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Influence of Maleic-Anhydride-Polypropylene (MAPP) on Wettability of Polypropylene/Wood Flour/Glass Fiber Hybrid Composites

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ABSTRACT

The influence of maleic anhydride-polypropylene (MAPP) (0, 2, 3 and 5%) as a compatibilizer on the wettability of polypropylene/wood flour/glass fiber hybrid composites was studied by using the contact angle determination technique. Sample slats with a cross section of 10×70 mm were made by a twin screw extruder. Specimens were conditioned at room temperature and the angles between the water droplets and surfaces of the hybrid composites were measured. Results revealed that the wettability of the composites was significantly decreased as the MAPP was increased to 3%. However, no significant decreasing effect was observed at MAPP contents above 3%.

Keywords: Contact angle, Polypropylene/Wood flour/Glass fiber hybrid composites, Wettability.

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INTRODUCTION

Wood plastic composites (WPCs) are a new generation of the composites experiencing considerable growth in production and demand in many countries. A wide range of polymers; such as polypropylene, polyethylene, polyesters, etc as well as lignocelluloses; such as wood flour, wood fibers, hemp, linen, etc are used for their production [1, 2].

Lignocellulosic materials are used in the WPCs as natural fillers and reinforcement, in powder or fiber forms. Lower bulk density, compatibility with the environment, recycling potential as well as low costs are the main reasons for the application of the lignocellulosic materials in the WPCs [3]. Hydrophilicity of those materials and incompatibility with the non-polar plastic polymers are the most important problems in the production of the WPCs [4]. There are other groups of the inorganic fillers which are used in the WPCs; e.g., minerals; mica, calcium carbonate, clay, and also synthetic fibers; such as glass fibers, carbon fibers and aramid.

Among synthetic fibers, glass fibers are mostly preferred and used in plastic industries due to economic and mechanical aspects [5]. Glass fibers have higher mechanical strengths than wood or lignocellulosic fibers [6]. However, they are fragile, corrosive and the damage could be irreversible to the environment.

Hybrid composites are a new generation of the composites which are used in different products; such as, flooring, decoration, cabinets, doors and window frames and balustrades. In the hybrid composites, different types of fillers are used in addition to the matrix polymer to benefit their properties at once.

Wettability is the potential capability of a liquid to wet the surface of a solid material and it relates to molecular interactions

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between surfaces of both phases (solid and liquid). Distribution of a liquid on surfaces of the solid materials is an indication of wetting power of the liquid or wettability of the solid. The wettability is determined by contact angle [7]. Orchon (1958) introduced the determination of the contact angle for the first time [8]. It was then used to explain surface tension, wettability, glueability, paintability and laminating properties of the materials [9, 10, 11]. Quality of the wettability in wood and the wood based composites is influenced by different factors; such as surface roughness, surface tension, moisture content, and surface contamination. Technique of contact angle determination has recently been used to indicate compatibility between the wood and the polymer in WPCs [7]. Wood constitutes a major part of WPCs. This part is polar due to polarity of its constituents making it unable to form proper bonds with the polymers, which are not polar. Therefore, compatibilizers are used to make stronger linkages between both polar and non-polar parts. Maleic anhydride polypropylene (MAPP) is a kind of compatibilizers commonly used in WPCs. MAPP has low surface energy and is expected to give good compatibility between the wood and the polymer by formation of stronger linkages in the interfaces and reducing WPCs surface tension. Bonding between the wood and the polymer is quite weaker when a compatibilizer has not been applied [12]. Among different compatibilizers, MAPP is known as a good one and has also been used for hybrid composites made from glass fibers and polypropylene [13].

The current research was planned to study the influence of MAPP on the wettability of the polypropylene/wood flour/glass fibers hybrid composites by determination of the contact angle.

Experimental

Materials

The polypropylene (PP) with a grade of SI-060 and melt flow index (MFI) of 9 g 10 min^{-1} was obtained from Tabriz Pertrochemical Co., Iran, and was used as the matrix polymer.

Maleic anhydride polypropylene (MAPP) (grade G 6070 3×8, Kymya Javid Co.) was applied as the compatibilizer. The MAPP had a melt flow index (MFI) of 100 g 10 min^{-1} and 1.1% of maleic anhydride (MA).

