Optimization of drilling parameters on hybrid natural fiber reinforced polymer matrix composites

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Abstract: The natural fiber reinforced composites are highly utilized in the applications of building and construction industry, storage containers, transportation industry and in other industrial applications. The natural fibers are preferred for its distinct properties than synthetic fibers. Natural fibers are economically cheaper, recyclable and ecologically biodegradable. Many studies were proposed by the researchers to improve the machinability and mechanical behaviour of natural fiber reinforced composites. The addition of filler material is a kind of approach to improve the property of natural fiber reinforced composites. In this study the composite laminates are created by reinforcing bi-directional bast type jute and unidirectional leaf made sisal fibers into an epoxy LY556 resin matrix material. The silicon carbide (SiC) is used as filler material. Two types of composite laminates are manufactured. The first sample is considered in the ratio of 70% epoxy resin to 30% Jute + Sisal fiber composition without any filler material. The second composition includes the ratio of 70% epoxy resin to 30% Jute + Sisal fiber along with 10% SiC as filler material. The Hardner HY951 of 10% is used in both compositions. The machining operation was performed by using HSS twist drill for three different machining parameters (Drill bit type, Spindle speed and Feed rate). The circularity and surface roughness are considered as output parameters. The machining is performed in the range of 20 different combinations as directed by the RSM software. The conformation tests are carried out to validate the RSM results. The optimization results shows that the sample with SiC filler exhibits better machinability behaviour than sample without filler material.

Keywords: Hybrid polymer composite; Natural fibers; Epoxy resin; Silicon carbide filler; Drilling parameters; Response Surface Methodology.

