Investigation of surface roughness and MRR in drilling of Al₂O₃ particle and sisal fibre reinforced epoxy composites using TOPSIS based Taguchi method

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Abstract. In this article, the surface roughness (SR) and material removal rate (MRR) in drilling of Al₂O₃ particle and sisal fibre/epoxy composites was investigated. The hand layup technique was employed to develop the epoxy/sisal fibre/Al₂O₃ composites. The drilling parameters such as cutting speed, feed rate and diameter of drill bit were considered to perform drilling operation. The drilling experiments were designed based on L₉ orthogonal array suggested by Taguchi technique. The single response optimization of SR and MRR was conducted by Taguchi technique. The influence of significant parameters on SR and MRR was identified by analysis of variance (ANOVA). The results of single response optimization revealed that the cutting speed is the most influencing parameters for both SR and MRR followed by the feed rate and diameter of drill bit. The technique for order preference by similarity to ideal solution (TOPSIS) approach was employed for multi-response optimization. From the results, it is observed that cutting speed is the most significant parameter on minimizing SR and maximizing MRR followed by feed rate and diameter of drill bit.

Keywords: Epoxy, surface roughness, MRR, Taguchi, TOPSIS

1. Introduction

The fibre reinforced polymer matrix composites are well suited for many engineering applications like automobile, aerospace, marine and defence industries because of their excellent performance. The machining operation is required for trimming, finishing and drilling the composite to make an assembly of product. But, the machining process of composite is different from the conventional engineering materials because of its non-homogeneous and anisotropic nature. In engineering industries, the drilling process is utilized nearly 40% of all the available machining operation [1, 2]. The quality of the hole surface is strongly influenced by the parameters like drill point geometry, drill point angle, cutting feed and speed. If these parameters are not selected properly it will lead to delamination, fibre pull out and micro cracking etc., which results in lowering the machining performance [3, 4]. Surface roughness is the quality characteristics in evaluating the quality of hole. Poor quality hole deteriorate the performance of the composite structure. The productivity (material
removal rate) is also a significant factor in drilling of composites. So, it is necessary to optimize the quality and productivity in drilling of composites. Many investigators have studied the optimization of drilling parameters on polymer matrix composite using Taguchi technique. This technique aimed at studying many variables with few numbers of experiments over the whole experimental space [5, 6].

Palanikumar et al. [7] analysed the optimization of drilling parameters like drill diameter, spindle speed and feed rate in drilling a glass fibre reinforced polymer (GFRP) composite using grey relational analysis. Feed rate is observed as the most significant parameter, which affects the total variance of responses optimized followed by drill diameter and spindle speed. Ranganathan et al. [8] studied the multi-objective optimization in drilling of glass fibre reinforced polymer composite using grey analysis. Feed rate is observed as the most significant parameter, which affects the delamination, torque and thrust force followed by spindle speed. Gallih Bagus et al. [9] studied the significance of tool geometries and drilling parameters in drilling GFRP composites using Taguchi and GRA method. They concluded that cutting feed is the most influential factor which affect the total variance of responses optimized followed by drill point geometry, drill point angle and spindle speed. Shunmugesh and Panneerselvam [10] studied the optimization of drilling parameters on CFRP using multi-objective Taguchi technique, TOPSIS and RSA. Their findings revealed that the results of TOPSIS technique are in good agreement with the multi-objective Taguchi technique. Feed rate is observed as the most predominant factor which affects the responses followed by cutting speed and drill bit type. The drilling condition on carbon fibre reinforced polymer laminates by using K20 carbide drill bit are optimized by Krishnaraj et al [11]. They noted that the spindle speed influenced the circularity of the drilled holes and lower feed rates reduced the exit delamination damage.

Kilickap et al. [12] analysed the influence of drilling parameters and drill point angle on delamination in glass fibre reinforced polymer composites. Cutting speed and feed rate are observed as the most influential parameters on the delamination of composites and the lower values of cutting speeds and feed rates resulted in reduction of delamination. Sonkar et al. [13] investigated the machining process parameters during drilling in glass fibre reinforced polymer composites against the responses like SR, torque, delamination factor and thrust force. They compared the results of Deng’s similarity approach with that of TOPSIS method. Tom sunny et al. [14] used three different drill bit to study the influence of feed and cutting speed on composite delamination behaviour. The experimental results revealed that the delamination is reduced and within limits while increasing the spindle speed and then increased for too high spindle speed. Initially, the delamination is reduced and within limits while decreasing the feed rate and then increased for too low feed rate. Hari Vasudevan et al. [15] optimized the drilling process parameters against multi objective performance based on Desirability coupled with Taguchi method. They observed that feed rate had the strong effect on the responses among the other parameters.

