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ORIGINAL RESEARCH ARTICLE

Reinforcing Effect of Jute Fibre on the Mechanical, Dynamic Mechanical and Physical Properties of Polypropylene

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ABSTRACT

Jute fibre is readily available, biodegradable and relatively cheap. These attributes make it a promising reinforcing fibre, making it find applications in engineering end-use. This work aims at establishing the effect of jute fibre inclusion in a jute fibre-reinforced polypropylene. The investigation involved the fabrication of composite plates by using the Carver Press Model and fibre loading (16 %, 22 % and 27 %). The tensile, flexural, impact, DMA, SEM, Water absorption and Density were all carried out according to ASTM Standards. The results show positive improvement in the mechanical and physical properties of the resulting composites. The results of the SEM micrographs and DMA (3.5 GPa at 25 ^oC) showed good fibre–matrix interaction. The highest tensile strength observed was 56.4 MPa, the tensile modulus was 741.8 MPa, the flexural strength was 58.68 MPa, the flexural modulus was 2479.7 MPa, and the impact strength was 8.611 kJ/m^2. These were possible considering the weave structure of the hessian cloth (plain weave), which enabled wetting of the fibre by the matrix during lamination; this was made possible by fabricating at 190 ^oC and a pressure of 500 psi for 4min. The set-up was preheated for 8min to enable the polymer matrix flow before the heat pressing. The Density of the resulting composites showed that the inclusion of the jute fibre did not significantly change the polymer's density, making it a good material for lightweight applications.

ARTICLE HISTORY

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KEYWORDS

Composite, Mechanical strength, DMA, Jute fibre, SEM

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INTRODUCTION

The use of natural fibres as reinforcements in the processing of thermoplastic composites has increased drastically in recent years (Prasad *et al.,* 2014).

Because of its low cost, renewable nature and the considerable low energy required for processing, Jute is a suitable natural fibre for use, as reinforcement in composite. Jute is a strong, coarse, rigid fibre with very low extensibility, making it suitable to act as a reinforcing material in the composite. Jute was chosen for this work due to its availability, relatively low cost, and ease of processing. It is also found to be relatively higher than hemp and flax in terms of impact strength. Other work carried out by Bhuiyan *et al.*, 2023, only considered the TGA and not the DMA. Their work used polypropylene waste and not virgin polypropylene. The DMA analysis provides information regarding the material behaviour over a temperature range regarding stiffness and interfacial adhesion. Polypropylene is widely used in carpets, blankets and geotextiles. Due to its bulk, inert nature and low density, preference is often, given to polypropylene. Composite fabrication using jute and polypropylene can help in maintaining cost (Saravanan and Dhurai, 2013; Berhanu *et al.,* 2014; Hong *et al.,* 2008; Sature and Mache, 2015; Gupta *et al.,* 2015; Misera *et al.,* 2015; Begum and Islam, 2013; Sahari and Sapuan, 2011; Sodhi and Parkash, 2015). On the other hand, many synthetic fibres are relatively expensive (Shivankar and Joshi, 2015).

Composite materials are needed in the development of engineering materials because combining two or more materials makes it possible to overcome the brittleness and poor processability of stiff and hard polymers (Ornagi *et al.,* 2010).

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Polymer matrix composites are widely used because they yield a unique combination of high performance, great versatility and processing advantages at a reasonable cost. The combination of a variety of fibres and polymers produces a wide range of composites, which are viable alternatives to conventional materials, e.g. metal and wood (Warbhe *et al.,* 2016; Rao *et al.,* 2015).

2.0 MATERIALS AND METHODS

2.1 Materials

Woven jute fibre (Hessian cloth), 250 g.m^{-2}, plain weave, was sourced from Metro Home Centre, Menlyn, Pretoria, South Africa. HLR 102 Polypropylene homopolymer was sourced from SASOL, South Africa, with a density of 0.905 g/cm^3, melt mass flow rate of 5.3 g/10min.

This work was carried out in South Africa at the National Centre for Nano-Structured and Advanced Materials, Council for Scientific and Industrial Research, Pretoria.

2.2 Methods

The methods used are as described in Danladi *et al*., 2020a. Table 1 shows the different compositions of the composites and the respective number of plies.

