Development, Manufacturing and Testing of a Steering Wheel Prototype Processed Out of Banana Fibre Composites

Vyankatesh Deokar[1], Vinay Gumma[2], Pratik Bhagwat[3], Akshay Dange[4]

[1,2,3,4]*Student, Dept. of Mechanical Engineering, PCCoE, Pune*

Abstract - Composites industry is flourishing in today's world for its application being made in automobile, aeronautics, shipping, energy sectors and many others. Automotive sector has already embraced use of natural fibers to replace many of its existing components to reduce weight, reduce cost and improve fuel efficiency.

This project deals with developing, manufacturing and testing of a steering wheel prototype processed out of natural fibres. It includes selection of materials for replacement by weighted point method considering all the parameters of selection. The project also shows the FEA analysis done and finalizing the layup pattern. The project also includes manufacturing and testing of this project. This project intends to come up with a steering wheel made out of banana fibre composites which will contribute in lowering weight and cost of the component, ultimately increasing fuel efficiency and promoting eco-friendliness.

***Key Words*: Bio-Composite, Banana Fibre, Steering wheel, ASTM D638, Bio-composites Analysis.**

1. INTRODUCTION

Composite industry is slowly grabbing a strong hold over the manufacturing sector. You can see traces of composites replacing conventional materials and delivering equal performance. Composite materials are predominantly preferred for their high strength to weight ratio. Plastics have also emerged as a successful alternative to material replacement owing to their low cost and low weight. But due to its non degradable nature and increasing threat to nature, it fails to be a successful option in the future. This is where Bio-composites come into picture. Using naturally available fibres or reinforcements can help in contributing towards making a greener earth.

A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite possesses superior properties which are not obtainable with a single constituent material. So, in technical terms, we can define a composite as 'a multiphase material from a combination of materials, differing in composition or form, which remain bonded together, but retain their identities and properties, without going into any chemical reactions.' The components do not dissolve or completely merge. They maintain an interface between each other and ad in concert to provide improved, specific or synergistic characteristics not obtainable by any of the original components acting singly. Bone is a simple example of a natural composite material having the best properties of its constituents. Bone must be strong and rigid; yet flexible enough' to resist breaking under normal use. These requisite properties are contributed by its components. A mature bone is made up of two basic kinds of materials--organic and inorganic. The organic component, consisting mostly of proteins, carbohydrates and fats, makes it pliable and gives the required softness. The inorganic component, made up of calcium phosphate, gives it the required strength and rigidity. [11]

The most common synthetic composite material is glass fibre reinforced plastics (GRP) which is made out of plastics and glass fibre. The individual components have altogether different properties to that of the composite material, GRP. Plastics are light, durable, have excellent corrosion resistance and can be easily molded to any complex shape. But they are not fit for load-bearing applications because of lack of sufficient strength, stiffness and dimensional stability. Glass fibre, on the other hand, possesses very high strength and is sufficiently stiff and durable. Like plastics, it also cannot be used for load bearing applications because of its brittleness and fibrous structure. But when both these are combined in the correct proportions and a particular glass fibre arrangement, we obtain GRP which has improved mechanical and other properties suitable for load bearing applications.

2. SCOPE OF THE PROJECT

2.1. To reduce the weight of automobile [5][2][1]

Composites are used successfully in automobile industry for reducing the weight of the car. Reduction of weight in structural applications in a car may go up to 50kg alone, which includes:

- Bumper carriers
- Pedestrian beam
- Engine cradle
- Front end carrier
- Instrumental panel
- Seating
- Hatchback structure and many more

While as far as the interior is considered, reduction in weight due to use of bio composite may go upto 8kgs, which includes:

- Panel toppers
- Tunnel cover
- Door panel inserts
- Head liners
- Parcel shelves
- Load floors
- Seat back cover
- Trunk liner and many more

If we consider a car made up of conventional material, weighing 1000kg, and if same car is manufactured using composite materials it would weigh 940kg i.e. up to 60kg weight can be reduced; which implies that up to 6% of weight is reduced from all above applications.

