Optimization of Machining Parameters in Milling Process for High Speed Machining using Taguchi Method for Best Surface Roughness

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Abstract. High-speed machining (HSM) in milling has known is one of the technologies in rapid tooling and manufacturing applications. The cutting mechanism, spindle speed and feed rate are not the same for HSM compared to traditional machining. Coated carbide cutting tools are widely used in high speed and cutting temperature situations. It is more efficient and providing a lower surface roughness in HSM. Throughout these days, the demand of standard surface roughness is very high aligned to achieve quality in product. This paper shows an optimization method of machining parameters in milling process for high speed machining of glass fibre reinforce polymer (GFRP) using coated carbide cutting tool to achieve better surface roughness. Taguchi Method are used and it is the best method to optimize a parameter, where a response variable can be determined. Standard orthogonal array of L9 (3²) was applied in this research using signal to noise (S/N) ratio response analysis from optimization process results and analysis of variance (ANOVA) to identify the most significant parameters affecting surface roughness. The common machining parameters are significantly affecting surface roughness are spindle speed and feed rate. Then, conformation tests were executed to analyse the improvement of the optimization. As result, the feed rate parameter are significant for affecting the surface roughness and 90.3 % improvement on the surface roughness performance of milling process for glass fibre reinforce polymer (GFRP).

1. Introduction
Rapid tooling and manufacturing application usually used high speed machining. However, the roughness of the machined surface that can effect to product appearance, function and reliability are highly demand for the best quality product. One of the processes that used for high speed machining is end milling that is widely used in industry because of its efficiency and versatility. Many industries ranging from large aerospace manufacturers to small tool and die shops used the application of end milling. End milling machining produces excellent results in machining glass fibre reinforced polymer and also produces good surface finish [1].

Milling of glass fibre reinforced polymer is a rather complex task owing to the heterogeneity of the material and a number of other problems, such as delamination damage and surface roughness that appear in machining process and give influence the characteristics of the cutting parameters and type
of material. Delamination factor and surface roughness are parameters that have influenced on dimensional precision and performance of mechanical pieces by milling of glass fibre reinforced polymer. The importance of surface roughness generated after machining that can be determines by reliability of the components such as fatigue life and wear resistance.

Glass Fibre reinforced plastic (GFRP) composites are widely utilized in engineering applications such as automotive, craft, and manufacture of spaceships and ocean vehicles industries. The characteristic of Glass Fibre reinforced plastic (GFRP) composites are superior corrosion resistance, light-weight weight construction, high specific strength/stiffness, low thermal conduction, high fatigue strength, resistance to chemical and microbiological attacks. Machining composite materials may be a rather advanced task because of their non-uniformity, anisotropy, and high abrasiveness of fibres, and it exhibits considerable issues in drilling method like de-lamination, fibres pull-out, hole shrinkage and thermal degradation Faraz A et al [2].

2. Literature Review
Taguchi optimisation methodology is applied to optimize cutting parameters of fibre reinforced composite material. The experimental set up is done by using CNC machining centre to show the relationship between cutting parameter and thrust force and torque [3]. An Orthogonal array and signal-to-noise (S/N) ratio are the element in Taguchi Method that is used for investigation of experiment to get the most influence of machining parameter.

GFRP has been used widely for different engineering applications because of unique characteristic. Composites have high capability and unique characteristic and commonly used as alternative material compared to conventional materials [4-5]. Bhatnagar et al. [6] focused on glass fiber reinforced polymer (GFRP) that need adjustment in machining method to achieve the dimensional accuracy and functional aspect that are required. While Davim et al. [7] discuss the influence of cutting parameters on surface roughness in turning glass-fiber reinforced plastics that are facing difficulties in machining process and need further experimental investigation to understand the behaviour of glass reinforced fibre. Santana et al. [8]. Palanikumar et al. [9] studied the cutting parameters effects on surface roughness on machining of GFRP composites by developing a second order model from polycrystalline diamond tool to predict the surface roughness. Palanikumar et al. [10] developed a procedure to optimize the chosen factors to obtain surface roughness by assist with taguchi method and analysis of variance (ANOVA) technique. For this research, an experimental measurement data and Taguchi Method was applied to predict the best machining parameter that effect surface roughness by using end milling for GFRP BAC5317 composite material.

3. Methodology
3.1 Taguchi’s orthogonal method
Taguchi orthogonal method design can be determined accurately by matrix experiments. By using this method, the frequency of simulation test can be reduced and the experimental data can be obtained [11-12]. The present variation can be showed by Signal-to-noise (S/N) response ratio in The Taguchi method. In this research, an experiment was designed with the assist of taguchi L9 orthogonal array [13]. Minitab18 is the software program used for DOE (Design of test).

