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Effect of Woven E - Glass Fibre Loading on the Mechanical, Morphological and Physical Properties of Reinforced Polypropylene Composite for Automobile Application

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Abstract
This research investigates the impact of glass fiber content on the mechanical, morphological, physical, and dynamic mechanical properties of polypropylene (PP) composites. The selection of PP and glass fiber is driven by their widespread availability, favorable mechanical characteristics, and cost-effectiveness. The study involves the fabrication of glass fiber-reinforced PP composites using a Carver Press Model with a fiber loading range of 13% to 22%. The following properties were evaluated for the composites with 18% fiber loading: Tensile strength: 55.2 MPa, Tensile modulus: 989.1 MPa, Flexural strength: 64.47 MPa, Flexural modulus: 1970.58 MPa, Impact strength: 28.76 kJ/m², Density: 1.038 g/cm³, Water absorption: 0.274%. Dynamic mechanical analysis (DMA) revealed poor fiber-matrix adhesion at elevated temperatures and high damping characteristics. Scanning electron microscopy (SEM) micrographs further confirmed the presence of delamination, matrix rupture, and fiber breakage within the composite. Based on the improved properties observed in the study, particularly increased tensile and flexural strength and modulus, polypropylene composites with optimized glass fiber content could be suitable for various applications such as Automotive components, Construction materials, Sporting goods, and Consumer electronics. Overall, with further optimization, polypropylene composites with tailored glass fiber content have the potential to find applications in various industries requiring lightweight, strong, and cost-effective materials.

Keywords: Polypropylene, Glass fibre, DMA, SEM

1.0 Introduction

The varied usage of thermoplastic polymers in structural and engineering applications is due to their better impact strength, specific strength and stiffness, shorter processing cycle, recyclability and infinite shelf life better than thermoset polymers. Some of the applications of thermoplastics found in the automobile industries are bus bumpers and seat back structures made up of glass fibre/polypropylene composites due to the ease of fabrication and it's lightweight (Suresh and Kumar, 2014; Rahman *et al*., 2014; Swolfs *et al*., 2014; Etchevery and Babosa, 2012; Nuruzzaman *et al*., 2016).

A lot of work has been done on glass fibre-reinforced composites (Gupta *et al*., 2015; Lin *et al*., 2015; Harper *et al*., 2009; Sorrentino *et al*., 2015; Krishna *et al*., 2015; Prasad *et al*., 2014; Fu *et al*., 2000; Wichmann *et al*., 2006; Santulli, 2003; Ansar *et al*., 2013; Kim *et al*., 2007; Panthapulakkai & Kai, 2007; Kim *et al*., 2010; Alagarraja *et al*., 2014; Nunes *et al*., 2013). Gupta *et al*., 2015 studied the effect of fillers on the tensile strength of protruded glass fibre-reinforced polymer composite. Lin *et al.,* 2015 investigated the effect of coupling agents on the mechanical properties, thermal behaviour and morphology of polypropylene/short glass fibre composites.

Harper *et al*., 2009 studied the impact of polypropylene–graft–maleic anhydride on the crystallization and dynamic mechanical properties of isotactic polypropylene. Krishna *et al.,* 2015 investigated the mechanical properties of glass fibre-reinforced polypropylene-based resin composite. Sorrentino *et al*., 2015, investigated the mechanical performance optimisation through interface strength gradation in polypropylene/glass fibre composites.

Rahuman *et al*., 2004 investigated the morphological, thermal and mechanical properties of glass fibre and nano-clay reinforced polypropylene composites. Prasad *et al*., 2014 studied the mechanical properties of composite materials reinforced by jute and E-glass fibres. Fu *et al*., 2000 report the tensile properties of short glass fibre and short carbon fibre-reinforced polypropylene composites. Wichmann *et al*., 2006 investigated the benefits and limitations of a nanoparticle-modified matrix on glass fibre-reinforced composites with enhanced thermal and electrical properties.

