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Mechanical properties of submicron glass fiber reinforced polypropylene composites

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Abstract: This study used maleic anhydride-modified polypropylene (MAPP) and silane to enhance the compatibility between submicron glass fiber (MGF) and polypropylene (PP) in composites.The effect of varying the MGF, MAPP, silane content and the mixing temperatureon tensile, flexural and impact properties of the PP composites were investigated. The results showed thatthe tensile, flexural, impact strength and tensile modulus of the composite were increased from 33.4 to 44.6 MPa, from 36.5 to 48.5MPa, from 2.11 to 3.85 KJ/m^2, and from 986.2 to 1248.5 MPa, respectively, in comparison with those of the neat PP, when 7.5wt% MGF with the presence of 7wt% MAPP and 2wt% silanewere dispersed in the PP matrix. Moreover, the SEM morphological analysis of the fracture surface of the composite showed that the phase interaction between polypropylene and submicron glass fiber was improved remarkably by adding both the MAPP compatibilizer and silane.

Keywords: Composites, Polypropylene, submicron glass fiber, Silane

I. INTRODUCTION

Due to its excellent chemical resistance, low density, low cost, and ease of molding, polypropylene (PP) are widely used in, automobiles, machinery, electrical appliances, and building materials. Moreover, it can be reinforced with fiber to enhance the properties [1]. The fibers used to strengthen the PP may be natural [2,3] or syntheticfibers [4,6]. In recent times, submicronfibers tend to be used a lot to strengthen the PP by a large surface area with low density. Accordingly, many studies have focused on reinforcing PP with micro fibrillated cellulose (MFC) [1,7,8], micro polyethylene terephthalate fiber (MPETF) [9] and microfibrillatedKevlarfibers [10]. However, it is difficult to disperse polar submicronfiber in a non-polar PP resin. Therefore, a compatibilizer must be added, in which maleic anhydride grafted polypropylene (MAPP) is the most widely used agent in the manufacture of PP composite [1,8,11]. Besides the addition of MAPP, surface modification of fiberis also used to improve the compatibility between PP and fiber [10,12]. Silane coupling agents have been broadly used to improve the compatibility between fiber and PP matrix [13,14]. The fibers can be modified before it is used as a reinforcement for PP. Prakash et al. soaked PET chopped fibers in a solution of silane coupling agent and isopropyl alcohol equal to the total weight of the fibers and then silane was added at 0.5% by weight of fiber [9]. The wood flour was modified with vinyl-trimethoxy-silane after a NaOH treatment to remove hemicelluloses and lignin [13].

In this work, the effect of using a combination of MAPP and silane to enhance the compatibility between submicron glass fiber (MGF) and PP on the mechanical properties of the composites was investigated.

II. EXPERIMENT

2.1 Materials

The polypropylene HP 544T was purchased from Saudi Arabia. Maleic anhydride-modified polypropylene Bondyram® 1001 (MAPP) was purchased from Polyram, Isarel. Silane organo functional Geniosil® GF 93 (SL) was purchased from Wacker, Germany. Submicron glass fiber (Japan) was used as the reinforcing agentfor preparing the composites.

2.2 Sample preparation

Before mixing, the neat PP, MAPP, and MGF were dried under vacuum at 80 °C for 4 hours. The PP and MAPP were pre-mixed into the vessel. After that, the mixture was mixed in the mixer,and the silane was addedbefore the MGF was introduced gradually. After loading all materials, the mixing time was kept constant within 5 minutes at a certain temperature. Finally, the composite was collected and flattened with a steel roller before being stored in plastic bags at room temperature.

The hot press machine: The composites were heated at 175^{o}C and pressed at 130 Kgf/cm² to get thin films of 500 µm thickness on average or bars of 4×10×80 mm dimensions.

The manual punch press: A manual punch press was used for producing dumbbell tensile specimens from the films.

