

Effect of Nano Clay on the Mechanical Properties of Sandwich Structure

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ABSTRACT

Sandwich composite materials are widely used in numerous engineering fields and applications due to their excellent mechanical properties and lightweight. The mechanical and physical properties, cost-effectiveness, and sustainability of composite materials can be improved by adding various organic and inorganic filler materials. In this study, nano clay was used as filler in epoxy resin to examine the mechanical properties of the composite material by conducting tension, bending, cyclic bending, and short beam shear tests. PVC foam, widely known as a load-bearing component was used as the core, and Aluminum sheet was used as the upper and lower facing of the sandwich structure. Epoxy resin of 10:1 ratio was chosen for the intermediate interface with a variation of nano clay containing 0.5%, and 1% of the total mixture by mass. While manufacturing the sandwich structure, pressure was applied by creating a vacuum chamber using thick polythene and a vacuum pump and sucking the air out of the chamber. The study reveals that incorporating nano-clay affects material properties variably. Bending strength, specific energy absorption (SEA), and short beam shear strength increase to 0.5% but decline or stabilize beyond that. Modulus of elasticity (MOE) and tensile strength decrease initially, then rise. Cyclic bending deformation increases with nano-clay content, peaking at 1%. No delamination occurs, though wrinkling is observed. The overall finding was negative and it was observed that the effect of nano clay was not significant due to the low strength of the soft PVC core.

Keywords: Sandwich structure, Aluminum sheet, PVC foam, Nano clay, Mechanical properties



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1. Introduction

Composites can be defined as materials that at least have two different constituents [1]. These constituent materials have very different mechanical & thermal properties. In recent times, research interest in composite structures has been rapidly increasing. Characteristics like biodegradability, eco-friendliness, low cost, and better mechanical properties such as high energy absorption ability have contributed to the fact [2]. Composite materials are being integrated into the fields of automobile engineering, aerospace engineering, energy sector, and marine structures as they show numerous superior features like high strength, high stiffness, lightweight, and possession of high corrosion resistance [3–5].

Composite structures can be subdivided into three categories, they are Particle Reinforced, Fiber Reinforced, and Structural. Structural composites are subdivided into laminates and sandwich structures. Reinforcement can be used in both types of composites. In particle reinforcement the particles can be either large or dispersion strengthened, whereas in the case of fiber reinforcement, some composites have continuously aligned fiber while others have discontinuous short fiber [6].

While laminated composites have multiple layers, the sandwich structure consists of a core and two facings that embed the core. The core and the skins are joined together using suitable binders. All three components can be of different materials. According to Birman et al., sandwich structure is one form of multilayered composite structures and they are usually optimized to enhance their lifetime loading conditions [7]. Quoting Allen [8], “Almost any structural

material which is available in the form of a thin sheet may be used to form the faces of a sandwich panel”. While choosing suitable skin for a composite, properties such as high stiffness, high flexural rigidity, and impact resistance are often taken into consideration. Skin or face materials are commonly divided into two groups; i) Metallic, and ii) Non-Metallic. Composite materials have been developed using the former group as the skin for example Cao et al. created a hybrid ship hull using steel as skin [9]. Another study researched the effect of mechanical behavior of sandwich structures made of perlite foam core and JFRP skin [10]. Research has also been done in recent years on developing composite. Several essential factors such as clay and resin chemistry, clay's dispersion in resin, core and resin compatibility, matrix formulation, processing parameters, and curing conditions have been considered while selecting the materials for a composite structure. Nano-clay of Bentonite group which comprises 60%-80% montmorillonite was purchased from Afroza pvt. Company Ltd. And PVC foam of thickness 5 mm was collected from the local market, Khulna. Materials using non-metallic skin like Formica sheet, plywood, and fiber composite [11], [12]. The core is the heart of a sandwich structure. There are several types of cores such as foam core, truss core, honeycomb core, and corrugated core. Foam cores are used for their lightweight properties in numerous engineering fields including structure, marine, and automotive industries [13].

