Influence of Compatibilizers on Date Palm Fiber and High Density Polyethylene Composite

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Abstract

The influence of three types of coupling agents [Polyethylene-co-methacrylic acid (PEMA), Polyethylene-graft-Maleic anhydride (PEGMA) and Polyethylene-co-methacrylic acid zinc salt (PEMA-Zn)] on organic fiber reinforced polymer synthesis with 10% of Date palm fibre was investigated. Thermal and mechanical properties and the relation with the interfacial adhesion and microstructure were explained. The Morphologies of composites were conducted out by Scanning Electron Microscope (SEM). The mechanical and thermal properties of different samples were evaluated by Tensile Test, Differential Scanning Calorimeter (DSC) and Thermo gravimetric Analysis (TGA) apparatus respectively. The Tensile strength and Young’s modulus were improved after the adding of the compatibilizers. The melting and crystallization temperature of the matrix were not influenced by the accumulation of the three types of MA. An increase in the transcrytalization, characteristic of the semicrytaline thermoplastic matrix composite, was taken into account because it enhanced tensile strength of the composites. The percentage and the type of the MA used in the 10% date palm fibre/HDPE composite improved the interfacial adhesion and the dispersion of the palm fillers within the polymer matrix but no preferred type or percentage can be advised as all of them have the approximate effect on the mechanical and thermal properties.

Keywords: Compatibilizers, Date palm Fiber, Polymer, and Composite.

1. Introduction

NFPC is the natural fiber polymer composites which are primarily price-driven product composites which offer good structural properties at a comparatively minimal price. The uses of natural fibers have several benefits for instance, being obtained from a renewable reserve and need small force responses in their fabrication\textsuperscript{1,2}. Presently, natural fibers used as reinforcements in scientific products mostly in the vehicle and wrapping trades in components where a high capacity hauling facility is not \textsuperscript{3–5}. There are many kinds of natural fibers for example flax, jute, banana, hemp, coir and date palm fiber\textsuperscript{6}. In this research, the natural fiber that's used is the date (Phoenix dactylifera) which is from the family of the palm tree [\textsuperscript{7–9}]. Different parts of this tree can be used as fillers such as: leaves, base of leaves and the trunk which is prepared as wood flour or palm fibers. Many aspects can affect the performances of
composites based on natural fiber such as the quantity of fiber content, the processing (extrusion and injection) and the interface between the material and the filler.

The performance of NFPCs is affected by the interfacial adhesion among the hydrophobic polymer and the hydrophilic fibers. Thus the fibers tend to agglomerate through the polymer matrix during compounding process, the result is a weak interfacial adhesion and it can affect the mechanical properties [10,11]. The experimental methodologies for improving blend properties of natural fiber/polymer composites involve optimization of processing conditions, surfactant treatment, physical and mechanical properties[12] and chemical alteration of the polymer matrix to enhance matrix-fiber’s adhesion[13]. Chemical amendment has always offered changes in the nature of fiber cell walls [14]: by polymers grafted onto fibers [15,16] or by the usage of coupling agents[17,18]. The walls fiber dimension may be stabilized by chemical modifications which might be linked to the reduction of the dynamic strength like impact strength that resulted from the embrittlement[19,20]. A significant flexibility in the chemical structure (quantity of cellulose, lignin, hemicelluloses, etc.) and in the supra molecular formation (microfibril angle, the volume of the cells) of natural fibers [19,21] passionately impact their total mechanical properties (tensile strength, flexibility) and thermo physical ones as well[22]. The coupling agents or the compatibilizers are functioned to produce a chemical link which connects the reinforcement and matrix. These kinds of materials permit the immiscible polymers to blend and produce a homogenous mixture and work as a surfactant. Thus, the interfacial adhesion is augmented by the coupling agent, which the molecule of the reinforcement end surface is bonded and functioned with other ends that react with the polymer phase [23–25]. Modifications in the surface of the natural cellulosic fibers develops the mechanical properties are increased either by chemical or physical treatment[8,26,27].