Wood flour was prepared from softwood sawdust (spruce) which was obtained from furniture industries as a waste material.

E-glass chopped strands (with a fiber length of 3 mm, diameter of 10 um and density of 2.54 g cm^{-3}, Diba Fiberglass Co.) were used to prepare sample slats.

Sample preparation

The sawdust was milled with a rotary mill prior to the sample preparation. It was then sieved to pass mesh +60/-40 and was oven dried at 103±2 °C for 24 hours. The oven dried wood flour, polypropylene (PP), MAPP and glass fibers were dry blended according to Table 1 in a typical laboratory mixer (1,500 rpm) for 20 minutes at room temperature to avoid melting of the PP. Afterwards, they were extruded with a twin screw extruder (Borna Pars Mehr WPC-

Table 1. Hybrid composites formulations.

No.	Treatment	Wood flour (%) [a]	Polypropylene (%)	Glass fibers (%)	MAPP (%)
1	MAPP 0%	55	30	15	0
2	MAPP 2%	55	28	15	2
3	MAPP 3%	55	27	15	3
4	MAPP 5%	55	25	15	5

[a] Percentages are based on weight.

4815 with a length to diameter ratio of 5.6) to prepare sample bars with a cross section of 1 cm (thickness)×7 cm (width). Rate of the screw rotation was adjusted as 90 rpm and temperatures of its barrel zones (1-6) were adjusted at 173, 175, 180, 183, 185, 187°C as well as two die zones at 144 and 109°C.

Contact Angle Determination

The bar samples were cut into sizes of 1×7×21 cm. The specimens were conditioned at room temperature (25°C) and 60-70% relative humidity for two weeks prior to the contact angle determination. Afterwards, water droplets (25 um) were dripped by a micropipette on the sample surface, and depletion of the droplets was immediately recorded by a digital camera, which was connected to a computer (Figure 1). Image capturing continued from the beginning of the test until when the droplets disappeared from the surface of the samples. Windows Movie Maker Software was used to record evolution of the droplets in WMA format. Images of the water droplet depletion were then made on the recorded movies in time intervals of 5 s since the beginning of the dripping time until disappearance of the droplets. The contact angle between the water droplet and the sample surface was measured statically by applying goniometry technique [7]. The angle was measured at both sides of the droplets. Image Tools software version 2.00 was used for measuring the contact angle [14]. Five samples were used for each test treatment. The contact angle of two droplets was measured on surface of the sample bars. All tests were carried out at room condition (temperature of 25 °C and a relative humidity of 60-70%).

Water Absorption

Small blocks of 1×2×2 cm were cut from the slats and oven dried at 103±2°C to determine dry weights prior to water soaking test. The blocks were immersed in distilled water at room temperature (25°C) and weighed after 2, 4, 6, 12 and 24 hours of soaking to determine their wet weights. Water absorption was calculated according to Equation (1).

$$(Ww-W0)/W0 * 100 \qquad (1$$

Where: A is water absorption (%) and W_w and W_o indicate wet weight and dry weight of the specimens (g), respectively.

RESULTS

The evolution of contact angle versus time increment is shown in Figure 2. It was revealed that the contact angle of the water droplets reached zero (nil) within 70 minutes in the hybrid composites containing no compatibilizer (MAPP). However, the depletion time was extended due to the

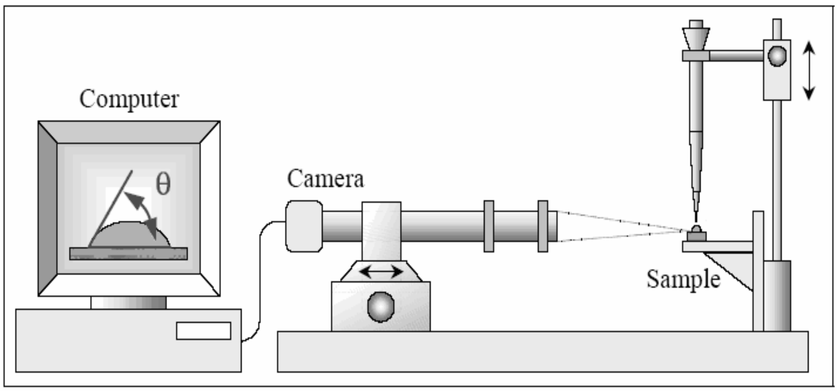

Figure 1. Scheme of contact angle determination device.

