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FINITE ELEMENT SIMULATION OF BUCKLING BEHAVIOR OF EPOXY COMPOSITE PLATE REINFORCED WITH NANO-AL PARTICLES

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Abstract- Mechanical structure buckling behavior is necessary to ensure stability when loaded. Critical buckling load referred to the maximum load can be sustained without losing stability and avoiding severe damage due to plate collapsing. The objective of this research was to assess numerically the influence of adding Nano-Al particles on the buckling characteristics of epoxy reinforced composite plate. Composite specimens with various Nano -Al particle weight fractions, namely (2, 4, 8 wt.%). Buckling tests were also carried out on specimens with varied plate thicknesses (1, 2, 3) mm and aspect ratios (1, 1.5, 2), applying three distinct boundary conditions (SSSS, SSSF, and SFSC). The experimental work consists manufacturing tensile test specimens with various weight fractions of Nano-Al to assess the mechanical characteristics that will be utilized as data input in the numerical solution. The critical buckling load was estimated numerically using the ANSYS 15.0 software. Results reveal that employing Nano-Al particle as a reinforcement improves buckling resistance when compared to pure epoxy, and that increasing plate thickness and aspect ratio increases critical buckling load. In addition, boundary condition type SSSS withstand high buckling load compare with other support types.

Keywords: Buckling Composite Plate, ANSYS Software, Reinforced, Nano-Al, Critical Load.

1. INTRODUCTION

Composite plates are used extensively in aeronautical constructions, robotic arms, vehicles, and architecture. Because they demand structural qualities in comparison to traditional materials such as corrosion resistance, high specific strength, particular stiffness, and lightweight. Composite stiffened structures have recently been popular in a variety of engineering and industrial applications, including aircraft, marine constructions, and bridges, due to their reduced weight and environmental friendliness. As a result, it is critical to comprehend the composite plate structure's behavior, including buckling loads, deflections, modal features, and failure characteristics. The stiffness of local bending, which is influenced by fiber orientation, stacking sequence, and spatial direction, determines the buckling load of composite plates.

Furthermore, buckling coefficients were calculated using finite element techniques, which took into consideration the plate's orthotropic features [1]. The following researchers studied various approaches for modifying composite plate buckling behavior. Thaier J. Ntayeesh, et al. prepared and fabricated an experimental investigation of buckling for five samples of nano composite plates. The plate samples contain woven reinforcing fiber and polyester matrix, as well as carbon. Nano additives make up (0%, 0.5%, 1%, 1.5%, and 2%) of the resin weight ratio. Buckling tests were performed on several nano plate samples that were simple-supported at two ends and at the other, it's free.

ANSYS R15.0 was used to perform the finite element analysis. The maximum buckling load is obtained at a Nano carbon weight ratio of 2%. [2]. Prashant K. C. and P.K. Mahato. consider the effects of shape and location of the elliptical hole on the thermal buckling behavior of ortho-tropic plates fabricate by composite materials, employing finite element model (FEM) to study the thermal buckling for different fiber orientation with a cutout exposed to uniform temperature rise. Results indicate that changing the direction of the elliptical cutout lowers the thermal buckling temperature [3]. Mahmud Rasheed Ismail, et al. assessed the critical buckling load Using two methodologies, experimental techniques and numerical technique by using ANSYS software as a tool for finite element method, the validity of both strategies was demonstrated by analyzing the result of the two methods.

The results reveal that delamination reduces the buckling strength of the composite plate structure as the delamination size is larger and the position approaches the maximum bending moment [4]. Muhannad Al-Waily, et al. evaluate thermal buckling activity for a composite plate structure with a variety of Nano fractions using analytical and numerical approaches. The mechanical characteristics of Nano composites were investigated in an experimental program. The results revealed that the thermal effect causes Nano particle strengthening for the plate's modified structure, resulting in increased thermal buckling strength. This accomplishment combined a strong thermal buckling strength with a low Nano volume fraction [5].

A.A. Zaman, et al. studied and classified the Influence of the behavior of delamination which is occurs following of buckling or post buckling, in laminated composites by shape, position, size and type effects in structures by an experimental and numerical approaches. The objective of the study review was to look out the behavior of delamination and kinds based on the practical and simulated methods [6]. A.M. Hashimov, et al. Prepared (Fe_3O_4) nano-particles and epoxy-based composites, the characteristics of the composites were assessed by X-ray diffraction, scanning electron microscopy, and resin with different nano-magnetite mass ratios. Maximum absorption coefficient values were noted (10%) for composites with the highest levels of magnetite. J.S. Chiad, et al. used the experimental approach to make and quantify the mechanical characteristics of composite materials with different powder weight ratios, different powder materials were employed to enhance the buckling behavior of composite plates [7]. Furthermore, the buckling behavior of the plate structure with varied powder characteristics was evaluated using both experimental and numerical methodologies.

