Sheet molding compounds (SMC) of glass fiber and textile grade carbon fiber

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Abstract

Composite materials are indispensable in modern industries, offering a unique blend of strength and lightness. The process of hybridizing glass fiber (GF) and carbon fiber (CF) within composite materials yields a synergistic material characterized by improved strength, stiffness, and impact resistance. This method offers a unique system balance between CF's high performance and tough, affordable GF. In this study, an innovative composite system was developed by hybridizing glass fiber sheet molding compounds (GF-SMC), with wet-laid textile grade CF nonwoven mats (TCF WL). The hybrid process was conducted as a single step process and the system was manufactured using compression molding. Optical microscopic images were captured on the interface of the H-SMC exhibited a good adhesion between G-SMC and TCF WL mat. Both SMC and wet-laid process exhibit random fiber orientation representing isotropic properties. Mechanical tests conducted on the hybrid samples in the X and Y-directions revealed a standard deviation of less than 5%, indicating that the fiber orientation distribution remained unaffected during the manufacturing process. An improvement of 21% and 40% in flexural strength and modulus respectively were monitored. 14.5 and 50% in tensile strength and tensile modulus were reported as well.

Keywords: Glass fiber sheet molding compounds, Textile grade Carbon Fiber, Wet laid, Hybrid, Interface bonding.

1. Introduction

The transportation sector in the United States accounts for over 70% of the country's total petroleum consumption, despite progress in alternative fuels. While enhancing fuel economy is crucial for reducing the carbon footprint and achieving energy security, the petroleum industry continues to meet 93% of the nation's transportation energy demand [1]. National Highway Traffic Safety Administration (NHTSA) has proposed new Corporate Average Fuel Economy (CAFE) standards for passenger cars, light trucks for heavy-duty pickups (2027-2035). The plan targets a 58 MPG fleet-wide average for cars and light trucks by 2032, with annual 2% and 4% fuel economy increase, respectively. Heavy-duty vehicles aim for a 10% yearly efficiency boost. The proposal, aligned with Congress' energy conservation goals, seeks public feedback [2]. Weight reduction is the game changer in the automotive industry to scope the government needs and decrease the carbon footprint [3, 4]. Fiber- reinforced sheet molding compound (SMC) is a versatile composite material used in diverse industries, featuring a resin matrix, reinforcing fibers, and additives for high-strength, lightweight components [5, 6]. Its molding process allows for complex shapes, making SMC a cost-effective solution for applications such as automotive body panels, electrical enclosures, and structural components. Glass fiber (GF) and carbon fiber (CF) are commonly used as reinforcement in the SMC manufacturing [7, 8]. However, there is more interest in automotive industry on using commercial grade GF-SMC due to the cost-effectiveness, and high strength compared to steel [9]. The short fiber length and the low property of commercial GF compared to carbon fiber make it unsuitable for some structural applications. Many studies suggested a hybrid SMC (H-SMC), consisting of GF overmolding with unidirectional prepreg tape (UD tape). Trauth et al [10] studied the effects of hybridization of continuous CF with discontinuous GF, by using 60% glass as a core and the 40% CF on top and bottom by volume fraction. The materials have been processed at once. The study showed a 171% increase in tensile modulus, 204 % in tensile strength and 151 % in compressive modulus. Wulfsberg et al [11] developed a new hybrid technology in the aerospace industry by combining GF with carbon fiber (CF-SMC) with Unidirectional (UD) prepreg fabric. The UD fabric was implemented in the middle between two layers of GF/CF-SMC and compressed at the same time. The study showed a significant increase in the tensile strength/modulus (~64/101%) as well as flexural strength/modulus (~32/103%) of the hybrid part compared to the neat GF/CF-SMC. However, the impact strength decreases due to the poor interlaminar bonding between the UD prepreg fabric and the GF/CF-SMC.

H-SMC would offer a high strength and stiffness compared to GF-SMC. However, the cost would be significantly increased by using UD tape in the final parts [11]. In this study H-SMC was manufactured using GF-SMC compression overmolded with wet laid textile grade carbon fiber (TCF WL). Mechanical and morphological properties were investigated following ASTM standards. To the best of the authors' knowledge, there are no publications in that field.

