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Study on the Effect of HGM on the Performance of PP/IFR/GF Composite Packaging Materials Used in e-Commerce Logistics

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The Hollow Glass Microspheres (HGM) appears in the PP/IFR/GF compound package materials for e-commerce logistics at different doses. How the HGM will change the flame retardance and mechanical properties of these materials, it is the keystone of this study. PP/IFR/GF/HGM as flame-retardant & reinforced package composites for e-commerce logistics are made from substrates Glass Fibre (GF), reinforced nitrogen-phosphorus compound (IFR), flame-retardant polypropylene (PP) composite package material added with a modified HGMs using the Melt-blending. Here is a profound analysis on their behaviors, e.g. combustion, bending, impact, tension strengthens and hardness. The results reveal that a certain amount of HGM additive can somewhat improve the flame retardant and mechanical properties of the composite package materials for e-commerce logistics. As HGM additive increases, the mechanical properties of these package materials get evidently poor. When the dosage of HGM is 10, their mechanical properties are optimal.

1. Introduction

As a commonly used general-purpose plastics, the PP features low price, easy to process, wide source, and excellent properties. Owing to these advantages, it has been widely applied in current e-commerce logistics for packaging containers, but there are some gaps such as lack of strength, flammability, and serious drippage during the combustion process, etc., which have limited its scope of services. Therefore, reinforcement and flame retardance are no doubt the hotspots in the field of PP composite materials (Bledzki et al., 2012; Monteiro et al., 2009; Idicula et al., 2010; Xu et al., 2013). by far, for the flame-retardant of PP, people often use the additive to achieve, but a mass of flame retardant will exacerbate mechanical properties of PP. GF is an inorganic non-metallic material with excellent properties such as low price, good insulation, strongly heat resistance, corrosion resistance, high mechanical strength. Modified GF have a good bond with the resin interface. Filled into the resin, it can improve the mechanical properties of composite package materials. However unfortunately, excessive GFs may cause part of them to be unimpregnated fully, which further worsens the interface bonding between the polymer substrate and the glass fiber, resulting in a poor strength of the composite package material. Beyond that, more GFs will reduce the flow properties of the composite package material (Jiang et al., 2015). The HGMs feature the large volume, low thermal conductivity, high compression strength, and good auto flowability. Due to the isotropy and high filling volume, it allows the material to have a highly dimensional stability. A proper amount of filler can not only improve the flame retardance, but also significantly boost the mechanical strength and the surface hardness of it. Thanks to its ball effect, its flow property is also improved.
On this basis, this paper intends to use the HGM modified PP/GF package composites for e-commerce logistics as study case to investigate how the HGMs impact the flame retardance and mechanical properties of PP/GF composite package material. It is hoped that modified PP will be used as reference to provide the clues to application of this package container material in the field of logistics.

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2. Experiment

2.1 Raw materials

PP: K8003, Dushanzi Petrochemical Co., Ltd;
GF: particle size 20nm, Gracia (Chengdu) Chemical Technology Co., Ltd.;
HGM: effective density 0.15-0.60g/cc, average particle size between 30-80um, Maanshan Mine Institute for New Material Technology Co., Ltd, the Sinosteel Corporation;
Silane coupling agent: KH-550, Nanjing Da Ning Chemical Co., Ltd;
Nitrogen and phosphorus compound flame retardant: FR-101, Qingdao Lianmei Chemical Co., Ltd;
Maleic anhydride grafted polypropylene: KH PP-GMAH 01, HKH National Engineering Research Center of Plastics Co., Ltd;

2.2 Major equipment and instruments

Pendulum Impact Tester: ZBC7501-B, MTS Systems (China) Corporation;
Horizontal and vertical burner: Model CZF-3F, Nanjing Jiangning Analytical Instrument Factory;
Precision open mill: ZG-120, Dongguan Zhenggong Precision Testing Instrument Factory;
High-speed mixer: SHR-10A, Zhangjiagang Spark Degradation Equipment Factory;
Oxygen Index Tester: Model JF-3, Nanjing Jiangning Analytical Instrument Factory;
Box-type resistance furnace: SX2-2.5-10, Shangyu City, Zhejiang Province, Hu Nan Electric Oven Factory;
Shaw Brothers Rubber-plastic durometer: LX-D type, Laizhou Lean Test Instrument Co., Ltd.
Plastic pulverizer: SWP/l60, Qingdao Jiaozhou Hongda Plastic Auxiliary Machinery Plant;
Flat vulcanizer: TP1400, Shanghai Wodi Technology Co., Ltd.;
Electronic universal tester: CMT-4304, MTS Systems (China) Corporation;
Universal sampling machine: ZHY-W, Hebei Chengde Experimental Machine Plant;

