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The Effect of Glass–Kevlar 49 Fibre Loading on the Mechanical, Thermal and Physical Properties of Polypropylene Hybrid Composites

*E. Danladi, P.A.P. Mamza, S.A. Yaro, M.T. Isa, E. R. Sadiku and S.S. Ray

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Abstract In order to improve properties of polypropylene, , hybrid composites of Glass–Kevlar reinforced polypropylene were fabricated by using the compression molding technique. Mechanical, thermal and physical properties of the hybrid composites were investigated. The percentage fibre loadings were 06/07, 12/07 and 11/13 (i.e., GF/KF). The effect of stacking sequence on the properties was also investigated and reported. The fibre loading increase the toughness of the hybrid composites with GF/KF (11/13) having the highest. The observed high damping was attributed to alteration in molecular motion in the hybrid composites. Hybridization did not significantly affect the density of the produced composites. The increase in water absorption capacities of the hybrid composites with increasing Kevlar fibre contents was attributed to the presence of hydrogen bonds in the Kevlar fibre.

Key Words: Composites hybrid, polypropylene, Kevlar 49, glass, mechanical, thermal and physical properties

***E. Danladi**
Department of Chemistry,
Federal University, Gashua, Nigeria.
Email: danladielijah@yahoo.com

P.A.P. Mamza
Department of Chemistry, Ahmadu Bello University,
Zaria, Kaduna State, Nigeria

S.A. Yaro
Department of Metallurgical and Materials Engineering,
Ahmadu Bello University, Zaria, Kaduna State, Nigeria.

M.T. Isa
Department of Chemical Engineering,
Ahmadu Bello University, Zaria, Kaduna State. Nigeria

E. R. Sadiku
Institute of Nano Engineering Research (INER),
Department of Chemical, Metallurgical and Materials Engineering,
Tshwane University of Technology, Pretoria, South Africa.

S.S. Ray
National Centre for Nano–Structured and Advanced Materials,
Council for Scientific and Industrial Research,
Pretoria, South Africa

1.0 Introduction

Hybridization is one of the effective and efficient ways of improving the energy absorbing capacity of fibre-reinforced composite armors (Banadaru *et al.* 2017). The use of composite armors is widely applied in the manufacture of lightweight body armor (Bandaru *et al.* 2015). Several studies have been reported on hybridization and their effect on the properties of Kevlar- glass fibre. For example, Bandaru *et al.* (2015) studied the effect of hybridization on the ballistic impact behaviour of Kevlar–glass hybrid composite. In their investigation, they reported that the stacking sequence and geometry of the projectile affected the ballistic impact behaviour of the hybrid composites. Ebrahiimnezhad-Khaijiri, *et al.* (2019), found that hybridization parameters fluctuate between positive and negative effects on mechanical properties of epoxy composites that was reinforced by oxidized polyacrylonitrile fibers and high-performance carbon/glass/Kevlar fibers in hybrid composites.

Their study also revealed that Kevlar and glass hybrid reinforced composites had the maximum hybridization parameters and that glass and Kevlar fibres and oxidized polyacrylonitrile fiber were pseudo-ductile because they have a ductile fracture. According to Kanitkar *et al*. (2019), composite materials are significant because they have superior properties and are inert to atmospheric impacts. Most of them have high tensile strength to weight ratio and can be moulded into the required shape that can offer better advantages than metals. In their study, they found that hybridization of glass Kevlar composites led to improved flexural strength and flexural modulus. Felipe *et al.* (2017) found that hybridization can positively influence the mechanical properties of fabric reinforced composites using two laminate reinforced with bi-directional woven, in which one of them was reinforced by hybrid strand (hybrid strand composite laminate) and the other with a different strand (hybrid fabric composite laminate). Pappu *et al*. (2019), manufactured and characterized hybrid composite using sisal and hemp fibres as reinforcement agent for poly (lactic acid) via injection moulding. The reinforced polymer showed great improvement in mean tensile strength (46.25 ± 6.75 MPa), Young's modulus (6.1 ± 0.58 GPa) and specific tensile strength (38.86 ± 5.0) compare to the neat poly (lactic acid).