Now consider a steering wheel which weighs 2.5 – 3 kg made up of conventional material, if same steering wheel is manufactured by using bio composites, we can achieve 50% of weight reduction i.e. it would weigh only 1 - 1.4 kg. So, we would achieve overall weight reduction of 0.4 – 0.5 % only by one application.

2.2 To enhance fuel efficiency [6][2]

Reduction of 10% of weight in an automobile leads to increase in fuel efficiency by 7%. Now by considering that 60 kg reduction due to bio composite in vehicle leads to 6% decrease in weight which implies 4.2% increase in fuel efficiency.

Now if we consider only for steering wheel that reduces the weight by 0.5%,it will increase fuel efficiency by 0.35%.

2.3 To reduce manufacturing cost

The commercial manufacturing cost of conventional steering wheel is Rs. 1000-1200. Cost reduction of 50-60% can be achieved by the bio-composite steering wheel.

Table -1: Estimated Cost of Project

Sr no.	Expenditure	Cost/ wheel (in Rs.)
1.	Banana fibre	25
2.	Resin + Hardener	50
3.	MDF Wood	18
4.	VMC cost	70
5.	Labour cost	112
6.	Miscellaneous	150
		Sum = 425

2.4. To promote the use of bio items[1]

Increasing demand for conventional material has increased the pollution and global warming. To counter check this it is necessary to shift to the renewable and non polluting materials that are bio composite. Bio material can be easily broken down during disposal. And also strict norms for pollution on automobile industry intends to use natural materials to reduce the pollution and as well as to increase the fuel efficiency.

3. DESIGN

3.1 Selection of steering wheel

Maruti Suzuki WagonR steering wheel is selected for project purpose.

Reasons for selecting WagonR's steering wheel are:

- Commercial vehicle
- Best seller car of the class.
- Easily available.

3.2 Force Analysis

There will be two types of forces acting on steering wheel

- Tangential Force :-

It is the force which will act on outer edge of steering wheel and due to this force, automobile steers.

Fig -1: Tangential force analysis

The figure shown above indicates how the force was calculated to steer the steering wheel to full steer.

Initially, a weighing spring balance was tied to steering wheel and then steering wheel was rotated to full steer. Maximum reading obtained was of 15 kg from one side of steering wheel. Now, this force was split into half to both sides. And couple was calculated as shown in figure.

Couple = R*mg = 173*(7.5 +7.5)*10 = 26 Nm.
Where R= radius of wheel = 173 mm.

- Braking Force :-

This force acts on steering wheel during braking of automobile due to inertia of driver. This force acts perpendicular to the surface of the steering wheel. The driver is constrained to the seat with the seat belts.

In our analysis we have considered the force of 300 N on steering wheel.

3.3 Material Selection

Selection of resin :-

Types of resins are :
1. Epoxy resin
2. Polyester resin
3. Vinyl-ester resin

Epoxy resin is been selected for the project commencement on the following basis:
Advantage of epoxy resin over polyester and vinyl-ester resins are [11][10] :-

- Better adhesive properties. (the ability to bond to the reinforcement or core)
- Superior mechanical properties (particularly strength and stiffness)
- Improved resistance to fatigue and micro-cracking
- Reduced degradation from water ingress. (diminution of properties due to water penetration)
- Increased resistance to osmosis. (surface degradation due to water permeability)

Selection of natural fibre :-

There are many types of natural fibers available with distinct properties which make them unique. Following table encompasses fibers and its properties:-

Table -2 :- Property Table

Marks allocated for weighted point method	20	25	25	15	15
Natural Fibre	**Density (g/cm^3)**	**Tensile Strength (MPa)**	**Modulus (GPa)**	**Cost (/Kg)**	**Availability**
Bamboo	0.6 – 1.1	140 – 230	11 – 17	250	Pune
Jute	1.3 – 1.35	200 – 460	20 -55	60	Pune
Banana	1.3 – 1.35	530 – 914	27 – 32	100	Pune
Sisal	1.5	100 – 800	9 – 12	280	Pune
Coir	1.2	240	4 - 6	20	Pune
Hemp	1.5	690	30 – 70	700	Chennai
Abaca	1.5	980	41	1000	N.A.
Flax	1.5	350 – 1040	28 – 70	200	Chennai

From above table we got properties and cost of different natural fibres.

