NOVEL LIGHT WEIGHT REINFORCED THERMOPLASTIC (LWRT) FOR AUTOMOTIVE APPLICATIONS

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Abstract

Reducing the overall weight of thermoplastic parts while maintaining mechanical properties has been a focus in the automotive industry over the past decades to improve fuel efficiency and lower CO_2 emissions. LWRT is widely used in automotive applications, including headliners, underbody shields, trunk trim, and rear window trim. A new LWRT has been developed which has an excellent strength-to-weight ratio and can be molded into complicated geometries with varying thicknesses. During the manufacturing process, to achieve better mechanical properties, a high consolidation level is applied to this novel LWRT. It is capable of maintaining the same level of mechanical properties with a significant basis weight reduction compared to a standard LWRT counterpart.

In this paper, the mechanical properties (flexural peak load and stiffness) were benchmarked against a traditional LWRT. The physical properties, including basis weight and as-produced density, can be adjusted to meet different requirements.

Introduction and Background

Reducing greenhouse gas emissions during transportation has been a focus in the past few years. In 2021, the federal government proposed and revised the standards for passenger cars and light-duty vehicles for the model year 2023-2026. The new standards were supported by the leading U.S. automakers, including General Motors, Stellantis, and Ford Motor Company. According to the new standard, the CO_2 emission was restricted to 160 g/mile by 2026. A lightweight design that is capable of reducing automotive weight is considered one of the most efficient approaches to achieving the goal of low emissions. Furthermore, Europe and Asia have also imposed stricter CO_2 limits or higher average fuel economy requirements over the past few years [1-2]. LWRT materials manufactured in Hanwha Azdel Inc. (e.g., SuperLite®) are able to provide a high strength-to-weight ratio. In addition, LWRT has much better formability than other types of materials (e.g., polyurethane), which can provide OEMs with more room for manufacturability and design.

A novel LWRT (N-LWRT) is introduced in this paper to further improve the strength-to-weight ratio over the standard LWRT. The LWRT manufacturing is based on a wet-laid process, which is demonstrated in Figure 1. Polypropylene (PP) and chopped glass fiber (GF) are stirred in city water to form an aqueous slurry suspension. Subsequently, the slurry is transferred to a web-forming section and the excess water in the PP-GF web is removed. A continuous PP-GF web is formed and the LWRT is produced followed by heating, pressing, and a high-consolidation process, which is to achieve a better resin wet-out around the glass fibers. An LWRT sheet will be thermoformed into desired shapes, and typical applications include headliners, parcel shelves, door panels, underbody shields, truck trim, and rear window trim. The LWRT material core substrate is typically sandwiched by two skin layers as needed for various applications (e.g., adhesive film, barrier film, non-woven, fire-retardant scrim, or protective layer). The entire structure is further consolidated to achieve a composite sheet. Generally speaking, the mechanical performance and formability of the resultant LWRT sheet are functions of core material formulation (e.g., PP/GF ratio), areal density (grams per square meter, gsm), functional/decorative skins attached to the core material, and corresponding thermo-forming thickness [3-6].

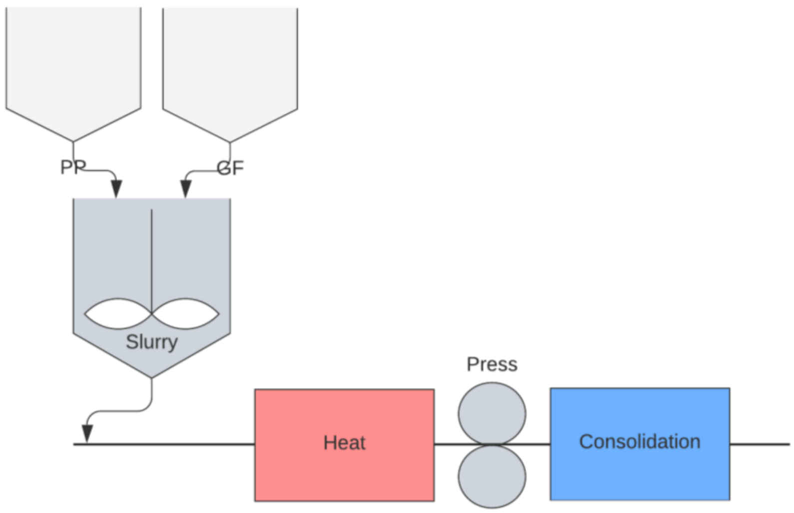

Figure 1. Schematic demonstration of LWRT composite material

The LWRT composite material mentioned in this paper consists of a core substrate with a protective scrim layer on each side of the core to form a composite substrate. A schematic illustration of the LWRT is shown in Figure 2. The physical properties (e.g., areal density, as-produced density, glass content, and lofted thickness) as well as the mechanical properties of S-LWRT and N-LWRT will be investigated later.

