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What is This?
Extrusion and injection-molding of glass fiber/MAPP/polypropylene: effect of coupling agent on DSC, DMA, and mechanical properties

Aziz Hassan, Normasmira Abd. Rahman and Rosiyah Yahya

Abstract
Glass fiber-reinforced PP composites compatibilized with maleic anhydride grafted polypropylene (MAPP) were compounded with a twin-screw extruder and injection molded. The composite specimens were subjected to DSC, DMA, tensile, and flexural property characterizations. DSC results showed that the presence of glass fiber loading and MAPP produced insignificant effect on the melting temperature of the composites. The melting enthalpy was decreased with glass fiber loadings, but no significant change was noted in the crystalline peak temperatures ($T_c$). Incorporation of the compatibilizer led to a reduction in $T_c$. Incorporation of glass fiber reduced the crystalline enthalpy of compatibilized and uncompatibilized systems. DMA results showed that composite properties were affected by the presence of the compatibilizer at low fiber loading ($\leq 14\%V_f$). Tensile and flexural properties also showed sensible improvement of compatibilized against uncompatibilized composite systems.

Keywords
glass fiber composites, compatibilizer, thermal properties, dynamic mechanical properties, mechanical properties

Introduction
Composite materials are engineering materials made from two or more components on a macroscopic scale to form a useful material. It is not a simple mass of fibers dispersed within a matrix. A ‘true’ composite might be considered to have a matrix material completely surrounding its reinforcing material in which the two phases act together to achieve superior characteristics not attainable by either constituent acting alone. Composites are composed of a heterogeneous combination of components differing in composition, morphology, and usually physical properties, made to produce specific physical, chemical, and mechanical characteristics. Fiber-reinforced polymer composite (FRPC) materials are quite attractive because of their ease of fabrication, economy, and superior mechanical properties. FRPC materials offer a number of distinct advantages over more conventional engineering materials, such as high specific modulus, specific strength, superior corrosion resistance, improved fatigue properties, and low manufacturing cost.

In general, high fiber content is required in order to achieve a high-performance FRPC. Therefore, the effect of fiber content on the mechanical properties of FRPC is of particular interest and significance. It is often observed that the increase in fiber content leads to the increase in the strength and modulus\(^1\) and also in the toughness if the matrix has a low toughness.\(^2\) However, the extent to which fibers can vary the properties of the resultant composite parts will depend on the difference between the properties of the fibers and the matrix. Moreover, the composite properties are also influenced by the nature of adhesion between the fiber
and the matrix. Among commodity thermoplastics, polypropylene (PP) possesses outstanding properties like low density, high Vicat softening point, good flex life, sterilizability, good surface hardness, scratch resistance, good abrasion resistance, and excellent electrical properties. However, the chemical incompatibility of the non-polar PP to be bonded onto the glass fiber results in inability of the composites to take full advantage of the reinforcement potential due to the poor adhesion between the matrix and fiber.

Maleated PP has been widely used as compatibilizer for natural fiber PP composites. A sharp improvement in the interfacial adhesion between bamboo, glass fiber, and PP was observed using maleic anhydride-grafted polypropylene (MAPP) pretreatment of bamboo. Mohanty et al. have established improved mechanical strength and thermal stability in MAPP-treated short jute fiber-reinforced PP composites. Based on these findings, MAPP was used to explore the possibility of enhancing the compatibility and interfacial adhesion between glass fiber and PP.

Compatibility between PP and GF is of main consideration in the application of GF/PP composites due to the organic and inorganic natures of PP and GF, respectively. Although a number of reports have been published on the use of MAPP as compatibilizer for composite systems, the area of focus was quite different. Numerous researchers have reported the effect of MAPP on natural fiber composites, such as sisal fiber/PP, bamboo fiber/PP, and jute fiber/PP. Others reported on the use of thermoset as polymer matrix in composites prepared by compression molding. In this report, we present the use of MAPP on synthetic GF/PP thermoplastic matrix, prepared from the compounding stage, injection molded and characterized. It should be noted that GF used in this study was not specifically manufactured for the PP application. For this reason, investigations were carried out, to establish the function/role of MAPP as coupling agent in GF/PP composites. The thermal, dynamic mechanical, and mechanical properties of the composites with different compositions of glass fiber, MAPP, and PP were investigated.