High Density Polyethylene (HDPE) was the thermoplastic polymer matrix applied in this investigation; it has low cost, high-level crystallinity and high mechanical strength. Because of these properties it is applied in different industrial fields [25]. Most researchers use the polyolefin and various chemical substances as coupling agents or compatibilizers for natural fibers mixed with polymers. The influence of the PEGMA as a coupling agent was utilized to study the mechanical behaviour of the composites of polypropylene (PP) and palm fiber, a composite design with adding 2% of coupling agent, 5% of palm fiber and 93wt% of PP was improved in the flexural strength and the modulus, studied by Goulart et al. [28]. Y. Lei et al. [29]examined the increase of tensile strength for composites of recycled HDPE/wood after adding the mixture of Polyethylene-co-methacrylic acid (PEMA), carboxylated polyethylene (CAPE), and titanium-derived mixture (TDM). They studied the coupling agent category effect, the influence of contents on rheology, the crystallization of RHDPE. The fiber content to RHDPE was fixed at 30:70 and the compatibilizers were changed between 0 to 5wt%. The reinforced composite of natural fiber and polymer with the adding of silane as coupling agent was studied by Y. Xie et al.[30]to understand the structure of silane and presented the interaction behaviours in the matrices of polymer and natural fibers. In addition, the silane influence on the mechanical and outside performing was investigated. In another study[31], silane agent improved the tensile strength for the composites which treated with an optimum concentration of
silane coupling agent. P.J. Herrera et al.[31] showed that in the continuous henequen fibers reinforced HDPE composites.

There are different coupling agents of anhydrides like Maleic(MA), Acetic(AA), Succinic(SA) and Phthalic Anhydride (PHA) which can be consist of two functional groups such as carboxylate groups that responsible to make a link with wood fibers by hydrogen bonding or esterification. Although, MA has α, β-unsaturated of carbonyl compound which contains one carbon-carbon double bond (C=C) and two carboxylate groups (-COO-). The conjugated form of carbon-carbon double bond on the heterocyclic ring will rise the reactive grafting with a matrix of polymer among the addition of the conjugate and throughout the radical initiator that was reported by Morrison and Boyd[32]. This will cause cross linking and strong interfacial adhesion. Nevertheless, the matrix of polymer and wood fibers are much longer than that of the MA’s molecular chain. The interface of adhesion is not so improved with the discrete nature of MA [33–35] while it applies a modification on matrices of polymers by using the graft copolymerization. The reinforcement of fibers composites which include fillers are usually strengthened when used the maleate coupling agents [25,36–38].

Furthermore to the variation of maleic anhydride in the surface of fibers, the polymer matrix (PP) can enhanced the mechanical properties and interfacial bonding of composites [39–41]. The PEMA is produced when maleic anhydride become cohesive with PE chain then this copolymer can be used to treat cellulose fibers when it is hot and would present covalent bonds during the interfacing. The copolymer activation is introduced from the response of maleic anhydride with PE and fiber after heated (170 °C) earlier than the fiber remedy then the cellulose fiber will become esterification [42]. Because of this treatment interfacial adhesion and the wet ability of fiber can be better and this is seen from the increase of the surface energy of cellulose fiber to become near the level of the matrix surface energy. Mohanty et al. [42] studied the jute fibers which modified the surface with a MAPP coupling agent then he found that to obtain good results with 6mm average length of 30% loading fibers, 0.5% of the MAPP content in toluene and impregnation time for 5 min should be used. The modified composites had raised flexural strength by 72%. Moreover, the treatment of different fiber-reinforced novolac composites like banana, hemp and sisal by maleic anhydride were reported by Mishra et al. [43] and showed great reduction on water absorption and increased the mechanical properties of these plant fiber-reinforced mixtures.