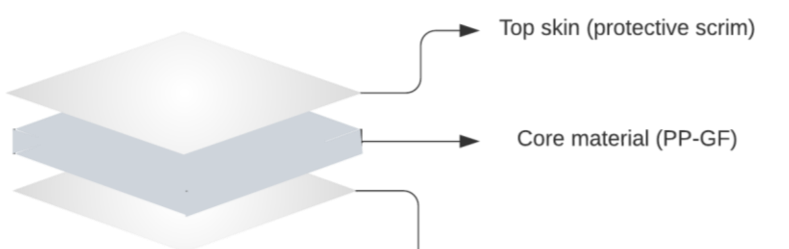

Figure 2. Schematic demonstration of LWRT composite material

Experimentation

Characterization

Basis weight, glass content, and as-produced thickness were measured following standard testing procedures in the internal lab. Each sample was tested by 5 replicates.

The flexural properties (3-point bending) of the molded specimens were evaluated using MTS mechanical testing system according to ISO 178 standard. Rectangular specimens (100 mm × 30 mm) were cut from plaques in the machine direction (MD) as well as the cross-machine direction (CD). The cross-head speed, span, anvil diameter, and nose diameter were 15 mm/min, 64 mm, 10.0 mm, and 10.0 mm, respectively. The tensile properties of the molded specimens were performed on an MTS mechanical testing machine according to ISO 527 standard. All the specimens were cut into dog-bone shape by a punch press. The span, test speed, and load cell were 115 mm, 5mm/min, and 5 kN, respectively. For the flexural and tensile test, each dot in the following charts represents the average of 5 replicates, unless stated otherwise. After the mechanical test, the areal density and glass content were re-checked to ensure the consistency and repeatability of the molded specimens.

Results and Discussion

Physical properties

The areal density, as-produced density, glass content, and lofted thickness of standard LWRT (S-LWRT) and novel LWRT (N-LWRT) are listed in Table 1 below. The overall weight of N-LWRT is around 25 % lighter than S-LWRT as shown in Table 1. The as-produced density of N-LWRT is higher than S-LWRT, which indicates a higher consolidation level for N-LWRT during the manufacturing process. It can be noticed that the lofted thickness of N-LWRT is around 30% higher than S-LWRT, which provides the capability of molding into a substrate with a higher desired thickness (e.g., > 4.0 mm).

Table I: Physical properties of S-LWRT and N-LWRT

Materials	Areal density (g/m^2)	Density as-produced (g/cm^3)	Glass content (%)	Lofted thickness (mm)
S-LWRT (Control)	1040	0.30	51.7	6.5
N-LWRT (with high consolidation)	790	0.52	39.5	8.4

Flexural properties

The flexural properties were evaluated on specimens molded into a variety of thicknesses. As shown in Figure 3 and Figure 4, the S-LWRT could only be molded up to approximately 3.5 mm substrate thickness due to its limited lofting capability. However, it was practical to thermoform the N-LWRT into higher thicknesses (e.g., 4.0 or 4.5 mm) without causing any surface cosmetic issues. In the automotive industry, a wider range of molding thickness gives the automotive design team much more room and flexibility. Overall, the general trend for both samples is better mechanical properties in the MD direction than in the CD direction, which can be ascribed to fiber alignment along the MD direction. Throughout the entire molding thickness range, the N-LWRT shows quite a comparable flexural stiffness and a slightly better flexural peak load than S-LWRT. It indicates that N-LWRT is capable of achieving around 25% (or 250 g/m^2 areal weight) weight reduction without significantly sacrificing the flexural properties compared to the control (S-LWRT). With a higher PP content in N-LWRT and the higher consolidation process, the bonding between the fiberglass and PP resin may be stronger than the S-LWRT material, which can effectively prevent the PP-GF matrix from ‘fiber pull-out’ or ‘fiber microbuckling’. Some literature has discussed similar failure mechanisms by investigating the microstructure and employing mathematical models [7-9].

