CHAPTER 4

MECHANICAL STRENGTH ANALYSIS

4.1 Introduction

This chapter presents the details of mechanical properties of developed samples. A comparative study of properties like tensile, flexural, compressive and impact strengths were made to investigate the samples exhibiting best behaviours. Influence of chemical pre-treatment to natural fibers on mechanical strengths have also studied during this comparison. Microstructural analysis were done on the best samples and worst samples in order to visualize the defects of preparation process.

4.2 Tensile strength analysis

The tensile strength plot for all tested samples were compared by using histograms as presented in Figure 4.1. It was observed that the two untreated samples namely, UV17G17 and UV17J17 shows least tensile strength of 53.21 MPa and 59.2 MPa respectively in comparison with remaining samples. Comparing samples UV17G17 and TV17G17 and comparing samples UV17J17 and TV17J17 it was observed that chemical treatment improved the strengths by 31.1 % and 21.16 % respectively (Girisha et al. 2012).

Among vetiver/glass samples, a 7 % increase in glass content increases the strength whereas a 14 % increase in glass content decreases the strength and a maximum tensile strength of 69.76 MPa was shown by sample TV17G17. This shows that too much inclusion of glass fibers is not suitable to achieve higher tensile strength. Hence, the optimum glass content among vetiver/glass composites was found to be 17 %. Among vetiver/jute samples, a maximum strength of 71.73 MPa was observed in sample TV17J17. It was also noted that the composite with equal proportion of vetiver and jute is better than the composites with unequal proportions. Comparing sample TV17G17 and TV17J17, it would be concluded that 17 % of glass fibers may be replaced by natural fibers without losing the composite properties.

Among tri-fiber composite sample, a 6 % increase in glass content decreases the strength of composite and a maximum strength of 74.14 MPa was observed in sample
TV13J13G8. This also shows that, too much inclusion of glass fibers reduces the tensile strength but, by correct proportion of hybridization of multiple fibers in to the matrix substantially improves the tensile strength of composites (Dixit & Verma 2012). From the discussions, best three composite samples identified are TV17J17, TV13J13G8 and TV10J10G14 respectively.

Figure 4.1. Tensile strength plot

4.3 Flexural strength analysis

Flexural strength is a measure of stiffness of the composite and it was analyzed by using three point bending test. During this test, the top layer of the specimen is subjected to compression and the bottom layer of the specimen is subjected to tension. The mid-layer is subjected to shear and hence, the failure of composite is due to a combination of bending shear. The flexural strength plot of tested samples were presented in Figure 4.2. It was observed that the two untreated samples namely, UV17G17 and UV17J17 show least flexural strength of 97.27 MPa and 101.26 MPa respectively in comparison with all treated samples. Comparing samples UV17G17 and TV17G17 and comparing samples UV17J17 and TV17J17 it was noted that chemical treatment improved the strengths by 35.62 % and 31.45 % respectively.
Among vetiver/glass composite samples, a 7% increase in glass content increases the strength whereas 14% in increase in glass decreases the strength and a maximum strength of 131.92 MPa was shown by sample TV17G17. Hence, too much inclusion of glass fibers is not suitable for achieving higher flexural strength and the optimum fiber proportion among vetiver/glass composites was found to be 17%. This behaviour is almost similar to the tensile strength behaviour of composites. Among vetiver/jute composites, a maximum strength of 133.11 MPa was shown by sample TV17J17.

It was observed that sample with equal proportion of vetiver and jute is better than composites with unequal proportions of natural fibers. Comparing sample TV17G17 and TV17J17, it would be concluded that 17% of glass fibers may be replaced by natural fibers without losing the composite properties. Among tri-fiber composite sample, a 6% increase in glass content increases the strength of composite and a maximum strength of 137.6 MPa was observed in sample TV10J10G14. Among tri-fiber composites, hybridization of glass fibers show a positive effect on flexural strength (Patel & Parsania 2012). From the investigations, the best composite samples identified are TV10G24, TV17J17, TV13J13G8 and TV10J10G14 respectively.

