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Impact of composite and aluminium face sheets on the properties of the 3D-printed cores under quasi-static three-point bending

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Abstract

3D printers have been the focus of many researchers in recent years. Many thin-walled structures can be produced using 3D printers. One of the thin wall structures that can be made with 3D printers is the core of sandwich panels. In this research, cores with rectangular cross section have been made using Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) filaments. These cores were reinforced using aluminum and composite face sheets and subjected to a three-point bending test. Glass fibers with a density of 200 g/m^2 were used to make composite shells. The results showed that the addition of aluminum and composite face sheets, although increasing the flexural strength, greatly reduces the flexibility of the core.

Keywords

Sandwich Panel, Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Glass Fiber Reinforced Polymer (GFRP), Energy Absorber

1. Introduction

Production materials and processes are constantly being updated. Among the manufacturing methods, technologies related to 3D printers have found their place in various industries. Sandwich panels and thin-walled energy absorbers are one of the types of structures that can be fabricated using a 3D printer. In recent years, researchers have tried to investigate the hidden aspects of 3D printing technology by presenting different structures and studying their mechanical behaviour. Sandwich panels and energy absorbers are widely used in various industries, including automotive (Chahardoli et al. 2021a; Chahardoli et al. 2021b) and aerospace (Aamir et al. 2019). What follows is a series of studies that have examined thin-walled energy absorbers and composite sandwich panels.

Inspired by structures in nature, Peng et al. (Peng et al. 2021) designed a new type of sandwich panel. The core of their sandwich panels was made of ABS. They also simulated their panels using ABAQUS and provided a semi-analytical relation for the bending of the introduced panels under three-point bending. The energy absorption behaviour of ABS-filled accordion tubes under impact load was investigated by Usta et al. (Usta et al. 2019) in 2018. They conducted their research both experimentally and numerically and used LS-DYNA software in numerical simulations. Other studies have been performed on ABS structures using LS-DYNA software, including references (Kucewicz et al. 2019a; Kucewicz et al. 2018; Özen et al. 2020). Comparison of experimental and numerical results obtained in these studies showed that LS-DYNA software could very well predict the mechanical behaviour of structures printed with ABS. The material models presented in these studies can be used in other simulations. In another study by Kucewicz et al. (Kucewicz et al. 2019b) on ABSplus, the mechanical behaviour of honeycomb structures under impact load was investigated using LS-DYNA.

The flexural behaviour of sandwich panels made of HDPE (high-density polyethylene) filament under bending load was investigated by Bharath et al. (Bharath et al. 2021). Their research predicted the flexural response of the proposed panels using the theoretical method. The mechanical behaviour under three-point loading for beams made of nylon filament was investigated by Xu et al. (Xu et al. 2019). Their study extracted the collapse mechanisms for end-trabecular beetle elytron beams. The effects of the wall thickness of honeycomb structures made of nylon on their collapse properties under quasi-static loading were investigated by Sahu et al. (Sahu et al. 2020). Their studies were performed numerically, and they used ANSYS software for finite element simulations. Other research has been done on thin-walled structures made of nylon filament, among which we can mention the references (Alshaer & Harland 2021; Ghazlan et al 2020; Sahu et al. 2018). In reference (Alshaer & Harland 2021), carbon fiber composite face sheets were used and in the reference (Ghazlan et al. 2020), ABAQUS software was used to simulate the collapse behaviour of lattice structures similar to bone tissue under pseudo-static load.