The results revealed that powder materials improved mechanical characteristics and buckling behavior [8]. A. Keshavarz and M. Yarmohammad Tooski studied the effect of openings on post-buckling and buckling behavior of Fiber Metal Laminate plates, epoxy resin reinforcing with 4 layer of woven basalt fiber, between two Aluminum plates using three samples, one without opening, and other with a (10 mm) opening and another with (20 mm) opening was fabricated and tested. In samples with opening, plasticity in Al plates and degradation in composite laminate are discovered, making restoration difficult and dangerous [9].

U.F. Samadova, et al. Analyze the main parameters M_s, M_r, H_c and M for magnetic composites based on the proportion of filler volume, and assess the magnetic characteristics of composite films based on poly-ethylene and solid solution. [10]. A. Shirkavand carried out experimental and numerical investigation of rectangular cutout composite cylinders under buckling mode. The major goals were to investigate the influence of orientation and rectangle cutout size on composite cylinders. The influence of initial defects on cylinder buckling was studied using both linear and nonlinear techniques in the numerical analysis. Several major conclusions were studied in depth, including the effects of size and direction of cutout, as well as the combined effects of cutouts and initial defect on buckling behaviors. In compared to the circumferential direction, the cutout in the axial direction increases buckling load [11].

It can be demonstrated from the prior work that employing reinforcing fibers, powders, or Nano-particles improved buckling behavior. The goal of this research is to utilize Nano-Al particles as epoxy composite reinforcing materials to increase critical buckling loads in composite plate structures. Also, to determine the best boundary condition among the three types used in this simulation.

2. EXPERIMENTAL

The experimental side consist of fabricating tensile test specimens to estimate the strength and young modulus of elasticity for epoxy composite materials reinforced with various weight fractions of Nano-AL (2%, 4%, and 8%), which will be used as an input mechanical property in numerical simulation. Tensile specimen manufacturing according to ASTM (D695) standard as shown in Figure 1. They were assessed by utilizing five tests for each weight fraction and calculating the average value. A (Zwick / Roell Z100) universal testing machine was used to carry out the tensile test. Table 1 lists the required mechanical properties for epoxy reinforced composite.

Figure 1. tensile test specimens ASTM (D695) standard for epoxy composite material [12]

Table 1. mechanical properties of epoxy for various wt

Wt. %	E (Mpa×10^3)	σ_y (Mpa×10^3)	σ_{ult} (Mpa×10^3)
0	14.588	26.1	33.22
2	21.1926	30.5	39.1
4	20.5041	24.32	32.3
8	14.588	26.1	33.22

3. NUMERICAL ANALYSIS

Finite Element (FE) simulations is an excellent technique for analyzing difficult problems like Nano composite plates since they are non-homogeneous and an-isotropic materials. As a result, the Finite Element Method will be utilized to locate the critical buckling load for a (rectangle) plate structure composed of epoxy composite reinforced with different weight fractions of Nano AL (2%, 4%, 8%) and variable plate thickness 1, 2, 3 mm, with varying aspect ratio (a/b). ANSYS 15.0 software is used for this analysis study. Therefore, the ANSYS program must first select the appropriate element type for the composite plate. The Shell 281 was the optimum element type for calculating buckling load for composite plate structures as illustrated in Figure 2. The element includes 8 nodes, each with 6 degrees of freedom: translations in the (x, y, and z axes), as well as rotations about the x, y, z axes, and is well-suited for linear and/or nonlinear applications with large strains, large rotation, such as modeling composite shells or sandwich construction [13], after selecting element type, numerical approach requires mechanical characteristics for composite materials as an input data, which can be obtained from table 1 in experimental work.