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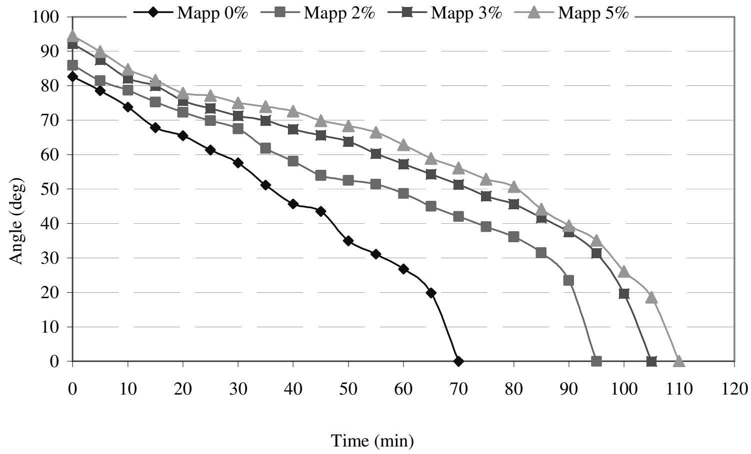

Figure 2. Contact angle depletion in hybrid composites versus time.

addition of the MAPP in the hybrid composites. As it can be seen in Figure 2, increase of the MAPP increased the contact angle at time zero. Also, depletion of the contact angle was slow at the beginning of the evolution and then sped up versus evolution time. At the first step, the angle decreased immediately. Similar results were also observed for rate of the depletion as shown in Figure 3.

According to Figure 3, rate of the depletion fluctuated during the evolution of the water droplets. Small peaks were appeared at the beginning of the evolution for all hybrid composites, however larger peaks were seen to the end of evolution time. Application of the compatibilizer caused a reduction in number and level of the depletion rate fluctuations. It was also revealed that using MAPP retarded the appearance of the higher peaks of depletion.

The contact angle of the water droplets at different evolution times is shown in Figure 4. According to the results, the contact angle was depleted by the evolution time. However, the rate of the depletion was reduced as the compatibilizer content was increased in the hybrid composites. Also, the

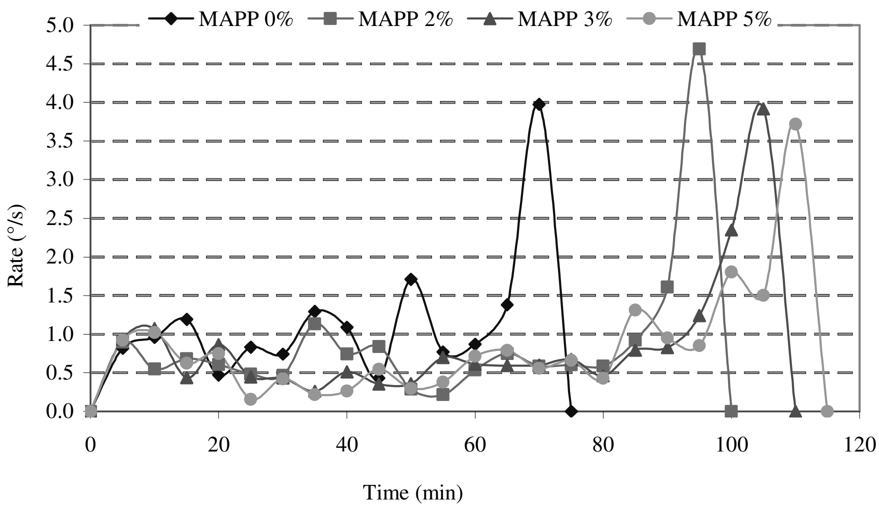

Figure 3. Variation of contact angle depletion rate in hybrid composites versus time.