Natural fibre was shortlisted on the basis of weighted method. Method is as follows:

Table -3: Weighted point method

	Density (20)	**Tensile strength (25)**	**Modulus (25)**	**Availability (15)**	**Cost (15)**	**Total**
Bamboo	20	9	6	15	13	63
Jute	18	13	18	15	14	78
Bana	**16**	**24**	**11**	**15**	**14**	**80**

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Sisal	7	20	7	15	13	62
Coir	14	9	2	15	15	55
Hemp	7	18	25	7	9	66
Abaca	7	24	15	0	5	51
Flax	7	25	25	7	13	77

From above table it can be concluded that banana is better fit for the purpose. As it has highest weight age.

3.4 Manufacturing of test specimen

Need of testing the specimen :-

When FEA analysis is to be performed for an anisotropic material it is mandatory to feed the value of Tensile strength in X, Y, Z directions, Shear strength in different planes, and also the modulus of the material.

So, as to go ahead with the FEA analysis it is most needed to perform test on specimen and to find out directional properties of the composite.

Test Specimen[7][8] :-

Testing specimen was manufactured and tested by conforming to ASTM D638 type1 standard. This standard is used for testing a composite for tensile strength. Specification of dimension for ASTM D638 code is as follows:

Table -4: ASTM D638 type1 standard specification[6]

Parameter's	ASTM D638 Type 1 All in mm
Full length, L3	165
Parallel length, L2	57
Gauge length, L1	50
Paralle section width	13
Thickness, h	<= 7mm
Grip section width	19
Distance between grips	115

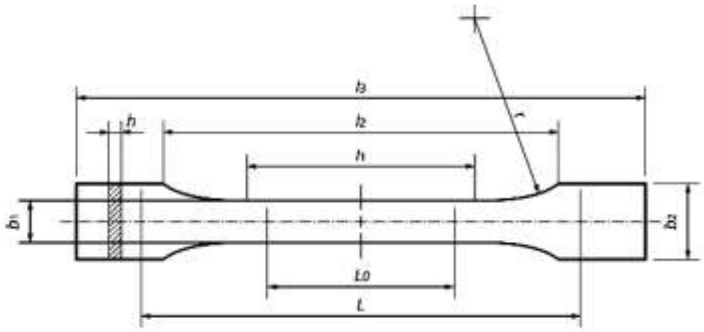

Fig -2: ASTM D638 specimen standard[6]

Mould Making :-

Mould was manufactured out of Styrofoam. 1cm thick foam was stuck on a ply such that it formed the negative image of test specimen conforming to the ASTM D638 standard. Then it was filled by putty to the level of 4mm from bottom. So that we can have 6mm left from top which results into 6mm thick specimen for testing.

Fig -3: Mould of test specimen

Manufacturing of specimen :-

60/40 fibre to resin weight ratio is used for preparing specimen because [11] –

Strength of composite is entirely dependent on fibre % in composite. But it is highly ineffective when it is not fully coated by resin. So, it is important to find the optimum mixture percentage which is highly dependent on manufacturing processes. Various combinations may lead to varying amount of imperfections and air inclusions. According to industrial practices 60/40% fibre to resin by weight is kept. In hand layup FVF's is kept between 30-40% while in higher quality and precise manufacturing process FVF's about 70% is kept.

Test specimen was hand-laid in the cavity of the mould. Several layers of fibres were laid and mixture of resin and hardener was applied on them. This specimen was left for curing at room temperature for a day. Then it was removed and post processed.

Fig -4: Test specimen

3.5 Testing

Testing was done on 3 specimen oriented in 3 directions [6][7][8]

1. X-direction (0° orientation)
2. Y-direction (90° orientation)
3. 45°orientaton

According to ASTM D638 standard, test was carried on three prototype of above mentioned directions.

In X direction :

Mean values of three X oriented specimen are as follows :-

- Tensile strength in X direction is 34.57 Mpa.
- Young's modulus is 5.3 Gpa.
- Modulus of rigidity in XY and XZ is 1.2 Gpa.

