DEVELOPMENT OF ULTRA-LIGHT HYBRID GLASS FIBER AND POLYMERIC FIBER REINFORCED POLYPROPYLENE COMPOSITES

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Abstract

It is a trend in the automotive industry to pursue materials with improved strength-to-weight ratio. Light weight reinforced thermoplastic (LWRT) composites represent one type of these desired materials. This study reports development of a new LWRT material with a significantly improved strength-to-weight ratio over standard LWRT materials.

A novel ultra-light reinforced thermoplastic composite, which features the mixed usage of glass fibers and bi-component polymeric fibers, is reported. Polymeric fibers provide a low density reinforcement, while glass fiber has better strength and stiffness. Through hybridization, it is possible to design the material to suit various applications more closely. The hybrid effects of glass and polymeric fibers on the flexural and physical properties have been investigated. It has been found that the partial substitution of glass fiber with bi-component polymeric fiber helps further reduce weight without sacrificing the mechanical strength of the material.

Introduction and Background

In the recent decade, there has been a fast growth in the use of thermoplastic composite materials [1,2]. For example, fiber reinforced composites have been widely employed by the automotive industry for seat backs, door panels, trunk trim, interior parts and headliners [3]. Car manufacturers are constantly pushing to use materials which provide lighter weight, lower cost, and more design freedom. To meet the market demand, it is critical to develop new materials responding to the need for weight reduction and improved formability.

Glass fiber reinforced polypropylene (PP) sheets/mats manufactured by wet-laid process, are excellent candidates as headliner materials for their light weight, good formability, and low coefficient of thermal expansion [4]. Normally, an aqueous suspension of well-dispersed thermoplastic resin and chopped glass fiber is transferred onto a web-forming section. A thermoplastic composite sheet can be manufactured by removing the water from the web, heating the web to a temperature above the melting point of the thermoplastic resin, and subsequently consolidating the web. A part can be produced by thermo-forming the thermoplastic composite sheet. During the thermo-forming process, when the resin melts, the residual stress among fibers is released. The thickness of the composite sheet becomes greater than that before being heated. This is a phenomenon called “loft”. In the whole porous structure, resin serves the function of adhesive to hold the chopped fiber together. Further improvement of the formability as well as the strength-to-weight ratio of the wet-laid LWRT composites can be achieved by addition of expanding agents during web forming, which further increase the loft and the porosity of thermo-formed parts. In this paper, we will report a novel glass/bi-component polymeric fiber hybrid polyolefin composite prepared by the wet-laid process. The adding of bi-component polymeric fiber with lower density retains more expanding agents, which allows higher degree of expansion at lower basis weight. Therefore, further weight reduction has been achieved without sacrificing

the mechanical strength of the material.

Experimental and Manufacturing

The glass/bi-component polymeric fiber hybrid LWRT (H-LWRT) and the standard glass fiber LWRT (S-LWRT) sheets were manufactured by using the same wet-laid process. Polyolefin resin, chopped glass fiber, and bi-component polymeric fiber for H-LWRT were dispersed in water. The aqueous suspension of well dispersed resin and fiber was transferred onto a web-forming section and expanding agents were added to the continuous web. The resulting web was drained, heated, laminated with surface materials (scrim and film) and consolidated to produce flat LWRT composite sheets. Materials with various basis weight (areal densities) can be produced by adjusting the manufacturing parameters. In this paper, the control sample (S-LWRT) has a basis weight of 650 g/m^2, which is about 14.4% heavier than the H-LWRT's 568 g/m^2.

After being heated above the melting point of the resin, the materials experience thickness increase due to the release of residual stress from bent fibers, as well as from the expanding agent. Therefore, all materials are capable of being molded into thicknesses of 3.5 to 7 mm, which are thicker than the as-produced status/thicknesses (Table 1). Figure 1 shows an example part which is molded from a sample B (H-LWRT) sheet. The material shows good formability to adapt to complicated shapes in a mold.

