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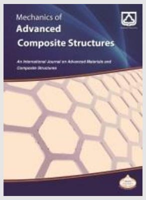

Investigation of Buckling Analysis of Epoxy/ Nanoclay/ Carbon Fiber Hybrid Laminated Nanocomposite: Using VARTM Technique for Preparation

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ABSTRACT

In the current study the effect of nanoclay content and carbon fiber orientation on the buckling properties of epoxy/nanoclay/ carbon fiber orientation is investigated. Buckling samples were prepared with 1, 3 and 5 wt% of nanoclay and 0, 30 and 45 degrees of fiber orientations based on VARTM technique. The results obtained from the buckling tests showed that adding 1wt% of nanoclay into the pure epoxy in different fiber orientations decreased the magnitude of critical buckling loads and the stress of starting the buckling process. Furthermore, in a constant fiber orientation, increasing the weight percentage of nanoclay increased the magnitude stress of starting the buckling process and the critical buckling load and then decreased them. Moreover, increasing the degree of fiber orientation decreased the buckling loads properties generally. The maximum values of stress of starting the buckling process and critical buckling load were 68.16 Mpa and 3.697 kN respectively which occurred with 3 wt% of nanoclay and 0 degree of fiber orientation.

1. Introduction

Composite materials are widely used in new industries in recent decades because of their environmentally likely nature, economical efficiency properties and high chemical resistance with the high stiffness and strength of fiber which are offered by polymer matrices [1]. Most of the researchers have been focused on improving the thermal and mechanical properties of the composite materials. In order to achieve this aim various materials can be added to composites such as fibers (macro), micro (nano materials). These materials are added as reinforcement and adding these additives has different effects on the composite, for instance fibers lead the stress to be distributed throughout the restoration and improve the structural properties of the material by acting as crack stoppers[2]. Different kinds of fibers can be added to the composite materials. The composites with carbon fiber as reinforcement are used to improve the mechanical properties of epoxy and other material matrices because of their specific strength and modulus. Glass fiber is the most commonly used fiber in comparison with the other kinds of fibers which can improve the in-plane mechanical properties much better than the others. Panthapulakkal et al. [3] studied the thermal and mechanical properties of hemp/glass fiber-polypropylene composite and reported that adding glass fiber into the hem- polypropylene composite improved the thermal properties. Eronat et al. [4] evaluated the effect of glass fiber layering on the flexural strength of microfill and hybrid composites and showed that glass fiber layering of microfill and hybrid composites had higher flexural strength. Bekyarova et al. [5] filled carbon fiber/epoxy with the carbon nanotubes and reported a great laminar strength (~ 50 MPa). Godaraaet al. [6] reinforced carbon fibers with Carbon Nano-Tubes (CNTs) and showed that the viscosity profile of the epoxy matrix indicated a strong de-

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pendency on the type of CNTs. Epoxy resins are the most important class of polymer matrix composite materials, due to their superior mechanical properties. The resin matrix creates a geometrical arrangement, protects the fiber and supports the reinforcement. Moreover, the epoxy resins are thermoset materials which have good wetting abilities, high activities, low viscosities, excellent mechanical and thermal properties and also fracture toughness [7]. But, the epoxy resins have a brittle nature due to their tight three dimensional molecular network structures. Solving this problem persuaded researchers to add nano materials such as Carbon Nano-Tube (CNT), nano clay, alumina, nano silica, etc. to the epoxy resin in order to reinforce it [8]. Inorganic nanoparticles can be also used as reinforcement because of their low cost, environmentally likely nature and ease of fabrication[8] . Xu Y et al. [9] showed that adding a low weight percentage of nano clay to the fiber/epoxy composites improved the flexural strength by 38%. Mirmohseni et al. [10] used 2.5 % wt organic nano clay into the epoxy resin and reported that the tensile strength and the impact strength were increased compared to those of the pure epoxy. Gojny et al. [11] showed that adding 0.3% wt multi-walled carbon nanotube to glass fiber/epoxy significantly increased the inter laminar shear strength of the glass fiber. Becker et al. [12]showed that filling the epoxy resin with nanomer I.30E nano clay increased the itselastic modulus and fracture toughness. Ragosta et al. [13] founded that adding 10 wt% silica particles into the epoxy resin improved its mechanical properties. Zheng et al. [14] added 3%wt silica into the epoxy matrix and showed that the tensile strength and the impact strength increased about 115 and 56% respectively.