The effect of tool materials on thrust force and delamination in drilling of sisal/glass fibre reinforced hybrid polymer composite investigated by Ramesh et al. [16]. From the results, it is concluded that the drilling process with high speed steel drill bit maximum delamination and thrust force. Ramesh et al. [17] analyzed the machining characteristics of glass/sisal/jute reinforced hybrid polymer composites and found that low feed rates and high or medium spindle speeds gave the best machining performance. Selvakumar and Panneer Selvan [18] analyzed the mechanical and machining characteristics of human hair/jute/epoxy hybrid composites fabricated by hand layup method. It is observed that the drill point angle and speed is the predominant parameters to affect the quality of hole. Jayabal et al. [19] investigated the mechanical and machining performance of glass/coir/polyester
hybrid composite. The minimum value of torque, thrust force and tool wear is obtained at 600 rpm spindle speed and 6 mm drill bit.

From the literature, it has been noted that not enough research work is attempted on drilling of hybrid epoxy composites containing sisal fibre and Al$_2$O$_3$ particle. In the current study, the hand layup technique was employed to develop the hybrid epoxy composites. In the drilling process, the parameters like cutting speed, feed rate and diameter of drill bit are optimized using TOPSIS based Taguchi method. This study aims to determine the optimum cutting parameters to minimize the SR and maximize the MRR of the epoxy composites.

2. Experimental procedures

2.1 Materials

Epoxy is a widely used thermosetting polymer matrix to produce the fibre reinforced composites because of their excellent resistance to the chemical environment, low level of shrinkage and simple procedure of processing. It finds many applications in the fields like automobile, aircraft, boats and electronics. So, in the current study, the epoxy resin (LY 556) and hardener (HY 951) was chosen as a matrix materials. The sisal fibre was selected as a reinforcement material due to its low cost, low density, easy availability and biodegradability. Aluminium oxide (Al$_2$O$_3$) with average particle size of 50 µm was used as filler to improve the properties of the matrix material and reduce the cost of hybrid composite.

2.2 Processing of composites

The epoxy resin and Al$_2$O$_3$ particles were preheated to 65°C for 1 hour to improve their wettability and then the filler material was mixed with matrix by using mechanical stirring. The Al$_2$O$_3$ particles of 10 vol. % were added with epoxy resin. After the addition of Al$_2$O$_3$ particles with the epoxy resin, the stirring was extended for 10 minutes to obtain the homogeneous mixing. The hardener was added with the mixture of epoxy and Al$_2$O$_3$ particles in the ratio 1:10 by weight. The sisal fibre with a volume fraction of 50% was utilised to prepare the composites. The mould with the dimensions 300 mm length, 300 mm breadth and 10 mm thick was designed to produce the composites. Teflon coated glass fabric separator was spread over the mould surface, which facilitate the easy removal of composites from the mould. Initially, the sisal fibres were aligned at an angle 0° and then the mixture of epoxy and Al$_2$O$_3$ particles poured over the surface of the fibres. Similarly, the fibres were aligned at an angle 45° and 90° and then the mixture of epoxy and Al$_2$O$_3$ particles poured over the surface of the fibres to get the required thickness of composite. Finally, the composite mixture was allowed to curing for approximately 24 hours at room temperature. After the curing, the composite was separated from the mould.