2.3Characterization techniques

Tensile strength and tensile modulus of the composite were measured according to ASTM D638 using Lloyd instrument (UK). The flexural strength of composite was measured according to ISO 178 using Instron (USA). Notched Izod impact strength of the compositeswas determined by Tinius Olsen (USA), according to ISO 180. The morphologies of the fracture samples were observed byscanning electron microscopy (SEM JEOL, Japan).

III. RESULTS AND DISCUSSION

3.1The effect of mixing temperatura on properties of the composite

In order to investigate the effect of mixing temperature on the properties of the composites, three MGF/PP composites were carried out at 165÷185°Cin whichthe content of MAPP was 5wt% of PP, the silane and MGF content were fixed at 1.5 wt% and 5wt%, respectively of the total weight of MAPP and PP. The results of tensile strength and modulus of composites at different MGF loadings were shown in Fig.1,and the results of impact and flexural strength were presented at Fig.2.

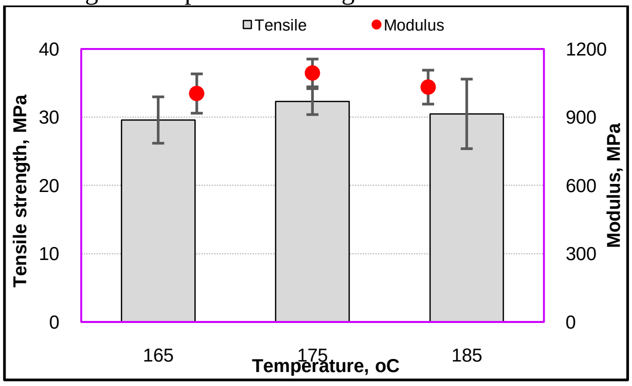


Figure 1: The effect of temperature on tensile strength and modulus of composites

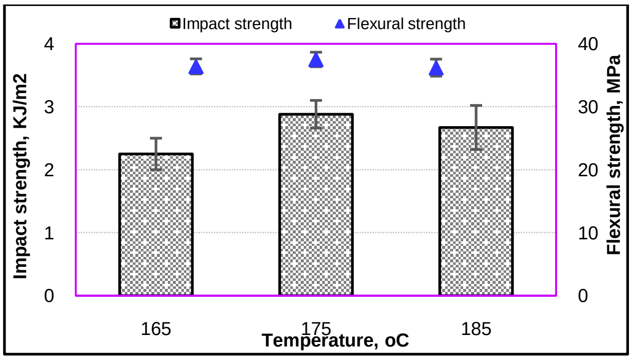


Figure 2: The effect of temperature on flexural and impact strength of composites

When the temperature ranged from 165°C to 175°C, the properties of the composite raised. The tensile, flexural, impact strength and tensile modulus of the composite increased from 29.6 to 32.3 MPa, from 36.4 to 37.5 MPa, from 2.25 to 2.88 KJ/m^2, and from 1004.1 to 1095.1 MPa. It is likely thatincreasing mixing temperature facilitates the dispersing of the MGFfiberin the PP matrix due to the lower viscosity of PP.

When the temperature raised to 185°C, all of the mechanical properties of the composite tended to reduce slightly as the silane decomposed and evaporated partially at the temperature quite close to its boiling point (Fig.1 and 2). Therefore, the temperature of 175°C was chosen forfurther composite manufacturing.

3.2. The effect of MGF content on properties of the composite

In order to study the effect of the MGF content on the properties of the composites, the series of MGF/PP composites were carried out. For all the composites,the content of MAPP was kept at5 wt% of PP, the silane content was fixed at 1.5 wt%, and the MGF content changed from 0 to 10 wt% of the total weight of MAPP and PP. The results of tensile strengthand modulus of composites at different MGF loadings were shown in Fig.3.