In this research, spindle speed and feed rate are the machining parameters that will obtain for Taguchi Method. The orthogonal array L9 (3^2) have been arranged are shown in table 1.
Table 1. Taguchi Method L9 (3^2) orthogonal array

| A Machining Parameter | B Machining Parameter |
|-----------------------|-----------------------|
| Spindle speed, (rpm)  | Feed rate, (mm/min)   |
| 1                     | 1                     |
| 1                     | 2                     |
| 1                     | 3                     |
| 2                     | 1                     |
| 2                     | 2                     |
| 2                     | 3                     |
| 3                     | 1                     |
| 3                     | 2                     |
| 3                     | 3                     |

Table 2. The machining parameters and levels for milling process

| Machining parameters | Factors | Units | Level 1 | Level 2 | Level 3 |
|----------------------|---------|-------|---------|---------|---------|
| Spindle speed A rpm  | 7427    | 10610 | 11034   |
| Feed rate B mm/min   | 1485    | 2122  | 2759    |

Table 2 shows the machining parameter and levels for milling process with three levels by using Taguchi Method.

3.2 Experiment details
The experimental milling process were carried out on a Jobs Jomach 5 axis CNC Gantry Machine, follows the recommendation by the tool supplier for the specific work material especially for GFRP BAC5317. Router end mill coated carbide used as insert for this milling process. The portable surface roughness tester Mitutoyo 178-563-01ASJ-210 are used to measure the surface roughness for this experiment. End milling process of high speed machining experimental set up is shows in Figure 1. The material used are glass fibre reinforced polymer GFRP BAC5317. Surface roughness of edges trimmed by other methods shall not exceed 125 micro-inches Ra follow the Standard: BAC5317 – Section 11 – Requirement –Discrepancy acceptance and rework criteria.

Figure 1. Experimental setup for end milling process of high-speed machining
4. Results & Discussion

4.1 Experimental result

Table 3. Responses of surface roughness observed in the Experimentation for Taguchi Design of Milling Process

| Experiment | Machining Parameter | Responses Surface Roughness Ra (μin) |
|------------|---------------------|-------------------------------------|
|            | Spindle Speed (Rpm) | Feed rate (Mm/Min)                 |
| 1          | 7427                | 2759                                | 291.11                            |
| 2          | 10610               | 2759                                | 176.054                           |
| 3          | 7427                | 2122                                | 230.438                           |
| 4          | 10610               | 1485                                | 210.252                           |
| 5          | 11034               | 2759                                | 232.198                           |
| 6          | 11034               | 2122                                | 157.018                           |
| 7          | 10610               | 2122                                | 169.784                           |
| 8          | 11034               | 1485                                | 93.486                            |
| 9          | 7427                | 1485                                | 155.848                           |

From table 3, the machining parameter spindle speed 11034 rpm and feed rate 1485 mm/min responses the surface roughness 93.486 micro-inches Ra that meet the standard of GFRP BAC5317.

Figure 2. Surface Roughness vs No. of Experiment for Milling Process

For experimental result, figure 2 shows the surface roughness vs number of experiments for milling process. Experiment number 8 shows the surface roughness 9.3486 Ra that meets the requirement of standard GFRP BAC5317.

4.2 Analysis of Signal to noise (S/N) response

Table 4 shows the response S/N ratio for milling process and the most accurate combination parameter can be determine by selecting the parameter with the level with the highest value. From the table 4 shows that the machining parameter feed rate can improve surface roughness that are required in milling process. Then, Figure 3 shows the taguchi response graph for milling process and also shows the feed rate is the most affect surface roughness in milling process.
Table 4. Signal to noise (S/N) ratios Milling Process

| Level | Spindle Speed (rpm) | Feed rate (mm/min) |
|-------|---------------------|--------------------|
| 1     | -46.80              | -43.24             |
| 2     | -45.32              | -45.26             |
| 3     | -43.55              | -47.17             |
| Delta | 3.25                | 3.93               |
| Rank  | 2                   | 1                  |

Figure 3. Taguchi Response Graph for Milling Process

Figure 4. Interaction Plot for Surface Roughness for Milling Process

From Figure 4 shows the interaction plot for surface roughness for milling process and its indicate that the machining parameter feed rate effect the surface roughness more than spindle speed for Milling Process of GFRP BAC5317.
4.3 Confirmation test
For this research, the confirmation test has been done by using the analysis of variance (ANOVA) to determine the most significant machining parameter that effect the surface roughness in milling process to achieve GFRP BAC5317 requirement. Table 5 below shows the analysis of result of ANOVA of surface roughness for milling process.

| Source      | DF | SS   | MS   | F    | % Contribution |
|-------------|----|------|------|------|----------------|
| Spindle Speed | 2  | 6445 | 3223 | 1.28 | 24.58          |
| Feed rate   | 2  | 9692 | 4846 | 1.92 | 36.97          |
| Error       | 4  | 10080| 2520 |      |                |
| Total       | 8  | 26217|      |      |                |

From Table 5, it shows that feed rate has statistical more significance (36.97%) on the surface roughness factor compared to spindle speed factor that has moderate significance (24.58%) on surface roughness.

5. Conclusion
In this research can be conclude that the machining parameters in end milling process that give influence on surface roughness during machining of GFRP BAC5317 are feed rate and spindle speed according to S/N Ratio response table. Then, ANOVA test shows that the most significant parameter that effect the surface roughness in milling process is feed rate. Furthermore, the best surface roughness 93.486 micro-inches Ra is achieved and meets the GFRP BAC5317 requirement for milling process.

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