Mechanical Properties Effect of Wood-plastic Composite by Basalt Fiber and MAPE

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Abstract. In order to protect biological resources, this article explores the use of tensile and bending tests and Thermogravimetry (TG), thermal differential scanning (DSC) and other experimental studies. The compatibilizer maleic anhydride grafted high-density polyethylene (MAPE) improves the mechanical properties of chopped basalt fiber (SBF, 20% by mass) and reinforces wood-plastic composites (WPC). The results show that: 1) WPC with a length of 6mm SBF, when the MAPE content is 5~6%, its tensile breaking strength and bending strength achieve the best results, of which the breaking strength is increased by about 90% compared with pure wood plastic; (2) Since the tensile and bending strength of MAPE itself is roughly similar to HDPE, when the content of MAPE is greater than 9%, it acts as a matrix HDPE. In addition to the plasticity continues to be improved, its strength index is gradually decreasing. 3) When the MAPE content is 6%, the TG curve has the slowest thermal weight loss and the DSC has the highest melting peak temperature, which means that the composite material is difficult to melt, and the bonding between the components in the material is firm, thereby having better mechanics. The performance also confirmed the results of mechanical testing.

1. Introduction

In recent years, with the increasing awareness of environmental protection and the declining of ecological resources such as forests, the research and development of ecological materials has become a hot topic. Wood plastic composites (Wood Plastic Composites, WPC for short) are made from plant fibers such as wood fibers and thermoplastics are prepared by extrusion, injection molding, molding and other molding methods. It inherits the original processing performance, texture and color of wood, and can be widely used in furniture, flooring, pallets, and automobiles [1-2]; it can use waste plastics and waste wood as raw materials, thereby directly achieving the conversion of "turning waste into treasure" process [3]. However, WPC also has shortcomings: compared with solid wood, it has high energy consumption, high production cost, high density and low strength. It is still difficult to apply to industries with high performance requirements such as structural materials [4]. On the other hand, Basalt Fiber (BF) is known as "the pollution-free green industrial material in the 21st century". It is a new type of fiber made of natural basalt ore after being melted at high temperature and drawn by platinum storage alloy. The raw material for BF has wide source, low cost, and excellent properties such as high temperature resistance, corrosion resistance, heat insulation, sound absorption and low moisture absorption with high cost performance [5], which has been widely used in many fields such as traffic pavement and building reinforcement.

In order to overcome the shortcomings of the above-mentioned wood-plastic, people have done a lot of research in terms of material formulation, glass fiber reinforcement, modification treatment, processing technology [6-9] and have achieved some gratifying results. As a compensation test, we
have directly added WPC with 3mm and 12mm chopped BF to commercial WPC, and found that it can improve the tensile and bending strength [10], but the improvement is related to the length of the chopped fiber, and the elongation at break has not been improved. And then refer to the addition of compatibilizers to significantly improve the bonding between the wood plastic and glass fiber interface. BF and MAPE with a short cut length of 6mm were used to study the compatibilization modification of WPC, and made a very good preparation from the sample. An important improvement, changing the sample preparation method described above after cooling for 12h before crushing, because such a sample preparation method may cause a certain degree of damage to the fiber. The experimental results show that when the MAPE content is 5-8%, the tensile and bending stress are optimized. Therefore, on the basis of the above results, this paper focuses on the mechanism of compatibilization modification from the aspects of thermal weightlessness and DSC of the sample, and provides a new BF-WPC environmentally friendly green material that can replace wood, petroleum and steel, to provide a new way to protect ecological resources.

2. Experimental

2.1. Experimental design and experimental materials

2.1.1. Experimental design. According to the 3mm, 12mm short-cut BF experiment, BF-WPC has good bending and tensile strength when the content of BF is 18%-30%, and for the purpose of investigation, the effect of different chopped fiber lengths on the mechanical properties of BF-WPC is determined by experiments. The chopped length of BF is 6 mm. On the basis of the previous experiment, BF: WPC = 1: 4 (weight ratio) is selected as the basic parameter. Then add MAPE according to the weight percentage of 0%, 3%, 6%, abbreviated as 0%, pure wood-plastic as the comparison sample number (numbered "0-0%") (Table.1), therefore, a total of 6 groups of experiments were designed.

| WP+BF (mass /%) | MAPE (mass /%) | BF/(WP+BF) (mass /%) | Codes |
|-----------------|---------------|----------------------|-------|
| 100             | 0             | 0                    | 0-0   |
| 100             | 0             | 20                   | 20-0  |
| 97              | 3             | 20                   | 20-3  |
| 94              | 6             | 20                   | 20-6  |
| 91              | 9             | 20                   | 20-9  |
| 88              | 12            | 20                   | 20-12 |

2.1.2. Experimental materials. Wood plastic pellets (teak powder: HDPE = 7:3, Shanghai Xinjixin Co., Ltd.); BF (Zhejiang Shijin Basalt Fiber Co., Ltd., short cut length 6 mm, diameter 17m); MAPE (KT-12, Shenyang Ketong Plastic Technology Co., Ltd.).

