Optimization of Process Parameters on CNC milling machine for Mild steel IS 2062:2011 E250 Gr. A with AlTiN coated tool insert in wet condition

Miss. Sumaiyya S.Nadafa, Prof. Mrs. Minakshi Y.Shinde

Abstract. Nowadays manufacturing industries want to increase the quality of product and reduce manufacturing cost. The aim of this project work is to reduction of energy consumption during the machining phase, reduce surface roughness and increase material removal rate by optimization of face milling process parameters of mild steel IS 2062:2011 E250 Gr. A with Taguchi orthogonal array. 27 experimental runs based on L27 orthogonal array of Taguchi method were performed. Spindle speed, feed rate and depth of cut this process parameters are optimized with multiple performance characteristics such as surface roughness (Ra), Material removal rate (MRR) and power consumption. The machining operation performed on VMC by using coolant with 63 mm cutter diameter. The analysis of variance (ANOVA) is also applied to identify the most significant factor using Minitab software. The analysis can be done on AlTiN insert coating. At the last conformation test were performed.

Keywords: CNC face milling, ANOVA, Surface roughness, MRR, Power consumption, Mild steel IS 2062:2011 E250 Gr. A.

1. Introduction

Optimizing the process parameters has become a priority in manufacturing area. Milling process is widely used for machining variety of shapes by feeding the workpiece against the rotating multiple tooth cutter. G.Tamil Kumaran et.al [01] studied the optimal face milling parameter of EN 19/EN31 steel material with PVD and CVD coated tools on Fanuc series vertical CNC milling ANOVA technique used. Total of 27 experiments conducted at 3 levels for input variables cutting speed, feed rate and depth of cut. They found that for high depth of cut with increasing in cutting speed MRR increases.by machining PVD insert better surface finish was produced. Balinder Singh et al (2014) [02] used Taguchi method for optimization of process input parameter on CNC vertical milling machine with EN24 steel as workpiece material and carbide end mill as cutting tool.L27 orthogonal array with control parameters as cutting speed, Feed rate and depth of cut that the response parameters are surface roughness and material removal rate. Output analyze by Minitab software and S/N ratio obtained by Taguchi methodology. For surface roughness smaller-the-better type S/N ratio was applied and for material removal rate (MRR) larger-the-better type S/N ratio was applied. Avinash A. Thakre et al (2013) [03] work includes effects of various milling parameters with 3 levels of cutting parameters. For face milling operation experiments were conducted using Taguchi technique L9 orthogonal array on 1040 MS material on CNC vertical milling machine using carbide inserts. By experimentation results found that surface roughness parameter was mainly controlled by coolant flow it is approximately 60%.better surface finish is obtained contribution with optimal coolant flow rate .The second most important contribution was spindle speed (=22%). Ritesh Kumar Singh et al (2018) [04] Experiments carried out on face milling operation n Mild steel E250 (IS 2062:2011) material with 3 levels
of input parameters with output parameters are material removal rate and surface roughness used to formulate combined objective function (COF) and Genetic algorithm (GA) used to optimize face milling parameter of L18 array. Cemented carbide milling cutter of 50 mm diameter with 5 numbers of cutting edges. Milon D Selvam et al (2012) [05] Use of Taguchi technique and genetic Algorithm (GA) for minimizing mild steel material with three zinc coated carbide tools inserted into face miller of 25 mm diameter.it is found that The surface roughness by Taguchi technique is 0.975 µm with 4.308% error form the predicted value and from genetic algorithm is 0.88 µm with 4.625% error from predicted value.

2. Material

This work is on Mild steel IS 2062:2011 E 250 Gr. A is one of the most commonly used construction materials. The Material is very strong and can be made from readily available natural materials. It has as a high resistance to breakage and is especially desirable for construction due to its good weldability and machinability. Dimension 40 x 38 x 21 mm was used for machining using face milling process. There are many applications of IS 2062 mild steel material.it is used in manufacturing of gears, forgings, fasteners, bearings, keyways, pinons etc.

Table 1. Composition of material.

| Elements | (C) | (Mn) | (Si) | (S)  | (P)  |
|----------|----|------|------|------|------|
| Measured Values (%) | 0.23 | 0.55 | 0.18 | 0.034 | 0.042 |

3. Methodology

The Taguchi philosophy provides two tenets one is reduction in variation (improved quality) of a product or process represent a lower loss to society and second is proper development strategy can intentionally reduce variation.

In this work “Smaller-the-better” performance characteristics used for Surface roughness and power consumption. “Higher-the-better” performance characteristic used for Material removal rate.