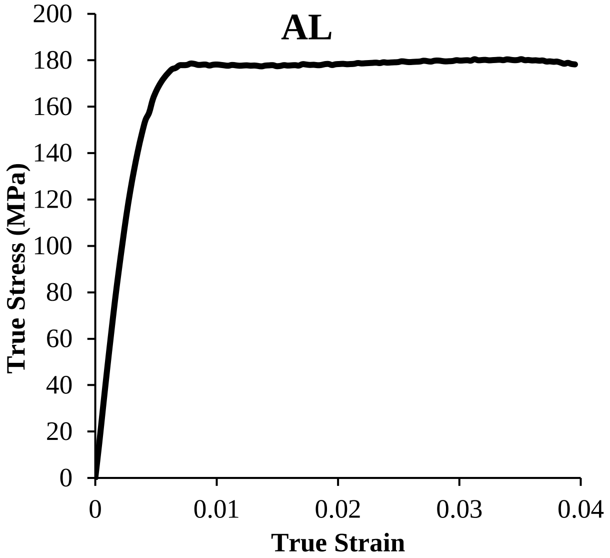
Another filament that many researchers have studied is PLA. This filament is the most commonly used polymer filament. The following are some studies on this filament in the field of thin-walled structures. Santos et al. (Santos et al., 2021) investigated the behaviour of panels made of PLA and PETg under low-velocity impact loads. Their studies were performed experimentally. In a study by Wang et al. (Wang et al. 2021) on energy absorbers, PLA filament was used as the core of the interlocking cylindrical shells of two tubes made of aluminium. Their research was conducted experimentally under quasi-static loading. In references (Chen et al., 2020; Li et al., 2020; Ye, Bi, & Hu, 2020), ABAQUS software was used to simulate the behaviour of structures made of PLA under pseudo-static and dynamic loads. LS-DYNA software is widely used in the discussion of numerical simulation of the behaviour of sandwich panels and energy absorbers under dynamic and quasi-static loads for PLA materials. In the case of impact loads we can refer to (Rebelo et al., 2019; Usta et al. 2021) and to (Daraei et al. 2023; Özbayrak et al. 2023; Usta et al. 2020) for quasi-static load.

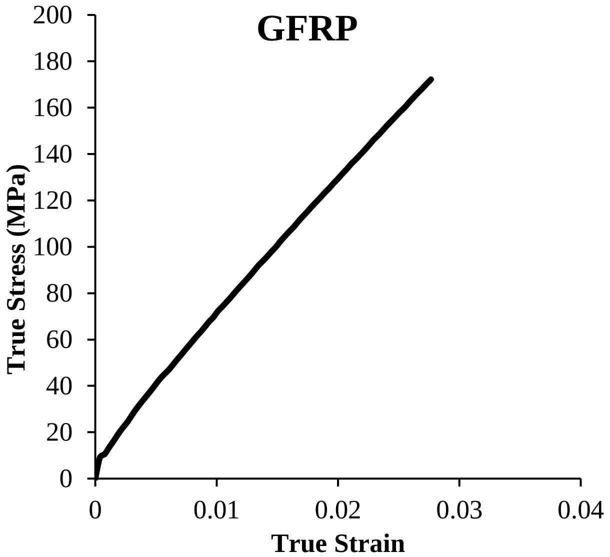
According to the review of literature, sandwich panels are a type of thin-walled structure that has always been of interest to researchers. Therefore, research on this issue is always ongoing. In this research, we have tried to introduce a new type of structure that can be used in various industries by introducing and examining sandwich panels with printed polymer cores. The materials investigated as the core in this study were PLA and ABS filaments. Aluminium tops and glass fibre reinforced composites (GFRP) were also used for sandwich panels.

