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COMPARATIVE STUDY OF PYROLYSIS AND SOLVOLYSIS RECYCLED CARBON FIBRE AS MICROFILLER IN GLASS FIBRE REINFORCED POLYMER COMSYSTEM

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ABSTRACT

The utilization of composite materials has been exponential over the years and especially the demand for carbon fibre reinforced polymer composite is increasing rapidly because of their high performance. However, the recycling aspects of these materials proves to be challenging.
The aim of our project is to recycle the fibre reinforced polymer composite in a cost-efficient method and to effectively use the recovered fibre in other applications. The project plan is to recover the fibres from two recycling processes – Pyrolysis and Solvolysis, and to pulverize the recovered fibres into fine powder. This powder is to be used as a microfiller in glass fibre reinforced polymer composite to enhance the mechanical properties. The final conclusion is to identify the best recycling method based on the analysis of the mechanical properties. Based on Tensile and Flexural tests, it was found that both the composite laminates with carbon fibre powder microfiller showed better structural properties than GFRP with plain epoxy. However, the carbon powder recovered from solvolysis process showed the best mechanical properties.

Keywords: Composite Recycling, Fibre Recovery, Microfiller, Composite Waste Management and Material Reuse.

1. INTRODUCTION

Composite materials are phenomenal in every aspect. When the fibres are combined with the resin, it will result in a strong material which can compete with conventional materials. The usage of composite materials has increased significantly over the past few years especially Carbon fibre reinforced plastics (CRPF). The advantages offered by the CRPF has created a major demand in almost every industry right from aerospace structures to the small sports equipment.

2. PROBLEM STATEMENT

The extensive usage of CRPF has many advantages, but on the other hand, this will create lots of waste every year which is inevitable. Despite the fact that the fibre and matrix form a really strong material, it is really challenging to separate them apart once they are cured, in order to recover the fibres and use them again. The composite materials formed have single use life-span. As of now, the most economical option is to landfill, which is completely useless and hazardous to the environment.

3. OBJECTIVE

The objective of this work is to extract the fibres from the two methods of recycling and to compare mechanical properties of the fibres recovered from both the processes. Number of trials were carried out in order to validate a low-cost recycling process. This research work makes use of several resources to examine hypotheses based on the experiments like FTIR, SEM, tensile and flexural testing.

4. METHOD OF APPROACH

The recycled fibres of two processes were pulverised and were used as microfiller in the Glass fibre reinforced epoxy laminates (300 x 300 x 3 mm). The two types of powders obtained from the recycling were analysed by FTIR and SEM, where tensile and flexural tests were carried out to the laminates. The structural analysis was performed to compare GFRP with pyrolysis microfiller, GRPF with solvolysis microfiller and plain GRPF. Lastly, the results were analysed and the future of carbon fibre recycling is discussed.

5. LITERATURE REVIEW

Recycling of Carbon Fiber-Reinforced Epoxy Resin by Sustainable Solvolysis, ACS Omega (2025) — Presents a greener solvolysis process using MEK/H_2O_2 to recover carbon fibres with minimal residues and study reuse in new composites.

Recycling carbon fibers by solvolysis: Effects of porosity and process parameters, Composites Part A (2025) — Investigates how manufacturing defects and solvolysis parameters affect recycling efficiency and fibre recovery.

Mechanical Characterization of Carbon Fibers and Their Interfaces Recycled Through Plasma-Assisted Solvolysis, Fibers (2025) — Details a comparison of pyrolysis and chemical recycling, focusing on fibres' mechanical properties post-recovery.

Recovering carbon fibers from waste CFRPs via pyrolysis-oxidation method, Waste Management (2024) — Analyses pyrolysis-oxidation recovery of carbon fibres and their reuse potential in remanufactured composites with high retention of properties.

Comparative Analysis of Thermal Recycling Approaches for Carbon Fiber Recovery, ACS Sustainable Resource Management (2024) — Compares conventional and microwave pyrolysis for CF recovery efficiency and property retention.

