LIGHT WEIGHT REINFORCED THERMOPLASTIC COMPOSITE WITH IMPROVED FORMABILITY

Hong Xu, Peter T. Evers
Hanwha Azdel, Inc.

Abstract

Light weight reinforced thermoplastic (LWRT) composites are widely used in the automotive industry, typically by being thermoformed into designed shapes. The ability of an LWRT composite sheet to form complex shapes is highly desirable for some automotive applications, and a trunk trim panel is a good example. In this work, a recently developed LWRT composite material with improved formability which also achieves a weight saving compared to the current trunk trim offering will be discussed.

Background and Introduction

Light weight reinforced thermoplastic (LWRT) composites are found in numerous applications in the automotive industry, both for exterior and interior parts.

LWRT composite sheets are typically thermoformed into parts with a desired geometry. Thermoforming is a stretch-forming process resulting in a reduction of the sheet's original thickness. The deeper the cavity of the geometry is designed, the thinner the wall thickness of the final part will be. The thinning effect may cause failure of a part during the forming operation. The formability of the sheet material is its ability to form into parts with desired geometry without failure. [1] The geometry of the parts varies according to different applications, and some applications have a very complex geometric design. A good example of such applications is trunk trim, which has a deep-drawn, multi-cavity geometry. Therefore, a LWRT composite sheet with good formability is highly desirable for applications like trunk trim.

The work reported in this paper is about a new grade of LWRT composite material (N-LWRT) with improved formability. The LWRT composite material discussed in the work is a polyolefin-based, chopped glass fiber reinforced composite. The N-LWRT has better formability than the standard LWRT composite material (S-LWRT). This new grade of LWRT sheet material is developed to address applications requiring a deep-drawn and / or complex geometry.

Materials and Experimental

The N-LWRT and S-LWRT sheets were fabricated by using the same wet-laid process. Polyolefin resin and chopped glass fiber were dispersed in water. The dispersed materials were disposed onto a mesh support structure to form a web of laid material. The resulting web was drained, dried, and consolidated to form a flat LWRT composite sheet. Different surface materials, such as film and scrims, can be laminated onto the web during the consolidation stage. As shown in Table 1, N-LWRT sheets with core area density around 500 g/m^2 and 600 g/m^2, and S-LWRT sheets with core area density around 600 g/m^2 were created. A light-weight non-woven scrim and an adhesive film were laminated to the two sides of the S-LWRT and N-LWRT sheets, respectively.

The flat sheets were thermoformed into parts with different shapes. Figure 1 is a schematic of the thermoforming process. The LWRT sheet was heated and lofted in an infra-red oven, and the lofted sheet was formed to the desired shape using a set of matched molds.

To analyze the formability of the sheets, two different types of molds were applied: torture molds and deep-draw molds. Torture molds are typically designed to evaluate whether the sheet materials can undergo the most critical shape change expected for the manufactured parts [2]. Two different formed shapes from the internally developed torture molds were tested: wedge and cupcake. The deep-draw molds were used to create parts that have similar shape complexity with trunk trim parts, to check if a sheet material is able to form into shapes desired for trunk trim or other deep-drawn applications.