Table 1: Formulations of the Jute Fibre/Polypropylene Composites

S/NO	PP (%)	JF (%)	NO OF PLIES
1	100	0	0
2	84	16	2
3	78	22	3
4	73	27	4

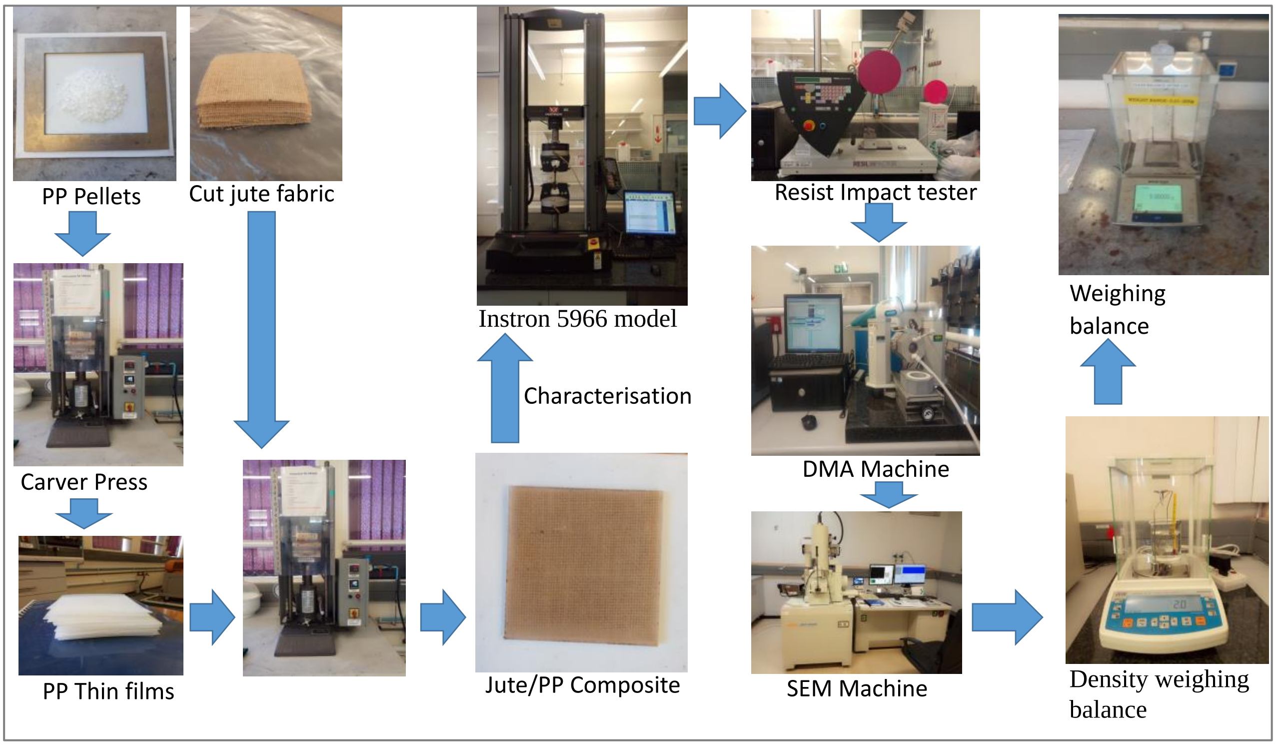

Figure 2.1: Schematic representation of the methods used

2.3 Standards for Characterisations, including Samples, dimensions and conditions

The standards for characterisation, including samples, dimensions and conditions, are described in Danladi *et al*., 2020a.

3.0 RESULTS AND DISCUSSION

Figure 3.1 shows that the addition of jute fibre into the polymer matrix had an almost, linear effect on the resulting composites. The jute fibre had an increase of ~36.2 % in the tensile strength of the composite. Literature findings reported Berhanu *et al.,* 2014 had a tensile strength of 27.5 MPa at a fibre loading of 40 %. Hong *et al*., 2008, reported a tensile strength of 27.8 MPa at fibre loading of 2 %. Plateau, 2017, had a tensile strength of 33.4 MPa at a fibre loading of 10 %. Chestee *et al*., 2017, reported a tensile strength of 17.5 MPa at 20 % fibre loading. Findings by Das *et al*., 2018, reported a tensile strength of 60 MPa at 50 % fibre loading.