The 3R (recycling, recovery, and reuse) of fiber reinforced thermoset composites: paving the way for a circular economy, RSC Applied Polymers (2026) — A 2026 review exploring all recycling methods including pyrolysis, solvolysis, and emerging hybrid techniques in FRP recycling.

A Comprehensive Review on the Recycling of Carbon Fibre–Reinforced Polymer Composites (2026) — Recent review summarizing current recycling technologies (pyrolysis, solvolysis, mechanical and thermal methods) and sustainability aspects.

Recycling of carbon fibre reinforced polymer composites with superheated steam – A review, Journal of Cleaner Production (2023) — Reviews advanced thermal processes including pyrolysis alternatives for CF-reinforced composites.

Mechanical Recycling of Carbon Fiber-Reinforced Polymer Composites — A Circular Economy Approach (2024) — Highlights mechanical recycling approaches and challenges, complementing chemical/thermal methods in CFRP recycling

José *et al.* (2025). This paper is a literature survey of most of the efficient recycling methods that were experimented by different authors. It does a comparision study between mechanical, thermal and chemical recyling methods and discusses about the mechanical properties of the recovered fibres under each method. This paper also mentioned the best manufacturing process that use recycled carbon fibre reinforced polymer (rCFRP).

6. METHODOLOGY

6.1 SOLVOLYSIS RECYCLING METHOD

Solvolysis employs a chemical treatment approach for reycling composite materials. It is a method which uses acids, bases or solvents under specific reaction time and concentration to degrade the matrix. During the chemical reaction, the polymers are converted into monomers or depolymerized to oligomers. This process limits the damage to the fibres, therefore has the ability to recover clean fibres with good mechanical properties. Catalysts are typically used for faster dissolution rate and higher dissolution efficiency.

Another promising recent chemical recycling method is by obtaining higher resin degradation rate with water by hydrolysis in supercritical conditions. In this process, the water aids in polymer resin breakdown. A supercritical solvent is used for supercritical solvolysis (eg, for water with temperature greater than 374□C and pressure greater than 221 bar). The di electric constant of water molecules gets reduced during supercritical conditions therefore it acts as a non-polar solvent which has the capacity to dissolve organic compounds. Supercritical solvolysis is predominantly applied to carbon fibre reinforced polymer composites to recover good quality carbon fibres. One of the present processes ensure the possibility of recovering the solvent by extracting the degraded polymer matrix by simple distillation process. There are numerous US-based companies presently selling carbon fibres recycled via solvolysis process like Shocker composites (Kansas), Mallinda (Colorado), Vartega Inc (Colorado) etc.

6.2 PULVERIZATION OF RECOVERED FIBRES

The recovered fibres must be pulverized into fine powders to be used as a microfiller for fabrication of laminates. Initially the fibres are milled in a ball mill apparatus consisting of metal container and metal zirconium balls all of which had same diameter. The fibres were not effectively powdered with this method. The fibres are then added to a ceramic ball mill apparatus containing alumina jar and alumina balls of different diameters. They are milled for 3 hours and the outcome was a fine powder of carbon fibre. Therefore, ceramic ball mill is the most suitable ball mill for pulverization of fibres.

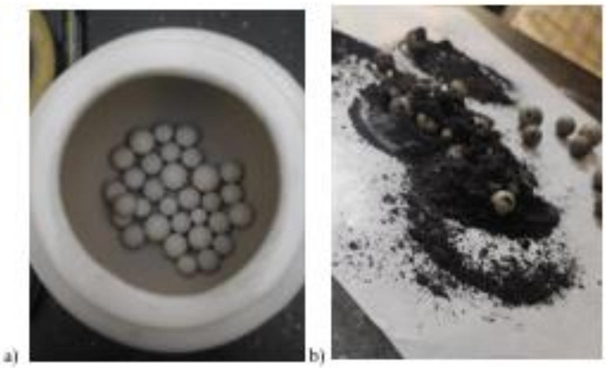


Figure: 1 a) Ceramic ball mill b) rCF after milling

6.3 MATERIALS AND FABRICATION METHOD

The reinforcement used in this project were bi-directional glass fibre fabric of 200 GSM and a thickness of 0.19 mm. The matrix used was Epoxy LY556 which is the most common resin available in commercial stores. The filler used in the matrix were two different types carbon fibre powder microfiller which was obtained by recycling CFRPs by pyrolysis and solvolysis process. 17 layers of Glass fibre sheets of dimensions 300 mm x 300 mm were used to obtain a composite plate thickness of 3 mm. The concentration of carbon fibre microfiller was 1% weight of the epoxy.

