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Mechanical and Morphological Behavior of Waste GFRP Powder Reinforced Polybutyrate composites

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Abstract
Biocomposites have emerged to become one of the most sought-after materials, these days. Yet, their high cost, limits their applications. On this regard, the blending of low-cost fillers into the biodegradable polymer may be an alternative solution.
This present work concentrates on the development of Polybutyrate/waste GFRP powder (Both Raw and Treated) composites. These composites were synthesized by melt mixing using a Haake Rheocord. Later, samples were prepared by Compression Moulding Technique, followed by Punching and Saw-Cutting. The samples were then tested for Mechanical (Tensile, Flexural and Impact Properties) and Morphological behaviour. The results indicate that the blending was highly successful in improving the fore said properties, while reducing the cost effectively. These biocomposites could be applied in packaging, garden products, waste bin liners, etc.
Keywords--Polybutyrate, Waste GFRP Powder, Treatment, Mechanical, Morphology.

1) Introduction

Biodegradable polymers are generally blended with low-price fillers, to produce biocomposites, which are widely used an alternative to the current commodity plastics. They have attracted considerable attention as green materials as they degrade naturally and avoiding disposal problems; yet, performing similar to the commodity plastics at an optimal cost.
Typical examples are the bio-polyesters like Polycaprolactone (PCL), Polyhydroxybutyrate (PHB), Poly(Lactic Acid) or Poly(L Lactide) (PLA), Poly(Butylene Succinate) (PBS) etc. They show similar properties compared to the non-biodegradable polymers, while degrade naturally.
Polybutyrate, which is Poly (Butylene Adipate-co-Terephthalate), is one such bio-polyester. However, its high cost limits its application. Thereby, In this work, Polybutyrate was reinforced with waste GFRP powder to reduce the cost, while improving the properties.

2) Experimental

2.1) Materials:

2.1.1) Polybutyrate:

It is aliphatic–aromatic polyester of butylene glycol and adipic, terephthalic acids and its high percentage elongation (flexible nature) makes it suitable for food packaging and agricultural film application.
For the current work, the biodegradable copolyester, Polybutyrate, was supplied by Harita-NTI Ltd., Chennai for use as the matrix material. The supplied copolyester had 57% of Butylene Adipate and 43% of Terephthalate. Determined by size exclusion chromatography (SEC), average molecular weight (MW) and polydispersity index (I) were 48000 g mol^{-1} and 2.4 respectively. Melt flow index (MFI) was 13g/10 min at 190˚C/2.16 kg. Density was $1.27 g/cm^3$ at 23˚C.

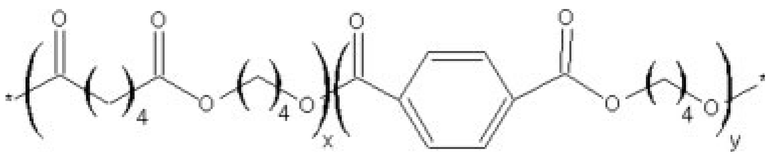

Figure 1: Structure of Polybutyrate.

2.1.2) GFRP:

Glass Fiber Reinforced Plastics (GFRP) are widely used in the building industry as domes, fountains, columns, balustrade, planters, panels, sculpture, entryways, moldings, facades, cornice, porticos, cupolas, signs and roofs due to their high strength, light weight, resistance to salts, water, chemicals, and the environment, seamless construction possibilities, ability to mold complex shapes, low maintenance requirement and durability.
Waste GFRP powder, based on epoxy, was procured from CIPET, to reinforce the Polybutyrate matrix.
The Glass Fiber % in the waste GFRP powder was determined to be 47.238% using the Thermo Gravimetric Analysis.

2.1.3) Vinyl Trimethoxy Silane:
Vinyl Trimethoxy Silane, procured from CIPET, was used as the coupling agent. It acts as an interface between resin and fillers to form a chemical bridge between the two.