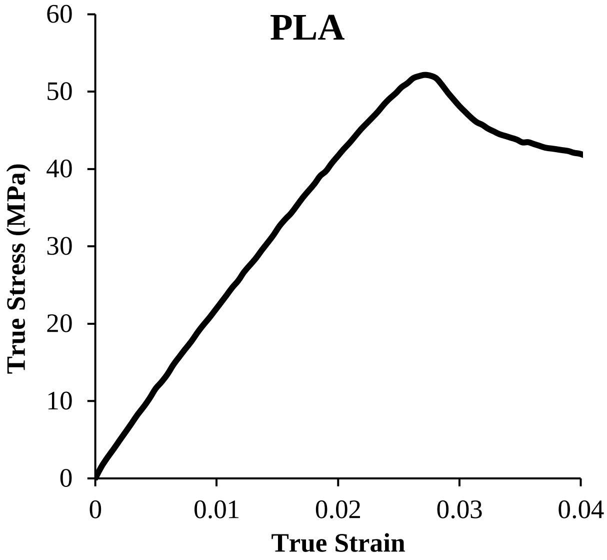
2. Materials and Properties

Materials used in the present study include aluminium sheets with a thickness of 0.9 mm, sheets made of glass fibres with a thickness of 1 mm and polymers printed with PLA and ABS filaments with a thickness of 2 mm. Using glass fibres with a surface density of 200 g/m^2 (Fig. 1) and PC105 resin with 15% hardener, a composite sheet reinforced with glass fibres was made. For this purpose, four layers with angles of 0, 45, 45 and 90 were placed on top of each other. Dumbbell specimens were prepared to determine these materials' mechanical properties and extract the strain stress curves according to the standard presented in the reference (ASTME8/E8M-09, 2011). A wire cut was used to extract the dumbbell sample from the aluminium sheet and laser was used to extract the dumbbell sample from glass fibre reinforced composite sheets. ABS and PLA dumbbell specimens were also made using a printer. The experiment involved testing dumbbell-shaped samples under tension at a rate of 1 mm/min. From this test, the true stress-strain relationship for different materials varies based on their properties and behavior under load, true strain stress curves were obtained based on the information shown in Fig. 2. Additionally, Fig. 3 illustrates how the ABS sample was positioned in the Centam device, as well as some examples of specimens following the tensile test. The bonding process between these materials requires careful consideration of surface treatments, adhesive selection, and precise application techniques to ensure a strong and durable bond. Specific methods and adhesives used may vary based on the characteristics of the materials, the intended application, and the environmental conditions the sandwich panel will encounter.

Fig. 1 Composite sheet made of glass fibers and PC105 resin with 15% hardener.







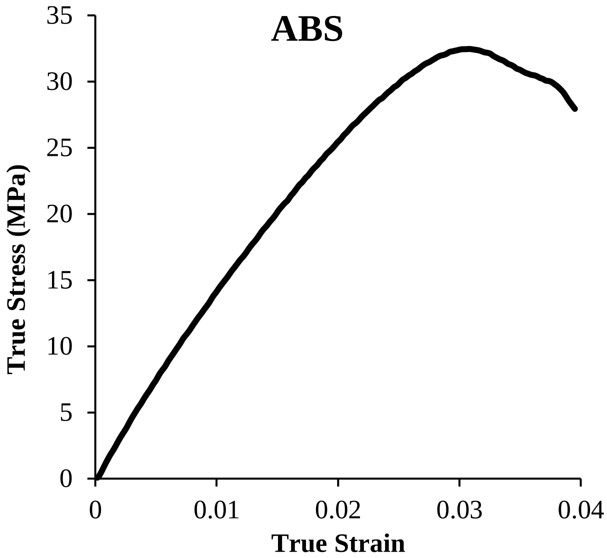


Fig. 2 True stress-strain relationship for AL, GFRP, PLA and ABS samples.

Fig. 3 Placement of ABS specimen in the device and dumbbell specimens after tensile test.

3. Three-Point Bending Test

The displacement force curve for the three-point bending of sandwich panels can be expressed using Eq. (1) given in reference (Peng et a. 2021). In this equation, δP and δE represent the elastic and plastic displacements under the influence of P force. In addition, LS shows the distance between the supports. (EI)eq and (AG)eq represent the equivalent flexural stiffness and equivalent shear stiffness, respectively, which for a shape like Fig. 4 can be represented by Eqs. (2) and (3).