2.3 Preparation of samples

Take 20ml silane coupling agent KH550, dissolve it in 980ml ethanol, make up a KH550/ethanol solution with a volume concentration of 2%, and weigh 200g GF, soak it in 2% KH550/ethanol solution for 12 h, after draining off it, dry it in an oven at 80°C, a modified GF is then prepared. According to the composition of the composite package materials listed in the Table 1, PP, modified GF, nitrogen-phosphorus compound flame retardant and maleic anhydride grafted polypropylene are added to a high-speed mixer to mix them until dual rollers of precision open mill reaches 170ºC. This mixture is then added to an open mill to be melted and mixed. After 3 minutes, the HGM is added. Slices are obtained after they are uniformly mixed. Crush the resultant slices in a plastic pulverizer in powder material, then press it with a flat vulcanizer at 175°C into a plate of 200 mm × 200 mm × 3 mm (hot pressing conditions: 14 minutes preheating and melting, 12 minutes hot-pressing, 12 minutes cold-pressing and 10 MPa pressure). Next, the plate is cut into strips in a specified size with a universal sampling machine for flame-retardance and mechanical property tests (Zhang and Wei, 2016).

Table 1: Composition of composite package materials for e-commerce logistics

number	PP/PP-g-MAH/GF/IFR (g)	HGM (g)
1#	75/15/25/25	0
2#	75/15/25/25	10
3#	75/15/25/25	15
4#	75/15/25/25	20
5#	75/15/25/25	25

2.4 Test and characterization

The PP composite package material plate available by pressing with a flat vulcanizer is cut into sample strips of predetermined size. In accordance with GB/T 2408-2008 and GB/T2406.2-2009, these sample strips are tested for level and vertical combustion properties with an appropriate burner, respectively, and determined for oxygen index with the Oxygen Index Tester (Liu et al., 2013). The hardness of composite package material should be measured as per GB/T 531 GB/T 1043-1993, its impact strength as per GB/T 1043-1993, tensile strength as per GB/T 1040-1992, and bending strength as per GB/T9341-1988

3. Results and discussion

3.1 Combustion behavior of composite package materials

Table 2 Horizontal and vertical combustion behaviors of PP/IFR/GF/HGM composite package materials for e-commerce logistics

Table2: Horizontal and vertical burning properties of PP/IFR/GF/HGM composites for e-commerce logistics

Number	Dripping	Self-extinguishing	Horizontal combustion	Vertical combustion
1#	Dripping	Self-extinguishing	FH-2	FV-1
2#	nothing	Self-extinguishing	FH-1	FV-0
3#	nothing	Self-extinguishing	FH-1	FV-0
4#	nothing	Self-extinguishing	FH-1	FV-0
5#	nothing	Self-extinguishing	FH-1	FV-0

As shown in Table 2, the horizontal and vertical burning behaviors of PP/IFR/GF/HGM composite package materials are given. The flame retardance of 1# material is lower than that of 2#, 3#, 4#, and 5#. When comparing components of their compositions, it is found that HGM added to the substrate of 1# composite package material make its flame retardance significantly improved. It is suggested that this additive obviously improves the flame retardance property of the composite package materials.

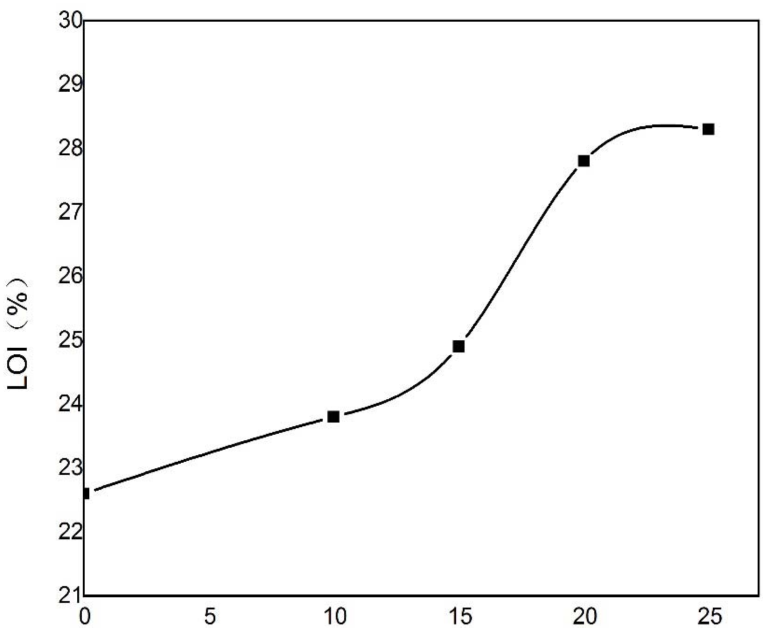

Figure 1: Effect of HMGs at different doses on the limit oxygen index of composite package materials for e-commerce logistics

As shown in Figure 1, there is a curve of the limit oxygen index of composite package materials as a function of dosage of HGM. As can be seen, with the increase in the dosage of HGM, the limit oxygen index of the composite package material multiplies. When the additive HGM is less than 15 grams, the limit oxygen index of the composite package material builds up slowly, when the additive reaches 20 grams, the limit oxygen index significantly increases. As the HGM is added continuously, the limit oxygen index tends to be smooth. When no HGM is added, the nitrogen-phosphorus compound flame retardant during the combustion process will expand on the surface of PP to form a dense carbon layer which insulates heat and traps air for flame retardance.