Sl no	Composite plate type	Weight of e glass fibre	Weight of epoxy used	Concentratio n of micro filler (%)	Weight of o filler (g)
1.	GFRP with plain epoxy	400	400	0	-
2.	GFRP with CFP-P	400	400	1	4

3.	GFRP with CFP-S	400	400	1	4

Figure: 2 Specification of the GFRP plates

The composite was fabricated by a hand lay-up technique followed by vacuum bagging process. A vacuum pressure of 0 bar was obtained by the vacuum pump in order to suck the maximum air voids in the composite. This process ensures even pressure distribution across the composite thereby giving the plate a constant thickness.

Figure 3 Vacuum bagging of fabricated plates

6.4 PREPARATION OF SPECIMEN

The composite plates need to be cut precisely according to the required ASTM standards with smooth edges. In traditional cutting techniques like bandsaw cutters the composite plates are prone to excessive vibrations during cutting process which might lead to fibre distortion and delamination in laminates, therefore waterjet cutting overcomes this drawback. Three samples of 250 mm x 25 mm and three samples of 127 mm x 12.7 mm were obtained from each composite plate.

Figure :4 Waterjet cutting machine

Figure :5 Cut specimens for tensile and flexural testing

7. RESULTS AND DISCUSSION

7.1 SCANNING ELECTRON MICROSCOPE (SEM) IMAGES OF rCF MICRO FILLERS

The rCF powder samples were inspected using a scanning electron microscope (SEM) to determine the size of the powder particle. The average length of the fibre and the diameter can be determined using the SEM. It is important to determine the particle size of powder for accurate understanding of the powder properties. Three images of different scanning levels of 10 □m, 20 □m and 50 □m were obtained at an operating voltage of 10 kV.

7.2 FOURIER TRANSFORM INFRARED (FTIR)

Fourier transform infrared (FTIR) is the most preferred method of Infrared spectroscopy. When infrared light is sent through the specimen, part of it will be absorbed and some flows through the specimen. The resulting signal at the detector is a spectrum that represents the sample's molecular "fingerprint.” The importance of FTIR arises because different chemical structures (molecules) produce different spectral fingerprints.

