MECHANICAL BEHAVIOR OF COMPRESSON MOLDED HYBRID COMPOSITES

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Abstract

A major challenge for the composite engineers is to develop stiff lightweight structural materials supporting modern design concepts. Hybrid composites are the material produced by two or more types of fibrous reinforcement combined in a single polymeric matrix, which offer a great diversity of mechanical properties. The focus of this study was to investigate the mechanical behavior of various hybrid sandwiches, which combine continuous woven composite and different discontinuous reinforcements. The discontinuous reinforcements included sheet molding (SMC), bulk molding (BMC) compounds and the discontinuous platelets. The platelets were produced from the trim scrap obtained during conventional layup, which was mechanically chopped to provide a usable form of the compression molding compound. Hybrid sandwich configurations using different core materials exhibited improvements in flexural mechanical properties, while digital image correlation analysis revealed different damage propagation behavior in sandwich structures. Combination of delamination and interlaminar shear failure were observed in the sandwich structure, indicating various failure modes in these composite systems.

Introduction

Compression molded composites have been utilized as an alternative material to metals in the automotive and aerospace industries because they offer short manufacturing cycles, lower production cost and allow for weight reduction [1-5]. Furthermore, composites manufactured by compression molding offer the ability to produce composites from various material forms including continuous, prepreg based systems, and discontinuous systems, e.g. sheet, bulk molding compounds [1-3, 6,7] or platelet based reinforcement [8-10]. The source of platelet reinforcement can be from traditional preimpregnated, prepreg, fiber system or from re-utilized trim scrap, which accounts for up to 30% of the material in some layups [11]. The latter one allows to effectively reutilize up to 40% of the overall material as a trim scrap waste into a usable form of compound for compression molding. Reutilization of the trim scrap materials is an important parameter for the cost effectiveness in composite manufacturing and can be performed by turning the scrap material into discontinuous material system for compression molding.

The combination of continuous and discontinuous fiber-based material forms is referred to as a hybrid composite system and can have applications in manufacturing structural components of various shape complexities. The hybrid system concept carries novel opportunities not achievable with a single type of fiber reinforcement. Specifically, a discontinuous composite system allows greater processability since it can be molded into complex shapes, which is often not possible with continuous fiber based material forms. However, discontinuous material systems alone have limited mechanical properties (stiffness and strength) with substantial variability caused by locally varying meso-scale morphology. Inclusion of continuous fiber composites can reduce variability and enhance strength of the hybrid systems [12-13]. For example, including discontinuous reinforcement between the continuous plies in a sandwich configuration can leverage superior mechanical properties in continuous lamina to improve bending rigidity, while discontinuous reinforcement in the core of the sandwich plate provides additional resistance to shear loads promoting damage tolerance. However, to achieve the aforementioned benefits offered by hybrid composite systems, the guidelines have to be established based on the processing-structure-property relationships that originate in these complex material systems. For instance, the size of a single chopped platelet may significantly affect the composite strength as the platelet size controls the stress-transfer within a composite and defines the attainable stiffness and strength level. The present study considered various discontinuous fiber material forms to study their effectiveness in symmetrical sandwich configuration. The fracture behavior was analyzed using digital image correlation (DIC) and enhanced greater understanding of the measured flexural properties of various sandwich structures.

Material Preparation

Glass-fiber woven fabric, pre-impregnated with epoxy resin was supplied by Mar-Bal Inc. (MBI). The trim scrap material from the same glass-fiber weave was provided by MBI. The provided scrap pieces of different size were mechanically cut into 1” wide strips then cut into two different sizes, 1”x1” and 1”x½” providing two different platelet dimensions for testing (Fig. 1). The chopped platelet material was stored in a negative 20-degree freezer to prevent curing and was removed and defrosted from the freezer prior to molding. Other discontinuous material systems provided by MBI included sheet molding and bulk molding compounds with glass fiber reinforcement. The materials were compressed with a 155 ton-force, and isothermally cured at 290°F for 170 seconds (Fig. 2).