**Experimental**

**Materials**

PP (HJ500) was manufactured by Samsung Atofina Co. Ltd. Neat PP was in the form of pellets with a melt flow index of 11 g/10 min and a density of 0.91 g/cm³. Chopped glass fiber with density of 2.55 g/cm³, diameter of 14 μm, and length of 6 mm was used as reinforcement, manufactured by KCC Corporation, Korea. Maleated PP (MAPP; PolyBond® 3200, Clariant®) was used as a compatibilizer. The density and maleic anhydride grafting level of MAPP were 0.91 g/cm³ and 1%, respectively.

**Specimen preparation**

The materials in different ratios of PP/MAPP/glass fibers were physically mixed and compounded using a Brabender (KETSE 20/40) twin-screw extruder. Temperature profile was set from 185°C to 190°C and the screw speed was 100 rpm. The extruded material was granulated into pellets with a length of about 6 mm. The dumb bell-shaped tensile test specimens, according to ASTM standard D638, were then injection molded using a Boy® 55M injection molding machine. The processing temperature was 175–185°C and the mold temperature was 25°C. Specimens were prepared with different levels of glass fiber and MAPP contents. Specimens were designated according to their composition; for example, PP80/C5/G15 was referred as specimen with PP/MAPP/GF of 80/5/15 w/w (%), respectively.

**Differential scanning calorimetry**

Differential scanning calorimetry (DSC) experiments were performed with a Diamond DSC (Perkin Elmer). Each sample was subjected to heating and cooling treatments at a scanning rate of 10°C/min under nitrogen atmosphere in order to prevent oxidation. A test sample of 5–10 mg was placed in an aluminum pan and tested over a temperature range of 0–190°C.

**Determination of dynamic mechanical properties**

The dynamic mechanical properties of specimens were analyzed with a dynamic mechanical analyzer, DMA Q800 (Thermal Analysis Instrument). Test specimens were taken from the middle section of the injection-molded dumb-bell test bar and were subjected to a three-point bending mode with a support span of 50 mm. Measurements were conducted over a temperature range of −100°C to 110°C with a heating rate of 3°C/min under a constant frequency of 1.0 Hz.

**Determination of tensile and flexural properties**

Tensile tests were carried out using a Universal Testing Machine, Instron 5569 with a constant cross-head speed of 5 mm/min at room temperature of about 25°C. ASTM standard D638 was used as a standard in calculating the tensile properties. Flexural tests were carried out using the same machine that was used for the tensile testing. The distance between the support spans was 50 cm. All the specimens were tested at a
constant cross-head speed of 1.28 mm/min. ASTM standard D790 was used as a standard in calculating the flexural properties.

**Results and discussion**

**Differential scanning calorimetry**

The DSC thermograms allow one to get information on the melting temperature \( T_m \), crystallization temperature \( T_c \), enthalpy of melting \( \Delta H_m \), enthalpy of crystalline \( \Delta H_c \). The degree of crystallinity \( X_c \) of the specimens can also be calculated using the following equation:

\[
X_c = \frac{\Delta H_m}{\Delta H_m^*} \times 100\%
\]

where \( \Delta H_m^* \) is enthalpy of melting of fully crystalline PP, taken as 209 J/g. The DSC characterizations of all the samples were subjected to first heating, cooling, and second heating. However, only the results from the cooling and second heating are displayed and taken into consideration in the discussion. Özümek et al. reported that the results from the second heating is useful to study as the first heating results may be influenced by the sample history, such as preparation and storage conditions.

DSC thermograms show the presence of single peak for both heating and cooling scans of the composites (Figure 1). The melting temperature of pure PP is 163°C. DSC thermograms from Figure 1 show that the presence of glass fiber at 6% \( V_f \) and MAPP has insignificant effect on the melting temperature of the composites. The same behavior was also reported by Nayak and Mohanty and Samal et al.

The \( \Delta H_m \) is an important parameter since its magnitude is directly proportional to the overall level of \( X_c \) possessed by the polymer. The \( \Delta H_m \) of unreinforced PP is 80.23 J/g; this value decreases to 80.02, 65.42, and 53.61 J/g with the addition of 6%, 14%, and 23% \( V_f \) glass fiber, respectively, for the uncompatibilized systems (Figure 2). This trend is expected due to reduction in the degree of crystallinity of the polymer matrix with incorporation of fibers. The same trend is also shown by the compatibilized composite systems.