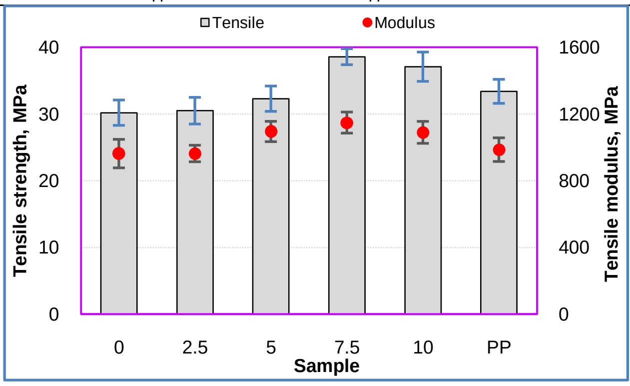


Figure 3: The effect of MGF content on tensile strengthand modulus of composites

As can be seen from Fig.3, without or with a small content (2.5 wt%) of MFG, the tensile strengthand the tensile modulus of the composite were slightly lower than those of neat PP. However, when adding 5% MGFto the PP composites,the modulus of this composite has improved by 11%whereas the tensile strength stayed constant. The MGF content continued to increase to 7.5,and10wt%, the tensile strength and the tensile modulus increased significantlyin comparison withthe neat PP. Notably, with MGF of 7.5 wt%, the tensile strength and the tensile modulus of the compositesraised by 15.6% and 16.5%respectively.Moreover, both the tensile strength and the tensile modulus of the composite with MGF of 10 wt% were lower than those of composite with MGF of 7.5 wt%. The decreasing can be explained by the agglomeration ofthe MGF in the PP matrix when the MGF content was higher than 7.5wt%.

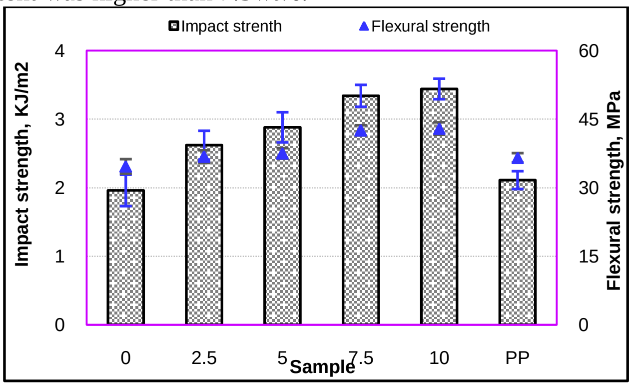


Figure 4: The effect of MGF content on flexural and impact strength of composites

Without submicron glass fiber, the flexural strength of the composite did not change, but the impact strength was lower than that of neat PP. On the contrary, the presence of submicron glass fiber increased in both flexural and impact strength. The more the MGF loading was, the higher the flexural and impact strength were. The flexural and impact strength of the composite with 7.5 wt% MGF content increased by16.4% and 58.3%, respectively (Fig.4).

3.3 The effect of MAPP content on properties of the composite

In order to evaluate the effect of the MAPP content on the properties of the composites, five MGF/PP composites were carried out,in which the fixed silane and MGF content were 1.5 and 7.5 wt% of total weight of MAPP and PP respectively, and the MAPP content changed from 0 to 9 wt% of PP. The results of tensile strength and modulus of composites at different MAPP loadings were shown Fig.5.

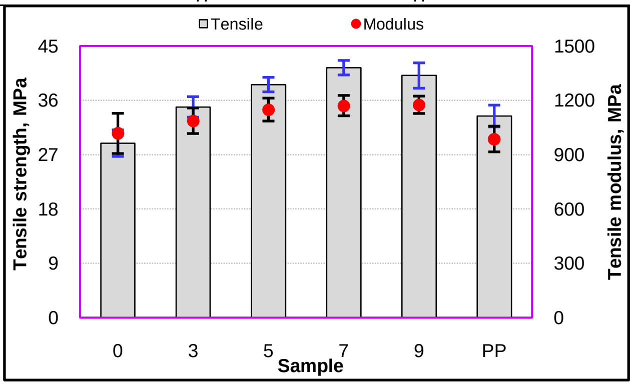


Figure 5: The effect of MAPP content on tensile strength and modulus of composites

The tensile strength of composite increased with the addition of MAPP compatibilizer. The more increasing the MAPP content, the more raising the tensile strength (Fig.5) until it reaches its peak at 7wt% MAPP content. The tensile strength of the composites is likely to decline after adding more than 7 wt% MAPP.At higher MAPP compatibilizer loading, only a part of the MAPP was located on the interfacial area, while the remaining was spread in the matrix, causing the drop in the tensile strength of the composites with 9wt% MAPP loading.