Several studies have been done on composite structures with PVC foam as core. One study investigated the impact response of sandwich composites having cores made of balsa

wood and PVC foam [14]. The performance of sandwich panels with a PVC foam core under air blast stress was examined in another investigation [15]. Ding et al. investigated the aging of sandwich composites with E-glass fiber/vinyl ester skins and PVC foam core in synergistic environmental agents [16]. In one study, the flexural behavior of composite sandwich panels with PVC foam core was examined experimentally, theoretically, and numerically. [17].

Nanoclays are nanoparticles that contain layered mineral silicates. Clays are categorized according to their crystalline structures as well as the number and location of ions inside the elementary mesh [18]. Nano clay has attracted the attention of researchers owing to its unique properties like adsorption [19], and positive effect on mechanical characteristics [20], flame retardant [21]. This also resulted in the widespread usage of nano clay while developing composite materials in the field of automotive industry [22], and additive manufacturing industry [23].

In this study, aluminum sheets were used as skin, and PVC foam was used as a core. Very few researchers have done that so far. To bind the different layers, epoxy resin was used. To examine the impact of nanoclay on the different mechanical properties of the composite material, varying percentages of nanoclay were added to the epoxy and hardener mixture. To investigate the values of bending strength, modulus of elasticity, and specific energy absorption, four distinct test types were conducted: three-point static bending, tension, and short beam shear testing.

2.0. Experimental details:

2.1 Materials:

Nano-clay of Bentonite group which comprises 60%-80% montmorillonite was purchased from Afroza pvt. Company Ltd. and PVC foam of thickness 5 mm was

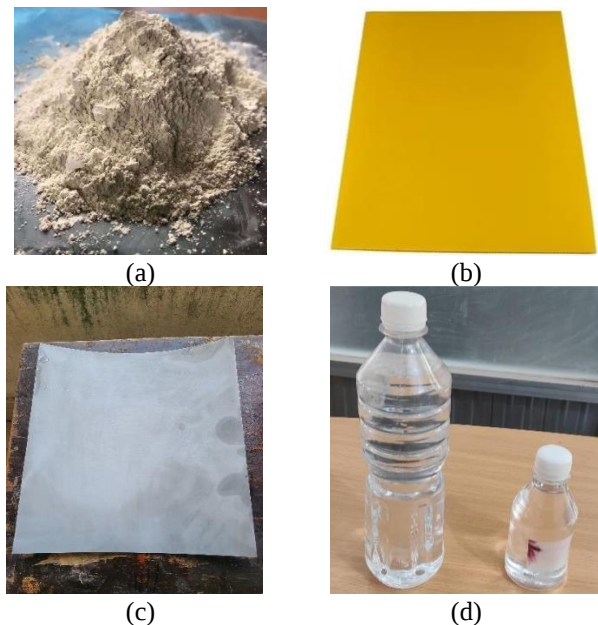


Fig.1 (a) Nano Clay (b) PVC Foam (c) Aluminum Sheet (d) Epoxy Resin & Hardener

collected from the local market in Khulna. The Aluminum sheet of thickness 0.5 mm was obtained from the local market in Dhaka. Epoxy was used as the matrix for the preparation of the adhesive interface layer between the core and two layers of sandwich structure. A chemical reaction occurs between the mixture of resin and hardener.

Epoxy resin with a recommended resin-to-hardener ratio of 10:1 was used to make the sandwich structure following the manufacturer's instructions. The epoxy-resin mixture transforms the binding agents into a solid state within 24 hours.

2.2 Specimen preparation:

At first, the aluminum sheet and the PVC foam sheet were cut at a dimension of 12 × 12 inches. Aluminum sheets were treated with 5% NaOH for 1 minute & then with 11% HCl for 2-3 minutes respectively. Treatment with NaOH removed any oxide formed on the surface of the aluminum sheet, and the HCl solution was used for etching the surface. Then, they were thoroughly washed with tap water for at least 2-3 minutes. After treatment, the sheets were dried in the open air under the sun. Simultaneously, we collected nano clay to use as filler.