For the uncompatibilized system, introducing glass fibers interrupts the linear crystallizable sequence of the PP chains and lowers the degree of crystallinity indicating more of flexible amorphous content. The same observation for the compatibilized system is obtained, with the exception of composite with 6% \( V_f \) of glass fiber. The addition of 6% \( V_f \) of reinforcement shows some increment in the degree of crystallinity from 38.4% for PP matrix to 40.0–42.1% for compatibilized system with 2–8 wt% of MAPP. For comparison, the value of property index (PI) as defined by previous studies is also calculated and tabulated in Table 1. From Figure 3 and Table 1, it can be seen that at the same fiber loading, incorporation of MAPP into the composites has increased the degree of crystallinity. This result indicates that the presence of compatibilizer has improved the nucleation of the matrix.

As for the crystalline peak temperature \( T_c \), no significant changes in \( T_c \) values are observed with incorporation of glass fiber into the system. However, at the same fiber loading (6% \( V_f \)), further incorporation of compatibilizer from 2 to 8 wt% of MAPP into composites has led into a slightly reduction in \( T_c \) value from 125°C to 121°C (Figure 1). The crystalline enthalpy, \( -\Delta H_c \) of unreinforced PP is 100.33 J/g, while those with glass fiber of 6%, 14%, and 23% \( V_f \), the \( -\Delta H_c \) decreases to 83.96, 68.46, and 56.9 J/g, respectively (Figure 2). The same trend was observed for compatibilized composites system. Since the addition of glass fiber interfered with crystallization, it is assumed that the decrease in \( -\Delta H_c \) is closely related to the decrease in \( X_c \) value.

**Dynamic mechanical analysis**

Results from the dynamic mechanical analyses (DMAs) of composite specimens are shown in Figures 4–6. The

![Figure 1](image1.png)  
*Figure 1.* The DSC thermograms of injection-molded 6% \( V_f \) glass fiber composite with different MAPP contents.

![Figure 2](image2.png)  
*Figure 2.* Enthalpies of melting and crystalline of PP/GF/MAPP hybrid composites.
Table 1. PI of thermal and mechanical properties of glass fiber composites

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<tr>
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Note: Ref, reference.

Figure 3. Degree of crystallinity, X_c of PP/GF/MAPP hybrid composites.

Figure 4. The storage modulus curves of injection-molded PP/GF/MAPP hybrid composites.

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Figure 4. The storage modulus curves of injection-molded PP/GF/MAPP hybrid composites.

thermomechanical data as extracted from these curves are tabulated in Table 2. From these figures, over a temperature range of −100°C to 110°C, only one major transition is detected between −25°C and 25°C which is related to glass transition region.

Storage modulus (E’)

The storage modulus (E’) is closely related to the load-bearing capacity of a material and is analogous to the flexural modulus (E) measured as per ASTM-D 790. Variation of E’ as a function of temperature for virgin PP and composites with and without MAPP is graphically enumerated in Figure 4. From this figure, a decreasing trend in the storage modulus over the whole temperature range is observed. A significant fall in E’ is noticed in the region between −25°C and 25°C which is believed to correspond to the glass transition region of the matrix polymer. However, with incorporation of fiber, decrease in E’ is being compensated by the interaction caused by the reinforcing effect of fibers in the matrix. It is evident from Figure 4 that there is a notable increase in the modulus (at −100°C) of virgin matrix with incorporation of glass fibers, probably due to increase in the stiffness of the matrix due to reinforcing effect imparted by the fibers allowing greater degree of stress transfer at the interface.

From Figure 4, it can also be seen that the dynamic mechanical properties of composites are affected by the presence of compatibilizer only at low fiber loading. The addition of 5 wt% of MAPP in 6% V_f of glass fiber gives increment of about 8% in the storage modulus (at −100°C) compared to the same composite formulation without compatibilizer. However, as the fiber volume fraction in the composite increases, incorporation of compatibilizer (5 wt%) into the system has led into a reduction of this value (Table 2). The storage moduli of the composites at room temperature (25°C) are increased from 2.4 to 3.4 GPa (43%) for PP80/C5/G15 and 3.9 to 4.8 GPa (23%) for PP65/C5/G30. As for the composite with higher fiber volume fraction (PP50/C5/G23), only 3% increment in storage modulus value is observed with incorporation of MAPP into the system. It is suggested that at V_f of 23%, the MAPP content used is insufficient to form a good fiber–matrix adhesion, thus reducing the stress transfer efficiency at the interface.