The equations for calculating signal to noise ratio are as follows;
For smaller-the-better performance characteristics than;

\[
S_N = -10 \times \log\left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{Y_i^2}\right] - \text{(Eq. 1)}
\]

For higher-the-better performance characteristics than;

\[
S_N = -10 \times \log\left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{Y_i}\right] - \text{(Eq. 2)}
\]

4. Experimental setup

This work is on Mild steel IS 2062:2011 E 250 Gr. A (40 x 38 x 21 mm) material using face milling process. This work is carried out on VMC machine named as HURCO VM20i with cutter of 63 mm diameter with insert having coating of AlTiN. In this work three machining parameters such as spindle speed, feed rate and depth of cut and three performance parameters such as Surface roughness (Ra), Material removal rate (MRR) and Power consumption are used for further experiments. The photograph of experimental setup used for the experimental runs is shown in the Figure 1.
The experiment was carried out in wet condition by using HICUT BIO 150 coolant. Experimentation is based on Taguchi design of experiment L27 orthogonal array is considered for experimentation.

| Process parameter       | Level 1 | Level 2 | Level 3 |
|-------------------------|---------|---------|---------|
| Spindle speed (rpm)     | 1000    | 1400    | 1800    |
| Feed (mm/min)           | 600     | 800     | 1000    |
| Depth of cut (mm)       | 0.2     | 0.3     | 0.4     |

5. Result and discussion

All 27 experiments run for AlTiN coated insert. The surface roughness was measured by Mitutoyo SJ210 surface roughness tester. The material removal rate of the workpiece is measured by ratio of the difference between weight of the workpiece before machining and weight of the workpiece after machining to the machining time that is achieved. In this power consumption AC three phase is measure by taking reading with non-contact type of clamp by holding cable between the clamps.

5.1. Surface roughness

| Expt.No | Level 1 | Level 2 | Level 3 | Surface Roughness (μm) | (S/N) ratio |
|---------|---------|---------|---------|------------------------|-------------|
| 1-1     | 1000    | 600     | 0.2     | 0.1301                 | 17.71445    |
| 2-1     | 1000    | 600     | 0.3     | 0.1402                 | 17.06504    |
| 3-1     | 1000    | 600     | 0.4     | 0.1612                 | 15.8527     |
| 4-1     | 1000    | 600     | 0.2     | 0.1905                 | 14.4021     |
| 5-1     | 1000    | 600     | 0.3     | 0.2295                 | 12.78435    |
| 6-1     | 1000    | 600     | 0.4     | 0.2413                 | 12.34885    |
| 7-1     | 1000    | 600     | 0.2     | 0.2725                 | 11.29267    |
ANOVA for Surface Roughness-

Effect of process parameters on surface roughness for smaller-the-better performance characteristics at various levels is shown in Figure 2.

![Main effect plot for S/N ratio of surface roughness (μm)](image)

**Fig. 2.** Main effect plot for S/N ratio of surface roughness (μm)

Figure 2 indicates surface roughness is directly proportional to feed rate and depth of cut. It shows that increase in feed rate and depth of cut there is increase in surface roughness. As spindle speed increases surface roughness decreases and then increases.

The ranking of process parameters is enumerated in Table 4 for obtaining the minimum surface roughness the parameters should be set as level 2 of speed, level 1 of feed rate, level 1 of depth of cut.
Table 4. Response table for S/N ratio of Surface roughness (µm)

| Level | Spindle Speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) |
|-------|---------------------|--------------------|------------------|
| 1     | 13.473              | 17.327             | 14.386           |
| 2     | 13.809              | 12.501             | 13.091           |
| 3     | 12.169              | 9.623              | 11.975           |
| Delta | 1.641               | 7.705              | 2.411            |
| Rank  | 3                   | 1                  | 2                |

The ranks indicate the relative importance of each factor to the response. The ranks and the delta values (Table 4) for various input parameters for surface roughness (Ra) shows that feed rate and depth of cut has the greatest effect on surface roughness (Ra) and least effect of spindle speed was seen.

Table 5. Analysis of variance for means of surface roughness (µm)

| Source                  | DF | Adj SS  | Adj MS  | F-Value | P-Value | % Contribution |
|-------------------------|----|---------|---------|---------|---------|----------------|
| Spindle Speed (rpm)     | 2  | 0.008987| 0.004493| 21.07   | 0.000   | 4.580          |
| Feed rate (mm/min)      | 2  | 0.167787| 0.083893| 393.41  | 0.000   | 85.517         |
| Depth of cut (mm)       | 2  | 0.015162| 0.007581| 35.55   | 0.000   | 7.727          |
| Error                   | 20 | 0.004265| 0.000213|         |         | 2.173          |
| Total                   | 26 | 0.196201|         |         |         | 100            |

It is observed that increase in feed rate and depth of cut, it produces a rough surface. Feed rate contributes 85.51% the largest as compared to the other process parameters, followed by depth of cut with 7.72%, spindle speed with 4.58%. All speed, feed rate and depth of cut are the significant parameters.

