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THE EFFECT OF VARIATIONS IN CURING TEMPERATURE OF CARBON FIBER/PVC FOAM BOARD SANDWICH COMPOSITES ON BENDING TEST FAILURE ANALYSIS

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Abstract

Curing is a method to improve the ability of sandwich composite materials by heating the sandwich composite in an electric oven for a certain time and temperature. This research aims to observe and analyze the effect of curing temperature on bending strength and elastic modulus as well as analyzing the fracture results of sandwich composites. The materials used are polyester resin, 240 gsm twill carbon fiber and PVC foam core with a thickness of 5 mm. The manufacturing method used is vacuum bagging and the curing process is carried out with temperature variations of 70°C, 80°C and without curing for 1 hour. The test carried out is a bending test using the ASTM C393 standard. The maximum bending strength value of the sandwich composite is found at a curing temperature of 80°C, namely 48.35 MPa, while the lowest bending strength value is found in the variation without curing, namely 30.07 MPa. The highest elastic modulus value is also found at a curing temperature of 80°C, namely 67.03 GPa and the lowest elastic modulus value is also found in the variation without curing, namely 33.67 GPa.

Key words: Sandwich Composite, Curing, Bending, Vacuum Bagging, Carbon Fiber, PVC Foam

INTRODUCTION

In this modern era, composite materials have become one of the materials that is in great demand in various engineering applications, especially in the automotive, aerospace and construction fields. One type of composite material that is often used is sandwich composite. Sandwich composites consist of two layers of skin sandwiching a core (Banea and Da Silva 2009)(Setiyawan, Respati, and Dzulfikar 2020). This combination offers advantages in terms of strength, stiffness, and relatively light weight compared to other solid materials (Kumar, Lal, and Sutaria 2023).

Sandwich composites generally consist of a skin made from high-strength materials such as carbon fiber and a core made from light but strong materials such as PVC (Polyvinyl Chloride) foam or board. This structure allows the material to withstand high loads with minimal mass, making it ideal for applications where the strength to weight ratio is critical (Tüfekci et al. 2023).

On the other hand, sandwich composites have disadvantages, such as being susceptible to failure, especially under certain loading conditions such as bending tests (Mack et al. 2024). Bending test is one method commonly used to assess the strength and flexibility of composite materials. In this test, the composite material is loaded until failure occurs to understand the strength limits and possible failure modes. These failure modes can vary, including delamination between the shell and core, cracking of the shell, or plastic deformation of the core (Zubaidah et al. 2024).

Failure analysis in bending tests of sandwich composites with a PVC core and carbon shell is essential to develop a deeper understanding of the mechanical characteristics and limitations of these materials. This knowledge can be used to improve the design and application of sandwich composites in industry. By identifying and understanding failure mechanisms, researchers can design more reliable and durable structures, as well as optimize material use for better efficiency.

Therefore, this research aims to carry out an in-depth analysis of the failures that occurred in the bending test of sandwich composites with a PVC foam board core and carbon fiber skin. This study will include identification of failure modes, analysis of critical parameters that influence bending strength, as well as recommendations for improving the performance of sandwich composites in practical applications.

METHODS

The materials used in this research were carbon fiber, PVC Foam Board and Polyester resin. The carbon fiber used as the skin has a 3K twill woven form with a surface density of 240 g/m^2. The core used is a PVC Foam Board type with dimensions of 5x38 x110mm. Meanwhile, the matrix used is Polyester Yukalac C-108 B with a Mepoxe type hardener or catalyst. The dosage of resin and catalyst used is 100:1.

The process of making sandwich composites using the vacuum bagging method with a pressure of 14 psi. Next, a curing process was carried out using an electric oven on the sandwich composite specimen. The curing temperature variations given are 70°C, 80°C and without curing for 1 hour. The curing process is carried out to improve the characteristics of the sandwich composite specimen and form a cross-linking bond between the resin and fiber (Ji et al. 2022),(Chen, Muhammad, and Ahmad 2021). Figure 1 shows the process of making sandwich composites.