This work focuses on the effect of three types of compatibilizers (1) Polyethylene-co-methacrylic acid (PEMA), (2) Polyethylene-graft-Maleic anhydride (PEgMA) and (3) Polyethylene-co-methacrylic acid zinc salt (PEMA-Zn) with 1, 2 and 3 wt.% on a composite of HDPE and 10% Date Palm Fiber and the thermo mechanical of the composites were explained with the correlation of the microstructure.
2. MATERIALS AND METHODS

Materials

High-density polyethylene (HDPE) was provided as pellets from Qatar Chemical Company LTD (Q-Chem). The Palm Fibre (PF) has been extracted from the female base of date palm leaves from (Ikhlas tree) shown in figure 1-A, collected from a local farm in Qatar. The interface material was Polyethylene-co-methacrylic acid (PEMA), Polyethylene-graft-Maleic anhydride (PEgMA) and Polyethylene-co-methacrylic acid zinc salt (PEMA-Zn), were supplied by Sigma-Aldrich Co. LLC, Germany. The specifications of the interface and the polymer in this study are reported in Table 1.

![Figure 1: A) Ikhlas tree at Qatar University, B) SEM 100x of Date Palm Fiber](image)

Table 1: Materials Specification.

<table>
<thead>
<tr>
<th>Materials \ Characteristics</th>
<th>PF</th>
<th>HDPE (g/cm³)</th>
<th>PEMA</th>
<th>PE-g-MA</th>
<th>PEMA-Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.423 g/cm³</td>
<td>0.955 g/cm³ (ASTM D 1505)</td>
<td>0.941 g/mL at 25 °C</td>
<td>0.92 g/mL at 25 °C</td>
<td>0.95 g/mL at 25 °C</td>
</tr>
<tr>
<td>Average Aspect Ratio</td>
<td>3.05µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melt Index</td>
<td>0.35 g/10m in (190°C/2.16 kg)</td>
<td>60 g/10 min (190°C/2.16kg)</td>
<td>No data</td>
<td>14.0 g/10 min (190°C/2.16kg)</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------</td>
<td>-----------------------------</td>
<td>---------</td>
<td>-------------------------------</td>
<td></td>
</tr>
<tr>
<td>Compositio n</td>
<td>Methacrylic acid, 15 wt%.</td>
<td>Maleic anhydride, ~0.5 wt%.</td>
<td>Methacrylic acid, 15 wt%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Impact</td>
<td>606 KJ/m²±(ASTM D1822S)</td>
<td>No data</td>
<td>760 KJ/m²± (23°C)(ASTM D1822S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition Temp.</td>
<td>62 °C (ASTM D1525, rate B)</td>
<td>107 °C (at peak DSC)</td>
<td>61 °C (Vicat, ASTM D1525-70)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formula</td>
<td>((\text{C}<em>6\text{H}</em>{10}\text{O}_5)_n)</td>
<td>([\text{C}_2\text{H}_4]_n)</td>
<td>((\text{CH}_2\text{CH}_2)_x [\text{CH}_2\text{C(}\text{CH}_3 \text{)(CO}_2\text{H})]_y)</td>
<td>((\text{CH}_2\text{CH}_2)_m [\text{CH}_2 \text{CH}(\text{C}_4\text{H}_3\text{O}_3)]_n )</td>
<td>((-\text{CH}_2\text{CH}_2-)_x [\text{CH}_2\text{C(}\text{CH}_3 \text{)(CO}_2\text{R})]_y )</td>
</tr>
</tbody>
</table>