In other words, this carbon layer features flame retardance, heat insulation, oxygen isolation, and safeguards against the formation of droplets, so as to achieve the effect of flame retardance; when adding the HGMs, the combustion will attach the HGMs on the surface of the carbon layer, increase the stress of the carbon layer

skeleton; thanks to the insulation property of HGM, both the heat transfer and the decomposition of internal polymers can be reduced to exert a role of the flame retardance.
As the HGM additive increases, it will be enriched on the surface during the combustion to further achieve the goal of heat insulation, oxygen barrier, thus improving the flame retardance of composite package materials (Feng et al., 2009; Li et al., 2013).

3.2 Effect of different dosage of HGMs on the mechanical properties of composite package materials for e-commerce logistics

3.2.1 Effect of different dosage of HGMs on the flexual strength of composite package materials for e-commerce logistics

Effect of different dosage of HGMs on the flexual strength of composite package materials for e-commerce logistics is shown in Figure 2. As we learn, with the increase in the dosage of HGMs, the flexural strength of the composite package material gains first and then lets up. When the HGM additive reaches 10 parts, the flexural strength of it hits upon a maximum value, as compared to that of PP/GF, it is increased by 31.3%, then gradually decreased with the increase of the additive. When it is added by more than 20 parts, the flexural strength swoops (Cai et al., 2010; Shang et al., 2011; Cockburn et al., 2012).

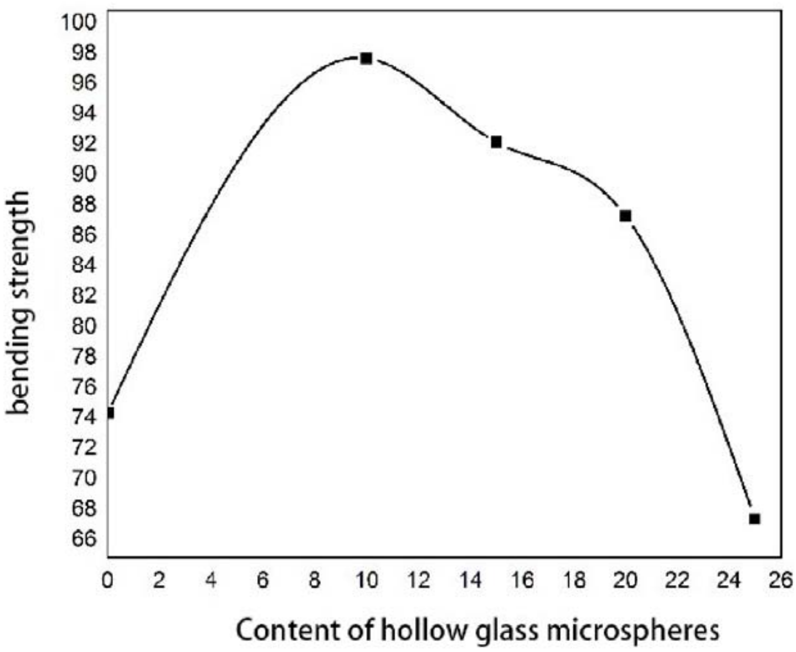

Figure 2: Flexual strength of composite package materials for e-commerce logistics at different dosage of HGMs

3.2.2 Effect of different dosage of HGMs on the impact strength of composite package materials for e-commerce logistics

The effect of different dosage of HGMs on the impact strength of composite package materials. As shown in Figure 3, as the dosage of HGM increases, the non-notch impact strength of the composite package material gets strong first and then weak. When the additive dosage is greater than 10 grams, its non-notch impact strength fall badly; while it is greater than 15 grams, the downward trend tends to be smooth. When the dosage of HGM is 10g, the impact strength value is 24.04KJ/m2, 7.6% higher than that of PP/GF composite package materials. It is mainly because of the fact that there is a good compatibility between modified HGM and PP materials. When subjected to impact force, the HGMs deform and are broken up to absorb certain energy and further improve the impact strength of the PP composite package material (Picouet et al., 2014).