Santulli, 2003 investigated the impact hysteresis curves on e-glass reinforced polypropylene laminates, while Ansar *et al*., 2013 worked on the fatigue analysis of glass fibre-reinforced composites. Kim *et al*., 2007 studied the effect of types of maleic anhydride grafted polypropylene on the interfacial adhesion properties of bio-flour-filled polypropylene composites.

Panthapulakkai & Sai, 2007 studied the water absorption properties of short hemp-glass fibre hybrid polypropylene composites. *Kim et al*., 2010 investigated the effect of processing on the mechanical properties of glass fibre-reinforced polymer composites for 49-metre recreational yachts.

Alagarraja *et al*., 2014 studied the fabrication and characterization of fibre-reinforced polymer composites. Nunes *et al.,* 2013 studied the processing conditions and properties of continuous fibre-reinforced GF/PP thermoplastic matrix composites manufactured from different pre-impregnated materials.

Ferreira *et al*., 1999 studied the static and fatigue behaviour of glass fibre reinforced polypropylene composites. Saravanan & Dhurai, 2013 studied the effect of process parameters on the impact strength of short jute fibre-reinforced polypropylene composite board.

Their findings revealed that jute/polypropylene composites could be manufactured successfully at a minimum temperature of 165 ^{o}C and processing time of 3 min and a moderate pressure of 8.13 bar. They also found that processing parameters affected the impact strength.

Karmaker and Youngquist studied the injection molding of polypropylene reinforced with short jute fibres (Karmaker & Youngquist, 1996), and the findings revealed that maleic anhydride improved the tensile and flexural strength of the composite than when the coupling agent was not added. Gibson *et al.,* 2010 studied the high temperature and fire behaviour of continuous glass fibre/polypropylene laminates. Gu *et al*., 2018 studied the interfacial designing of PP/GF composite by binary incorporation of MAH– g – PP and Lithium bis(trifloromethanesulfonyl) imide. Their investigation revealed a new possibility of using various interfacial bonding between the matrix and reinforcement to achieve the interface between glass fibre-reinforced composites with excellent antistatic performance.

2.0 Materials and Methods

2.1 Materials

The glass fibre and polypropylene used are as described in the work of Danladi *et al*., 2020

2.2 Fabrication

The fabrication technique used and characterization techniques and dimensions are as described in Danladi *et al*., 2020

Table 1 shows the different compositions of the composites

Table 1: Fabrication compositions

S/N	PP (%)	GF (%)	No. of Piles
1	100	0	0
2	87	13	2
3	82	18	3
4	78	22	4

3.0. Results and Discussion

Fig. 1 illustrates the changes in the tensile strength with the % fibre loadings. The results show that there was a significant increase in tensile strength as the polymer matrix was loaded with glass fibre. Fu *et al*., 2000 reported a tensile strength of 50 MPa at a fibre loading of 25 % for short glass/polypropylene composite while Lin *et al*., 2015 reported a tensile strength of 67.6 MPa at fibre loading of 25 % for short glass fibre/polypropylene composites. These findings are similar to the present work.

Fig. 2 illustrates the changes in the tensile modulus at different % fibre loadings of the polymer matrix. There was almost a linear increase in the tensile modulus, which is an indication of the resistance of the composite when subjected to tensile stress. Fu *et al*., 2000 reported a tensile modulus of 8 GPa for a short glass fibre/polypropylene composite, this could be attributed to a better fibre–matrix interfacial bond, while Lin *et al*., 2015 reported a tensile modulus of 1.9 GPa for a short glass fibre/polypropylene composite.

Fig. 3 illustrates the change in the flexural strength with the % glass fibre loadings. The results showed that when the polymer matrix was loaded, there was almost a linear increase in the flexural strength. The results also showed that the flexural strength is greater than the tensile strength. Sorrentino *et al*., 2015 reported a flexural strength of 146.0 MPa at a fibre loading of 42.1

% and the thickness was 3.63 mm. Lin *et al.*, 2015 reported a flexural strength of 99.3 MPa at a fibre loading of 25 %.

Fig. 4 illustrates the change in flexural modulus with % fibre loading. The results show that the 22 % fibre loading had a significant increase in the flexural modulus of the composite. Sorrentino *et al.*, 2015 reported 1440 MPa. Lin *et al.*, 2015 reported a flexural modulus of 3.5 GPa.