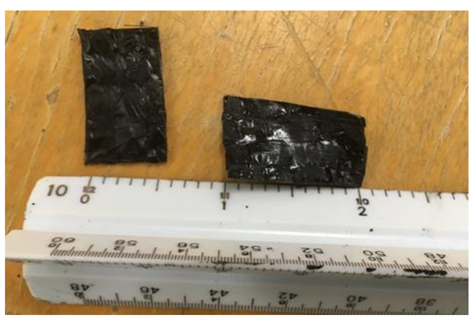


Figure 1: Discontinuous material used to prepare chips

Different configurations that were molded included bulk molding compound (BMC), sheet molding compound(SMC), 2 ply SMC/BMC/2 ply SMC sandwich, 2 ply prepreg/BMC/2 ply prepreg sandwich, 2 ply prepreg/ SMC/ 2 ply prepreg, 2 ply prepreg/ 1”x1/2” prepreg chip/ 2 ply prepreg, 2 ply prepreg/ 1”x1” prepreg chip/ 2 ply prepreg, 1”x1/2” prepreg chip, 1”x1” prepreg chip and 8 ply prepreg.

Figure 2: Hot press and mold for plaque manufacturing

The molded samples received from MBI were a 12” x 12” square. To test each material system, samples were cut into 3” x 1” pieces. The test samples were cut to size using a Fanuc Robodrill (Oshino-mura, Japan), to have a tolerance of +-.005”. The sample dimensions were measured using a digital caliper. All samples were cut to about 1”in width. Single component produced either from trim scrap, BMC, SMC as well as all sandwich configurations were about 9.5mm. Thickness of woven laminate was 5.9 mm.

Methods

Flexural Test

A MTS TestWorks 4 (MTS corporation, Eden Prairie, MN) was used to perform the flexural test in accordance with the test standard from the American Society for Testing and Materials (ASTM) D7264, Procedure A (3-Point bending test). The samples were tested in displacement controlled configuration with the crosshead speed of 1 mm/min. The span for 3-point bending test was selected to be 60 mm, close to short beam configuration, for studying the effectiveness of sandwich hybrid structures in carrying increased shear loads. Figure 3 below shows the setup configuration used in the present work.

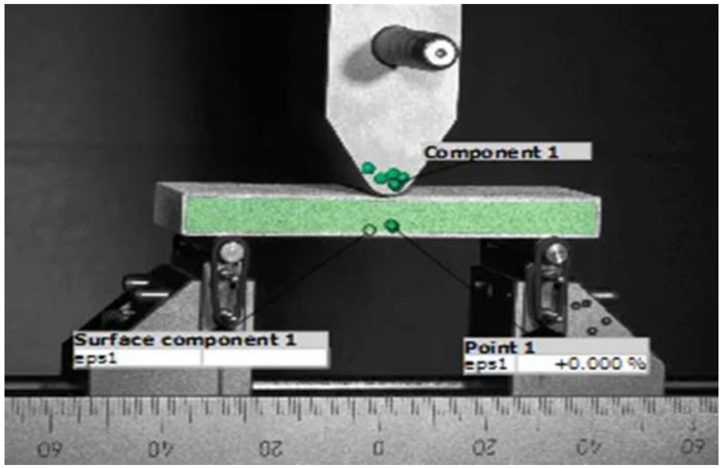


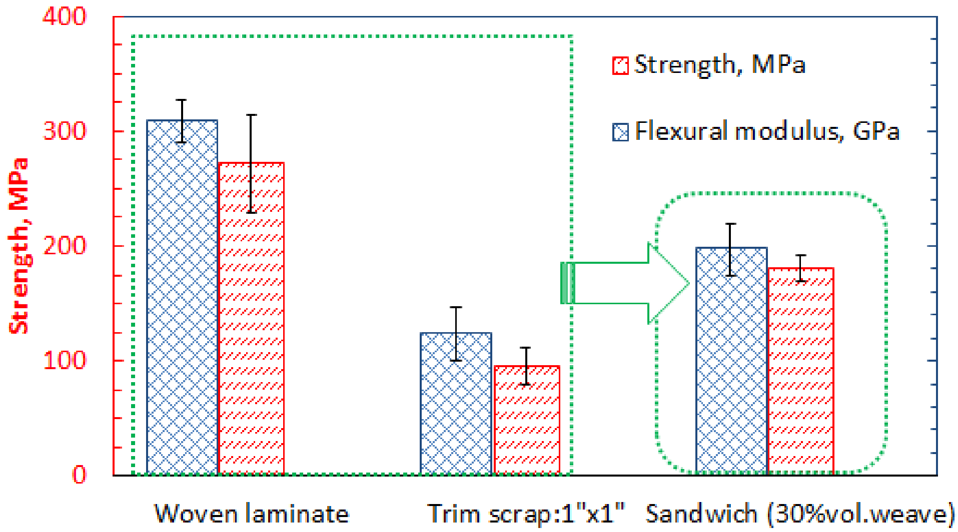
Figure 3. Short beam 3-point bending configuration for testing hybrid sandwich configurations