Figure 3.2 illustrates the effect of the fibre loading on the stiffness (modulus) of the resulting composites when compared to the pure polymer matrix. There was a near-linear effect on the tensile modulus of the resulting composites. The combination of jute fibre and the polymer matrix led to an increase of ~33.6 % in the tensile modulus of the composites. Berhanu *et al*., 2014 had a tensile modulus of 550 MPa at a fibre loading of 40 %; this could be due to the processing temperature applied, 165 ^{o}C, Hong *et al*.,2008 found a tensile modulus of 1542.7 MPa at a fibre loading of 2 %. Literature findings show that Chestee *et al*., 2017, reported a modulus of 0.6 GPa at a fibre loading of 20 %. Das *et al*., 2018, had a tensile modulus of 2500 MPa at 50 % fibre loading.

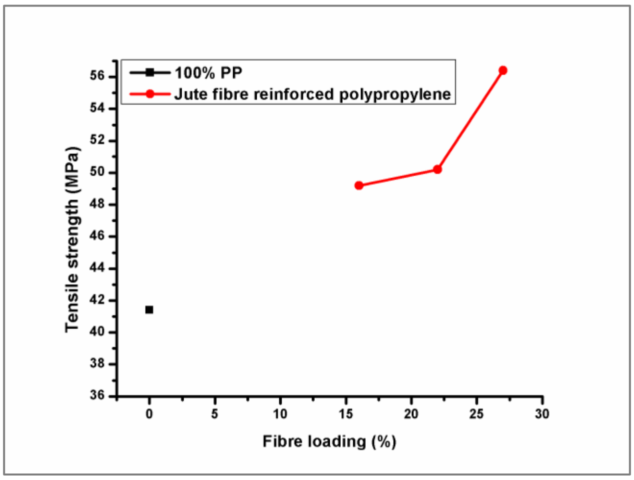

Figure 3.1: Tensile strength VS Fibre loading.

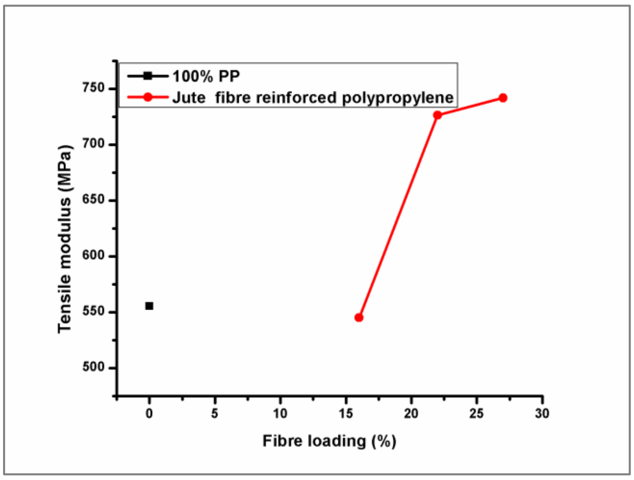

Figure 3.2: Tensile modulus VS Fibre loading

Figure 3.3 shows the effect of fibre loading on the flexural strength of the composites. The fibre loading had a linear effect. An increase in the flexural strength of ~34.7 % was recorded in the resulting composites. Das *et al.*, 2018 had a flexural strength of 95 MPa at 50 % fibre loading. At 40% fibre loading, Berhanu *et al.*, 2014 reported a flexural strength of 67.5 MPa. Literature findings also showed that Chestee *et al.*, 2017 had a flexural strength of 32.5 MPa at 20% fibre loading.

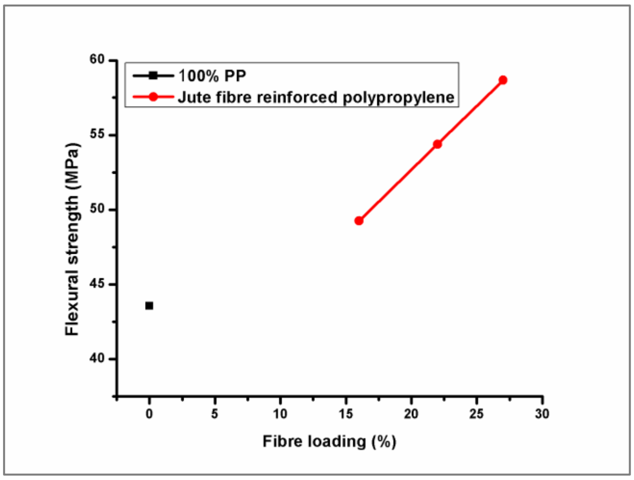

Figure 3.3: Flexural strength VS Fibre loading.