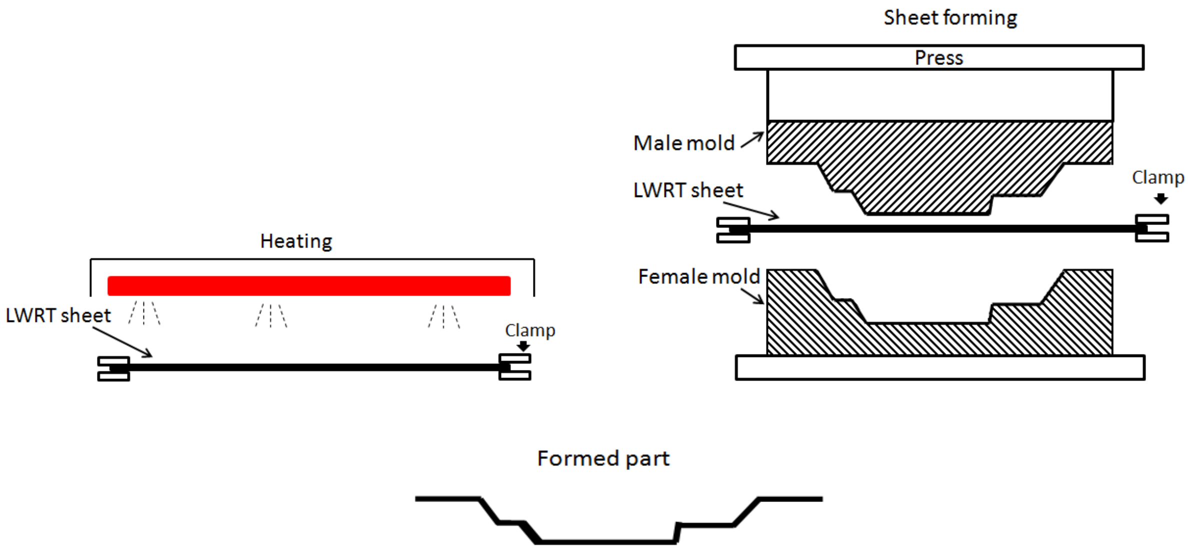

Figure 1: Schematic of the thermoforming process.

Results and Discussions

In this study, N-LWRT sheets with a core area density around 600 g/m^2 and 500 g/m^2 were compared to S-LWRT sheets with a core area density around 600 g/m^2.

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

Materials	Core area density (g/m^2)	Sheet area density (g/m^2)	Density (g/cm^3)	Thickness (mm)	Ash (%)
Control (S-LWRT)	607	722	0.30	2.37	46.8
Sample A (N-LWRT)	596	714	0.32	2.26	45.5
Sample B (N-LWRT)	517	635	0.31	2.02	45.9

Physical Properties

Table 1 summarizes the physical characteristics of the S-LWRT and N-LWRT sheets. The S-LWRT control and N-LWRT sample A have similar physical properties, including area density, density, sheet thickness, and ash after burning. N-LWRT sample B has lighter area density and lower sheet thickness than control and sample A, but similar density and ash content after burning.

Formability

The most important characteristic of the LWRT sheet is its formability. [3] To study the 3-dimensional forming behavior of the sheet materials, the LWRT sheets were shaped into parts with different geometries.