Analytical properties including basis weight (areal density), as-produced thickness, and glass (ash) content were measured following standard internal testing procedure. The tensile properties of samples with thickness of 3 mm were measured according to ASTM D790. The flexural properties of the molded specimens with thicknesses of 3.5, 4, 5.5 and 7 mm, were evaluated according to ASTM D638.

Table 1: Physical properties of S-LWRT and H-LWRT

Materials	Basis weight (g/m^2)	Thickness (mm)	Ash (%)
Control (S-LWRT)	650	1.02	33.50
Sample A (H-LWRT)	568	1.12	29.72
Sample B (H-LWRT)	568	1.20	34.18

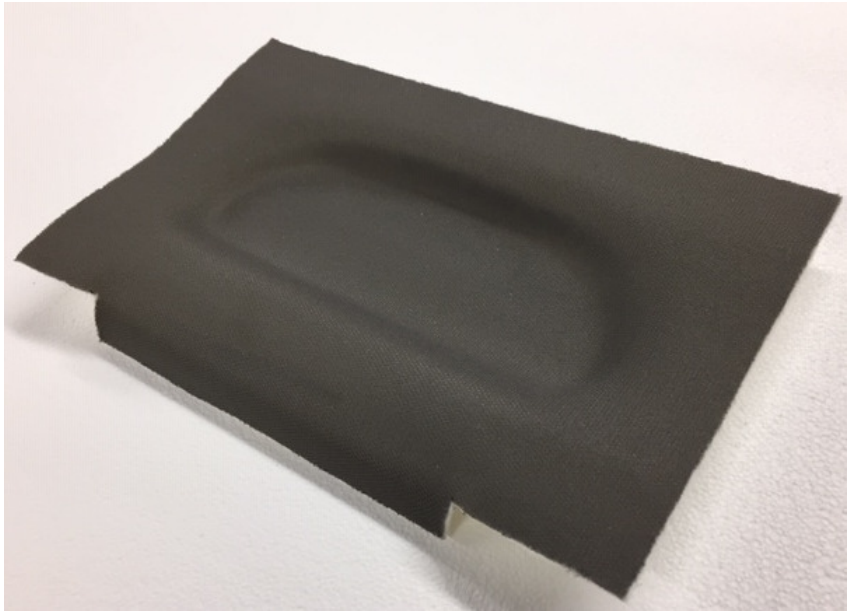


Figure 1: An example of a part molded out of the H-LWRT sheet.

Results and Discussion

Physical properties

The basis weight, thickness, and glass content (ash %) were measured and summarized in table 1. The control sample S-LWRT is 82 g/m^2 (14.4%) heavier than the two H-LWRT samples. The S-LWRT shows a slightly lower thickness, indicating a slightly higher consolidation level. Samples A and B (H-LWRT) have different glass contents, due to the different weight percentages of bi-component polymeric fiber.