Higher mechanical properties and crack propagation resistant can be achieved using two or more kinds of nano or other nano particles as reinforcement. These types of composite materials are named hybrid nano composites [15]. Fereidoon et al. [16] reported that using multi-walled carbon nanotube and high impact polystyrene improved the tensile strength, compression and impact properties. Rostamiyan et al. [17] filled epoxy resin with High-Impact Polystyrene (HIPS) as thermoplastic phase and nano silica as nano reinforcement and reported that the combination of HIPS and silica nanoparticles increased the epoxy resin tensile strength and damping properties. Mirmohseni et al. [18] reported that epoxy/ABS/nano clay/TiO_2 hybrid nanocomposite improved the impact strength compared to the neat epoxy. Rostamiyan et al. [17] also filled the epoxy resin with nano clay as a nano reinforcement and HIPS as a thermoplastic phase and they reported that the tensile, compression, and impact strengths were improved up to 60 %, 64 %, and 402 %, respectively, which were higher than those of the neat one. There are different ways for producing composite materials. The VARTM technique is one of them. In this technique the resin is infused into dry fabric, formed on a mold near product shape under vacuum pressure and cured in an oven. This process can be applied to the fabrication of aircraft primary structures. Compared to the conventional composite fabrication methods, this process is an ideal technique using low cost composite materials without prepregs and autoclaves. As mentioned before the most important aim of conducting a research on nanocomposites is improving their mechanical properties. Buckling resistance is an important and notable consideration in designing the laminated composites. Most of the laminated composite structures are often at risk of failure, such as buckling phenomena due to their light weight and thin thickness which lead to the breaking mode. Various factors can be effective on the mechanical properties of nanocomposites, such as the type of fiber, fiber orientation, laminate structure, number of incorporated nanoparticles as reinforcement, the weight percentage of nanoparticles, kind of nanoparticles, etc. In the current study the effect of the weight percentage of nanoclay as reinforcement and fiber orientation on the buckling load properties of epoxy/ carbonfiber/ nanoclaynanocomposites was investigated. Also, morphological and structural characteristics of the desired mechanism were investigated using Scanning Electron Microscopy (SEM).

2. Experimental Details and Analysis

2.1. Details of materials

The epoxy resin utilized in this study was EC 130LV. Its epoxide equivalent weight was 185-192 g/eqiv and was provided by Shell Chemicals Co. Epon 828 is basically DGEBA (Diglycidyl ether of bisphenol-A). The curing agent was a nominally cycloaliphatic polyamine, Aradur® 42 supplied by Huntsman Co. The organo clay Cloisite 30B was purchased from Southern Clay Products (Gonzales, TX, USA).

2.2. Sample preparation

In this study, the unidirectionl carbon fiber/epoxy composite plates were fabricated in dimensions 500 mm - 1000 mm, as 16 layers. Nanoclay with 1 wt%, 3 wt% and 5 wt% of was added into epoxy resin in order not to dramatically increase the viscosity of resins and bring a processing problem. The mixture of resin and nanoclay was mixed with heater magnetic stirrer about 2 hours. In this step 27 phr of hardener was added to the mentioned mixture and the mixtures were thoroughly mixed for 30 minutes using a mixer. For preparation of the filled composite laminates, carbon fibers were put on a table with smooth surface and were impregnated by hand successive plies, with mixture resin. Fig .1 shows a symmetric laminate composite plies structure.

After the impregnation, a plastic vacuum bag was placed on top of the prepared composite plates and vacuum was applied. Thus, the high quality and void-free composite plates were fabricated. Finally, the composite laminated plate was cured for 24 hours at room temperature, followed by post-curing from 50°C to 90°C each 2 hours with 20°C temperature interval enhancement and at 120°C for 2 hours to ensure complete curing [17]. The buckling test samples were cut with a circular diamond blade saw from the fabricated composite plates. Fig.2 indicates the vacuum procedure and the prepared samples after cutting with dimond blade saw.

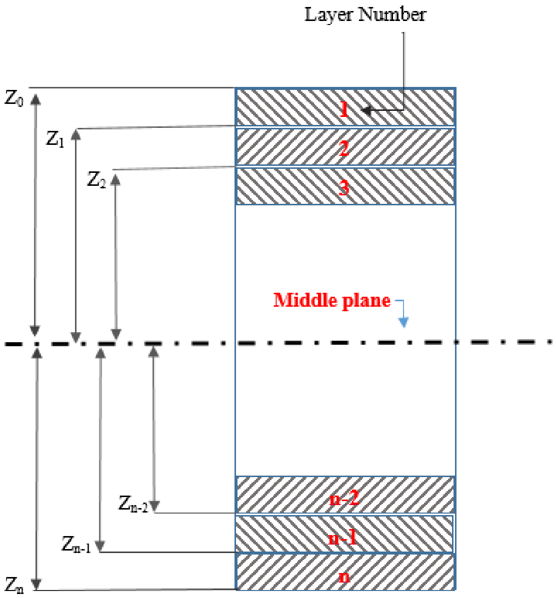


Figure 1. The laminate stacking of plies [(±θ)$_2$] sym.