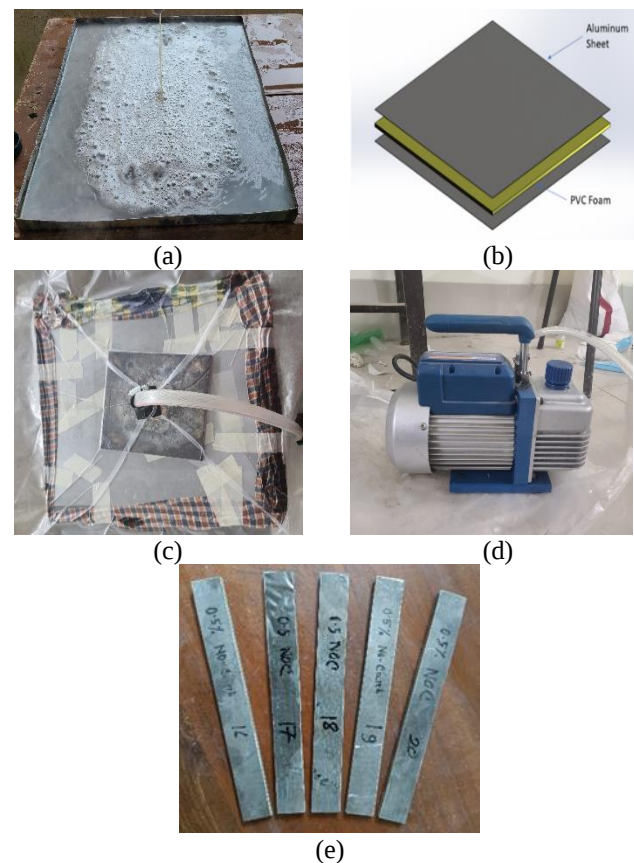


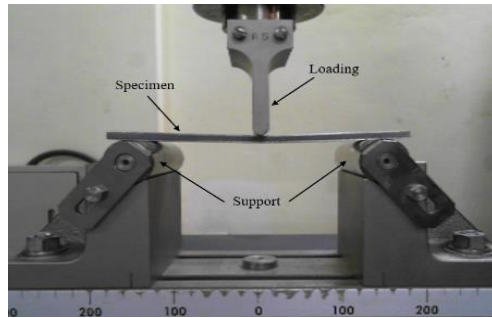
Fig.2 (a) Etching (b) Isometric view of the layup, (c) Setup of the vacuum chamber, (d) Pump (e) Sample specimen.

For the composite material's construction, we first washed the sheets with acetone with a piece of fabric to remove any debris. We then made different mixtures of epoxy with nano clay. The percentages we used were 0%, 0.5%, and 1%. After that, the binder was brushed on the surfaces of the Core and skins evenly and they were stacked as seen in Figure 1. To be noted, both sides of the PVC foam sheet were brushed and for the aluminum sheets only the inner surface was given the epoxy layer. Two mold plates were placed on the top and bottom of the layup and the edges were wrapped using cloths. The purpose of using the cloths was to soak the extra epoxy that would spill out from the intermediate interface as this extra epoxy may cause irregularities and challenges for

separating the mold plate from the sample. The complete mold was then enclosed in a vacuum bag and a constant pressure was created using a vacuum pump. The pressure helped to distribute the binder throughout the surface evenly. The vacuum pump was turned off after 3 hours. Finally, the whole setup was left for 24 hours at room temperature for curing. The final composite material was then cut into specific dimensions. The accurate dimensions of the specimens were then measured and then weighed. The density was also calculated.

2.3 Mechanical Testing:

The Shimadzu AGX 300KN universal testing machine was used to conduct the mechanical tests following ASTM standards D7264, D3039, and D2344 for flexural and cyclic bending, tension, and short beam tests, respectively.



(a)



(b)



(c)

Fig.3 (a) Flexural and Cyclic bending test setup, (b) Tension test setup, (c) Short beam shear test setup

For flexural and cyclic bending the speed of the crosshead was 6mm/min while for tension, and short beam shear tests it was 2 mm/min. Five specimens were tested for all the tests. The tests were carried out at room temperature.