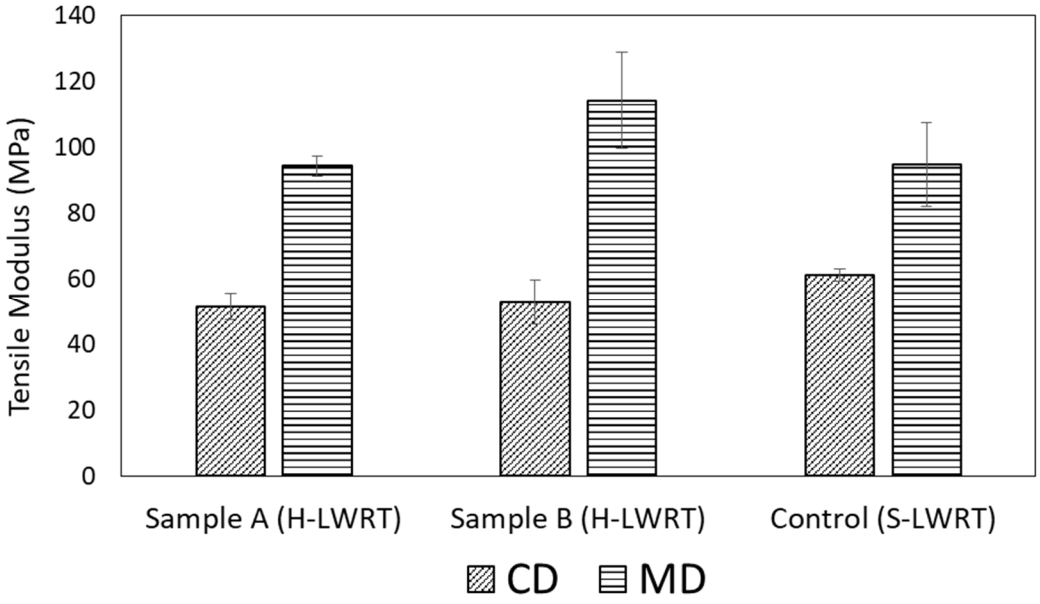
In the 500 to 700 g/m^2 range, a material with an additional 82 g/ m^2 normally has much better mechanical properties than the lighter counterpart. Therefore, the mechanical properties will be compared between S-LWRT and H-LWRT. If the lighter H-LWRT has comparable or even better properties than the heavier S-LWRT, then there would be a good chance to save 82 g/m^2 for applications emphasizing these properties.

Tensile properties

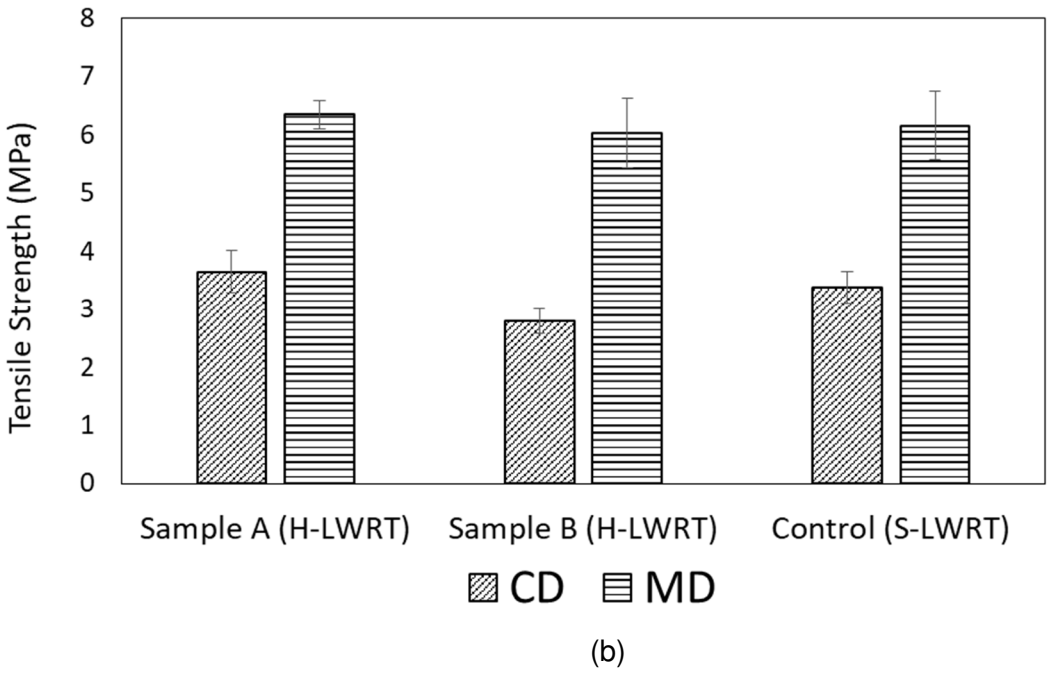
To evaluate the tensile properties, molded plaques with a thickness of 3.5 mm were cut into dog-bone tensile specimens by a punch press. Figure 2 summarizes tensile modulus (Figure 2a) and tensile strength (Figure 2b) of sample A (H-LWRT), sample B (H-LWRT), and control (S-LWRT). For both tensile modulus and strength, all three samples show significantly better results in machine direction (MD) than those in the cross-machine direction (CD). This is due to the fiber orientation biases favoring the machine direction, which primarily occurs in the head-box. The flow in the head-box is a mix of both shearing and extension. Specifically, the complicated flow features shearing close to the walls and stretch toward the machine direction within the entire domain. As a result, the fibers are strongly aligned toward the flow direction leading to better