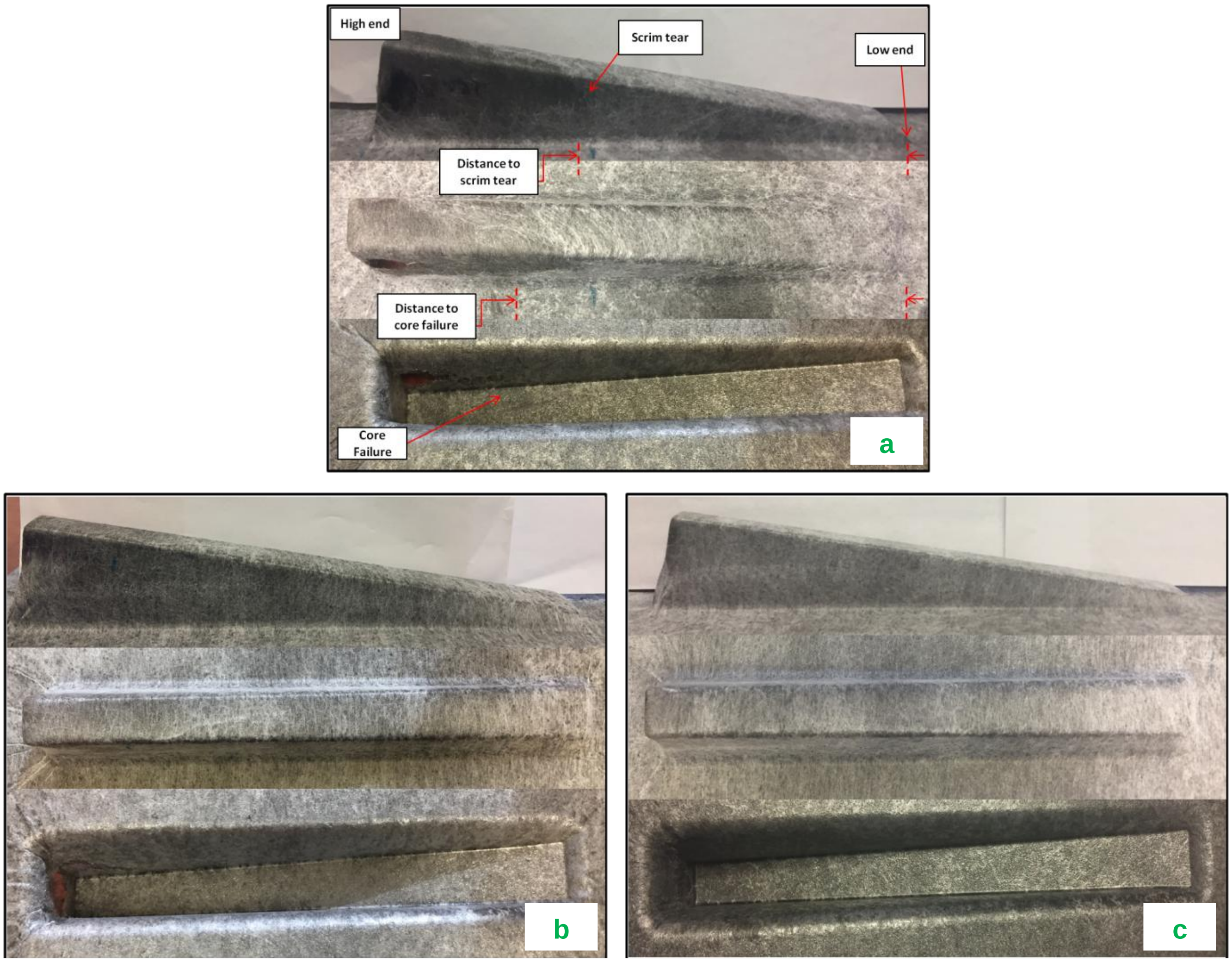

Figure 2: Formed wedges (side view, top view, back view): a. S-LWRT control; b. N-LWRT sample A; c. N-LWRT sample B.

Wedge Shape

The LWRT sheets were molded into wedge-shape parts by using torture molds. The wedge shape is about 300 mm long, 40 mm wide and 50 mm deep. The photographs of the formed wedges from side, top and back views were displayed in Figure 2. The appearance of the light-weight scrim of the formed wedges can be observed from the photographs. For S-LWRT control, scrim tear was observed near the high end of the wedge. For the N-LWRTs, both sample A and sample B, the wedge was fully formed without any scrim tear. The surface appearance can be represented and quantified by the distance from the point where scrim starts tear to the low end of the wedge. Figure 3 shows a plot of the average distance for 3 different samples (averaged from 9 wedges formed for each sample). It shows that the S-LWRT control parts have an average distance of about 190 mm from scrim tear start point to the low end of the wedge, while N-LWRT sample A and sample B have no scrim tear throughout the wedge shape. It demonstrates that the surface appearance integrity of the new grade LWRT sheet materials is dramatically enhanced, compared with the standard LWRT sheet materials. The integrity for the formed parts surface appearance is of particular interest because the surface integrity has to be maintained to obtain a useful part.

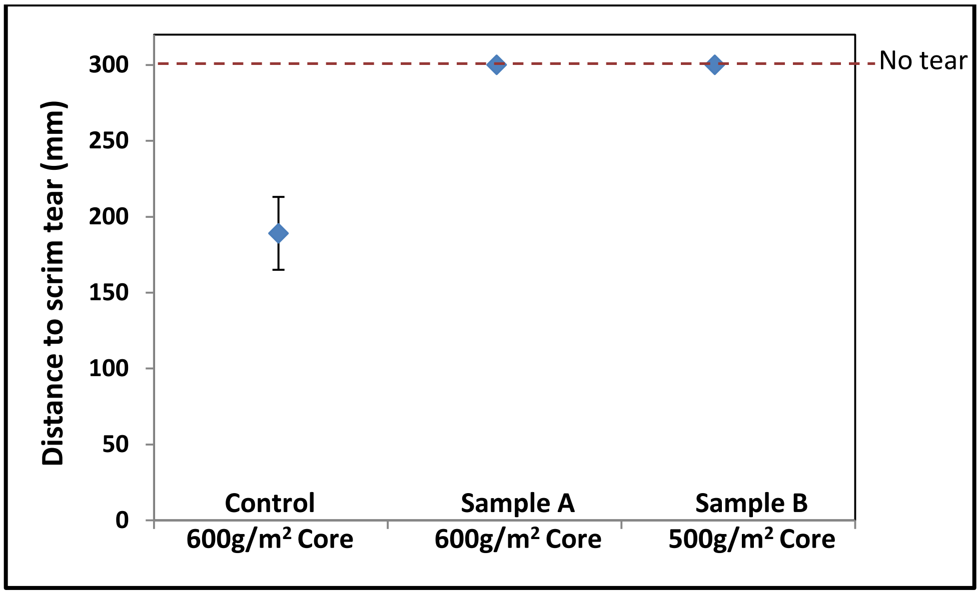

Figure 3: Distance between scrim tear point and low end.