Fig. 5 illustrates the change in the impact strength with % fibre loadings. There was a near-linear increase in the impact strength as a result of the fibre loading. Lin

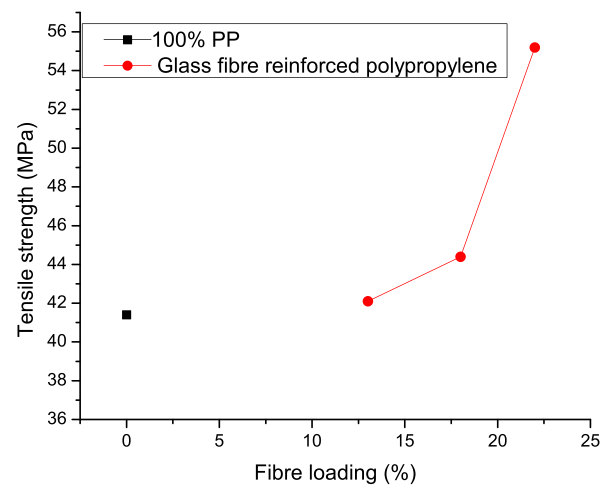

Fig 1: Change of tensile strength with % glass fibre loading

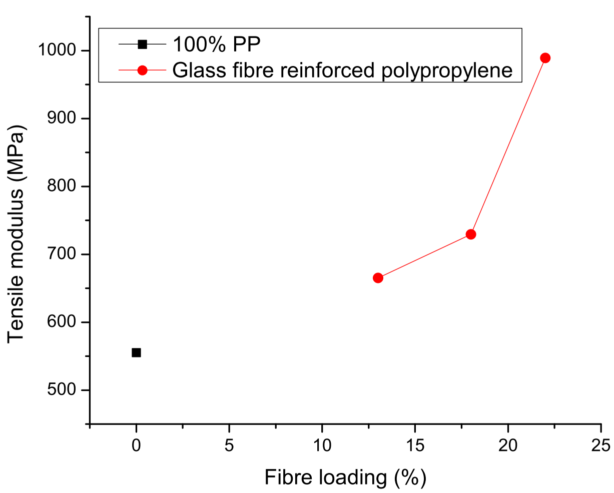

Fig. 2: Change of tensile modulus with % glass fibre loading

et al., 2015 reported an impact strength of 73.7 J/m for short glass fibre-reinforced polypropylene composite.

Fig. 6 illustrates the change in water absorption with % fibre loadings. There was a linear increase in the water absorption.

Fig. 7 illustrates the change in density with the % fibre loadings. The results show that there was no significant increase in density as a result of fibre loading. Ota *et al.*, 2005 reported a density of 1.010 gcm^{-3} at a fibre loading of 20 %.

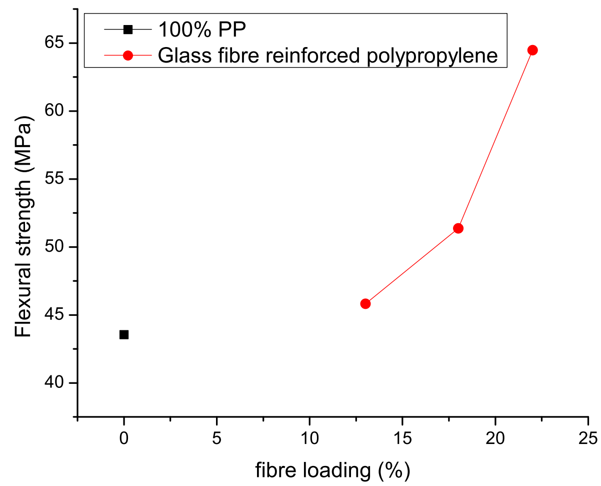

Fig.3: Changes in the flexural strength as a function of the % glass fibre loadings

