Logistic regression model for the grooving process of hybrid polyester resin composite materials reinforced with natural fibers and fiberglass

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Abstract. Greencomposites materials are being integrate into the manufacturing of products in diverse fields. For its assembly, are required secondary manufacturing processes such as the machining of slots and holes. In these processes, the greencomposites present great sensitivity to their manufacture. For the study of this concept, an experimental design was developed to analyze the grooving process and verify the effects of the cutting parameters with two types of tools (HSS and HSC) on surface quality (Ra) and the delamination factor (Fd) of the material. An analysis of the experiment was carried out to verify the significant effects of the different factors involved, in addition a multiple linear regression analysis and binomial logistic regression to predict surface quality and delamination in other conditions. The results obtained show the logistic regression model gave a better prediction for the grooving process of the greencomposites, both for the surface roughness and for the delamination factor. Finally, this study concludes that the carbide tool (HSC) has better surface quality with respect to the conventional tool of high speed steel (HSS).

1. Introduction

Studies on natural fiber have generated greater interest for its mechanical characteristics similar to synthetic fibers that meet conditions such as: low density, high resistance to stress and deformation, ease of surface modification and wide availability [1-3]. The manufacture of composite materials reinforced with natural fiber has been made by means of techniques such as: manual conforming with resins, pultrusion, filament winding, vacuum bag molding and resin transfer molding. [4]. As result of these industrial processes, components for vehicles, machines, furniture, etc. are obtained. There are some components that must necessarily be assembled in a system, machine or mechanism; for this reason, machining is an essential option to generate coupling geometries and inherently determine the structural integrity of the compound in these geometries [5-8].

Slot manufacturing is considered the most important machining process in assembly operations. However, there are untoward when evaluating the surface quality due to the non-homogeneity of the fibers and anisotropic characteristics of the material. Mechanical fatigue delamination [7, 9], it is a problem faced by composite materials, resulting in superficial damage to the cutting geometry when machined.

In addition, another defect that occurs in the machining is the surface roughness (Ra), this feature influences the quality of fit, tolerance and friction between elements and therefore the quality of
assembly [10, 11], this is unfavorable in the performance of mechanical parts and consequently leads to production costs.

According [4], these two phenomena involve great interest at the moment of being evaluated due to the variation and behavior according to the material that is being experienced and establishes that it is essential to determine the appropriate cutting parameters. According to studies conducted by [12], that behavior of load displacement in composite materials reformed with glass fiber / epoxy with circular cuts, concluded that as the size of cut increases, the maximum load of the composite plate decreases. An investigation carried out by [13], studied the residual tensile strength after drilling in fiberglass reinforced epoxy matrix composites and determined the cutting parameters for machining.

There are several studies that use experimental techniques of analysis and optimization; as factorial designs, Plakett-Burman, Taguchi and response surface [10, 14, 15]; all of them have made viable the studies to improve the machining processes. In addition, have identified that the main cutting parameters that affect the surface quality of the machining are between others the cutting speed, feed speed, type of tool and variables such as the properties of the composites. On the other hand, authors like [16, 17], used orthogonal matrices and analysis of variance to determine the level of influence that each factor has on the response variables. Research on the subject referring to the search for probabilistic logistic regression models to predict the best machining conditions in terms of quality, cost and time [18-23].

In the present study, the approach based on the design of experiments (DOE) [24], the relationship focused on the level of dependence and interaction between the different factors (cutting speed, feed speed, tool and fiber orientation) generating a minimum appearance of surface roughness (Ra) and delamination factor (Fd) in green composites. Finally, a logistic regression model is used to obtain an acceptable level of roughness and delamination on grooved surfaces from suitable cutting parameters.