Table 1: Mixture quantity for the production of the intermediate interface (NC0 = 0% Nano Clay, NC5 = 0.5% Nano Clay, NC1 = 1.0% Nano Clay)

Batch No	Epoxy (g)	Hardener (g)	Nano Clay (g)
NC0	90	9	0
NC5	90	9	4.95
NC1	90	9	9

3. Results and discussions:

For the prepared samples, at first, the effect of nano clay on average bending strength was plotted which can be seen in Fig 4. The bending strength increased slightly with the addition of 0.5% nano clay and then a slight decrease was observed for the case of 1% nano clay. So, the Nano Clay did not add any significant value to the bending strength and the range of the strength is within 34 to 35 N/mm².

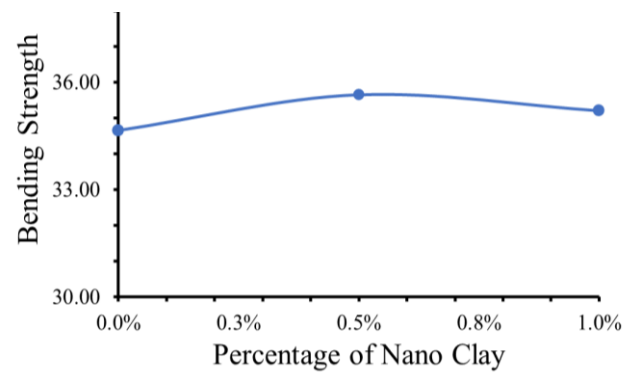


Fig.4 Bending Strength for various percentage of nano clay

The specific energy absorption (SEA) of the samples during the bending test for different wt.% of nano-clay is shown in Figure 5. The SEA is found to be maximum for 0% of nano clay content. For 0.5% the value of energy absorption started to decrease and in the case of 1%, it decreased prominently. The value of SEA which was above 7 MPa decreased to a value close to 5 MPa.

The modulus of elasticity, at first decreased from 70 N/mm² to below 60 N/mm² when 0.5% nano clay was added to the intermediate interface but the MOE increased to around 80 N/mm² for the case of 1% nano clay in the binder.

When the clay particle level is increased to 1% the extra particle can obstruct resin flow which results in a poor interfacial bonding between the core and metal layer. In addition, a higher amount of nano clay may disturb the resin matrix and generate voids and defects, and it results in lower mechanical properties. The tensile strength of the composite decreased slightly from 21.5 N/mm² to 19.5 N/mm² when 0.5% nano clay was added to the binder then it further rose to the maximum value which is 23 N/mm²

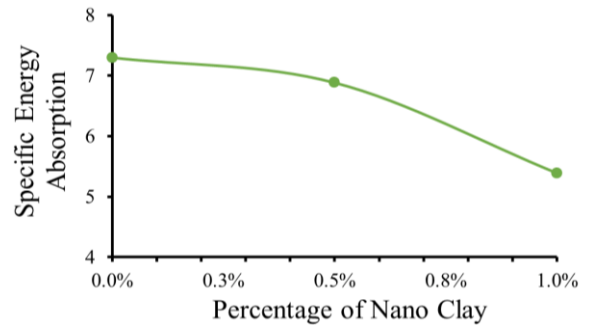


Fig.5 : Specific Energy Absorption for different percentage of nano clay

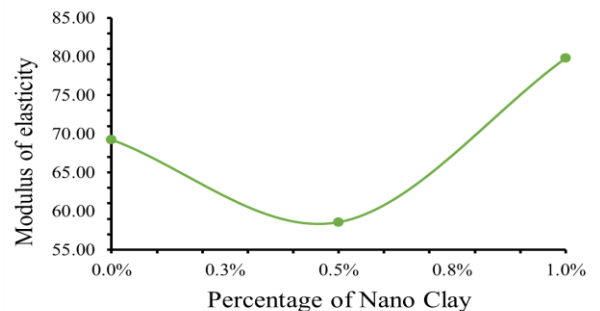


Fig.6 Bending Modulus of elasticity for different percentages of nano clay.