mechanical performances in MD.

Sample B (H-LWRT) has the best average tensile modulus in MD, while the control (S-LWRT) shows only slightly larger average modulus than both sample A and B in CD. For the tensile strength, all three samples show very comparable performances in MD. In CD, sample A shows a similar result to the control, and sample B is only slightly lower than the other two. Notably, the control (S-LWRT) is 82 g/m^2 heavier than both H-LWRT samples. This means that an up to 82 g/m^2 weight reduction without sacrificing the tensile properties is achieved by hybridizing glass fiber with bi-component polymeric fiber. Particularly for tensile properties, the strength is highly dependent on the bonding between resin and fibers [5]. The bi-component polymeric fiber has a component with a melting point lower than the matrix resin. During the heating and consolidation stages, the component with the lower melting point in the polymeric fiber melts and bonds to the glass fiber surface, which is considered to contribute to better resin wet-out around glass fibers.



(a)

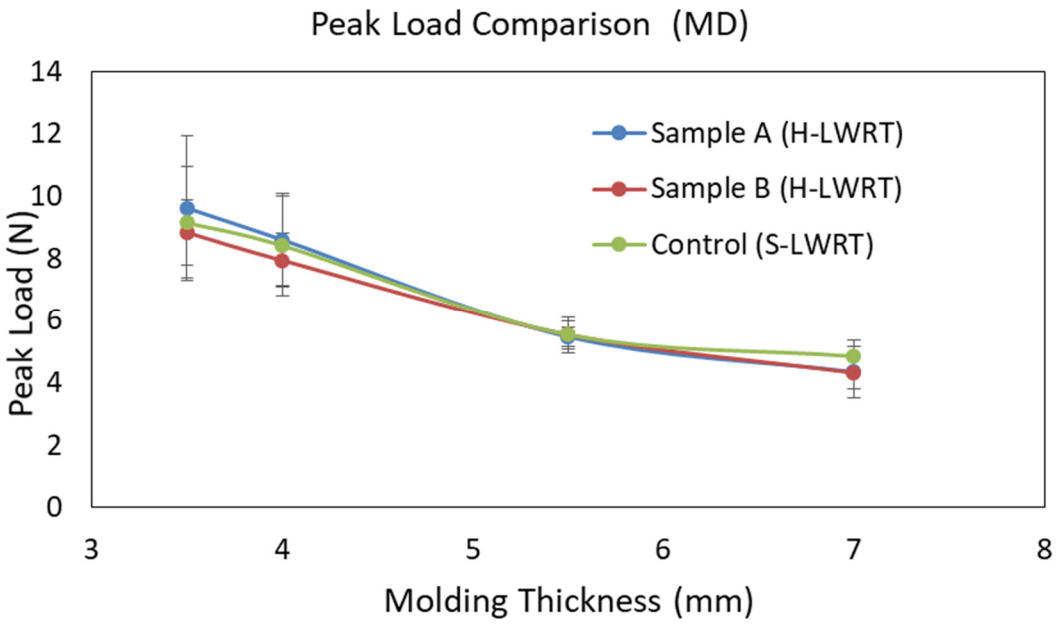


(b)

