Fabricating Different Laminate Composites by Manual Layup and Estimating the Optimum Parameters for CNC Milling Machine

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Abstract

In this paper the ability of fabricating laminate composites by manual layup was discussed. Heating method was used to manufacture the composites; heat was applied to approximately 12 hours with specific heat temperature. There were four types of laminate composites fabricated and studied in this research, containing Aluminum alloy 6061 as the common element in all types, two types of fibers; woven Carbon fiber with two different orientations: ±45°, ±60°, random fiberglass and with two types of resin; epoxy resin and polyester resin. Different types of composites were made to determine the effect of CNC milling machine to the measured surface roughness and for specified parameters. The weight fraction ratio of the fibers is 37%, polymer is 34% and 29% of these parameters; it was analyzed by MINITAB 17 program. The results showed that the parameter were significant more to the epoxy resin specimens than polyester resin specimens. The optimal milling parameters for good surface finish for Aluminum – Carbon fiber composite are at 3000RPM, 1200mm/min, 1.2mm, and for Aluminum – Fiberglass composite are 5000RPM, 1800 mm/min, 2.0mm.

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1. Introduction

Composite material are structural materials can be divided into four basic categories: metals, polymers, ceramics, and composites. Composites, which consist of two or more separate materials combined in a structural unit, are typically made from various combinations of the other three materials. Composite materials are usually classified according to the type of reinforcement used [1]. Fiber Metal Laminates (FML) is a kind of hybrid materials and it can be fabricated from an alternating laminate of thin metal sheets and thin composite layers. Since several variables are involved in the composition of this laminate, a wide range of different combinations lamination seems to be possible. Some of these variables are the type of metal alloy, the type of fibers, the type of polymer, the thickness of layers, the number of layers, the orientation of fiber layers. Therefore, FMLs are regarded as a family of laminates, and GLARE and Carbon Fiber Reinforced Polymer (CFRP) are the best-known member of these laminates [2].

Soltani et al. [3] in this paper, the carbon fiber and epoxy had been used as the material. Methodology of this paper is an industrially accessible out-of-autoclave carbon fiber epoxy was utilized to create laminated composites and a co cure and secondary composites bonding cohesive was utilized as resin. The composites were first cured at 122°C for 1 hour and subsequently post cured for two hours at temperatures going from 122°C to 177°C. It was seen that the short beam shear strength of the cured laminated composites expanded by expanding the post-restoring temperature.

Ashok Rai et al. [4] this work deals with a random arranged fiberglass example has been set up so that the strands are in direct contact of the resin. Holes of different diameters were done (10, 12, 16mm) by CNC processing machine, Taguchi structure with L9 orthogonal array is utilized for the analyses. The four parameters taken in processing fiberglass sheet are tool radius, cutting velocity, and tool geometry instead of the spindle speed, feed rate, fiber direction (15°, 60° and 105°), and solid carbide with mill gear about 25°, 35° and 45° helix angle, to ensure a useful machinability list. The results showed that surface roughness increase with increase of fiber direction and the helix angle and the feed rate.

Tan et al. [6] the author in his research used woven carbon fibers, woven E-glass fibers, in EpoxAmite matrix and hardener resin as the materials. The direction of woven carbon (C) and glass (G) fibers were organized in the grouping of [CGCG] these fibers were stacked in the glass mold until thickness 4 mm has been accomplished and they were fixed and compacted with vacuum sack under a vacuum from 11 to 15mBar. Response surface methodology (RSM) was used in finding the exact connections between test parameters and surface roughness dependent on the Taguchi results. Three parameters had been selected with three levels; spindle speed, feed rate and tool geometry with L27 orthogonal array. The test examinations showed that surface roughness is incredibly affected by feed rate and tool geometry instead of the spindle speed. Surface roughness increase with increase of feed rate.

Hassan et al. [7] in this research, the material used in the manufacturing GLARE are woven E-glass fiber, epoxy resin and aluminum alloys sheet of 0.5 mm thickness. The GLARE composites are fabricated using hand layup technique. Mainly, the treatment of aluminum surface should be taken into consideration upon fabrication procedure because it is a dominant factor to increase de-bonding between aluminum and other component of the composite material. The proposed procedures for manufacturing the GLARE material is an effective and having good durability. Increasing the number of glass fiber composite laminates gives good strengths but increases the thickness of the whole specimen, results in weakening the specimen in form of delamination failures. Plasticity regions are affected with increasing number of glass fiber composite laminates.