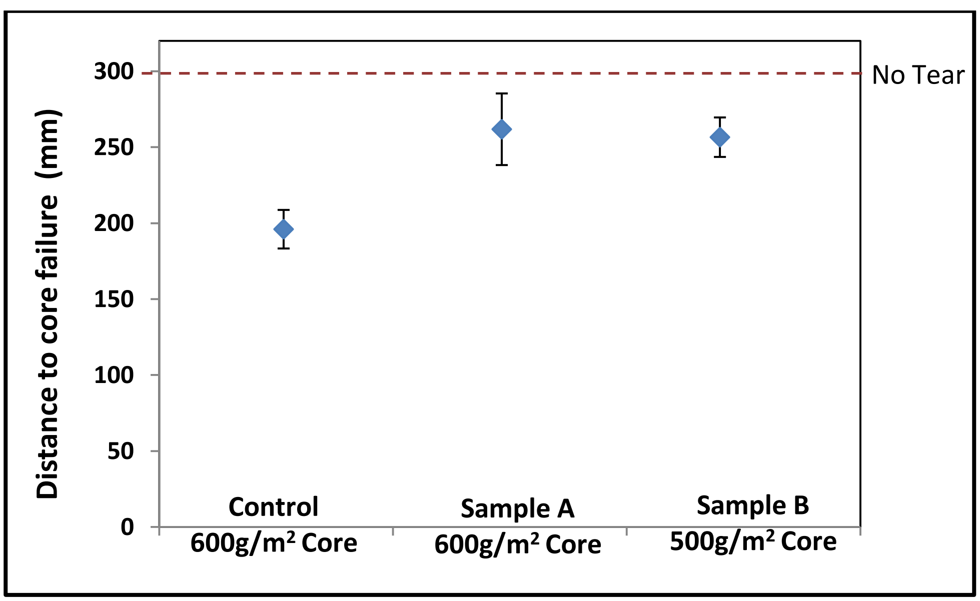

Figure 4: Distance between core failure point and low end.

Core fracture was found on side walls of the wedge-shape cavity close to the high end of the wedge. Figure 4 is a plot of the average distance between the point where the core starts failure and the low end of the wedge. As the figure shows, the average distance of N-LWRT sample A wedges is larger than that of S-LWRT control wedges. The height of the wedge increases with an increase in distance to low end. It illustrates that N-LWRT sample A can withstand larger local deformation in stretch forming than S-LWRT control. The core area density and sheet area density of N-LWRT sample A are approximately the same as those of S-LWRT control. It can be concluded that the new grade LWRT sheet materials have better core integrity during forming than the standard grade LWRT sheet materials at the same area density or weight. It is also pointed out in Figure 4 that the average distance between the core failure start point and the low end of N-LWRT sample B is larger than that of S-LWRT control, which indicates that N-LWRT sample B sheet can undergo larger deformation in stretch forming than S-LWRT control sheet. N-LWRT sample B sheet is about 100 g/m^2 lighter than S-LWRT control sheet. Consequently, the new grade LWRT sheet materials with about 12% weight saving have better core integrity than the standard grade LWRT sheet materials.

In general, the new grade LWRT sheet materials achieve both improved formability (better surface and core integrity), and weight saving in the stretch forming of wedge-shape parts.