**Composite Preparation**

High Density Polyethylene (HDPE) granules and Palm Fibre (PF) were dried in oven at 70°C for 30 minutes before mixing them independently mixed manually with Polyethylene-co-methacrylic acid (PEMA), Polyethylene-graft-Maleic anhydride (PE-g-MA) and Polyethylene-co-methacrylic acid zinc salt (PEMA-Zn) with 1,2, and 3 wt%[44]. The palm fibre was grinded by commercial grinder and the remaining fibres from the shaker with a maximum size of 500µm were extracted, see figure 1-B. These materials were melt-blended by twin extruder (Brabender) with a temperature around from 190°C to 220°C and the feeding was done manually, the screw speed was 50 rpm[45]. After that the extrusion composites were cut by pelletizer. Polyethylene-co-methacrylic acid (PEMA), Polyethylene-graft-Maleic anhydride (PE-g-MA) and Polyethylene-co-methacrylic acid zinc salt (PEMA-Zn) granules were mixed in separate groups with HDPE and PF with different percentages as listed in Table 2. Before processing the mechanical testing all materials were dried up in furnace for two hours at 70°C. A method of the investigational technique is demonstrated in figure 2.
Table 2: Compositions of the processed samples: HDPE / Interface / Palm Fibre.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Composition</th>
<th>HDPE (wt.%)</th>
<th>Interface (wt.%)</th>
<th>PF (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>HDPE</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HDPE/PF</td>
<td>HDPE/PF</td>
<td>90</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>PEMA 1</td>
<td>HDPE/PF/PEMA 1</td>
<td>89</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>PEMA 2</td>
<td>HDPE/PF/PEMA 2</td>
<td>88</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>PEMA 3</td>
<td>HDPE/PF/PEMA 3</td>
<td>87</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>PEGMA 1</td>
<td>HDPE/PF/PEGMA 1</td>
<td>89</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>PEGMA 2</td>
<td>HDPE/PF/PEGMA 2</td>
<td>88</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>PEGMA 3</td>
<td>HDPE/PF/PEGMA 3</td>
<td>87</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>PEMA-Zn 1</td>
<td>HDPE/PF/PEMA-Zn 1</td>
<td>89</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>PEMA-Zn 2</th>
<th>HDPE/PF/PEMA-Zn 2</th>
<th>88</th>
<th>2</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEMA-Zn 3</td>
<td>HDPE/PF/PEMA-Zn 3</td>
<td>87</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

Characterization

**Tensile test Measurements:** Tensile testing was performed using a Lloyd instrument testing machine. This analysis was performed as per the ASTM D638-02 standard[46]. At least ten specimens were used for each measurement of the composition. Tensile properties of the samples were studied at 25± 2°C and a speed of 100 mm/min[47]. A total of 12 samples are tested for their tensile and Modulus properties, tensile tests are executed in accordance to ASTM D638 procedure using 6 specimens per variable[48].

**Morphology:** The composites were examined by a scanning electron microscope (Nova Nano SEM 450) to inspect the surface morphology of fracture surface by liquid nitrogen. All the samples have the same dimensions and coated with a thin sheet of gold. SEM images were taken below conventional secondary electron imaging requirements with an acceleration voltage of 3 kV[49].

**Differential Scanning Calorimeter (DSC) Measurements:** The crystallization and the melting behaviour of the composites were determined using DSC 8500 Perkin Elmer under nitrogen gas environment at a flow ratio of 30 ml/min. The prepared samples were cut into minor sections with 5 – 8 mg[50]. The tests were heated up to 170°C, held for 10 min at 170°C then cooled to 30°C at a rate of 10°C/min. The crystallization temperature (T<sub>c</sub>°C), melting fusion temperature (T<sub>m</sub>°C), and heat of fusion were determined from the second heat scan. The crystallinity of samples (X<sub>c</sub>%) was established utilizing the subsequent expression [51]:

\[
X_c\% = \frac{\Delta H_f \cdot T_m}{\Delta H_f^o \cdot T_m^o} \times 100
\]  

The crystallinity (X<sub>c</sub>%) was assessed from the relationship among the melting fusion enthalpy (ΔH<sub>f</sub> Tm) amount from the second scan of the DSC assessment and the melting enthalpy of the 100% crystalline stage (ΔH<sub>f</sub>°Tm°)of 287.3 J/g [52]as used in (Kong and Hay)[53].