2.2. Preparation of samples, performance testing and equipment

2.2.1. Preparation of samples. A two-roll mill (SK160-B, Shanghai No. 1 Rubber Machinery Factory) was used to plasticize and mix each sample number. The temperature of the front and rear rollers was 160°C and 170°C, opened for 10min. The difference from the previous article is that after taking samples out, the square cavity mold is used, and the flat vulcanizing machine (XLB-400 D high-temperature flat vulcanizing machine, Shanghai First Rubber Machinery Factory XLB-25 D flat vulcanizing machine, Shanghai No.1 rubber machinery factory) is hot pressed into a flat plate (the previous method [10] is cooling for more than 12 hours, and then crushing the material), molding
temperature 180 °C, preheating 5 minutes, holding pressure 10 min, pressure 8 MPa, the mold is cold pressed for 15 minutes, then the mold is taken out, and a square plate with a thickness of 4 mm is obtained after remolding at room temperature. The plate materials are in accordance with GB/T 1040.2-2006 / ISO527-2: 1993 and GB/T 1449-2005. After cutting and ironing with a peripheral milling cutter, dumbbell-shaped tensile specimens and strip-shaped bending specimens were prepared.

2.2.2. Test of chemistry performance. The above-mentioned dumbbell-shaped tensile specimens and strip-shaped bending specimens were tested for tensile and bending properties on an electronic universal testing machine (REGER-200A, Shenzhen Ruige Instrument Manufacturing Co., Ltd.). The sample sizes are all 5, but considering the importance of the comparison sample number data, the two sets of comparison sample numbers with MAPE 0% are repeated once, so the sample size of 0-0 is 10.

2.2.3. TG and DSC Curves. Thermogravimetry and Differential Scanning Calorimetry (DSC) curves of the printing paper were obtained using a NETZSCHSPA499F3 instrument under a nitrogen atmosphere (20 ml/min) and the heating rates were 5°C/min.

3. Results and discussion

3.1. Mechanical properties of BF-WPC

Fig. 1 is the measured mechanical properties of each sample number. Because the abscissa "0-0" is a pure wood-plastic comparison sample without BF, and the abscissa "3" to "12" samples each contains BF and MAPE. Therefore, with the sample number of the abscissa "0" as the boundary, the sample numbers on the left and right sides need to be treated separately. There are only two points on the left side connected by a dotted line to form a straight line, and the five points on the right side are the regression curve (solid line) of ORIGN. Table 2 shows the compatibilization modification effect at the maximum value of the regression curve.

![Figure 1: Relationship between mechanical properties of WPC and the mass fraction of BF and/or MAPE](image)

Table 2. WPC compatibilization modification with 20% BF and added value not compared with pure wood-plastic (%).

|                | Highest value after adding | Without MAPE / pure wood-plastic | Highest Value after adding MAPE in previous article [10] |
|----------------|----------------------------|----------------------------------|--------------------------------------------------------|
| Tensile Strength | 96                        | 15                               | 43                                                     |
| Elongation      | 54                        | -18                              | 7                                                      |
| Bending strength| 86                        | 6                                | 33                                                     |

Table 2. WPC compatibilization modification with 20% BF and added value not compared with pure wood-plastic (%).
In Fig.1, The dotted line shows that after adding 20% chopped BF to pure wood-plastic, its tensile strength and bending strength have been improved to a certain extent (about 10%), but the elongation at break has dropped by 18%. After adding MAPE, the mechanical properties of BF-WPC vary with the content of MAPE. In general, the elongation at break has been increasing with the increase of MAPE content, and the tensile and bending strength peaked around 6%, and then decreased with the increase of MAPE content.

From the numerical comparison of the value of the above table, we can see that after improving the preparation process of the experimental samples, under the same remaining experimental conditions, the data obtained in this experiment is much better than the previous data, the strength and plasticity indicators are on the original basis increased by nearly 50 percentage points. Therefore, it can be considered that the sample mentioned in this article is prepared by the milling method, and the high-speed rotating peripheral milling cutter is used for milling, which can obtain better surface roughness, greatly reduce the initial cracks on the sample surface, and ensure the sample to the greatest extent. It is not damaged in the preparation process, which is the fundamental reason why the experiment in this paper is superior to the previous experiment in both strength and plasticity.

3.2. TG and DSC curves
In Fig.2(a), the two curves with the fastest weightlessness can be seen. It shows the lines are the two sample numbers without solubilizers, 0-0 and 20-0, respectively, and the slowest weight loss is the two sample numbers containing 3% and 6% of MAPE, namely 20-3 and 20-6, while 12% of the samples are bounded by a temperature of 300°C. The weight loss was slower before, and then accelerated. After 400°C, it began to approach the sample with the fastest weight loss; In Fig.2(b), It can be seen that each curve can be divided into two groups according to the temperature of the melting peak. The high temperature group only has two sample numbers with a MAPE content of 3% and 6%, and the rest are low temperature groups.