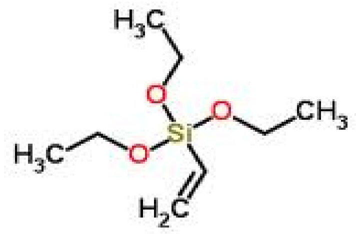

Figure 2: Structure of Vinyl Trimethoxy Silane.

2.2) Synthesis of Polybutyrate/GFRP powder Composites:
2.2.1) Drying:
Polybutyrate is initially, dried for 2 hours at 80˚C in hot air oven before mixing. It removes the moisture, trapped gases and other volatiles.

2.2.2) Melt Mixing:
Polybutyrate and GFRP powder, both raw (untreated) and that treated with Vinyl Trimethoxy Silane, were melt mixed using a Haake Rheocord at 140˚C in 6 different formulations as shown in the tables 1 and 2. (The composition containing treated GFRP powder was selected based on the optimization of the untreated composite):

2.2.3) Specimen Preparation:
The melt mixed Polybutyrate/GFRP powder composites were, initially, dried in hot air oven for 2 hours at 80˚C. Subsequently, they were compression moulded into sheets. These sheets were then cut into tensile bars by means of punching method. However, the specimens for flexural and impact test were cut by means of a band saw. The dimensions of the specimen were in accordance with the ASTM standards.

2.3) Testing:

The specimens were, initially, tested for mechanical properties; viz. tensile, flexural, impact; using the ASTM standards on an UTM (Tensile, Flexural) and an Impactometer (Impact). The optimised, impact fractured specimens were then observed for morphological properties using a SEM.

3) Results & Discussions

3.1) Mechanical Properties
3.1.1) Tensile Properties:
The following were the observations from the tensile test, administered to the Polybutyrate/untreated GFRP powder composites and an optimised Polybutyrate/treated GFRP powder composite:

Standard : ASTM D 638

From the tables 3 and 4, it may be inferred that the tensile strength of the composites increased with the increase in untreated GFRP powder content up to 20%, beyond which it decreases. Compared to the neat Polybutyrate matrix, an increase of 50%, 62.5%, 33.75%, 12.5% in the tensile strength was observed in the composites filled with 10%, 20%, 30% and 40% of untreated GFRP powder.
However, the tensile modulus of the composites increased with the increase in untreated GFRP powder content, throughout. The modulus increase was 77.80%, 175.96%, 196.69% and 195.23% with 10%, 20%, 30% and 40% addition of untreated GFRP powder.
On the other hand, elongation at break continuosly decreased with the increase in untreated GFPR powder

content, throughout. The decrease was 13.58%, 35.76%, 53.86%, 69.41% with 10%, 20%, 30% and 40% addition of untreated GFRP powder. All the above tensile properties could be attributed to the reinforcing effect of the untreated GFRP powder.

Optimisation was observed at 20% of the untreated GFRP powder. The GFRP powder was now treated with silane coupling agents and incorporated into the neat matrix. The resulting Polybutyrate/treated GFRP powder composite showed the highest tensile strength and modulus. Also, the elongation at break was the least. A 100% increase in the tensile strength, 295.25% increase in modulus and 70.68% decrease in the elongation at break was seen at 20% of treated GFRP powder in the Polybutyrate matrix, compared to the neat matrix.

The betterment of the tensile properties is due to good welting of treated GFRP powder in the matrix, which increases the interfacial adhesion and promotes the efficient load transfer.

3.1.2) Flexural Properties:

The following were the observations from the flexural test, administered to the Polybutyrate/untreated GFRP powder composites and an optimised Polybutyrate/treated GFRP powder composite:

Standard : ASTM D 790
Type : 3 Point Loading
Specimen Size : 3.2mm * 12.7mm * 125mm (0.125” * 0.5” * 5.0”)

From the tables 5 and 6, it may be inferred that the flexural properties increased with the increase in untreated GFRP powder content, throughout. The increase was about 89.52%, 191.19%, 222.38% and 249.29% respectively for 10%, 20%, 30% and 40% of untreated GFRP powder.

