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FABRICATION OF THERMOPLASTIC COMPOSITE SANDWICH PANLES WITH RECYCLED PET FOAM CORE USING HOT PRESS

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ABSTRACT

Thermoplastic composite materials are gaining more attention due to their specific properties such as strength-to-weight ratio. These materials are also known for their superior impact resistance, making them ideal for applications where durability is crucial. Their inherent recyclability further contributes to environmental sustainability, aligning with the growing demand for eco-friendly materials. In the current paper, the hot press lamination technique has been evaluated to manufacture Glass/Polypropylene (Glass/PP) thermoplastic-based composite sandwich panels. Due to the escalating environmental concerns, fully recycled Polyethylene Terephthalate (PET) closed-cell foam is selected as the core material in the present research. Process modification and mechanical testing are required to ensure the quality of the product before entering the market. The impregnation of the composite facesheet and the establishment of proper bonding between the facesheet and the PET foam core present challenges due to the relatively high viscosity of PP resin. Therefore, a parametric study was performed to optimize the hot press manufacturing process conditions. Mechanical testing was conducted to evaluate the adhesion bonding characteristics between the skin and core of laminated composite sandwich panels. The final results of both peel-off and flatwise tensile tests indicated that a satisfactory connection was formed between the composite facesheets and the PET core in sandwich panels laminated through the optimum process conditions.

1 INTRODUCTION

Sandwich panels have become an integral part of nowadays' industries requiring load-bearing yet lightweight structures with excellent thermal and acoustic insulation properties. Thermoplastic-based composites are particularly noted for their favorable mechanical properties, manufacturing ease, and environmental benefits [1,2]. Thus, several researcher have been examining the efficacy of sandwich panels featuring various combinations of skin and core materials to optimize their performance. Modifications to the composite facesheets, core configurations, or enhancements with adhesive layers have been shown to substantially influence the load-bearing capacity and failure modes of these panels [3–5]. Efforts to enhance the bonding between layers are crucial as they ensure effective load distribution across the composite skin, with certain studies specifically focusing on this aspect of thermoplastic composite sandwich panels [6,7].

Recent trends in the industry reflect a growing shift toward using recycled or recyclable thermoplastic materials, touching the sustainability and environmental footprint of the products. Particularly, PET material, with recycling potential, is gaining attention. Assessments were performed revolving around innovative applications such as recycled bottle caps and eco-friendly PET foam cores for sandwich panels [6,8,9]. Kang et al. have undertaken a thorough investigation into the entire lifecycle, including the fabrication and recycling, of glass fiber PET core composite sandwich panels [10]. Nevertheless, the use of recycled thermoplastic materials in composite fabrication processes is quite new and requires further evaluation.

Extensive research has been conducted to refine the compression molding process for thermoplastic-based sandwich panels [11]. In the present study, fully recycled PET foam material was used, while eliminating the need for any additional adhesive layers. The PET foam core assessed in this research, post-processed from waste water bottles, emphasizes our commitment to environmental sustainability. Furthermore, the compression molding manufacturing parameters were thoroughly optimized to enhance the panel's structural integrity. Finally, in order to assess the bonding quality formed between the composite facesheet and the PET core, complementary flatwise and peel-off tests were conducted. These steps were essential to verify the efficacy of the fusion bonding technique used in laminating the thermoplastic-based composite sandwich panels.

2 MATERIALS AND MANUFACTURING

In this investigation, 100% recycled closed-cell Polyethylene Terephthalate (PET) foam materials made of water bottle waste were used as the core of sandwich panels. In order to reduce the possible footprint of the fabricated composite panels, thermoplastic-based E-Glass/Polypropylene (Glass/PP) composites were selected for the skin. The facesheets of the sandwich panels were made of a single layer of 2/2 twill weave glass/PP composite with a nominal thickness of 1 mm and fiber weight fraction of 60 percent. Moreover, three distinct core thicknesses of 10 mm and 20 mm, each with a density of 80 kg/m^3, and a 50 mm thick core with a density of 100 kg/m^3 (ArmaPET Struct GR80 and GR100) were used. It is important to note that in the nomination used within this research, “G” signifies the glass/PP composite layer and any upper-case numerals following “PET” indicate the nominal thickness of the foam core in millimeters, providing a clear reference to the specific core material used in each sample.