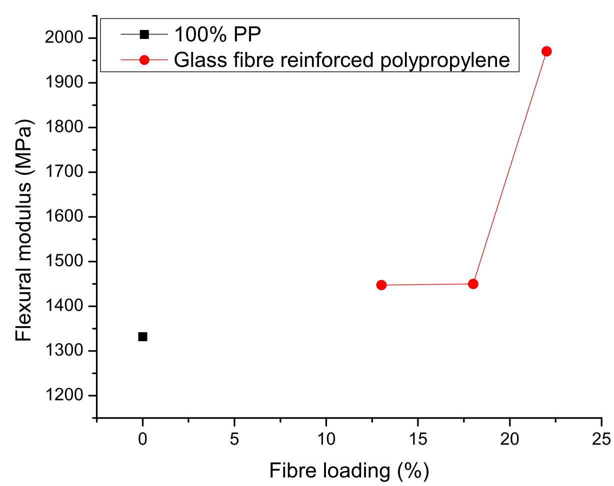

Fig. 4: Change in the flexural modulus as a function of the % glass fibre loadings

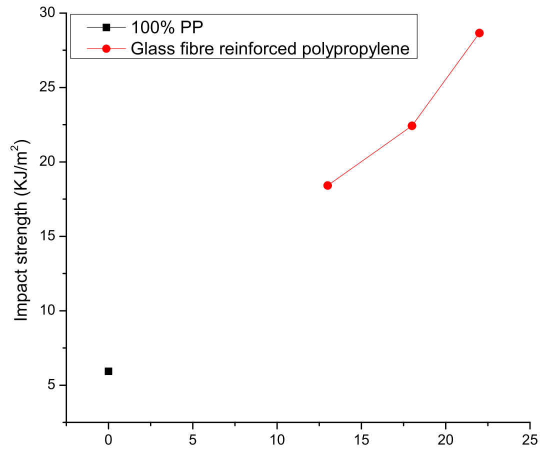

Fig. 5: Change in the impact strength as a function of the % glass fibre loadings

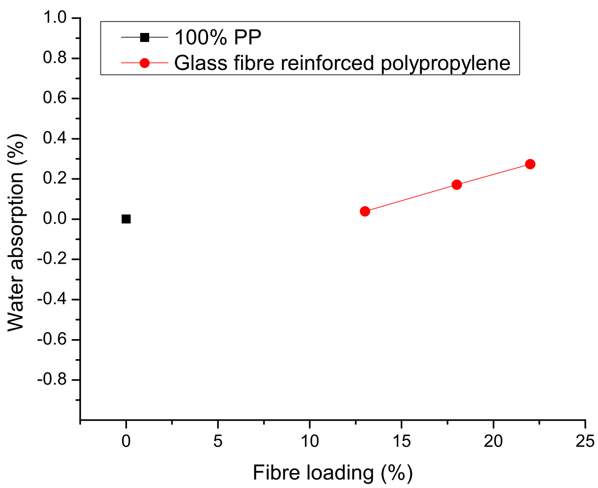

Fig. 6: Change in water absorption with % glass fibre loading

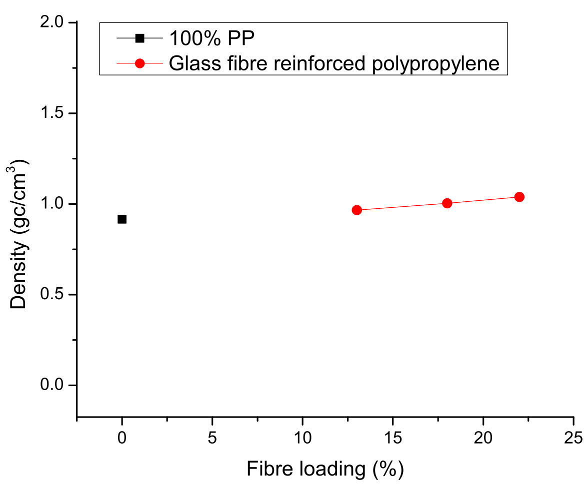

Fig. 7: Change in density with % glass fibre loading

Fig. 8 illustrates the storage modulus at different temperatures with % fibre loading. The contribution of the elastic component of the composite is the storage modulus (Etaati *et al*., 2014). There was increase in the storage modulus of the composite due to the rigidity imposed on the polymer matrix fibre loading. There was no significant molecular motion as the temperature increased from 75 ºC, for the 13% fibre loading; this means that the composite was more rigid when compared to the 18 % and 22 % fibre loadings.