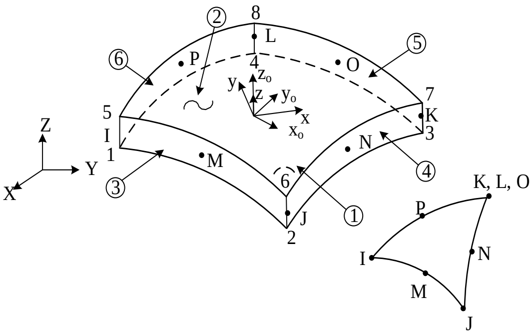


Figure 2. The shape and geometry of element shell 281

After that, the specimen models are meshed. Meshing is created automatically by selecting different levels of precision for mapped facial meshing. The mesh's size, shape, and fineness are all adjusted. The mesh shape and size must be carefully selected, since they have an effect on the accuracy of the result. After a mesh convergence analysis, each model has about 100 elements and 341 nodes. The composite plate structure is then supported using three different plate supports: SSSS (simply, simply, simply, simply), SSSF (simply, simply, simply, free), and SFSC (simply, free, simply, clamped). Pressure of 1 N/mm is applied to the plate's upper surface which compresses in the x-direction, as shown in Figure 3. Finally, the problem is solved by utilizing Eigenvalue buckling analysis to determine the critical load buckling for a rectangular plate structure.

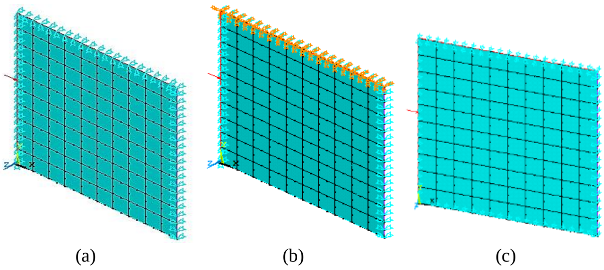


Figure 3. Load and boundary condition for rectangular epoxy composite plate in three different support type, (a) SSSS support, (b) SSSF support, (c) SFSC support

4. RESULTS AND DISCUSSION

The critical buckling loads of epoxy composite plate structure with various relevant factors employed in this study is provided in Table 2. Three boundary condition are applied (SSSS, SSSF, and SFSC), for epoxy composite plate reinforced with (2, 4, 8%) weight fractions of Nano AL at different plate thicknesses (1, 2, 3) mm, and aspect ratio (1, 1.5, 2).

4.1. Effect of Nano AL particles

Figure 4 shows the numerical analysis findings of the four epoxy composite plate specimens reinforced with Nano–Al particles, for each fabricated specimen, the buckling mode and critical buckling load are depicted in this figure. As it is clear from the figure, specimen with the largest weight fraction of Nano-Al particles has the maximum value of critical buckling load, neat specimens (pure epoxy) showed the lowest resistance to buckling load of all (thickness and aspect ratio), and hence buckled early than reinforced specimens.

Table 2. Summary of critical buckling load with different boundary conditions for epoxy rectangular composite plate

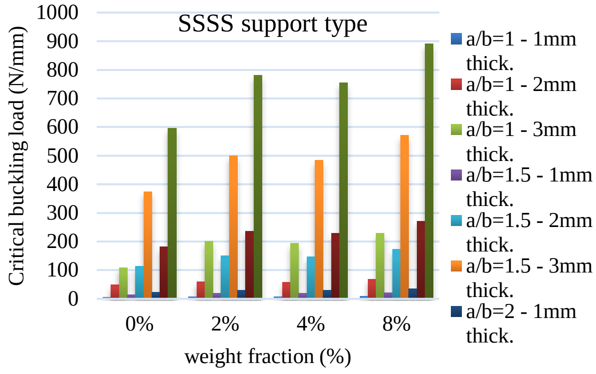
Weight fractions w.f. %	Support type	Aspect ratio (a/b)	Plate thickness 1 mm	2 mm	3 mm	
0% (Pure epoxy)	SSSS	1	6.16	48.79	108.49	PCR (N/mm)
		1.5	14.36	113.02	373.90	
		2	23.22	181.67	596.12	
	SSSF	1	1.92	15.23	51.01	
		1.5	2.66	20.97	69.81	
		2	3.55	27.90	92.39	
	SFSC	1	2.29	18.22	61.01	
		1.5	4.14	32.74	109.08	
		2	4.50	35.49	117.88	
2%	SSSS	1	7.59	60.09	200.49	PCR (N/mm)
		1.5	19.17	151.03	500.21	
		2	30.12	236.65	780.39	
	SSSF	1	2.78	22.13	74.11	
		1.5	3.86	30.46	101.43	
		2	5.16	40.53	134.21	
	SFSC	1	3.33	26.47	88.63	
		1.5	6.01	47.56	158.46	
		2	10.46	82.54	274.34	
4%	SSSS	1	7.34	58.14	193.98	PCR (N/mm)
		1.5	18.55	146.12	483.96	
		2	29.13	228.92	754.91	
	SSSF	1	2.69	21.40	71.69	
		1.5	3.73	29.47	98.12	
		2	5.00	39.22	129.86	
	SFSC	1	3.22	25.61	85.76	
		1.5	5.82	46.01	153.31	
		2	10.12	79.86	265.44	
8%	SSSS	1	8.67	68.63	228.99	PCR (N/mm)
		1.5	21.89	172.49	571.26	
		2	34.39	270.22	891.10	
	SSSF	1	3.18	25.27	84.64	
		1.5	4.41	34.79	115.82	
		2	5.90	46.29	153.28	
	SFSC	1	3.81	30.23	101.23	
		1.5	6.87	54.31	180.97	
		2	11.94	94.27	313.32	