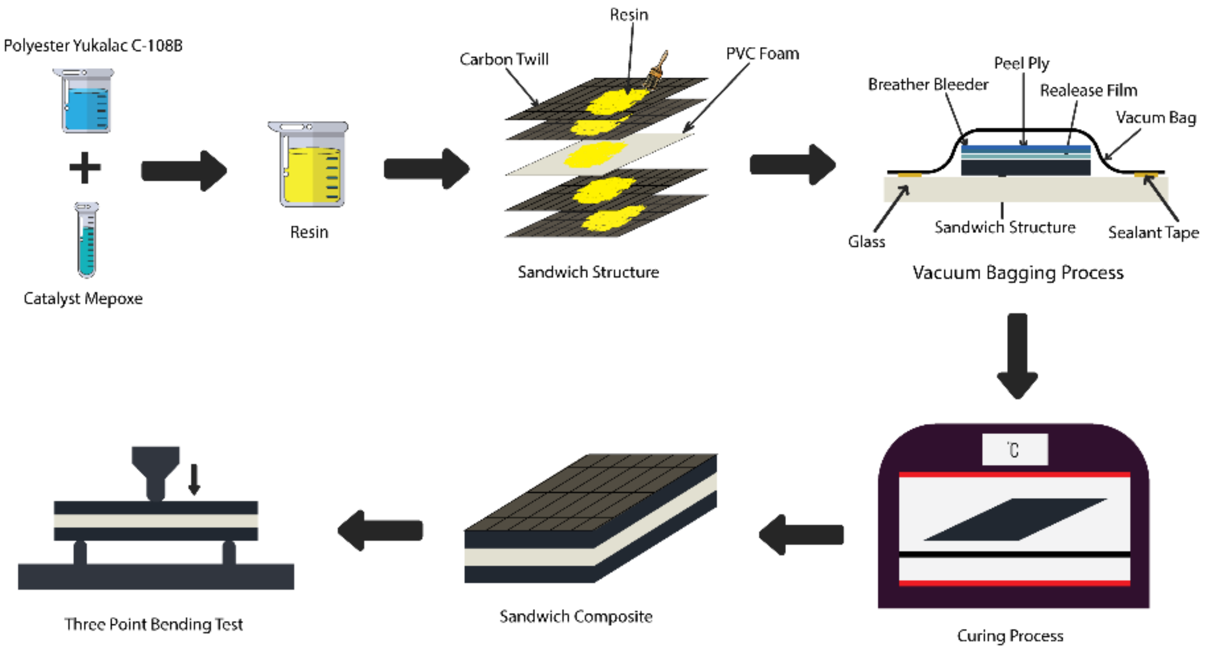

Figure 1. Schematic of the composite manufacturing process

The test carried out was bending using the three point bending method. Three point bending is a bending test using two points at the bottom as supports and one point at the top as an indenter or pressure. The machine used is UTM Zwickroell 250 kN Universal Testing Machine Z250SR with a pressing speed of 5 mm/s. The standard used is ASTM C393.

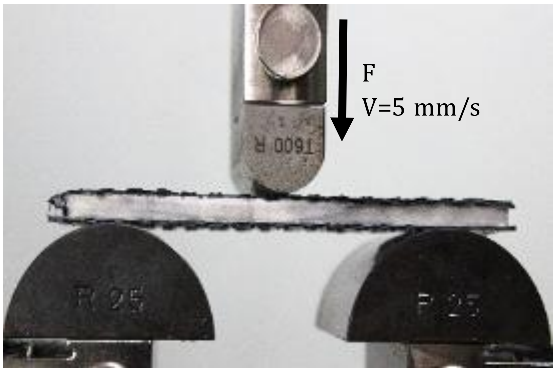

Figure 2. Bending test

The maximum bending strength from bending tests using the three point bending method can be determined using the following equation;

$$\sigma_b = \frac{3PL}{2bt^2} \quad (1)$$

Keterangan:
σ_b = Maximum bending (MPa)
P = Force (N)
L = Specimen length (mm)
b = Specimen width (mm)
t = Specimen thickness (mm)

Meanwhile, to obtain the elastic modulus value from the bending test, you can use the following equation;

$$Eb = \frac{P \times L^3}{48 \times l \times \delta} \quad (2)$$

Keterangan:
Eb = Bending Modulus of Elasticity (MPa)
P = Force (N)
L = Distance between two supports (mm)
l = Moment of Inertia (mm^4)
δ = Deflection (mm)

RESULTS AND DISCUSSION

Bending strength is the greatest bending stress that a material can withstand when subjected to an external load without experiencing large yields or failure. The value of flexural strength depends on the type of material and the load applied (Pramadyanti, Adi Atmika, and Ary Subagia 2021). The higher the curing temperature, the higher the bending strength value. This is due to the presence of cross-links which help molecules such as resin and hardner move actively to form larger bonds. Thus, the skin and core become denser and the presence of voids in the composite composite becomes increasingly reduced (Mohammad et al. 2023). A graph of the maximum bending strength value of the sandwich composite against variations in curing temperature can be seen in the following figure.