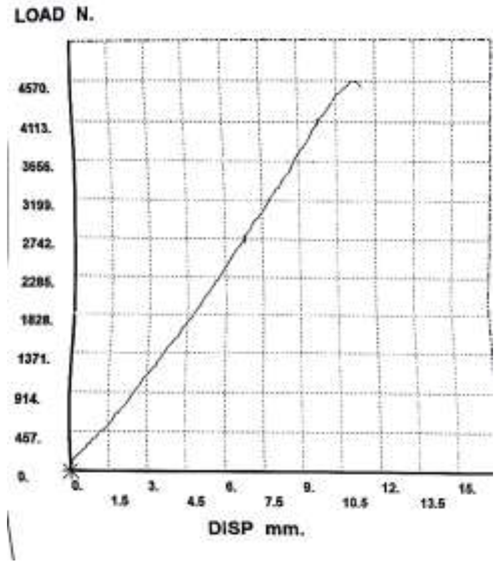

Fig 5 :- Graph of tensile test in X direction

In Y direction :

Mean values of three Y oriented specimen are as follows:-

- Tensile strength in Y/Z direction is 9.681 Mpa.
- Young modulus in Y/Z direction is 1.99Gpa.
- Modulus of rigidity in YZ is 1.2 GPa

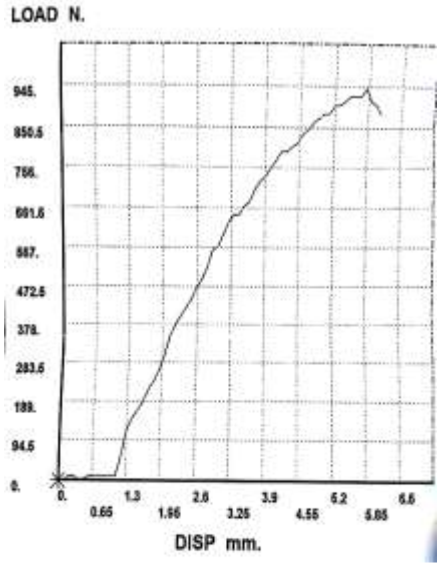

Fig 6 :- Graph of tensile test in Y direction

In 45⁰ Orientation :

Mean values of three 45⁰ oriented specimens are as follows:-

- Tensile strength in X direction is 10.098 Mpa.
  Now as per the theory, for 45° orientation
  Shear stress= tensile strength/2

Therefore, shear strength is 5.05 Mpa.

- Shear strength in xy plane is 4.518 MPa

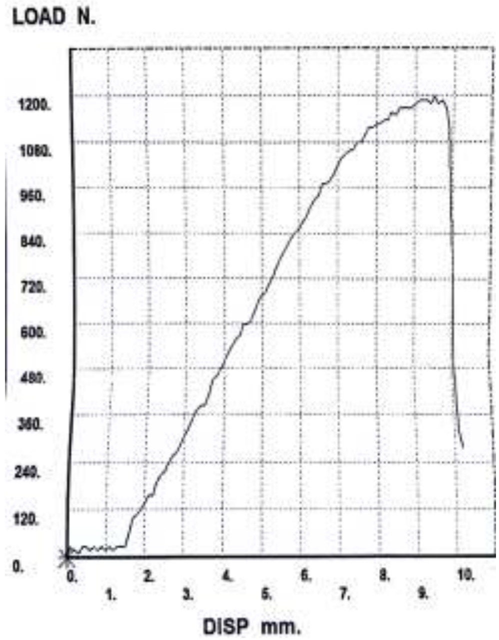

Fig 7 :- Graph of tensile test in 45^o direction

3.6 45^0 shear stress theory

A tension test on [+-45^o] laminate is popularly used test for the measurement of in-plane shear modulus G_{12}.