5.2. For Material removal rate

Table 6. Experimentation results by using AlTiN coated insert.

| Expt.No | Level 1 | Level 2 | Level 3 | Material Removal Rate (gm/min) | (S/N) ratio |
|---------|---------|---------|---------|-------------------------------|-------------|
| 1-1     | 1000    | 600     | 0.2     | 9.9800                        | 19.98265    |
| 2-1     | 1000    | 600     | 0.3     | 11.9760                       | 21.56627    |
| 3-1     | 1000    | 600     | 0.4     | 14.0894                       | 22.97789    |
| 4-1     | 1000    | 600     | 0.2     | 14.9700                       | 23.50447    |
| 5-1     | 1000    | 600     | 0.3     | 21.6434                       | 26.70653    |
| 6-1     | 1000    | 600     | 0.4     | 27.8512                       | 28.8969     |
| 7-1     | 1000    | 600     | 0.2     | 17.1086                       | 24.66431    |
| 8-1     | 1000    | 600     | 0.3     | 24.6083                       | 27.82164    |
| 9-1     | 1000    | 600     | 0.4     | 31.9361                       | 30.08565    |
| 10-1    | 1400    | 800     | 0.2     | 11.9760                       | 21.56627    |
| 11-1    | 1400    | 800     | 0.3     | 14.9700                       | 23.50447    |
| 12-1    | 1400    | 800     | 0.4     | 15.9680                       | 24.06505    |
| 13-1    | 1400    | 800     | 0.2     | 17.1086                       | 24.66431    |
| 14-1    | 1400    | 800     | 0.3     | 24.9501                       | 27.94145    |
| 15-1    | 1400    | 800     | 0.4     | 32.3677                       | 30.20224    |
ANOVA for Material removal rate -

Effect of process parameters on material removal rate for larger-the-better performance characteristics at various levels is shown in Figure 3

![Main Effect Plot for S/N ratio of Material removal rate (gm/min)](image)

**Fig. 3.** Main effect plot for S/N ratio of Material removal rate (gm/min)

Above Figure 3 indicates that the level 3 of feed rate gives the maximum material removal rate. Figure 3 show that material removal rate is directly proportional to the speed, feed rate and depth of cut. As these process parameters increases MRR is increases. At level 1 of each process parameter shows minimum MRR that is MRR decreases with low speed, low feed rate and low depth of cut.

For obtaining the maximum material removal rate the parameters should be set as level 3 of speed, feed rate and depth of cut.

| Table 7. Response table for S/N ratio of Material removal rate (gm/min) |
|-----------------|-----------------|-----------------|-----------------|
| Level           | Spindle Speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) |
| 1   | 25.13 | 22.86 | 24.05 |
| 2   | 26.51 | 27.63 | 26.79 |


The ranks indicate the relative importance of each factor to the response. The ranks and delta values indicate that Depth of cut has greatest effect on Material Removal Rate and is followed by Feed rate and Spindle Speed in that order.

**Table 8. Analysis of variance for means of Material removal rate (gm/min)**

| Source                  | DF | Adj SS  | Adj MS  | F-Value | P-Value | % Contribution |
|-------------------------|----|---------|---------|---------|---------|----------------|
| Spindle Speed (rpm)     | 2  | 218.2   | 109.082 | 12.18   | 0.000   | 10.10          |
| Feed rate (mm/min)      | 2  | 1083.1  | 541.558 | 60.49   | 0.000   | 50.138         |
| Depth of cut (mm)       | 2  | 679.8   | 339.906 | 37.96   | 0.000   | 31.469         |
| Error                   | 20 | 179.1   | 8.953   |         |         | 8.290          |
| Total                   | 26 | 2160.2  |         |         |         | 100            |

The MRR is increases with increases in feed rate, so that the contribution of feed rate is largest with 50.13 % as shown in Table 8. The contribution of depth of cut is 31.46 % and spindle speed is 10.10 %. The spindle speed, Feed rate and depth of cut has contribution for MRR and it is significant parameter.