2. Materials and manufacturing processes

2.1 Materials

GF-SMC intermediate (20% by weight glass fiber reinforcement) has been procured from IDI Composites International, Noblesville, IN. 1 inch chopped textile grade carbon fiber (TCF) was delivered by carbon fiber technology facility (CFTF) at Oak Ridge National Laboratory. The fiber was processed through wet laid and delivered by Endeavor Composites, Inc. Knoxville, TN

2.2 Manufacturing process

A 10-gsm carbon fiber wet laid mats (WL) were processed using Endeavor Composites technology [12]. The compression molding process has been carried out using a 150 T WABASH press. 11 x 11 inches plates have been manufactured using a metal additive manufacturing mold. Two sets of plates were prepared (GF-SMC and H-SMC). For the GF-SMC, 2 layers of glass (6.5 x 6.5 in) were consolidated at 1000 Psi for 90 seconds and a temperature of 300°F. All the materials were produced as a one-step process. In the H-SMC manufacturing, the same process was maintained except adding one layer of WL mat, as shown in Figure 1.

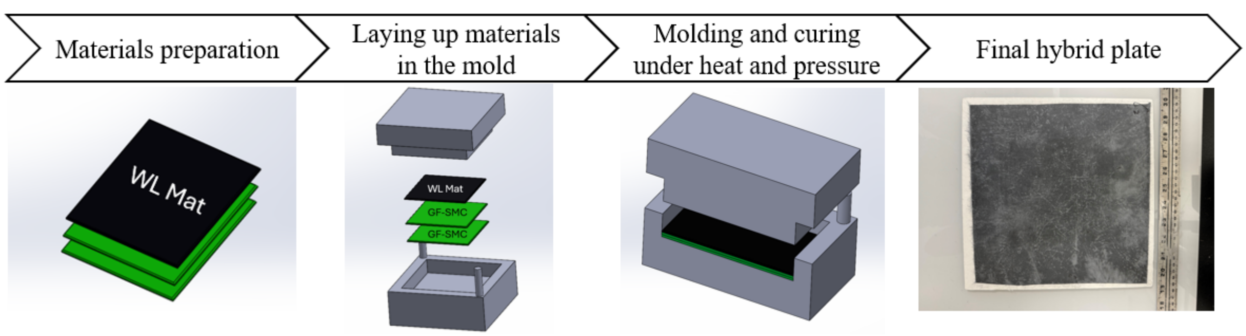

Figure 1. Schematic process for the manufacturing of the H-SMC parts.

2.3 Samples preparation

Two sets of plates were prepared, one without (GF-SMC) and the other set with TCF WL mat (H-SMC). Coupons were extracted from different locations of the plates, a minimum number of 10 coupons were secured for each test. The samples used were cut using a JETOM 2026 water jet system. The flexural, interlaminar shear strength, tensile and izod tests were conducted in accordance with the ASTM standard associated with each one of them on a TestResources, Inc, Shakopee, MN test frame, with a load cell of 50 kN. Digital images were captured before and after testing using KEYENCE optical microscope.

3. Results and discussion

3.1 Three-point bending (flexural)

The flexural strength and modulus were analyzed in accordance with ASTM D790. The tests were carried out with a control rate of 1.341 mm/min. Figure 2 is a typical load vs displacement plot showing the failure behavior of the tested coupon. Figure 2a shows the flexural strength of H-SMC with an increase of 21% (122 MPa) compared to GF-SMC (101 MPa). An improvement in the stiffness of the H-SMC (10.8 GPa) specimens was also noticed with an increase of 40% in flexural modulus compared to GF-SMC (6.5GPa). Both GF-SMC and H-SMC exhibited a linear behavior before reaching the ultimate strength (failure point). GF-SMC suddenly dropped after reaching its ultimate strength at 145N. However, for the H-SMC a small drop was noticed at the failure point and the specimens were able to hold the load for a longer period. That could be due to the TCF WL mat layer that has been added. In addition to the improvement in the maximum load attained before failure (197 N).