Digital Image Correlation Analysis

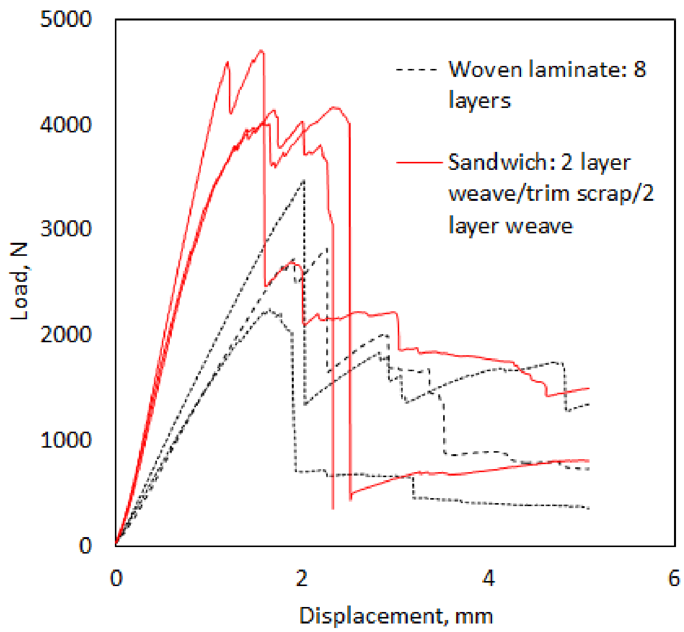
Digital Image Correlation (DIC) was used to quantify full field 3D deformation and strain profiles during 3-point bending of the samples. ARAMIS 3D DIC system was collected with 1Hz frequency. The white and black speckle pattern was generated on the side surface of the sample by spraying white and black spray paint. The representative speckle pattern is shown in Fig. 3. The major strain components were considered, which were calculated with GOM Correlate software using the measured in-plane strain components during the 3-point bending testing.

Discussion

The advantage of using sandwich configuration can be seen in Fig. 4. The sandwich configuration implementing symmetric arrangement of woven glass fiber at 30% vol. and 1"x1" platelets in the core allows to reach 65% of strength and 70% of stiffness of the woven composite (Fig. 4a). The other advantage of using sandwich configuration can be seen in terms of the structural response, which is shown in Fig. 4b. The load displacement response of 5.9 thick woven composite is improved both in terms of stiffness and strength when 9.5 mm thick sandwich is used. It is important to notice that in the case of sandwich structure only half of glass fiber weave was used, while the core material was produced from the trim scrap produced during layup of woven plies.



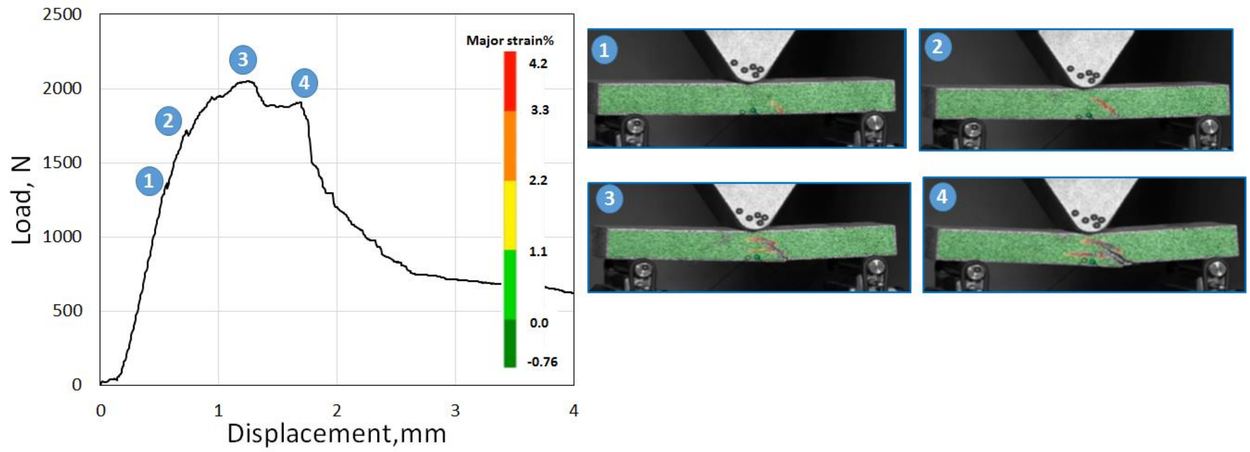
a.