Fig. 9 illustrates the change in the loss modulus at different fibre loadings. Loss modulus is a measure of the energy dissipated in the composite material (Chandra *et al*., 1999; Gao *et al*., 2015). The results are in agreement with the storage modulus since there are increases in the loss moduli with % increases in fibre loadings.

Fig. 10 illustrates the change in the damping factor of the composite at different temperatures for different fibre loading. The 13 % and 18 % fibre loadings showed a higher damping factor between 25 ºC – 50 ºC when compared to the 18 % fibre loading. This is attributed to the strength of the composite, whereas the increase in the damping factor of the 18 % and 22 % fibre loadings was due to poor fibre–matrix bond that led to molecular motion observed

Fig. 11 illustrates the scanning electron micrographs of the 100 % PP and that of various composites. The results show that there was a weak interfacial interaction between the fibre and the polymer matrix (Kim *et al*., 2007); this can lead to debonding when subjected to projectile impact, which is an energy-absorbing mechanism (Carrilo *et al*., 2012). The weaker the interfacial bond, the stronger the energy absorption (Gao *et al*., 2015; Ota *et al*., 2005).

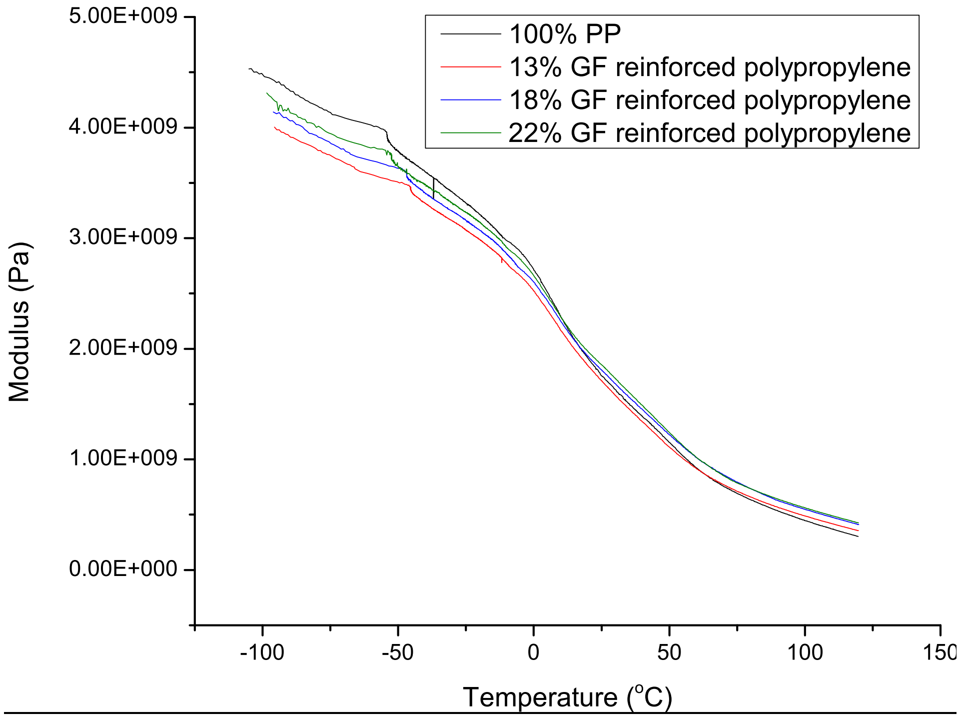

Fig. 8: Storage modulus of the glass fibre-reinforced polypropylene composite

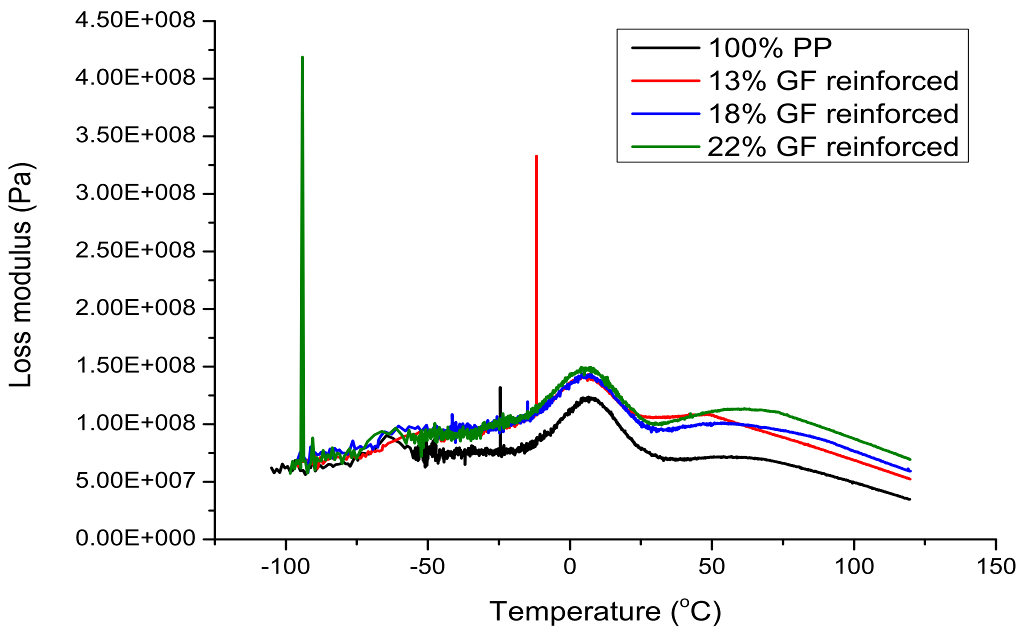

Fig. 9: Loss modulus of the glass fibre-reinforced polypropylene composite

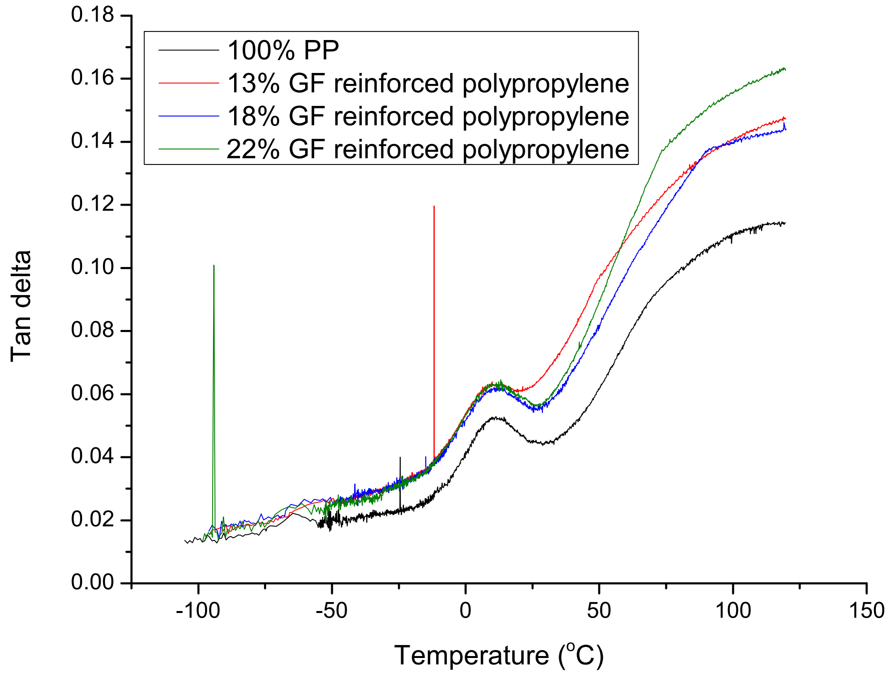

Fig. 10: Damping factor of the glass fibre reinforced polypropylene composite

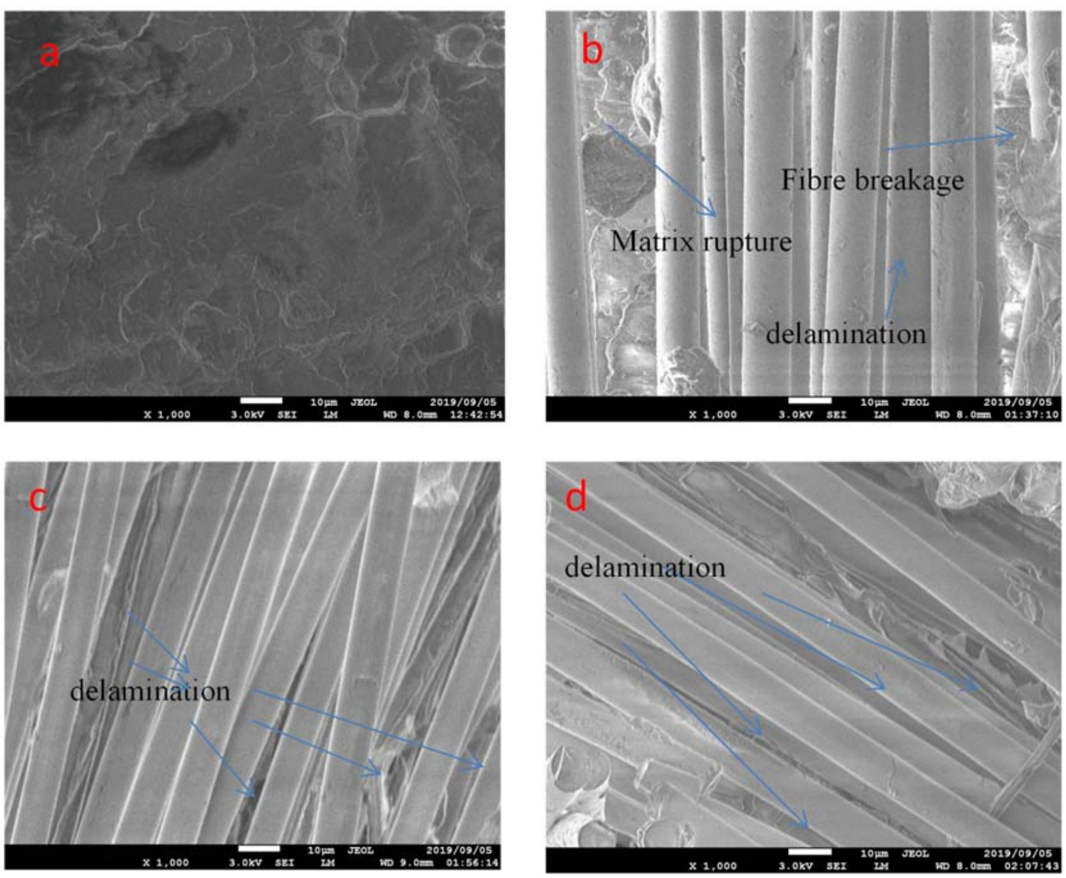

Fig. 11: Scanning electron micrographs of (a) 100 % Polypropylene (b) 13 % Glass fibre reinforced (c) 18 % Glass fibre-reinforced (d) 22 % Glass fibre reinforced

4.0 Conclusions

The effect of woven glass fibre loading on the mechanical, physical and morphological properties of polypropylene was successfully investigated. The inclusion of glass fibre, had increases in the mechanical and physical characteristics of the polymer matrix and the composite. The DMA results showed that there was an increase in damping factor due to the glass fibre inclusion and the 13 % fibre loading had less molecular motion when compared to the 18 % and 22 % fibre loadings. It also showed that reinforcing polypropylene results in a low stiffness and high damping composite. This implies for applications where low stiffness is required and high damping factor are required, this composite would be a good material. The morphology of the composites revealed that there was poor fibre – matrix adhesion as shown by delamination, matrix rupture and fibre breakage; this is a good characteristic for composites intended for automobile application.

5.0 Acknowledgement

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