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Analysis of the Nano-composite Column using Static and Dynamic Methods

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Abstract: A nano-composite is a multi-phase material characterised by its size, which is typically smaller than 100 nanometers. The material is formed by repeating distances between the phases. The material has garnered significant attention from researchers worldwide because to its superior mechanical, physical, and biological qualities in comparison to traditional composite materials. Nano-composites have been employed in the fabrication of aerospace vehicle components, such as wings, tails, and propellers, as well as high-performance racing car bodies, owing to their exceptional durability and lightweight characteristics. The primary goal of this research is to do both static and dynamic analysis on a nano-composite column composed of metal, ceramic, and polymer matrix nano-composites. The ANSYS simulation software will be utilised to analyse the deformation and equivalent (von-Mises) stress. The simulated analysis would employ compressive force. In addition, the nano-composite column will be examined under 4 distinct boundary conditions to demonstrate how it deflects in response to compressive force. This research aims to investigate the possibilities of nano-composite materials and their potential for effective utilisation in the near future.

Keywords: Nano-composite; ANSYS; Static; Dynamic

1. Introduction

Dynamic analysis examines the alterations in the physical behaviour of the column, where the loads change rapidly in relation to the column's natural periodicity. A nano-composite is a solid substance consisting of many phases, each with dimensions smaller than 100 nanometers that form the structure of the material. Nanotechnology refers to the precise manipulation of matter within the range of 1 to 100 nanometers. The nanoscale size of materials often leads to significant improvements in their physical, mechanical, and biological properties and functions, offering numerous advantages. This project aims to conduct an analysis and research on the nano-composite column in order to explore its possible uses in the engineering industry.

Nano-composites incorporating nanoparticles have been identified for the purpose of investigating their potential to enhance the physical, chemical, and mechanical characteristics of composite materials (Okpala, 2014). Nihara (1991) conducted an investigation and experimentation on enhancing the mechanical properties of ceramic nano-composites. The findings indicate a significant improvement in toughness, thermal shock resistance, and fracture resistance as a result of combining micro-composites and nano-composites. In addition, he discovered that the incorporation of silicon carbide (SiC) into the aluminium oxide (AI2O3) matrix significantly enhances the mechanical properties of the material. The initial maximum strength of 6.7 Mpa at 25 vol% SiC has been enhanced to a maximum strength of 1500 GPA following dispersion. Srinivas (2017) has endorsed research on Ceramic matrix composites utilising nano-technology. Modified SiC fibres have been utilised to reinforce Silicon Carbide for armour applications, owing to its benefits of superior material hardness and low density. The optimal concentration of nanoparticles added to the materials typically ranges from 0.5% to 5% by weight. Gao (2006) conducted tests and experiments to investigate the characteristics of carbon nanotube ceramic composites. The results indicate that the fracture toughness of the material exhibits a 1.6-fold improvement, from 3.7 to 4.9 MPa, when reinforced with a weight percentage of 0.1% of carbon nanotubes in combination with aluminium oxide. The addition of carbon nanotubes to a barium titanate composite, at a concentration of around 1 wt%, has been observed to enhance the toughness by a factor of 2.4, increasing the value from 0.68 to 1.65 Mpa. Malaki (2019) conducted a study on metal matrix nanocomposites (MMNC). MMNCs are known for their inherent lightweight and high strength properties, making them suitable for a diverse range of heavy industrial and biomedical applications. Various synthesis processes, such as stir casting and accumulative roll bonding, can be employed to generate MMNC. Regardless of the procedures employed, achieving a thorough dispersion of nano-particles inside a metal matrix is of utmost importance.

