CHAPTER 5

APPLICATION OF BORASSUS FRUIT FIBER REINFORCED EPOXY COMPOSITES

5.1 FABRICATION OF TWO WHEELER BUMPER

The green manufacturing is the present day global requirement. The composite materials are preferred in the engineering applications due to their key property of high strength to weight ratio. The synthetic fibers are conventionally used as reinforcements in composite materials. Unfortunately, the synthetic fibers are non-degradable and cause serious environmental concern. This has triggered the researchers to find new eco-friendly natural fibers for these applications wherever possible. Borassus fruit fibers are bio-degradable and eco-friendly in nature. They are of high specific strength and are low in density. They are available abundantly in nature and are renewable. Also less energy is consumed for the fiber extraction process. The microstructures of the natural fibers contain cellulose, hemicellulose, lignin, moisture, wax and other impurities. The fuel efficiency of automobiles can be improved by reducing the weight of the components. Two wheeler bumpers are usually made of stainless steel and Aluminum alloys. They add additional weight to the two wheelers. An attempt is made in this work to apply conceptual design methodology to identify the best two wheeler bumper design and fabricate light weight, low cost bio-based composite bumper by reinforcing naturally available Borassus fruit fibers in epoxy matrix.
5.1.1 Design and Fabrication Process

5.1.1.1 The design methodology of composite bumper

The design methodology starts from the need and ends with the product manufacturing. The needs are identified and the features to be incorporated in the new design are selected. The design methodology is shown in Figure 5.1.

![Diagram of the design methodology](image)

**Figure 5.1 Architecture of design methodology**
The conceptual design is the process of choosing the best concept among the several for the detailed design. The needs are identified based on the market study, through the literature, journals, patents and customer feedbacks. The outputs of the needs are condensed into product design specifications. The input of the product design specifications are shown in Figure 5.2. The conceptual design methodology for the manufacturing of two wheeler bumper was described. The design of Borassus fruit fiber reinforced epoxy composite bumper was also exemplified. Concept generation emerged during the brainstorming activity. The various possible concepts to meet the identified needs were developed at this stage. The concepts thus generated were suitably evaluated against product design specifications and the promising concept was selected. The selected concept was tested and the manufacturing of the product was initiated.

![Figure 5.2 Product design specifications of bumper](image)

5.1.1.2 Conceptual design of Borassus fruit fiber reinforced bumper

Conceptual design is the preceding step to the detailed design process after identifying the need. The brainstorming activity associated with creativity brings out possible alternatives as well as viable solutions. This decision making phase involves knowledge of science, manufacturability, skill and business aspects to select the best concept.
5.1.1.3 Concept generation

The concepts are generated based on the structured approach. This work instigated subsequent techniques to bring out the concepts. The various concepts which satisfy the needs were identified. The brainstorming activity was initiated based on continuous questioning and linked answers for the problem chosen. The technical and commercial viability were taken into consideration during this stage. The ideas were converted as drawings that identify the structure. The questions which need to be resolved while making commercial products were also recorded before proceeding.

5.1.1.4 Concept selection

Those ideas which were found not feasible were removed. Some ideas were clubbed together to suit new ideas. The morphology chart is the solution chart, which contains all possible solutions to a particular problem. The concepts thus emerged were modeled with the help of modeling software. After careful considerations six ideas were created, modeled and recorded (Figure 5.3).

![Concepts C1-C6](image)

Figure 5.3 Two wheeler bumper - Concepts C1-C6
5.1.1.5 Concept evaluation

The six concepts identified were modeled with the help of 3D modeling software and recorded in the evaluation table. The weighted objective method mentioned below was employed to evaluate the concepts. Each concept was evaluated against the product design specifications and the scores were assigned by this method. The scores were allotted as follows,

\[ N_j = \sum_{i=1}^{n} s_{ij} w_i \]  \hspace{1cm} (5.1)

where

- \( N_j \) = Total score of concept j
- \( w_i \) = Weight value for the \( i^{th} \) criterion
- \( s_{ij} \) = Rating of the concept j for the \( i^{th} \) criterion
- \( n \) = Number of concepts

