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Influence of amine and vinyl functional groups of silanes on total performance of thermoplastic-based composites

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HIGHLIGHTS

- Silane treated mineral fillers improved the total performance of neat HDPE and WPC.
- The electrostatic forces were responsible for the affinity between filler and matrix.
- Amine functional groups considerably broadened the elongation of HDPE at break.
- The affinity of Vinyl group and HDPE resulted in the agglomeration of mineral fillers.
- No covalent bonding was occurred between organofunctional groups of silane and HDPE.

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ABSTRACT

The influence of amine (polar) and vinyl (nonpolar) functionalized organosilanes were investigated on the total performance of neat high-density polyethylene (HDPE) and wood-HDPE composites. Thus, micro-size silicate-based mineral fillers were treated with 3 mass% amine and vinyl silanes and then 15 and 30 mass% plus 1 and 5 mass% of treated mineral fillers were blended with neat HDPE and wood-HDPE composites, respectively. Based on the achieved mechanical, thermal, rheological, water absorption, and microstructural results, the affinity of amine functional group and HDPE matrix predominantly decreased the rigidity, improved the thermal stability, reduced the water uptake, and facilitated the dispersion of fillers within the polymeric composite. As demonstrated by FTIR test, due to the lack of chemical bonding between the polyethylene and amine/vinyl functional groups, the electrostatic forces can explain the affinity between the filler and matrix. The affinity of the non-polar vinyl group and non-polar HDPE matrix resulted in the agglomeration of mineral fillers that can represent the repulsive electrostatic forces between the vinyl treated filler and the polymeric matrix.

1. Introduction

Polymer-based composites have been extensively used in different industries such as marine and transportation for decades. The use of different composites in building industries is growing rapidly especially in sound dampening and insulation since providing superior properties. Several novel technologies are employed to further improve the polymeric composite performance and applicability in building and construction industries.

The addition of various fillers-fibres (e.g., wood and mineral fillers) into the polymer-based composites (e.g., wood plastic composites) may offer different advantages such as mechanical performance improvement, eco-friendliness, flexibility, low cost, and biodegradation [1,2]. The addition of mineral fillers in polymer-based composites may change the dimension and orientation of polymer chain and broaden the applicability of filled polymer. The higher thermal conductivity of mineral fillers over the neat polymer and wood filler raises the volumetric output of filled molten polymer and screw speed while the drive amperage, head pressure, and the final operational costs may also be decreased [3–5]. However, since being hydrophilic and highly prone to the

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agglomeration due to the high specific surface energy, mineral fillers are not compatible with polymeric materials, hence it is essential to improve the dispersion, adhesion, and affinity of which within the polymeric matrix [6].

Organosilanes containing a polar or a non-polar organic group linked to the silicon molecule can form a covalent bridge between the polymeric matrix and inorganic substrate such as mineral filler (M) [7]. The silane treatment occurs through the sol-gel process when a silane agent firstly hydrolyzes and converts to silanols (SiOH) and then reacts with OH groups of an inorganic substrate *via* hydrogen bonding. Next, the condensation of hydrogen bonds to the siloxanes occurs between the silane molecules and inorganic substrate (Si-O-M) and silane-silane molecules (Si-O-Si) depending on the pH and temperature [8,9]. The copolymerization of organofunctional groups of silanes with polymeric matrix depends on different factors including the polymer's backbone reactivity, the presence of an accelerator or an activator, and the temperature [10–13]. The interdiffusion of polymeric matrix into the layered siloxane network at the surface of silane treated substrate may also occur while constructs a "grid" type structure and causes the electrostatic forces to interpenetrate and become part of the copolymerization system [14,15]. Thus, the polymer chains grow at the surface of an inorganic substrate and a higher density of grafted molecules will be generated [16]. Fig. 1 illustrates a typical interdiffusion structure of the polymer and organosilane.

Between different organosilanes, amine and vinyl-based silanes are well-known due to the high crosslinking ability and flexibility [17]. As a nonpolar organic group, the vinyl organic chain makes the substrate hydrophobic in contrast to the amine as a polar functional group [18]. Therefore, the chemical affinity and the influence of amine and vinyl groups within the non-polar HDPE matrix are different. Typically, a solution containing 0.5 to 5 mass% of organosilanes is sufficient to provide the organic functionality to the inorganic substrate [19].