2.3 Plan of experiments

Taguchi method was chosen to design the drilling experiments. The experiments were planned by varying the parameters like cutting speed, feed rate and diameter of drill bit. The process parameters and their levels are given in Table 1. The experimental plan was developed based on L$_9$ orthogonal array, which has 9 rows and 3 columns as shown in Table 2. In this work, the statistical and analysis software MINITAB 15 was employed to design and analyse the drilling experiments.
Table 1. Process parameters and levels.

| S.No | Parameters                              | Level  | Level  | Level  |
|------|-----------------------------------------|--------|--------|--------|
| 1    | Cutting speed (rpm) A                   | 800    | 1200   | 1600   |
| 2    | Feed rate (mm/rev) B                    | 0.050  | 0.125  | 0.200  |
| 3    | Diameter of drill bit (mm) C            | 8      | 10     | 12     |

2.4 Drilling process

As per the experimental design in Table 2, the drilling process was performed on BMV 35 T12 CNC drilling machine as shown in figure 1(a). The HSS drilling tool was used to make a hole on the composite plates and the drilled composite plate is shown in figure 1(b). The experiments are conducted by varying the drilling parameters like cutting speed, feed rate and diameter of drill bit with three different levels. Tokyo seimitsu surfcom was employed to measure the surface roughness of the inner surface of the hole.

Table 2. Taguchi L9 Orthogonal array.

| Experiment No. | A (rpm) | B (mm/rev) | C (mm) |
|----------------|---------|------------|--------|
| 1              | 800     | 0.050      | 8      |
| 2              | 800     | 0.125      | 10     |
| 3              | 800     | 0.200      | 12     |
| 4              | 1200    | 0.050      | 10     |
| 5              | 1200    | 0.125      | 12     |
| 6              | 1200    | 0.200      | 8      |
| 7              | 1600    | 0.050      | 12     |
| 8              | 1600    | 0.125      | 8      |
| 9              | 1600    | 0.200      | 10     |
The material removal rate (mm$^3$/s) in drilling process is calculated using the following equation

$$\text{MRR} = \pi D^2 f L N / 4 L$$  \hspace{1cm} (1)$$

where $D =$ Diameter of the hole (mm), $L =$ Length of the hole (mm), $f =$ Feed rate (mm/rev) and $N =$ Cutting speed (rpm). The average values of SR and MRR is presented in Table 3.

| Experiment No. | A (rpm) | B (mm/rev) | C (mm) | SR ($\mu$m) | MRR (mm$^3$/s) |
|---------------|---------|------------|--------|-------------|----------------|
| 1             | 800     | 0.050      | 8      | 3.90        | 130.90         |
| 2             | 800     | 0.050      | 10     | 4.78        | 78.54          |
| 3             | 800     | 0.125      | 12     | 5.21        | 418.88         |
| 4             | 1200    | 0.050      | 10     | 7.31        | 301.59         |
| 5             | 1200    | 0.050      | 10     | 3.76        | 282.74         |
| 6             | 1200    | 0.050      | 12     | 5.43        | 150.80         |
| 7             | 1600    | 0.050      | 12     | 6.35        | 33.51          |
| 8             | 1600    | 0.125      | 8      | 8.83        | 200.11         |
| 9             | 1600    | 0.200      | 10     | 5.43        | 167.55         |

3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS approach was developed by Hwang and Yoon in the year 1981. The TOPSIS approach was used to optimize the multiresponse drilling processes because which is simple and more reliable for getting appreciable results. In this process, the alternative was chosen based on the distance between ideal solution and alternative and then the extent of closeness to the ideal solution is measured. The TOPSIS method converts the multi-objective responses into a single response for obtaining optimal process parameters and the procedure is presented in Figure 2.
4. Results and discussion

4.1 Single response optimization

In this work, L9 orthogonal array is used to determine the effect of drilling parameters like cutting speed, feed rate and drill bit diameter on the individual responses like SR and MRR by using S/N ratio and ANOVA. Taguchi’s “smaller the better” and “larger the better” characteristics were selected to analyze the SR and MRR of composites. The experimental results were transformed into S/N ratio and ANOVA was used to determine the statistically significant parameters. The S/N ratio for SR and MRR is given in Table 4. The S/N ratio of SR for cutting speed at levels 1, 2 and 3 is determined by finding average S/N ratio for experiments 1-3, 4-6 and 7-9 respectively. In the same way, the average S/N ratio of SR for other parameters is determined.
Table 4. S/N ratio for SR and MRR.