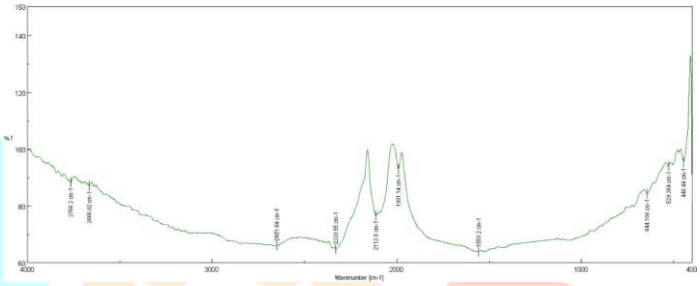


Figure :6 IR analysis for fibre powder recycled from Pyrolysis

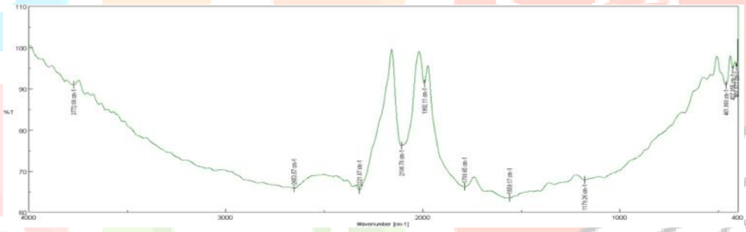


Figure :7 IR analysis for fibre powder recycled from Solvolysis

Amine cross-linked BADGE epoxy is used as a matrix for the Carbon fibre samples which are used for recycling. The Infrared analysis of the recycled fibre powders shows the absorption peaks at 1100 cm^{-1} by representing the C-N bond in solvolysis sample. It is absent in the pyrolysis sample. Peaks are identified on the spectrum representing C-OH bond at 1179.26 cm^{-1}, and C=O at 1788.66 cm^{-1} for powder recovered by solvolysis, where aromatic ring vibrations were detected for both; at 1558.2 cm^{-1} for powder recovered by pyrolysis and 1559.17 cm^{-1} for powder recovered by solvolysis. Other peaks at 3766.3 cm^{-1}, 3666.02 cm^{-1} were detected for powder recovered by pyrolysis and a single peak of 3772.08 cm^{-1} was detected for powder recovered by solvolysis which represents O-H stretch. To conclude this, it was found that both the spectrums showed similar changes in properties at almost each stage.

7.3 TENSILE TEST

The tensile test is a destructive test which is performed on a Universal testing machine (UTM) to determine the mechanical properties of a material like tensile strength, yield strength etc., In this test, the specimen is fixed between two jaws of the UTM and load is applied on the specimen by pulling one upper jaw. The ASTM D3039 standard has been followed to perform this test on the UTM. Aluminum sheets are attached on both the sides of the specimen in order to avoid the slip while the load is applied.

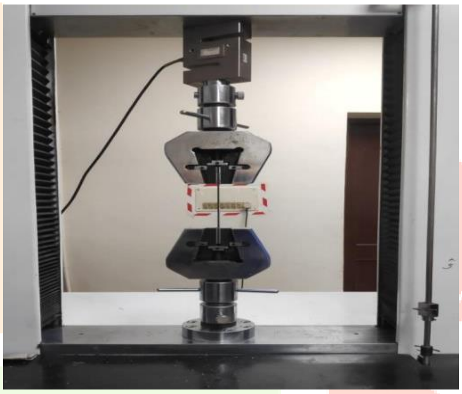
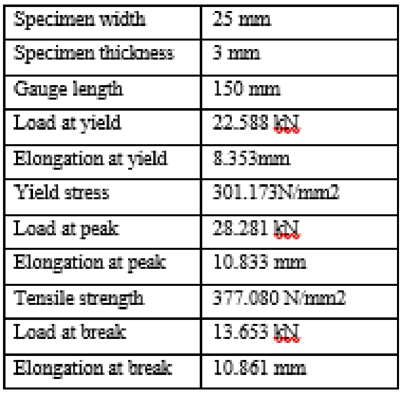


Figure :8 Tensile testing of a specimen in UTMTensile test result of G1 specimen

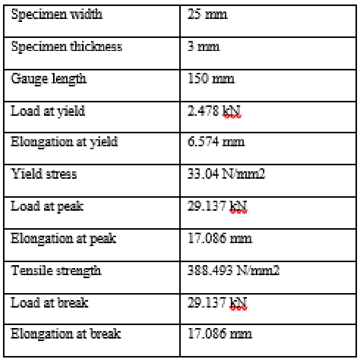


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	22.588 kN
Elongation at yield	8.353mm
Yield stress	301.173N/mm2
Load at peak	28.281 kN
Elongation at peak	10.833 mm
Tensile strength	377.080 N/mm2
Load at break	13.653 kN
Elongation at break	10.861 mm

Figure :9 UTM output of G1 tensile test specimen

Figure :10 G1 specimen after tensile test

TENSILE TEST RESULT OF G2 SPECIMEN

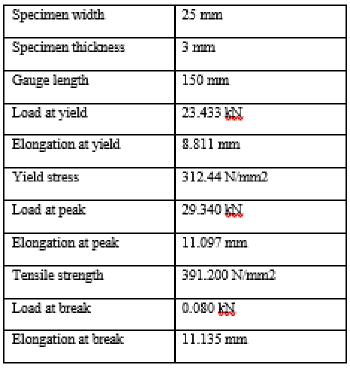


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	2.478 kN
Elongation at yield	6.574 mm
Yield stress	33.04 N/mm2
Load at peak	29.137 kN
Elongation at peak	17.086 mm
Tensile strength	388.493 N/mm2
Load at break	29.137 kN
Elongation at break	17.086 mm