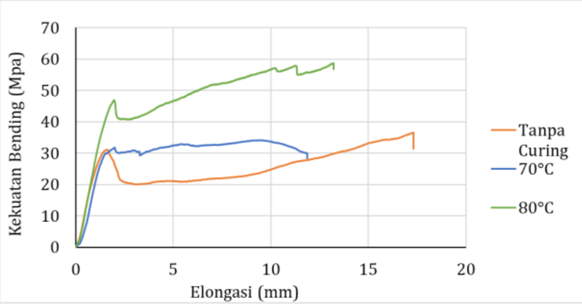

Figure 3. Bending strength graph

Figure 3 shows a graph of the maximum bending strength of sandwich composites against curing temperature. The highest bending strength value was obtained by the sandwich composite specimen with a curing variation of 80°C of 48.35 MPa. With a curing variation of 70°C, a bending strength value of 35.25 MPa was obtained. The lowest bending strength value was obtained by the sandwich composite specimen with the variation without curing, namely 30.07 MPa. The bending strength value of sandwich composites tends to increase followed by an increase in the given curing temperature. This is influenced by the effects of the sandwich composite curing process so that it forms a cross-linking bond between the fiber and resin (Nurul Lailatul et al. 2021),(Utomo 2021).

Material, the smaller the elastic strain resulting from the applied stress. The modulus of elasticity is needed to determine how much flexibility the sandwich composite specimen has. The elastic modulus is a property that cannot be easily changed because the elastic modulus value is determined by the binding force between atoms. The properties of the modulus of elasticity can only be slightly changed by the addition of alloys, heat treatment or cold working (Marsono, Ali, and Luwis 2019). The following is a graph of the modulus of elasticity value of the sandwich composite.

Figure 4 shows a graph of the effect of varying curing temperature on the elastic modulus value of the sandwich composite. The highest elastic modulus strength value was obtained by the 80°C curing sandwich composite specimen, namely 67.03 GPa. Followed by a curing temperature variation of 70°C of 54.26 GPa. The lowest elastic modulus value was obtained by the sandwich composite specimen with the variation without curing, namely 33.67 GPa. Just like the maximum bending strength value, the elastic modulus value also increases with each increase in curing temperature variation. The increase in the elastic modulus value is influenced by the influence of the curing process which produces cross-linking bonds between the fiber and resin (Cagla and Evren 2022).

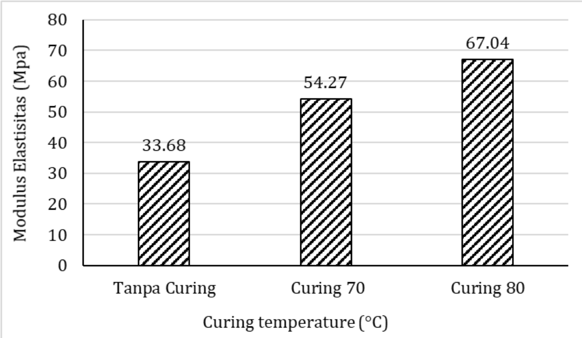

Figure 4. Elastic modulus graph

a. Without *curing*

The stages of failure in the bending test without curing are shown in Figure 5. Figure 5c shows that the micro buckling failure is getting bigger and new failures are appearing on the core in the form of indentation. Indentation failure is influenced by the strength and thickness of the core. This type of failure causes a greater deflection than other types of failure that occur in sandwich composites (Gibson 2007). Apart from that, failure also occurred in the form of delamination between the core lamina. This failure occurs due to the shear force that occurs in the core which is distributed towards the adhesive layer, resulting in layer damage. Core damage occurs gradually starting from the top towards the (Epasto et al. 2024). In Figure 5d and Figure 5e, failures in the form of micro buckling, in-dentation and delamination between core lamina are increasingly visible. Then in Figure 5f the bending test on the sandwich composite has been completed.