The trend of tensile modulus graph was similar to that of the tensile strength, but it continued to increase slightly if the MAPP content raised to 9 wt% (Fig.5). With 7wt% of MAPP, the composite had 41.4 MPa of tensile strength and 1170.5 MPa of tensile modulus, improving by 24% and 19% respectively as compared to the neat PP.

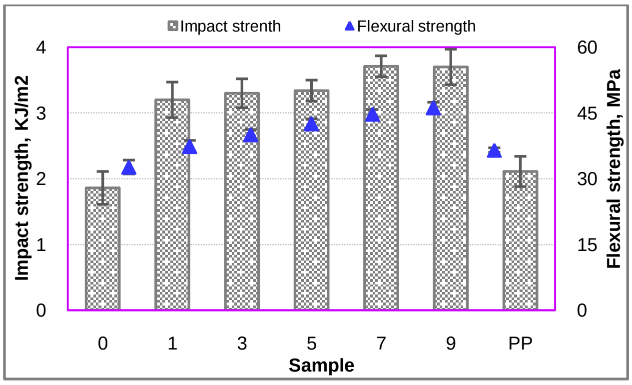


Figure 6: The effect of MAPP content on flexural and impact strength of composites

As can be seen from Fig.6, the flexural and impact strength of composite with MGF but without MAPP were slightlylower than those of neat PP. Conversely, the presence of MAPP compatibilizercontributed to raising the properties remarkably. The higher MAPP loading was, the more increasing flexural and impact strength were. The impact and flexural strength of composite with 7wt% MAPP loading were the highest at 3.71 KJ/m^2 and 44.74 MPa, increasing by 75.8% and 22.4% (Fig.6).Adding the MAPP could improve the adhesion between the MGF and PP matrix due that the polypropylene segment in MAPP interacted with the PP matrix and the anhydride group in MAPP created a secondary bond with the silane coupling agent whichprobably grafted on the submicron glass fiber surface.

3.4 The effect of silane content on properties of the composite

In order to study the effect of the silane content on the properties of the composites, sixMGF/PP composites were carried outwhen the content of MAPP was 7wt% of PP, the MGF content was fixed at 7.5 wt%,and the silane content changed from 0 to 3 wt% of total weight of MAPP and PP. The results of tensile strengthand modulus of composites at different MGF loadings were shown Fig.7.

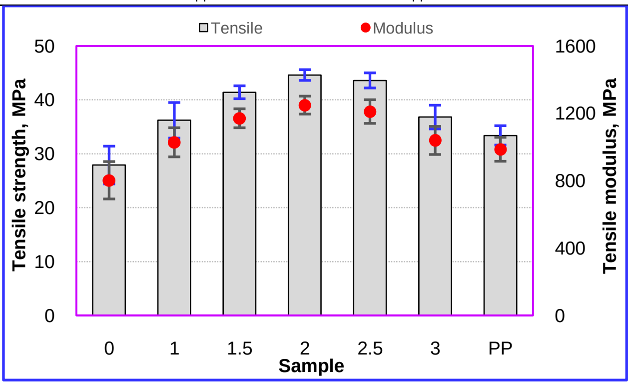


Figure 7: The effect of silane content on tensile strength and modulus of composites

Fig.7 shows tha tthe tensile strength and tensile modulus of composite increased with the addition of silane. It is likely that a chemical bond between MAPP and silane whichprobably grafted on the MGF surface can be formed. That means, the phase interaction between PP and MGF becomes much better than the case with only MAPP.