The flexural modulus, which signifies the toughness of the composites and the polymer matrix, is shown in **Figure 3.4**. It was observed that the jute fibre had a positive effect, increasing the stiffness of the composites when subjected to a bending force. The inclusion of jute fibre led to an increase of ~86.2 %. Literature findings show that Berhanu *et al.*, 2014, reported a flexural modulus of 7.75 GPa at 50 % fibre loading. Chestee *et al.*, 2017 reported a flexural modulus of 2 GPa at 20 % fibre loading. Using fibre loading of 50%, Das *et al.*, 2018 had a flexural modulus of 4500 MPa.

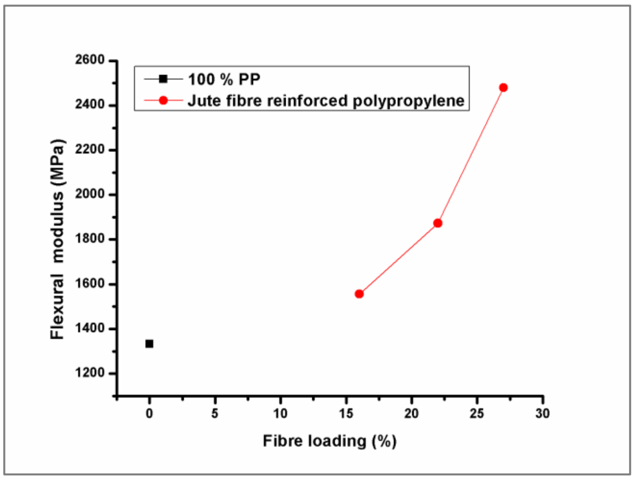

Figure 3.4: Flexural modulus VS Fibre loading.

Figure 3.5 illustrates the effect of fibre loading on the impact strength of the composites. The jute fibre increased the polymer's impact strength by 45.2 %. This is highly significant and similar to the findings of Das *et al.*, 2018.

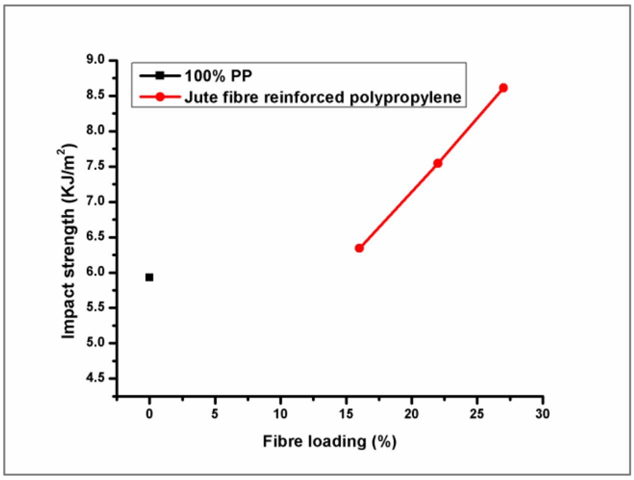

Figure 3.5: Impact strength VS Fibre loading.

Figure 3.6 shows the dynamic mechanical characteristics (storage modulus) of the polymer matrix as well as that of the composites as temperature varies. Generally, the composites had improved storage modulus than the polymer matrix from 0 °C to 125 °C. The 16 % and 22 % fibre loadings had almost the same values of storage modulus, and this phenomenon is attributed to the molecular motion. The 27 % fibre loading had a higher storage modulus all through the temperature range; this is attributed to the strong rigidity and stiffness of the composite. Hong *et al.*, 2008, reported similar findings.