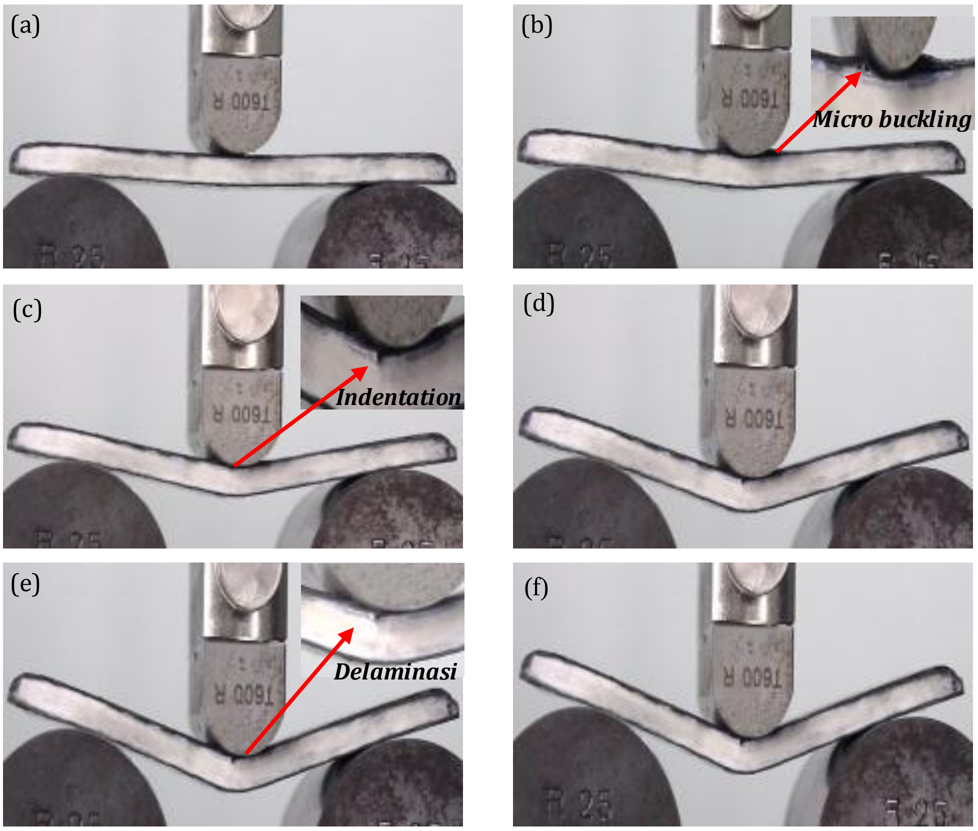

Figure 5. Stages of failure in the bending test without curing

b. *Curing* 70°C

Figure 6 is a picture of the sandwich composite bending test process with a curing variation of 70°C using the three point bending method using ASTM C393. Figure 6a shows a sandwich composite specimen with a curing variation of 70°C starting to be subjected to a bending test load. Then in Figure 6b failure begins to occur in the sandwich composite specimen core in the form of a type of delamination failure between the core lamina. Failure of this type of core is caused by the shear force contained in the core during the bending test which is distributed slowly towards the adhesive layer, so that the core layer experiences damage in stages starting from the top to the bottom (Setiyawan, Respati, and Dzulfikar 2020). It can be seen in Figure 6c that failure in the form of delamination between core lamina is increasingly visible, but on the other hand there are no defects in the sandwich composite skin such as micro buckling or face yield because there are more crosslinking bonds in the resin and hardener. This has an impact on increasing the bond strength of the resin to the skin and core of the sandwich composite. The existence of this crosslink-ing bond is due to the influence of the curing process at a temperature of 70°C using an electric oven(Azissyukhron and Hidayat 2020) (Ji et al. 2022).

Figure 6d shows that the core is increasingly experiencing failure in the form of delamination between core lamina followed by the emergence of a new type of failure in the form of core crush. Failure in the form of cracking of the core of the sandwich composite specimen was influenced by the main factor, namely the inability of the core in the form of PVC foam to withstand the load when the bending test was carried out (Paundra et al. 2024). Core failure in the form of delamination between core lamina and core crush is getting bigger, shown in Figure 6e. Then in Figure 6f the bending test on the composite sandwich specimen with a curing variation of 70°C has been completed. After bending tests were carried out, there were several types of failure in the sandwich composite specimens with a curing variation of 70°C. The failure that occurred was delamination failure between the core lamina and core crush that occurred in the sandwich composite core. A failure occurred in the sandwich composite skin in the form of face yield, but this failure was only visible after the sandwich composite specimen had completed the bending test process (Perdana et al.2023).