The need for high strength, high stiffness and lightweight materials for structural applications has increased the use of composites in high performance applications, such as: aircraft, land-based vehicles and amour (Naik *et al*. 2006). There are several techniques that are available for reinforcing polymer composites. These include the use of hybrid composites, dispersion of nanoparticle with high-energy absorbing capacity in polymer/polymers/polymer matrix composites, development of sandwich structures, etc (Pandya *et al.* 2013). Hybridization of Kevlar (which is an expensive fibre) with glass (which is very cheap) can save cost and improve sustainability (Afshari *et al.* 2012; (Safri *et al.* 2018).

According to Singh and Samanta, (2015), hybridization of Kevlar with glass and carbon fibre can improve the interlaminate fracture toughness and modulus of Kevlar reinforced composites. In spite of the stated advantages, literature is relatively scanty on the use of Kevlar glass fibre for reinforcement of polypropylene with respect to mechanical, physical and thermal polypropylene. Therefore, this study is aimed at - investigating the effect of Kevlar 49 - glass fibres loading on the mechanical, physical and thermal properties of polypropylene hybrid composites.

2.0 Materials and methods

2.1 *Materials*

HLR 102 grade polypropylene homopolymer with a density of 0.905 g/cm^3 and melt mass flow rate of 5.3 g/10minute was sourced from SASOL, South Africa. Kevlar 49 woven fabric, 2/2 Twill weave, with a linear density of 42 tex and areal density of 110 g.m^{-2} were sourced from AMT Composites, Kempton Park, Johanessburg, South Africa.

2.2 *Fabrication of composite*

The composite was fabricated by first melting 9.1 g of the polymer into thin films of 1 mm thickness on a Carver Press Model using a mold measuring 100 x 100 mm. This was followed by stacking of the polymer and fabric and placement in a mold in between two Teflon sheets of 2 mm thickness at the top and bottom of the mold in order to avoid sticking of the polymer to the mold, before being placed into the Carver Press. The system was preheated at190 ^oC for 8 minutes (in order to ensure adequate flow of the polymer) to enable wetting of the fabric and to remove the moisture content present in the material, before a pressure of 500 psi was applied for 4 min. This was followed by cooling for another 4min by using the tap cooling system, before the removal of the sample from the mold. Table 1 shows the different compositions of the composites and the respective number of plies.

Table 1: **Fabrication compositions**

S/NO	PP (%)	GF/KF (%)	NO OF PLIES
0	100	0	0
1	87	06/07	1/2
2	81	12/07	2/2
3	76	11/13	2/4

2. 3 *X – ray analysis*

Powder X–ray diffraction (PXRD0 determination was carried out using an X–ray diffractometer (XPERT PRO PAnalytical, Netherland) for phase identification. The patterns were run with CuK$_\alpha$ radiation of wavelength λ= 0.1545 nm with secondary, monochromator at 45 kV and 40 mA. The diffraction measurements were conducted at room temperature in a Bragg–Brenton geometry with a scan range of 2θ between = 5–90º by using a continuous scanning rate of 0.02º/s.

2.4 Determination of tensile strength

Tensile properties were determined according to ASTM 638–14 type, dimension of 28 mm x4.1 mm x3.2 mm by using the Instron 5966 model, computer equipped with Bluehill software, at a crosshead speed of 5mm/min and an applied load of 10 kN.

2.5 Flexural analysis

Flexural strength was carried out using a specimen with dimensions 80 mm x 13 mm x 3.2 mm according ASTM D790–03 by using the Instron 5966 model, computer equipped with Blue hill software, at a crosshead speed of 1.4mm/min and an applied load of 10 kN.

2.6 Determination of impact strength

Impact strength of the composite was determined by using a specimen with dimensions 85 mm x 10 mm x 3.2 mm, according to ISO 179-01 by using a speed of 3.681 m/s and Hammer Potential Energy of 7.5 J at room temperature.

2.7 Mechanical analysis

Dynamic mechanical analysis was carried out by using a specimen with dimensions 40 mm x 10 mm x 3.2 mm according to ASTM 1640–04 at a single frequency by using a double cantilever.

2.8 Morphological analysis

Morphological examinations were carried out using scanning electron microscopy (SEM). Model - JEOL JSM -7500, Japan, which operated with an accelerating voltage and an emission current of 2 kV and 10µA respectively.