**Thermo gravimetric Analysis (TGA):** The thermal decomposition performance of the mixtures was performed by Perkin Elmer-Pyris Analyzer 6. The specimens with masses of 10 mg were heated from 30 to 550 °C with heating rates10 °C/min in a nitrogen environment with a flow rate of 20 ml/min[54].
3. RESULTS AND DISCUSSION

Mechanical Properties:

The tensile strength of PF-filled HDPE mixtures is demonstrated in figure 3-A, as a function of the filler filling. The tensile strength of the HDPE/PF composites and HDPE does not change, due to the low filler loading of 10%[55]. The Tensile strengths slightly improve with increasing the percentage of PEMA group. There is a 6% improvement in the PEMA 3 sample as compared to HDPE/PF sample which indicates a good stress shift from the matrix to the fibre because of the good adhesion[56]. The tensile strength behaviour of the PEgMA addition is slightly different as a modification is noticed at 1% and 2% of the compatibilizers[57]. A reduction is noticed in the tensile strength with the adding of 3% of PEgMA because of the low interfacial connection and small compatibility among the hydrophilic palm fibre and hydrophobic PE at 3% loading. Different loading of PEMA-Zn did not change the tensile strength, but a modification of NFPC is noticed. The increase in tensile strength may suggest stronger interface bonding amid the matrix and palm fibre, which increased the stress transfer efficiency of the composite as a response or hydrogen bonding, at the interface, among the hydroxyl sets of the palm fibre on one cross and the carboxylic sets of the PEMA diffused matrix polymer on the rival is formed[55]. In general the coupling agent system led to relatively balanced values in all properties, and enhanced mechanical properties of the system and shown positive effects in the modifying the properties of the composite with material [55,58–64]. This behaviour of the coupling agents is clearly seen in the SEM micrographs in Figure 4-C, an increase in the interfacial adhesion and the dispersal of the palm fillers within the polymer matrix[65].
Figure 3: compares between the all composite, A) tensile strength and B) Young’s Modulus.

The Young’s modulus of all experiments is demonstrated in figure 3-B. The Young’s modulus changes are more pronounced than the tensile strength. This may be owing to the variation in the molecular structure and the crystallinity of the matrix as will be seen later in the thermal analysis. The existence of the surface crystallized layer around the fibre has high moduli compared to the amorphous regions [66]. The transcrystalline layers may occur with the addition of PEMA, PEGMA and PEMA-Zn. Young’s modulus for the pure HDPE is 730 MPa and improved slightly for HDPE/PF composite. Date palm filler has a higher modulus when compares to polymer matrix accordingly to their blend produces modulus amount greater than the polymer; this is the advantage of using the palm fibres. The fibre–matrix interface performs an essential role in defining the mechanical properties of complex materials[46]. PEMA coupling system enhanced the Young’s modulus for the addition of 1% however it decreased after that. On the other hand PEGMA group of 1% has the lowest modulus, 2% and 3% addition of the PEGMA improve the Young modulus. The reduction observed in the PEGMA group with high ratio was initiated by the interaction among the PEGMA and the NFPC system, the anhydride of PEGMA maintains loop verifications within the composite system [67]. In the PEMA-Zn composites, the same difference of the tensile strength happened on the tensile modulus, it could happen as it has more prone at the structure than the other group [49-52].

Coupling agents with more polar sets in the backbone cause to favour the creation of ester linkages (chemical bonds) amid the cellulosic hydroxyl series in PF and Maleicsets in the coupling agent, that in order, improves interfacial adhesion Furthermore, the coupling agent in the composite allowed the maleic group in the functionalized polyolefin coupling agent responded with the surface hydroxyl groups of PF, the visible polymer chain of the coupling
agent diffused well into the polyolefin matrix phase and tangled mostly with palm fibre and virgin HDPE chains, that in sequence, caused in improved mechanical properties[2,68].

Morphology Properties:

SEM micrographs of the cryo-fractures samples of HDPE, HDPE/PF and the composites are demonstrated in Figure 4. The fractured surface of the polymer shown in figure 4-A but for the HDPE/PF the surface has many voids as seen in figure 4-B. Which indicate relatively poor bonding between the core martials and had large holes and agglomerate of PF in the matrix. Adding the compatibilizers caused fewer voids when compared with the samples without the compatibilizers as shown in figure 4-C, D, and E for 3% of the all compatibilizers. PEMA 3 composite had less voids compared to PEGMA 3 composite while PEMA-Zn 3 presented a network shape. As a result the interfacial adhesion among the filler and the matrix was enhanced which indicate the transferring of stress with the presence of coupling agent will lead to higher tensile strength [69]. The esterification mechanism can enhance the interfacial bonding among the fibres and polymer matrices [70]. This result confirms that the compatibilizers have a positive effect of interface compatibility and there are small changes in the mechanical properties of the three types[71].
Figure 4: SEM micrograph of A) HDPE, B) HDPE/PF, C) PEMA 3, D) PEGMA 3 and E) PEMA Zn 3