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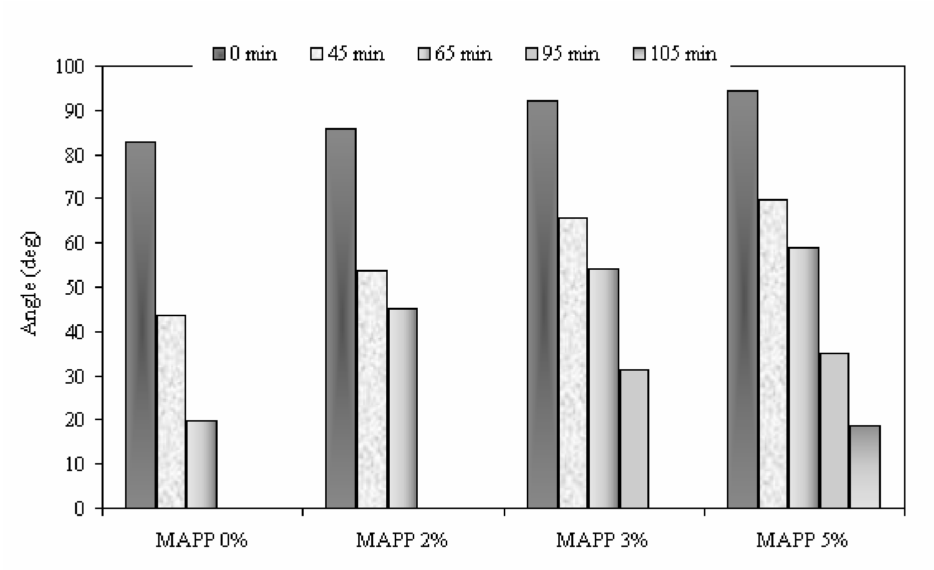


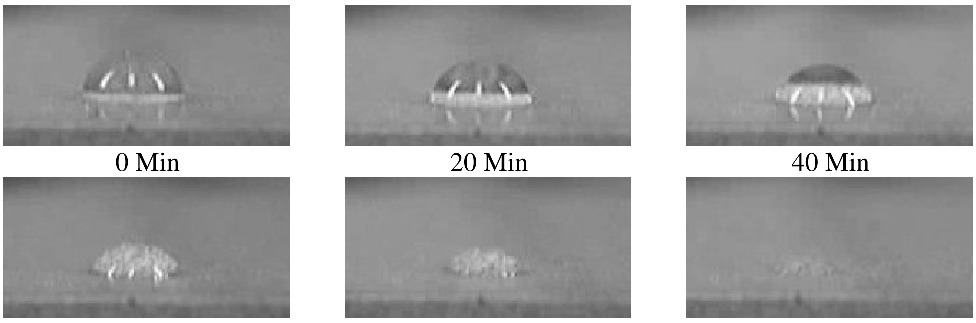
Figure 4. Influence of MAPP on contact angle.

contact angle of the water droplets increased at dripping time (time zero) and later time due to increase of the compatibilizer. As it has been shown in Figure 4, the contact angle still did not reach zero even after 95 minutes of the evolution time in the hybrid composites containing more than 3% MAPP. The evolution of the water droplets on the surface of the hybrid composites is presented in Figure 5. As it can be understood, distribution of the water droplet on the sample surface is an indication of the contact angle changes.

Effect of the MAPP on the water absorption is shown in Figure 6. It was revealed that application of the MAPP causes reduction of the water absorption in the hybrid composites. Increase of the MAPP to more than 3% did not affect the water absorption, significantly. As it is shown in the Figure 5, the water absorption was prominent after 2 hours of the immersion time in all hybrid composites. However, level of the water absorption was lower in composites containing the compatibilizer. Given the results, application of the MAPP increased hydrophobicity of the hybrid composites.

DISCUSSION

Results indicated that increase of the compatibilizer reduced depletion of the contact angle and its rate. The water absorption was also decreased due to the



0 Min 20 Min 40 Min

60 Min 80 Min 100 Min

Figure 5. Depletion of water droplet versus time in hybrid composites.