2.9 Water absorption analysis

Water absorption of the composite was determined according to ASTM D570–98 for 24-housr immersion at room temperature by using a specimen with dimensions 30 x 30 x 3.2 mm.

2.10 Density measurement

Density was determined according to ASTM D792–08 recommended method using a specimen with dimensions of 40 x 10 x 3.2 mm, at 22 ºC in 99 % ethanol.

3.0 Results and Discussion

Fig. 1 shows the effect of fibre loading on the tensile strength of the hybrid composites. The results indicate that a decrease in tensile strength was observed by increasing the fibre loading of glass. However, there was an increase in the tensile strength with increasing fibre loading of Kevlar. The observed trends indicate that Kevlar fibre has better strength than glass fibre. It is also evident from the plot that equal composition of the fibres resulted in great improvement compared to the proportion 2:1 for GF: KF. Loading is generally observed to improve the strength of the composite. The results obtained in this study however give different results from that reported by Felipe *et al*. (2017) who obtained a tensile strength of 146.96 MPa at fibre loading of 52 % (GF/KF 20/32.).

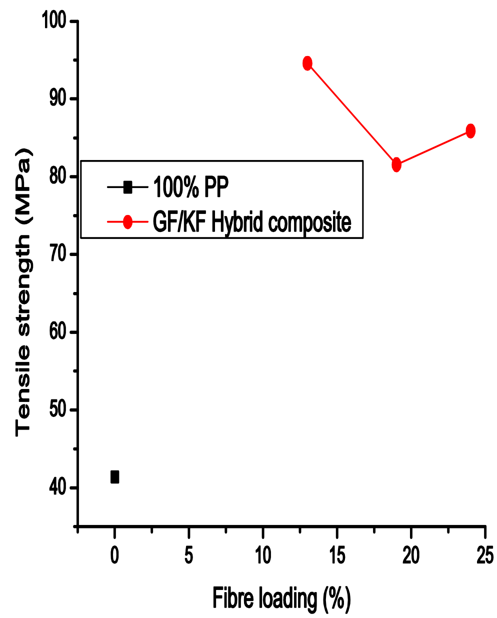

Fig. 1: Variation of tensile strength with % fibre loading

Fig. 2 shows the variation of tensile modulus of the hybrid composites with percentage fibre loading. The results indicate that the tensile modulus increases with increase in percentage fibre loading which implies that hybridizing the fibres has a significant effect on the toughness of the composites. Felipe *et al*. 2017 reported a tensile modulus of 5.27 GPa at fibre loading of 52 % which is not significantly different from our results.

Fig. 3 is a plot showing the variation of flexural strength with percentage fibre loading. The results show that on increasing the percentage fibre loading of glass, there was a decrease in the flexural strength, but on increasing the Kevlar fibre loading, the was a sudden increase in the flexural strength. Felipe *et al*.2017, reported a flexural strength of 253.87 MPa at fibre loading of 52 %.