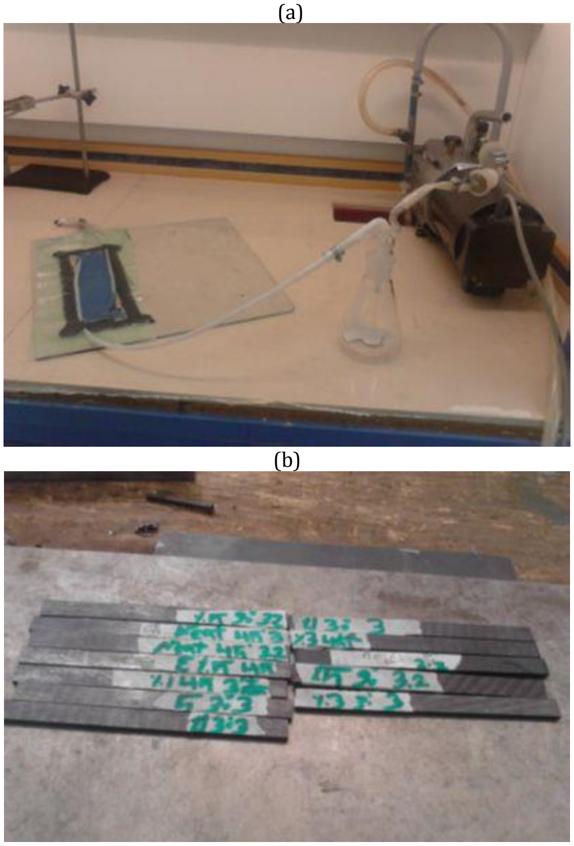


Figure 2. (a) the vacuum procedure and (b) the prepared samples after cutting with diamond blade saw.

2.3. Characterization

The critical buckling loads of carbon fiber/epoxy /nanoclay plates were experimentally determined. The dimensions of the samples were 12mm×140mm in width ×length and the thickness of the samples was 4.8mm. The buckling samples were tested by applying compression loads in axial direction using ASTM D: 6641 standard with a loading rate of 1 mm/min. The results of this mechanical test were measured by an STM-150 universal testing machine from Santam Company (Iran). All experiments were performed at room temperature. The critical buckling load of each composite was determined from the load–displacement curves. The initial point of the load– deflection curve deviated straight line represents the critical buckling load. All the tests were done using a constant velocity of 1 mm/min. Fig.3 indicates the samples under buckling load. Also, a Scanning Electron Microscope (SEM1530) was used to observe the dispersion of the fracture surfaces of the desired composite. Each fracture surface was coated with gold prior to the SEM to avoid charging of the specimen.

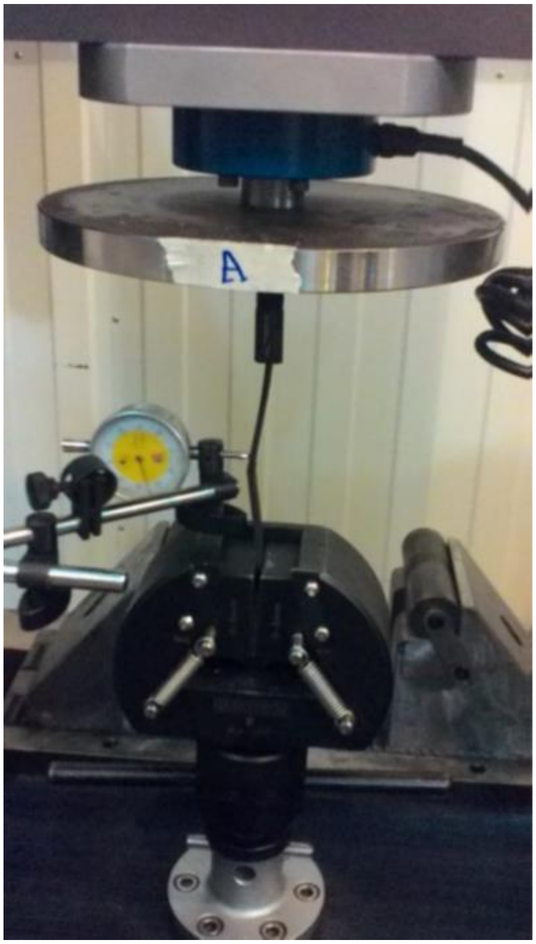


Figure 3. The sample under buckling test.

3. Results and Discussion

As mentioned before the input parameters selected for the current study are carbon fiber orientation[19]and nanoclay wt% and the effect of these parameters on the buckling load properties of the desired nanocompositehas is considered. The levels of fiber orientations are 0 degree, 30 degrees and 45 degrees and the levels of nanoclay wt% are assumed to be 1 wt%, 3 wt% and 5 wt%. In the first step, the stress strain plots for different fiber orientations and different wt% of nanoclay are considered and measured. Then, the effect of variation in nanoclay content on critical buckling load and elastic modulus is experimentally evaluated and finally the effect of fiber orientation on critical buckling load is investigated.

3.1. Stress- strain plots and critical buckling load analysis

In this section stress-strain plots have been used for measuring the effect of nanoclay content on stress at the point of starting the buckling process in a constant fiber orientation and also for measuring the effect of variation in fiber orientation on buckling process.