Christje et al. [8] in this paper the materials used were 6.35mm Aluminum alloy 2024 and CFRP with and without polymer metal laminate (PML) thermal protection. The metal substrate was Aluminum alloy rolled plate cut into 600 mm long, 50 mm wide test specimens. The CFRP was fabricated from unidirectional carbon fiber-epoxy prepreg tape. The advantage of the PML is that, in non-fire conditions, it contributes to the appearance and load-bearing capability of the structure without being at risk to damage or water absorption.

Azghan and Eslami-Farsani [9] the aim of this paper is to examine the impacts of various stacking sequence and thermal cycling at the flexural residences of FMLs. FMLs had been made out of
two aluminum 2024 sheets and epoxy resin that have four layers of basalt as well as glass strands with 5 different stacking sequences. For FML tests the thermal process duration was around 6 min. Temperature cycles were from 25 °C to 115 °C. The discoveries showed that flexural modulus were most extreme for basalt strands principally based FML, least for glass fibers, basically based FML simultaneously as basalt/glass fibers based FML lies between them. After thermal cycling, due to the great thermal residences of basalt strands, flexural properties of basalt filaments based of FML structures decreased lesser than various composites. 

Prasanth et al. [10] the authors studied the milling of GFRP composites due to becoming basic and necessary so as to upgrade its surface quality by improving its dimensional tolerances, and limiting the surface imperfections. this work’s examinations were done to upgrade the four significant processing parameters, spindle speed, feeds and depth of cut and sort of processing device on a surface roughness R_a. Taguchi L25 orthogonal arrays was utilized for design of experiments, and investigation of variance (ANOVA) has been utilized to distinguish the commitment of each considered parameters on execution the parameter optimization, spindle speed=1950rpm, feed rate=1mm/s, depth of cut=1mm, and tool type as two-fluted brazed carbide tipped end mill. Surface roughness decreased with increase of spindle speed. R_a increased with increase of feed rate.

In this research, the optimum parameters for each type of laminate composite material for milling process had been estimated and the also effect of the parameters to the measured surface roughness have been analyzed. Manufacturing of several types of laminate composite has been studied, with different layers of carbon fiber and fiberglass which have been used with common metal as the aluminum alloy 6061, and the epoxy resin and polyester resin as the binder. Three parameters selected were; spindle speed, feed rate and depth of cut applied on nine experiments. Experiments had been carried out by make a groove by CNC milling machine onto the composite and measure the surface roughness after each experiment, then by MINITAB17 the optimum parameters were found by the S/N ratios and ANOVA tables.

2. Materials and Methodology
Materials used in this research are: Aluminum alloy 6061 with 0.1mm, as the metal in all the composites. In addition to fibers as in figure (1) (a) and (b), two types had been chosen, Random Fiberglass and also continues woven carbon fiber in ±45° orientation and ±60° orientation. And the resins, first, Epoxy (Sikadur®-52) that is two parts, solvent free, low viscosity as in figure (1) (c); Secondly, polyester resin part A and part B as in figure (1) (d).

Surface preparation is necessary for good coherency between the layers. The aluminum alloy 6061 is smooth in surface, so it had been roughened with an iron brush to get a better surface for the fabrication process as illustrated in figure (2).

Four different specimens, with 100×100mm and thickness of 2.8mm, that had been made up manually. Multiple Layers were stacked together using hand layup in the four specimens depending on the weight of the fiber used, the weight fraction ratio of the fibers is 37%, polymer is 34% and 29% for Aluminum. Stacking sequence was in certain order and different orientation angles as described in Table 2 and in Figure (3) and (4). To begin the manufacturing, first releasing agent must be applied on the glass mold to prevent the workpieces from sticking in the mold, the specimens were made by applying some of the resin on the aluminum alloy layer and then on the fiber layer till the last layer of aluminum as in figure (5), after that the specimen was placed in a glass mold and then in the oven for curing. The heating method included applying heat to the composites, then immediately specimens were placed in the oven at 52°C for 5 hrs. then followed by 74°C for 6 hrs., depending on the researcher work Patil et al. [11] and Baumert et al. [12], the epoxy resin mixing ratio was 2:1 and polyester resin was
50:1 then the specimen is left in open air for 7 days for full solidification of the resin. The four specimens are shown in figure (6).