When a [+-45^o] is subjected to axial tensile stress σ_{xx} then stresses in principal material coordinates developed in each of the +45^o and -45^olamina. For a special case with Θ = 45^o we get the shear stress as,

$$\tau_{12} = (\pm\theta) = \mp \frac{\bar{\sigma}_{xx}}{2}$$

Need of FEA :-

Advantages of Finite Element Analysis (FEA):

- Main advantage of FEA is "**Virtual Testing**"
- Problems can be solved even there is no prototype or product is available. Which means the problems can be solved in the conceptual phase from CAD model itself.
- Car steering crash test, pedestrian safety test can be carried out without a produced car. It can be done by FEA
- Predict the Stress concentrations, Strains and displacement (Static analysis) for complicated structures.
- Good visualization of structural behavior and failure under various loading conditions
- Increased accuracy of solutions to the complex real time problems.
- Optimized structures(Light weight structures, Slimmest products like Mobile, Laptop, Cars)
- Better insight into critical design parameters (Weight, Strength, Cost)
- Fewer hardware prototypes (Physical prototypes) required in the testing phase to correlate the FEA results
- Faster and less expensive design cycle (R&D, Design, CAE, Production, Testing)
- Increased productivity

a) These tests can be done from CAD model, based on FEA Results CAD Design can be updated can be tested in FEA.
b) The process can be repeated number of times, until we have achieved the satisfactory results.
c) Then we can produce few Prototypes, and test it with optimized design.
d) If we are testing the physical model, that is having failure, then the design needs to improve.

Fig 8 :- CAD surface model

Ansys software was used for FEA analysis. ACP Pre-Post module was used for analysis as it is dedicated purely for composite applications only.

Fig 9 :- Ring fibre direction

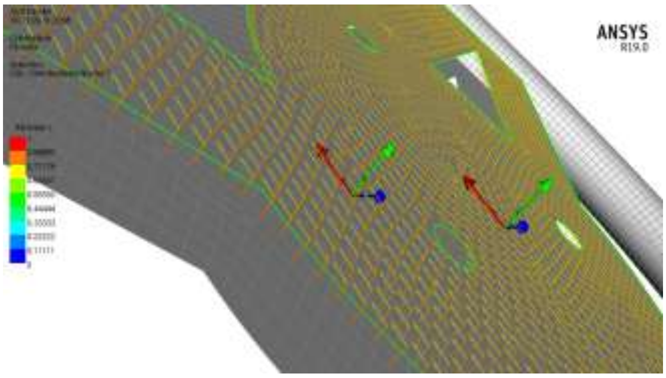

Fig 10 :- Y section fibre layup direction

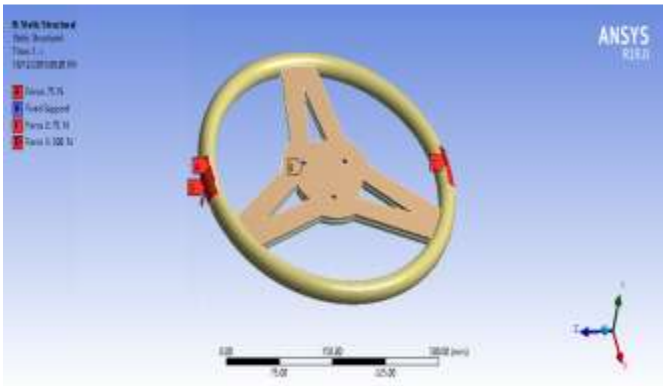

Fig 11 :- Free Body Diagram

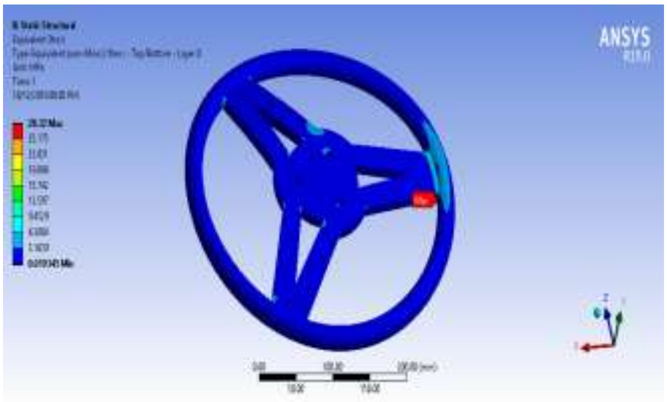

Fig 12 :- Stress induced (Max. value = 28.32MPa)