2. Experimental Development

2.1 Preparation of greencomposites

The composite materials for the experimental study have been reinforced with different natural and synthetic fibers: polyester reinforced with cabuya fiber plus glass (CGFRP) and polyester reinforced with abaca fiber plus glass (AGFRP). The configuration of the natural fibers used in the biocomposite presents unidirectional flat tissue. The main properties are described in Table 1. To elaborate the test pieces, a vacuum stratification process was used according to the following volumetric fractions: 70% (polyester matrix) and 30% (natural fibers plus glass fiber 375 gr/cm³). The dimensions of the test specimens for the experimental test are (400x250x6mm) with a total volume of 600 cm³.

| Description | Density (g/cm³) | Tensile strength, ultimate (MPa) | Young’s modulus (MPa) | Flexural strength (MPa) | Elasticity modulus (MPa) |
|-------------|----------------|---------------------------------|----------------------|------------------------|-------------------------|
| CGFRP       | 1.46           | 80                              | 5272                 | 120                    | 8053                    |
| AGFRP       | 1.48           | 138                             | 4473                 | 127                    | 5091                    |

2.2 Machines, equipment and tools

For the analysis of grooves in the specimens of composite material has been established to use two types of drills diameter 6mm; the first HSS high speed cutter (SU’S_EM-4144) of 8% Co, right propeller 30 ° and 4 teeth and a HSC carbide drill (CERIN_66SU.060063575) right propeller 10 ° with breaker and 6 teeth. A machining center M-1000 TRAVIS Fagor control was used, that works with speeds of 0 to 8000 rpm. To measure the values of the surface roughness, a SJ-210 Mitutuyo rugosimeter with 1cm probe displacement was used. To evaluate the level of surface delamination, the scanning microscope SEM "Scanning Electron Microscope VEGA3 SEM" was used.

2.3 Design of experiments
The methodology established for the experimental test was a design of experiments (DOE). The two quantitative variables \((V_c)\) and \((V_f)\) and the categorical variable \((H)\) and the orientation factor (parallel \(PA\) and perpendicular \(PE\)) was evaluated at two levels respectively as detailed in table 2, solving a factorial design 2\(^4\). The experimental model consists of four replicates having a total of 64 experimental runs as shown in table 3.

| Machining parameters          | Low  | High |
|------------------------------|------|------|
| Cutting speed \(V_c\) (m/min)| 48   | 60   |
| Feed rate \(V_f\) (mm/rev)   | 0.1  | 0.15 |
| Tool \(H\)                   | HSS  | HSC  |
| Orientation \(M_o\) (machined according to orientation of natural fibers) | PA | PE |

2.4 Grooving process
The process of grooving in two directions was carried out according to the scheme shown in figure 1a, where the combination of machining parameters \((V_c, V_f, H)\) is detailed. The depth of the slot is 4mm; being, the depth per pass of the tool of 1 mm. The path of each slot has a length of 100mm.

![Grooving parallel to fiber](image1a)

**Figure 1.** Scheme for the manufacture of grooves (Grooving). a) Combination of machining parameters, b) arrangement of the experiment.

![Grooving perpendicular to fiber](image1b)

2.5 Measurement of delamination
The measurement of the delamination was done experimentally, where the direction of grooving was parallel \(PA\) and perpendicular \(PE\). The delamination found was 0.24 mm in both \(PA\) and \(PE\) directions, with a depth of 2 mm.

![Delamination measurement](image2a)

**Figure 2.** Measurement of the delamination in the two machining directions. a) Parallel, b) perpendicular.
2.5 Measurement of surface roughness (Ra) and delamination factor (Fd)

Measurements were made on the walls of the grooves in both machining directions. To determine the surface delamination, a SEM scanning microscopy was used, as shown in figure 2. Four measurements of delamination by orientation were obtained. The delamination factor (Fd) from the delamination measurement that is calculated by equation 1 [4]; where \( W_{\text{max}} \) is the maximum measure of delamination and \( W \) is the width of the slot.

\[
Fd = \frac{W_{\text{max}}}{W}
\]

2.6 Logistic regression analysis

A logistic regression has been used to model in depth the interpretation of the estimators, that is, the experimental test consists of independent variables (Vc, Vf, H, Mo) with two categories or levels also known as dichotomous, and the dependent variable is (Ra and Fd) also dichotomous. The equation of the logic model are presented below:

\[
\pi_i = \frac{e^{Z_i}}{1 + e^{Z_i}}
\]

Where \( \pi_i \) is the probability of success, \( (Z_{ab}) \) is the independent variable linearly combined.

\[
Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n
\]

For the resolution of this model, two logical conditions were established to establish a level of surface quality acceptability with a level of significance of 5%. First, Ra > 0.5 "Surface roughness Ra is not acceptable" and Ra < 0.5 "Surface roughness Ra is acceptable"; second, Fd > 1.06 "The delamination factor Fd is not acceptable" and Fd < 1.06 "The delamination factor Fd is acceptable".