### Table (1): Stacking sequence of the layers.

| Composite material | Fiberglass-Aluminum Seven Layers | Carbon fiber-Aluminum Nineteen Layers |
|--------------------|----------------------------------|--------------------------------------|
|                    | aluminum alloy, fiberglass,      | aluminum alloy, +45, +60, -45, -60,  |
|                    | fiberglass, aluminum alloy,      | +45, +60, -45, -60,                  |
| Stacking sequence  | fiberglass, aluminum alloy,      | Carbon fiber, aluminum alloy,        |
| from bottom to top | fiberglass, aluminum alloy,      | -60, -45, +60, +45, -60,            |
|                    | fiberglass, aluminum alloy,      | Carbon fiber, aluminum alloy,        |
|                    | from bottom to top               |                                      |

Figure (3): Stacking sequence of the layers for carbon fiber workpiece.

Figure (4): Stacking sequence of the layers for fiberglass workpiece.

Figure (5): Manual layup of composite specimen.

![Figure 6](image_url)  (a) fiberglass–aluminum with epoxy resin specimen. (b) fiberglass–aluminum with polyester resin specimen, (c) carbon fiber–aluminum with epoxy resin specimen, (d) carbon fiber–aluminum with polyester resin specimen.

### 3. Experimental design

CNC Milling Machine, A vertical CNC milling machine model ACCUWAY UM-85, were used to perform the experimental work as shown in figure (7). Uncoated Carbide end mill cutter was used with diameter 6mm; and the number of flutes is 4. Figure (8) shows the end mill cutter.

Figure (7): CNC milling machine.

### 4. Design of experiments (DOE)

The objective of using DOE is to find the optimum parameters for the milling process to get smallest surface roughness of machined surface using the smaller the better, as in the equation bellow [13].

$$\frac{S}{n} = -10 \log_n \left( \sum_{i=1}^{n} x_i^2 \right) \quad \text{smaller is better}$$

Where n is the number of observations and x is the observed data [13]. After manufacturing the specimens, experiments are curried out to select the optimum parameters for each composite workpiece. Design of Experiments (DOE) and Taguchi method had been used to minimize experiment number and also to find the optimum parameter for the surface roughness. In this study L9 orthogonal array (OA) has been used and three parameters with three levels have been selected to apply on the composites. Table (2) describes the parameters and their levels.
5. Surface roughness

The surface roughness of the nine experiments for each composite were measured by using roughness measuring device POCKET SURF shown in figure (8). Four values were measured to each groove in a certain order as illustrated in figure (9), for all the experiments and analyzed using MINITAB 17 software.

6. Results and discussion

The composites that had been manufactured from heat method and after the milling process the results showed that, the measured surface roughness for the carbon fiber (Ra_{min,CF}=1.92 μm) has a better value than the fiberglass (Ra_{min,FG}=3.1 μm) due to the nature and characteristics of each fiber. The effect of the parameters on surface roughness of the composite after the milling is that the surface roughness decrease with the increase of spindle speed as in the researchers [13] and [14]. Surface roughness increases with the increase of feed rate and depth of cut as in [4] and [10]. After the milling, the separation between the layers have been in sixteen experiments of thirty six experiments. Table (3) illustrated the contribution results for each composite type.