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addition of MAPP to the polypropylene/wood flour/glass fibers hybrid composites. Contact angle is an indication of the surface tension of the samples. When forces of the surface tension in the sample overcome cohesion forces between the water molecules, the water can be absorbed by those molecules, which are on the sample surface. The result of the absorption is reduction of the contact angle [14] due to distribution of the water droplet on the sample surfaces or its penetration into the sample. When the forces of the surface tension do not overcome the cohesion forces, the water droplet keeps its spherical shape, thereby increasing the contact angle. Therefore, in the former case, the sample behaves as a hydrophilic material and in the latter case it behaves as a hydrophobic material. Application of the MAPP in the WPCs blocks hydrophilic ends in the wood and alters its chemistry to hydrophobic. Increase of the contact angle could therefore be related to the performance of MAPP in WPCs.

According to the results, application of the compatibilizer increased hydrophobicity of the hybrid composites and caused increase of the contact angle. As it has been indicated, the composites initially showed much hydrophobic behavior seen as higher contact angle; however, it was later turned to less hydrophobic due to reduction of the contact angle as the evolution time was extended.

According to the earlier report by Mohebby et al [15], decreased water absorption is related to reduction of the microgaps within the structure of the hybrid composites due to application of the compatibilizer. The current hybrid composite consists of two different hydrophilic and hydrophobic parts. The wood flour constitutes the hydrophilic part whereas the polypropylene as well as the glass fibers form the hydrophobic part in the composites. The wood part plays a major role in the water absorption and the surface tension. Therefore, application of the MAPP decreased the mentioned microgaps in the hybrid composites and it caused the hydrophilic part less accessible for the water molecules due to good encapsulation of the wood flour by the hydrophobic part as well as decreased number of hydroxyl groups in the wood part [15, 17]. The hydroxyl groups are involved in the bonds between the wood and the MAPP. The consequence of the hydroxyl groups blocking is increase of the hydrophobicity of the hybrid composites also seen in decreased water absorption and increased contact angle.

Later increase of the water absorption and also decreased contact angle can be related to the presence of free hydroxyl groups in the composite structure. According to Mittal (2006), the water droplet tends to hydrophilic part in a heterogeneous structure [17] such as the hybrid composites in the current study.

Low level of the fluctuated rates of the contact angle depletion in the hybrid composites can be related to inaccessibility of encapsulated wood flours as well as reduced number of the microgaps in the hybrid composites structure. It could be expressed that reduction of the microgaps due to application of the MAPP decreased penetrability of the hybrid composites. Besides that, reduction of the hydrophobicity retarded depletion of the contact angle in the polypropylene/wood flour/glass fibers hybrid composites.

CONCLUSIONS

Influence of the MAPP compatibilizer on hydrophobicity of the polypropylene/wood flour/glass fibers hybrid composites was studied in this paper by the application of the contact angle determination technique and the following results were drawn:

Incorporation of the MAPP caused increase of the contact angle of the water droplet on the hybrid composite surface. It also retarded the contact angle depletion rate.

Increase of the MAPP up to 3% significantly decreased water absorption in

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the hybrid composites. However, increase of the compatibilizer to more than 3% did not significantly decrease water absorption.

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اثر مالئیک انیدرید-پلی‌پروپیلن (MAPP) بر ترشوندگی چندسازه هیبریدی پلی‌پروپیلن/آرد چوب/الیاف شیشه

ب. محبی، پ. فلاح مقدم، ع. ر. قطبی‌فر، س. کاظمی نجفی

چکیده

اثر مالئیک انیدرید-پلی‌پروپیلن (MAPP) (۰، ۲، ۳ و ۵٪) به عنوان سازگارکننده بر ترشوندگی چندسازه هیبریدی پلی‌پروپیلن/آرد چوب/الیاف شیشه به روش اندازه گیری زاویه تماس مورد بررسی قرار گرفت. نمونه‌ها با استفاده از اکسترودر دو ماردونه با مقطع عرضی 10×70 میلی‌متر ساخته شدند. نمونه‌ها در شرایط معمولی متعادل سازی شدند و زاویه تماس بین قطره‌های آب و سطح چندسازه هیبریدی اندازه گیری شد. نتایج نشان دادند که ترشوندگی چندسازه‌ها با افزایش مقدار MAPP تا ۳٪ به طور معنی‌داری کاهش می‌یابد. با این وجود، افزایش مقدارMAPP به بیش از ۳٪ اثری بر زاویه تماس نداشت.

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