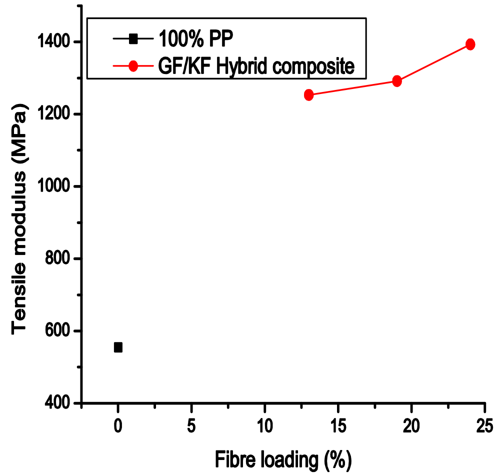

Fig. 2: Variation of tensile modulus with % fibre loading

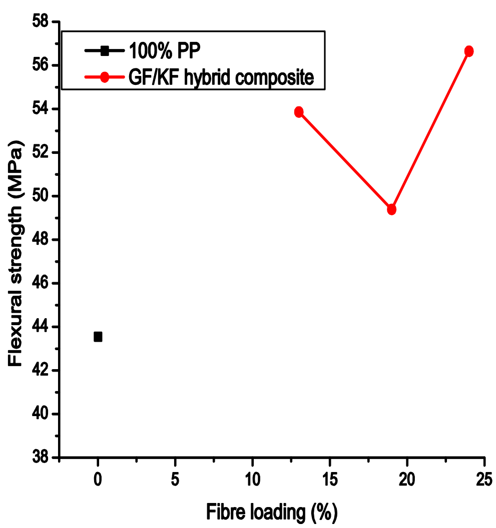

Fig. 3: Variation of flexural strength with fibre loading

Fig. 4 shows a plot for the variation of flexural modulus of the hybrid composite with percentage fibre loading. The flexural modulus is seen to increase with increase in the percentage fibre loading indicating that there is a significant rise in toughness of the materials as a result of increase in loading, which may be attributed to the fact that the glass fibre formed the core of the fibres. Felipe *et al.* (2017), reported a flexural modulus of 9.85 GPa at fibre loading of 52 % which is relatively comparable to our results.

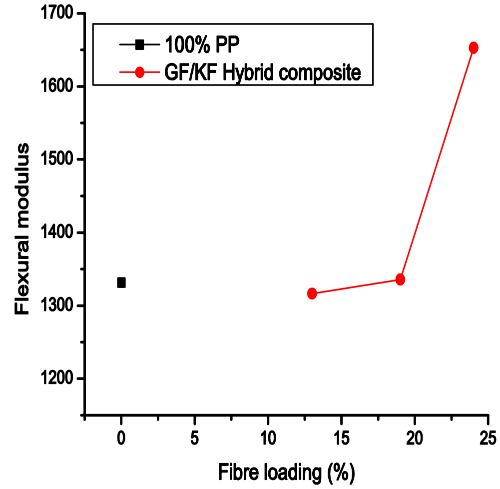

Fig. 4: Variation of flexural strength with % fibre loading

Fig. 5 shows the variation of impact strength of the hybrid composites with percentage fibre loading. The plot indicates better impact strength than the crude materials and a linear relationship between impact strength and percentage fibre loading. Therefore, the impact strength increases linearly with percentage fibre loading. The observed linear relationship suggests that glass fibre and Kevlar fibre can be hybridized successfully without the Charpy impact strength being compromised.

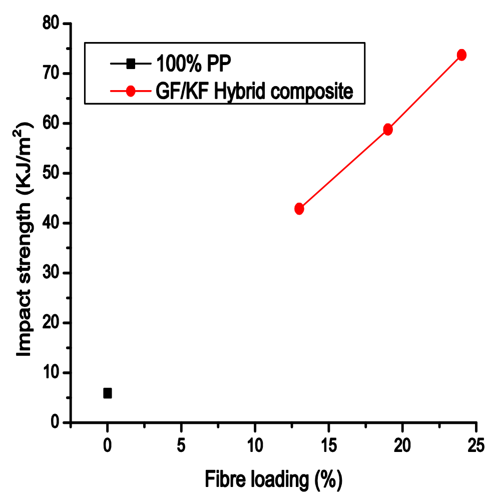

Fig. 5: Variation of impact strength with % fibre loading

Fig. 6 is a plot showing the variation of storage modulus of the fibre composites with percentage fibre loading. At 100 °C, the trend for the storage modulus was 100 % PP>19 %GF/KF >13% GF/KF > 24% GF/KF which did not follow expected regular trend with respect to percentage loading. This can be attributed to irregular molecular behaviour at very low temperature. However, above 100 °C, the trend was regular, been highest for 24 % GF/KF and least for 100% PP. The sequence responded exactly at higher temperature. Generally, the storage modulus decreases with increase in temperature.