3.1.1. Adding different contents of nanoclay in 0 degree of fiber orientation

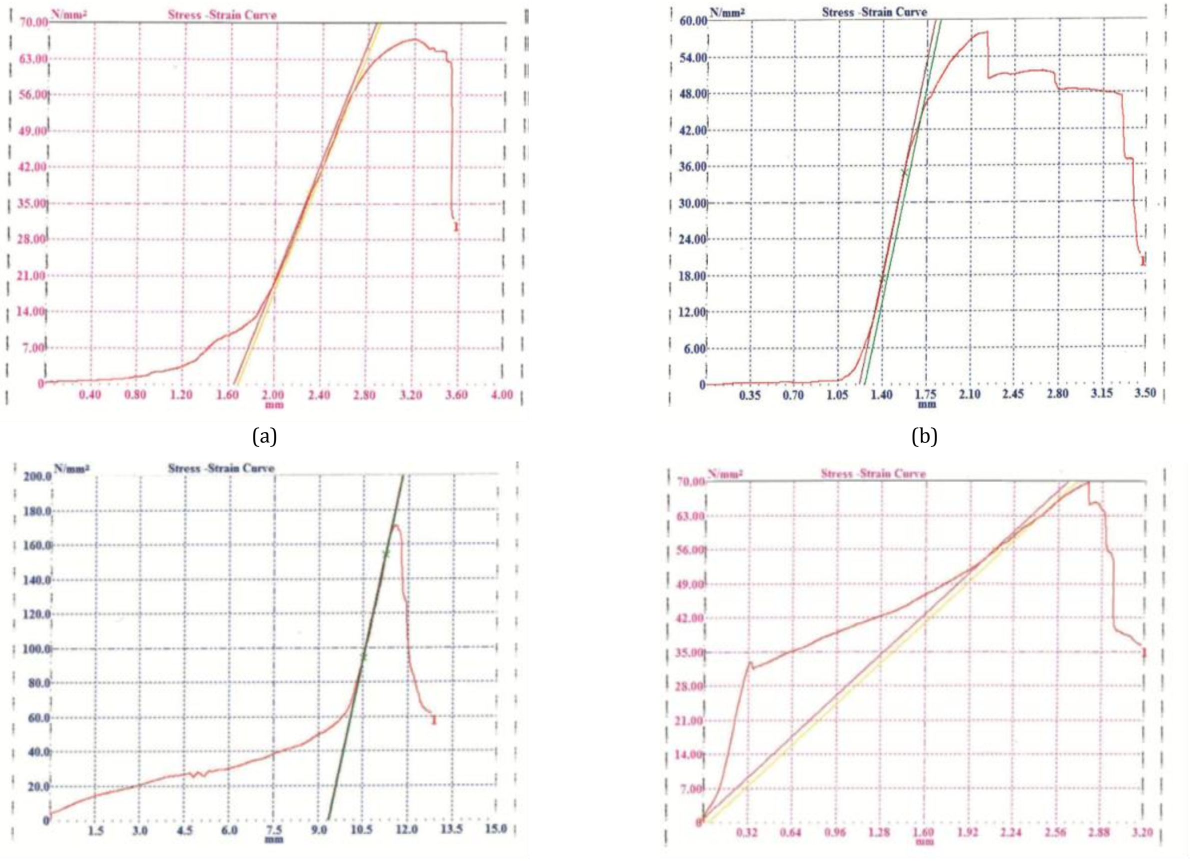
Four parts of Fig. 4 display the stress-strain plot for 0 degree of fiber orientation and (a) without adding nanoclay, (b) 1 wt% of nanoclay, (c) 3 wt% of nanoclay and (d) 5 wt% of nanoclay respectively. Also, Table 1 shows the data's obtained from buckling test for this condition. From part (a) and part (b) of this table it can be seen that with adding 1 wt% of nano clay into the pure epoxy in 0 degree of fiber orientation, the stress of starting the buckling process reduces and the buckling process starts earlier. The buckling point for pure epoxy occurrs in 15.8 mm of displacement while the buckling point for composite with 1 wt% of nano clay is 7.8mm, so the buckling properties of the nanocomposite reduce, compared to the pure epoxy and its critical buckling load, which is lower than pure epoxy.

Comparing part (b) and part (c) of Table 1 indicates that increasing the weight percentage of nanoclay from 1 wt% to 3 wt% at 0 degree of fiber orientation has a considerable effect on the stress of starting the buckling process. As seen, the buckling process starts at a larger value of strain for 3 wt% of nanoclay (68.16 Mpa), compared to 1 wt% of nanoclay and the buckling occurrs in a higher value of displacement (17.23mm), compared to 15.16mm for 1 wt% of nanoclay. Moreover, the critical buckling load increases for 3 wt% of nanoclay, compared to 1 wt% and pure epoxy according to the Table 1.

Also, the effect of adding 5 wt% of nanoclay can be seen in part (d) of fig. 4 and also part (d) of table1. Measuring part (c) and (d) of table 1 shows that increasing the weight percentage of nanoclay decreases from 3 to 5 and the stress of stating buckling process occurrs from 68.16 Mpa to 53.99 Mpa. The buckling behavior earlier compared with 3 wt% of nanoclay and later, compared to 1 wt% of nanoclay and pure epoxy and also the critical buckling load are lower than 3 wt% of nanoclay and higher than 1 wt% of nanoclay and pure epoxy.