A precise assessment was necessary to ensure the proper connection forming between the PET foam core and PP-based composite facesheets. The production of these thermoplastic-based composites requires careful examination of pressure, temperature, and process duration, as these factors critically influence the final product's quality. A parametrical study was conducted with a series of iterative experiments for each manufacturing technique to determine the most effective input parameters. The sequenced layers of commingled raw glass/PP cloth and the PET foam were subjected to a temperature range of 160-165°C under a pressure of 0.5 MPa, maintaining them for a duration of 1 minute. Subsequently, the temperature was gradually reduced to ambient conditions at a cooling rate of 15°C/min. The incorporation of a steel mold, designed to correspond to the intended final thickness of the sandwich panels, was crucial in preventing compression of the PET foam core and controlling the resin flow during the pressing phase. These optimized parameters should be precisely followed to avoid unexpected in-plane fiber waviness due to the melting and flow of the PP resin. Taking advantage of the fusion bonding technique using a hot press machine depicted in figure 1, PET core sandwich panels with final thicknesses of 12.30 mm, 21.14 mm, and 52.36 mm were manufactured. It should be noted that Teflon sheets are required as a nonstick layer between the glass/PP composite facesheet and the surface of the heating element.

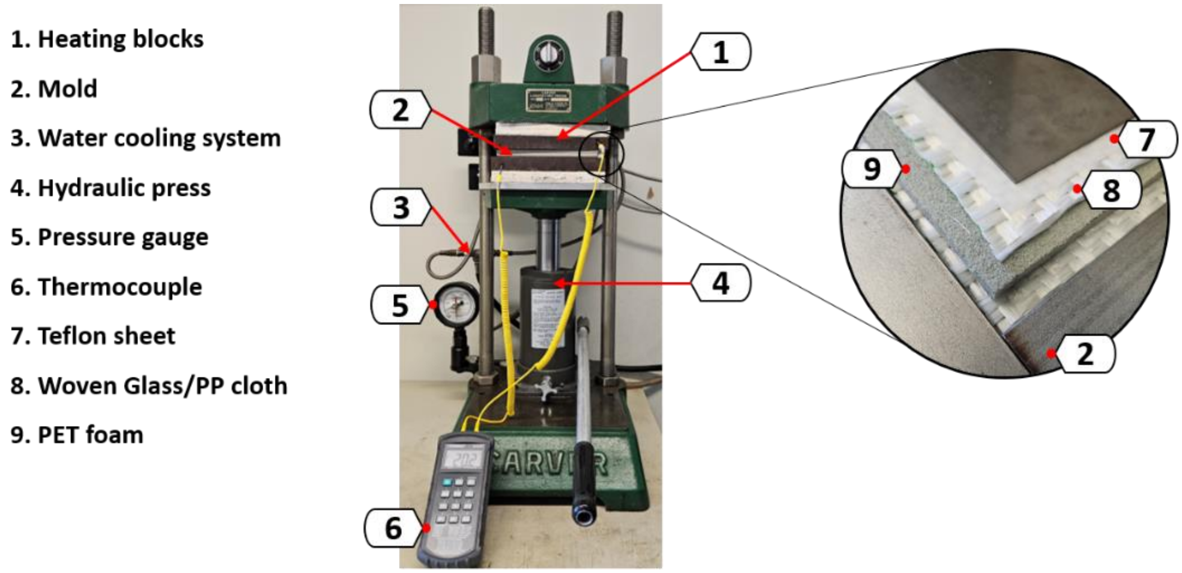

Figure 1. A display of the compression molding fabrication procedure of sandwich panels using the hot press machine.

3 EXPERIMENTAL PROCEDURE

3.1 Flatwise tensile test

As discussed in the previous section, since sandwich panels were fabricated without using any additional adhesive layers, the formed skin-to-core connection quality requires specific assessments. Thus, flatwise tensile tests were conducted to evaluate the adhesion formed between the glass/PP composite facesheet and the PET foam core. The flatwise tests were performed according to the ASTM C297 standard [12], at a head displacement rate of 0.5 mm/min. Sandwich panels with a core thickness of 10 mm and 20 mm were cut to dimensions of 1 inch × 1 inch, whereas panels with a 50 mm thick PET core were sized at 2 inches × 2 inches. Surface preparation involved a coarse sanding process to enhance the adhesion of the samples' skin to the steel fixture blocks, while DP 460 epoxy adhesive was used to secure the samples between the blocks.