For neat specimens at the same amount of loads increment, the magnitude of deformation increase was larger than Nano-Al reinforced ones, due to an early loss of stability resulted from increasing the load. Figure 5 show magnitude of deformation for rectangular plate of epoxy composite reinforced with 8 wt.% for SSSS supported type. An increasing trend was seen for critical buckling loads up to the Nano-Al particle content of 8 wt.% (max. values). The highest critical buckling load achieved was 891 N/mm from the specimen filled 8 wt.% Nano-Al with 3 mm plate thickness and 2% (a/b), which was 49.48% greater than the critical buckling load of the neat specimen (596.12 N/mm).

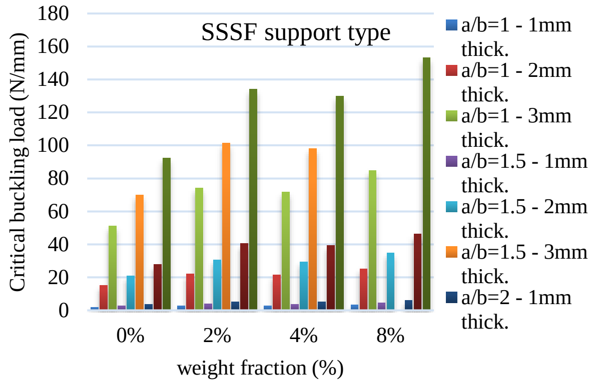
In summary, specimens reinforced with Nano-Al particles displayed greater stiffness properties when late stability was lost. This is due to changes in epoxy properties, which resulted in increased load transmission between the matrix and the Nano-AL particle.

4.2. Effect of Boundary Condition

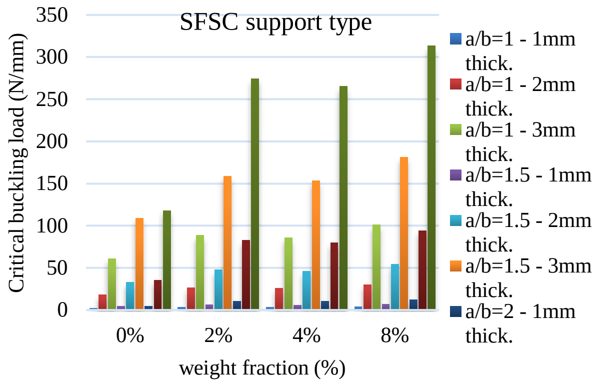
Figure 6 depicts the influence of boundary conditions on an epoxy composite plate, the results demonstrate that SSSS has the largest critical buckling load and SSSF has the lowest. SFSC is the boundary condition having the second least buckling load. This illustrates that boundary conditions with simply supported boundary conditions SSSS have 63.32% enhancement in critical buckling load than boundary conditions with simply-fixed /supported SSSF, and 56.05% than SFSC.



(a)



(b)



(c)

Figure 4. effects of weight fraction on critical buckling-load for three types of plate support (SSSS, SSSF, and SFSC)

4.3. Effect of Thickness

In Figure 7 the critical buckling loads were presented for various specimen thicknesses. It was obvious that increasing thickness led to a reduction in critical loads. Tensile and compressive forces act on the top layers of the plate. As a result, the laminate will be more resistant to these loads if these layers are greater. This condition was compatible with the Euler buckling formula, which states that the unsupported thickness and critical buckling load of thin-walled composites are inversely related [14].