1.Introduction

The natural fiber reinforced composites are highly researched to find out its capability for replacing the use of conventional fibre reinforced petroleum based composites [1]. Numerous natural fibre compositions are extracted from different bio materials. These biocomposites are highly utilized in many critical applications [2]. In most of the cases instead of natural resins, the synthetic resins provided better bonding strength and strength to weight ratio when it is mixed with natural fibers like sisal, jute and coir etc.[3]. Natural fibre reinforced composites exhibits low density lightweight property and other specific properties which makes them ideal for many industrial applications.[4]. The cost of the natural fibre extracts are very low comparing to synthetic fibres which is mostly extracted from depleting crude oil based refining process as a by product,[5]. The natural fibres are classified into two broad categories as non wood natural fibers and wood based natural fibers. The examples of non wood based natural fibers are straw fibers, bast fibers like flax, kenaf, jute, hemp, fruit based, seed based and grass based fibers. The examples of wood based fibers are like soft wood fibers and hard wood fibers etc…[6]. S.Harish et.al [7] developed an epoxy based composite reinforced with coir material. The mechanical properties and the machining properties of the epoxy-coir based composite was found good than equivalent synthetic fiber composition.The qualitative evaluation of the fractured surface was carried out by using scanning electron microscope and the interfacial properties are better than conventional
synthetic composite. Wang wei et.al [8] prepared a natural fibre reinforced composite with a coir fiber stack. The characteristics of the coir fiber is initially determined. The length of the fibers used in the study are at the range of 8 to 337 mm long fibers. The rubber is used as matrix material. The fabrication of composite is done by using heat press machine. The tensile properties of coir-epoxy composites are very high when compared to other compositions. Drilling of banana glass fibre hybrid composites of two different proportions was carried out by using a standard twist drill. The feed rate and speed was considered as parameters. The hole quality was studied by using ANNOVA method and it was found that the feed rate has major influence than drilling speed on the hole quality [9] {V.Santhanam et.al}. The Coir–polyester composites were prepared by using hand layup method. The prepared composite laminates were subjected to study their mechanical and machinability characteristics. The experiments were carried out by using a twist drill of 6mm diameter. The minimum value of thrust force, torque and tool wear are found at spindle speed of 600 rpm and feed rate of 0.3 mm/rev [10]. The drilling behavior of unidirectional sisal-epoxy and sisal-polypropylene composite laminates has been experimentally investigated. Chip formation characteristics in the context of both thermoset and thermoplastic natural fiber composite laminates have been discussed. Further, the analysis of drilling force signals has been reported and the mapping of drilling forces has been proposed. Influence of drill geometry, feed, and spindle speed on drilling forces and a comparative analysis of damage characteristics of drilled hole have also been reported.[11]. The traditional drilling process carried out by using a twist drill is the highly used machining process for creating a hole or riveting or fastening process of structural component assemblies in the aerospace and automotive industries. [12]. The important objective of developing composite materials are environment friendliness and light weight, with high specific properties. For satisfying these criteria the natural fibers are incorporated into manmade fibers, and partially ecofriendly hybrid composites have been developed by using glass, sisal and jute fibers as reinforcing material in the polymer resin matrix. The drilling of composite materials is difficult when compared to metals, because the tool has to pass alternately through the matrix and reinforcement, which have different properties [13]. An effort to utilize the advantages offered by renewable resources for the development of biocomposite materials based on biopolymers and natural fibers has been made through fabrication of Natural fiber powdered material (Sisal (Agave sisalana), Banana (Musa sepientum), and Roselle (Hibiscus sabdariffa)) reinforced polymer composite material by using bio epoxy resin. The present work focuses on the prediction of thrust force and torque of the natural fiber reinforced polymer composite materials, and the values, compared with the Artificial Neural Network [14]. Recently, Jute fiber is being used as a reinforcement material in the development of reinforced plastics for various engineering applications. Its biodegradability, low cost, and moderate mechanical properties make it a preferable reinforcement material in the development of polymer matrix composites. [15]. The results reveal that, the mechanical properties of polypropylene based composites are substantially improved on account of the addition of the Jute fiber reinforcement. It has also been observed that the significance of the enhancement of the mechanical properties increased as the weight percentage of the Jute fiber reinforcement increased up to 40% [16]. The results show that the jute reinforced epoxy composite exhibited better mechanical properties than Jute-polyester composite. [17]. Composite prepared with 0.02% K2Cr2O7 treated jute fabrics showed the highest values of the mechanical properties. [18]. Natural fibers have the advantage that they are renewable resources and have marketing appeal [19]. The objective of this work is to perform drilling analysis of all the composites are studied by using Response surface experimental design Fabrication of natural fiber (sisal & jute) reinforced epoxy based composite. Valuation of mechanical properties (tensile strength, flexural, hardness, impact strength etc.). Besides the above all the objective is to develop new class of composites by incorporating sisal and jute fiber reinforcing phases into a polymeric resin Also this work is expected to introduce a new class of polymer composite that might find many engineering applications.

2. Experimentation

Materials Used
The materials used in this work are
1. Sisal Fiber
2. Jute Fiber
3. Particulate Filler Material (SiC 600mesh)
4. Epoxy Resin (LY556)
5. Hardener (HY951)
6. Mould for sample preparation
7. Releasing Agent

Matrix Material
Matrix materials are of different types like metals, ceramics and polymers. Polymer matrices are most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared to metal and ceramic matrices. Polymer matrices can be either thermoplastic or thermoset. Thermoset matrices are formed due to an irreversible chemical transformation of the resin into an amorphous cross-linked polymer matrix. Due to huge molecular structures, thermoset resins provide good electrical and thermal insulation. They have low viscosity, which allow proper fiber wet out, excellent thermal stability and better creep resistance. Normally, these resins can be formulated to give a wide range of properties upon the requirement. The most commonly used thermoset resins are epoxy, polyester, vinyl ester and phenolics. Among them, the epoxy resins are being widely used for many advanced composites due to their excellent adhesion to wide variety of fibers, superior mechanical and electrical properties and good performance at elevated temperatures. In addition to that they have low shrinkage upon curing and good chemical resistance. Due to several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) is chosen as the matrix material for the present work.