3.1.2. Adding different contents of nanoclay at 30 degrees of fiber orientation

The stress-strain plots and also the data obtained from the buckling tests at 30 degrees of fiber orientation are displayed in four parts of fig.5 and Table 2. From comparing part (a) of this table with part (a) of Table 2 it can be seen that increasing the degree of fiber orientation from 0 degree to 30 degrees increases the stress of starting buckling process and also buckling point while decreases the critical buckling load. Part (b) of table 2 indicates that adding 1wt% of nanoclay into the pure epoxy leads to a decrease in the magnitude of stress in comparison with pure epoxy in both 0 degree and 30 degrees of fiber orientation and also 1wt% of nanoclay in 0 degree of fiber orientation. Similar results are observed for the critical buckling load in this condition.



(a) (b)

(c) (d)

Figure 4. The stress-strain plot for 0° of fiber orientation and (a) without adding nanoclay, (b) 1 wt% of nanoclay, (c) 3 wt% of nanoclay, (d) 5 wt% of nanoclay

Table 1. The data's obtained from buckling test for 0° of fiber orientation and (a) without adding nanoclay, (b) 1 wt% of nanoclay, (c) 3 wt% of nanoclay, (d) 5 wt% of nanoclay

	stress of starting buckling (MPa)	point of starting buckling process (mm)	buckling poin (mm)	Displacement (mm)	maximum load (kN)	cross section (mm²)	Dimension (mm*mm)
a	12.94	1.82	7.80	15.30	2.465	36.84	12*3.07
b	9.42	1.31	15.16	7.80	2.436	42.00	12*3.50
c	68.16	10.08	17.23	8.80	3.697	42.00	12*3.50
d	53.99	2.02	4.32	8.78	2.925	41.88	12*3.49

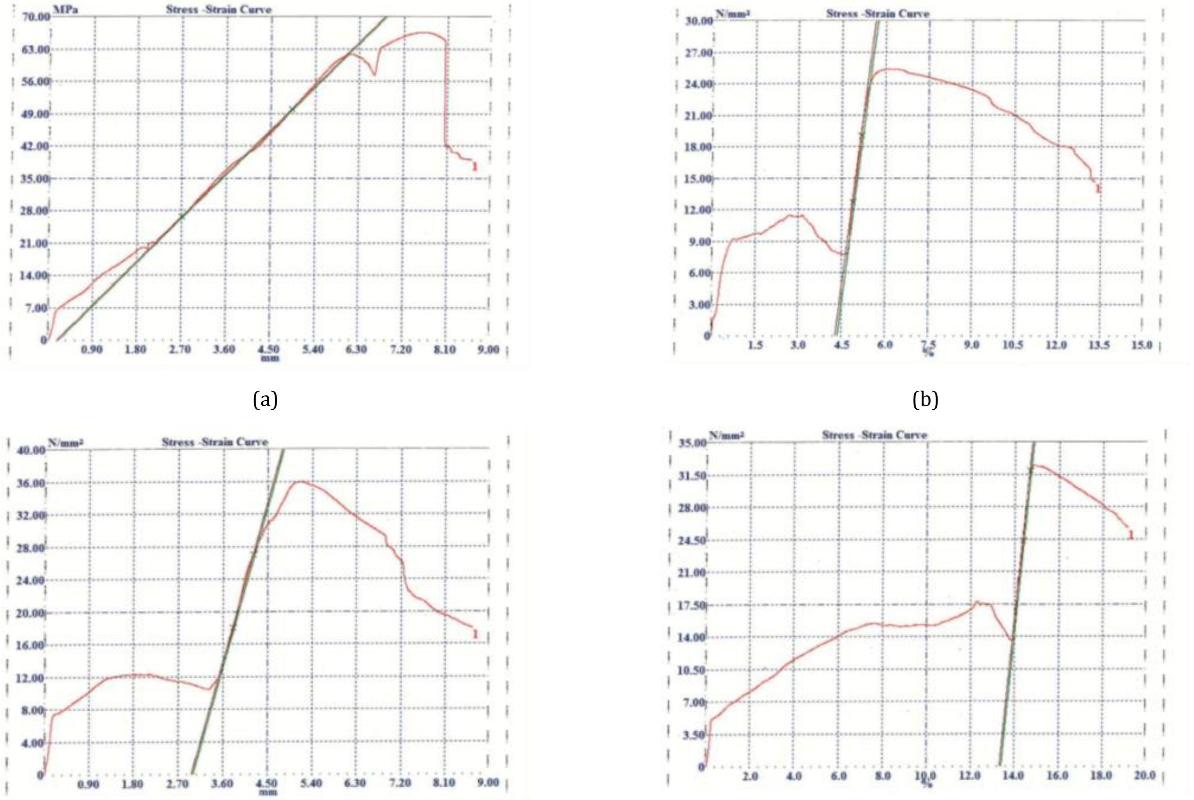
Comparing part (b) and part (c) of Table 2 indicates that increasing the weight percentage of nanoclay to 3 increases the stress of starting the buckling process and displacement of buckling point in comparison with 1 wt% of nanoclay and pure epoxy in 30 degrees of fiber orientation. Also, the critical buckling load in this situation is higher than 1wt% of nanoclay and lower than pure epoxy. Moreover, comparing the 3 wt% of nanoclay in 0 degree and 30 degrees of fiber orientations shows that increasing the fiber orientations decreases the stress of starting buckling process, displacement of buckling points and critical buckling points.