![Figure 4.2. Flexural strength plot](image-url)
4.4 Compressive strength analysis

The compressive strength plot of tested composite samples is presented in Figure 4.3. It was observed that the two untreated samples namely, UV17G17 and UV17J17 show least compressive strengths of 91.84 MPa and 95.83 MPa respectively in comparison with all treated samples. Comparing samples UV17G17 and TV17G17 and comparing samples UV17J17 and TV17J17 it was noted that chemical treatment improved the strengths by 28.4 % and 27.5 % respectively. Among vetiver/glass samples, a 7 % increase in glass content and also a 14 % increase in glass content increases the compressive strength. Hence 24 % of glass with 10 % vetiver could be the correct combination to achieve a good compressive strength.

![Figure 4.3. Compressive strength plot](image)

Among vetiver/jute samples, maximum strength of 122.21 MPa was observed in sample TV17J17. Here also it was observed that sample with equal proportion of vetiver and jute is better than composites with unequal proportions of natural fibers. Comparing sample TV17G17 and TV17J17, it would be concluded that 24 % of glass fibers may be replaced by natural fibers without losing the composite properties. Among tri-fiber composite sample, a 6 % increase in glass content increases the strength of composite and a maximum strength of 128.23 MPa was observed in sample TV10J10G14.
Among tri-fiber composites, hybridization of glass fibers shows a positive effect on compressive strength (Reddy et al. 2008) and this behaviour is similar to that of the flexural behaviour of composites. From the analysis, best three samples identified are TV17J17, TV13J13G8 and TV10J10G14.

4.5 Impact strength analysis

Impact strength is a measure of resistance offered by the composite against fracture during application of high speed stress. In other words, it is a measure of toughness of the composite. Impact strength depends upon the fiber pull-out during fracture. Inclusion of more fibers increases the pull-out force and hence there is an increase in impact strength (Rahman et al. 2010). The energy absorbed during Charpy impact test for all samples are observed and plotted is in Figure 4.4. It was observed that untreated samples namely, UV17G17 and UV17J17 shows least impact strengths of 8.67 J and 7.8 J respectively in comparison with all treated samples.

Comparing samples UV17G17 and TV17G17 and comparing samples UV17J17 and TV17J17 it was observed that chemical treatment improved the impact strengths by 65.3 % and 49.6 % respectively. Among vetiver/glass samples, a 7 % increase in glass content increases the impact strength and further, a 14 % increase in glass content also increases the impact strength. Hence among vetiver/glass composites, 24 % of glass with 10 % vetiver could be the correct combination to achieve a good impact strength. Among vetiver/jute samples, maximum strength of 12.05 J was observed in sample TV24J10.

The strengths shown by vetiver/jute composites are lesser than other glass reinforced composites. This is due to the fact that glass fibers have the ability to absorb high energy during impact than the natural fibers. So, glass fibers are responsible for obtaining good impact properties in a composite. This indicates that the presence of glass fibers is very important to achieve good impact property (Idicula et al. 2010). Among tri-fiber composite samples, a 6 % increase in glass content increases the strength of composite and a maximum strength of 18.33 J was observed in sample TV10J10G14.
Among tri-fiber composites, hybridization of glass fibers shows a positive effect on impact strength. Hence, a minimum glass content of 14 % must be maintained in order to achieve good impact properties. From the investigations, the best samples identified are TV10J24, TV13J13G8 and TV10J10G14 respectively.

Figure 4.4. Impact strength plot

4.6 Stress-strain analysis

A consolidated tensile stress-strain plot of all tested samples is presented in Figure 4.5. It was observed that stress increases with increase in strain for all samples until the ultimate point then decreases slightly before breaking point. The plot may be divided into two regions namely low strain region and high strain region. At low strain levels, the stress increases linearly for all samples and at high strain levels the samples show a plastic behaviour. This plastic behaviour is due to the formation micro cracks in the matrix. These cracks propagate due to the presence of random vetiver fibers and hence the bonding between fiber and matrix breaks; as a result, there would be an abrupt decrease in strength (Idicula et al. 2010).