Reinforcements
The present investigation employs sisal and jute as the natural fiber in the epoxy matrix to fabricate a series of hybrid composites. The pictorial views of bi-directional jute fiber mats and unidirectional sisal fiber are used for composite fabrication for this study are given in figure 1 as follows. Conventional filler chosen for this work is SiC, which has a great potential to be used in various polymeric matrices. It is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, and ceramics and in numerous high-performance structural and wear applications. SiC is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. Due to its bonding nature SiC produces a very hard and strong material. SiC is not attacked by any acids, alkalis or molten salts up to 800°C. It has low density of about 3.1 gm/cc, low thermal expansion, high elastic modulus, high strength, high thermal conductivity, high hardness, excellent thermal shock resistance and superior chemical inertness. This can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components.

Figure 1. Bi-directional Jute Fiber and Unidirectional Sisal Fiber
Fabrication of Composites

The fabrication of the various composite materials is carried out through the hand lay-up technique. The schematic diagram of hand layup technique is shown in figure 2 as follows. Sisal and Jute fibers are reinforced with Epoxy LY 556 resin, chemically belonging to the ‘epoxide’ family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The low temperature curing epoxy resin (Araldite LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Two different types of composites has been fabricated with same orientations with and without the addition of filler material. Each composite consisting of 30% of fiber and 70% of epoxy resin. Epoxy resin and hardener are weighed and mixed vigorously. It is fabricated with 300gms of fiber (2 layers of sisal 60gms & 3 layers of jute 90 gms), resin 700gms and hardener 10%. The orientation of both hybrids are shown below in figure 3. Suitable mould of dimension 300x300mm is taken. First of all releasing agent is applied for easy removal of finished composite. The mixture of resin and hardener is applied over the lay of releasing agent. Jute bidirectional mat fiber is placed over the lay of resin mix, once again resin is applied over the jute fiber and rolled using a roller to remove air bubbles. Unidirectional sisal fiber is placed above and once again resin is applied following the same procedure to remove air bubbles. Likewise alternate layer of bidirectional layer of jute fiber and sisal fibers are stacked one above the other. After the completion of fabrication, the composite is cured under a load of about 50 kg for 24 hours before it removed from the mould. Then this cast is post cured in the air for another 24 hours after removing out of the mould. Specimens of suitable dimension are cut using a diamond cutter for mechanical testing. Utmost care has been taken to maintain uniformity and homogeneity of the composite. The same procedure is followed for fabricating the second sample, the only difference is that, in this fabrication SiC filler material of about 10% is added to the resin mix to improve the mechanical properties. It is fabricated with 300gms of fiber (2 layers of sisal 60gms & 3 layers of jute 90 gms), resin 700gms and hardener 10% and SiC filler material 10%. The figure 4 shows the various processing steps involved in the preparation of samples. The figure 5 and 6 shows the prepared sample after hand layup technique.
Figure 3. Ply Orientation of Samples

Figure 4. Preparation of Samples.

Application of releasing agent  Place the jute fiber on the mould and apply resin  Place the sisal fiber over the jute and apply resin
Figure 5. Sample 1 without filler material

Figure 6. Sample 2 with filler material
Drilling of composites

Conventional drilling machine was used for drilling the composites specimens. Three types of drill tools such as spur, brad and straight flute of 10mm diameter is used for drilling the holes. The speed was varied as 500 rpm, 1000rpm and 1500 rpm. Since 8mm diameter tool was used in the drilling operation the cutting speed (peripheral) was kept in between 20m/min up to 60m/min. Most of the conventional machines operate in this range of cutting speed. Also if higher cutting speed is used, the matrix material which is soft may get softened due to the heat generated. The feed rate was also varied as 0.2mm/rev, 0.4mm/rev and 0.6mm/rev in this experiment. The tool material used in this experiment was HSS twist drill. The table 1 shows the drilling parameters used for machining and the corresponding responses after machining. The figure 7 shows the drilling setup used for this study. The drilled samples were shown in figure 8 and 9 respectively. Circularity of both the hybrids were measured by using video measuring machine as shown in figure 10. The surface roughness was measured by using surface roughness tester.