Part (d) of Table 2 displays the effect of adding 5 wt% of nanoclay into the pure epoxy. From the obtained results it can be implied that the stress of starting buckling process.

Critical buckling point decreases compared to the pure epoxy at 30 degrees of fiber orientation and also compared to 5 wt% of nanoclay in 0 degree of fiber orientation while the displacement of buckling point in this condition is higher than that of pure epoxy at 30 degrees and 5 wt% of nanoclay at 0 degree of fiber orientation.

3.1.3. Adding different contents of nanoclay at 45 degrees of fiber orientation

Fig. 6 shows that the stress-strain plot for different contents of nanoclay and pure epoxy in 45 degrees of fiber orientation. Also, different parts of Table 3 indicate buckling test results in this condition. Comparing part (a) of Table 3 with part (a) of Tables 1 and 2 shows that the critical buckling load at 45 degrees is lower than the critical bulking load at 30 degrees while it is higher than that at 0 degree. Similar results are obtained for the stress. Also, the displacement of buckling point at 45 degrees is higher than 30 and also higher than 0 degree of fiber orientation. Part (b) of Table 3 indicates the effect of adding 1wt% of nanoclay into pure epoxy at 45 degrees of fiber orientation. As seen, the stress of starting the buckling process and critical buckling load is lower than pure epoxy at 45 degrees of fiber orientation, but the displacement of buckling point for nanocomposite with 1 wt% of nanoclay is higher than pure epoxy. Also, comparing part (b) of Tables 1, 2 and 3 shows that the buckling load for nanocomposite with 1 wt% of nanoclay at 45 degrees is lower than that at 30 degrees and the one at 30 degrees is lower than 0 degree. The stress of starting the buckling process for 45 degrees (5.78 MPa) is higher than the one for 30 degrees (5.12 MPa) and the one for 30 degrees is lower than 0 degree (9.42 MPa).



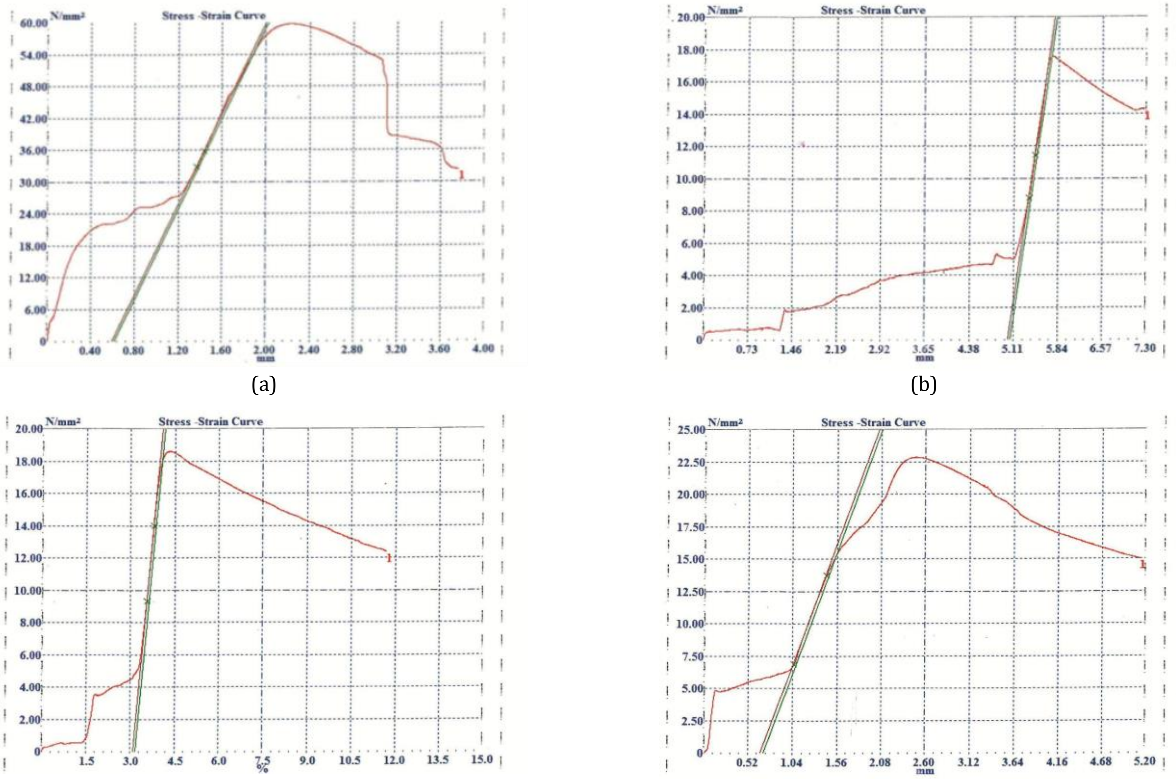
(a) (b)

(c) (d)

Figure 5. The stress-strain plot for 30° of fiber orientation and (a) without adding nanoclay, (b) with 1 wt% of nanoclay, (c) with 3 wt% of nanoclay, (d) with 5 wt% of nanoclay.