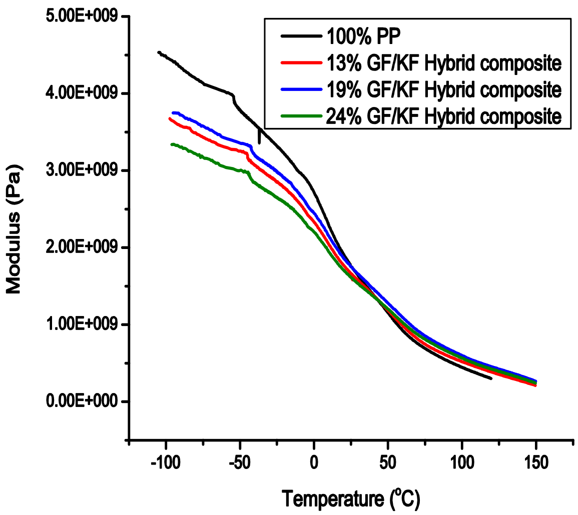

Fig. 6: Variation of storage modulus with temperature for different % fibre loading

Fig. 7 shows the effect of fibre loading on damping. As the temperature rises, there was an increase in damping between 25 ºC and 150 ºC, with 24 % fibre loading having the highest damping. This may be due to the delamination between the interface of the polymer, fibres and the hybridization of the fibres (Chandra et al. 1999). The T_g was not significantly affected by the hybridization, as depicted in Fig. 7.

Fig. 8 shows the scanning electron micrograms of the polymer matrix and those of the hybrid composites. The results show that there was a weak polymer–fibre interaction. This is vital in the case of ballistic application because it enables energy absorption by delamination.

Fig. 9 shows the diffractograms of the polymer matrix and the hybrid composites. The results indicate that hybridization had a decreasing effect in the crystallinity of the composites, thereby making them less crystalline when compared with the polymer matrix. Increase in intensity of the XRD pattern, implies increase in crystallinity, which is in support of Weindinger-Herman's equation (Terinte et al. 2011).

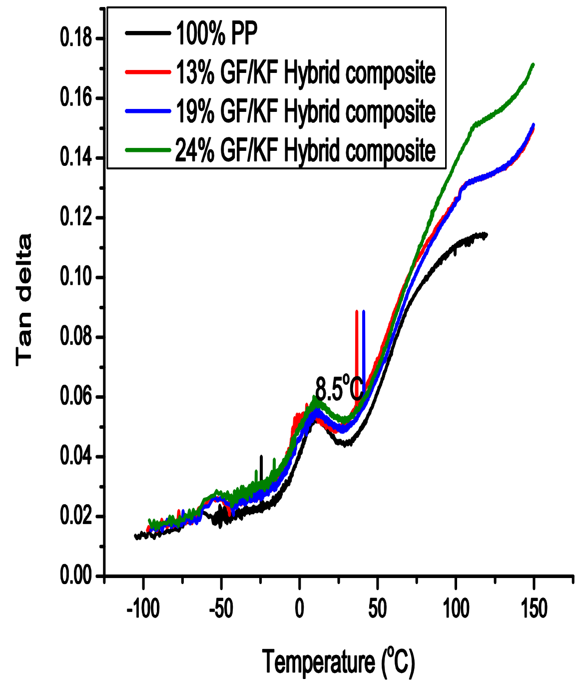

Fig. 7: Variation of damping factor with temperature for different fibre loading

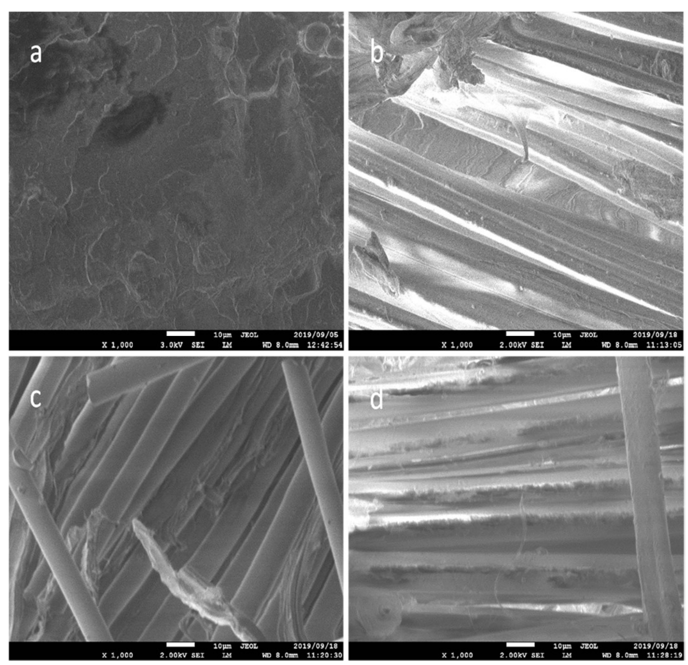

Fig. 8: Scanning electron micrograms of: (a) 100 polypropylene, (b) GF/KF 06/07, (c) GF/KF 12/07 and (d) GF/KF 11/13

