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Effect of Carbon Nanotubes on CNT Reinforced FGM Nano Plate under Thermo Mechanical Loading

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Abstract

This study analysis the effect of Carbon Nanotubes (CNT) on CNT reinforced Functionally Graded Materials (FGM) nano plate under mechanical and thermo mechanical loading using finite element analysis. Material properties of the plate are considered to be graded in the thickness direction linearly by varying numbers of CNTs in each layer. FGM plate results are compared with plane Al nano plate and CNT reinforced composite nano plate (same overall percentage of CNT) of same dimension and same boundary conditions.

In investigation, it is found that CNT increases significant strength in both FGM and composite. But in mechanical loading, CNT provides more strength in composite compare to FGM, while in thermo mechanical FGM stronger than composite.

Peer-review under responsibility of the organizing committee of ICIAME 2016

Keywords: FGM, CNT, Composites, Mechanical Analysis, Thermo Mechanical Analysis, Strength

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Nomenclature

CNT	Carbon Nanotubes
FGM	Functionally Graded Material
Al	Aluminium
L, B, T	Length, Breadth, Thickness of the plate

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Introduction

History is often marked by materials and technology that reflects human capability and understanding. As a result of intensive studies into the fundamental nature of materials and better understanding of their structure property relationship, it has become possible to develop new composite materials with improved physical and mechanical properties.

As all we know, Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus respectively[1]. It have remarkable mechanical properties as well as chemical, electrical and thermal etc properties, such as high strength, high stiffness and high aspect ratio with very low density. It is created by rolling graphene sheet seamlessly to be a cylinder. It have young's modulus of the best nanotubes can be as high as 1000 GPa which is approximately 5x higher than steel, tensile strength, or breaking strain of nanotubes can be up to 63 GPa, around 100 times higher than steel and density of CNT is 1300 kg/m3; almost half of aluminium.

We are well aware that from carbon nanotubes, we cannot create structures of real application. So its properties has been used by reinforcing this CNTs in some other material for real type structural / engineering application.

Many studies have been carried out which shows that CNTs have excellent mechanical, electrical and thermal properties, which make it an excellent reinforcement material. It has been observed that CNTs reinforced composites have shown significant improvement in the properties.[2][3]

In last few decade, much development work has been done in fiber reinforced composites. Fiber is mainly made from alumina, glass, boron etc. These fibers are of the meso scale with diameter of tens of micron and length order of millimeters. In these composites, mechanical, thermal or physical properties do not vary at the macroscopic level because reinforcements are distributed either uniformly or randomly in the composites.

In advanced application of material, Functionally Graded Material [4] have come in limelight. It is a revolutionary material, belongs to a class of advanced materials with varying properties, over a changing dimension. Functionally graded materials occur in nature as bones, teeth etc., nature designed this materials to meet their expected service requirements. This idea is emulated from nature to solve engineering problem the same way artificial neural network is used to emulate human brain. Functionally graded material, eliminates the sharp interfaces existing in composite material which is where failure is initiated. It replaces this sharp interface with a gradient interface which produces smooth transition from one material to the next. One unique characteristics of FGM is the ability to tailor a material for specific application [5].

In traditional composites, properties don't vary spatially, which is not the case of FGM. In FGM properties varies spatially as per the requirement of the application, or we can say FGM is developed in such a manner such that its properties vary spatially as per the requirement of application.

Some of the applications of functionally graded materials are highlighted below:

Aerospace Functionally graded materials can withstand very high thermal gradient, this makes it suitable for use in structures and space plane body, rocket engine component etc. If processing technique is improved, FGM are promising and can be used in wider areas of aerospace.[6]

Medicine Living tissues like bones and teeth are characterized as functionally graded material from nature, to replace these tissues, a compatible material is needed that will serve the purpose of the original bio-tissue. The ideal candidate for this application is functionally graded material. FGM has find wide range of application in dental and orthopedic applications for teeth and bone replacement.[7]

Defence One of the most important characteristics of functionally graded material is the ability to inhibit crack propagation. This property makes it useful in defense application, as a penetration resistant materials used for armor plates and bullet-proof vests.[8]

Energy FGM are used in energy conversion devices. They also provide thermal barrier and are used as protective coating on turbine blades in gas turbine engine. [9]

Optoelectronics FGM also finds its application in optoelectronics as graded refractive index materials and in audio-video discs magnetic storage media. Other areas of application are: cutting tool insert coating, automobile engine components, nuclear reactor components, turbine blade, heat exchanger, Tribology, sensors, fire retardant doors, etc.

The list is endless and more application is springing up as the processing technology, cost of production and properties of FMG improve.

CNT Reinforced FGM Plate

Till now most of the research had been completed by considering layer wise material property variation, where layers have constant material properties. But in each layer also at nano level, properties variation are there, as per configuration of mixing material, which has been considered in this analysis.[10][11]

For analyzing mechanical and thermo mechanical properties of CNT reinforced FGM, base material is aluminium is considered, because it has lots of engineering application. It will be a replacement of light weight, high strength material.

