e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:03/Issue:09/September-2021 Impact Factor- 6.752 www.irjmets.com

MECHANICAL RECYCLING OF CFRP ALONG WITH CASE STUDY OF BICYCLE FRAME

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ABSTRACT

Composite materials are becoming popular in various industries such as aerospace industry, automotive industry, and wind energy. We have seen global surge in the demand of composites particularly carbon fiber reinforced plastic (CFRP) composites, which has led to huge volume of manufacturing and end-of-life waste material. The most common way for disposing of composite waste is through landfills. However, current, and impending legislations such as Directive on Landfill of Waste, have limited the amount of composite waste permitted for landfilling. Also, for making of pristine carbon fiber requires high amount of energy if we compare it to other materials like steel and aluminium. This generates a need to find out a way to recycle and reuse the waste material or the end-of-life material in different sector applications. This study mainly focuses on the strength comparison of pristine(virgin) CFRP with recycled CFRP and conducting finite element analysis on some parts made from virgin and recycled material. Also, details about mechanical recycling, cost estimation for producing virgin material as well as for recycling the material must be taken into account.

Keywords: Composite, Pristine, Recycle, Estimation.

I. INTRODUCTION

Carbon Fiber

Fibers of the size 5 to 10 micrometers in diameter and composed mostly of carbon atoms are called Carbon fibers which has several advantages including high stiffness, high tensile strength, low weight to strength ratio, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports. Carbon fibers are relatively expensive than similar fibers like glass fiber, basalt fibers, or plastic fibers.

Carbon fibers are produced by bonding of carbon atoms together in crystals that are aligned parallel to the long axis of the fiber because the crystal alignment gives the fiber high strength-to-volume ratio (in other words, it is strong for its size). Thousands of carbon fibers are bunched together to form a tow, which can be either used by itself or woven into a fabric.

Composites are made by combining carbon fibers with other materials. By permeating with a plastic resin and baking, carbon-fiber-reinforced polymer (often referred to as carbon fiber) are formed which has a very high strength-to-weight ratio and is extremely rigid being little brittle. Carbon fibers are also composited with other materials, like graphite, to form reinforced carbon-carbon composites, to have a very high heat tolerance.

Mechanical recycling

One of the most mature recycling technologies is mechanical recycling. It is widely used in industries for recycling waste composites, carbon fibre & glass fibre reinforced plastic. After size reduction, the material is ground in a hammer mill and graded into different lengths. Using mechanical recycling, CFRP wastes are reduced to two parts: resin powder and a fibrous fraction, which are generally used as fillers in economical materials, such as bulk moulding compound / sheet moulding compound.

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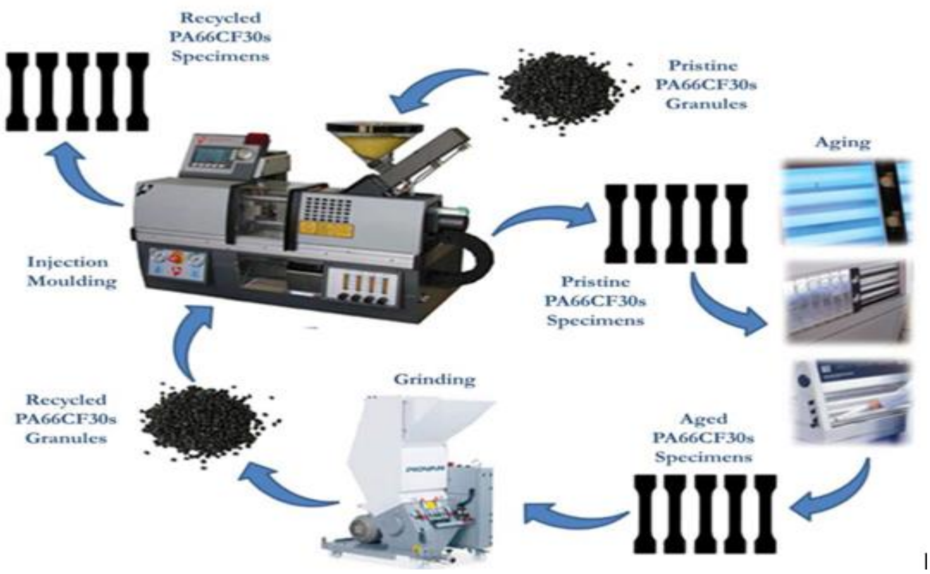