Figure :11 UTM output of G2 tensile test specimen

Figure :12 G2 specimen after tensile test

TENSILE TEST RESULT OF THE G3 SPECIMEN

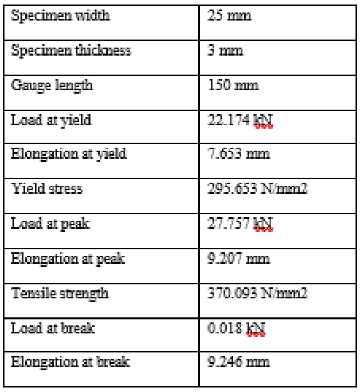


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	23.433 kN
Elongation at yield	8.811 mm
Yield stress	312.44 N/mm2
Load at peak	29.340 kN
Elongation at peak	11.097 mm
Tensile strength	391.200 N/mm2
Load at break	0.080 kN
Elongation at break	11.135 mm

Figure :13 UTM output of G3 tensile test specimen

Figure :14 G3 specimen after tensile test

TENSILE TEST RESULT OF GP1 SPECIMEN

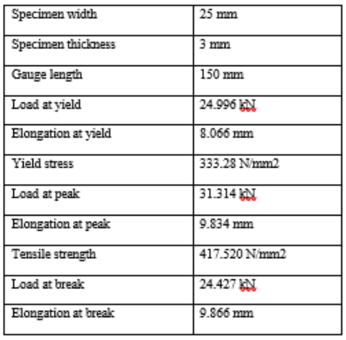


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	22.174 kN
Elongation at yield	7.653 mm
Yield stress	295.653 N/mm2
Load at peak	27.757 kN
Elongation at peak	9.207 mm
Tensile strength	370.093 N/mm2
Load at break	0.018 kN
Elongation at break	9.246 mm

Figure :15 UTM output of GP1 tensile test specimen

Figure :16 GP-1 specimen after tensile test

TENSILE TEST RESULT OF GP-2 SPECIMEN

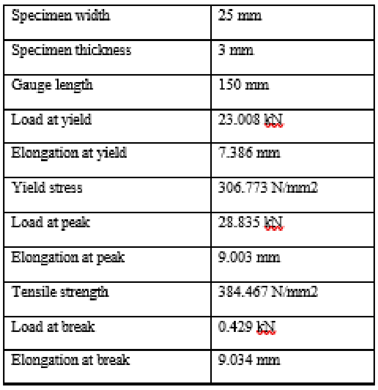


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	24.996 kN
Elongation at yield	8.066 mm
Yield stress	333.28 N/mm2
Load at peak	31.314 kN
Elongation at peak	9.834 mm
Tensile strength	417.520 N/mm2
Load at break	24.427 kN
Elongation at break	9.866 mm

Figure :17 UTM output of GP2 tensile test specimen

Figure :18 GP-2 specimen after tensile test

TENSILE TEST RESULT OF GP-3 SPECIMEN

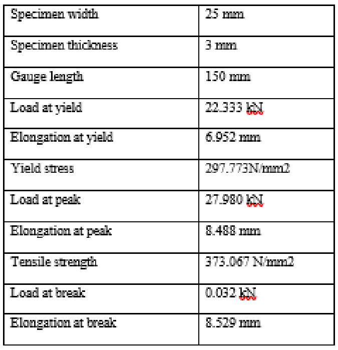


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	23.008 kN
Elongation at yield	7.386 mm
Yield stress	306.773 N/mm2
Load at peak	28.835 kN
Elongation at peak	9.003 mm
Tensile strength	384.467 N/mm2
Load at break	0.429 kN
Elongation at break	9.034 mm