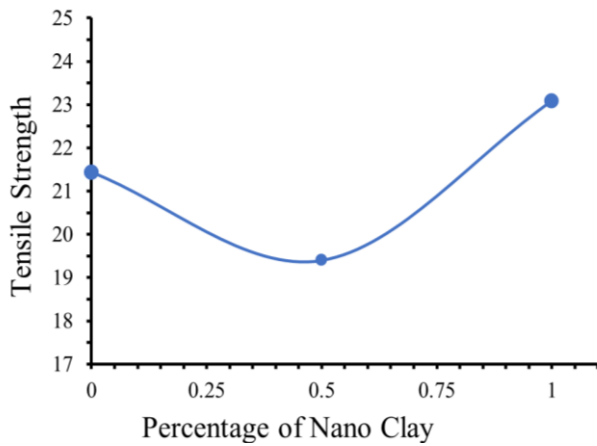


Fig.7 Tensile strength for different percentage of nano clay

In the case of modulus of elasticity, the graph shows a similar trend as of tensile strength. The MOE at first decreased slightly and then again increased but did not go past the value of 0% Nano Clay.

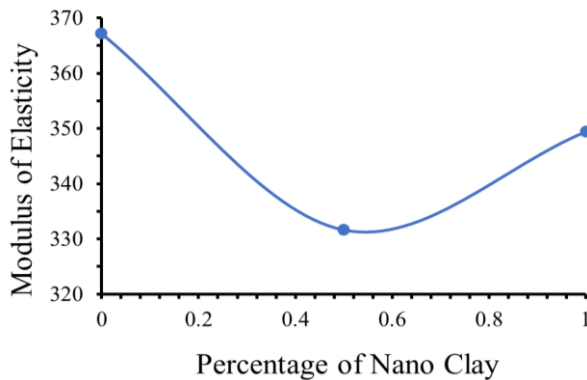


Fig.8 Tensile Modulus of Elasticity for percentage of nano clay in the binder.

However the specific energy absorption data shows very unusual characteristics. Where the strength and the modulus of elasticity increase the specific energy absorption shows the opposite result. The curve has a peak value for the 0.5% samples.

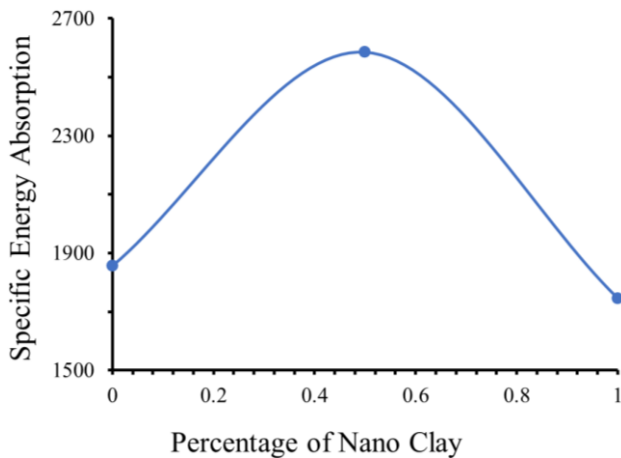


Fig.9 Specific energy absorption for tensile test under various percentage of nano clay in the binder.

For the short beam shear test, the graph in Figure 10 illustrate that the shear strength increases if nano clay is added to the binder but the variation of the amount of nano clay doesn't have any effect on the strength of the sample.