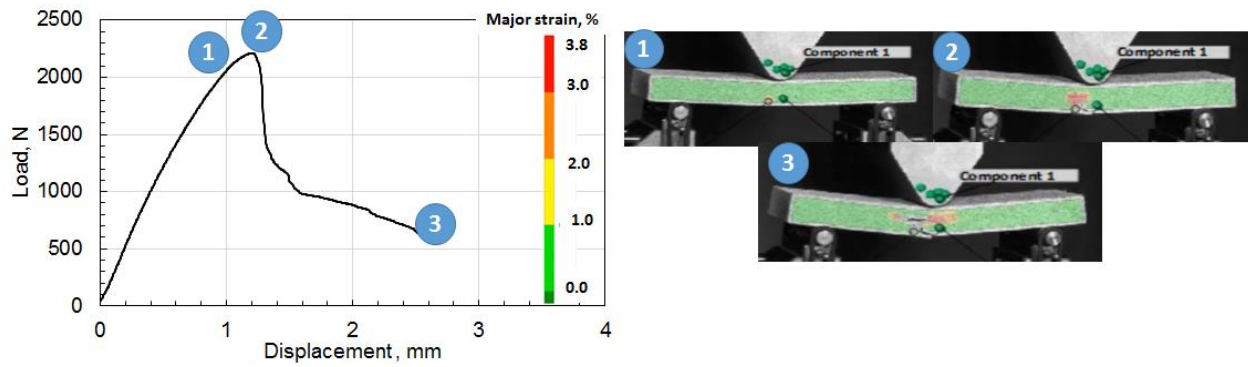
b.

Figure 4. Load displacement response of woven laminate and sandwich utilizing trim scrap

The insight into the damage initiation and propagation of single component composites was gained by means of DIC results collected during 3-point bending test. Fig. 5 shows that use of trim scrap platelet molding compound provided the material with significant ability to progressive failure. Specifically, damage originated on the tensile side of the sample and propagated towards the loading pin on the top surface with the significant extent of crack branching and deflection, which corresponds to the plateau on the load-displacement curve. This progressive damage behavior was not observed with the BMC, which showed rather brittle fracture. In case of both woven laminate and SMC delamination was the primary failure phenomena (Fig. 5b).



a.



b.

Figure 5. Comparison of damage propagation and load displacement in 1x0.5" trim samples (a) and BMC (b)

The comparison of average flexural strength and modulus with standard deviations are shown in Fig. 6 below. The summary of 3-point bending shows that all material configurations followed similar trend for flexural modulus and strength, namely BMC having the lowest mechanical properties, while woven glass fiber showed about 10% higher strength and about the same stiffness than SMC.