![Figure 2. TG and DSC Curves for WCPS](image)

3.3. Strengthening mechanism of BF and MAPE
This article discusses WPC after adding BF and MAPE compatibilization. For comparison, this article takes pure wood plastic (0-0) and wood plastic (20-0) without BF addition as a reference. Lignocellulose is a naturally growing plant, contains a large number of hydroxyl groups, and has strong hydrophilicity. BF is an inorganic material formed by the melting of rock and has a surface affection. The resin HDPE is also a hydrophobic polymer material. If there is no additive such as MAPE, there is a lack of chemical bonding between the above three groups. The interface is mainly through physical van der Waals force adsorption, mechanical friction and other effects for force transmission, and due to the existence of inter-group activity and emotion (Hydrophilic and hydrophobic) are mutually exclusive, so the interface is relatively weak. The experiment in this paper also confirmed this. From the comparison between the sample numbers 20-0 and 0-0 in Fig.1 and the second column of data in Table 2, it can be seen that the strength index of the BF-reinforced WPC
material without the addition of MAPE. The increase is relatively limited, but the plasticity index has dropped by 18%, and the reduction is equivalent to the amount of BF added.

At the same time, it also shows that the original additives in WPC did not play a much compatibilizing role between BF and WPC. This is also confirmed from the SEM image of 261 above. When MAPE is not added, the surface of BF fiber is relatively smooth, and it is easy to distinguish it from wood plastic under the action of external force, so its tensile performance is improved by a small amount, which is only 15% higher than that of pure wood plastic. The addition weakens the connection of the wood-plastic matrix itself, so it shows a reduction in its plasticity.

After adding 3% MAPE, the plasticity of BF is enhanced and WPC immediately returned to the original wood-plastic level after compatibilization. This is because after the addition of the compatibilizer MAPE, its anhydride group reacts with the alcohol hydroxyl group in the wood fiber to reduce the polarity and hydrophilicity of the fiber, which further enhances the compatibility between the wood fiber and HDPE. At the same time, it also increases the compatibility of the inert BF with the surface and presents the "soft and dense" fracture state as described above (see Fig. 3), thereby enhancing the bonding strength between the wood-plastic and BF.

The experiment in this paper shows that adding about 5% of MAPE, the strength and plastic properties show the optimal values, which are improved by 96% and 54%, respectively. As the MAPE compatibilizer continued to increase, the strength began to decrease (Fig. 1a-c, return to solid line and Table 1), mainly because the excess compatibilizer acted as the matrix HDPE and the plasticity continued to increase.

These phenomena and the differences in their mechanical properties can also be found in Fig.2. The thermophysical characteristics are well confirmed: as mentioned above, MAPE can indeed improve the thermal stability of the composite material. When the MAPE content is 3% and 6%, it is not only the slowest thermal weight loss on the TG curve. Moreover, the melting peak on the DSC is about 5°C higher than other samples, and the sample has the slowest thermal weight loss, and the melting peak temperature is high, indicating that the composite material is difficult to melt, which means that the bonding between the components in the material is stronger. Therefore, the maximum value of each mechanical performance index appears in the range of 3-6% MAPE content. Excessive MAPE will reduce the thermal stability of the composite. One explanation for this fact is that the composite material exhibits more interfacial interactions due to the reaction between the acid group of the maleic anhydride group and the hydrophilic group on the fiber surface. This larger interaction promotes more interaction between the degradation processes of the two components, i.e., the degradation of one component may accelerate the degradation of the other component. Another explanation may be due to the presence of peroxide residues used to graft maleic anhydride onto polyethylene.

![Figure 3](image)

**Figure 3.** Conceptual diagram of BF and wood-plastic interface layer before and after MAPE modification [11]
In summary, adding BF and MAPE, can effectively improve the mechanical properties of BF-WPC: Compared with pure wood-plastic, the maximum increase in tensile strength and bending strength is 80–92%. In the meantime, the increase in plasticity (expressed by the elongation at break) is also around 50% (see Table 2), thereby overcoming the shortcomings of the wood-plastics listed in the preface and broadening the application field of WPC.

4. Conclusions
This article discusses the mechanical properties of WPC after the addition of BF and MAPE from the aspects of the interface microstructure of the material, the physicochemical interaction between the components, and the thermophysical properties, and draws the following conclusions:
(1) Wood-plastic composites with a chopped length of 6 mm and 20% by weight of SBF when compared with pure wood-plastic materials, strength performance indicators such as tensile strength and bending strength increased slightly, but plasticity (elongation at break) decreased 18%;
(2) Since the tensile strength of MAPE itself is roughly similar to HDPE, when the content of MAPE is greater than 9%, the excess compatibilizer acts as the matrix HDPE. Except that the plasticity continues to be improved, its strength indicators gradually decrease, the peak appears at 3-6%, and the maximum peak is about 92% higher than that of pure wood-plastic material.
(3) When the MAPE content is 3% and 6%, not only does it show the slowest thermal weight loss on the TG curve, but also the melting peak on the DSC is about 5 °C higher than that of several other samples, and the thermal weight loss of the sample. The slowest and the high melting peak temperature indicate that the composite material is difficult to melt, which means that the components in the material are firmly bonded, which confirms the above conclusion 2 and has better mechanical properties.

5. References
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