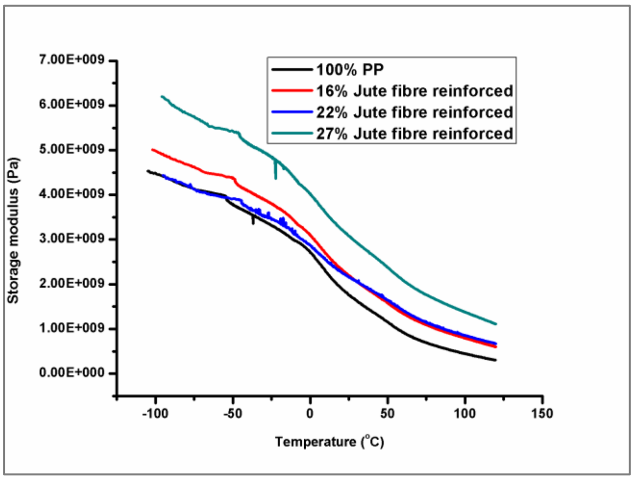

Figure 3.6: Storage modulus VS Temperature

The glass transition temperature is a function of damping with respect to temperature. Figure 3.7 shows that the inclusion of the jute fibre, continuously reduced the glass transition temperature of the composites when compared to the polymer matrix. However, as the temperature rises, there is a continuous decrease in damping in the composites when compared to the polymer matrix. This is attributed to the fact that increases in stiffness and strength resulted in a decrease in damping (Plateau, 2017). Literature findings showed that Hong *et al., 2008,* reported similar results.

Chandra *et al.*, 1999 defined the damping factor as the ratio of loss modulus to storage modulus, meaning the higher the storage modulus, the lower the damping factor and the stronger the material due to good fibre–matrix interaction.