Thermal Properties:

The impact of Palm fiber with PEMA, PEGMA and PEMA-Zn on the thermal properties of HDPE was analysed by DSC thermo grams. The melting temperature ($T_m$ °C), crystallization temperature ($T_c$ °C), enthalpy content (ΔH) and the crystallinity percentage ($X_c$) are summarized in Table 3. The DSC measurements indicate that both the melting and crystallization heights of composites were not affected by the addition of palm fibre and the different percentages of compatibilizer. The $X_m$ and $\Delta H$ of HDPE were raised after the addition of palm fibers which can employ as nucleation agent in the polymer matrix [72]. The nucleation behaviour increases the crystallization degrees because of the trans-crystallization for higher surface of fibers [73]. PEMA and PEGMA caused the $X_m$ to increase by 6% for the 1% of PEGMA. This coupling agent with palm fibres was efficient to increase the rate of polymer crystallization [74]. For the PEMA-Zn, it did not affect the $X_m$ much. This indicates that the PEMA-Zn did not alter the crystallinity and microstructure of the composite. The reduction of crystallinity degree of composites may be explained that fibre's surface for this coupling agent had not the trans crystallinity effect [74]. According to many studies the nucleation impact of the NFPC is properly known, while the influence of the coupling agent system additionally be likely to offer similar result and thus even though the motive for this effect remains uncertain [45].

Table 3: DSC thermo grams for the composites

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>$T_m$(°C)</th>
<th>$T_c$(°C)</th>
<th>$\Delta H_m$(J.g$^{-1}$)</th>
<th>$X_m$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>134.1</td>
<td>119.48</td>
<td>156.54</td>
<td>54.49</td>
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<tr>
<td>HDPE/PF</td>
<td>133.38</td>
<td>119.20</td>
<td>159.47</td>
<td>55.51</td>
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<tr>
<td>Composites</td>
<td>T1</td>
<td>T50</td>
<td>T90</td>
<td>T90%</td>
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<tr>
<td>---------------</td>
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<tr>
<td>PEMA 1</td>
<td>133.41</td>
<td>119.47</td>
<td>164.79</td>
<td>57.36</td>
</tr>
<tr>
<td>PEMA 2</td>
<td>133.54</td>
<td>119.99</td>
<td>168.89</td>
<td>58.78</td>
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<tr>
<td>PEMA 3</td>
<td>133.19</td>
<td>119.70</td>
<td>162.3</td>
<td>56.49</td>
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<td>PEGMA 1</td>
<td>133.32</td>
<td>119.62</td>
<td>169.76</td>
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<td>119.40</td>
<td>164.46</td>
<td>57.25</td>
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<td>119.23</td>
<td>156.62</td>
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<td>119.78</td>
<td>162.64</td>
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<tr>
<td>PEMA-Zn 3</td>
<td>133.31</td>
<td>119.60</td>
<td>156.04</td>
<td>54.31</td>
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</table>

The thermal decomposition TGA temperature for the HDPE and its composites are shown in Table 4, the observation of degradation for compatibilizer and polymer take place at 400 –600°C. The thermal oxidative degradation temperatures related to a mass failure of 10%, 50% and 90% separately, are recorded in Table 4. It can be detected that the composite exhibited a lower thermal-oxidative stability as to T 10%, T 50% and T 90%, than whichever the HDPE pure polymer or the HDPE/PF. By introducing the three coupling agents, the weight loss percentage of the HDPE/PF composites increased slightly due to the existence of (MA) Maleic Anhydride which improved the dispersion degree and the thermal stability [2,58,75,76].