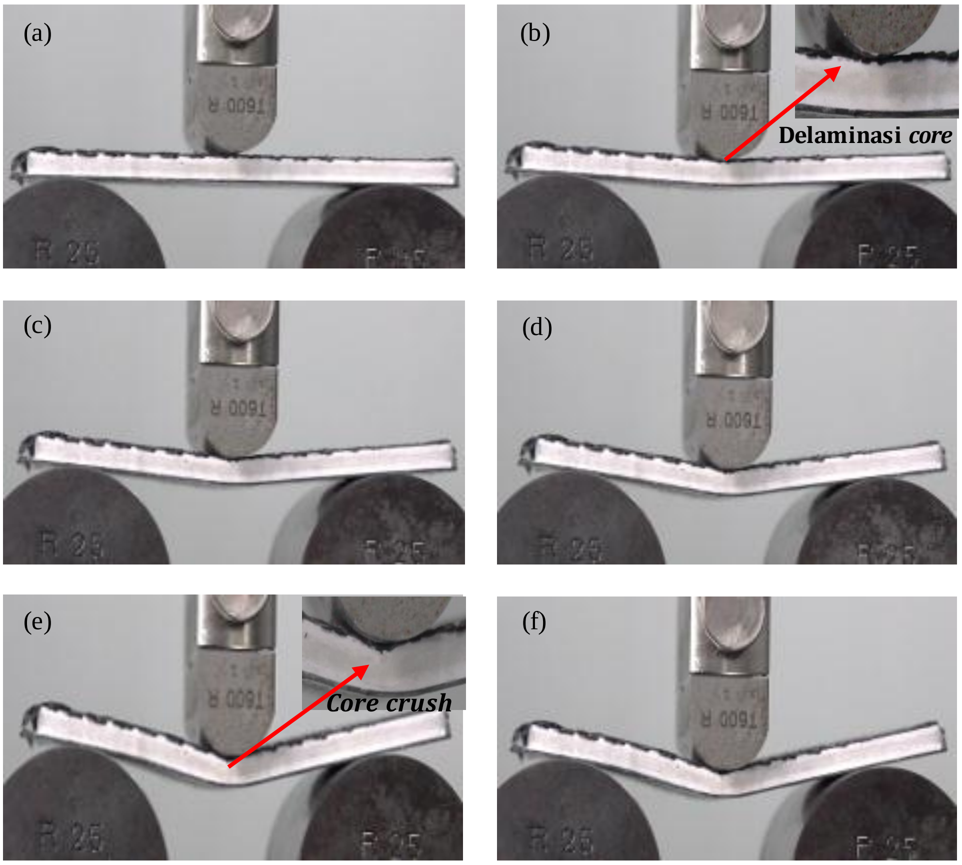

Figure 6. Stages of bending test failure at 70°C variations

c. *Curing* 80°C

Figure 7 is a picture of the bending test process on sandwich composite specimens with a curing variation of 80oC using the three point bending method according to ASTM C393 standardization. Seen in Figure 7a, the sandwich composite specimen with a curing variation of 80oC is starting to be subjected to a bending test load. Then in Figure 19b, deformation begins to occur in the sandwich composite specimen, but no failure has been seen in the skin or core of the sandwich composite specimen (Azissyukhron and Hidayat 2020). Failure began to occur in the form of cracking of the core of the sandwich composite specimen as shown in Figure 7c. This failure is a core crush type failure. This type of failure, in the form of cracking of the sandwich composite specimen core, is influenced by the main factor, namely the inability of the PVC foam core to withstand the load when the bending test is carried out (Structures 2023)(Robiansyah 2021).

Figure 7d and Figure 7e show that the cracks in the sandwich composite specimens are increasing, but there is no damage or failure to the sandwich composite skin. There was no failure in the sandwich composite specimen skin due to the influence of the curing process at a temperature of 80oC. The curing process that has been carried out has an impact on increasing the density between the fiber and resin, or what is better known as crosslinking (Al Ali et al. 2024)(Structures 2023). Finally, in Figure 7f, the bending test on the sandwich composite specimen with a curing variation of 80oC has been completed.