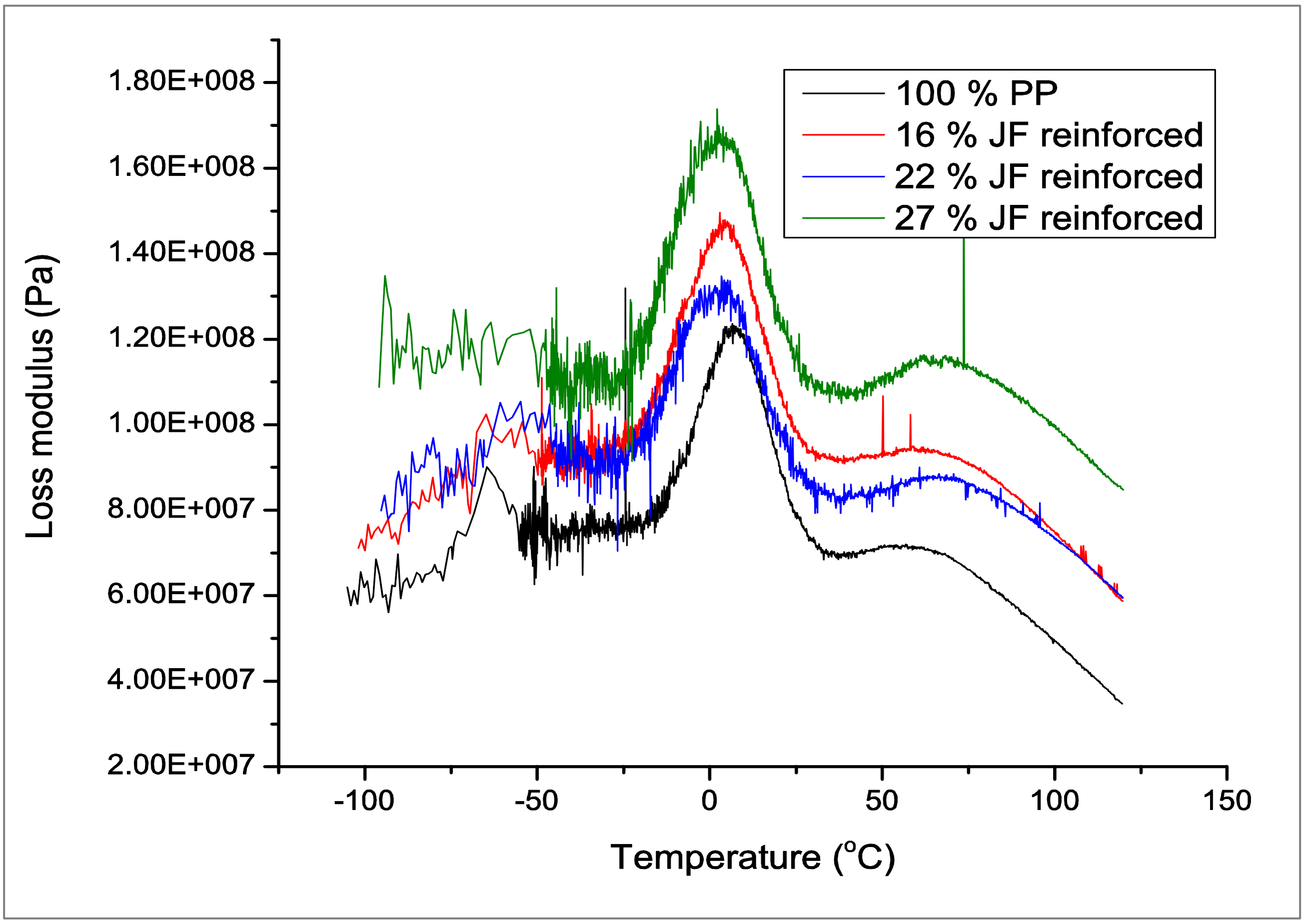

Figure 3.7: Loss Modulus VS Temperature

The Scanning Electron micrographs of the impacted samples of the polymer matrix and the composites are shown in Figure 3.9. The micrographs show relatively good fibre matrix interaction, as seen by the fibre pull-out and fibre breakage in Figure 3.9. This also agrees with the results from the Dynamic Mechanical Analysis Figure 3.6 to 3.8 (3.6, 3.7 & 3.8). Berhanu et al. 2014; Hong et al., 2008) reported similar findings. The fibre breakage and fibre pull-out resulted from the adhesion between the fibre and the matric. A poor adhesion would have led to delamination and not pull, as shown in the SEM sample analysis; however, because the impact strength of jute fibre is lower than that of synthetic fibres, e.g. glass fibre.

The composite density was not significantly affected by using jute fibre as reinforcement, as shown in Figure 3.10. Fibre loading showed a minimal increase in density (7.2 %).

The effect of the fibre loading on the water absorption capacities of the composites is illustrated in Figure 3.11. The inclusion of jute fibre in the polymer matrix displayed an increase in water absorbing capacity from 0.001 % to 1.277 % when compared with that of the polymer matrix. Das *et al.*, 2018, reported water absorption of 12.5 % at 50 % fibre loading.