Fig 13 :- Deformation (Max. value = 1.175, mm)

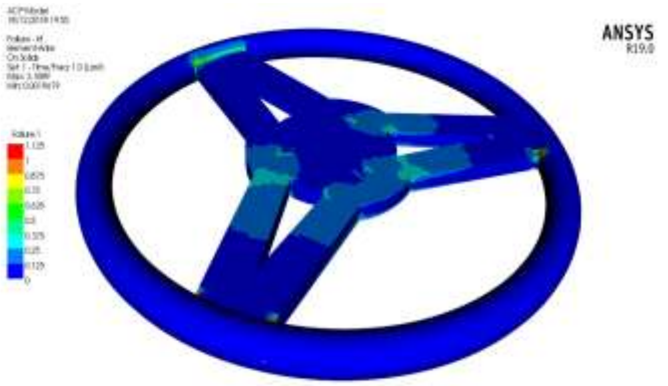

Fig 14 :- Failure index(max. value = 1.1)

4. MANUFACTURING OF STEERING WHEEL

4.1 Mould Making

Design of mould :-

A negative replica of the finalized steering wheel was developed in a CAD model. This replica would serve as the mould for the desired product.

A two piece mould was designed accordingly. Both the halves were identical and had holes on the corners for combining the two halves by bolts with proper alignment. Draft angles were also provided for easy Demoulding of the product.

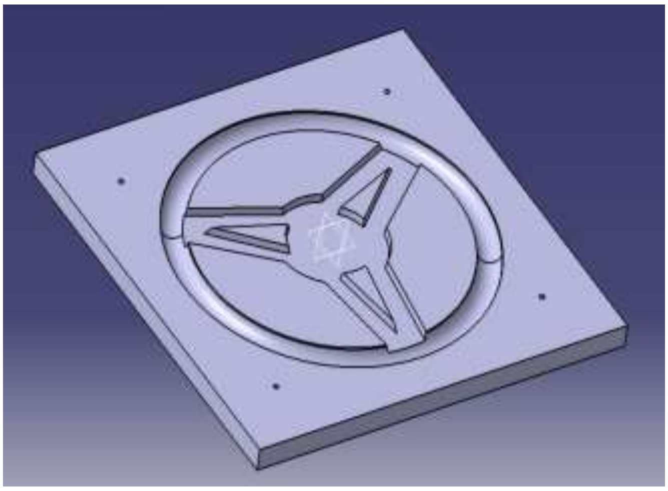

Fig 15 :- CAD model of mould

Material of mould :-

The mold is one of the major components in the processing of any composite product. The accuracy and finish of the mould is reflected on to the product processed out of it.

So the material to be chosen for mold manufacturing is important. There are multiple options for mould materials such as MDF wood, Polystyrene or High density foam, Glass fiber composites, PVC foam, etc.

Depending upon the type of application, the material for the mould can be finalized. For single type use, foam could be a better option. But for multiple uses, MDF wood is a better option for its sustainability and sturdy nature.

MDF wood was selected as the material for mould manufacturing for:

1. Good machinability.
2. High surface finish.
3. Sturdy in nature.
4. Cheap.
5. Easy availability.

Machining of mould :-

The machining of the mould was done on CNC machine as per the design of the mould.

Fig 16 :- Machined mould on MDF wood

Mould finishing :-

Generally moulds (after its manufacturing phase) don't possess smooth surface finish which is purely required for a good quality product. So, to achieve that kind of finish, there are some operations that are to be performed on mould those can be; sanding and applying putty etc. These processes are repeated till the required finish is achieved.

Putty application consists of two layers, the primary one being a normal 'wall putty'. This layer mainly serves the purpose of undulation reduction and base coat for next layer i.e. 'NC putty'. Secondary layer of NC putty is applied for smoother finish.

Every layer is sanded after its application. Purpose of sanding is to reduce the undesired undulations.