| Exp No | Tool Type | Spindle Speed (rpm) | Feed Rate (mm/rev) | Circularity | Surface Roughness |
|--------|-----------|---------------------|-------------------|-------------|------------------|
|        |           |                     |                   | With SiC     | Without SiC      |
|        |           |                     |                   | With SiC     | Without SiC      |
| 1      | Spur      | 500                 | 0.2               | 4.94/9.88   | 4.96/9.92       |
| 2      | Spur      | 1500                | 0.6               | 4.93/9.86   | 4.98/9.97       |
| 3      | Spur      | 1500                | 0.6               | 4.99/9.98   | 5.07/10.15      |
| 4      | Spur      | 1500                | 0.4               | 4.95/9.90   | 4.95/9.90       |
| 5      | Spur      | 1500                | 0.2               | 4.96/9.92   | 4.91/8.82       |
| 6      | St.Flute  | 1500                | 0.4               | 5.20/10.41  | 5.01/10.02      |
| 7      | St.Flute  | 1000                | 0.4               | 5.17/10.34  | 5.09/10.18      |
| 8      | St.Flute  | 1000                | 0.4               | 5.13/10.27  | 5.10/10.21      |
| 9      | St.Flute  | 1000                | 0.4               | 5.07/10.14  | 5.10/10.21      |
| 10     | St.Flute  | 1000                | 0.4               | 5.13/10.26  | 5.12/10.24      |
| 11     | St.Flute  | 1000                | 0.4               | 5.14/10.28  | 5.02/10.05      |
| 12     | St.Flute  | 1000                | 0.4               | 5.10/10.21  | 5.07/10.14      |
| 13     | St.Flute  | 1000                | 0.2               | 5.10/10.20  | 5.04/10.08      |
| 14     | St.Flute  | 1000                | 0.6               | 4.86/9.73   | 5.10/10.20      |
| 15     | St.Flute  | 1000                | 0.4               | 5.14/10.29  | 5.00/10.00      |
| 16     | Brad      | 1500                | 0.2               | 4.99/9.98   | 4.92/9.85       |
| 17     | Brad      | 500                 | 0.6               | 4.98/9.96   | 4.96/9.92       |
| 18     | Brad      | 1500                | 0.6               | 5.01/10.01  | 5.01/10.03      |
| 19     | Brad      | 1000                | 0.4               | 4.98/9.97   | 4.95/9.91       |
| 20     | Brad      | 500                 | 0.2               | 4.93/9.86   | 4.94/9.89       |

Figure 7. Drilling Machine setup
Figure 8 Drilled Sample (Hybrid 1)

Figure 9 Drilled Sample (Hybrid 2)
3. Results and Discussion

The parameters are optimized using Response Surface Methodology. The following steps are to be followed to generate optimum input parameters for machining of Hybrid laminated sheet using drilling. All preliminary tests are done and journals are studied in order to find out the machining parameters which are most influential in machining Hybrid laminated sheet. The levels of the input parameters are derived. After finding levels of parameters, design matrix as shown in Table 1 was prepared with the help of Design Expert V 7.0 software. Experiments were done as per the design matrix. Circularity is measured after making the drills with respective input parameters. Then the Surface Roughness was measured after each trial and all the data was recorded. The control parameters used in this study are shown in Table 2. Table 3 shows the factors with level values. Table 4 shows the ANNOVA for circularity with SiC. The figure 11 to 14 shows the graphs showing predicted vs actual values.

| No. | Factor A | Tool Type (mm) |
|-----|----------|----------------|
| 1   |          | Spur           |
| 2   |          | St.Flute       |
| 3   |          | Brad           |