3. Results and Discussion

3.1 Experimental Analysis

The factorial designs have been resolved graphically in Minitab®18.1 Statistical Software. Table 3 shows the average results of (Ra) and (Fd) of the four replicates obtained. From the analysis of factorial design graphs were obtained that demonstrate the influence of the parameters of cut according to the surface rugosity (Ra) and delamination factor (Fd). Figure 3, shows the interaction of the cutting speed as a function of surface roughness; this specifies that as the cutting speed increases from 40 to 60 m/min the surface roughness decreases from 0.7510 to 0.6845 μm for the CGFRP, a Unlike the AGFRP, the surface roughness decreases from 0.6971 to 0.6845 um. On the other hand, the surface roughness of the AGFRP presents a significant variation when a forward speed of 0.10 mm / rev is applied, the roughness decreases from 0.7573 to 0.6245 μm, but, if you work with the same forward speed, the roughness presents a percentage variation of 5.81% in the CGFRP.

| N°   | Vc | Vf | Tool | Orientation | Ra Abacá | Fd Abacá | Ra Cabuya | Fd Cabuya |
|------|----|----|------|-------------|-----------|-----------|-----------|-----------|
| 1    | 48 | 0,10 | HSS | PA | 0.716 | 1.077 | 1.126 | 1.133 |
| 2    | 60 | 0,10 | HSS | PA | 0.716 | 1.186 | 0.97 | 1.072 |
| 3    | 48 | 0,15 | HSS | PA | 0.804 | 1.185 | 1.016 | 1.103 |
| 4    | 60 | 0,15 | HSS | PA | 1.062 | 1.27 | 0.791 | 1.155 |
| 5    | 48 | 0,10 | HSC | PA | 0.475 | 1.129 | 0.291 | 1.053 |
| 6    | 60 | 0,10 | HSC | PA | 0.297 | 1.038 | 0.422 | 1.01 |
| 7    | 48 | 0,15 | HSC | PA | 0.691 | 1.048 | 0.245 | 1.084 |
| 8    | 60 | 0,15 | HSC | PA | 0.438 | 1.038 | 0.396 | 1.095 |
| 9    | 48 | 0,10 | HSS | PE | 0.78 | 1.154 | 1.26 | 1.083 |
| 10   | 60 | 0,10 | HSS | PE | 1.128 | 1.141 | 0.843 | 1.058 |
| 11   | 48 | 0,15 | HSS | PE | 1.084 | 1.068 | 1.328 | 1.177 |
Table 1. Effects of machining parameters on Ra.

| Tool  | Feed Rate | Cutting Speed | Ra     | HSS | PE   | 12   | 13   | 14   | 15   | 16   |
|-------|-----------|---------------|--------|-----|------|------|------|------|------|------|
| HSS   | 0.10      | 60            | 1.122  | 1.149| 0.723| 1.278|      |      |      |      |
| HSC   | 0.15      | 48            | 0.521  | 1.007| 0.273| 1.167|      |      |      |      |
| HSC   | 0.10      | 60            | 0.371  | 1.082| 0.609| 1.157|      |      |      |      |
| HSC   | 0.15      | 48            | 0.507  | 1.123| 0.47 | 1.135|      |      |      |      |
| HSC   | 0.15      | 60            | 0.351  | 1.023| 0.593| 1.033|      |      |      |      |

Figure 3. Effects of machining parameters on Ra.

Figure 4 shows that the surface quality is directly influenced by the type of tool, so the use of a tool (HSC) provides a minimum surface roughness and a minimum delamination factor compared with the tool (HSS). In addition, the parallel orientation is influenced at the time of obtaining a minimum surface roughness in the composites; but, when evaluating the delamination factor the AGFRP behaves better when working in a perpendicular direction.