The more increased the silane content, the more raised the tensile strength and tensile modulus (Fig.7). At higher than 2.5wt% silane loading, the decline of the properties may be caused by the formation of siloxanes regions, resulting in a phase separated structure. The silane hydrolyses autocatalytically in the presence of moisture to form silanols. At higher silane loading, only a part of the silanols was responsible for modifying fiber surface, while the remaining can subsequently react with themselves to produce siloxanes, which was spread in the matrix as impurities, causing the drop in the tensile strength and tensile modulus of the composites. The tensile strength and tensile modulus of the composite with 2wt% silane loading were 44.6 MPa and 1248.5 MPa, respectively and they were 33.5% and 26.6% respectively higher than those of neat PP (Fig.7).

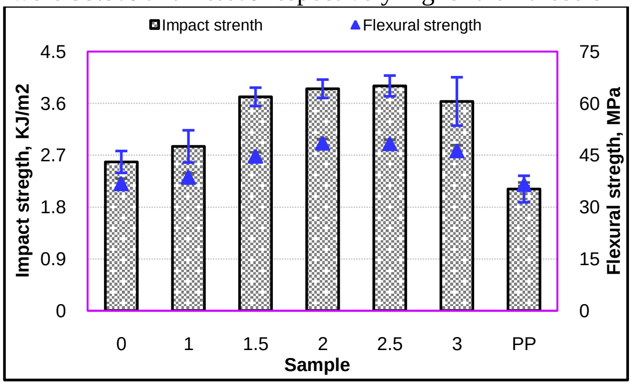
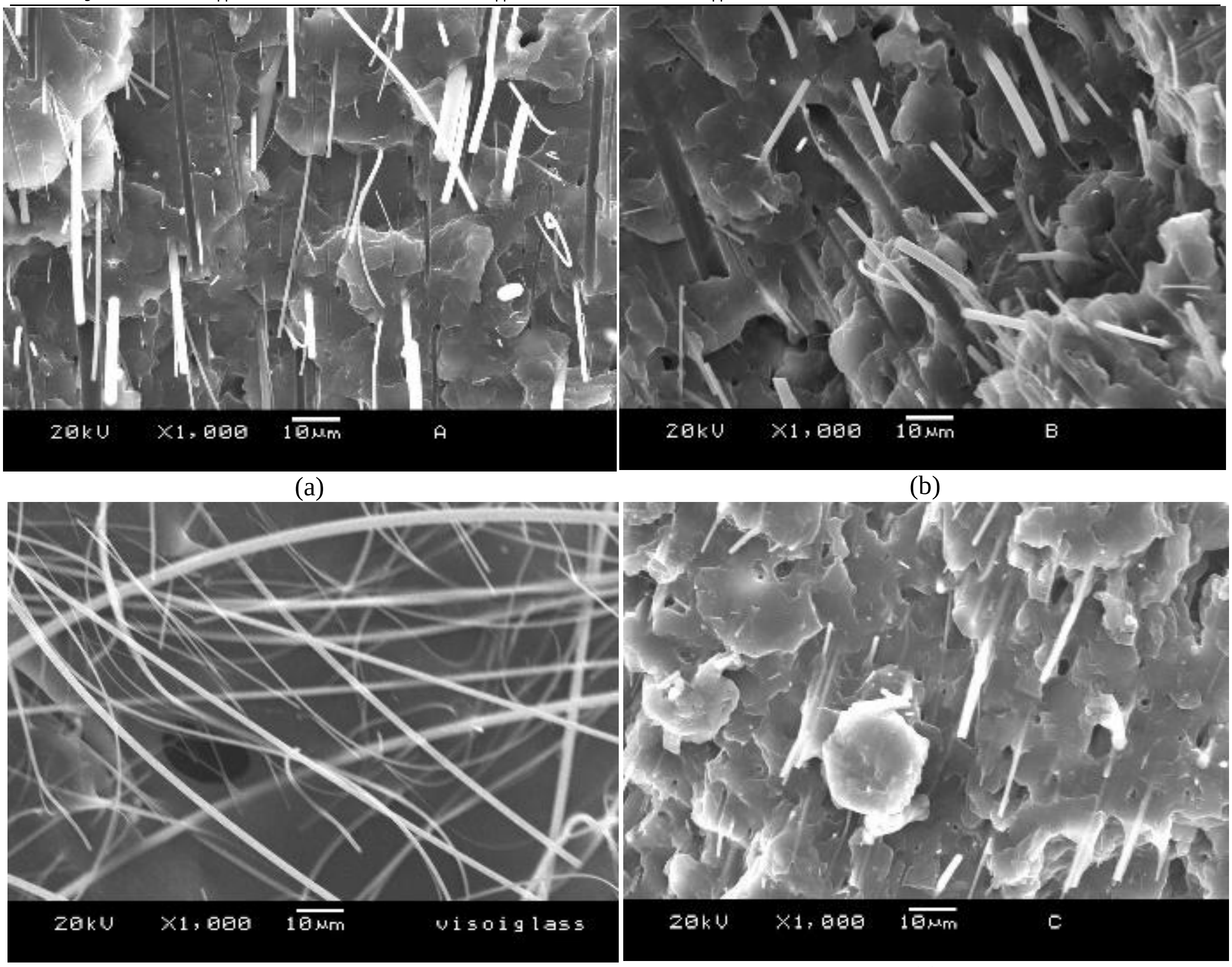