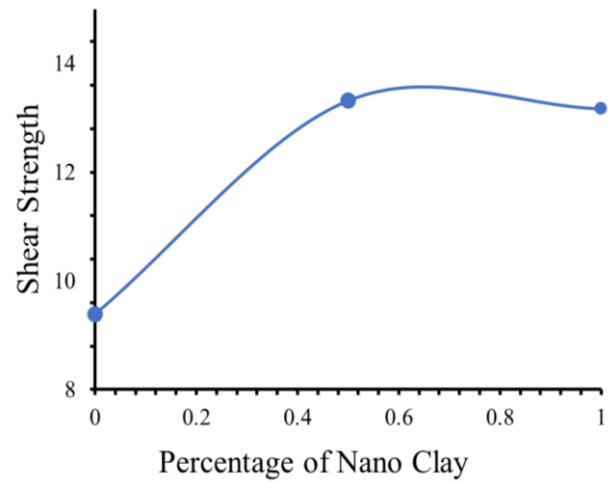


Fig.10 Shear strength for varying percentage of nano clay

While conducting the cyclic bending test, a clear uptrend of permanent deformation was observed concerning the increase in the number of cycles and the deformation becomes constant from the 8th cycle. Furthermore, the addition of 1% nano clay causes to increase in the permanent deformation of the beam.

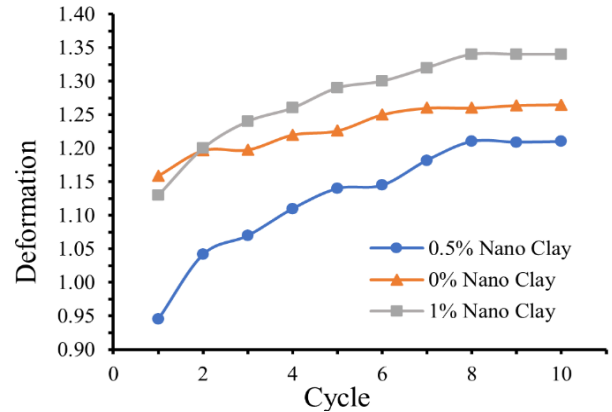


Fig.11 Permanent deformation vs number of cycle

For the samples in which nano clay was used, the modulus of elasticity was very high for the first cycle compared to the rest of the cycles in which the values of MOE remained fairly constant.

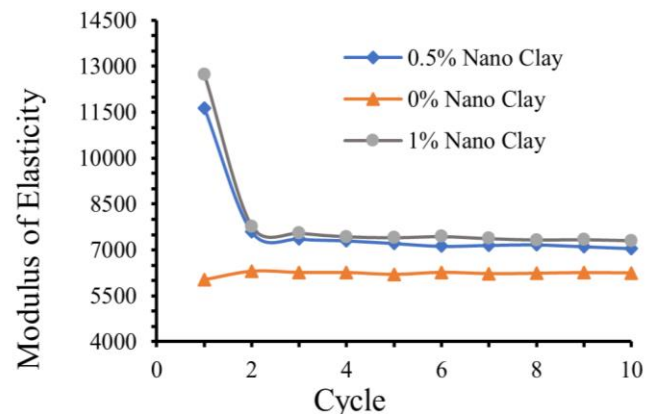


Fig.12 Change of modulus of elasticity per cycle

4.0 Conclusion

In this work, sandwich structures were manufactured where the constituent materials were nano clay, Aluminum sheet, and PVC foam. The shear strength, modulus of elasticity, and energy absorption of the samples

were investigated. The findings of the study are summarized as follows:

The bending strength and specific energy absorption remain nearly constant up to incorporating 0.5% of nano-clay. After 0.5% the trend starts to decrease up to 1%. However the modulus of elasticity (MOE) decreases up to 0.5% and then increases. The tensile strength and modulus of elasticity of the tensile test follow a similar trend. They both decrease up to 0.5% and then increase up to 1% incorporation of nano-clay. But the SEA shows an opposite trend. It increased up to 0.5% and then started to decrease. The short beam shear strength increases up to 0.5% and then it becomes almost constant. For the cyclic bending the deformation increases with the increases of the percentage of nano clay. The deformation is higher for 1% of nano-clay. The modulus of elasticity has no effect if there is no nano-clay present in the sample. But for 0.5% and 1%, the MOE increases up to 2nd cycle and then becomes constant. For all types of samples, the face is wrinkled but no skin delamination has occurred.

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