PROPERTIES OF LIGHT WEIGHT REINFORCED THERMOPLASTIC (LWRT) WITH DIFFERENT FORMULATIONS PRODUCED IN A WET-LAID PROCESS

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Abstract

Light weight reinforced thermoplastic (LWRT) is a type of polymer composite with a porous structure and reinforcing fiber. LWRT is widely used in automotive markets due to the advantages of light weight, good formability, high strength-to-weight ratio, low cost part-forming process, and good durability. To suit the requirements of different applications, large varieties of LWRT have been developed. One way to tune the properties of an LWRT is by changing the formulation of the product.

In this work, we study LWRT with three different formulations produced in a wet-laid process: 1. Glass-and-polymeric-fiber-reinforced polypropylene (PP) composite with blowing agent; 2. Glass-fiber-reinforced PP with blowing agent; and 3. Glass-fiber-reinforced PP (without blowing agent). The mechanical properties are tested by ASTM-D638. The weight reduction potential due to strength-to-weight ratio differences between the LWRT with different formulations is studied. It has been found that the wet-laid process has great flexibility to produce LWRT with different performance by changing the formulation. The mechanism of how the formulation affects the performance of the product produced in the wet-laid process is discussed.

Introduction and Background

Weight reduction of the vehicle has been one of the most popular topics in the automotive industry for decades. This topic becomes even more important nowadays due to the growing popularity of electric vehicles. It is found that a 10% weight reduction can lead to about 7% increase of fuel efficiency of the vehicle [1]. A lot of efforts have been made to reduce the weight of the vehicle, such as reducing the size of the vehicle, using aluminum alloy instead of steel, and the application of light weight reinforced thermoplastic (LWRT) [2]. In modern cars, LWRT is widely used in many interior parts such as headliners, door panels, and trunk trim. Car manufacturers have differing requirements for the material used in different interior parts which requires the supplier to have the capability to manufacture products with different properties [3,4].

LWRT can be manufactured by many different manufacturing processes such as injection molding, extrusion molding, liquid molding, dry-laid, and wet-laid process. The fiber-reinforced polymer sheet manufactured by the wet-laid process has great potential to be used in many interior parts of automotive due to the advantage of light weight, small thermal expansion, good sound absorption performance, good formability, and decent mechanical performance.

In this paper, we demonstrate that the wet-laid process has good flexibility to produce LWRT products with different properties (density, post-molding capability, mechanical performance) by changing the formulation of the product.

Experimental and Manufacturing

Three types of LWRT sheets with different formulations were manufactured using the same wet-laid process. These three types of LWRT are Type 1: Glass-and-polymeric-fiber-reinforced polypropylene (PP) composite with blowing agent; Type 2: Glass-fiber-reinforced PP with blowing agent; and Type 3: Glass-fiber-reinforced PP. In the manufacturing process, polyolefin resin, glass fiber, and a bi-component polymeric fiber (type 1 only) were first dispersed in water forming an aqueous suspension, then the aqueous suspension was pumped onto a web forming section. Forming agents and blowing agent (type 1 and type 2 only) were then sprayed onto the continuous web. Next, the web was transferred into a dryer; after drying the skin material (plastic film or scrim) was applied on both sides of the web. After the consolidation process, the final product (LWRT sheet) was obtained. The schematic of the process used to produce the three types of material studied in this work is shown in Figure 1. The area density, thickness, and ash content of the product can be adjusted by changing the processing parameters. The physical properties of the three types of product are shown in Table 1; these properties were measured by an internal standardized procedure.