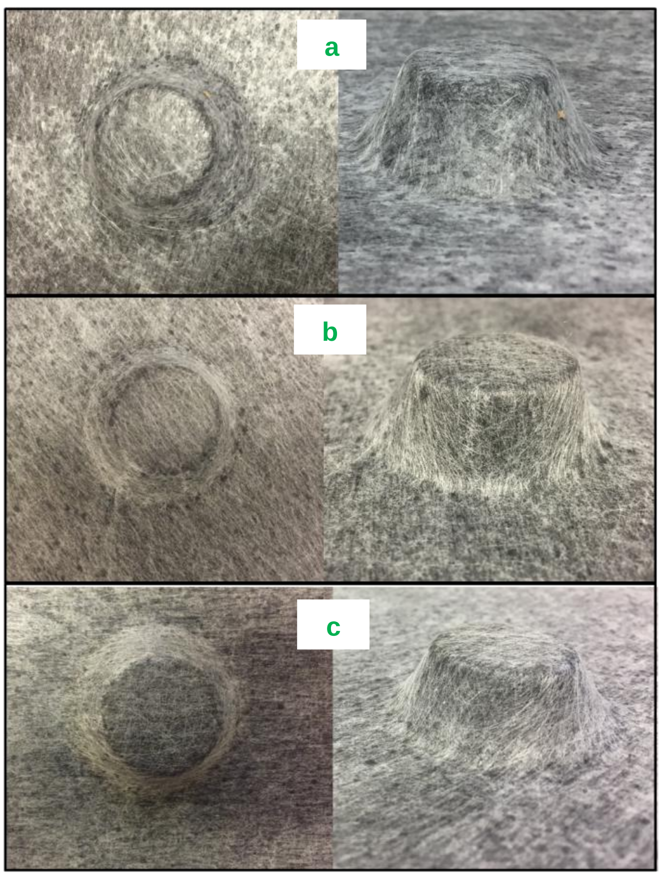

Figure 5: Formed cupcakes with 15mm depth: a. S-LWRT control (top view, side view, back view); b. N-LWRT sample A; c. N-LWRT sample B.

Cupcake Shape

A cupcake shape was also formed from the S-LWRT and N-LWRT sheets to analyze the formation behavior, as depicted in Figure 5 and 6. The formed cupcake-shape cavity has a diameter of about 27 mm. The molds can form the sheets into cupcakes with 5 different cavity depths. Only the cupcake shapes with cavity depth 15 mm and 30 mm were studied in this work. Ranks were given to the formable sheets with different formability, as shown in following:

- Rank1 : Cupcakes cannot be completely formed;
- Rank 2: Cupcakes can be completely formed but have holes through the core;
- Rank 3: Cupcakes can be completely formed but have soft spots;
- Rank 4: Cupcakes can be completely formed and maintain the structure integrity;
- Rank 5: Cupcakes can be completely formed without scrim tear and maintain the structure integrity.

3 sheets of each sample were formed into parts with a cupcake-shape cavity, and a rank was given to each sheet. The formability rank value of each sample was the average value of 3 sheets, and is listed in Table 2. At the cavity depth of 15 mm, both the S-LWRT control parts and the N-LWRT parts show highest rank number of 5. It indicates that all the sheets can fully form into cupcake shape with 15 mm cavity depth without scrim tear, and still maintain the structure integrity without core failure. At the cavity depth of 30 mm, the S-LWRT control parts have an average rank number of 3.7, which indicates that the cupcake-shape cavity formed from S-LWRT control sheets has scrim tear at surface, and loses core structure integrity at some spots of the side walls of the cavity. The N-LWRT sample A parts still have the highest rank number of 5, which means that N-LWRT sample A sheets can fully form cupcakes with 30 mm-deep cavity without scrim tear or core failure. Therefore, the new grade LWRT sheet materials have better formability than the standard grade LWRT sheet materials at the same weight. Additionally, the N-LWRT sample B parts with 12% weight saving also have the highest formability rank number of 5.

In general, the new grade LWRT sheet material provides a solution for both improved formability and weight saving, and it is in agreement with the conclusion drawn in the wedge-shape forming process.

Deep-drawn Shape

The internally developed deep-draw molds are employed to check if the new grade LWRT sheet materials have the ability to form into parts of which the complexity of geometry is similar with that of trunk trim parts. The photographs of deep-drawn parts are shown in Figure 7. The new grade LWRT sheets can be formed into deep-drawn shapes and maintain the integrity of both surface and core structure. This result demonstrates the advantage of the new grade LWRT sheet material that it is able to form a deep drawn, multi-cavity shape at very low core weight down to 500 g/m^2. This weight-saving choice is believed to be attractive for trunk trim applications due to the good formability and reduced cost of the sheet materials.

Summary

The LWRT sheets were molded into different demanding geometries to analyze the forming ability. The new grade LWRT sheet material shows improved formability at reduced weight, compared with the standard LWRT sheets materials. It not only is capable of forming difficult geometries which cannot be molded using standard LWRT, it allows a weight reduction and provides a cost-effective solution for trunk trim application.