Table 2. The data obtained from buckling test for 30° of fiber orientation and (a) without adding nanoclay, (b) with 1 wt% of nanoclay, (c) with 3 wt% of nanoclay, (d) with 5 wt% of nanoclay.

	stress of starting buckling (MPa)	point of starting buckling process (mm)	buckling poin (mm)	Displacement (mm)	maximum load (kN)	cross section (mm^2)	Dimension (mm*mm)
a	9.00	4.28	11.23	5.78	2.800	42	12*3.50
b	5.12	3.27	21.07	10.50	1.063	41.88	12*3.49
c	11.67	3.50	23.95	12.05	1.511	42	12*3.50
d	14.43	7.00	11.61	5.85	1.366	42	12*3.50



(a) (b)

(c) (d)

Figure 6. The stress-strain plot for 45° of fiber orientation and (a) without adding nanoclay, (b) with 1 wt% of nanoclay, (c) with 3 wt% of nanoclay, (d) with 5 wt% of nanoclay.

Table 3. The data obtained from the buckling test for 45° of fiber orientation and (a) without adding nanoclay, (b) with 1 wt% of nanoclay, (c) with 3 wt% of nanoclay, (d) with 5 wt% of nanoclay.

	stress of starting buckling (MPa)	point of starting buckling process (mm)	buckling poin (mm)	Displacement (mm)	maximum load (kN)	cross section (mm²)	Dimension (mm*mm)
a	27.68	1.22	12.41	6.62	2.510	41.88	12*3.49
b	5.78	5.18	15.12	7.92	0.738	42.00	12*3.50
c	5.30	1.65	22.89	11.56	0.780	41.76	12*3.48
d	6.81	1.05	19.15	9.63	0.960	42.00	12*3.50

Table 4. The critical buckling load for different nano clay wt% and different fiber orientations.

Fiber Orientaion	Pure epoxy	1 wt%	3 wt%	5 wt%
0°	2.465	2.436	3.697	2.925
30°	2.800	1.063	1.511	1.366
45°	2.510	0.738	0.78	0.96

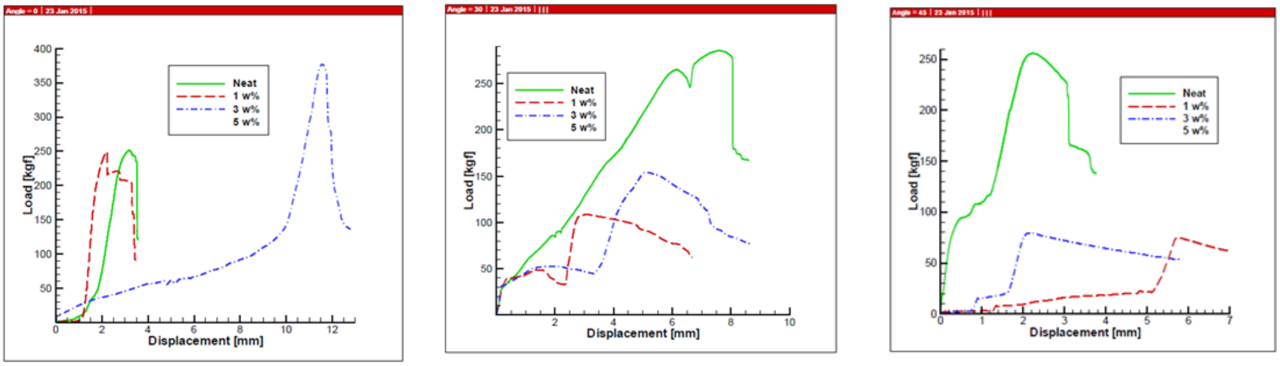
Adding 3 wt% of nanoclay into the epoxy as seen in part (c) of Table 3, decreases the stress of starting the buckling process and critical buckling load in comparison with the pure epoxy in this fiber orientation while the displacement of buckling point increases. Also, comparing 5 wt% of nanoclay at 0 degree, 30 degrees and 45 degrees of fiber orientation shows that increasing the fiber orientation decreases the buckling properties of the mentioned nanocomposite according to part (c) in Tables 1, 2 and 3.

Table 3 (d) displays the results obtained from the buckling tests by adding 5 wt% of nanoclay into the epoxy at 45 degrees of fiber orientation. Comparing this nanocomposite with pure epoxy and also nanocomposites with a similar weight percentage of nanoclay and different fiber orientations exactly shows similar results to what is obtained in the previous section. Moreover, comparing Table 3 (b), (c) and (d) of indicates that increasing the weight percentage of nanoclay first decreases the stress of starting the buckling process and critical buckling load then decreases them while the displacement of buckling point increases continuously. From what is mentioned above it can generally be concluded that the critical buckling load is increased with increasing weight percentage of nanoclay to 3 wt% and without changing in the fiber orientation and then is decreased.