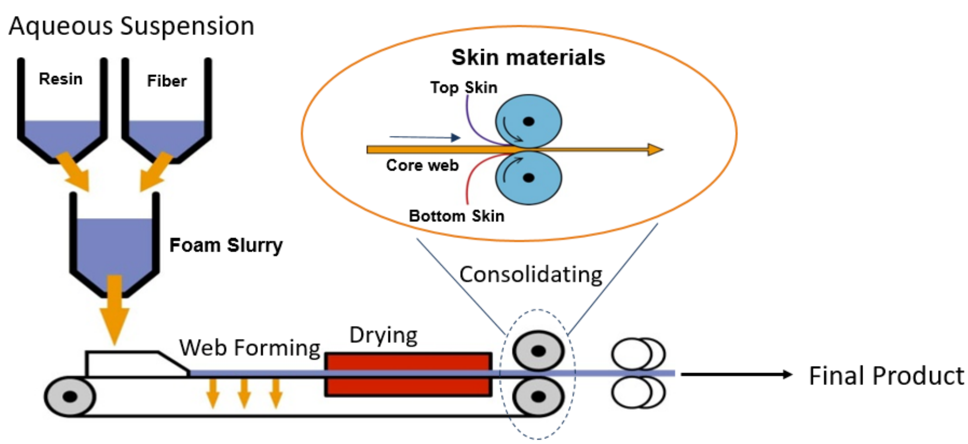


Figure 1. Schematic of a wet-laid process used to produce the three types of products studied in this work.

Table 1: Physical properties of the three types of products as produced

Materials	Basis weight (g/m²)	Thickness (mm)	Ash (%)
Type 1	568	1.1	30
Type 2	739	1.5	32
Type 3	1224	4.1	54

When molding the product into a certain thickness, the sheet is heated to a temperature above the melting temperature of the resin. Due to residual stress in the reinforcing fiber and the swell of the blowing agent, the thickness of the product is increased during the heating process which enables us to compress and mold the product into the desired thickness. In this study, we molded all three types of products to 3 mm. The capability to mold Type 1 and Type 2 products into much higher thickness gives greater flexibility to the customer when the post molding is performed.

The tensile properties of the molded specimens of three types of products were measured according to ASTM D638.

Results and Discussion

Physical properties

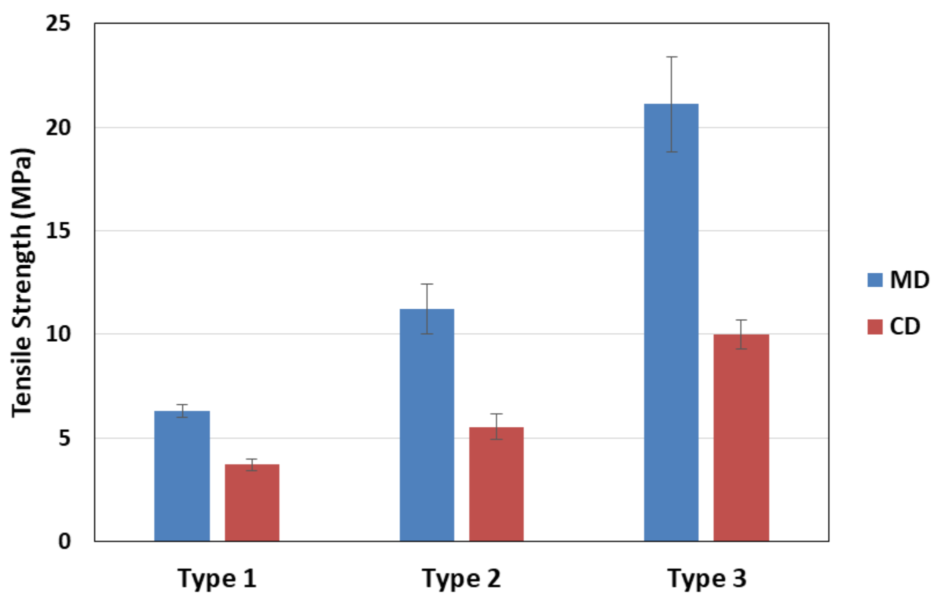
The basis weight, thickness, and the ash content (or glass fiber content) of three types of products is shown in Table 1. As can be seen in Table 1, the wet-laid production process can not only produce different formulations, but it can also produce the products with a range of basis weight, thickness and ash content by simply changing the processing parameters.

Formulation and the physical properties shown in Table 1 have direct influence on the mechanical properties of the product. In this work we mainly studied tensile and flexural properties of the three types of products.