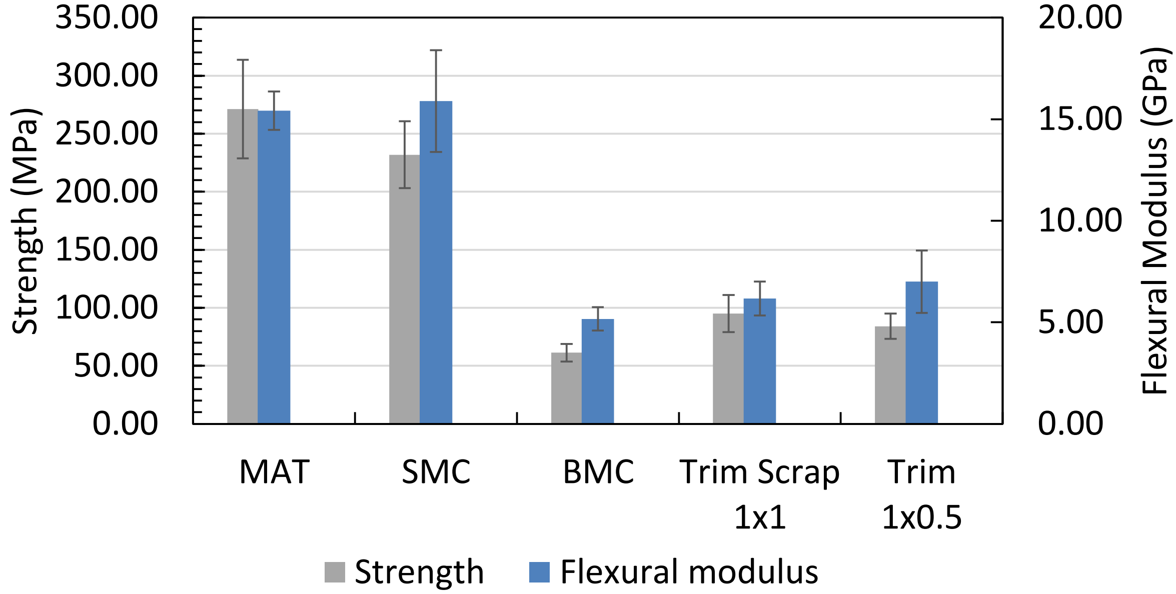
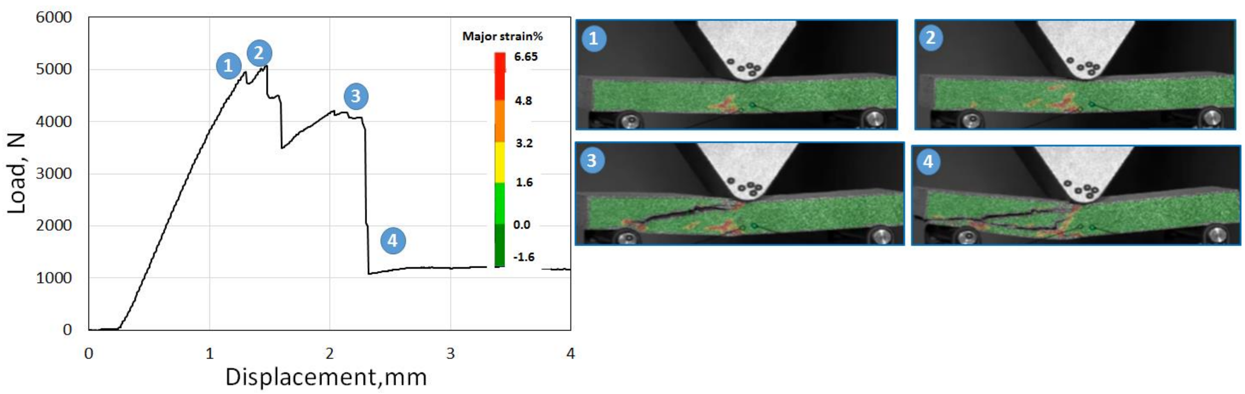
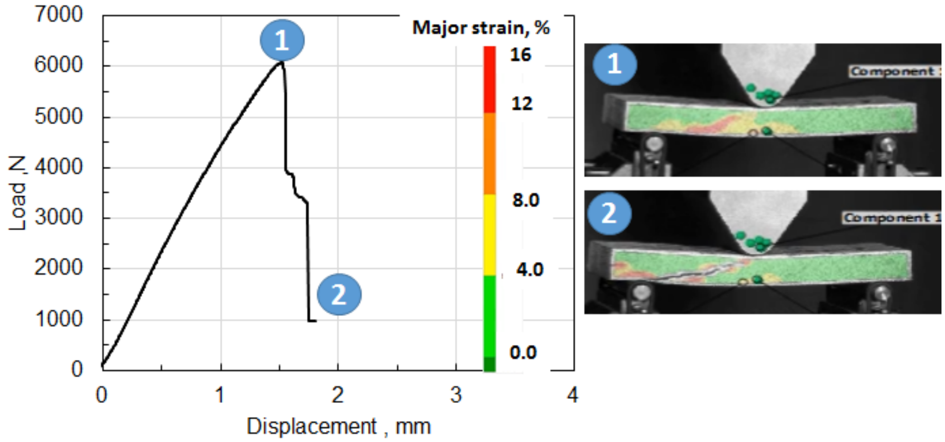