Figure 1: Mechanical recycling of CFRP

Advantages of Mechanical Recycling:

- It is simple process as compared to other methods.
- It has less impact on environment.
- The equipment used in mechanical recycling remains same even if the material to be recycled changes.
- Very small number of changes need to be done for recycling different materials or for changing the input parameters.

II. METHODOLOGY

Steps involved in mechanical recycling process:

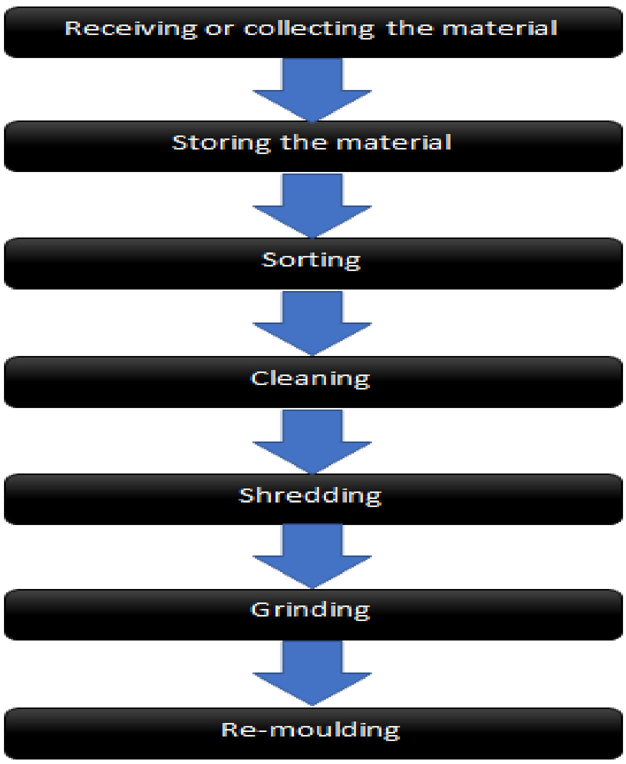

Figure 2: Flowchart (Mechanical Recycling)

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Major limiting factors in the large-scale use of carbon fiber (CF) in manufacturing sector is its very high cost. Main elements of this higher cost involved in manufacturing the carbon fiber have been formalized into the cost model so that it can facilitate the overall understanding of these factors. In fact, it can play a key role in manufacturing CF in a cost-effective method. This cost model consists mainly two parts, the fixed cost and the variable costs involved in all stages of manufacturing, in addition to the consideration for price variability of other balance elements like raw materials, energy consumption, maintenance cost etc.

Now since all the costs that go into manufacturing the carbon fiber have been taken into calculations from the cost model, the result must be compared to the known market values of the carbon fibers. The comparison will be done mainly on the fixed costs and elastic value of the variable costs which have been calculated.