After the bending test was carried out, several failures were seen in the sandwich composite specimens. Failure only occurred in the core of the composite specimen, while the skin did not experience failures such as micro buckling or face yield. This failure is in the form of core crush failure which is characterized by cracking of the core of the Sandwich composite specimen due to the bending test (Ubago Torres and Jalalvand 2022)(Mack et al. 2024).

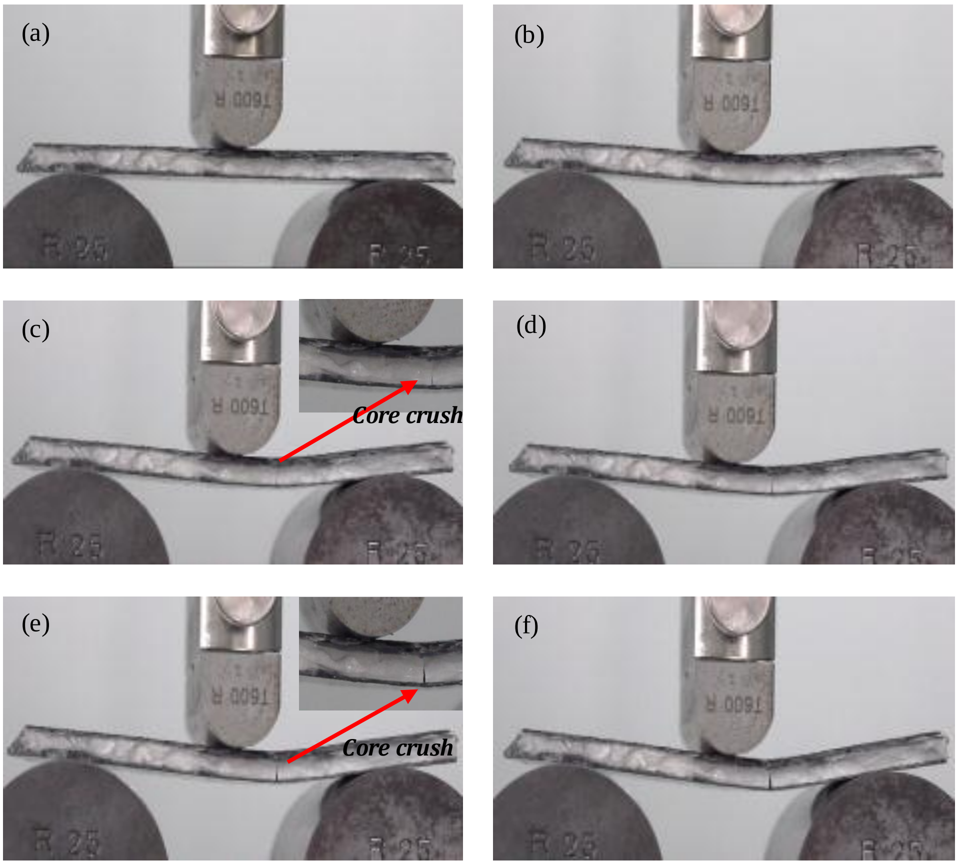

Figure 7. Stages of bending test failure at 80°C variations

CONCLUSIONS

After carrying out the bending test process on the sandwich composite specimen, several conclusions were obtained from the research regarding carbon fiber sandwich composites with PVC Foam cores. The conclusions from this research are as follows:

1. The highest bending strength and elastic modulus values were obtained by sandwich composite specimens with a curing temperature variation of 80°C. Meanwhile, the lowest bending strength and elastic modulus values were obtained by sandwich composite specimens with variations without curing.
2. The increase in bending strength and modulus of elasticity values is in line with the higher curing temperature given to the sandwich composite specimen. This means that the higher the curing temperature given, the higher the bending strength and modulus of elasticity of the carbon fiber sandwich composite specimen with PVC Foam core. Please note that the temperature given does not exceed the glass transition temperature limit (tg) of PVC Foam and carbon fiber.
3. Failures that occurred in sandwich composite specimens after the bending test were core crush, indentation, delamination between core lamina, micro buckling and face yield.

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