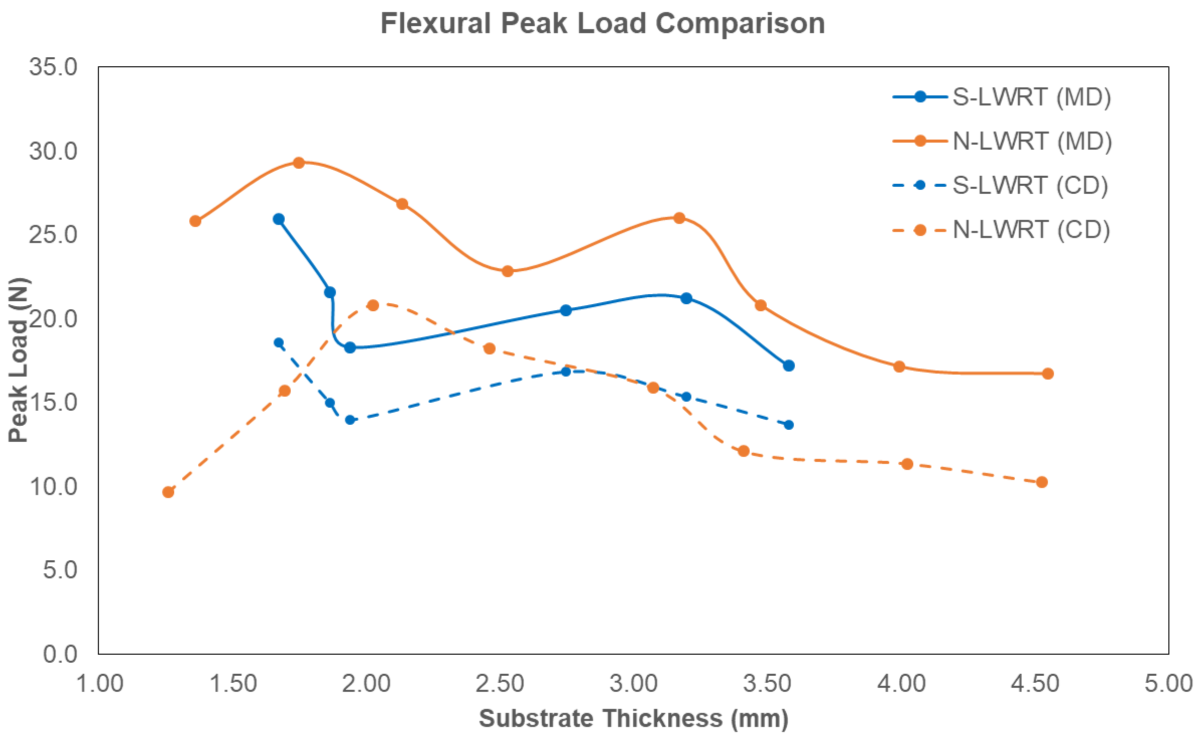

Figure 3. Flexural peak load (ISO 178) comparison between standard LWRT (S-LWRT) and novel LWRT (N-LWRT). The solid lines represent trend of the MD values and the dashed lines represent the trend of CD values.