Figure 6. Summary of flexural testing for single component composites

3-point bending flexural testing was used to study mechanical properties of the sandwich structures using various core materials. All sandwich configurations had the same thickness. The example of DIC damage propagation in 2MAT/Trim1x1/2MAT is shown in Fig. 7a. It is evident that damage initiation took place at the bottom location of the sample near the interface between glass woven laminate and the platelet molding compound. As the load increased, other damage site originated in the sample and became dominant, producing a crack, which extended to the top interface between the core and the laminate face sheet. The improved mechanical response of hybrid sandwich structure was observed when considering the configuration with BMC core (Fig. 7b). BMC sandwich configuration showed significantly higher mechanical properties than the other configurations even outperforming the platelet and SMC based hybrids (Fig. 8). This result can be explained by the increased role of shear failure in the core material as opposed to the tensile failure in the single component composite. However, similar to single component composite, BMC sandwich showed brittle behavior when compared with trim sandwich. This result suggests that BMC, which provides the 3D random fiber orientation, yielded improved shear carrying capacity when used in sandwich configuration. The other materials, SMC and platelet compound, which were used for the sandwich core show more laminar structure, which is prone to delamination in the case of SMC and combination of delamination and fiber failure in case of platelets. Furthermore, trim scrap platelets allowed for greater damage tolerance due to higher load carrying redundancy when compared to traditional discontinuous fiber reinforcement. From the structural response it is evident that hybrid sandwich configuration provides additional source for enabling damage tolerance in composites.



a.



b.

Figure 7. Damage propagation and load-displacement response in 2MAT/Trim1x1/2MAT (a) and 2MAT/BMC/2MAT (b)

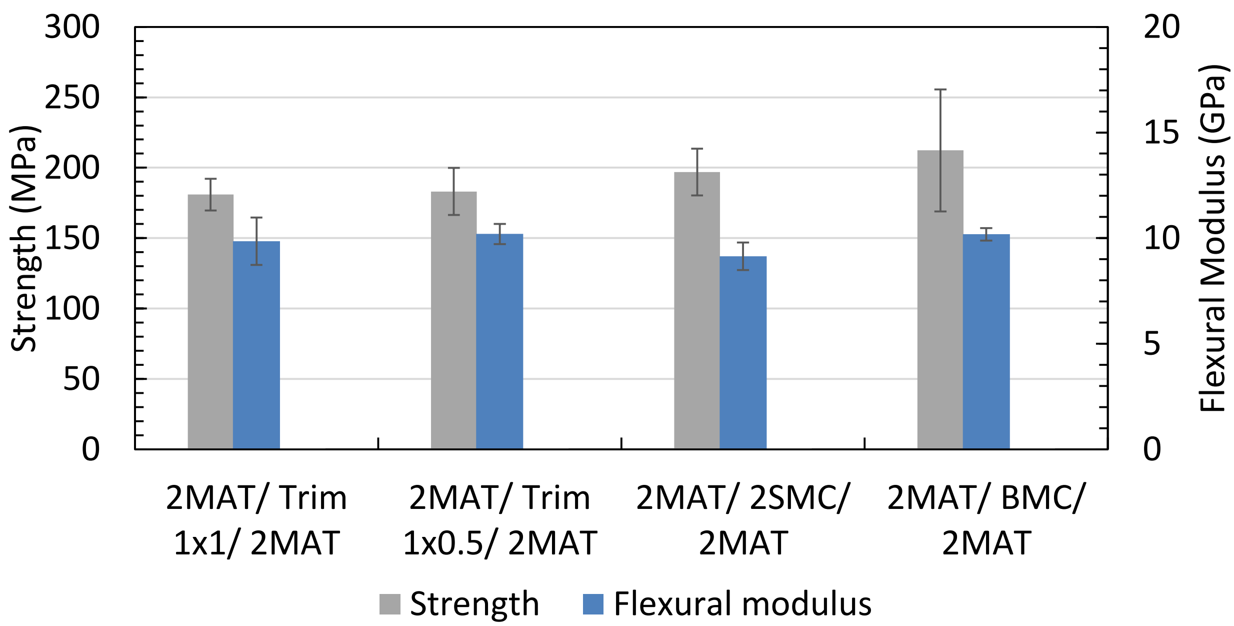


Figure 8. Comparison of hybrid sandwich structures with different core material

Conclusions

The study considered different sandwich configurations using various discontinuous fiber forms. Specifically, discontinuous 3D random fiber arrangement (BMC), discontinuous 2D random fiber arrangement (SMC) and platelet reinforced composites. Symmetrical sandwich configurations were considered and revealed that 3D random arrangement of discontinuous fiber is more efficient material form in short 3-point beam testing, even though the nominal properties of BMC composite were found to be the lowest among other molding compounds used in sandwich core. Furthermore, the results of DIC analysis indicate that platelet reinforced composites and its hybrid structures allow for improved progressive damage prior to loss of structural capacity. This result can be explained that platelet reinforcement is more efficient material form for load transfer than individual fibers, while irregular orientation of the platelets in compression molded composites allows for greater structural redundancy and load redistribution upon damage initiation.

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