Figure 4. Effects of machining parameters on Fd.
3.2 Binary logarithmic regression analysis

For the analysis the program R "Rstudio" was used, where the dependent variables (Ra) and (Fd) and the factors of the experiment are modeled and analyzed (x1: cutting speed, x2: Forward speed, x3: tool, x4: orientation). To determine the surface quality of the AGFRP according to the logic model established in tables 4 and 6, is specified that the factors cutting speed and tool are significant when evaluating the surface roughness (Ra). In the same way, only the tool is influential in the moment of evaluate the delamination factor (Fd).

| Table 4. Binary logistic regression, Ra Abacá |
|------------------------------------------------|
| Estimate  | Std. Error | z value | Pr(>|z|) |
| Intercept | -5.07E+03  | 4.70E+03 | -1.078  | 0.281088 |
| x1        | 2.99E+02   | 1.03E+02 | 2.911   | 0.003598 |
| x2        | -3.13E+04  | 1.93E+04 | -1.617  | 0.105796 |
| x3        | -5.98E+03  | 1.56E+03 | -3.839  | 0.000124 |
| x4        | 7.89E-13   | 8.88E+02 | 0.000   | 1.000000 |

| Table 5. Binary logistic regression, Ra Cabuya |
|------------------------------------------------|
| Estimate  | Std. Error | z value | Pr(>|z|) |
| Intercept | -4.20E+01  | 2.60E+01 | 0.016   | 0.9875  |
| x1        | -0.21E+02  | 9.00E-01 | -0.218  | 0.0215  |
| x2        | -1.88E+01  | 2.01E+01 | -0.938  | 0.3480  |
| x3        | -2.29E+01  | 2.60E+01 | -0.009  | 0.9932  |
| x4        | 2.57E+01   | 1.11E+01 | -0.219  | 0.0215  |

| Table 6. Binary logistic regression, Fd Abacá |
|------------------------------------------------|
| Estimate  | Std. Error | z value | Pr(>|z|) |
| Intercept | 2.54E+03   | 4.71E+02 | 0.721   | 0.471   |
| x1        | 0.01E+01   | 0.05E+02 | 0.323   | 0.747   |
| x2        | 1.25E+03   | 1.09E+03 | 0.956   | 0.339   |
| x3        | -2.97E+01  | 7.53E+02 | -3.946  | 0.001   |
| x4        | -1.03E+01  | 6.67E+02 | -1.550  | 0.121   |

| Table 7. Binary logistic regression, Fd Cabuya |
|------------------------------------------------|
| Estimate  | Std. Error | z value | Pr(>|z|) |
| Intercept | -1.26E+03  | 3.13E+02 | 0.385   | 0.7004  |
| x1        | 0.11E+01   | 0.05E+02 | 2.009   | 0.0446  |
| x2        | -1.85E+03  | 1.22E+03 | -1.480  | 0.1389  |
| x3        | -1.62E+01  | 6.52E+02 | -2.485  | 0.0130  |
| x4        | -0.56E+01  | 6.17E+02 | -0.908  | 0.3641  |

Likewise, the factors that intervene in the surface quality of the CGFRP are the following (table 4 and 6). The cutting speed and orientation are clearly significant when evaluating the Ra. On the other hand, the cutting speed and tool are significant when evaluating the delamination factor. Finally, the following predictive logarithmic equations for (Ra) and (Fd) respectively are obtained:

Greecomposite with Abacá:

\[ Z_i = 299(cutting \ speed) - 598(tool) \]

\[ Z_i = -2.97388(tool) \]

Greecomposite with Cabuya:

\[ Z_i = -0.21427(cutting \ speed) - 257127(Orientation) \]

\[ Z_i = 0.10677(cutting \ speed) - 1.62258(tool) \]

4. Conclusion

Experimental analysis shows that machining with the HSC carbide tool gives us a much better surface quality of grooving than the conventional HSS tool, as the primary effects figures show. The binomial
logistic regression method was used to determine the appropriate parameters for the grooving of the mechanized biocomposites. In other words, for the AGFRP the use of a cutting speed of 60m/min is obtained, the minimum surface roughness (Ra) is obtained and the use of an HSC tool results in a minimum delamination factor (Fd). Likewise, the surface quality of the composite hybrid CGFRP, is subject to the use of a cutting speed of 48m/min, to obtain a minimum surface roughness (Ra) and a cutting speed of 60m/min to obtain a delamination factor minimum (Fd), and the use of an HSC tool to obtain a minimum delamination factor (Fd).

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