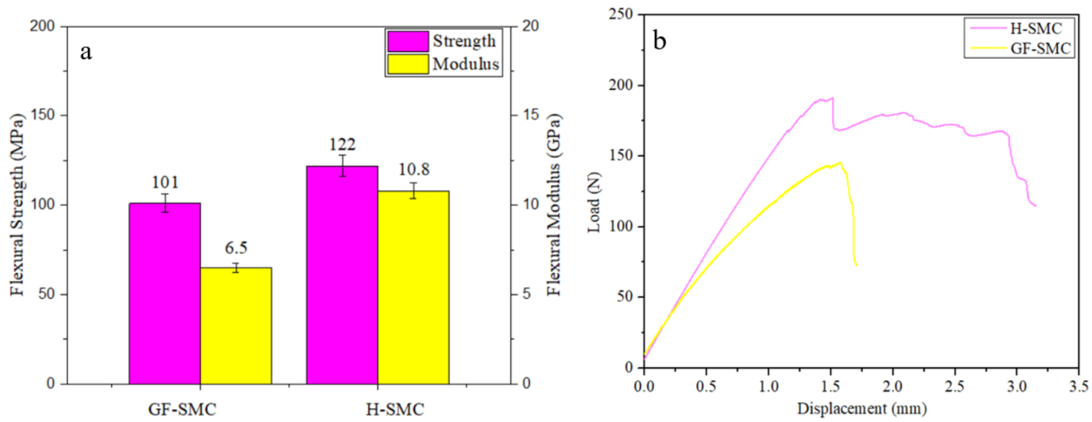

Figure 2 (a, b). Three-point bending data showing an increase in the flexural strength and modulus of H-SMC compared to G-SMC. The typical load vs displacement plot highlighted the failure behavior of both sets.

3.2 Interlaminar shear strength (ILSS)

The assessment of short beam strength, referred to as ILSS, followed the guidelines outlined in ASTM D2344. A consistent control rate of 1 mm/min was maintained throughout the testing procedure. ILSS results for H-SMC displayed a remarkable enhancement of 75% compared to GF-SMC. This substantial improvement is believed to be linked to the effective integration of the rCF mat, which notably bolstered the adherence at the interface and facilitated bonding between the fiber and the matrix during the manufacturing phase. Digital images were captured before and after the tests to analyze the failure mechanisms of the samples as illustrated in Figure 3 (a, b).

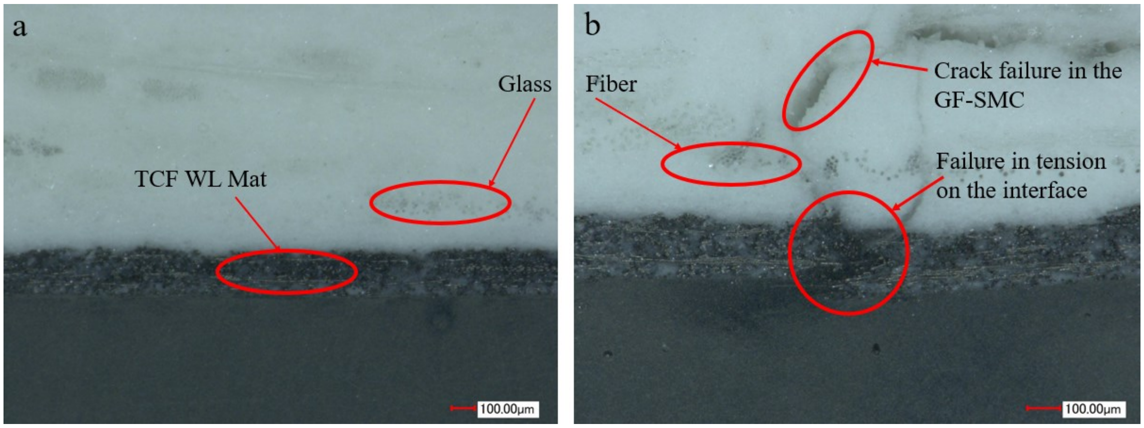

Figure 3 (a, b). Cross section OM images for the H-SMC before and after testing. The OM images shows a good bonding between the GF-SMC and the TCF WL mat on the interface. A crack failure in the GF-SMC was monitored near the interface and a failure in tension for the specimens without noting any delamination on the interface in the H-SMC samples.