The weight values for each product design specifications were arrived at. For each concept utility score was assigned. The product values of the weight function and the utility scores were recorded. These values were summed up together to find the total values of each concept. Based on the total scores, the concepts were ranked and the best concept was identified for the fabrication of Borassus fruit fiber reinforced composite bumper. Here concept 3 (C3) emerged as the promising concept since it scored a higher value than the others (Table 5.1). The utility values and the weight scores were assigned based on expertise. The conceptual design methodology thus employed total scores as a factor for ranking the concepts.
Table 5.1 Weighted objective table for evaluation of bumper concepts

<table>
<thead>
<tr>
<th>PDS</th>
<th>Weight</th>
<th>Concept1</th>
<th>Concept2</th>
<th>Concept3</th>
<th>Concept4</th>
<th>Concept5</th>
<th>Concept6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S  V</td>
<td>S  V</td>
<td>S  V</td>
<td>S  V</td>
<td>S  V</td>
<td>S  V</td>
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<td>Cost</td>
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<td>10 1</td>
<td>6 0.6</td>
<td>10 1</td>
<td>8 0.8</td>
<td>7 0.7</td>
<td>9 0.9</td>
</tr>
<tr>
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<td>10 1</td>
<td>8 0.8</td>
<td>9 0.9</td>
<td>8 0.8</td>
<td>8 0.8</td>
<td>10 1</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0.15</td>
<td>7 1.05</td>
<td>7 1.05</td>
<td>10 1.5</td>
<td>9 1.35</td>
<td>7 1.05</td>
<td>8 1.2</td>
</tr>
<tr>
<td>Weight</td>
<td>0.15</td>
<td>10 1.5</td>
<td>9 1.35</td>
<td>10 1.5</td>
<td>9 1.35</td>
<td>9 1.35</td>
<td>10 1.5</td>
</tr>
<tr>
<td>Ease of assembly</td>
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<td>10 1</td>
<td>9 0.9</td>
<td>10 1</td>
<td>10 1</td>
<td>10 1</td>
<td>10 1</td>
</tr>
<tr>
<td>Performance</td>
<td>0.15</td>
<td>8 1.2</td>
<td>9 1.35</td>
<td>10 1.5</td>
<td>9 1.35</td>
<td>9 1.35</td>
<td>8 1.2</td>
</tr>
<tr>
<td>Stability</td>
<td>0.10</td>
<td>7 0.7</td>
<td>8 0.8</td>
<td>10 1</td>
<td>7 0.7</td>
<td>7 0.7</td>
<td>7 0.7</td>
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<tr>
<td>Complexity</td>
<td>0.15</td>
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<td>7 1.05</td>
<td>9 1.35</td>
<td>8 1.2</td>
<td>8 1.2</td>
<td>8 1.2</td>
</tr>
<tr>
<td>Total utility value</td>
<td>1.0</td>
<td>72 8.95</td>
<td>63 7.9</td>
<td>78 9.75</td>
<td>68 8.55</td>
<td>65 8.15</td>
<td>70 8.7</td>
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<td>Ranks</td>
<td></td>
<td>2 6</td>
<td>1 4</td>
<td>5 3</td>
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<td></td>
</tr>
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</table>

*S-Score, V-Value
5.1.1.6 Fabrication of light weight composite bumper

The alkali treatment of the fibers removed the hemicellulose, lignin and other impurities from the fiber surface and made the fiber surface rough. This led to better fiber matrix interface, fiber wetting characteristics and bonding. 5% alkali treatment to the fibers favouring better mechanical properties to the Borassus fruit fibers. The Borassus fruit fibers were washed in water to remove any short fibers and particulates. They were dried at room temperature for 48 hours. The fibers were soaked in 5% Sodium hydroxide (NaOH) solution for half an hour at room temperature. The fibers were neutralized with 2.5% Hydro Chloric acid (HCl) solution. The fibers were washed with distilled water and dried at room temperature for 24 hours.