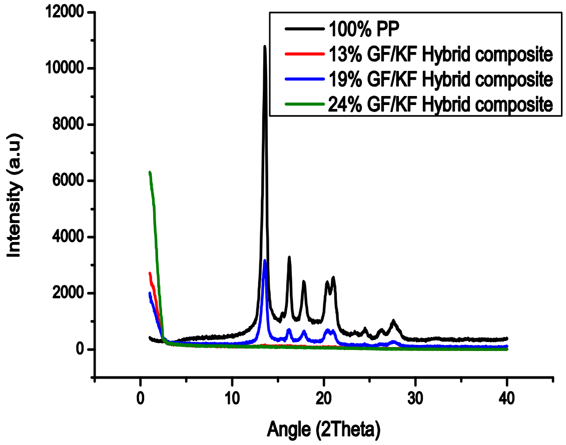

Fig. 9: **XRD diffractograms of polymer matrix and hybrid composites**

Fig. 10 shows the effect of fibre loading on the density of the hybrid composites. The results reveal that there was a marginal increase in the density of the hybrid composites as the fibre loading was increased. This shows that the material can be used when lightweight application is desired.

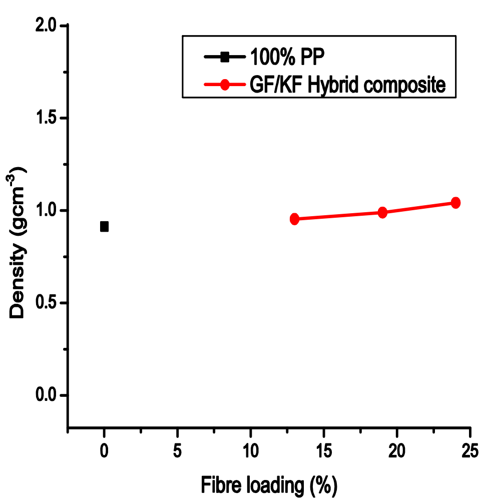

Fig. 10: Effect of fibre loading on density of hybrid composites

Fig. 11 shows the effect of fibre loading on the water absorbing capacity of the hybrid composites. The results show that increase in the fibre loading of glass had a negative effect on water absorption; whereas increase in the fibre loading of Kevlar led to an increase in water absorption. This is because Kevlar fibre has better water absorption capacity than glass fibre. Felipe *et al*. (2017) reported a density of 1.55 gcm^{-3} at fibre loading of 52 %.

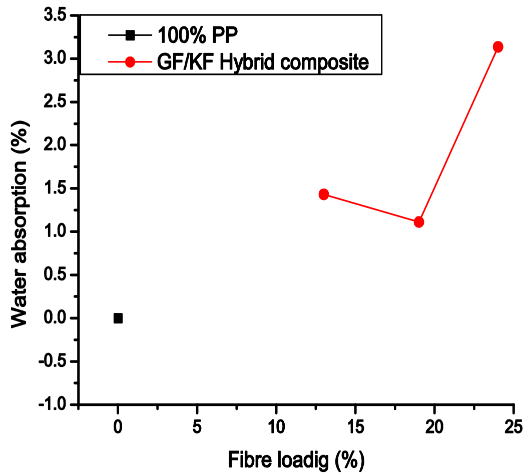

Fig. 11: **Effect of fibre loading on water absorption**

4.0 Conclusion

From the result and finding of the study, the following conclusions are made,

(i) The polymer matrix was successfully hybridized by using glass and Kevlar fibres
(ii) There was high damping due to the delamination and molecular motion in the hybrid composites.
(iii) Hybridization had no significant effect on the density of the resulting hybrid composite
(iv) The fibre loading had an effect (increase) in the toughness of the hybrid composites
(v) Water absorption capacities of the hybrid composites increased by increases in the Kevlar fibre contents of the fibre loading than the glass fibre contents, due to the presence of hydrogen bonds in Kevlar fibre.

5.0 Acknowledgement

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