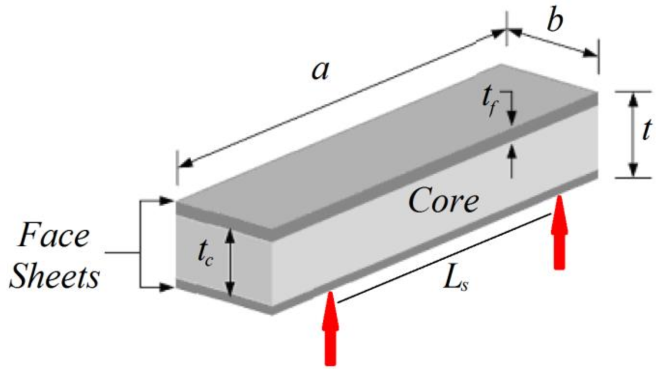


Fig. 4 Geometric schematic of sandwich panels

$$\delta = \delta_E + \delta_P = \frac{P{L_s}^3}{48(EI)_{eq}} + \frac{PL_s}{4(\mathrm{AG})_{eq}} \quad (1)$$

$$(EI)_{eq} = \frac{E_f b t_f^3}{6} + \frac{E_c b t_c^3}{12} + \frac{E_f b t_f (t_c + t_f)}{2} \quad (2)$$

$$(AG)_{eq} = \frac{b(t_c + t_f)^2 G_c}{t_c} \quad (3)$$

The schematic of the three-point bending test for the samples of this research is shown in Fig. 5. In this test, the lower jaws were fixed, and the upper jaw moved downwards at a 2 mm / min speed. According to this figure, the length of the samples in this study was 140 mm and the distance between the two lower supports was 120 mm. For three-point bending tests, samples with PLA and ABS cores along with composite and aluminium surfaces were prepared experimentally according to Fig. 6. The AA model has an ABS core and an aluminium surface, and the PA model consists of a PLA core and an aluminium surface. AF and PF specimens were composite specimens with ABS and PLA cores, respectively. Instant glue was used to glue the cores to the surfaces. The AA, PA, AF and PF specimens were placed in the Centam device according to Fig. 7 and the force-displacement curves were extracted for them.

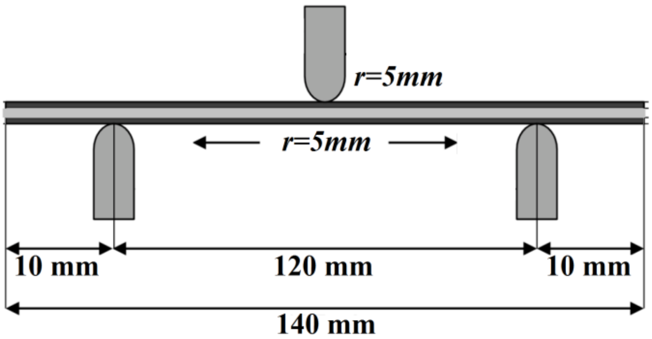


Fig. 5 Schematic of three-point bending test

AA

AF

PA

PF

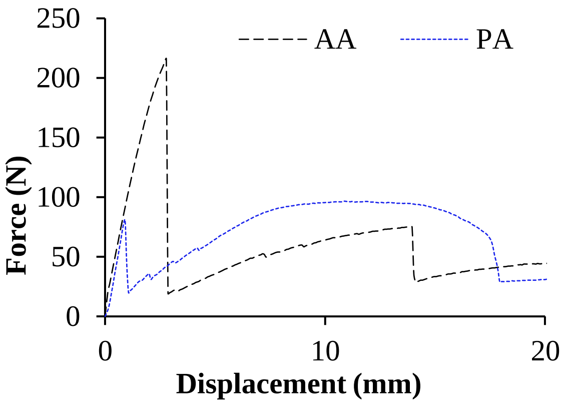
Fig. 6 Sandwich panels with PLA and ABS cores with aluminium and fibreglass tops