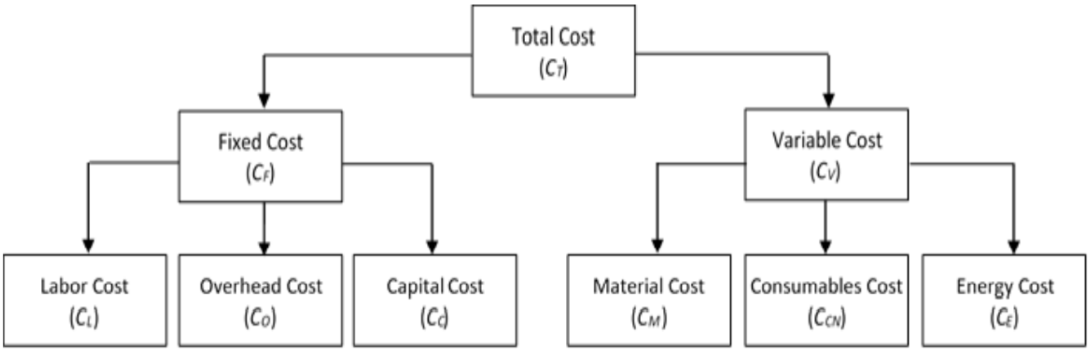

Figure 3: Different components of costs

Cost for Virgin CFRP

Table 1: Cost for Virgin CFRP

Description	**Cost/kg (in USD)**
Fixed cost	0.04
Consumable and energy specific cost(manufacturing)	4.00
Energy cost for oxidation process	1.02
Consumable cost for carbonisation process	0.60
Energy cost for carbonisation process	0.90
Consumable cost for surface treatment	1.62
Energy cost for surface treatment	1.35
Consumable cost for Sizing process	0.30
Energy cost for Sizing process	0.04
Total	**9.87**
Market Cost	**15(approx.)**

As the market demand for manufacturing low-cost carbon fiber keeps growing, research efforts on that behalf are being conducted are also increasing significantly. Recent advances have been made in the development of lignin as an alternative precursor. This polymer offers many important advantages like a low cost, abundant and renewable resource which are very much vital from usage as well as environment point of view. The properties for the lignin-based carbon fiber are not very good as compared to the conventional carbon fibers, but currently undergoing research indicates that those downsides can be overcome through proper identification of lignin for the manufacturing process which are more suitable from practical point of view.

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Cost of Mechanical Recycling of CFRP

Table 2: Cost for Recycled CFRP

Description	Cost/kg (in USD)
Collecting End of Life CFRP	0.6
Grinding	0.9
Filtering and Sizing	0.8
Total Recycling Cost	**2.3(approx.)**

III. MODELING AND ANALYSIS

The process of FEA was performed on a "Bicycle Frame", it involves the following steps:

1. Creating a new CAD model for bicycle frame in a 3D Modelling Software.

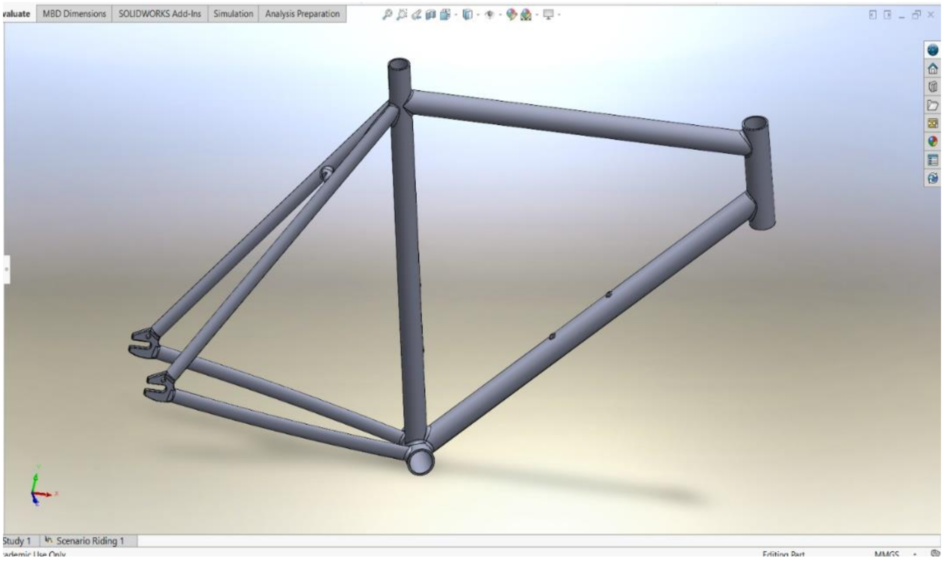

Figure 4: 3D model (Appearance before applying material)