Figure :19 UTM output of GP3 tensile test specimen

Figure :20 GP-3 specimen after tensile test

TENSILE TEST RESULT OF GS-1 SPECIMEN

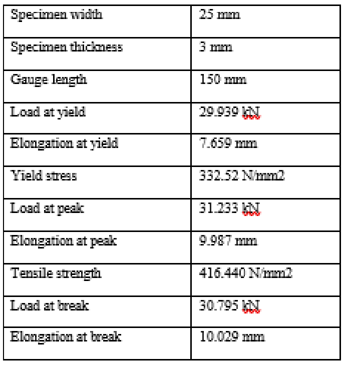


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	22.333 kN
Elongation at yield	6.952 mm
Yield stress	297.773N/mm2
Load at peak	27.980 kN
Elongation at peak	8.488 mm
Tensile strength	373.067 N/mm2
Load at break	0.032 kN
Elongation at break	8.529 mm

Figure :21 UTM output of GS1 tensile test specimen

Figure :22 GS-1 specimen after tensile test

TENSILE TEST RESULT OF GS-2 SPECIMEN

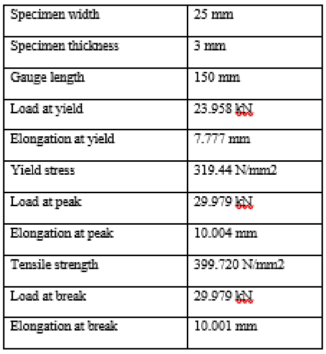


Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	29.939 kN
Elongation at yield	7.659 mm
Yield stress	332.52 N/mm2
Load at peak	31.233 kN
Elongation at peak	9.987 mm
Tensile strength	416.440 N/mm2
Load at break	30.795 kN
Elongation at break	10.029 mm

Figure :23 UTM output of GS2 tensile test specimen

Figure :24 GS-2 specimen after tensile test

TENSILE TEST RESULT OF GS-3 SPECIMEN



Specimen width	25 mm
Specimen thickness	3 mm
Gauge length	150 mm
Load at yield	23.958 kN
Elongation at yield	7.777 mm
Yield stress	319.44 N/mm2
Load at peak	29.979 kN
Elongation at peak	10.004 mm
Tensile strength	399.720 N/mm2
Load at break	29.979 kN
Elongation at break	10.001 mm

Figure :25 UTM output of GS3 tensile test specimen

Figure :26 GS-3 specimen after tensile test

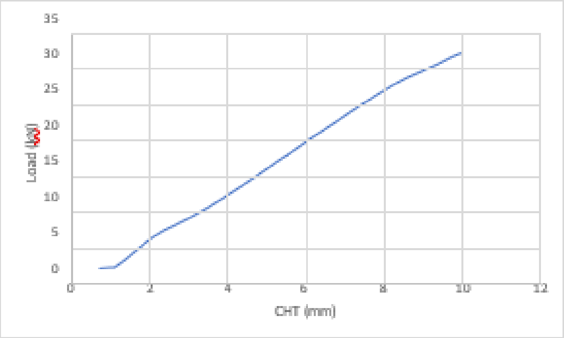


Figure :27 Load vs CHT graph of GS-3 tensile test specimen

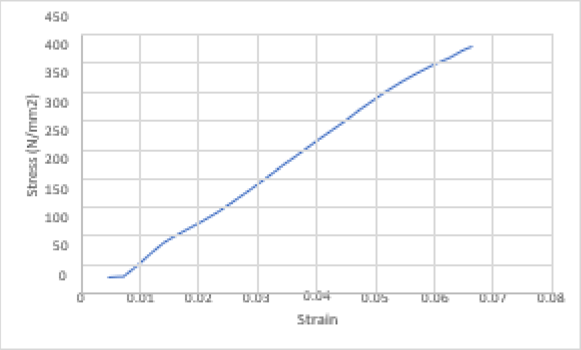


Figure :28 Stress vs strain graph of GS-3 tensile test specimen

7.4 THREE POINT FLEXURAL TEST

The three-point flexural test is a destructive test which is performed on a Universal testing machine to determine the mechanical properties of the material like flexural strength etc. In this test, the specimen is placed on the supports. The upper jaw is set in a way that it resembles 3 points of contact. Load is applied on the specimen by forcing the upper jaw down. The ASTM D790 standard has been followed to perform this test. The span length is calculated as 16 times of the thickness of the specimen.

