NEW MATERIAL DEVELOPMENTS FOR LARGE SCALE PRODUCTION IN AUTOMOTIVE SECTOR

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1 Introduction

The increasing shortage of natural resources as well as the bud of alternative driving concepts focuses the improvement in efficiency in the automotive sector. Because the potential of metal alloy is nearly utilized, the interests in fiber reinforced composites are a steadily growing. They are featured with good mechanical properties and low weight at the same time. Presently, the use of fiber reinforced composites mostly fails because of different reasons, e.g. difficult handling, low process speed and high material prices. One way out is the use of semi-finished parts, so-called organic sheets. These are fiber reinforced composite parts with thermoplastic matrix materials, which are already fully impregnated. Thus, it is possible to realize short cycle times and easy handling as well. However, high melt viscosity of thermoplastic resins for fiber impregnation is difficult because, in most cases, fiber weight fraction is more than 60% and the continuous fibers are fully aligned and highly packed, resulting in micron-sized gaps between fibers for the resin to flow toward the inside of the fiber bundle [1,2]. This nature of high loading of aligned continuous fibers makes the resin impregnation process slow and is believed to be the main cause of delayed market penetration of continuous fiber based organic sheets [3, 4].

2 Objectives

The scope of the paper is to introduce a newly developed continuous fiber thermoplastics (CFTs) based on PP+GF combination. A proprietary Multi-Layered-Hybrid (MLH) roving technique was applied before impregnation and consolidation [5]. This MLH roving provides the reinforcement fibers and the matrix material in a specific ratio. Another aim of the paper is to show the producibility of the material with a semi-continuous process. Furthermore the usability of the MLH-Material for the production of profiles should be introduced. The forming and the joining of the material will be presented. Concludingly, the mechanical properties of the new material will be demonstrated.

3 Results

A new production method enables the production of glass fiber prepregs with polypropylene matrix material in a stable, pre-industrial process. The technology turned out to be more cost effective than other methods, which are used for commercial prepreg materials, e.g. TwinTex®. Different textures and also different fraction of weft and warp yarn could be realized.

The use of the woven fabrics based on MLH-roving for differently formed composite parts was successfully demonstrated with the continuous compression molding technique (Fig. 1). The overall impregnation quality of the produced organic sheets was qualitatively acceptable with seemingly low void contents (see Fig. 2).

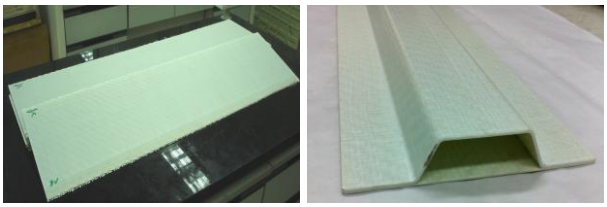


Fig. 1. Differently formed CFTs with MLH roving (PP+GF70wt%) based woven fabrics (left: plates, right: closed-cap profile)

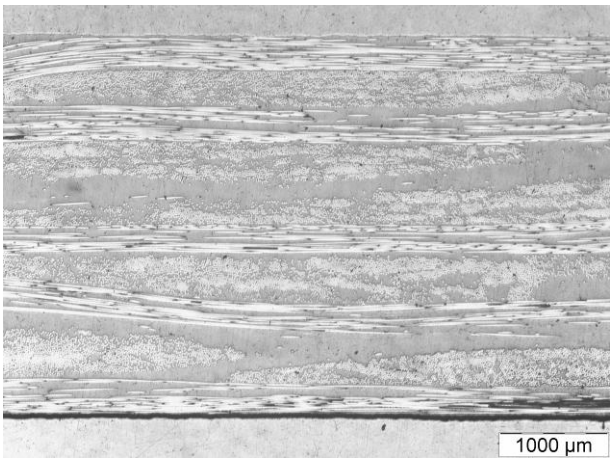


Fig. 2. Impregnation and consolidation quality of the CFT (5 layers) based on the fabric of MLH roving

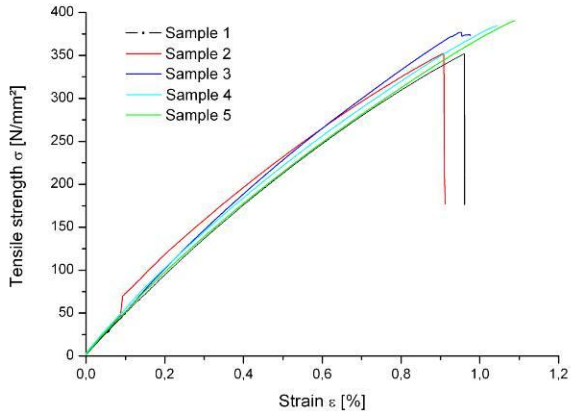


Fig. 3. A tensile stress-strain curve for the consolidated CFTs (PP+GF70wt%, 2:2 twill).