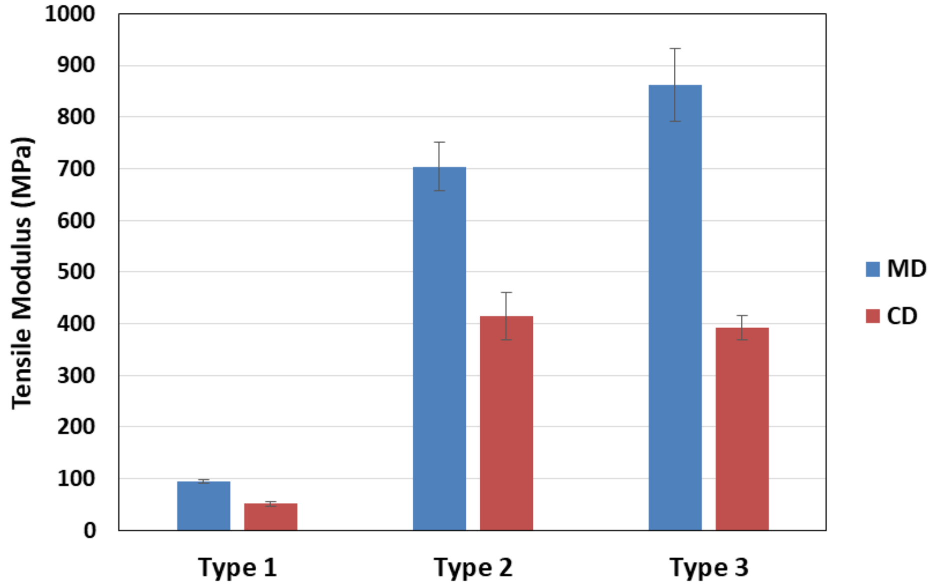
Tensile properties

To characterize tensile properties of three types of products, the materials were molded to 3 mm thickness and then cut into the dog-bone shape. The tensile tests were carried out based on ASTM D638 standard. The tensile properties of the three types of material are shown in Figure 2.

From Figure 2 we can see that Type 2 and Type 3 material have better tensile properties in both machine direction (MD) and cross direction (CD). This is mainly due to type 2 and 3 material having much higher basis weight (highest areal density) compared to type 1 material; low basis weight material has a more porous structure inside which leads to a reduction of the tensile performance. Mechanical performance in the MD direction is better than CD for all materials due to the tendency of the fibers to be oriented along the MD during the wet-laid process.



(a)

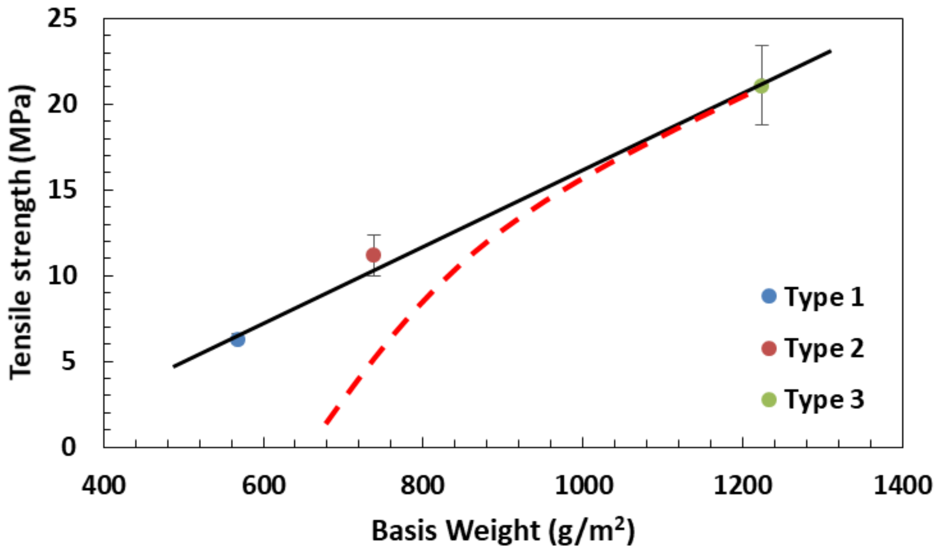


(b)