Greatest weight loss percentages [Derivative Thermo Gravimetric-DTG] of the composite between the 470 – 490 °C. The decomposition summarizes of the NFPC were described by 2-3 steps of degradation which is shown by two to three peaks in the thermograms. The degradation ranged began at about 400 °C, the decomposition rate recorded maximum about 490 °C for neat HDPE and the maximum DTG for HDPE/PF was 479.95 °C. The DTG for PEGMA group and PEMA-Zn group was branded by three peaks, the first one was very weak, took place in 130 – 140 °C, it was assigned to the water evaporation [75]. The second peak, which corresponded to the decomposition of the hemicelluloses, cellulose and lignin which is the palm fibre components [76–78]usually happened at 300 to 350 °C. At the third peak, composite degradation happened between 440 and 510 °C with DTG between 470 and 480 °C. For PEMA coupling agent group had two peaks , the first one among the 300 – 350 °C which is the fibre components and the second peak was around 440-500°C expect the PEMA 3 had 3 peaks similar behaviour [45,58].

The thermal stability of composite was described to be contingent on their composition and chemical structure. Different perspectives like the variation of phenomena and/or the
Combination that occur through the composites reprocess must be taken into account to explain the results. Indeed, a partial degradation of HDPE/PF might be obtained or the level of the response among Maleic groupings of the compatibilizer and hydroxyl groups of cellulose will result. This condition will generate an enhanced interface adhesion therefore the explanation of enhancing the mechanical properties and thermal stability of the mixtures after reprocessing would be lead to the polymer process and that phenomenon [79–81].

Table 4: The Temperature of degradation for the composites.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>TGA (°C)</th>
<th>DTG (%/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T 90%</td>
<td>T 50%</td>
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<tr>
<td>HDPE</td>
<td>450.26</td>
<td>478.86</td>
</tr>
<tr>
<td>HDPE/PF</td>
<td>425.97</td>
<td>472.36</td>
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<tr>
<td>PEMA 1</td>
<td>416.07</td>
<td>467.88</td>
</tr>
<tr>
<td>PEMA 2</td>
<td>428.43</td>
<td>472.39</td>
</tr>
<tr>
<td>PEMA 3</td>
<td>434.92</td>
<td>471.61</td>
</tr>
<tr>
<td>PEGMA 1</td>
<td>428.91</td>
<td>471.21</td>
</tr>
<tr>
<td>PEGMA 2</td>
<td>436.51</td>
<td>479.65</td>
</tr>
<tr>
<td>PEGMA 3</td>
<td>425.25</td>
<td>474.95</td>
</tr>
<tr>
<td>PEMA-Zn 1</td>
<td>429.49</td>
<td>475.28</td>
</tr>
<tr>
<td>PEMA-Zn 2</td>
<td>401.88</td>
<td>468.63</td>
</tr>
<tr>
<td>PEMA-Zn 3</td>
<td>410.79</td>
<td>472.1</td>
</tr>
</tbody>
</table>

CONCLUSION

Compatibilizers are extremely effective in enhancing the adhesion of date palm fibers with the matrix of HDPE. This study investigated three different types of compatibilizers (PEMA, PEGMA and PEMAZn) for a matrix of HDPE and 10% DPF. Increase in tensile strength was observed for all samples. The rise in the tensile strength can be recognized to mechanical attaching among the fibre and matrix, to the distribution phenomenon of the polymer on to the fibre and to the aspect ratio of the coupling agent at the composite. Also, the
transcrystallization, characteristic of the semicrystalline thermoplastic matrix composite, was taken into account because it enhanced tensile strength of the mixtures. Young’s modulus was also advanced by the addition of PEMA and PEGMA due to the change in the crystallization layers of the polymer chains next to the fibres which was detected also by the DSC thermograms. PEMAZn did not change Young’s modulus and the crystallinity percentage much. All compatibilizers did not change the melting and crystallization temperature of the polymer matrix. The used compatibilizers improved the interaction amongst the fibre and the polymeric matrix. The morphology of the composites was improved which present superior adhesion among the palm fibre and the polymer matrix.

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