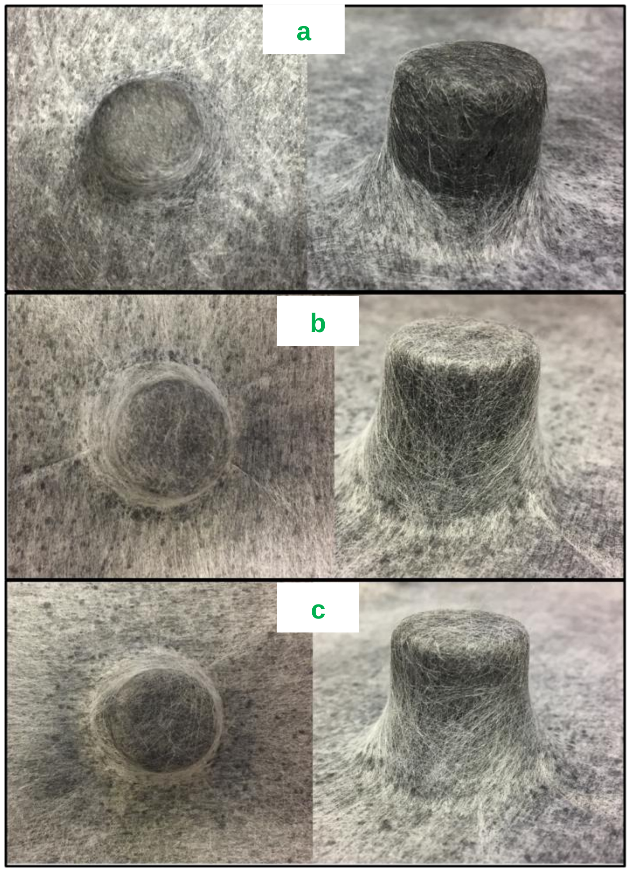

Figure 6: Formed cupcakes with 30mm depth: a. S-LWRT control (top view, side view, back view); b. N-LWRT sample A; c. N-LWRT sample B.

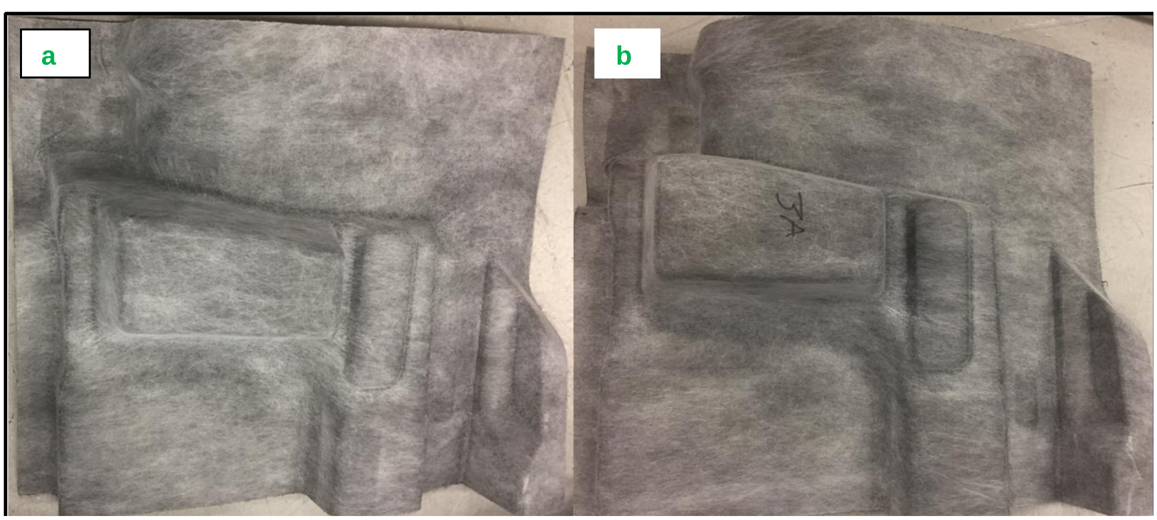

Figure 7: Deep-drawn parts of N-LWRT samples: a. N-LWRT sample A; b. N-LWRT sample B.

Bibliography

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