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# Thermal and impact study of PP/PET fibre composites compatibilized with Glycidyl Methacrylate and Maleic Anhydride

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ABSTRACT

In this paper, two grafted copolymers, Glycidyl Methacrylate grafted polypropylene (PP) (PP-g-GMA) and Maleic Anhydride grafted PP (PP-g-MA) were used in PP reinforced with short poly(ethylene terephthalate) (PET) fibre composites. Transcrystallization (TC) of PP on PET fibres was investigated using a polarized optical microscope, which revealed no TC for either of the modified composites at the fibre–matrix interface. Heat deflection temperature (HDT) results of GMA modified composites revealed more enhancement than HDT of MA modified samples. The composite strength results showed enhancement for both modified composites up to 10 wt.%, and this growth was bigger for GMA modified composites. The morphological analysis of GMA modified PP/PET composites pointed out a marked improvement of fibre dispersion and interfacial adhesion as compared to non-compatibilized PP/PET composites. The results of impact strength showed about 43% enhancement for 15 wt.% PET fibre composites. It was found that at low fibre percentages, using either of the modifiers reduces the impact strength a little in comparison to impact strength of the unmodified samples. According to linear elastic fracture mechanics LEFM, impact fracture toughness ($G_c$) and critical stress intensity factor ($K_c$) were evaluated for these composites based on the fracture energy obtained from impact tests.



## 1. Introduction

Fibre-reinforced composite plastics offer a combination of strength, durability, stiffness, low weight, thermal stability and corrosion resistance that has led to their adoption in a variety of applications. Thermoplastic-based composites are becoming more popular in many application fields due to the possibility of combining the toughness of thermoplastic polymers with the stiffness and strength of reinforcing fibres [1]. Among the thermoplastic matrices, PP is one of the most used ones for short fibre composites due to economic reasons, ease of processing, environmental and working security, and recyclability [1,2]. Glass and carbon fibre reinforced thermoplastic matrices are the most popular ones used to produce short fibre reinforced PP; nonetheless, the tendency to regard these materials as non-recyclable and the common practice to discard them in landfills has caused increasing environmental concerns. Besides, even if they are recycled, they show a degradation of their mechanical performance [3]. It is well known that organic textile fibres can be used to prepare polymer composites and it is possible to obtain good composites using PP with short organic fibres [1,4]. Poly(ethylene terephthalate) (PET) fibre could be a good option to reinforce PP. Since its introduction in 1953, PET fibres have progressively found new and interesting applications in plastics. Owing to its low density, PET fibre is lighter than cotton, wool and silk, and can mimic their properties. Besides, its low cost, high impact strength, high tenacity, high thermal stability, and more importantly, recyclability make it effective to use in PP composites [1,2,5,6]. Therefore, PP/PET composites provide some specific features, such as recyclability, ease of production, and low cost. One major problem of PP/PET composites is that they are not compatible, causing reduction in the final composite strength due to having weak fibre/matrix interaction [3,7]. To resolve this problem, chemical modification of matrix is usually applied in order to enhance the interaction at the fibre–matrix interface. Of all the modifiers used in PP/PET composites, Maleic Anhydride (MA) is the most common [2,5,7]. Glycidyl Methacrylate (GMA) is another interesting modifier owing to its epoxy group, which is capable of reacting with various other groups like hydroxyl, carboxyl, amine, and anhydride. GMA which can react with both hydroxyl and carboxyl end groups of the PET fibre has not been used before in PP/PET composites. Furthermore, unlike MA, GMA does not produce side product of water through its chemical reactions by the PET chain end groups [8–12]. GMA reaction with PET end groups is depicted in Fig. 1.

For composites based on semi crystalline polymers, their crystallinity is an important factor, which determines the stiffness of

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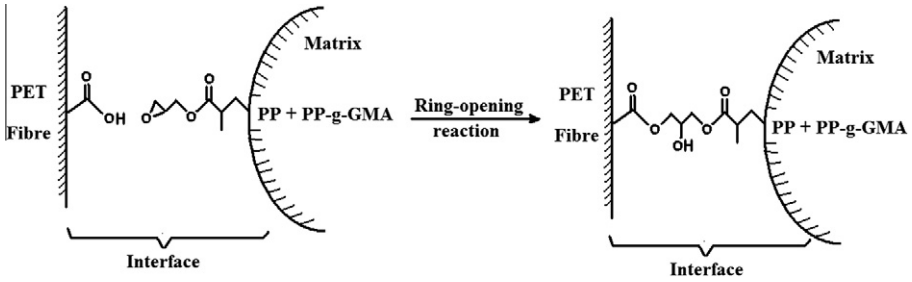


**Fig. 1.** Schematic representation of reaction between PET end-groups and GMA moieties grafted onto PP backbone.

the composite. Under appropriate conditions, a highly oriented layer is developed at the fibre–matrix interface. This distinct morphology is called transcrystalline (TC) layer. PP matrix TC layer on the PET fibre has been studied by many researchers [13–15]. Embedding PET fibres into PP matrix can also increase thermal stability of the matrix due to higher heat deflection temperature (HDT) of PET fibres, causing enhancement in the HDT of the resultant composite. Moreover, properly designed PP/PET composites can also have a noticeable increase in impact strength. Workers in this area have managed to show satisfactory results in their impact tests [2,4–6].