Table (4): Surface roughness results for FG-Al with epoxy.

| Exp. | Ra1 (μm) | Ra2 (μm) | Ra3 (μm) | Ra4 (μm) | Ra_{Av.} (μm) |
|------|----------|----------|----------|----------|---------------|
| #1   | 4.27     | 4.77     | 5.37     | 2.93     | 4.335         |
| #2   | 4.12     | 4.21     | 5.72     | 4.41     | 4.615         |
| #3   | 4.97     | 1.88     | 3.46     | 5.39     | 4.346         |
| #4   | 4.33     | 4.95     | 5       | 4.74     | 4.755         |
| #5   | 3.97     | 2.06     | 3.86     | 5.98     | 3.967         |
| #6   | 3.22     | 3.8      | 4.47     | 4.21     | 3.925         |
| #7   | 6.38     | 3.3      | 3.34     | 5.07     | 4.522         |
| #8   | 2.91     | 5.78     | 3.01     | 2.84     | 3.635         |
| #9   | 3.88     | 2.61     | 4.82     | 3.77     |               |

Table (5): The input parameters and the output Ra for FG-Al epoxy.

| Exp. | Spindle speed (r.p.m) | Feed rate (mm/min) | Depth of cut (mm) | Ra_{Av.} (μm) | Ra pred. (μm) |
|------|-----------------------|--------------------|-------------------|-------------|--------------|
| #1   | 3000                  | 800                | 1.2               | 4.33        | 4.907        |
| #2   | 3000                  | 1200               | 1.6               | 4.61        | 5.307        |

A. Fiberglass-Aluminum with epoxy resin composite

For this composite specimens the optimum parameters for the best surface roughness are A3B3C3 (A3=5000r.p.m, B3=1600mm/min, C3=2mm) that is illustrated in figure (10). The nine experiments that had been applied to the composite and the measured surface roughness, four values for each experiment, are all listed in table (4) and the input parameters with their results of Ra are illustrated in table (5). The experiments work well in the final square shape, but there are fiber burr in most of the experiments, also separation occurs only in Exp. 9, the last layer have been a fiber layer, that means two layers were separated from the base square. As seen in table (6) and (7), SN ratios and ANOVA tables, showed results of the significant factors, F-value and P-value and contribution of each parameter. Feed rate is the most significant factor by 70%, while spindle speed affects the lowest by 6%. Model summary of the process leads to that R-sq is 83%.
The nine experiments were almost at the same effect 33%, and separation occurs in Exp.3, Exp.5, and Exp.9. Also separation occurs in Exp.4 and Exp.5 no separated layer in the square. But in Exp.1 and Exp.2 only the first layer of metal has been separated. Also, separation occurs in Exp.3, Exp.5, Exp.7, and Exp.9, three layers had been separated from the square. As seen in table (10) and (11), S/N ratio and ANOVA tables showed results of the significant factors, F-value and P-value and contribution of each parameter. All the parameters were almost at the same effect 33%, the parameters are not so effective on the output value due to the R-square number, which is 55% only.

Table (6): Response table for SN ratios for FG-Al with epoxy.

| Level | A  | B  | C  |
|-------|----|----|----|
| 1     | -12.25 | -13.13 | -11.94 |
| 2     | -12.46 | -12.15 | -12.78 |
| 3     | -11.35 | -11.38 | -11.93 |

Table (7): ANOVA results for FG-Al with epoxy.

| Source | DF | Adj SS | Adj MS | F-value | P-value | Contribution |
|--------|----|--------|--------|---------|---------|--------------|
| A      | 2  | 0.08839 | 0.04429 | 0.31    | 0.763   | 6%           |
| B      | 2  | 1.0316  | 0.51555 | 3.01    | 0.217   | 70%          |
| C      | 2  | 0.33531 | 0.16785 | 1.18    | 0.453   | 23%          |
| Error  | 2  | 0.28531 | 0.14266 |         |         |              |
| Total  | 8  | 1.74088 |         |         |         |              |

B. Fiberglass–Aluminum with polyester resin composite

For this composite the optimum parameters for the best surface roughness are A3B2C1 (A3=5000 r.p.m, B2=1200 mm/min, C1=1.2 mm) that is illustrated in figure (11). The nine experiments that had been applied to the composite and the measured surface roughness, four values for each experiment, are all listed in table (8) and the input parameters with their results of Ra are illustrated in table (9). The experiments work well in the final square shape, but there are fiber burr in most of the experiments. Also separation occurs but in Exp.4 and Exp.5 no separated layer in the square. But in Exp.1 and Exp.2 only the first layer of metal has been separated. Also separation occurs in Exp.3, Exp.5, Exp.7, and Exp.9, three layers had been separated from the square. As seen in table (10) and (11), S/N ratio and ANOVA tables showed results of the significant factors, F-value and P-value and contribution of each parameter. All the parameters were almost at the same effect 33%, the parameters are not so effective on the output value due to the R-square number, which is 55% only.