Figure 3a. shows a cross-section image of the H-SMC prior testing. A fair amount of resin and glass fiber could be observed on the TCF WL mat layer on the interface, that would be a good indicator of good bonding between the GF-SMC and the TCF WL mat. A failure in tension has been pragmatic in all the H-SMC samples, and a crack was noticed in the GF-SMC part as seen in Figure 3b. No delamination was monitored on the interface after failure, sustaining the strong bonding between the WL mat and the GF-SMC. As shown in the OM images, there was no porosity detected in either GF-SMC or H-SMC. Void content was calculated using images captures with a Phenom XL, scanning electron microscopy (SEM), as shown in Figure 4. Samples have been extracted from both plates, GF-SMC and H-SMC and placed in a circular tube filled with resin to polish the surface before SEM. The surface was polished using Buehler equipment and supplies on a Minitech 300PSI.

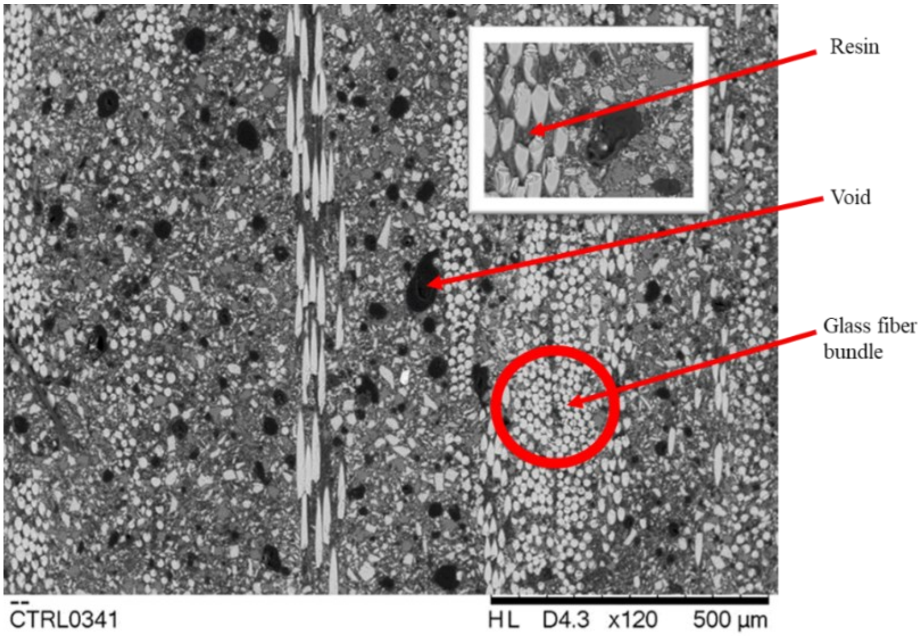

Figure 4. SEM image showing the void content on the GF-SMC samples. Void content was calculated using threshold software to quantify the void in each coupon.

It shows that the void content decreased from 5.14% in the GF-SMC to 3.07%, noting that both were processed at the same parameters. However, the decrease could be related to the load applied by the mats on the GF-SMC while manufacturing the plate, a further experiment will be conducted to reach a void content less than 1% in future.

3.3 Tensile test

The in-plane tensile properties of the GF-SMC and H-SMC were carried out in accordance with ASTM D3039, an axial extensometer (Model 3542, Epsilon tech) was used to measure the deflection in the sample and to calculate the tensile modulus. A control rate of 2mm/min was maintained during testing. Figure 5 showed a slight increase in tensile strength of around 6.25% and an improvement of 50 % in tensile modulus. Recalling that TCF WL mats are discontinuous 1 in short fiber, and the layer added was 10 gsm which is around 3% by weight of the final manufactured plate.