**5.3. Power consumption**

**Table 9. Experimentation results by using AlTiN coated insert**

| Expt.No | Level 1 | Level 2 | Level 3 | Power consumption (KW) | (S/N) ratio |
|---------|---------|---------|---------|-------------------------|-------------|
| 1-1     | 1000    | 600     | 0.2     | 1.9031                  | -5.58933    |
| 2-1     | 1000    | 600     | 0.3     | 1.9769                  | -5.92002    |
| 3-1     | 1000    | 600     | 0.4     | 2.5507                  | -8.13336    |
| 4-1     | 1000    | 600     | 0.2     | 1.9315                  | -5.71801    |
| 5-1     | 1000    | 600     | 0.3     | 2.3860                  | -7.55342    |
| 6-1     | 1000    | 600     | 0.4     | 2.6132                  | -8.34359    |
| 7-1     | 1000    | 600     | 0.2     | 2.0849                  | -6.38176    |
| 8-1     | 1000    | 600     | 0.3     | 2.5223                  | -8.03609    |
| 9-1     | 1000    | 600     | 0.4     | 2.6643                  | -8.51189    |
| 10-1    | 1400    | 800     | 0.2     | 2.1000                  | -6.44439    |
| 11-1    | 1400    | 800     | 0.3     | 2.2212                  | -6.93197    |
| 12-1    | 1400    | 800     | 0.4     | 2.6586                  | -8.49335    |
| 13-1    | 1400    | 800     | 0.2     | 2.0905                  | -6.40539    |
| 14-1    | 1400    | 800     | 0.3     | 2.4200                  | -7.67663    |
| 15-1    | 1400    | 800     | 0.4     | 2.6814                  | -8.56727    |
| 16-1    | 1400    | 800     | 0.2     | 2.3121                  | -7.28032    |
| 17-1    | 1400    | 800     | 0.3     | 2.5905                  | -8.26773    |
| 18-1    | 1400    | 800     | 0.4     | 2.7382                  | -8.74938    |
| 19-1    | 1800    | 1000    | 0.2     | 2.1474                  | -6.63827    |
ANOVA for Power consumption-

Effect of process parameters on power consumption for smaller-the-better performance characteristics at various levels is shown in Figure 4

![Main effects plot for S/N ratio of power consumption (KW)](image)

Fig. 4. Main effect plot for S/N ratio of power consumption (KW)

Figure 4 indicates power consumption is directly proportional to spindle speed, feed rate and depth of cut. It shows that increase in spindle speed, feed rate and depth of cut there is increase in power consumption.

The ranking of process parameters is enumerated in Table 10. For obtaining the minimum power consumption the parameters should be set as level 1 of speed, level 1 of feed rate, level 1 of depth of cut.

| Level | Spindle Speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) |
|-------|---------------------|--------------------|-------------------|
| 1     | -7.132              | -7.210             | -6.629            |
| 2     | -7.646              | -7.607             | -7.654            |
| 3     | -8.100              | -8.061             | -8.594            |
| Delta | 0.968               | 0.851              | 1.965             |
| Rank  | 2                   | 3                  | 1                 |

The ranks indicate the relative importance of each factor to the response. The ranks and the delta values shows that depth of cut and spindle speed has the greatest effect on power consumption (KW) and least effect of feed rate.
Table 11. Analysis of variance for means of power consumption (KW)

| Source                  | DF | Adj SS   | Adj MS   | F-Value | P-Value | % Contribution |
|-------------------------|----|----------|----------|---------|---------|----------------|
| Spindle Speed (rpm)     | 2  | 0.2970   | 0.14852  | 18.92   | 0.000   | 14.891         |
| Feed rate (mm/min)      | 2  | 0.2347   | 0.117372 | 14.95   | 0.000   | 11.767         |
| Depth of cut (mm)       | 2  | 1.3056   | 0.652817 | 83.18   | 0.000   | 65.463         |
| Error                   | 20 | 0.1570   | 0.007848 |         |         |                |
| Total                   | 26 | 1.9944   |          |         |         | 100            |

It is observed that increase in spindle speed, feed rate and depth of cut, it produces maximum power consumption (KW). Depth of cut contributes 65.46 % the largest as compared to the other process parameters, followed by spindle speed with 14.89 %, feed rate with 11.76 %. All speed, feed rate and depth of cut are the significant parameters.

6. CONCLUSION

Results of surface roughness (Ra) we conclude that minimum surface roughness was obtained as 0.0857 μm and maximum as 0.3810 μm. Surface roughness is most significantly affected by feed rate, depth of cut and speed with 85.51 %, 7.72 % and 4.58 % contribution respectively.

Results of material removal rate (MRR) we conclude that maximum material removal rate is obtained as 43.0793 gm/min and minimum is 9.9800 gm/min. Material removal rate is most significantly affected by feed rate, depth of cut and speed with 50.13 %, 31.46 % and 10.10 % contribution respectively.

Results of power consumption (KW) we conclude that minimum power consumption was obtained as 1.9031 (KW) and maximum as 2.8291 (KW). Power consumption is most significantly affected by depth of cut, speed and feed rate with 65.46 %, 14.89 % and 11.76 % contribution respectively

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