2. Methodology

The nanocomposites are modelled using silicon carbide, aluminium oxide, resin epoxy as the matrix, and multi-walled carbon nanotubes as the filler (Table 1). The following material qualities are explicitly incorporated into the engineering data of ANSYS. The nanocomposite column is modelled at the nanoscale, with an inner tube diameter of 0.015 µm and an outside tube diameter of 0.019 µm. Subsequently, the pattern function was employed to generate several tubes that serve as representations of the multi-walled nano carbon tubes. Four copies were arranged along the X-axis with a 0.02µm displacement, while thirty copies were arranged along the Y-axis with a 0.025µm displacement. Subsequently, the column is formed by extruding a rectangular-shaped drawing with a height of 0.775µm and a width of 0.1µm. Both column and nano carbon tubes have an identical depth of 0.1µm. The nanoscale modelling column assigned for the matrix consists of resin epoxy, silicon carbide, and aluminium oxide. These materials can be found in the composite materials section of the ANSYS engineering data source. The tubes are designated as multi-walled carbon nanotubes with specific material characteristics. In addition, the ANSYS programme is utilised to examine the deflection of the nano-composite column under compressive stresses by considering four distinct boundary conditions.

Table 1: Material properties used in engineering data of ANSYS

Material type	Density (Kg/m^3)	Young's Modulus (GPA)	Poison's ratio	Shear Modulus (GPA)	Bulk Modulus (GPA)
Silicon Carbide (SiC)	3170	137	0.37	50	176
Aluminium Oxide (Al2O3)	3960	371	0.22	152	221
Resin Epoxy	1160	3.78	0.35	1.4	4.2
Multi-walled Carbon Nanotubes(MWCNT)	2100	800	0.0687	374	309

3. Result

The simulation on ANSYS software displays all four boundary conditions of the column under compressive force (Figure 1-4). A specific mode shape is chosen to illustrate the buckling pattern of the column in response to various compressive forces and boundary conditions. The following findings depict the column's deformation along the journey, as determined by the eigenvalue buckling analysis.