The stress-strain curve for sample TV10G24 increases until the maximum strain and suddenly breaks without decrease in stress. This behaviour looks like a pure glass and this may be due to the presence of 24 % of glass in the composite sample. The stress-strain curve of remaining samples increases linearly at low strain levels, increases nonlinearly at high strain levels with a slight deflection in slope until maximum stress limit followed by a sudden drop before complete breakage.
The tensile strain plot is presented in Figure 4.6. It was observed that among vetiver/glass composites, increase in glass content decreases the strain and a maximum strain of 8.5% was obtained for sample TV24G10. The same behaviour was observed for tri-fiber composites. Failure of glass fibers transfers high stress to the natural fibers and hence, glass fibers are more responsible in determining the breakage of composites. Among vetiver/jute composites a maximum strain of 9.5% was observed for sample TV17J17 and it was observed that, sample with equal proportion of vetiver and jute shows high strain than samples with unequal proportions of natural fibers. Hence, composite samples with only natural fibers are better than glass reinforced hybrid samples for achieving high strain levels.
Based on the mechanical strength analysis, three samples namely TV17J17, TV13J13G8 and TV10J10G14 were selected as best samples respectively. Surface morphology shows the bonding of fibers with the matrix, adhesive property of the matrix, matrix cracking, cavities, micro-holes, pull-outs etc. Scanning electron microscopic images of fractured samples have been captured and presented in Figure 4.7. The surface morphology of three best samples were compared with an untreated sample namely UV17G17 in order to make a comparative analysis and between treated and untreated samples. The morphology of sample UV17G17 shows improper adhesion between matrix and resin.

This resulted in formation of more cavities and poor interfacial strength due to which stress transfer mechanism fails. Also, fiber pullouts are more when compared to treated samples. These reasons make the untreated sample to break earlier than the remaining ones. Comparing the morphology of untreated sample with treated samples, it could be concluded that chemical pretreatment to natural fibers improved the mechanical properties (Zabihzadeh et al. 2010 & Jannah et al. 2009).

**Figure 4.6. Tensile strain plot**
The morphology of treated samples shows denser distribution of vetiver fibers in between the glass layers and there found to be proper bonding between vetiver and glass fiber layers. An abrupt breakage of vetiver fibers happens where there was a strong bond between matrix and fiber and pullouts takes place where there was a weak bond between matrix and fiber.

Figure 4.7. Microstructure of samples (a) UV17G17 (b) TV17J17 (c) TV13J13G8 (d) TV10J10G14

The morphology also indicates that damage is initiated from the area where vetiver was present and then it moves to the area where jute and glass fibers were present. Hence vetiver behaves like a brittle material in combination with vinyl ester matrix. It was also observed that the bonding between jute and resin is qualitatively better than between vetiver and resin and this may be due to random distribution of vetiver fibers on the resin.
Summary

- The mechanical properties like tensile, flexural, compressive and impact behaviour of treated and untreated samples are addressed. A comparative study between each category of samples have been extensively made.

- The results showed that chemical pre-treatment to natural fibers improved tensile, flexural, compression and impact strengths. It was concluded that the presence of glass fibers is very important in order to achieve good impact properties.

- The chapter addressed the behaviour of each sample in tensile stress-strain curve and concluded that there found to be a combined elastic and plastic behaviour of all samples during loading. It was also examined that the sample with high glass content behaves like a pure glass.

- Strain analysis have been carried out and concluded that strain is inversely proportional to the presence of glass fibers and hence glass fibers are responsible for earlier breakage of composites.

- Microstructure analysis showed the details of various defects present in untreated samples and a qualitative enhancement of those defects in treated samples.