Table 3. Factors with level values

| No. | Symbols | Machining parameters | Levels | Units |
|-----|---------|----------------------|--------|-------|
| 1   | A       | Tool Type            | Spur, St.Flute, Brad | mm     |
| 2   | B       | Speed                | 500, 1000, 1500 | rpm    |
| 3   | C       | Feed                 | 0.2, 0.4, 0.6 | mm/rev |

The Model F-value of 18.92 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 0.51 implies the Lack of Fit is not significant relative to the pure error. There is a 76.27% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.
### Table 4. ANOVA for circularity (With SiC)

| Source          | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|-----------------|----------------|----|-------------|---------|-----------------|
| Model           | 0.613          | 9  | 0.06811     | 18.9168 | < 0.0001        |
| A-Tool Type     | 0.00784        | 1  | 0.00784     | 2.17746 | 0.1708          |
| B-Speed         | 0.01444        | 1  | 0.01444     | 4.01053 | 0.0731          |
| C-Feed          | 0.00225        | 1  | 0.00225     | 0.62491 | 0.4476          |
| AB              | 0.00781        | 1  | 0.00781     | 2.16982 | 0.1715          |
| AC              | 1.25E-05       | 1  | 1.25E-05    | 0.00347 | 0.9542          |
| BC              | 0.00451        | 1  | 0.00451     | 1.25329 | 0.2891          |
| A²              | 0.19445        | 1  | 0.19445     | 54.0049 | < 0.0001        |
| B²              | 0.0571         | 1  | 0.0571      | 15.8577 | 0.0026          |
| C²              | 0.111          | 1  | 0.111       | 30.8295 | 0.0002          |
| Residual        | 0.03601        | 10 | 0.0036      |         |                 |
| Lack of Fit     | 0.01212        | 5  | 0.00242     | 0.50755 | 0.7627          |
| Pure Error      | 0.02388        | 5  | 0.00478     |         |                 |
| Cor Total       | 0.649          | 19 |             |         |                 |

![Graph representing predicted Vs actual values of circularity](image1)

**Figure 11. Graph representing predicted Vs actual values of circularity**

![Graph representing circularity vs Speed and Tool Type](image2)

**Figure 12. Graph representing circularity vs Speed and Tool Type**
The Model F-value of 3.06 implies the model is significant. There is only a 4.29% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.
The "Lack of Fit F-value" of 0.29 implies the Lack of Fit is not significant relative to the pure error. There is a 94.01% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

**Table 5. ANOVA for surface roughness (With SiC)**

| Source       | Sum of Squares | df | Mean Square | F Value | p-value | Prob > F |
|--------------|----------------|----|-------------|---------|---------|----------|
| Model        | 3.02646        | 6  | 0.50441     | 3.061283| 0.0429  | significant |
| A-Tool Type  | 0.1            | 1  | 0.1         | 0.606904| 0.4499  |           |
| B-Speed      | 0.42025        | 1  | 0.42025     | 2.550513| 0.1343  |           |
| C-Feed       | 0.41616        | 1  | 0.41616     | 2.525691| 0.1360  |           |
| AB           | 0.6962         | 1  | 0.6962      | 4.225264| 0.0605  |           |
| AC           | 0.5618         | 1  | 0.5618      | 3.409585| 0.0877  |           |
| BC           | 0.83205        | 1  | 0.83205     | 5.049743| 0.0426  |           |
| Residual     | 2.14202        | 13 | 0.164771    |         |         |           |
| Lack of Fit  | 0.682537       | 8  | 0.085317    | 0.292285| 0.9401  | not significant |
| Pure Error   | 1.459483       | 5  | 0.291897    |         |         |           |
| Cor Total    | 5.16848        | 19 |             |         |         |           |