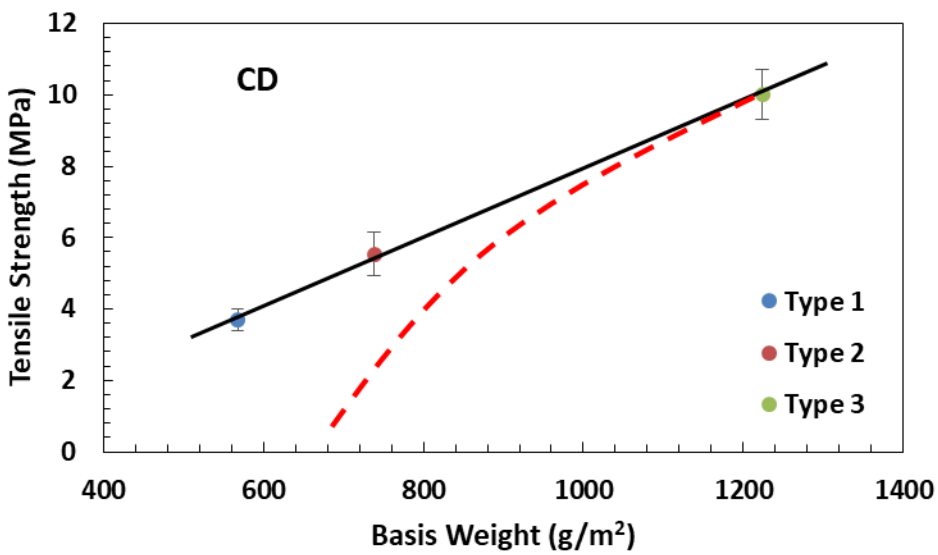
Figure 2. Tensile properties of three types of materials.

Achieving a material with low weight and high mechanical performance is challenging; we have put a lot of effort to design the formulation of the product to achieve this goal. To further demonstrate how the formulation can alter the typical behavior of polymer foam, we plot tensile strength against basis weight for the three types of material shown in Figure 3.

From Figure 3(a) and (b) we can see that the data points of three types of product fall on a straight line for both MD and CD. Based on the results reported by Dai, Zhou, Sun, Chen and Wang [5], the density dependence of tensile strength for the same type of fiber-reinforced polymer foam should follow the red dashed line shown in Figure 3, which is a quadratic function rather than a linear function. This is because in the high density region, the failure mode of the product is due to damage to the bonding between the reinforcing fiber and polymer matrix; at low density, the failure mode is due to damage to the polymer foam itself (due to the high density of micro voids in the product). So, according to this model, when the density of fiber-reinforced polymer foam reaches a very low level, the mechanical performance is reduced drastically. Due to the advanced formulation design (mixing usage of both glass fibers and polymeric fibers), the type 1 product which has very low basis weight maintains relatively high tensile strength compared to the behavior on the red dashed line. The advantage of using polymeric fiber is the density of polymeric fiber is lower compared to the glass fiber, while it still has decent mechanical performance. The detailed description of Type 1 product has been reported elsewhere [6].



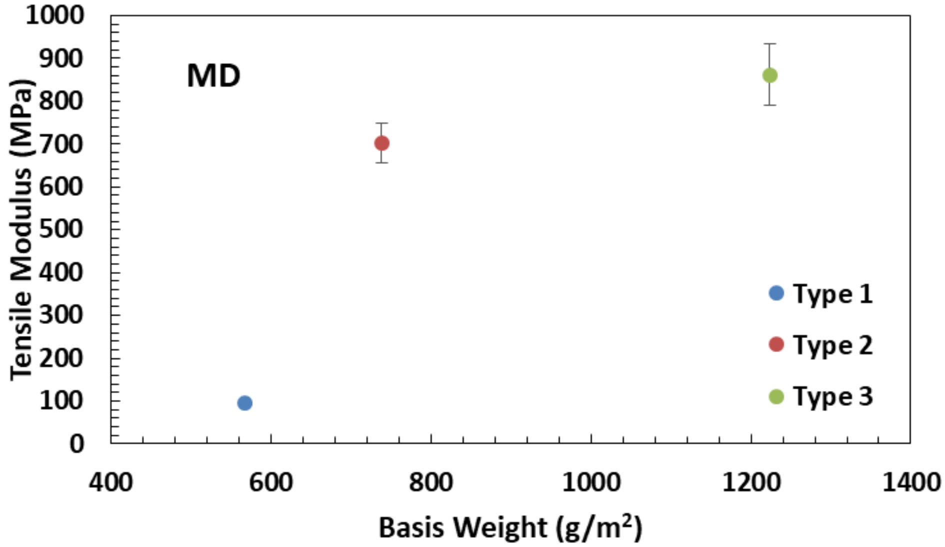
(a)