Density and basic mechanical properties of newly developed CFT were measured. Table 1 shows typical tensile and flexural properties of consolidated woven fabrics (twill 2:2 balanced).

Composite Density (PP+GF70wt%)		1.68 g/cm^3	ASTM 792
Tensile	Strength	415 MPa	ASTM 3039
	Modulus	20.5 GPa	
Flexural	Strength	370 MPa	ASTM 790
	Modulus	19.8 GPa	

Table 1. Density, tensile and flexural properties of MLH prepreg-based laminates

The forming process and the joining of organic sheets were demonstrated by means of different geometries. It is shown that the mechanical properties of the tested material are comparable to currently available continuous fiber thermoplastic composite based on PP+GF. For the impact properties, instrumented high-speed puncture tests were carried out. Also, a small-size beam was used to evaluate additional flexural properties in consideration of automotive bumper beams.

High-speed puncture tests based on ASTM 3763 was carried out using Dynatup 9250 (Instron) as seen in Fig. 4 in order to assess exerted load values and absorbed impact energy during the instrumented impact event. 12.7mm hemi-sphere striker was used with 23.2kg of weight and 0.56m of height to generate 127 Joule of impact energy. The specimens were 100mm x 100mm rectangle with 3mm thickness.

Fig 4. Experimental device for the instrumented high-speed puncture

Four types of impact specimens were prepared using GMT (advanced GMT, mixture of random long fiber and aligned continuous fibers in the glass mat), and newly developed CFT as seen in Fig. 5.

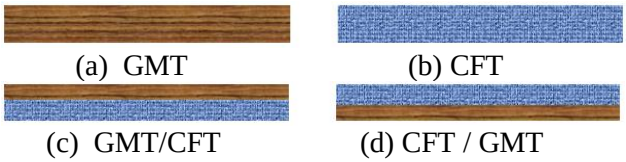


Fig. 5. Test specimens for comparison of high-speed puncture properties

Advanced GMT is commercially available and typically used for rear bumper beams in the automotive vehicles. For the mixture of advanced GMT and CFT, CFT was placed on the bottom (c) and top (d) in Fig. 5 to observe different energy absorbing performance. Table 2 shows density, specimen thickness, weight, peak load and absorbed energy of each specimen for the high-speed puncture tests.

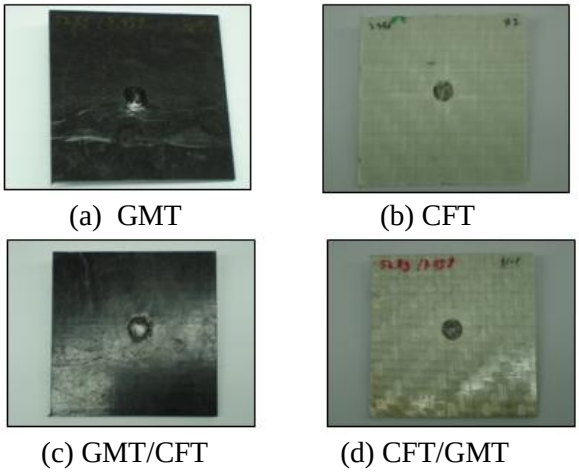
When comparing (a) and (b) for GMT and CFT, respectively, it is clearly seen that both peak load and energy absorption of CFT are nearly two times of GMT owing to continuous fiber characteristic (less crack propagation and hence gradual increase of the load until the end of penetration). In case of GMT, lower peak load and energy absorption could be explained by larger crack propagation and enlarged hole size thus easier penetration, which results in limited load bearing during the impact time.

In cases of GMT+CFT mixture, placing CFT on the backside (i.e. placing GMT as a striking face) shows slightly better impact performance than the other case, which can be naturally explained by better tensile properties of CFT.

