | 0.25                 |
| TN 2           | 0.075                     | 30                         | 0.5                  |
| TN 3           | 0.075                     | 30                         | 0.75                 |
| TN 4           | 0.075                     | 60                         | 0.25                 |
| TN 5           | 0.075                     | 60                         | 0.5                  |
| TN 6           | 0.075                     | 60                         | 0.75                 |
| TN 7           | 0.075                     | 90                         | 0.25                 |
| TN 8           | 0.075                     | 90                         | 0.5                  |
| TN 9           | 0.075                     | 90                         | 0.75                 |
| TN 10          | 0.1                       | 30                         | 0.25                 |
| TN 11          | 0.1                       | 30                         | 0.5                  |
| TN 12          | 0.1                       | 30                         | 0.75                 |
| TN 13          | 0.1                       | 60                         | 0.25                 |
| TN 14          | 0.1                       | 60                         | 0.5                  |
| TN 15          | 0.1                       | 60                         | 0.75                 |
| TN 16          | 0.1                       | 90                         | 0.25                 |
| TN 17          | 0.1                       | 90                         | 0.5                  |
| TN 18          | 0.1                       | 90                         | 0.75                 |
| TN 19          | 0.125                     | 30                         | 0.25                 |
| TN 20          | 0.125                     | 30                         | 0.5                  |
| TN 21          | 0.125                     | 30                         | 0.75                 |
| TN 22          | 0.125                     | 60                         | 0.25                 |
| TN 23          | 0.125                     | 60                         | 0.5                  |
| TN 24          | 0.125                     | 60                         | 0.75                 |
| TN 25          | 0.125                     | 90                         | 0.25                 |
| TN 26          | 0.125                     | 90                         | 0.5                  |
| TN 27          | 0.125                     | 90                         | 0.75                 |

The most favourable and reliable tool of optimization such as Taguchi technique with the orthogonal array of L27 is created and mentioned in the table 1. The considered three participation considerations were feed rate with the variation of 0.075 mm/ teeth, 0.100 mm/ teeth and 0.125 mm/teeth, cutting velocity with the ranges of 30 m/min, 60 m/min and 90 m/min similarly the cutting depth with the variation of 0.25 mm, 0.50 mm and 0.75 mm.
There are twenty seven combinations of the operating conditions as per the table 1 in end milling operation were created in the same machine, same tool with different specimens through same dimensions for the two major responses such as roughness on the machined surface (ROMS) and the Rate of material removal (RMR). These two parameters were also measured with sensors and the surface testing machine with high accuracy of 0.00001 microns similarly RMR have the accuracy of 0.00001 mm³/Sec. Then the experiments were conducted as per the table 1 and the corresponding results were noted for the optimization of the inputs.

3. Results and discussion

| Testing Number | ROMS micron | RMR mm³/Sec |
|----------------|-------------|-------------|
| TN 1           | 0.224815    | 4.61915     |
| TN 2           | 0.237315    | 4.5874      |
| TN 3           | 0.249815    | 4.55565     |
| TN 4           | 0.216805    | 6.26405     |
| TN 5           | 0.229305    | 6.2323      |
| TN 6           | 0.241805    | 6.20055     |
| TN 7           | 0.208795    | 7.90895     |
| TN 8           | 0.221295    | 7.8772      |
| TN 9           | 0.233795    | 7.84545     |
| TN 10          | 0.25399     | 4.76915     |
| TN 11          | 0.26649     | 4.7374      |
| TN 12          | 0.27899     | 4.70565     |
| TN 13          | 0.24598     | 6.41405     |
| TN 14          | 0.25848     | 6.3823      |
3.1 Roughness on machined surface (ROMS)
The twenty seven operation conditions based experimental outcomes were tabulated in table 2. The leading consequence drawing for SN fraction founded on ROMS is clearly shown in figure 2 with the condition of minimum ROMS is favourable. For the ROMS with the less significant is preferable condition provided the feed rate is 0.075 mm / teeth, the cutting velocity of 90 m/ min and the cutting depth of 0.25 mm to achieve the greater response such as 0.208795 microns of ROMS which is obtained in the testing number of 7.

| TN 15 | 0.27098 | 6.35055 |
| TN 16 | 0.23797 | 8.05895 |
| TN 17 | 0.25047 | 8.0272 |
| TN 18 | 0.26297 | 7.99545 |
| TN 19 | 0.283165 | 4.91915 |
| TN 20 | 0.295665 | 4.8874 |
| TN 21 | 0.308165 | 4.85565 |
| TN 22 | 0.275155 | 6.56405 |
| TN 23 | 0.287655 | 6.5323 |
| TN 24 | 0.300155 | 6.50055 |
| TN 25 | 0.267145 | 8.20895 |
| TN 26 | 0.279645 | 8.1772 |
| TN 27 | 0.292145 | 8.14545 |

**Figure 2.** Leading consequence drawing for SN fraction founded on Roughness on machined surface (FR – Feed rate (mm / teeth), CV – Cutting velocity (m/ min), CD – Cutting depth (mm))
Figure 3. Relations comparison based on Roughness on machined surface (FR – Feed rate (mm / teeth), CV – Cutting velocity (m/ min), CD – Cutting depth (mm))

The ROMS based comparison of result plot is mentioned in the figure 3. The comparison of the all the parameters verses each other category were clearly plotted in the same figure 3. There is FR versus CV and CD interactions, CV versus FR and CD interactions similarly CD versus CV and FR interactions was clearly plotted as six graphs in a single image for the clear comparison on the parameters. In Figure 4 with variations on the responses based on the experimental results on ROMS plotted as contour plot with the clear mention with regions with colours with identically.