Loss modulus (E’’)

The variation in E’’ of virgin PP and PP/GF/MAPP hybrid as a function of temperature is shown in Figure 5. Samal et al. reported that the matrix polymer exhibits two transition peaks (a and b) at different temperatures within their investigated temperature range.
The a-transition is due to the glass transition temperature, \( T_g \), within \(-10^\circ C \) to \( 10^\circ C \) and is associated with the motion of the long-chain segments in the amorphous region of the PP. The \( \beta \)-transition around \(-100^\circ C \) is related to the relaxation of amorphous propylene segments of the PP chain. In this study, the \( \alpha \)-transition peak of the matrix was observed around \(-3^\circ C \). However, \( \beta \)-relaxation peak of the matrix polymer was not detected under the present test temperature range. In this study, \( T^\infty_\alpha \) is referred to temperature at the maximum value of loss modulus in \( \alpha \)-transition. As observed from Figure 5(A) and (B), the \( T^\infty_\alpha \) of the compatibilized composites shifts to higher temperature compared to the uncompatibilized

\[ (-150^\circ C \text{ to } 150^\circ C). \]

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composites as well as virgin PP, which is probably due to restricted segmental motion of the amorphous PP chains at the fiber–matrix interface. This suggests that in the presence of MAPP, the polymer molecules are more restricted in motion due to the increased fiber–matrix adhesion resulting in less distinct and broader transition peaks.

Loss tangent (tan δ)

The ratio of loss modulus to storage modulus is measured as the mechanical loss or damping factor (tan δ). The damping properties of the material give the balance between the elastic phase and viscous phase in a polymeric structure. In this investigation, the variation of tan δ as a function of temperature is represented in Figure 6. The transition region, as indicated by damping maxima, is usually known as α-transition. The peak at maximum value of tan δ in α-transition, $T_{\alpha}$, is generally known as the glass transition temperature, $T_g$.

As shown in Figure 6(A) and (B), the incorporation of the fibers in both compatibilized and uncompatibilized systems has slightly shifted the $T_g$ to lower temperatures. Data from Table 2 show that composite with 23% $V_f$ of glass fiber has the lowest $T_g$ (0°C), compared to the other compositions (2°C for both 6% and 14% $V_f$). At higher glass fiber loading ($V_f$ of 23%), fiber/matrix wetting problem might have occurred (poor adhesion), leading to increase in segmental mobility of the polymer chain, thus resulting in decrease in $T_g$. In addition, the presence of the glass fiber reduces the magnitude of tan $\delta$ values dramatically. Higher reduction for composites with higher fiber loadings is believed to be due to the strengthening effect by the fibers and limiting the mobility of polymer matrix. Tan $\delta$ of composites with 23% $V_f$ shows a maximum decrease of about 30% compared to the pure matrix (0.0667–0.0468). In this case, the incorporation of fibers acts as barriers to the mobility of polymer chain, leading to lower degree of molecular motion and hence lower damping characteristics.

Mechanical properties

Tensile properties. The tensile properties (strength, modulus, and strain) of glass fiber-reinforced PP composites are shown in Figures 7 and 8. It is well known that the properties of short-fiber composites are determined by the nature of the fiber, the fiber volume fraction, the fiber orientation factor, the aspect ratio of the reinforcement, and by the quality of the fiber/matrix interface.

Tensile strength. The PP matrix has a tensile strength of 31 MPa and a modulus of 2.0 GPa. Reduction in tensile strength is observed when glass fiber is incorporated to the polymer matrix. Figure 7 shows a continual decrease in reinforcement efficiency as the fiber content increases. The tensile strength reduced from 31 MPa for pure PP to 26 MPa for 23% $V_f$ of glass fiber composites. The addition of fibers did not improve the strength which is an indication of poor adhesion between the fibers and the matrix and that the stress cannot be transferred from the matrix to the stronger fibers. At high deformations, as in tensile tests, it is assumed that when there is a poor adhesion at the interface, the presence of fillers or fibers in a polymer matrix gives rise to defects at the interface, which are responsible for the strength reduction. Through microscopic studies, it can clearly be seen that fiber surface is smooth.
without adhered resin particles which indicates poor fiber–matrix bonding at glass fiber surfaces (Figure 9(A)). Composite failure could be mainly due to fiber/matrix interfacial debonding, rather than fiber fracture.