Figure 8: The effect of silane content on flexural and impact strength of composites

Fig.8 shows that without silane, the flexural strength and the impact strength the composite was slightly higher than thoseof neat PP. However, the presence of silane loading of 1.5 to 3 wt%, both impact and flexural strength were much higher than those of neat PP. The impact and flexural strength of composite with 2wt% silane loading were almost equal to those of composite with 2,5 wt% silane loading. Similarto the tensile strength trend (Fig.7), when the silane content higher than 2.5 wt%, the impact and flexural strength tended to reduce because of the formation of siloxanes regions.

The SEM image of the fracture surface composites and MGF were shownin Fig.9.

It can be seen in Fig. 9(d) that the diameter of the MGF was less than 1 micrometer. It can be seen in Fig.9(a) that the phenomenon of pull-out fiber occurred dominantly on the fracture surface of the composites. In the picture corresponding to the composites with 7wt% MAPP, Fig.9(b), a lesser extent of the pull-out fiber and a few tearing of the fibercould be observed because of slightly better adhesion between the MGF and PP matrix. The effect of the silane coupling agent and MAPP compatibilizerwas shown in Fig.9(c) where almost all the MGFwasfractured,and there was litter evidence of fiber pull-out due to the more significantimprovement in the bonding between the MGF and PP matrix.



(a) (b)

(d) (c)

Figure 9: SEM imagesofthe PP composites with 7.5 % MGF (a);the PP composites with 7.5 % MGF and7 wt% MAPP (b);the PP composites with 7.5 % MGF,7 wt% MAPP and 2 wt% silane(c); and the MGF (d)

IV. CONCLUSION

The morphological analysis of the composite through the SEM image showed that the phase interaction between polypropylene and submicron glass fiber was improved remarkably by the addition of MAPP compatibilizer and silane. The effect of the temperature, the MGF, MAPP and silane content on the properties of the compositewas determined by tensile, flexural, impact strength and tensile modulus. The results presented that the temperature of 175^{o}C were suitable conditions for composite manufacturing. Moreover,the results showed that 7.5 wt% of fiber, 7wt% of MAPP and 2wt% of silanes were the most suitable values for composite production with 44,64 MPa of tensile strength, 1248.5 MPa of modulus, 3.85 KJ/m^2 of impact strength and 48.52 MPa of flexural strength.

V. Acknowledgements

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