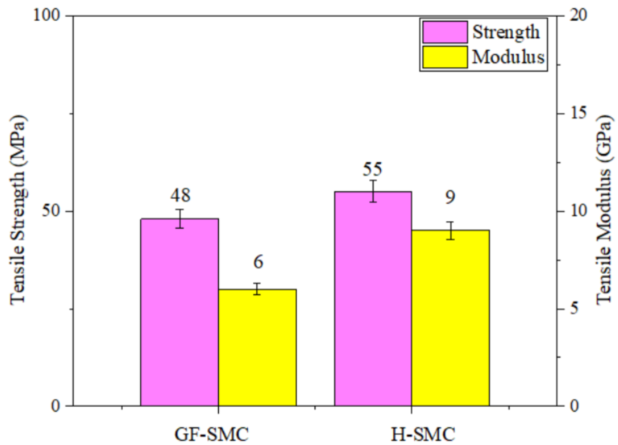

Figure 5. Tensile strength and modulus of G-SMC and H-SMC. An improvement of 14.5% in tensile strength and 50% in tensile modulus.

3.4 Izod impact test

The Izod impact strength test was conducted on Tinius Olsen Inc, Horsham, PA Model impact 104. All the samples were prepared using a water jet system with dimensions of (63.5 x 12.7 x 3.1mm) in accordance with ASTM D256. Figure 6 shows the impact strength of GF-SMC and H-SMC. A reduction of 3.5% was noticed in the H-SMC compared to GF-SMC. The reduction is reasonable since glass fiber performed better in impact, and the reduction amount (3.5%) could be related to the amount of TCF added in the H-SMC (3.5%) by weight fraction. Noting both samples performed with the same thickness, the only difference is in the H-SMC a part of the 3.1mm is carbon fiber and that could explain the small decrease in the impact strength, within the range of standard deviation.

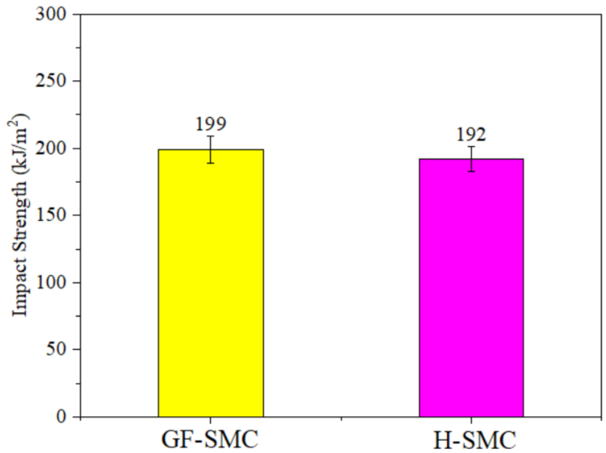

Figure 6. Impact strength of GF-SMC and H-SMC, a reduction of 3.5% in impact strength has been noticed.

Conclusions

A novel hybrid (H-SMC) system was successfully manufactured by compression molding as one step the TCF WL mat and GF-SMC. No fibre attrition or disorientation was observed in the final part after consolidating the WL mat with GF-SMC. Microstructural analysis showed strong bonding on the interface between the TCF WL mat and the GF-SMC. The void content decreased from 5.14% to 3.07 %. The bonding mechanism on the interface between the TCF WL mat and the GF-SMC was analyzed using various mechanical tests such as three-point bending, ILSS, Tensile and Izod impact. ILSS showed an improvement of 75% in the H-SMC compared to GF-SMC. An increase of 21% and 40% has been reported in the flexural strength and modulus respectively. A 14.5% and 50% enhancement in tensile strength and modulus was stated as well. However, a small reduction of 3.5% has been noticed in the Izod impact test, which is within the range of standard deviation. Overall, this study was able to prove that TCF WL mat could be integrated with GF-SMC to manufacture a new system that can be produced quickly while maintaining higher mechanical properties. Further investigations will be done in the future and a finite elements analysis model will be adapted to predict the fiber orientation prior manufacturing. H-SMC could be a promising technology to be adapted for high-volume automotive applications.

Acknowledgments

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