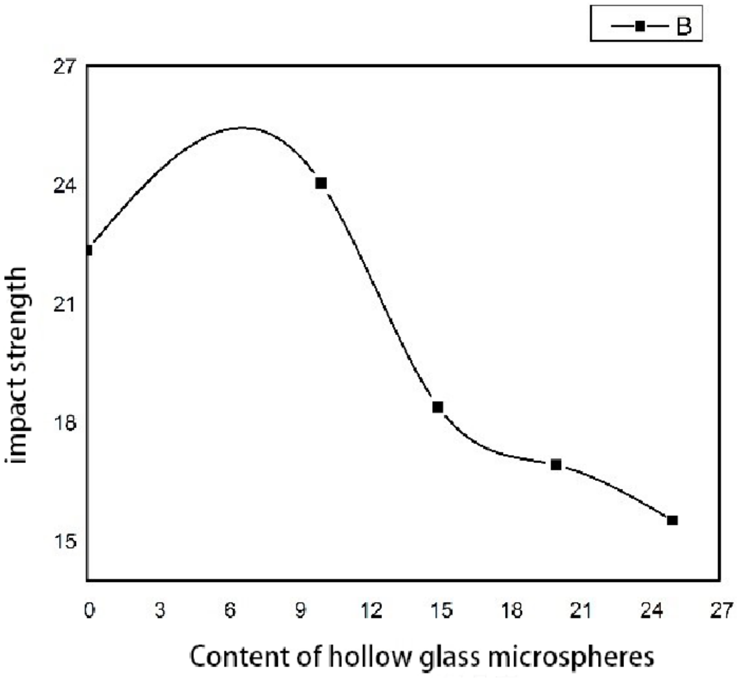

Figure 3: Impact strength of composite package material at different dosage of HGMs

3.2.3 Effect of different dosage of HGMs on the hardness of composite package materials for e-commerce logistics

The effect of different dosage of HGMs on the hardness of composite package materials is shown in Figure 4. It is obvious that, as the dosage of HGMs increases, the hardness of the composite package material gets stronger. When the additive dosage is 10 grams, the hardness reaches a maximum value of 68.5 HD, higher than that of PP/GF, and is increased by 14.2%. Then as the additive dosage continues to increase, its hardness tends to decrease. It is mainly due to the fact that the isotropy and high filling volume of HGMs improve the stability of composite package materials. With the appropriate filler ratio, the surface hardness of composite package materials can be significantly improved; on the other hand, the HGMs are also act as a nucleation catalyst to boost the crystallinity and hardness of the composite package material (Lu et al., 2010).

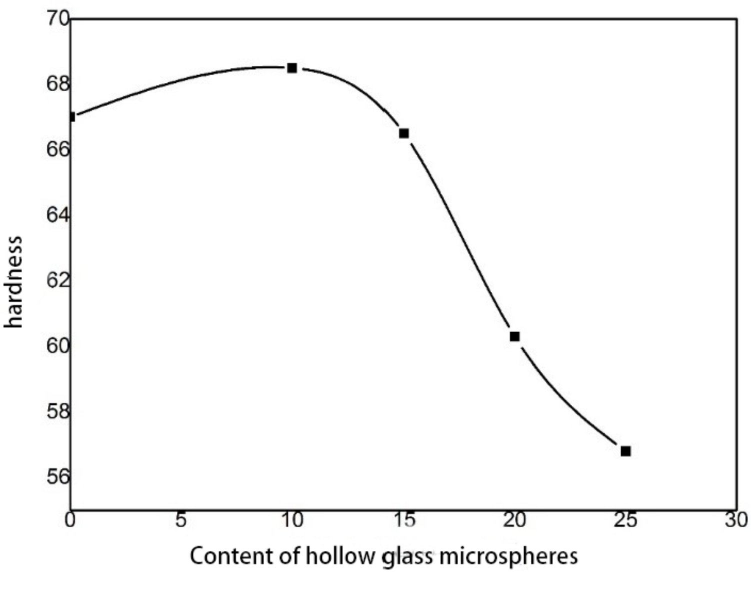

Figure 4: Hardness of composite package material for e-commerce logistics at different dosage of HGMs

4. Conclusions

(1) HGN, as a tiny sphere with a larger curveture, can increase the fluidity, and reduce the interstress of the composite package materials. thanks to its isotropic and high filling feature, the moderate dose of HGMs are added based on the GF and reinforced PP can further improve the mechanical properties of composite package materials such as tensile strength, flexural strength, and hardness, etc.
(2) As a halogen-free material, the HGMs feature flame-retardance and heat-insulation. The combustion of HGMs added in the composite package materials makes it enrich on the surface of the carbon layer to insulate heat and cut off oxygen, while increasing the support strength of skeleton on the carbon layer, playing flame retardant effect, and contributing more to green and environmental friendliness.
(3) The density of HGMs is only a fraction of that of the resin, so that it not only maintains the composite package material light as it is but also significantly reduces the cost.

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