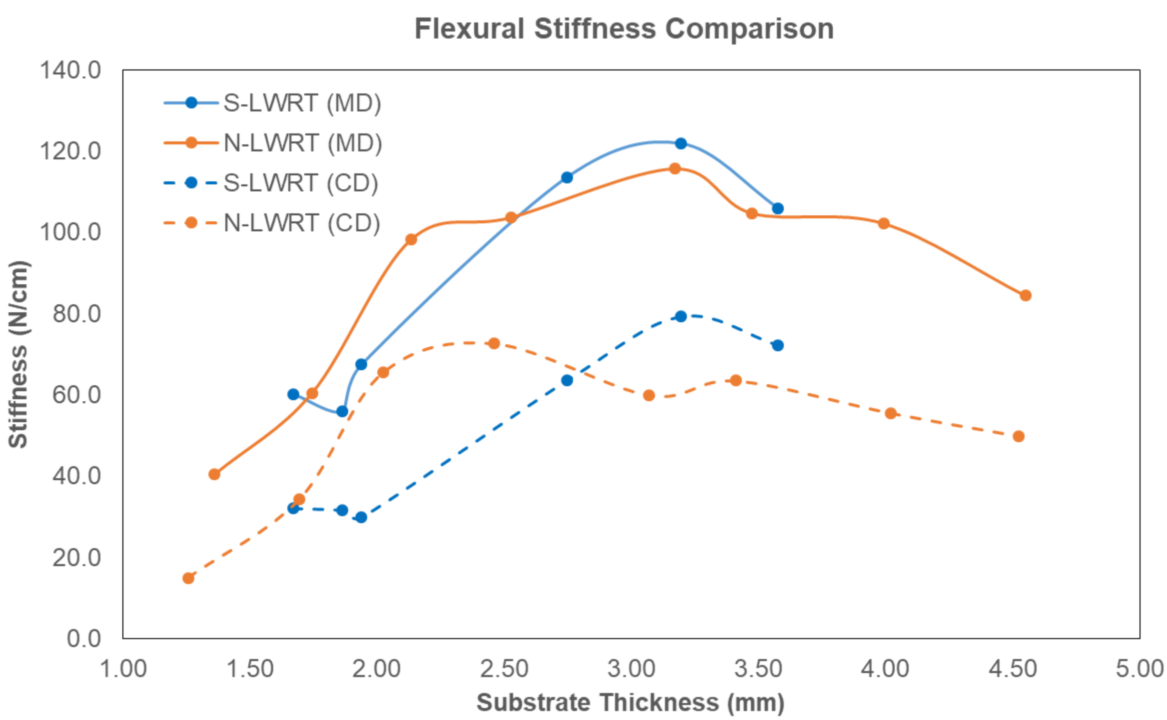

Figure 4. Flexural stiffness (ISO 178) comparison between standard LWRT (S-LWRT) and novel LWRT (N-LWRT). The solid lines represent trend of the MD values and the dashed lines represent the trend of CD values.

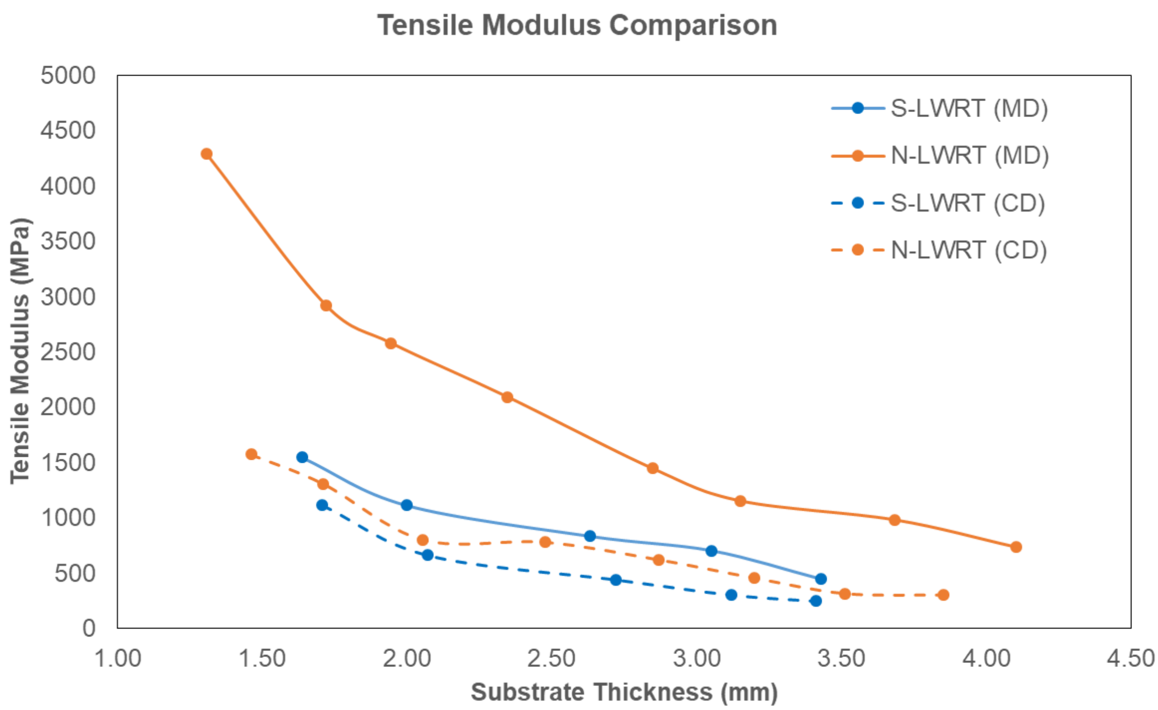

Figure 5. Tensile Modulus (ISO 527) comparison between standard LWRT (S-LWRT) and novel LWRT (N-LWRT). The solid lines represent trend of the MD values and the dashed lines represent the trend of CD values.