2. Applying the material to be tested to the bicycle frame.

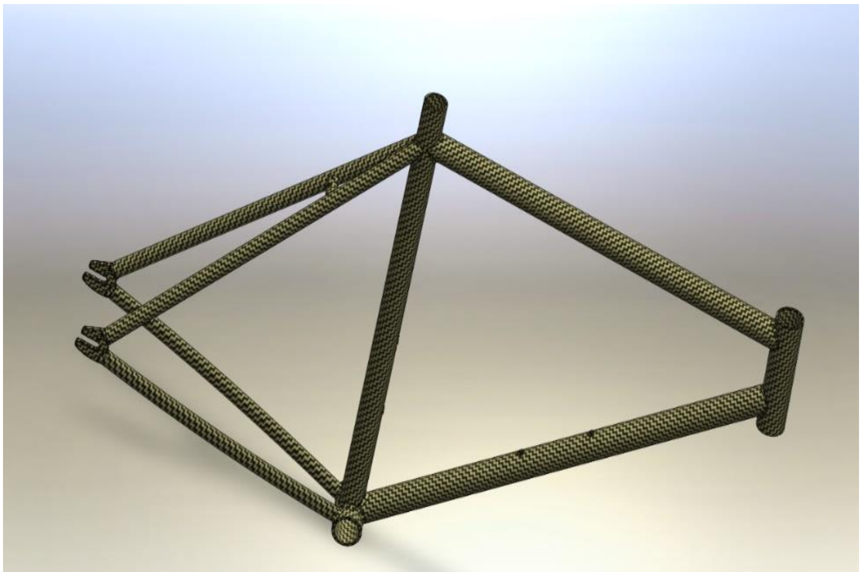

Figure 5: 3D model after applying material.

a) Firstly, applying the virgin CFRP as the material.
b) Next by applying recycled CFRP as the material for comparison with virgin CFRP.

3. Applying the similar constraints and loads onto both the models.

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Figure 6: Application of Load and constraints