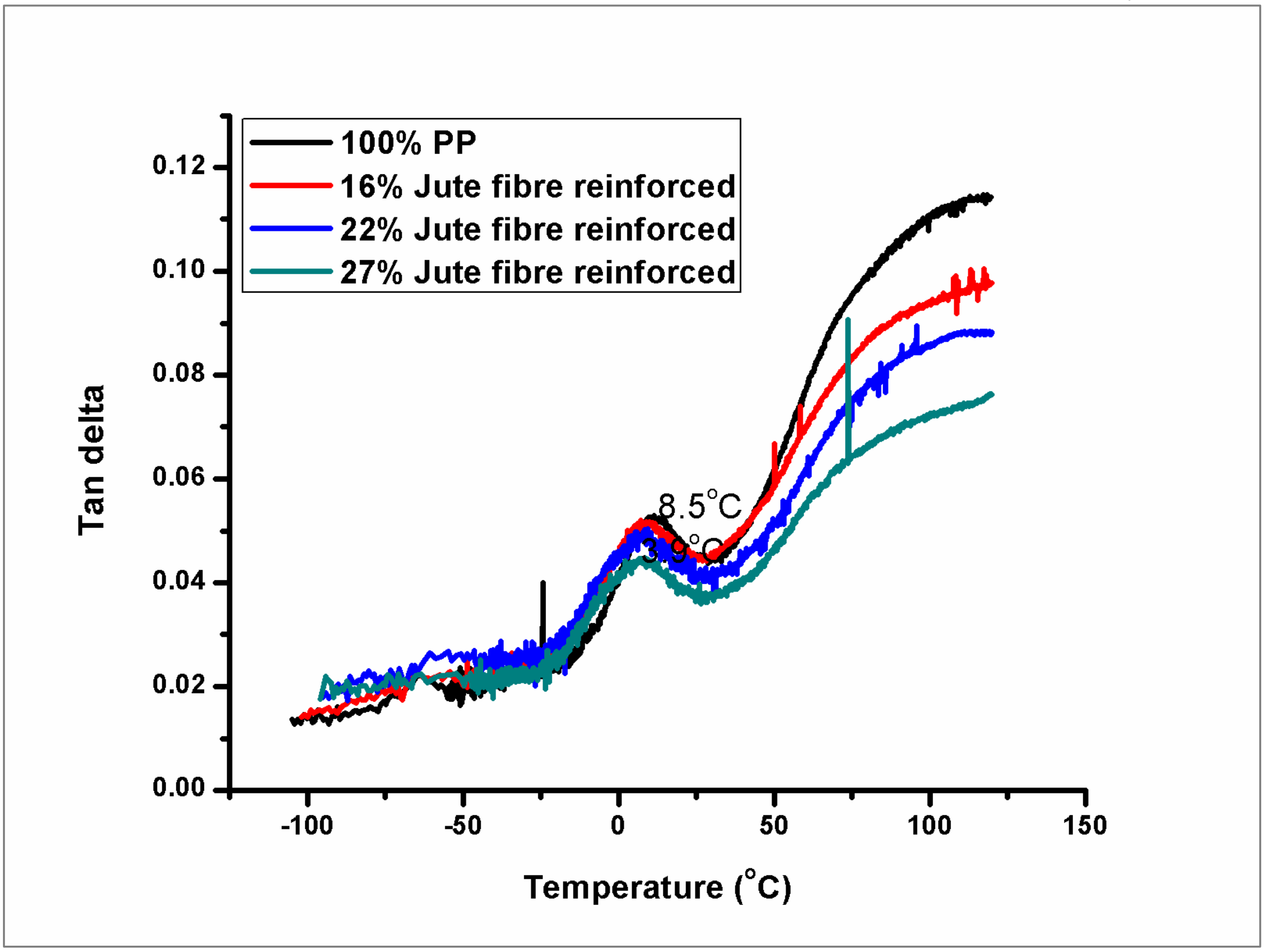

Figure 3.8: Glass transition and damping VS Temperature.