The matrix material preferred was epoxy since it offers excellent adhesion, low shrinkage and there will not be any volatile matters during curing. At elevated temperatures also, they offer better performance. The matrix used for fabricating the composite was epoxy LY556 of density 1.15 g/cm$^3$ and hardener HY951 of density 0.98 g/cm$^3$. The weight ratio for the mixture of epoxy and hardener was 10:1.

The two halves of the Galvanized Iron mould namely male and female moulds were prepared. The moulds were covered with anti-adhesive sheet to prevent sticking of composites to the mould surface. The moulds were prepared in such a manner that the male and female moulds can be clamped together after moulding (Figure 5.4).
The 5 mm length Borassus fruit fiber reinforced composites yielded better mechanical properties. Hence, it was decided to reinforce 5 mm length 5% alkali treated Borassus fruit fiber in epoxy to make the bumper. The 5 % alkali treated Borassus fruit fibers were cut into the required length of 5 mm. The epoxy resin with hardener was thoroughly mixed with the required fibers in the ratio of 65:35. The fiber resin mixture was spread uniformly in the male and female moulds upto the required thickness. The moulds were carefully clamped together. The mould was kept in an oven at a temperature of 60 °C to remove void contents and to make sure uniform wetting. The mould was allowed for curing up to 24 hours. The bumper was removed from the mould (Figure 5.5).

Concept 1 also emerged as a promising concept with rank 2. Hence, this concept (C1) was implemented and the mould was prepared as shown in Figure 5.6. As like concept 3, this mould also consisted of two halves and both could be clamped together after moulding. The 5 mm length 5% alkali treated Borassus fruit fiber was used as reinforcement in epoxy and in a similar manner as discussed above, the bumper was made. The bumper was fitted to the two wheeler (Figure 5.10).
Figure 5.5 Borassus fruit fiber reinforced composite bumper (C3)

Figure 5.6 Bumper mould (C1)

Figure 5.7 Bumper mould covered with anti-adhesive sheet (C1)
Figure 5.8 Borassus fruit fiber-epoxy composite bumper moulding (C1)

Figure 5.9 Machining of Borassus fruit fiber-epoxy composite bumper (C1)

Figure 5.10 Borassus fruit fiber-epoxy composite bumper fitted in two wheeler (C1)
5.2 FABRICATION OF TUMBLER GEAR

Tumbler gears are interposed between spindle and stud gears in a lathe gear train and are used to reverse the rotation of lead screw or feed rod. They are conventionally made of Grey cast iron. After a thorough study of tribological characteristics of Borassus fruit fiber-epoxy composites, it was decided to manufacture tumbler gear with this new composite material.

Figure 5.11 a Line diagram of tumbler gear mechanism of lathe
Figure 5.11 b Pictorial view of tumbler gear mechanism of lathe

The specifications of the required tumbler gear are given as follows.

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Specification</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diametric Pitch</td>
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</tr>
<tr>
<td>2</td>
<td>Number of teeth</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>Outer Diameter</td>
<td>79.375 mm</td>
</tr>
<tr>
<td>4</td>
<td>Root diameter</td>
<td>72.152 mm</td>
</tr>
<tr>
<td>5</td>
<td>Pitch Circle Diameter</td>
<td>76.2 mm</td>
</tr>
<tr>
<td>6</td>
<td>Addendum</td>
<td>1.587 mm</td>
</tr>
<tr>
<td>7</td>
<td>Deddundum</td>
<td>1.83 mm</td>
</tr>
<tr>
<td>8</td>
<td>Depth of cut</td>
<td>3.424 mm</td>
</tr>
<tr>
<td>9</td>
<td>Clearance</td>
<td>0.24 mm</td>
</tr>
<tr>
<td>10</td>
<td>Pressure angle</td>
<td>20°</td>
</tr>
<tr>
<td>11</td>
<td>Thickness of gear</td>
<td>16 mm</td>
</tr>
</tbody>
</table>