**Figure 16.** Graph representing Surface Roughness vs Tool Type and Speed

**Figure 17.** Graph representing Surface Roughness vs Feed and Speed
Figure 18. Graph representing Surface Roughness vs Tool Type and Feed

The Model F-value of 5.97 implies the model is significant. There is only a 0.50% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case, C, A2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 0.50 implies the Lack of Fit is not significant relative to the pure error. There is a 76.92% chance that a
"Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Figure 19. Graph representing predicted Vs actual values of Circularity

Figure 20. Graph representing Circularity vs Tool Type and Speed

Figure 21. Graph representing Circularity vs Feed and Speed
Figure 22. Graph representing Circularity vs Tool Type and Feed

Table 8. ANOVA for Surface Roughness (Without Sic)

| Source       | Sum of Squares | df | Mean Square | F Value | p-value | Prob > F |
|--------------|----------------|----|-------------|---------|---------|----------|
| Model        | 2.32529        | 3  | 0.775097    | 4.322316| 0.0206  | significant |
| A-Tool Type  | 2.27529        | 1  | 2.27529     | 12.68812| 0.0026  |
| B-Speed      | 0.049          | 1  | 0.049       | 0.273248| 0.6083  |
| C-Feed       | 0.001          | 1  | 0.001       | 0.005376| 0.9414  |
| Residual     | 2.86919        | 16 | 0.179324    |         |         |          |
| Lack of Fit  | 1.317107       | 11 | 0.119737    | 0.38573 | 0.9127  | not significant |
| Pure Error   | 1.552083       | 5  | 0.310417    |         |         |          |
| Cor Total    | 5.19448        | 19 |             |         |         |          |

Figure 23. Graph representing predicted Vs actual values of Surface Roughness
Figure 24. Graph representing Surface Roughness vs Tool Type and Speed

Figure 25. Graph representing Surface Roughness vs Feed and Speed

Figure 26. Graph representing Surface Roughness vs Tool Type and Feed
The Model F-value of 4.32 implies the model is significant. There is only a 2.06% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 0.39 implies the Lack of Fit is not significant relative to the pure error. There is a 91.27% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

### Table 9. Solution (Without SiC)

| Number | Tool Type | Speed | Feed | Circularity | Surface Roughness | Desirability |
|--------|-----------|-------|------|-------------|-------------------|--------------|
| 1      | 2.92      | 710.91| 0.6  | 9.999983    | 0.533522         | 0.915819     |

### Table 10. Confirmation Test Results

| Parameters     | Units     | H1   | Conformation Test | H2   | Conformation Test |
|----------------|-----------|------|-------------------|------|-------------------|
| Tool Type      | mm        | 2.92 | 3                 | 2.99 | 3                 |
| Speed          | Rpm       | 710.91| 700               | 500  | 500               |
| Feed           | mm/rev    | 0.6  | 0.6               | 0.53 | 0.6               |
| Circularity    | Mm        | 9.99 |                   | 10   |                   |
| Surface Roughness | mm    | 0.533|                   | 0.577|                   |

**Conclusion**

In this study the composite laminates are created by reinforcing bi-directional bast type jute and unidirectional leaf made sisal fibers into an epoxy LY556 resin matrix material. The silicon carbide (SiC) is used as filler material. Two types of composite laminates are manufactured. The first sample is considered in the ratio of 70% epoxy resin to 30% Jute + Sisal fiber composition without any filler material. The second composition includes the ratio of 70% epoxy resin to 30% Jute + Sisal fiber along with 10% SiC as filler material. The hardner HY951 of 10% is used in both compositions. The machining operation was performed by using HSS twist drill for three different machining parameters (Drill bit type, Spindle speed and Feed rate). The circularity and surface roughness are considered as output parameters. The machining is performed in the range of 20 different combinations as directed by the RSM software. The conformation tests are carried out to validate the RSM results. The optimization results shows that the sample with SiC filler exhibits better machinability behaviour than sample without filler material.

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