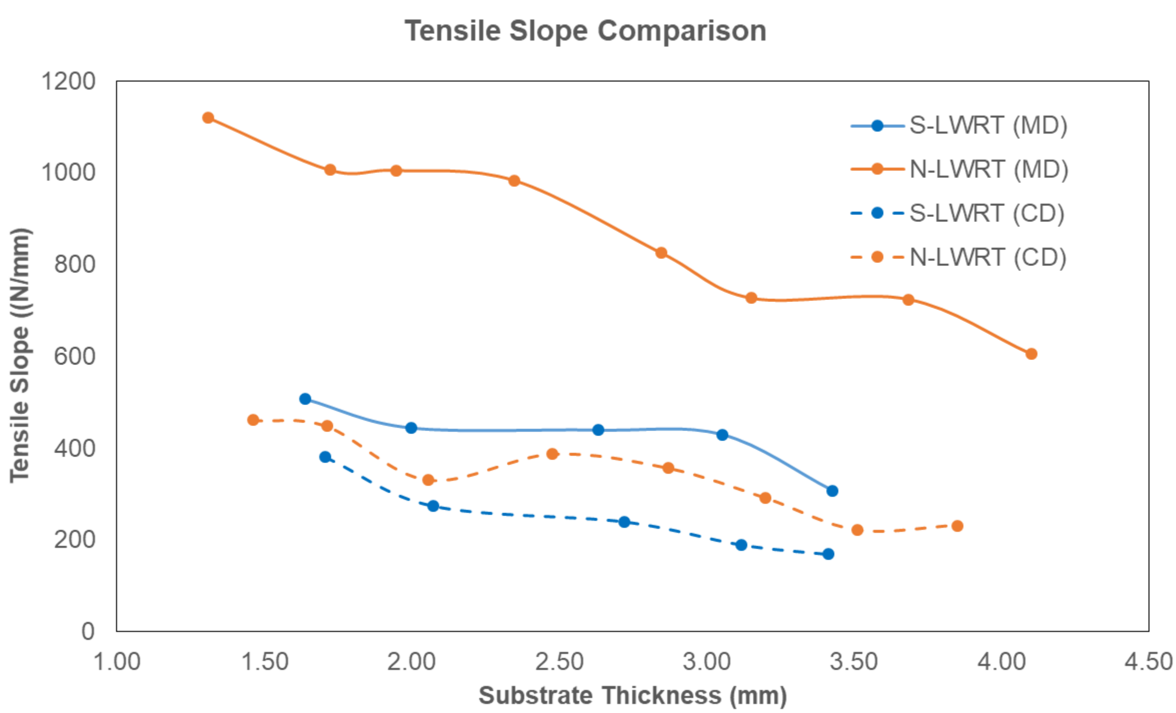

Figure 6. Tensile Slope (ISO 527) comparison between standard LWRT (S-LWRT) and novel LWRT (N-LWRT). The solid lines represent trend of the MD values and the dashed lines represent the trend of CD values.

Tensile properties

The tensile property was also evaluated with a range of thicknesses (target substrate thickness from 1.0 mm to 4.5 mm). The tensile modulus and tensile slope were summarized in Figure 5 and Figure 6, respectively. It can be seen that the N-LWRT specimens could be molded into higher thicknesses since the lofting capability of N-LWRT is better than that of S-LWRT at the same molding condition. It is worth mentioning that the N-LWRT is about 250 g/m^2 lighter than the control (S-LWRT) but both the machine direction (MD) and cross direction (CD) of the N-LWRT's tensile modulus and tensile slope are observably higher than the S-LWRT counterpart. It can be ascribed to the higher consolidation level that the N-LWRT underwent through Hanwha Azdel's new manufacturing line.

Summary and Next Steps

A new grade of LWRT has been developed by altering the PP-GF ratio and applying a higher consolidation level. The N-LWRT not only improves or at least maintains the mechanical properties of its S-LWRT counterpart with a 25% weight reduction but also enables a wider range of thermoforming thickness. In the future, we will look into the possibility of achieving further weight reduction without sacrificing any critical properties.

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