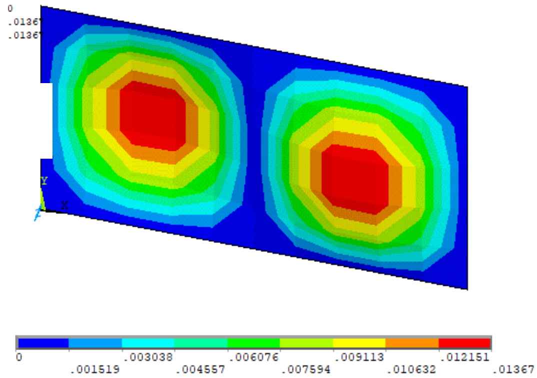


Figure 5. Magnitude of deformation resulted from applying buckling load on rectangular plate reinforced with 8 wt. % for SSSS support type

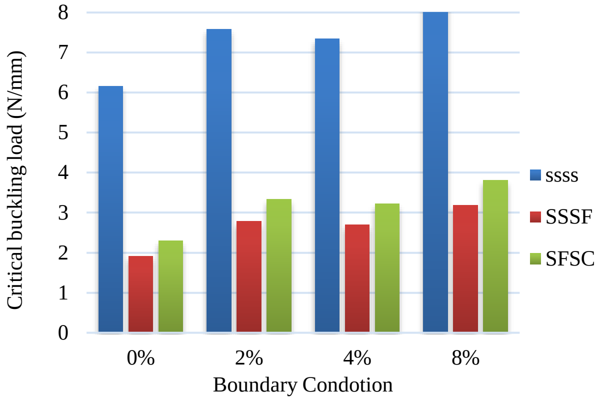


Figure 6. effects of boundary condition on critical buckling-load for various weight fraction

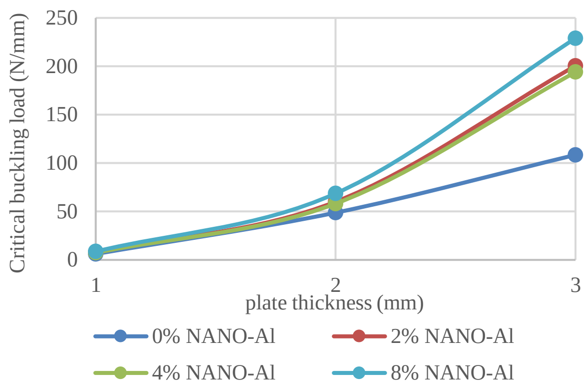


Figure 7. represent critical buckling load VS. Plate thicknesses for different weight fraction of Nano-Al particles

4.4. Aspect Ratio

The effects of the different aspect ratio are shown in Figure 8 for epoxy composite plate reinforced with Nano-Al weight fractions. When the aspect ratio was increased the critical buckling load increase as well. Since the height is kept constant while the width is varied, the laminate becomes wider as the aspect ratio increases. As a result, buckling load rises as the plate becomes wider and the location on which the load is put expands. This is attributed to the moment of inertia. The laminate stiffens and the buckling stress increases as the moment of inertia increases (notice Euler's buckling load Equation [15]).

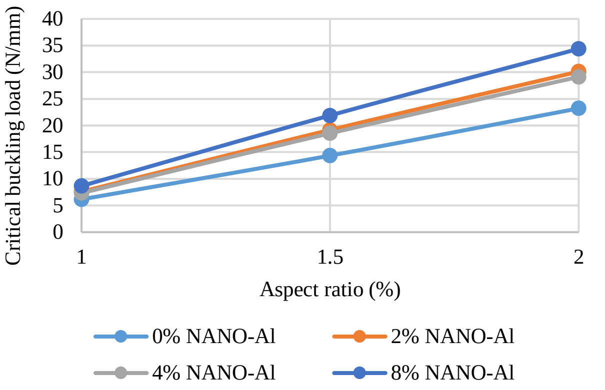


Figure 8. show effect of Aspect ratio on critical buckling-load for different weight fraction

5. CONCLUSION

This paper provides a numerical evaluation of the behavior of buckling for rectangular epoxy composites plate reinforced with Nano-Al particles. Considering four different parameters. ANSYS 15.0 software was adopted in this simulation to design and analyze buckling characteristics of epoxy composite plate and also to establish the effect of various parameters on the buckling characteristics.

The following conclusions may be drawn from the findings of this investigation on epoxy composite plates:

1. The addition of Nano-Al increased the buckling stability of the structure by enhancing the critical buckling load.
2. The maximum improvement in critical buckling loads was achieved when 8% wt. of Nano-Al particles were added into epoxy composite.
3. For thicker plates, the effect of Nano-Al particles on critical buckling loads appears to be more significant.
4. Critical buckling load was influenced by differences in aspect ratio (a/b). As the (a/b) ratio increase, the buckling load goes increase.
5.also critical buckling load affected by the boundary condition types; simply supported boundary conditions (SSSS) will show increasing trend in its buckling load of approximately (891.10) N/mm, while the lowest value occurs with (SSSF) of about 153.28 N/mm.
6. Nano-Al particles presenting high dispersion within the epoxy system allowed effective load transmission, which enhanced buckling properties in the specimens.

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