3.2 Peel-off test

Peel-off test is a well-known alternative method which was employed to assess the bond integrity between the composite skin and the PET foam core. Utilizing a roller drum peel-off fixture, the adhesion between the skin and the core material was tested. All the peel-off tests were carried out in accordance with the ASTM D3167 standard [13]. Due to the design constraints of the drum peel-off fixture, which has a maximum thickness limitation of 10 mm, it was necessary to trim the sandwich panel samples with core thicknesses of 20 mm and 50 mm on one side to fit within the fixture. Consequently, the PET foam core sandwich panels were trimmed to dimensions of 260 mm × 25.4 mm. To facilitate testing, a 35 mm long pre-existing crack was introduced at the start of the test region to serve as the non-adhered section, ensuring adequate grip on the flexible skin during the test. The peel-off tests were performed at the displacement rate of 25.4 mm/min. Finally, peel strength values were measured by recording the data beyond the initial 25 mm of the peel length and normalizing them to the width of the specimen. All the flatwise and peel-off tests were performed on an MTS universal testing machine, which is equipped with a 5 kN load cell. To guarantee the precision of the findings, each test was conducted at least three times with a data sampling frequency set at 2000 Hz.

4 RESULTS AND DISCUSSION

The parametric optimization of temperature, processing idle time, and pressure in the hot press machine is crucial for enhancing product quality. These parameters were determined through a set of trial and error. Carefully controlled settings reduce defects like resin washout and fiber waviness, thereby improving the structural integrity and performance of the composite panels. This precise control ensures consistently high-quality materials with adequate bonding and minimal imperfections. In the current compression molding technique, a continuous and robust bond was achieved between the skin and the PET core. Nevertheless, employing fully recycled closed-cell PET foam as the core material introduces the possibility of trapping air bubbles at the adhesion interface. Furthermore, the presence of trapped air between the core and the skin, alongside facesheet voids and foam deformation, represents typical defects encountered in the manufacturing process. During the hot press lamination, the pressure and dimension of the panels were constrained by the mold's tolerances. These production adjustments resulted in a notably reduced void content in the composite facesheets and prevented any permanent deformations of the foam core during the lamination.

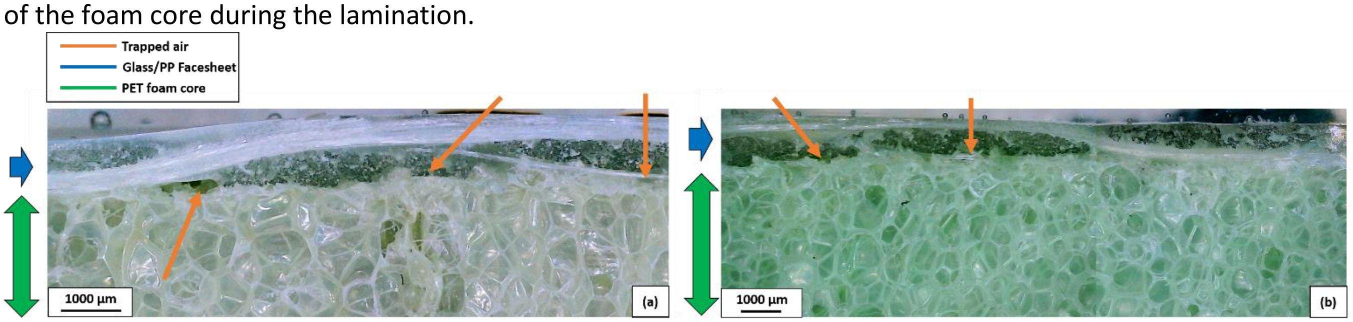

Figure 2. Microscopic view of composite sandwich panels with PET foam core densities of (a). 80 kg/m^3, and (b). 100 kg/m^3.

As depicted in figure 2, observations of magnified regions near the PET foam surface indicate satisfactory adhesion between the glass/PP composite skin and the core. Proper adhesion between layers is critical for effective load transfer, while inadequate bonding can lead to premature damage or delamination [14]. Further assessments are necessary to confirm the durability of the formed skin-to-core bond. Hence, peel-off and flatwise tensile tests were performed to evaluate the adhesive strength, with results presented in Table 1.

The effectiveness of the bonding is dependent on the ability to maintain production parameters that favorably affect the adhesion between the facesheet and the PET core. Moreover, thinner panels, compared to those with a 50 mm thick PET core, present a smaller available bonding surface, which reduces adhesion properties. This decrease is primarily due to fewer contact points and interactions between the core and the melted PP resin of the composite skin, which leads to a significant reduction in bonding strength.

Table 1. Peel-off, and flatwise tensile strength of PET foam core sandwich panels with Glass/PP facesheets.