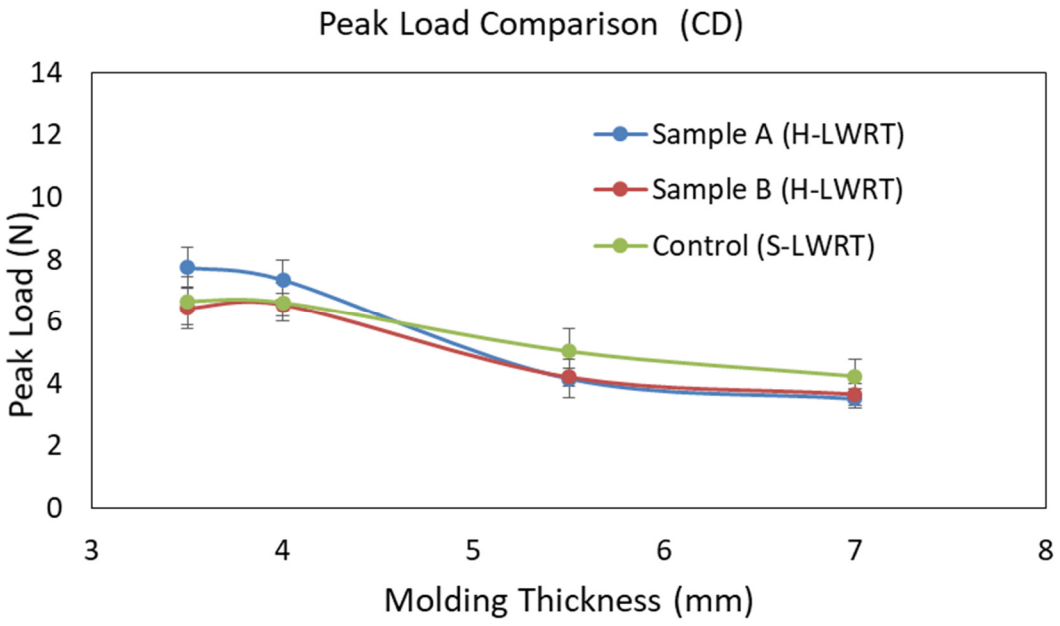
Figure 2: Tensile properties comparison (all tensile specimens have a thickness of 3 mm) between sample A (H-LWRT), sample B (H-LWRT), and control (S-LWRT), for a) tensile modulus, and b) tensile strength.

Flexural properties

Flexural tests were conducted on specimens molded into 3.5, 4, 5.5 and 7 mm. Figure 3 compares the peak load at both MD, and CD, amongst sample A (H-LWRT), sample B (H-LWRT) and Control (S-LWRT). Just like the tensile properties, peak load results in the MD are also better than those in CD. The peak load is decreased as the thickness increases, owing to the increase of porosity. Through the entire molding thickness range, all three samples show very comparable peak load results. This indicates that an up to 82 g/m^2 weight reduction without sacrificing the flexural peak load is achieved by hybridizing glass fiber with bi-component polymeric fiber.



(a)



(b)

Figure 3: Peak load comparison among sample A (H-LWRT), sample B (H-LWRT) and Control (S-LWRT), at (a) machine direction (MD), and (b) cross-machine direction (CD).

Summary and Next Steps

A new grade of LWRT has been developed by the mixed usage of glass fibers and bi-component polymeric fibers. This new grade maintains the physical properties of traditional LWRT and demonstrates good molding characteristics on conventional thermo-forming equipment. Moreover, owing to the hybridization, the new materials show comparable tensile properties (modulus and strength) and flexural peak load to the heavier standard LWRT. We have demonstrated that this new grade achieved an 82 g/m^2 (about 15%) weight reduction without sacrificing these properties.

For future work, we will investigate the possibility of achieving further weight reduction by adjusting the formulations.

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