In this paper, PP/PET fibre composites were prepared in presence and absence of PP-g-GMA and PP-g-MA by melt impregnation technique. Morphological properties were investigated using polarized optical microscopy and scanning electron microscopy (SEM) techniques. Thermal studies such as DSC and HDT measurements were conducted and mechanical behaviours like tensile and impact tests were also investigated. According to linear elastic fracture mechanics (LEFM) concept, $G_c$ and $K_c$ were measured based on the information obtained from impact results and drawn on the basis of fibre content.

## 2. Experimental

### 2.1. Materials

A commercial grade of PP under the trade name of C30S in powder form from Iran Petrochemical Co. was used. PP had the Melt Flow Index of 3–5 g/10 min (190 °C, 2.16 kg) and density of 0.9 g/cm$^3$. PET fibre was a commercial grade of textile polyester (FOY[1], tensile strength 550 Mpa, tensile modulus 12,000 MPa, and 11.2 μm in diameter) provided by Polyacryle Company, Iran, chopped to the average length of 4 mm. PP-g-GMA was prepared in our laboratory by melt grafting method in an internal mixer according to Parcella and Chionna [8]. Mixing time, rotor speed, temperature, styrene/GMA molar ratio, Dicumyl Peroxide (DCP) and GMA amounts were 5 min, 60 RPM, 190 °C, 1, 0.5, and 9 Phr[2], respectively.

PP-g-MA (MFI = 150–200 g/10 min at 230 °C and 2.16 Kg) was used as the second compatibilizer which was provided by OREVAC corporation under the trade name of CA100.

### 2.2. Composite preparation

PET fibres were dried in an oven at 100 °C for 4 h. Three types of pre-pegs of PP/PET, WO (without compatibilizer), WG (with PP-g-GMA), and WMA (with PP-g-MA) with fibre loads of 5, 10, 15, 20, and 30 wt.% were mixed in an internal mixer at 180 °C and 60 RPM for about 10 min to ensure the proper wetting of PET fibres by PP melt. The amount of campatibilizers in each run was 10 Phr. Then, pre-pegs were moulded by hot press technique at 180 °C and 100 bar.

### 2.3. Composite characterization

#### 2.3.1. Morphological study

In order to study crystallinity of composites, a Leica polarized optical microscope (DMRX model) was used. SEM technique (AIS2100 model microscope from Seron Technology company) was applied to study the sample fracture surfaces and fibre–matrix interface.

#### 2.3.2. Thermal tests

DSC tests were performed at the heating rate of 10 °C/min using DSC 200F3, NETZSCH. Heat deflection temperature (HDT) test is the temperature at which the material deflects by 0.25 mm at an applied force, where the specimen is placed in a three-point bending mode. HDT of PP/PET composites was measured according to ASTM D648 by a Ray–Ran testing machine, and bars with dimensions of 127 × 12 × 3 mm$^3$ were prepared. The test was conducted on three samples of each specimen with the load applied at its centre to give maximum fibre stresses of 1.82 MPa.

#### 2.3.3. Mechanical behaviour

Tensile properties of the samples were determined using a Universal testing machine (Testometric) at the cross head speed of 5 mm/min (ASTM D638). Impact properties were measured according to ASTM D256 using a ZWICK/Roel impact testing machine (L-HIT, HIT5.5P model). Bars used in the impact tests had the dimensions of 55 × 10 × 10 mm$^3$.

### 2.4. $G_c$ and $K_c$ measurement

Short PET fibres are usually added to PP to improve the impact strength of the composite as a result of enhancement of its impact fracture toughness [2,5,7]. The impact fracture toughness of a material is usually evaluated by means of impact test: the simplest being the notched Charpy and Izod impact tests. They provide the total energy ($U_c$) consumed during the whole impact fracture process. Even though polymeric materials display viscoelasticity when tested in a tensile mode, they tend to fail in a brittle manner under impact due to the high loading rate exerted on the test pieces. The effect is further exaggerated by introducing a razor-sharp crack in the sample, minimizing the plastic zone ahead of the crack tip and extending the application of linear elastic fracture mechanics (LEFM) to this group of materials. Thus, toughness parameters like the stress intensity factor and the critical strain energy release rate ($K_c$ and $G_c$ respectively) can be determined [16]. In recent years, impact testing of plastics has been rationalized to a certain extent by the use of fracture mechanics and the most successful results have been achieved by assuming that LEFM assumptions (bulk linear elastic behaviour and presence of sharp notch) apply during the

[1] FOY, fully oriented yarn.
[2] Phr, parts per hundred resin.