PET foam thickness (mm)	Foam density (kg/m^3)	Peel strength (N/m)	Flatwise tensile strength (MPa)
10	80	2975.5	0.85
20	80	3021.4	0.88
50	100	3368.4	1.05

Focusing on the modes and appearances of failure, the integrity of the bond between the composite facesheet and PET foam core can be carefully evaluated. Figure 3 illustrates the appearance of the composite skin's surface after detachment from the PET foam core during the peel-off tests. The observed greenish clusters of PET foam material adhering to the skin indicate a substrate failure, while the presence of white-colored glass/PP facesheet signifies an adhesion failure. These findings suggest that a combination of failure modes occurred, indicating variations in peel strength across different sections of the panels.

It was depicted that the density of the PET foam plays an important role in the adhesion process. Panels fabricated with higher density foam provide more potential bonding points, which results in improving the adhesion strength. Panels with a 50 mm thickness and 100 kg/m^3 core density exhibited higher flatwise tensile strength compared to those with lower densities, confirming the positive impact of increased foam density on bonding quality. Figure 3 shows the failure patterns after the flatwise tensile tests, revealing a combination of adhesion and substrate failures. These failure responses can be translated into a proper and robust bond forming between the skin and the foam core during the compression molding.

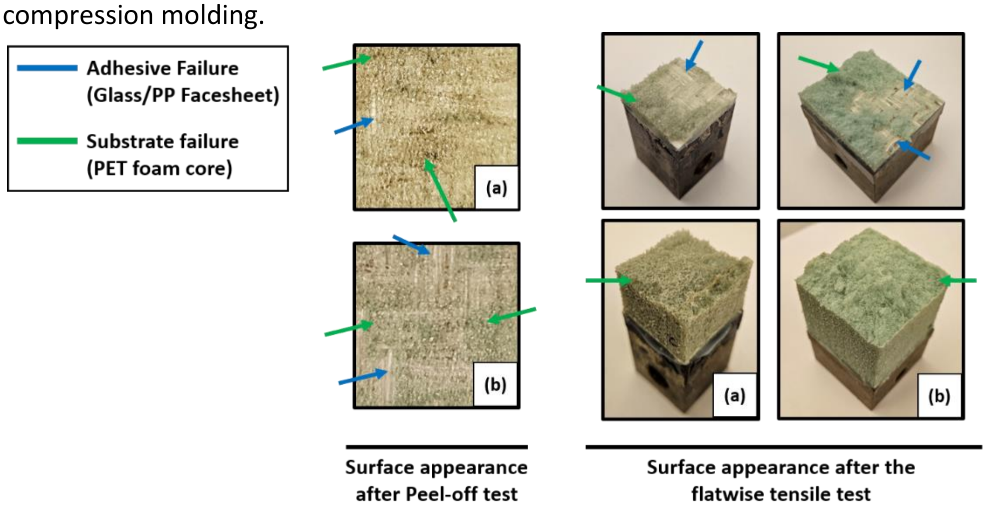

Figure 3. Peel-off and flatwise test surface of sandwich panels with PET core densities of (a). 80 kg/m^3, and (b). 100 kg/m^3.

Finally, the application of optimized parameters in the present study for the compression molding method has successfully facilitated the fabrication of high-quality thermoplastic-based PET foam core composite panels. The current process established a robust skin-to-core bonding. However, despite achieving a reliable connection through this method, it comes with certain limitations such as procedural variability and dimensional constraints. Looking forward, the successful demonstration of laminating thermoplastic panels without the need for additional adhesive layers between the core and facesheet paves the way for further research. This approach would broaden the applicability of the techniques developed and enhance the overall use of thermoplastic composite panels in various industrial applications.

5 CONCLUSION

In the current research, A parametric study was conducted using the hot press machine to identify the optimal settings for the fusion bonding lamination of recycled PET foam core to thermoplastic-based composite facesheets. Temperature, applied pressure, heating time and mold thickness were carefully assessed to minimize potential defects in the final production. Common defects such as resin washout and fiber waviness were mitigated by adjusting the fabrication parameters. The process has been adjusted to fabricate sandwich panels with three different PET foam core thicknesses.

The results from the flatwise and peel-off tests indicate that a consistent and robust bond was successfully established between the skin and the PET core. The occurrence of both substrate and adhesion failures in the tested samples showed proper skin-to-core adhesion. This robustness was achieved without the inclusion of any additional adhesive layers within the fabrication process. Lastly, these evaluations showed that using the hot press machine, effective integration of the layers is achieved through the lamination of PET core sandwich panels.

6 ACKNOWLEDGMENTS

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