Several studies had already shown the important effect of MAPP on the mechanical properties of fiber-reinforced composites. In this study, the effect of different amounts of MAPP on the tensile properties of glass fiber-reinforced PP composites is presented. The mechanical properties of composites comprising of 5 wt% MAPP content are illustrated in Figures 7 and 8. From the results, the effectiveness of MAPP as compatibilizer is clearly seen. The addition of MAPP coupling agent improved the tensile strength in all composites with different fiber contents (Figure 7). Obviously, with the addition of 5 wt% of MAPP, tensile strength of the composites increases to about 32–41% compared to the same composite formulations without the compatibilizer.

For uncompatibilized systems, tensile strength of composite with 14% $V_f$ is 4% lower compared to composite with 6% $V_f$. Further increase in fiber content to 23% $V_f$ results in more reduction of the composite strength of about 9%. In contrast, with addition of 5 wt% MAPP into the system, composite with 14% $V_f$ shows 2% increment in tensile strength, compared to composite with 6% $V_f$. Further increase in fiber content up to 23% $V_f$ only results in reduction of strength of about 3%. The existence of 5 wt% MAPP was probably not enough to compatibilize the system with 23% $V_f$ glass fiber composites.

**Tensile modulus.** Despite the reduction in tensile strength (uncompatibilized system), tensile modulus increases with increase in fiber volume fraction; for example, the modulus increases from 2.0 GPa for pure PP to 4.8 GPa for composites with 23% $V_f$ (Figure 7). The same behavior has also been reported by previous researchers.

The contrary effect of increase in modulus is believed to be due to this property being measured at low strain of 0.5% compared to that at fracture for tensile strength. At low strain, stress applied causes the specimen to deform in a total elastic manner, where fiber–matrix adhesion may not really be in a stretchable condition, whereas at fracture point, all possible mechanisms of fracture, such as fiber pull-out and fiber breakage may exist. Any poor fiber–matrix interface may lead to premature failure leading to reduction in tensile strength. In addition, from the fiber length point of view, at low strain, most of fibers are super-critical or longer than the critical fiber length ($L > L_c$) and fiber failure mainly due to breakage mechanism. On the other hand, at higher strain, most fibers turn sub-critical ($L < L_c$) leading to fiber failure by pull-out.

In relation to the compatibilizer, it can be observed that the use of MAPP as coupling agent further improves the stiffness of the composites (Figure 7). With the addition of 5 wt% of MAPP, tensile modulus of the composites increases by about 27–37% compared to the uncompatibilized systems. These results confirm that with incorporation of compatibilizer into

![Figure 9](image-url). Scanning electron microscopy image taken from tensile fracture surface of injection-molded PP/GF/MAPP composite (A: PP85/G15 and B: PP80/C5/G15).
the system, the fibers act as an effective reinforcing agent for PP, giving rise to a more rigid material. Haneefa et al. suggested that the addition of glass fiber increases the effective mechanical interlocking, which in turn increases the frictional force between the fiber and matrix. Increasing the amount of glass fiber leads to higher stiffness of composite; thus, more energy is required to break the specimens. The enhancement of the tensile properties of the composites is attributed to the improved interfacial adhesion between the fiber and matrix. The applied load is transferred to the strong and stiff fibers through the fiber–matrix interface. As the volume fraction of fiber reinforcement in composites increases, more fiber–matrix interfacial area was created, resulting in more applied load being transferred to the fiber by the interface. Through microscopic studies, it can clearly be seen that some polymer matrix adheres at the fiber surface indicating a good fiber–matrix bonding. However, if the fiber–matrix adhesion is weak, cracks tend to form at the interface and link up quickly through highly stressed sections of the matrix, resulting in premature failure of the composite. Nevertheless, it can be seen that the strength and modulus of composites increase with increase in the fiber loading.

**Tensile strain.** All specimens of fiber-filled materials failed at strain below the normal yield strain of the matrix. The tensile strain as a function of $V_f$ is shown in Figure 8. The tensile strain is reduced from 10% for pure PP to 3% for composites with 23% $V_f$ of glass fiber content. This trend is also reported by previous researchers who explained that the stress concentrations at the fiber ends lead to matrix cracking, which ultimately causes failure when the surrounding matrix and fibers can no longer support the increased load caused by the local failure.