Also, an increase in the fiber orientation from 0 degree to 30 degrees and 30 degrees to 45 degrees decreases the critical buckling load in different weight percentages of naoclay generally. Similar results can be observed for the stress of starting buckling process. The highest obtained values for critical buckling load and stress of starting buckling process occurr at 0 degree of fiber orientation and 3 wt% of nano clay with the magnitudes of 3.67KN and 68.16Mpa respectively. Table 4 displays the critical buckling load for different fiber orientations and different wt% of nanoclay and Fig. 7 shows the load-displacement plots for different wt% of nanoclay and different fiber orientations. Also, fig.8 indicates the effect of changing in nanoclaywt% and fiber orientation on the stress of starting buckling process.

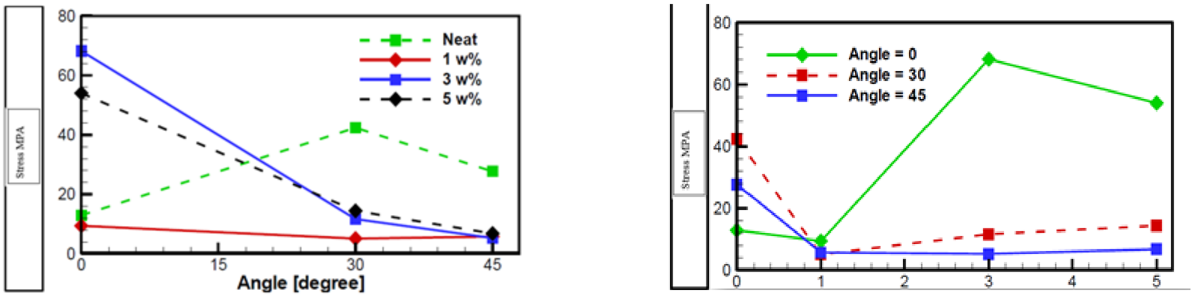
3.1.4. SEM analysis

As mentioned before the scanning electron microscopy device 1530 type is used in the current study. Fig.9 shows the micrograph of cut surface of buckling specimens with different contents of nanoclay. As seen, a homogeneous dispersion of nanoclay in epoxy resin and also a little agglomeration are observed.



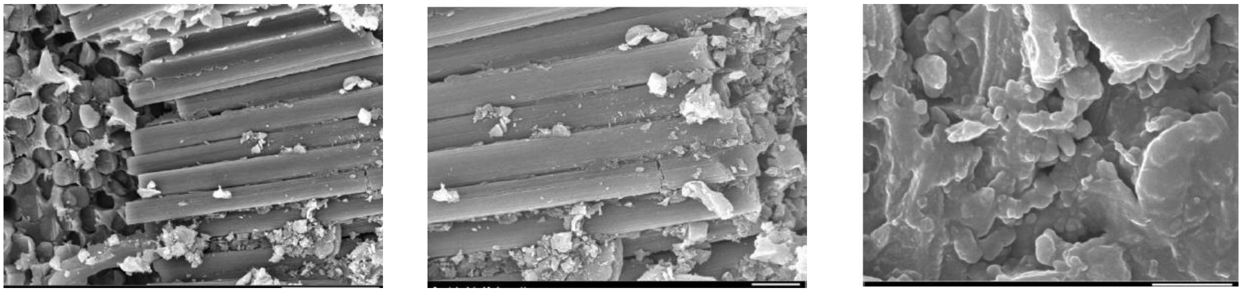
(a) (b) (c)

Figure 7. The load- displacement plots for different wt% of nanoclay (a) with 0 degree of fiber orientation, (b) with 30 degrees of fiber orientation and (c) with 45 degrees of fiber orientation.



(a) (b)

Figure 8. The effect of (a) changing in wt% of nanoclay and (b) degree of fiber orientation on stress of starting buckling.



(a) (b) (c)

Figure 9. The scanning electron micrographs of fracture surface for buckling samples.

4. Conclusion

The effect of carbon fiber orientation and weight percentage of nanoclay on the buckling properties of epoxy / carbon fiber/nanoclay was investigated. 1, 3 and 5 wt% of nanoclay and 0, 30 and 45 degrees of fiber orientations were selected as input parameters in order to prepare samples and the VARTM technique was used. The buckling tests were done and the results showed that adding 1wt% of nanoclay into the pure epoxy in different fiber orientations decreased the magnitude of the stress of starting buckling process and critical buckling load. In a constant fiber orientation increasing the weight percentage of nanoclay increased the magnitude stress of starting buckling process and critical buckling load at the same time and then decreased. Moreover, increasing the degree of fiber orientation decreased the critical buckling load and stress of starting buckling process generally. The scanning electron microscopy was done and obtained micrographs showed that a good dispersion of nanoclay in epoxy resin with little agglomeration occurred.

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