| Exp. No. | A (rpm) | B (mm/rev) | C (mm) | SR (µm) | S/N Ratio For SR | MRR (mm³/s) | S/N Ratio for MRR |
|----------|---------|------------|--------|---------|-----------------|--------------|-----------------|
| 1        | 800     | 0.050      | 8      | 3.90    | -11.8213        | 130.90       | 194.90          |
| 2        | 800     | 0.125      | 10     | 4.28    | -12.6289        | 78.54        | 259.73          |
| 3        | 800     | 0.200      | 12     | 3.31    | -10.3966        | 418.88       | 167.58          |
| 4        | 1200    | 0.050      | 10     | 3.71    | -11.3875        | 301.59       | 182.94          |
| 5        | 1200    | 0.125      | 12     | 4.67    | -13.3863        | 282.74       | 294.37          |
| 6        | 1200    | 0.200      | 8      | 5.13    | -14.2023        | 150.80       | 334.24          |
| 7        | 1600    | 0.050      | 12     | 4.56    | -13.1793        | 33.51        | 307.58          |
| 8        | 1600    | 0.125      | 8      | 6.43    | -16.1642        | 200.11       | 447.83          |
| 9        | 1600    | 0.200      | 10     | 5.63    | -15.0102        | 167.55       | 363.36          |

Table 5. Response table of mean S/N ratio for SR and MRR.

| Level | A (rpm) | B (mm/rev) | C (mm) | A (rpm) | B (mm/rev) | C (mm) |
|-------|---------|------------|--------|---------|------------|--------|
| 1     | -11.62  | -12.13     | -14.06 | 46.19   | 46.93      | 49.77  |
| 2     | -12.99  | -14.06     | -13.01 | 48.37   | 50.23      | 48.25  |
| 3     | -14.78  | -13.20     | -12.32 | 51.33   | 48.72      | 47.87  |
| Delta | 3.17    | 1.93       | 1.74   | 5.14    | 3.30       | 1.89   |
| Rank  | 1       | 2          | 3      | 1       | 2          | 3      |

Table 6. ANOVA table for SR and MRR.

| Source | DOF | SS  | MS  | F    | P   | %C | SS  | MS  | F    | P   | %C |
|--------|-----|-----|-----|------|-----|----|-----|-----|------|-----|----|
| A      | 2   | 4.452 | 2.226 | 45.235 | 0.022 | 57.52 | 41867 | 20934 | 23.56 | 0.041 | 61.01 |
| B      | 2   | 1.737 | 0.868 | 17.645 | 0.054 | 22.44 | 16799 | 8400  | 9.456 | 0.096 | 24.48 |
| C      | 2   | 1.453 | 0.727 | 14.765 | 0.063 | 18.77 | 8176  | 4088  | 4.602 | 0.179 | 11.92 |
| Error  | 2   | 0.098 | 0.049 | 1777  | 888   | 68619 |
| Total  | 8   | 7.740 | 68619 |

S = 0.221836  R-Sq = 98.73%  R-Sq (adj) = 94.91% (SR)
S = 29.8047   R-Sq = 97.41%  R-Sq (adj) = 91.64% (MRR)

The same procedure is followed to get the average S/N ratio of MRR for all the parameters at various levels. The average S/N ratio response table for SR and MRR is shown in Table 5. From the S/N ratio analysis, the optimum drilling parameters for SR are cutting speed at level 1, feed rate at level 1 and diameter of drill bit at level 3. Similarly, the optimum drilling parameters for MRR are cutting speed at level 3, feed rate at level 2 and diameter of drill bit at level 1. From the Table 6, it is observed that the cutting speed is having P value less than 0.05, which means that it is significant at 95% confidence level. So, cutting speed is the most significant factor followed by feed rate and diameter of drill bit.
4.2 Multi response optimization

As per the procedure given in figure 2, the drilling parameters are optimized using TOPSIS method. Initially, the responses like SR and MRR are normalized and then equal weight is assigned to obtain the normalized weighted response. The normalized weighted response is computed by multiplying the normalized response with its assigned weight, which is presented in Table 7. From the normalized weighted responses, the positive and negative ideal solutions are determined and these are 0.116965 and 0.227216 for surface roughness and 0.251518 and 0.094119 for material removal rate. The separation of each alternative from the positive and negative ideal solutions is computed, which is presented in Table 7. The closeness coefficient value is computed from separation measures value of each alternative, which is also presented in Table 7.