Table 2. Density, thickness, weight, peak load and absorbed energy of each specimen for high-speed puncture specimen.

Specimen	(a) GMT	(b) CFT	(c) GMT/CFT	(d) CFT/GMT
Density (g/cm^3)	1.26	1.68	1.51	1.51
Thickness (mm)	4.0	3.3	3.6	3.6
Weight (g)	50	55	55	55
Peak Load (kN)	5.1	10.8	11.6	8.3
Absorbed Energy (J)	33.1	82.9	64.0	50.8

Figure 6 shows tested specimens after the high-speed puncture experiments. It was found that irregular punctured shape was created for the GMT case ((a) in the figure) due to larger crack propagation while the other three cases (CFT and CFT+GMT) indicates much less crack propagation.



(a) GMT (b) CFT

(c) GMT/CFT (d) CFT/GMT

Fig. 6. Specimens after the high-speed puncture tests.

Additionally, 3D shaped small-size bumper beam was fabricated to evaluate the flexural properties of CFT as a local reinforcement. Cross-sectional shape of the bumper beam was typical "U" and 3-point bending test was performed. In consideration of complex shape of the beam ends, LFT (more specifically D-LFT PP/GF40wt%) was used with CFT (LFT/CFT in Fig. 7). LFT filled the outer region of the beam while the inner region was occupied by CFT. For the baseline, GMT beam was also fabricated and compared to the LFT/CFT beam (left in Fig. 7).

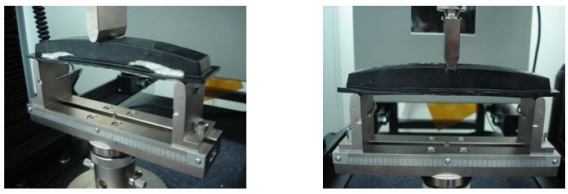


Fig. 7. Flexural test of small-scale beams made of LFT/CFT (left) and GMT (right, baseline)

The length, width and height of the "U" shaped beam was 220mm, 50mm and 30mm. Weight of the GMT beam was 97g whereas LFT/CFT beam was 82g. As depicted in Fig. 8, deformation and fracture were observed after the 3-point bending tests. Fig. 11 displays load-deflection curves for the LFT/CFT

and GMT. Three beams were tested for each case and the average peak load for both cases shows similar values (4.0 ton vs. 4.3 ton in Table 3). However, the energy absorption for LFT/CFT beam was 1.75 times higher (83.5 J) than the base GMT case (47.7 J). As in Fig. 9, the difference of maximum strain between the two material combinations results in much higher energy absorption capabilities. The strain level for LFT/CFT was 15-40% while GMT was only 10-15% in Fig. 9. However, due to the uncontrolled fiber orientation in the LFT layers of LFT/CFT combination, remarkable variation in the maximum strain of the three specimens was observed (upper graph of Fig. 9), which indicates that careful LFT processing is required to minimize the performance fluctuation.

Fig. 8. Small-scale "U" beams made of CFT/LFT (left) and GMT (right)

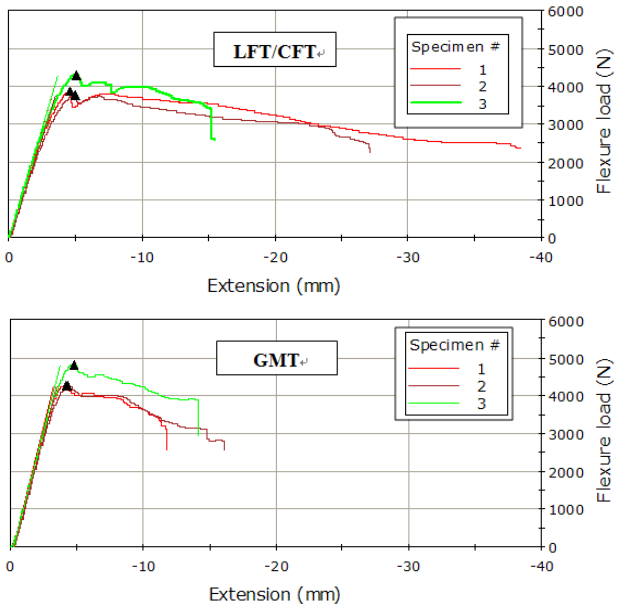


Fig. 9 Load-deflection curve for LFT/CFT (upper) and GMT (lower, baseline)

Table3. Results of 3-point bending tests for the small-size bumper beams with two different composite materials.