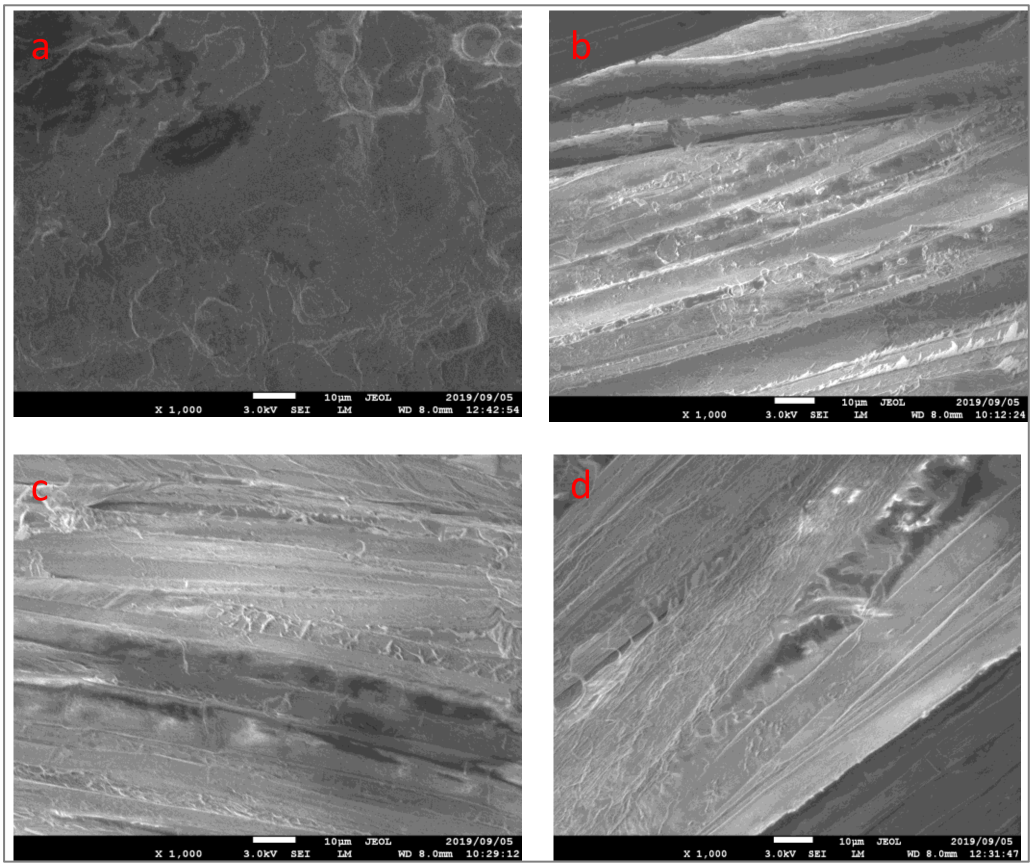

Figure 3.9: SEM micrographs of (a) Polypropylene, (b) 16 % Jute Fibre, (c) 22 % Jute fibre and (d) 27 % Jute fibre

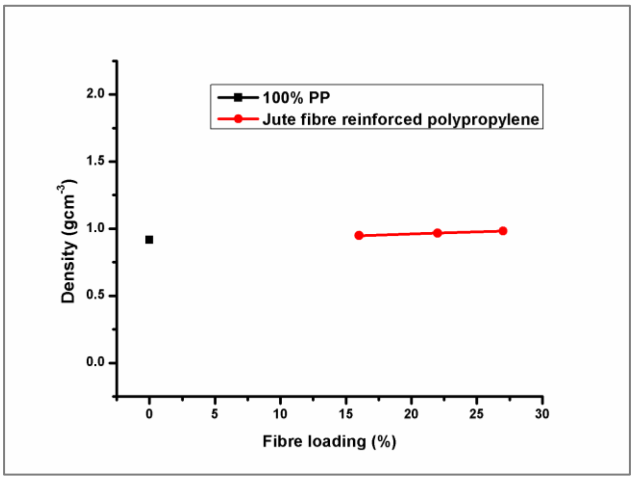

Figure 3.10: Density VS Fibre loading

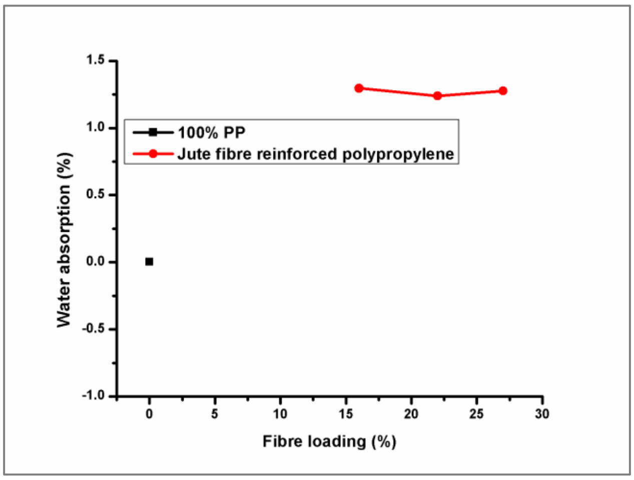

Figure 3.11: Water absorption Fibre loading

4.0 CONCLUSIONS

In conclusion, the addition of jute fibre significantly improved the material's mechanical properties.

The morphological results showed that there was a good matrix–fibre interaction.

The density of the resulting composites showed that the inclusion of the jute fibre did not significantly change the polymer's density, making it a good material for lightweight indoor applications.

The jute fibre-reinforced composites can be improved, should they it be required for application in ballistic vest, by hybridising it with high strength fibre like Kevlar.

Jute fibre has a relatively higher impact strength than others, such as hemp and flax.

5.0 RECOMMENDATIONS

1. The impact strength of the composites can be improved further by hybridisation using a synthetic fibre.
2. Further investigations should be carried out to determine the maximum fibre loading where the composite characteristics will take a downward trend.
3. Further studies should be carried out on the long-term exposure to water to determine the maximum water absorption level.

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