Table 7. Normalized, separation measures and closeness coefficient value.

| Exp. No. | Normalization of the responses | Normalized weighted responses | Separation measures | Closeness coefficient |
|----------|-------------------------------|-------------------------------|---------------------|-----------------------|
|          | SR                           | MRR                          | SR                  | MRR                  | $S_p^+$ | $S_n^-$ | $CC_i$ |
| 1        | 0.275627                     | 0.218926                     | 0.137814            | 0.109463             | 0.143577 | 0.090709 | 0.387173 |
| 2        | 0.302483                     | 0.291748                     | 0.151242            | 0.145874             | 0.111065 | 0.091927 | 0.452860 |
| 3        | 0.233930                     | 0.188238                     | 0.116965            | 0.094119             | 0.157399 | 0.110251 | 0.411922 |
| 4        | 0.262199                     | 0.205492                     | 0.131100            | 0.102746             | 0.149442 | 0.096502 | 0.392375 |
| 5        | 0.330046                     | 0.330658                     | 0.165023            | 0.165329             | 0.098682 | 0.094545 | 0.489296 |
| 6        | 0.362556                     | 0.375443                     | 0.181278            | 0.187722             | 0.090588 | 0.104267 | 0.535102 |
| 7        | 0.322272                     | 0.345497                     | 0.161136            | 0.172748             | 0.090309 | 0.102709 | 0.532121 |
| 8        | 0.454431                     | 0.503036                     | 0.227216            | 0.251518             | 0.110251 | 0.157399 | 0.588078 |
| 9        | 0.397892                     | 0.408153                     | 0.198946            | 0.204076             | 0.094719 | 0.113533 | 0.545172 |

Table 8. S/N ratio for Closeness coefficient ($CC_i$).  

| Experiment No. | Closeness coefficient ($CC_i$) | S/N Ratio |
|----------------|-------------------------------|-----------|
| 1              | 0.387173                      | -8.2419   |
| 2              | 0.452860                      | -6.8807   |
| 3              | 0.411922                      | -7.7037   |
| 4              | 0.392375                      | -8.1260   |
| 5              | 0.489296                      | -6.2086   |
| 6              | 0.535102                      | -5.4313   |
| 7              | 0.532121                      | -5.4798   |
| 8              | 0.588078                      | -4.6113   |
| 9              | 0.545172                      | -5.2693   |
Table 9. Response table of mean S/N ratio for $CC_i$.

| Level | A (rpm) | B (mm/rev) | C (mm) |
|-------|---------|------------|--------|
| 1     | -7.609  | -7.283     | -6.095 |
| 2     | -6.589  | -5.900     | -6.759 |
| 3     | -5.120  | -6.135     | -6.464 |
| Delta | 2.489   | 1.382      | 0.664  |
| Rank  | 1       | 2          | 3      |

The S/N ratio for closeness coefficient ($CC_i$) is presented in Table 8. The average S/N ratio response table for closeness coefficient ($CC_i$) is shown in Table 9. From the response plot for closeness coefficient (Figure 3), the optimum drilling parameters are cutting speed at level 3, feed rate at level 2 and diameter of drill bit at level 1 for minimizing SR and maximizing MRR. From the table 10, cutting speed is observed as the most significant factor followed by feed rate and diameter of drill bit for combined response.

Table 10. ANOVA table for $CC_i$.

| Source | DOF | SS    | MS    | F     | P   | %C   |
|--------|-----|-------|-------|-------|-----|------|
| A      | 2   | 0.0289| 0.0144| 9.677 | 0.094 | 66.52|
| B      | 2   | 0.0091| 0.0045| 3.046 | 0.247 | 20.94|
| C      | 2   | 0.0025| 0.0012| 0.825 | 0.548 | 5.67 |
| Error  | 2   | 0.0030| 0.0015|       |       |      |
| Total  | 8   | 0.0434|       |       |       |      |

![Main Effects Plot for SN ratios](image)

Figure 3. Response plot for Closeness coefficient ($CC_i$).

5. Conclusion

In this work, Al$_2$O$_3$ particle and sisal fibre reinforced epoxy composites were prepared by using hand layup technique. The drilling parameters like cutting speed, feed rate and diameter of drill bit
were optimized by TOPSIS against the responses like SR and MRR. The optimum drilling parameters are cutting speed at 1600 rpm, feed rate at 0.125 mm/rev and diameter of drill bit at 8 mm to minimize SR and maximize MRR. From the ANOVA results, cutting speed was observed as the most predominant parameter on the combined response followed by feed rate and diameter of drill bit.