5.2.1 Fabrication process

Epoxy resin and Borassus fruit fibers were mixed with the ratio of 65:35. The removal of surface impurities from the fiber due to 5% alkali treatment favored better fiber matrix adhesion and hence bonding. The 5% alkali treated Borassus fruit fibers were cleaned, dried and chopped into 5 mm
fiber length. Borassus fruit fibers and epoxy resin were mixed thoroughly. The mould was made from cast iron block with 84 mm diameter and 20 mm thickness. The mould was covered with anti-adhesive sheet to prevent the sticking of matrix with the mould during removal. The Borassus fruit fiber-epoxy matrix was spread uniformly over the mould up to the required thickness and was gently pressed for the compact packing. The mould was kept in an oven at a temperature of 60 °C to remove void contents, to make sure uniform wetting and allowed for curing up to 24 hours under compressive load. The gear blank was removed from the mould.

**Figure 5.12 Tumbler gear mould (Cast Iron)**

**Figure 5.13 Tumbler gear mould covered with anti-adhesive sheet**
Figure 5.14 Borassus fruit fiber-epoxy tumbler gear blank moulding

Figure 5.15 Borassus fruit fiber-epoxy tumbler gear blank

Figure 5.16 Borassus fruit fiber-epoxy tumbler gear
The Borassus fruit fiber-epoxy composite gear blank was then machined to the required specifications in a milling machine. Better dimensional accuracy was achieved during machining and the tumbler gear with precise dimension was made. The Grey cast iron tumbler gear of lathe was replaced by this gear and it functioned effectively without wear. The weights of both the gears were measured and the result showed that the weight of the tumbler gear was reduced up to 85% than the conventional gear. Weight of the Grey cast iron tumbler Gear is 433.62 g and the Weight of the Borassus fruit fiber – Epoxy composite tumbler Gear is 54.96 g. The cost of the gear is also reduced upto 50 % and this may further be reduced during mass production. The Friction coefficient values at dry sliding for Grey cast iron is 0.2, whereas for 5% alkali treated Borassus fruit – epoxy composite is 0.3-0.35. Also the tensile strength for Grey cast iron is 150-250 MPa and for Borassus fruit – epoxy composite is 159.5 MPa. The Rockwell hardness value of the Grey cast iron is B90 and Borassus fruit-epoxy composite is B70.
The comparison conveyed that the 5 mm length alkali treated Borassus fruit fiber reinforced gears have properties similar to that of conventional Grey cast iron gear. Hence, they may be applied in the low load bearing applications like tumbler gears.

5.3 FABRICATION OF PORTABLE GAS CYLINDER

The domestic gas light cylinders are made of steel sheets. These gas cylinders are used to store the Liquefied Petroleum Gas inside them above atmospheric pressure. The weight of the domestic gas cylinders can be reduced by reducing the weight of the cylinder. The conventional steel sheets are damaged during the prolonged use and handling. Corrosion is also a problem in the conventional steel cylinders. The Borassus fruit fiber – epoxy composites eliminated all these drawbacks when they replaced the conventional steel gas light cylinders. Hence, it was decided to manufacture the Borassus fruit fiber – epoxy cylinder for this application.

Epoxy resin and Borassus fruit fibers were mixed in the ratio of 65:35. The 5% alkali Borassus fruit fibers were cleaned, dried and chopped into 5 mm fiber length. Borassus fruit fibers and epoxy resin were mixed thoroughly. Wax was melted and moulded into a solid shape. Then the wax was machined to the required shape and dimension as shown in Figure 5.18. Then the wax is placed in a bottom mould in which the clearance was maintained equal to the thickness of the cylinder shell. The Borassus fruit fiber- epoxy matrix was spread and packed in this clearance area. The matrix was applied over the top surface of the wax mould and the top plate was placed in its position. The top plate was clamped tightly with the help of bolt and nuts as shown in the Figure 5.19.
Figure 5.18 Wax mould

Figure 5.19 Moulding with top plate in clamped position

Figure 5.20 Gas cylinder blank
Figure 5.21 Gas cylinder blank under semi-finished condition