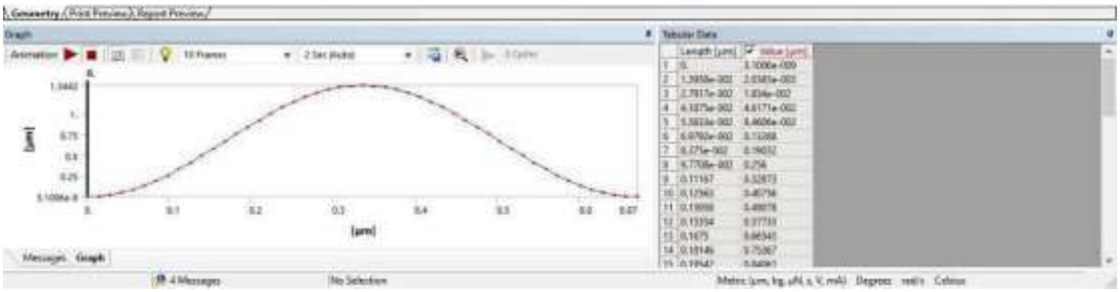


Figure 1: Fixed-fixed boundary condition column analysis

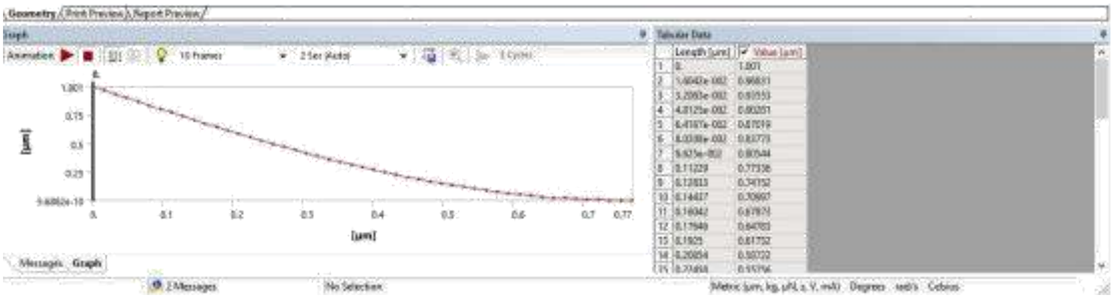


Figure 2: Fixed-free boundary condition column analysis

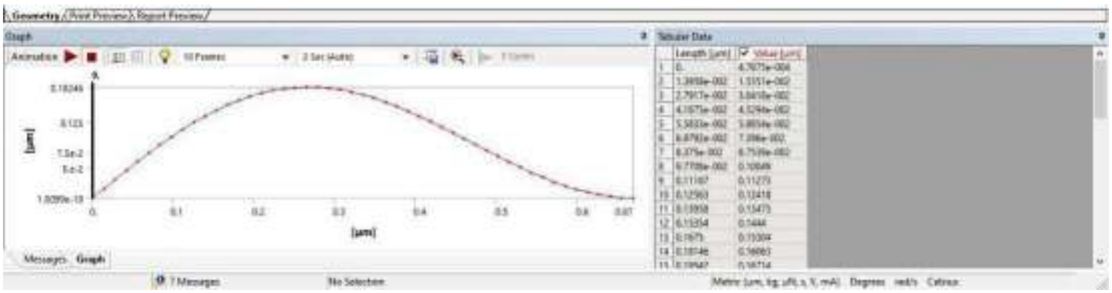


Figure 3: Fixed-pinned boundary condition column analysis

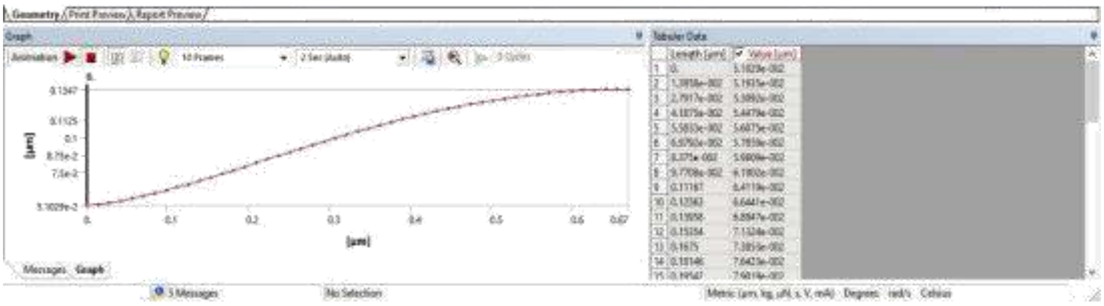


Figure 4: Pinned-free boundary condition column analysis

MMNC, PMNC and CMNC column are measured in this dynamic loading analysis. The tabular results below are derived from the ANSYS parameter sets, which are immediately exported from the table of design points. The following results demonstrate the simulated analysis of a nano-composites column's response to dynamic compressive loadings.

Table 2: Aluminium Oxide MWCNT nanocomposites modelling analysis from ANSYS

Force Magnitude [uN]	Directional Deformation Minimum [um]	Directional Deformation Maximum [um]	Equivalent Stress Minimum [MPa]	Equivalent Stress Maximum [MPa]	Total Deformation Maximum [um]
1	-2.40E-06	2.36E-06	32.31	167.42	0.000139
2	-4.80E-06	4.72E-06	64.62	334.85	0.000278
3	-7.21E-06	7.08E-06	96.93	502.28	0.000417
4	-9.61E-06	9.43E-06	129.25	669.71	0.000556
5	-1.20E-05	1.18E-05	161.56	837.13	0.000695

Table 3: Resin Epoxy MWCNT nanocomposites modelling analysis from ANSYS

Force Magnitude [uN]	Directional Deformation Minimum [um]	Directional Deformation Maximum [um]	Equivalent Stress Minimum [MPa]	Equivalent Stress Maximum [MPa]	Total Deformation Maximum [um]
1	-2.98E-04	2.79E-04	0.12	603.83	0.00548
2	-5.96E-04	5.59E-04	0.24	1207.67	0.0109
3	-8.95E-04	8.38E-04	0.36	1811.51	0.0164
4	-1.19E-04	1.11E-03	0.48	2415.34	0.0219
5	-1.49E-04	1.39E-03	0.60	3019.18	0.0274