Fig 17 :-Finished Mould

4.2 Processing of the Product

Hand Lay-up :-

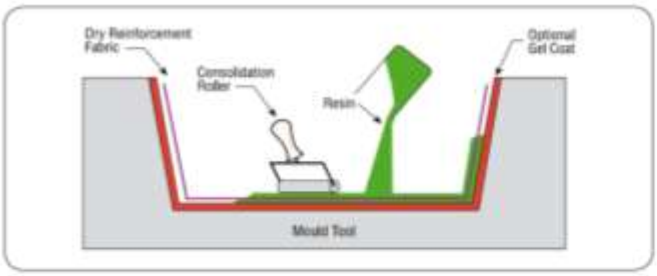

Fig 18 :- Hand Lay-up[11]

Resins are impregnated by hand into fibres which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions.

Description

1. Application of thin **wax** layer.
2. Application of four thin **release gel** layers
3. Every release gel and wax layer is left to dry up for 15 to 20 minutes.
4. Once the above setup is ready, Lay-up procedure can be started which includes Resin application along with addition of reinforcement.
5. Banana fibers were laid on the mould in a specific fashion and orientation which contributed in adding strength to the component.

Fig 19 :- Banana fibre lay up

6. Then resin was applied on Banana fiber with help of brush.

Fig 20 :- Final fiber lay up

7. A Balsa wood ring was also sandwiched on the circumferential part for enhancing the stiffness of the end product.

Fig 21 :- Balsa wood ring

8. Same process was carried on for the other half.
9. Once the layup was done, both the halves were combined and bolted.

4.3 Demoulding

Once the product is cured (after 24 hrs), it is ready for removal. Product can simply be removed from mould by applying slight jerks over the surface of the product. After completion of curing time, product was removed from the mould.

Fig 22 :- Demoulded product

4.4 POST CURING FINISHING

The product that was removed from the product had excess material over it. The excess resin had flown out of the mould cavity pertaining to the pressure applied in combining the two halves of the mould. All unwanted material was got rid off by grinding and sanding the excess material.

Fig 23 :- Final finished product

5. TESTING

5.1 Mounting of wheel

For testing the wheel under the forces, wheel was mounted on the triangular flange. This flange was welded to the square box pipe which acts as a steering column. Now, drilling was done on outer periphery of steering wheel and flange. And lastly, they were bolted. As shown in figure,

Fig 24 :- Mounting of wheel

5.2 Procedure of testing :-

1. Square box pipe was fixed in bench-vice. That offered a fixed support constrain.

2. Then to apply a tangential force, spring balance was attached to the one arm and was pulled till spring balance reads 15 kg. (By earlier force analysis, 15 KG was tangential force required)

Fig 25 :- Testing for tangential force

3. Now, for braking force, Four weights of 8 kg each was hanged on the wheel. Now, this weight accounts for the 32 kg's (i.e. 320,N).
   (By earlier force analysis, 300N force was assumed for the analysis.)

Fig 26 :- Testing for braking force

5.3. Conclusion of testing

Our product didn't fail in terms of any mechanical failure. That implies, our steering wheel is safe and has the potential to replace the conventional steering wheel.

6. CONCLUSIONS

1. Research on material that can replace the conventional material was done.
2. Steering wheel was manufactured by natural fibre.
3. Total weight of the steering wheel was successfully brought down with no comprise on strength of wheel.

Conventional steering wheel weighs up to 3 kg's while steering wheel manufactured by banana fibre weigh's up to 1.1 kg. i.e. more than 50% weight reduction is achieved.

4. We have provided the material solution for the conventional steering wheel which is more cleaner, more greener and more economical.

7. FUTURE SCOPE

1. Weight optimization

Further study for weight and size optimization should be carried out.

2. Mountings of Accessories

Study for various mounting methods of accessories like horn, airbag, cruise control should be carried out.

3. Advancement's in manufacturing methods

Various methods of manufacturing should be explored for flawless manufacturing of wheel.

4. Fibre alignment

Study of various fibre orientation and finding out the optimized orientation should be done.

5. Spoke design

Study on steering wheel spoke design should be carried out to come up with the optimized structure.

6. Life cycle

Study of product life cycle should be carried out.

7. Testing

More detail testing should be done by preparing the proper fixture and using strain gauges.
This would help us to plot the stress vs. strain graph so that we can judge the performance of wheel under various loading condition.

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