It is noticed that the pure matrix can initate cracks under flexural loading. As the load increases, crack propagation also increases. As it can not terminate the crack propagation, it leads to low flexural strength. When it is filled with GFRP powder, the glass fiber stops the propagation of the crack and the loads are efficiently transfered from the matrix to the filler. It leads to greater flexural compared to pure Polybutyrate.

When GFRP is treated with silane coupling agent, it promotes interfacial bonding between Polybutyrate matrix and GFRP powder. This interfacial bonding slows down the propagation of crack and promotes crack termination. It leads to greater flexural strength. The same is evident from the increase in the flexural strength by 263.57% upon addition of 20% treated GFRP powder to the matrix, compared to that of the neat matrix.

3.1.3) Impact Properties:

The following were the observations from the impact test, administered to the Polybutyrate/untreated GFRP powder composites and an optimised Polybutyrate/treated GFRP powder composite:

Standard : ASTM D 256 & ASTM D 6110
Type : Izod & Charpy, respectively.
Specimen Size : Izod-64.5mm* 12.7mm*3.2mm & Charpy-127mm*12.7mm*3.2mm.

From the tables 7 and 8, it may be inferred that both the Izod and Charpy impact strength decreased with the increase in untreated GFRP powder content, throughout. GFRP powder has thermoset epoxy and glass fiber. Both epoxy and glass fiber have low impact strength compared to pure Polybutyrate, leading to the reduced impact impact strength of the end composite.

Further, it is also noticed that the impact strength of composite loaded with 20% of treated GFRP powder exhibits impact properties, better than untreated composite. Treatment using silane coupling agent, favours the energy absorbtion of composite, due to the flexible chain in the silane coupling agent. It also increases the adhesion between the matrix and the GFRP powder.

3.2) Morphological Properties

3.2.1) SEM Imagery:

The following were the micrographs of the optimized composite, obtained using the SEM analysis:

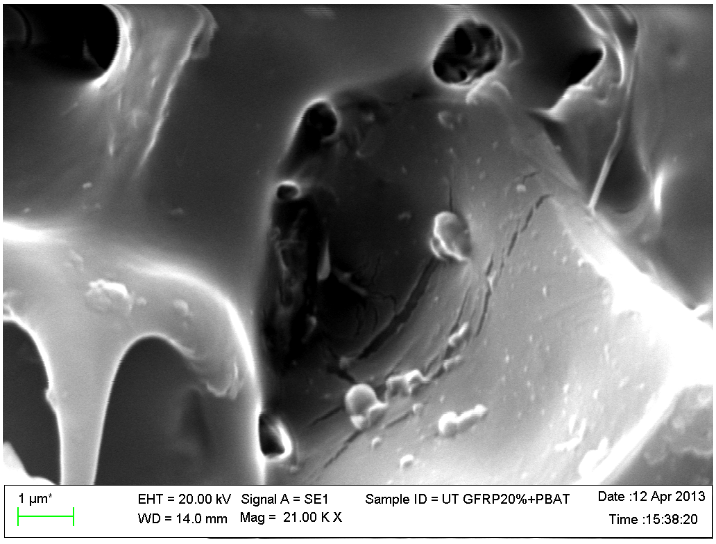

Figure 3: SEM micrograph of Polybutyrate 80% + Untreated GFRP 20%.

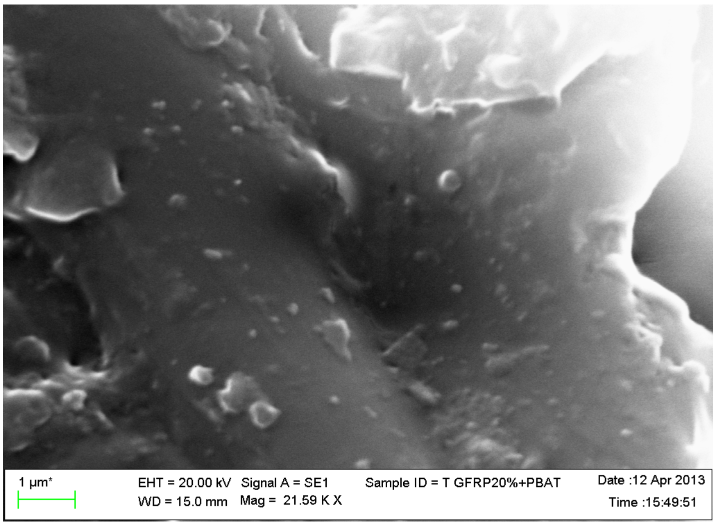

Figure 4: SEM micrograph of Polybutyrate 80% + Treated GFRP 20%.