Previous workers have also reported the decrement in tensile strain as the $V_f$ increases. Due to the introduction of fibers, the composites become less ductile as the molecular rearrangement does not have time to take place. The notching effect of the fibers is also important in which considerable stress concentration is induced in the matrix at the fiber end and matrix flow is constrained by adjacent fibers. Takahashi and Choi who studied the failure mechanisms have shown that under loading of tensile stress, the cracks start at the fiber ends and propagate along the fiber–matrix interface or cross through the matrix and finally the failure takes place. From this figure, it can also be seen that the tensile strain of composites is greatly affected by the presence of MAPP. Obviously, with the addition of 5 wt% of MAPP, tensile strain of the composites reduces by 55%–66% compared to the uncompatibilized systems.

**Flexural properties**

Flexural testing provides information about the behavior of material in bending. Figure 10 shows that increase in fiber content leads to an increase in flexural strength and flexural modulus. This indicates that glass fiber-reinforced PP results in materials possessing flexural strengths better than the pure matrix. This observation is expected and can be explained by the contribution of the glass fiber as a brittle and tough material. The loss of ductility is confirmed by increasing the glass fiber content. In general, an increase in fiber content results in an increase in stiffness and flexural strength.

In flexural test, maximum stresses in stress–deflection curves occur not at maximum deflection. Within that region, the effect of even poor interfacial adhesion may not fully affect the flexural properties. In tensile test, however, maximum stress in stress–strain curves occurs when specimen break. The specimens are most likely to break at the poor interfacial area. This could explain the reduction in tensile strength, and increment in flexural strength with incorporation of glass fiber.

Figure 10 also clearly demonstrates that the incorporation of MAPP significantly improves the flexural strength of compatibilized composite. With the addition of 5 wt% MAPP, flexural strengths of the composites increase by about 33%, 32%, and 18% for composites with $V_f$ of 4%, 8%, and 12%, respectively, compared to uncompatibilized composite systems.

The flexural moduli of the compatibilized composites also show significant improvement with the addition of MAPP (Figure 10). It increases from 1.9 GPa (PP85/C0/G15) to 2.5 GPa (PP80/C5/G15) (33%) and from 3.0 GPa (PP70/C0/G30) to 3.9 GPa (PP65/C5/G30) (29%). As for the composite with higher fiber volume fraction (PP50/C5/G23), only 1% increment
in flexural modulus value is observed with incorporation of MAPP into the system. This result agrees with those obtained by DMA (Table 1). The storage modulus of the compatibilized composite at room temperature (25°C) shows a notable increment for 6% and 14% $V_f$, compared to the uncompatibilized system. However, for 23% $V_f$ composites, only a slight improvement is observed with incorporation of MAPP into the composites. It is suggested that at $V_f$ of 23%, the MAPP content used is not enough to compatibilize the system to form a good fiber–matrix adhesion, thus reducing the stress transfer efficiency at the interface. Flexural displacement values decrease with increase in glass fiber volume fraction (Figure 11). This means that the material becomes tougher with the increase of fiber content. Incorporation of MAPP into the composites further reduces the flexural displacement as it enhances the stiffness of the material significantly.

Conclusions

Introducing glass fibers lowers the melting enthalpy of specimens. For the uncompatibilized and compatibilized composites with higher fiber loading, introducing glass fibers lowers the degree of crystallinity. There are no significant changes in $T_m$ and $T_c$ of composites with the addition of glass fiber and MAPP, except at 6% $V_f$, $T_c$ is reduced with increase in MAPP.

Storage modulus of composites is affected by the presence of compatibilizer only at low fiber loading. Temperature at maximum loss modulus of the compatibilized composites shifts to higher temperature compared to the uncompatibilized composites as well as virgin PP. Incorporation of fibers in both compatibilized and uncompatibilized systems has slightly shifted the $T_g$ to lower temperatures. On the other hand, the presence of the glass fiber reduces the magnitude of tan $\delta_{\text{max}}$ values dramatically.

Tensile strength and tensile modulus are decreased and increased, respectively, with an increase in fiber loading. The addition of MAPP as coupling agent has improved these properties. Flexural strength and flexural modulus are both increased with an increase in fiber loading and further improvement is observed with addition of MAPP.

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Figure 11. Flexural displacement of PP/GF/MAPP hybrid composites.