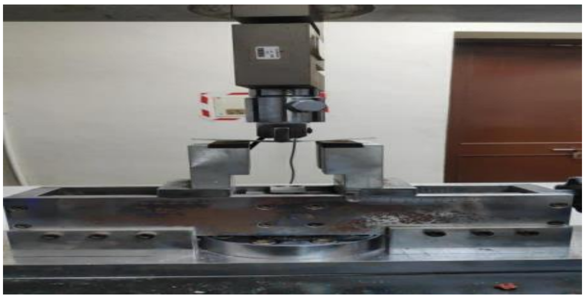


Figure :29 Flexural testing setup

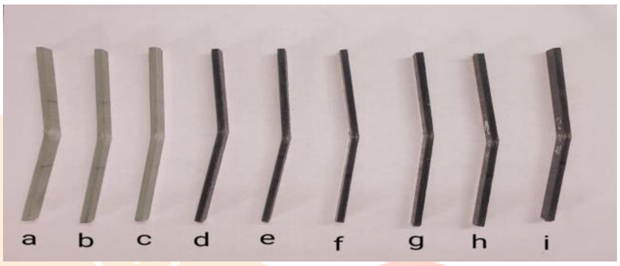


Figure :30 Shape of the specimens after flexural test a) G1 b) G2 c) G3 d) GP1 e) GP2 f) GP3 g) GS1 h) GS2 i) GS3

Specimen Type	**Specimen Name**	**Tensile strength (MPa)**	**Young's modulus (MPa)**	**Flexural strength (MPa)**	**Flexural modulus (MPa)**
Glass fibre with plain epoxy	G1	377.080	6590.541	452.283	15.656
	G2	388.493	6464.684	470.551	16.025
	G3*	-	-	-	-
Average		382.786	6527.612	446.824	15.746
Glass fibre with CFP-P	GP1	370.093	7490.651	577.008	20.125
	GP2	417.520	7447.090	582.677	20.285
	GP3	384.467	7468.402	629.921	21.537
Average		390.693	7468.714	596.540	20.649
Glass fibre with CFP-S	GS1	373.067	7507.476	599.055	22.052
	GS2	416.440	7520.035	654.488	21.190
	GS3	399.720	7469.154	634.331	20.445
Average		**396.410**	**7498.888**	**629.291**	**21.229**

*- indicates specimen failure during test

Figure :31 Final results of UTM and modulus calculation

8. CONCLUSION

As the world is witnessing major rise in composites utilization, the recyclability aspects should be on par with the growing demand. New technologies should be developed that allow these materials to be reused. Thus, this is an area which requires extensive research. This project reports two recycling methods, one with pyrolysis method at high temperatures and ambient atmosphere, and the other with solvolysis using peracetic acid. The present solvolysis process involves high amounts of acids under high temperatures and pressures, which is not economically feasible. This project was able to provide a solution by powdering the composite before using them in solvolysis. This process reduced acid consumption thereby making it economically feasible. Tensile and flexural tests were conducted and the results were analyzed. The GFRP with CFP-P micro filler had an increase in tensile strength by 2.06 % and flexural strength by 33.52 % compared to GFRP with plain epoxy. The GFRP with CFP-S micro filler had an increase in tensile strength by 3.5 % and flexural strength by 40.8 % compared to GFRP with plain epoxy. So, it shows that GFRP with CFP-S had the best tensile and flexural strength along with high young's modulus and flexural modulus. Therefore, it is evident that solvolysis method provided the best recycled carbon fibre properties, however pyrolysis method is the most viable solution due to its less complexity in the recycling process.

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