Figure 5.22 Gas cylinder blank under leakage testing

Figure 5.23 Borassus fruit fiber -epoxy composite gas cylinder in application
24 hours curing time was allowed with the clamping pressure of the top plate and bottom plate. Afterwards the gas cylinder block was carefully removed from the mould (Figure 5.20). The gas cylinder block was machined to the suitable dimension. The wax was removed from the cylinder block by the exposure of the same to boiled water. The extra projection on the top surface was cut to the required dimension. Then necessary finishing operation was made and primer coating was given before painting (Figure 5.21). The expected pressure of Liquefied Petroleum Gas inside the cylinder is 2.7 bar. The gas cylinder was tested for any leakage by passing 3 bar pressure air inside and immersing the cylinder in water (Figure 5.22). The gas cylinder was painted aesthetically and the accessories assembled together to get domestic gas light for use (Figure 5.23).

5.4 FABRICATION OF DOOR MODEL

The Borassus fruit fiber-epoxy composites finds applications in plated structural applications also. Fiber reinforced polymeric composites have received widespread attention in the past four decades because of their high specific strength and modulus. The main reason for many potential users to choose a natural fiber reinforced composite is because of the assumed environmental benefits that these materials can provide. The general feeling of many people on materials like Borassus fruit fiber is that they will be friendly for employees in the processing industry, for instance, giving no skin irritation like glass fiber. Wood has been a convenient and traditional material to use, but it is limited in strength and weight. Also, the weight of the wooden door can be considerably reduced by imparting Borassus fiber-epoxy composites in this application. Moreover, the wooden door materials are damaged during their life time due to pests and insects. The replacement of conventional wooden materials in plated structural applications like door panels, avoids all these drawbacks discussed above. Hence, it was decided to manufacture a wooden door model with the help of Borassus fruit fiber-
epoxy composites. The 5% alkali treated Borassus fruit fibers were cleaned, dried and chopped into 5 mm fiber length. Epoxy resin and Borassus fruit fibers were mixed thoroughly in the ratio of 65:35. The door model mould was prepared in plywood material and was cleaned (Figure 5.24). The mould was covered with anti-adhesive sheet to prevent the sticking of the matrix material with the mould surface. The Borassus fruit fiber- epoxy matrix was spread uniformly over the mould. Gentle pressure was applied to allow the entrapped air to escape and for compact moulding (Figure 5.25). The mould was kept under compressive load for curing upto 24 hours. The door panel was then removed from the mould, cleaned and finished (Figure 5.26). The primer coating and the painting was done for aesthetic appearance.
5.5 FABRICATION OF SOLID ROD MODEL

The machining characteristics of the natural fiber reinforced polymers need to be explored. The Borassus fruit fiber-epoxy composites are lighter in weight and are of high strength. By exploring the machining characteristics of these composites, they can cater to any complicated shaped applications. As an attempt it was decided to manufacture a solid rod and subject the same to different machining operations.

5% alkali treated Borassus fruit fibers were cleaned, dried and chopped into 5 mm fiber length. Epoxy resin and Borassus fruit fibers were mixed thoroughly in the ratio of 65:35. The matrix was loaded in the tubular mould. Anti-adhesive coating was applied to prevent the matrix from sticking to the mould surface. The mould was kept in an oven at a temperature of 60 °C to remove void contents. After 24 hours curing the solid rod was removed from the mould.

Figure 5.26 Borassus fruit fiber -epoxy composite door
The different machining operations like turning, facing, step turning, parting off, threading and knurling were done on the solid rod. The dimensional stability was monitored and it was found to be satisfactory. It was concluded that the Borassus fruit fiber – epoxy composites are capable of being subjected to all types of machining operations and can be machined to any complicated shape.

![Borassus fruit fiber -epoxy composite solid rod subjected to machining operations](image)

**Figure 5.27  Borassus fruit fiber -epoxy composite solid rod subjected to machining operations**

Summary: The application products made from Borassus fruit fiber reinforced Epoxy composites are rigid, light in weight, aesthetic. The products can be machined and finished to the expected shape and size. The outcomes will be helpful in developing various economically and commercially viable products with the help of Borassus fruit fiber reinforced Epoxy composites.