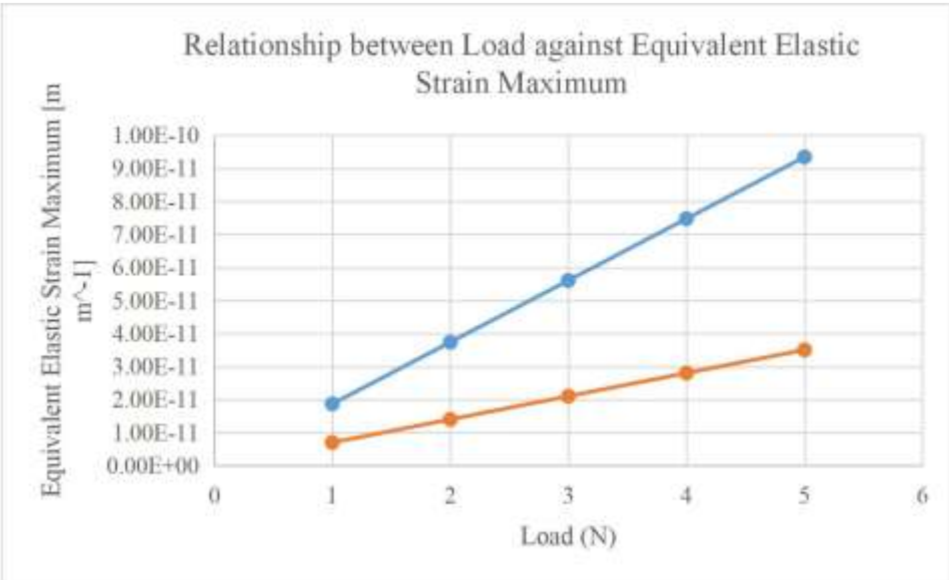
Table 4: Silicon Carbide MWCNT analysis from ANSYS

Force Magnitude [uN]	Directional Deformation Minimum [um]	Directional Deformation Maximum [um]	Equivalent Stress Minimum [MPa]	Equivalent Stress Maximum [MPa]	Total Deformation Maximum [um]
1	-1.01E-05	9.70E-06	9.98	285.71	0.000227
2	-2.02E-05	1.94E-05	19.96	571.43	0.000454
3	-3.04E-05	2.91E-05	29.94	857.14	0.000682
4	-4.05E-05	3.88E-05	39.93	1142.86	0.000909
5	-5.06E-05	4.85E-05	49.91	1428.57	0.00113

Based on the data shown in Tables 2 to 4, it can be observed that the aluminium oxide MWCNT nanocomposites exhibit the lowest values for minimum, maximum directional deformation, maximum deformation, maximum equivalent stress, and the greatest value for equivalent minimum stress when subjected to various compressive forces. The aforementioned results display the deflection and equivalent stress, commonly referred to as von-Mises stress, in response to a compressive force of 1μN. In addition, the aforementioned results display the analysis outcomes for column boundary conditions of fixed-fixed, fixed-free, fixed-pinned, and pinned-free. The graph below illustrates a comparison of the analysis results between the Epoxy MWCNT nano-composite and the Epoxy Carbon UD composite. The initial load applied to both columns is 1N, with subsequent step loads rising by 1N until reaching a total load of 5N.