Table (8): Surface roughness results for FG-Al with polyester.

| Exp. | Ra 1 (μm) | Ra 2 (μm) | Ra 3 (μm) | Ra 4 (μm) | Ra_{As} (μm) |
|------|-----------|-----------|-----------|-----------|--------------|
| #1   | 4.54      | 4.56      | 3.9       | 3.02      | 4.005        |
| #2   | 4.16      | 2.81      | 3.78      | 3.49      | 3.56         |
| #3   | 5.43      | 5.15      | 3.74      | 3.8       | 4.53         |
| #4   | 4.57      | 3.95      | 4.47      | 3.63      | 4.155        |
| #5   | 3.14      | 4.57      | 6.19      | Hi        | 4.633        |
| #6   | 3.28      | 4.78      | 2.57      | 4.54      | 3.792        |
| #7   | 3.17      | 3.18      | 2.24      | 4.62      | 3.302        |
| #8   | 2.9       | 4.07      | 1.3       | 4.49      | 3.19         |
| #9   | 5.64      | 5.99      | 2.24      | 4.31      | 4.545        |

Table (9): The input parameters and the output Ra for FG-Al polyester.

| Exp. | Speed (r.p.m) | Feed rate (mm/min) | Depth of cut (mm) | Ra_{As} (μm) | Ra pred. (μm) |
|------|---------------|--------------------|-------------------|--------------|---------------|
| #1   | 3000          | 800                | 1.2               | 4.005        | 3.968         |
| #2   | 3000          | 1200               | 1.6               | 3.56         | 3.968         |
| #3   | 3000          | 1600               | 2                 | 4.53         | 3.968         |
| #4   | 4000          | 800                | 1.6               | 4.155        | 3.968         |
| #5   | 4000          | 1200               | 2                 | 4.633        | 3.968         |
| #6   | 4000          | 1600               | 1.2               | 3.792        | 3.968         |
| #7   | 5000          | 800                | 2                 | 3.302        | 3.968         |
| #8   | 5000          | 1200               | 1.2               | 3.19         | 3.968         |
| #9   | 5000          | 1600               | 1.6               | 4.545        | 3.968         |

Table (10): Response table for SN ratios for FG-Al with polyester.

| Level | A  | B  | C  |
|-------|----|----|----|
| 1     | -12.07 | -11.60 | -11.24 |
| 2     | -12.42 | -11.47 | -12.18 |
| 3     | -11.20 | -12.62 | -12.27 |

Table (11): ANOVA results for FG-Al with polyester.

| Source | DF | Adj SS | Adj MS | F-value | P-value | Contribution% |
|--------|----|--------|--------|---------|---------|---------------|
| A      | 2  | 0.4151 | 0.2076 | 0.39    | 0.720   | 31.75%        |
| B      | 2  | 0.4648 | 0.2324 | 0.44    | 0.696   | 35.55%        |
| C      | 2  | 0.4275 | 0.2137 | 0.40    | 0.714   | 32.69%        |
| Error  | 2  | 1.0658 | 0.5329 |         |         |               |
| Total  | 8  | 2.3732 |         |         |         |               |
C. Carbon fiber–Aluminum with epoxy resin composite

For this composite the optimum parameters for the best surface roughness are A1B2C1 (A3=3000r.p.m, B2=1200mm/min, C1=1.2mm) that is illustrated in figure (12) and the input parameters with their results of Ra are illustrated in table (12). The nine experiments that had been applied to the composite and the measured surface roughness, four values for each experiment, are all listed in table (13). The experiments work well in the final square shape. Also separation occurs in Exp.1 and Exp.2 just the first layer of metal was separated from the square. For Exp.8 the large square was separated into two parts, from the middle metal layer. For Exp.3, Exp.4, Exp.5, Exp.6 and Exp.7 the separation occurs from the middle layer of the metal that means ten layers were separated from the square. As seen in table (14) and (15), S/N ratio and ANOVA tables showed results of the significant factors, F-value and P-value and contribution of each parameter. Spindle speed and feed rate has almost the same effect 43%, the parameters are effective on the output value due to the R-sq number, which is 97%.