6. References
[1] Koeing W, Wulf C, Grass P and Willerscheid H 1985 Machining of Fiber Reinforced Composite Annals of the CIRP 34 (2) 536-548.
[2] El-Sonbaty I, Khashaba UA and Machaly T 2004 Factors affecting the machinability of GFR/epoxy composites J Compos Struct 63 313–327.
[3] Ragunath S, Velmurugan C and Kannan T 2017 A Review of Influential Parameters in Drilling Delamination on Fiber Reinforced Polymer Composites International Journal of Chem Tech Research 10 (7) 298-303.
[4] Wong TL, Wu SM and Croy GM 1982 An analysis of delamination in drilling composite material 14th National SAMPE Technology Conference Atlanta 471–83.
[5] Taguchi G 1986 Introduction to Quality Engineering Asian Productivity Organization Dearborn MI: Distributed by American Supplier Institute Inc.
[6] Phadke SM 1989 Quality Engineering Using Robust Design Englewood Cliffs NJ Prentice Hall.
[7] Palanikumar K, Latha B, Shentilkumar VS and Paulo Davim J 2012 Analysis on Drilling of Glass Fiber-Reinforced Polymer (GFRP) Composites Using Grey Relational Analysis Materials and Manufacturing Process 27(3) 297-305.
[8] Ranganathan S, Senthivelan T and Gopalakannan S 2012 Multiple Performance Optimizations in Drilling of GFRP Composites Using Grey Analysis IEEE-International Conference on Advance in Engineering, Science, and Management.
[9] Gallih Bagus W, Bobby OP, Soepongkat and Iwan Krisnanto 2016 Multiple-Performance Optimization of Drilling Parameters and Tool Geometries in Drilling GFRP Composite Stacks Using Taguchi and Grey Relational Analysis (GRA) Method ARPN Journal of Engineering and Applied Sciences 11(2) January 2016.
[10] Shunmugesh K and Panneerselvam K 2017 Optimization of Machining Process Parameters in Drilling of CFRP Using Multi-Objective Taguchi Technique TOPSIS and RSA Techniques Polymers & Polymer Composites 25 (3) 185-192.
[11] Vijayan Krishnaraj A Prabukarthy Arum Ramanathan N Elanghovan M Senthil Kumar Redouane Zitoune and Davim JP 2012 Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates Composites Part B: Engineering, 43 1791-1799.
[12] Kilickap E 2010 Optimization of Cutting Parameters on Delamination based on Taguchi Method during Drilling of GFRP Composite Expert Systems with Applications 37 6116-6122.
[13] Vikas Sonkar, Kumar Abhishek, Saurav Datta and Siba Sankar Mahapatra Multi-Objective Optimization in Drilling of GFRP Composites: A Degree of Similarity Approach, 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science 6 538 – 543.
[14] Tom sunny, Babu J and Jose Philip 2014 Experimental Studies on Effect of Process Parameters on Delamination in Drilling GFRP Composites using Taguchi Method 3rd International
Conference on Materials Processing and Characterisation (ICMPC 2014) Procedia Materials Science 6 1131 – 1142.

[15] Hari Vasudevan, Ramesh R Rajguru and Naresh C Deshpande 2014 Multiobjective Optimization of Drilling Characteristics for NEMA G-11 GFRP/Epoxy Composite using Desirability coupled with Taguchi Method Procedia Engineering 97 522 – 530.

[16] Ramesh M, Palanikumar K and Hemachandra Reddy 2014 Influence of tool materials on thrust force and delamination in drilling sisal-glass fibre reinforced polymer (S-GFRP) composites Procedia Materials Science 5 1915 – 1921.

[17] Ramesh M, Palanikumar K and Hemachandra Reddy 2014 Experimental Investigation and Analysis of Machining Characteristics in Drilling Hybrid Glass-Sisal-Jute Fiber Reinforced Polymer Composites 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India

[18] Selvakumar K and Panneer Selvan S 2014 Study and Analysis of Mechanical Properties and Machining Parameters on Natural Fiber Hybrid Composites, Asian Review of Mechanical Engineering 2(1) 24-30.

[19] Jayabal S, Natarajan U and Sekar U 2011 Regression modeling and optimization of machinability behavior of glass-coir-polyester hybrid composite using factorial design methodology, International Journal of Advanced Manufacturing Technology 55 263–273.