4. Creating a mesh.

Figure 7: Meshing of model

5. Checking if the solver has all the inputs to obtain a solution.

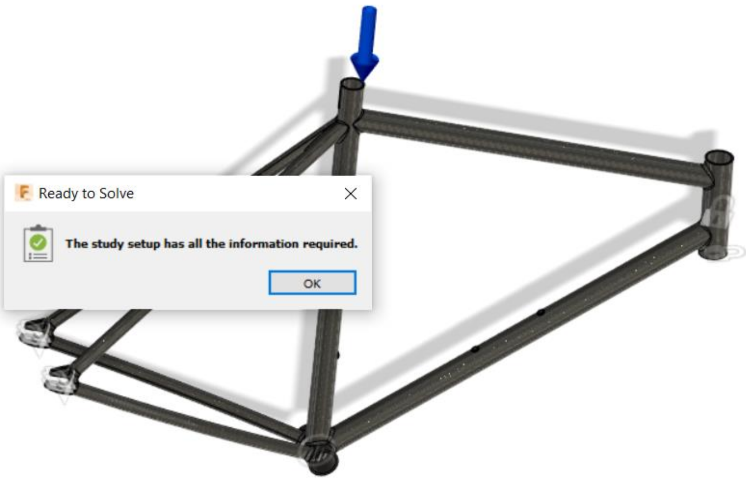

Figure 8: Completion of study setup

6. Solving the study either on cloud or locally on the PC.

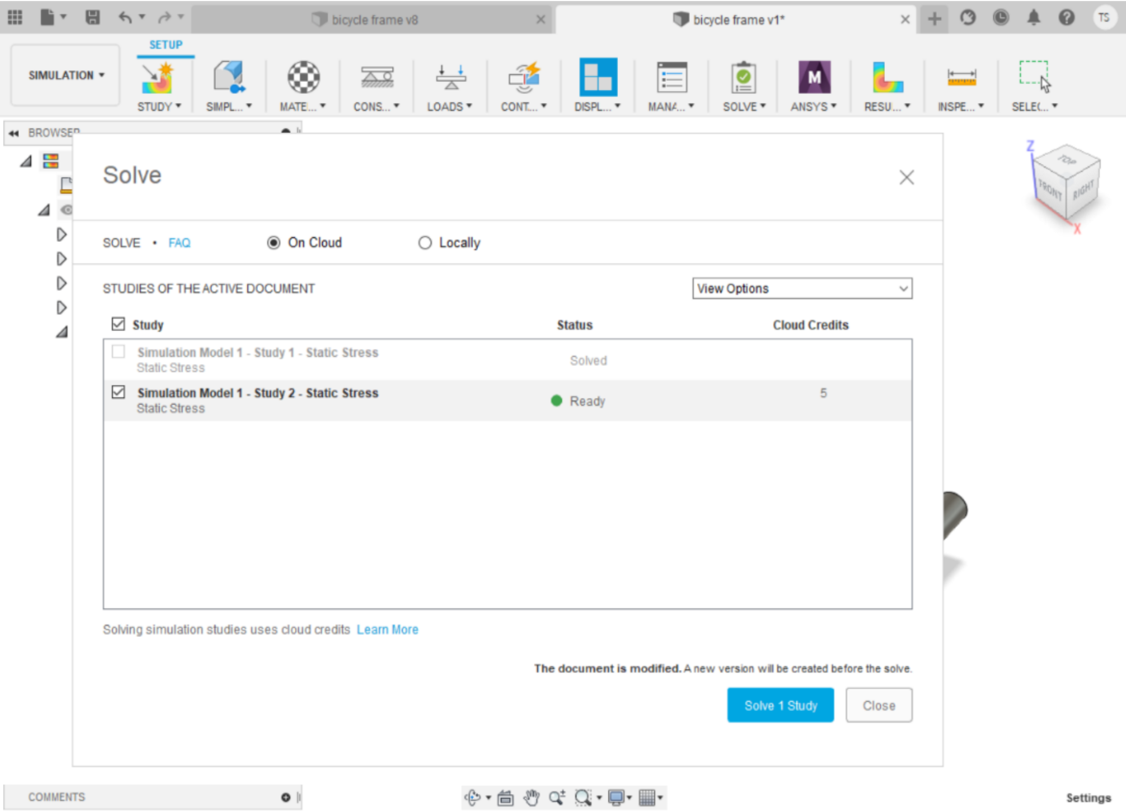

Figure 9: Solving the studies

7. Comparing the displacement plots and other results.

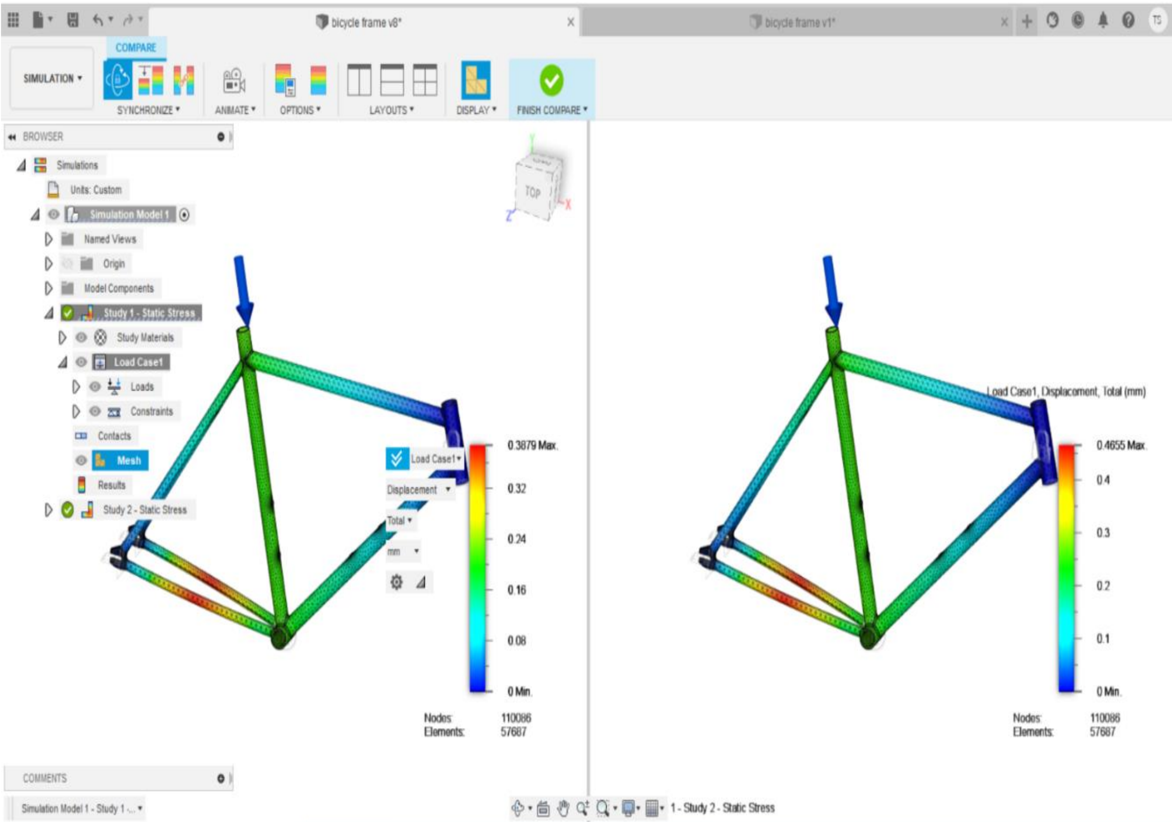

Figure 10: Comparison of Results

IV. RESULTS AND DISCUSSION

The FEA was carried out first on the pristine(virgin) CFRP material and also on the recycled CFRP material. The mechanical properties of the respective materials were fed into the simulation software (Autodesk Fusion 360). The tabular form below shows the difference in mechanical properties of pristine and recycled materials and the same properties were fed into the simulation software.

Table 3: Comparison of Mechanical properties

	Pristine	Vs	Recycled
Tensile Strength (Mpa)	240		180
Young's Modulus (Gpa)	24		20
Poisson's Ratio	0.39		0.34

Also, for finite element analysis the minimum element size was set to 2mm along with adaptive mesh refinement. The parameters set for creating the mesh are as follows:

Table 4: Mesh Setting

Case Study	Bicycle Frame
Minimum Element Size	2 mm (Adaptive Meshing)
Element Type	TET4
Nos. of Elements	110086
Nos. of Nodes	57687

For conducting FEA both the components i.e., one made from pristine material, and another made from recycled material were stressed for a load of 1000N (approx. 102 Kg). The criteria for comparison of results was the displacement and the factor of safety and not the von Mises stress as the load applied and the geometry on which the load is applied is similar, so the value of stress obtained through study would be identical.

Results Obtained

Table 5: Result Obtained (Pristine Vs Recycled)

	Pristine	Vs	Recycled
Max. Displacement	0.3879mm		0.4655mm
FOS	6.46		4.85

From the above obtained results we can see that the maximum displacement of component made from recycled material was more as compared to component made from pristine material. Also, the factor of safety for the bicycle frame made from pristine material was found to be 6.46, whereas for the bicycle frame made from recycled material was found to be 4.85 i.e., the factor of safety decreases for the recycled component. Also, a set of input parameters were selected for carrying out the mechanical recycling process, which have an impact on the quality of the recycled component.

Input Parameters

Table 6: Input Parameters

1.	Pallet size	50µm - 6mm
2.	Melting Temperature	280 °C
3.	Drum speed (Grinding)	200 RPM
4.	Processing Time	6 min/Kg

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V. CONCLUSION

It can be concluded that Mechanical recycling is an economical process in terms of cost and can be used for cost cutting in place of manufacturing products from pristine material. Also, it can be seen that there is not significant difference in the maximum displacements (0.3879mm vs 0.4655mm) as can be seen in the FEA models and hence proves that the recycled CFRP can be used in the making of the products wherever suitable.

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