![Figure (12): Main effect plots for SN ratios (y-axis) of the parameters (x-axis) for CF-Al with epoxy.](image)

| Table (12): Surface roughness results for CF-Al with epoxy. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Exp.  | Ra 1 (μm) | Ra 2 (μm) | Ra 3 (μm) | Ra 4 (μm) | RaM. (μm) |
|-------|------------|------------|------------|------------|-----------|
| #1    | 4.19       | 1.73       | 2.62       | 2.24       | 2.695     |
| #2    | 3.46       | 1.29       | 2.92       | 0.13       | 1.95      |
| #3    | 6.08       | 2.63       | Hi         | 2.35       | 3.686     |
| #4    | 6.15       | 2.82       | 4.6        | 1.73       | 3.825     |
| #5    | 3.48       | 2.89       | Hi         | 3.64       | 3.336     |
| #6    | 3.65       | 3.56       | 2.74       | 5.53       | 3.87      |
| #7    | Hi         | 4.1        | 3.17       | 2.19       | 3.153     |
| #8    | 1.83       | 2.14       | 3.09       | 1.39       | 2.112     |
| #9    | 2.63       | 3.4        | 2.09       | 3.87       | 2.997     |

| Table (13): The input parameters and the output Ra for CF-Al epoxy. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Exp.  | Spindle speed (r.p.m) | Feed rate (mm/min) | Depth of cut (mm) | RaM. (μm) | Ra Pred. (μm) |
|-------|----------------------|---------------------|-------------------|-----------|--------------|
| #1    | 3000                 | 800                 | 1.2               | 2.69      | 3.069        |
| #2    | 3000                 | 1200                | 1.6               | 1.95      | 3.069        |
| #3    | 3000                 | 1600                | 2                 | 3.68      | 3.069        |

![Table (14): Response table for SN ratios for CF-Al with epoxy.](image)

| Level | A     | B     | C     |
|-------|-------|-------|-------|
| 1     | -8.852| -10.080| -8.954|
| 2     | -11.291| -7.588| -8.996|
| 3     | -8.669| -10.874| -10.591|
| Rank  | 2     | 1     | 3     |

| Table (15): ANOVA results for CF-Al with epoxy. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Source | DF | Adj SS | Adj MS | F-Value | P-value |
|--------|----|--------|--------|---------|---------|
| A      | 2  | 1.66204| 0.83102| 19.16   | 0.050   | 42.63%  |
| B      | 2  | 1.766204| 0.88343| 20.37   | 0.047   | 45.31%  |
| C      | 2  | 0.46980| 0.23490| 5.42    | 0.156   | 12.05%  |
| Error  | 2  | 0.08675| 0.04337|         |         |         |
| Total  | 8  | 3.98544|        |         |         |         |

D. Carbon fiber–Aluminum with polyester resin composite

For this composite the optimum parameters for the best surface roughness are A3B2C1 (A3=5000r.p.m, B2=1200mm/min, C1=1.2mm) with Ra=2.0125 μm, that is illustrated in figure (13). The nine experiments that had been applied to the composite and the measured surface roughness, four values for each experiment, are all listed in table (16). The experiments work well in the final square shape better than the fiberglass, also separation occurs only in Exp.1. The top ten layers were separated from the square. As seen in table (17) and (18), S/N ratio and ANOVA tables showed results of the significant factors, F-value and P-value and contribution of each parameter, F-value showed that neither of the parameter is effective on the surface roughness. Depth of cut has the most effect on the Ra by 60%, and the feed has the lowest effect by 15%. The parameters were not effective on the output value due to the R-sq number, which is 66%.