ROMS Regression Equation =0.1226 + 1.077 FR - 0.000246 CV + 0.04615 CD

(1)
Figure 4. Experimental results of Roughness on machined surface based Contour plot (FR – Feed rate (mm / teeth), CV – Cutting velocity (m/ min), CD – Cutting depth (mm))

3.2 Rate of the material removal (RMR)
From the figure 5 obviously expressed the leading consequence drawing for SN fraction founded on RMR in the condition of maximum RMR is preferring condition. For the RMR with the higher significant have a preference circumstance afford the feed rate is 0.125 mm / teeth, the cutting velocity of 90 m/ min and the cutting depth of 0.25 mm to achieve the greater response at the testing number of 25 such as 8.20895 mm3/Sec of RMR which is achieved. Similarly the lower RMR have the circumstance afford the feed rate is 0.075 mm / teeth, the cutting velocity of 30 m/ min and the cutting depth of 0.75 mm.
**Figure 5.** Leading consequence drawing for SN fraction founded on Rate of the material removal (FR – Feed rate (mm / teeth), CV – Cutting velocity (m/ min), CD – Cutting depth (mm))

**Figure 6.** Relational association based on Rate of the material removal (FR – Feed rate (mm / teeth), CV – Cutting velocity (m/ min), CD – Cutting depth (mm))

The evaluation of RMR result plot is clearly point out in the figure 6 with association of the all the parameters verse every one category. There is FR versus CV and FR versus CD interactions, CV versus FR and CV versus CD interactions similarly CD versus CV and CD versus FR interactions was visibly design as six graphs in a solo image in favour of the understandable judgment on the parameters. The responses differences based on the investigational consequences on RMR mentioned
with the help of contour plot by means of the clear point out among area by means of colours in figure 7.

RMR Regression Equation = 2.610 + 6.126 FR + 0.05598 CV - 0.1297 CD

\[ \text{RMR} = 2.610 + 6.126 \text{FR} + 0.05598 \text{CV} - 0.1297 \text{CD} \]  \hspace{1cm} (2)

**Figure 7.** Experimental results of Rate of the material removal based Contour plot (FR – Feed rate (mm/teeth), CV – Cutting velocity (m/min), CD – Cutting depth (mm))

### 3.3 Roughness on machined surface (ROMS) and rate of the material removal (RMR)

By means of the figure 8 observably articulated the leading consequence diagram for SN fraction based on the both responses of ROMS and RMR with the provision of nominal have a preference circumstance. For the superior significant of the ROMS and RMR afford at the feed rate is 0.125 mm/teeth, the cutting velocity of 30 m/min and the cutting depth of 0.75 mm to accomplish the superior response at 21st testing number of such as 0.308165microns of ROMS and 4.85565mm³/Sec of RMR were accomplished. The figure 9 also expressed the relational association based on the both responses ROMS and RMR interactions with all the parameters with each other.
**Figure 8.** Leading consequence drawing for SN fraction founded with Roughness on machined surface and rate of the material removal (FR – Feed rate (mm / teeth), CV – Cutting velocity (m/ min), CD – Cutting depth (mm))

**Table 3.** Ranking comparison table for SN relation

| Level | FR – Feed rate (mm / teeth) | CV – Cutting velocity (m/ min) | CD – Cutting depth (mm) | FR – Feed rate (mm / teeth) | CV – Cutting velocity (m/ min) | CD – Cutting depth (mm) | FR – Feed rate (mm / teeth) | CV – Cutting velocity (m/ min) | CD – Cutting depth (mm) |
|-------|-----------------------------|--------------------------------|------------------------|-----------------------------|--------------------------------|------------------------|-----------------------------|--------------------------------|------------------------|
| 1     | 13.50                       | 12.22                          | 12.92                  | 15.86                       | 13.69                          | 16.12                  | -11.361                     | -9.493                          | -11.190                 |
| 2     | 12.46                       | 12.49                          | 12.49                  | 16.08                       | 16.28                          | 16.08                  | -10.917                     | -11.051                          | -10.932                 |
| 3     | 11.53                       | 12.77                          | 12.07                  | 16.29                       | 18.27                          | 16.03                  | -10.527                     | -12.261                          | -10.683                 |
| Delta | 1.97                        | 0.54                           | 0.85                   | 0.43                        | 4.58                           | 0.09                   | 0.833                       | 2.768                            | 0.507                  |
| Rank  | 1                           | 3                              | 2                      | 2                           | 1                              | 3                      | 2                           | 1                              | 3                      |
The responses based ranking comparison table is clearly tabulated in the table 3 with the responses of individual and combinations of both with three different conditions. For ROMS based operation have the first rank for the feed rate and last rank for cutting velocity but the RMR and combination of the both responses have the same first rank and last ranks as cutting velocity and cutting depth respectively also the second preference is given to the feed rate.

4. Conclusion
In this experimental study of optimization on end milling operating parameters for super alloy of Inconel 617 by Taguchi’s L27 orthogonal array produced the followings as the conclusions.
- In favour of only ROMS based optimized parameters were the feed rate is 0.075 mm / teeth, the cutting velocity of 90 m/ min and the cutting depth of 0.25 mm.
- Testing number of 7 have the greatest results of ROMS reached as 0.208795 microns.
- For only RMR based optimized parameters were feed rate is 0.125 mm / teeth, the cutting velocity of 90 m/ min and the cutting depth of 0.25 mm.
- Testing number of 25 has the greatest results of RMR have 8.20895mm3/sec.
- For both responses of ROMS and RMR based optimized parameters were feed rate is 0.125 mm / teeth, the cutting velocity of 30 m/ min and the cutting depth of 0.75 mm.
- Testing number of 21st have the results of ROMS of 0.308165 microns and RMR of 4.85565 mm3/sec under nominal is best condition.
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