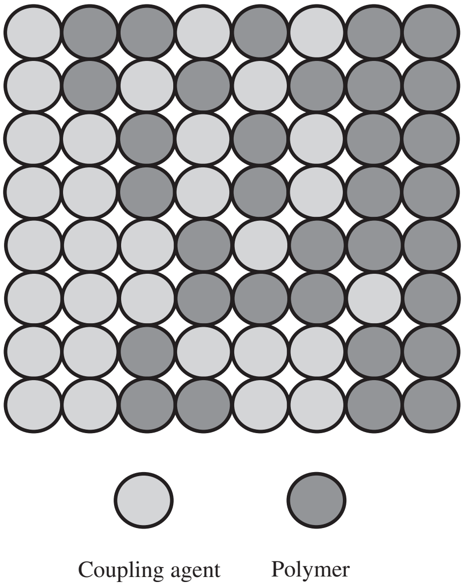

Fig. 1. Interdiffusion mechanism of organosilane and thermoplastic polymer.

Most of the studies in this field focused on the coupling influence of silanes and interfacial properties improvement between an inorganic substrate and polymeric matrix in a controlled condition. The novelty of the present study was to mainly initiate the organofunctional groups to the polymeric matrix and not to necessarily establish a chemical linkage (covalent bonding) between them. Thus, by performing different tests and analyses including mechanical, thermal, rheological, etc., this study compared the influence of amine and vinyl functional groups of silanes on different properties of WPCs and neat HDPE containing silane treated mineral fillers.

2. Materials and methods

2.1. Materials collection and preparation

The average specific gravity and the specific surface area values of the mineral fillers used in this study were 2.4 and 22.97 m^2/g respectively. The main mineralogical compositions of the used mineral fillers include muscovite (~10%), albite (~12%), and quartz (~68%) as determined by XRD analysis while the main granule's size changed from 2 to 200 μm. The preparation of such mineral fillers was discussed elsewhere [9]. Maple wood filler with the physical specifications including cell wall specific gravity 1.5, specific surface area 1.1 m^2/g, and particle size from 200 to 1000 μm was used in this study. Maple wood fillers contain approximately 30% hemicellulose, 42% cellulose, and 22% lignin [20].

High-density polyethylene (HDPE) (DOW DMDA-8907 NT7, Dow Chemical) and maleic anhydride polyethylene (MAPE, Fusabond E226, Dupon) were used as the polymeric matrix and grafting agent respectively. Vinyl-trimethoxy silane (XIAMETER OFS-6300) and amino-ethyl amino-propyl trimethoxy silane (XIAMETER OFS-6020) purchased from Dow Corning and the pertinent characteristics and configurations were given in Table 1 and Fig. 2 respectively. The only difference between the used organosilanes is the organic part. For the treatment, 3 mass% silane agent was used in an organic solvent (toluene) deposition method [21].

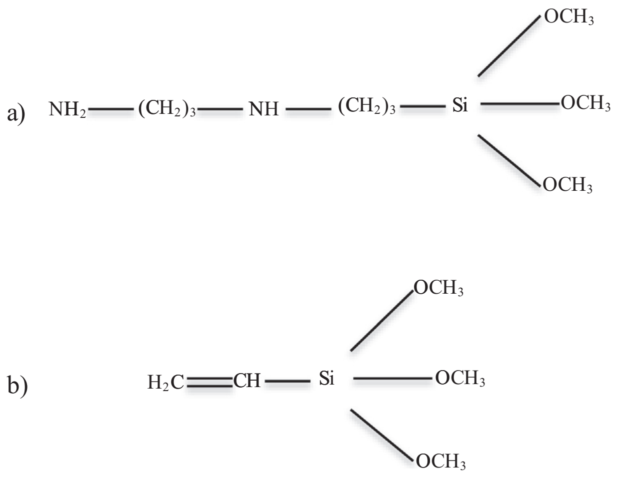

Fig. 2. (a) Amino-ethyl amino-propyl trimethoxy silane (b) vinyl-trimethoxy silane.

Table 1
Characterization of the used silanes.

Silane type	Appearance	Flash point (°C)	Specific gravity	Color	Kinematic viscosity (mm2/S)
Aminosilane	Clear liquid	85	1.03	Light straw	5
Vinylsilane	Clear liquid	125	0.97	Transparent	0.56