![Figure (13): Main effect plots for SN ratios (y-axis) of the parameters (x-axis) for CF-Al with polyester.](image)
Table (16): Surface roughness results for CF-Al with polyester.

| Exp. | Ra 1 (μm) | Ra 2 (μm) | Ra 3 (μm) | Ra 4 (μm) | Ra av. (μm) |
|------|-----------|-----------|-----------|-----------|------------|
| #1   | 1.69      | 3.22      | 1.54      | 1.23      | 1.92       |
| #2   | 1.35      | 1.81      | 5.64      | 1.36      | 2.54       |
| #3   | 3.03      | 1.4       | 3.04      | 4.61      | 3.02       |
| #4   | 5.68      | 2.34      | 2.17      | 4.42      | 3.6525     |
| #5   | 2.14      | 2.09      | 3.81      | 0.94      | 2.245      |
| #6   | 2.37      | 1.41      | 2.15      | 2.95      | 2.22       |
| #7   | 3.04      | 2.42      | 1.95      | 2.23      | 2.41       |
| #8   | 3.94      | 1.54      | 1.02      | 1.55      | 2.0125     |
| #9   | 2.23      | 2.53      | 1.76      | 2.46      | 2.245      |

Table (17): The input parameters and the output Ra for CF-Al polyester.

| Exp. | Spindle speed (r.p.m) | Feed rate (mm/min) | Depth of cut (mm) | Ra av. (μm) | Ra pred. (μm) |
|------|----------------------|--------------------|------------------|-------------|--------------|
| #1   | 3000                 | 800                | 1.2              | 1.92        | 2.47         |
| #2   | 3000                 | 1200               | 1.6              | 2.54        | 3.47         |
| #3   | 3000                 | 1600               | 2                | 3.02        | 3.47         |
| #4   | 4000                 | 800                | 1.6              | 3.54        | 4.47         |
| #5   | 4000                 | 1200               | 2                | 2.24        | 2.47         |
| #6   | 4000                 | 1600               | 1.2              | 2.22        | 2.47         |
| #7   | 5000                 | 800                | 2                | 2.41        | 2.47         |
| #8   | 5000                 | 1200               | 1.2              | 2.01        | 2.47         |
| #9   | 5000                 | 1600               | 1.6              | 2.24        | 2.47         |

Table (18): Response table for SN ratios for CF-Al with polyester.

| Level | A | B | C |
|-------|---|---|---|
| 1     | -7.788 | -8.186 | -6.223 |
| 2     | -8.401 | -7.065 | -8.891 |
| 3     | -6.913 | -7.851 | -8.088 |
| Rank  | 2 | 3 | 1 |

Table (19): ANOVA results for CF-Al with polyester.

| Source | DF | Adj. SS | Adj. MS | F - value | P - value | Contribution% |
|--------|----|---------|---------|-----------|-----------|---------------|
| A      | 2  | 0.3521  | 0.1761  | 0.39      | 0.717     | 23.62%        |
| B      | 2  | 0.2360  | 0.1180  | 0.26      | 0.791     | 15.83%        |
| C      | 2  | 0.9023  | 0.4511  | 1.01      | 0.491     | 60.54%        |
| Error  | 2  | 0.8943  | 0.4471  |           |           |               |
| Total  | 8  | 2.3847  |         |           |           |               |

5. Conclusion

- Different laminated composite manufacturing have been successful using mold and heating method. The cohesive between the metal and the fiber was good in the final workpiece. A small increase about 0.1mm in the depth of the specimens can be noticed due to heating source to the composite without any compression on the mold.

- The effect of the parameters on surface roughness of the composite after the milling is that the surface roughness decrease with the increase of spindle speed, surface roughness increases with the increase of feed rate and depth of cut.

- The best specimen with the most significant parameters is Carbon fiber – Aluminum with epoxy resin, the optimum parameters, spindle speed, feed rate, depth of cut are 3000RPM, 1200mm/min, 1.2mm respectively. After that Fiberglass – Aluminum, epoxy resin comes the second to the effect of parameters. The optimum parameters, spindle speed, feed rate, depth of cut are 5000RPM, 1600mm/min, 2.0mm respectively.

- For Carbon fiber – Aluminum, and Fiberglass – Aluminum, polyester resin specimens the parameters were not significant to the surface roughness. The parameters, spindle speed, feed rate, depth of cut for each specimen are 3000RPM, 1200mm/min, 1.2mm, 5000RPM, 1200mm/min, 1.2mm respectively.

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