Material	Peak Load	Energy Absorption
LFT/CFT	4.0 ton	83.5 J
GMT	4.3 ton	47.7 J

As a next step, a full scale industrial application was considered to explore look for benefits of using CFT. A real-scale bumper beam was designed and manufactured for 1700kg SUVs. As in the case of bending tests of small-size beams, same material configuration (LFT/CFT vs. GMT) was used and compared. The main performance index of the impact beam for automotive vehicle was intrusion of beam during the impact testing. Impact speed was 10KPH for the full barrier impact tests as shown in Fig. 12 where upper and lower antenna-type rulers measure intrusion and deflection of bumper beams. Deformable (black) and rigid (blue) barriers are covered by a plastic cover in orange.

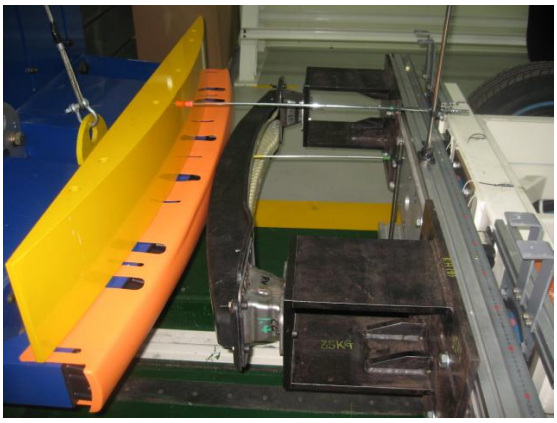


Fig.12 10 km/h RCAR full barrier impact test

Fig. 13 shows schematic design of LFT/CFT and GMT bumper beams used for the full barrier impact tests. In order to compare the intrusion performance, the two beams were manufactured having similar weight (5.0kg for LFT/CFT beam and 5.1kg for GMT beam). Due to the density difference between the two material configurations, GMT beam was manufactured slightly thicker (~10%) than LFT/CFT case.

Fig.13 Full-size bumper beams made of LFT/CFT (left) and GMT (right)

After the full barrier tests, intrusion values were measures and visual inspection of the beam damage were carried out. LFT/CFT beam showed 125mm of intrusion which is 20mm less than the GMT beam (145mm). This implies that back panel (made of steel) can be better protected by 20mm when using LFT/CFT beam. This also means that repair cost for back panel and tailgate of an SUV can be reduced with CFT reinforced composites beams made of LFT or GMT. In both cased, major damage region was center of the beams, but LFT/CFT beam showed qualitatively better damage mode thank to highly loaded continuous fibers.

4 Summary

A newly developed continuous fiber thermoplastics (CFT) was presented with high mechanical properties. Also, this research work combines the CFT to commercially available LFT (Long Fiber Thermoplastics) and compared conventional GMT in order to demonstrate better energy absorbing capabilities in both static and dynamic loading cases.

(1) High-speed Puncture Test

GMT/CFT mixture showed 2 times higher impact properties than GMT having same weight. This implies CFT can help weight reduction of a composite part with same performance.

(2) Flexural Test

GMT/CFT mixture showed 75% higher energy absorption capability than GMT due to higher strain value when fractured.

(3) Full-size Barrier Impact Performance

- A full-scale bumper beam was manufactured made of LFT/CFT and conventional GMT for 10 km/h full barrier impact testing. LFT/CFT configuration showed 20mm less intrusion than GMT version, thus better protection for back panel and tailgate can be expected when CFT is used for the beam with typical long fiber thermoplastics (including GMT).

Currently, PP/GF based CFT has been developed and demonstrated the contribution for vehicle weight reduction (or performance enhancement with same weight). Further work will include creating various material combinations for widening applications (PA/GF, PA/CF, PET/GF for example). Also, process optimization for parts manufacturing should be thoroughly conducted when combining CFT with conventional composites such as LFTs and GMTs. Since CFT has inherent weakness in out-of-plane properties, delamination during manufacturing process or various static/dynamic loading cases.

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