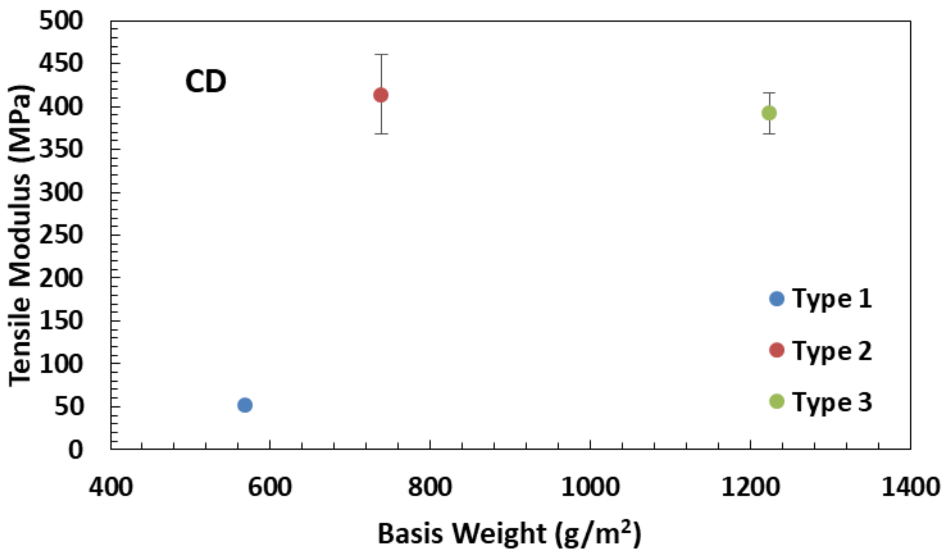
(b)

Figure 3. Tensile strength vs basis weight on (a) MD and (CD) for three types of materials.

The tensile modulus of the three types of products plotted against basis weight is shown in Figure 4. For typical polymer foam, the relationship between modulus and density is linear [7]; due to different formulations, however, the data points of these three types of products is spread rather than following linear relationship. This also demonstrates that by using different formulations, we are able to fine tune the property of the product manufactured in our wet-laid process. Although type 2 product has about 40% lower basis weight and 41% less usage of glass fiber compared to type 3 product, the tensile modulus of type 2 product is comparable to type 3 product in both MD and CD. This is due to the adding of blowing agent to the type 2 product. When molding the product into a certain thickness, the blowing agent will supply extra pressure during the molding, which enhances the wetting of polymer melt around glass fiber and also makes the micro void structure more uniform inside the product. The good bonding between polymer matrix and reinforcing fiber and uniform micro voids structure can benefit the stress transfer from matrix to reinforcing fiber under small deformation which leads to an improved tensile modulus.



(a)



(b)

Figure 4. Tensile Modulus vs basis weight on (a) MD and (CD) for three types of materials.

Summary and Next Steps

In this work we present properties of three types of LWRT manufactured by the wet-laid process. We demonstrate that the flexibility of the wet-laid process can allow us to produce products with different formulations and physical properties. Being able to produce the product with different formulations can enlarge the performance matrix of the products and can give us the opportunity to develop more new products to satisfy different requirements in the future.

Acknowledgements

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