Fig. 7 Placing the samples of Figure 5 in the Centam device

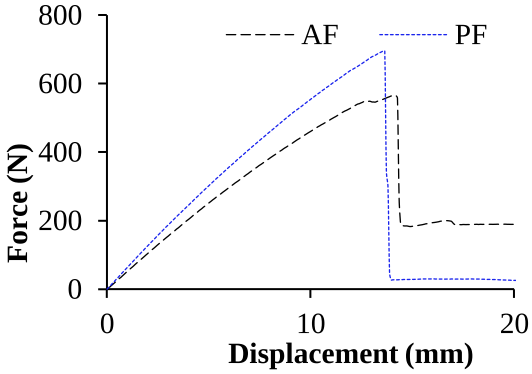
4. Results and Discussion

The force-displacement diagrams for AA, PA, AF and PF samples are shown in Fig. 8. In these diagrams, two critical factors are present. The first factor is the highest amount of force exhibited in the diagram, while the second factor is the region underneath the force-displacement curve, which indicates the amount of energy that the structure has absorbed. According to Fig. 8-a, AA models (ABS core and aluminium surface) had higher flexural strength than PA models (PLA core and aluminium surface). The sudden drop in force in the force-displacement curves of Fig. 8-a indicates ruptures between the surface and the core in specimens with an aluminium surface. However, no rupture was observed between the core and the surface for samples with a composite surface, and only the specimens collapsed in the middle. Fig. 9 illustrates the collapsed state of a specimen with aluminium and composite surface for the PLA core. Improving adhesion between aluminum and PLA involves Surface roughening to enhance mechanical interlocking and conducting thorough adhesion tests for validation are essential steps in addressing and confirming the effectiveness of the enhanced bonding approach.

Based on Fig. 8-b, when glass fibre composite procedures were used for PLA and ABS cores, the performance of PLA cores in energy absorption was better than aluminium face sheets, but these samples have a higher maximum force. This is because of the higher yield stress of PLA dumbbell specimens compared to ABS specimens in the true stress-strain curve. Comparison of Figs. 8-a and 8-b shows that composite-coated panels have less flexibility (displacement) and more maximum strength than aluminium-coated panels.



(a) AA and PA models



(b) AF and PF models

Fig. 8 Force-displacement curves for single-core models

Fig. 9 Collapsed state of samples with aluminum and composite surface for PLA core

5. Conclusions

The investigation of sandwich panels with polymer cores was the focus of this study. PLA and ABS were the two types of fiber that were used to make these cores. The sandwich panel framework was completed with aluminum face sheets and composite materials. The metal sheets were handmade especially for this study. To learn more about the mechanical properties of the raw materials, tensile tests were conducted on them. During testing, controlled forces were applied to evaluate the strength and performance of the various fibers (PLA and ABS).

After evaluating the raw materials, numerous sandwich panels were made with varied face sheets and polymer cores that were manufactured. Notable results were obtained from the analysis that followed. First, compared to sandwich panels with aluminum face sheets, those with composite face sheets showed a greater capability for energy absorption. This suggests that the panel's capacity to absorb and release energy is improved by the composite surface, which makes it more appropriate for uses requiring impact resistance or shock absorption. The study also found that the elasticity of the polymer cores was greatly impacted using composite face sheets. In contrast to panels with aluminum face sheets, sandwich panels with composite face sheets showed less flexibility in the polymer cores.

To sum up, the research provided a substantial comprehension of the characteristics and functions of sandwich panels with polymer cores. The experiment demonstrated the effects of different face sheet materials, highlighting the greater energy absorption capacity of the composite face sheets. It also brought attention to the differences between the impacts of aluminum and composite face sheets, illuminating how the choice of face sheet influences the polymer cores' flexibility. These findings pave the way for further advancements in structural engineering and their applications in various industries by contributing to the growing body of knowledge on sandwich panel design and material selection.

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