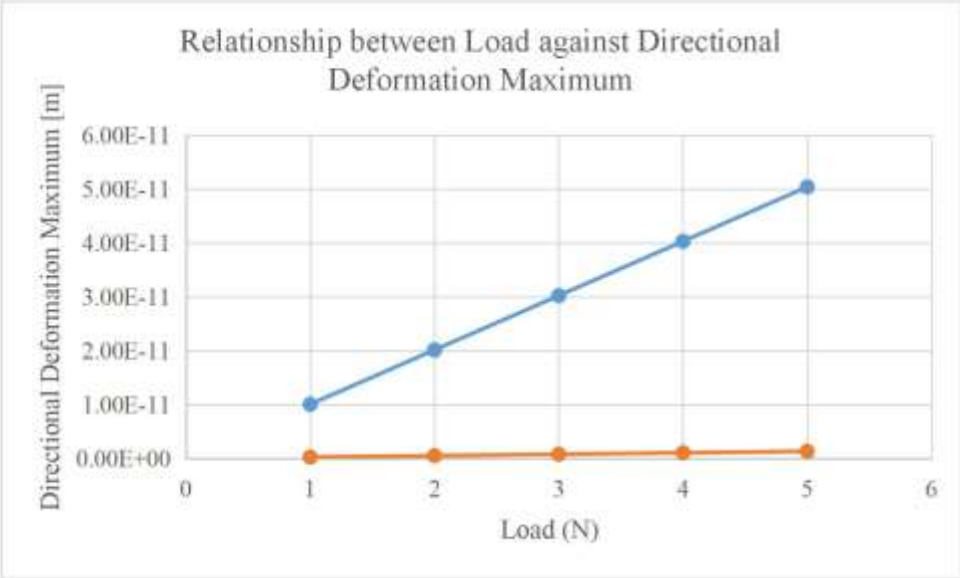
● Epoxy MWCNT nanocomposite ● Epoxy Carbon UD composite

Figure 5: Comparison of results between nanocomposite and composite column on the load and maximum deflection



● Epoxy MWCNT nanocomposite ● Epoxy Carbon UD composite

Figure 6: Comparison of results between nanocomposite and composite column on the load and equivalent elastic strain.



Epoxy MWCNT nanocomposite Epoxy Carbon UD composite

Figure 7: Comparison of results between nanocomposite and composite column on the load and maximum directional deformation.

Epoxy MWCNT nanocomposite Epoxy Carbon UD composite

Figure 8: Comparison of results between nanocomposite and composite column on the loadand maximum equivalent stress

4. Discussion

Based on the analysis results comparing nano-composite and composite materials (Figure 5-9), it can be observed that the compressive mechanical strength of the epoxy carbon UD composite is higher than that of the Epoxy MWCNT nano-composite. The reduced compressive mechanical strength of the nano-composite may be attributed to the deterioration of the Epoxy Young's modulus ratio resulting from the influence of asmall quantity of CNT (Robert, 2019).

Based on the results of the dynamic loading analysis simulation, the Aluminium Oxide MWCNT nanocomposites exhibit the lowest maximum total deformation, indicating superior stiffness properties compared to the other two nanocomposites. Consequently, according to the obtained analysis results, it possesses the greatest mechanical strength out of the three nanocomposites. The aluminium oxide MWCNT would exhibit the least deformation in response to the applied compressive loads. In addition, it possesses the capacity to withstand the highest level of stress before succumbing to bending-induced collapse. The purpose of the eigenvalue buckling analysis is to model the maximum load that the column can withstand before it fails. The stability of the column's equilibrium is maintained when a small axial load is applied. As the axial force under compression rises, the column will undergo deformation, resulting in a bent shape and reaching a state of neutral equilibrium. Under increased axial load, the equilibrium becomes unstable and is prone to collapsing due to bending.

5. Conclusions

The simulation assessed the behavior of three nanocomposite columns subjected to varying force magnitudes, each containing 0.1% weight fraction of MWCNT nano-fillers uniformly dispersed within their matrices. Results indicate that the aluminum oxide MWCNT composite exhibited the highest elastic characteristics, requiring greater stress for deformation. Eigenvalue buckling analysis revealed buckling occurrence in the column with four boundary conditions, pinpointing the critical section susceptible to buckling. Dynamic loading analysis established a direct relationship between compressive forces, equivalent stress, and column deformation. This study assumed uniform alignment and spacing of nano-carbon tube fillers within the matrix. Future research could explore nanocomposite columns with randomly distributed MWCNTs to contrast with uniformly aligned ones. Additionally, adjusting the MWCNT filler weight fraction could optimize nanocomposite mechanical properties, leading to the ideal weight fraction ratio. Such investigations offer potential for advancing the applications of nanocomposite materials.

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