Figures 3 & 4 show the micrographs of impact fractured specimens of 20% untreated and 20% treated GFRP powder composites. It is also noticed that glass fibers are well distributed throughout the matrix. Well distribution of GFRP powder is reflected on the increased tensile properties of composite. Also, the particle sizes were observed to be in the nanoscale.

4) Conclusion

Thus,

- Polybutyrate/untreated GFRP powder composites were prepared sucessfully in 5 different compositions, viz. 0%, 10%, 20%, 30% and 40% of untreated GFRP powder. With the increase in untreated GFRP powder content, tensile and flexural properties had increased, while the impact properties suffered. Optimization was observed at 20% of the untreated GFRP powder.
- Secondly, Polybutyrate/treated GFRP powder composite containing 20% treated GFRP powder was prepared. This treatment of GFRP powder improved the properties drastically, with respect to the neat matrix and the untreated composite.
- Thirdly, SEM observations confirmed that the blends of Polybutyrate/treated and untreated GFRP powder are miscible. Also, the level of dispersion was found to be excellent.

These composites could be applied in packaging, garden products, waste bin liners, etc.

5) References

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6) List of Tables

Table 1. Melt mixing formulation for Polybutyrate/Untreated GFRP powder Composite

S. No.	Sample	Polybutyrate (%)	Untreated GFRP (%)
1	A	100	0
2	B	90	10
3	C	80	20
4	D	70	30
5	E	60	40

Table 2. Melt mixing formulation for Polybutyrate/Treated GFRP powder Composite (Based on Optimization from the above)

S.No.	Sample	Polybutyrate (%)	Treated GFRP (%)
1	A	80	20

Table 3. Tensile properties of Polybutyrate/untreated GFRP powder composites

S. No.	Sample	Polybutyrate (%)	Untreated GFRP (%)	Tensile Strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)
1	A	100	0	8.15	27.83	392.29
2	B	90	10	12.50	49.59	339.00
3	C	80	20	13.82	76.57	252.00
4	D	70	30	10.10	82.85	181.00
5	E	60	40	9.10	81.92	120.00

Table 4. Tensile properties of Polybutyrate/treated GFRP powder composites

S. No.	Sample	Polybutyrate (%)	Treated GFRP (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)
1	A	80	20	16.00	110.80	115.00

Table 5. Flexural properties of Polybutyrate/untreated GFRP powder composites

S. No.	Sample	Polybutyrate (%)	Untreated GFRP (%)	Flexural strength (MPa)
1	A	100	0	4.20
2	B	90	10	7.96
3	C	80	20	12.23
4	D	70	30	13.54
5	E	60	40	14.67

Table 6. Flexural properties of Polybutyrate/treated GFRP powder composites

S. No.	Sample	Polybutyrate (%)	Treated GFRP (%)	Flexural strength (MPa)
1	A	80	20	15.27

Table 7. Impact properties of Polybutyrate/untreated GFRP powder composites

S. No.	Sample	Polybutyrate (%)	Untreated GFRP (%)	Izod Impact Strength (J/m)	Charpy Impact Strength (J/mm^2)
1	A	100	0	489.12	78.60
2	B	90	10	459.98	71.80
3	C	80	20	314.40	68.58
4	D	70	30	217.87	54.13
5	E	60	40	159.00	40.57

Table 8. Impact properties of Polybutyrate/treated GFRP powder composites

S. No.	Sample	Polybutyrate (%)	Treated GFRP (%)	Izod Impact Strength (J/m)	Charpy Impact Strength (J/mm^2)
1	A	80	20	385.96	70.21