A plate has been modelled having 600nm width, 600nm depth & 30 nm thickness. This plate is having five layer of 6 nm thickness having different ratio of CNT percentage. Layers having CNT percentage respectively 2%, 1.5%, 1%, 0.5% and 0% CNT from top layer to bottom layer, rest Al alloy (over all 1% CNT). CNT have been reinforced having length of 100nm, OD 4.34nm and ID 3.66nm. So this CNT is of thickness 0.34nm.

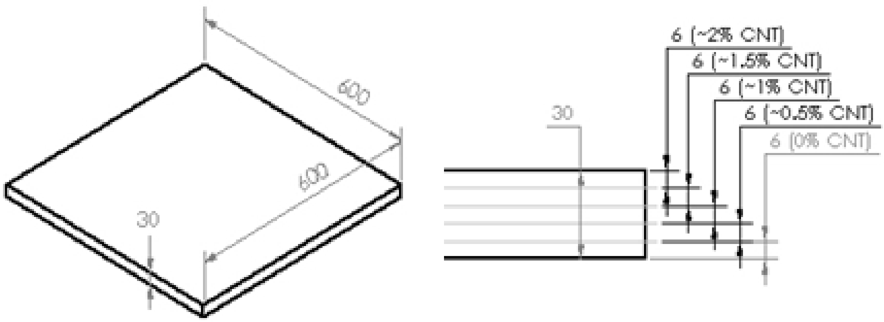


Fig.1:. Schematics of FGM Nano plate with dimension and percentage of CNTs layer wise.

Nos. of CNT in each layer has been calculated using following formula:

$$Nos\ \text{ of CNTs} = \frac{\text{Volume of CNT}}{(\text{Volume of Rest Material} + \text{Volume of CNT})} \times \% CNT$$

$$Nos\ \text{ of CNTs} = \frac{\left[\frac{\pi}{4}\left\{(OD)^2 - (ID)^2\right\} \times L\right] CNT}{\left[(\mathrm{L} \times \mathrm{W} \times \mathrm{T}) Al - \frac{\pi}{4}(OD)^2 CNT\right] + \left[\frac{\pi}{4}\left\{(OD)^2 - (ID)^2\right\} \times L\right] CNT} \times \frac{\% CNT}{100}$$

Layer	% CNT	Nos. of CNT	Arrangement
1	2%	100	5 x 20
2	1.5%	75	5 x 15
3	1%	50	5 x 10
4	0.5%	25	5 x 5
5	0%	0	0
Total	**1%**	**250**	

Analysis has been carried out using COSOMOS simulation from Dassault system, which comes with Solidworks simulation package. In this analysis 4 nodded solid elements has been used.

Results has been compared with Al plate and 1% CNT Reinforced Al composite[12][13] of same dimension with same boundary conditions.

CNT Arrangement Layer wise

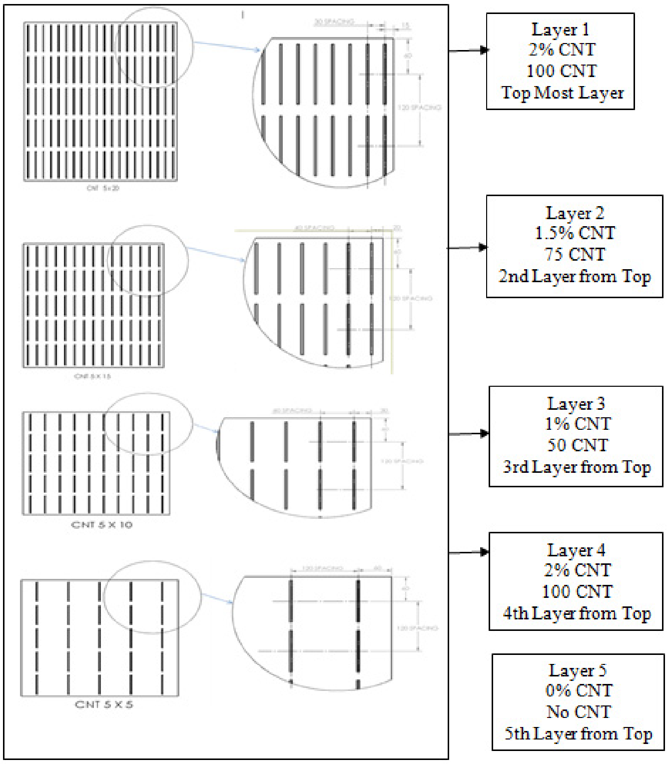


Fig.2:. Orientation and quantities of CNTs in each layer

Boundary Conditions

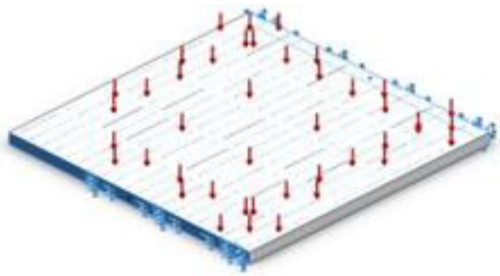


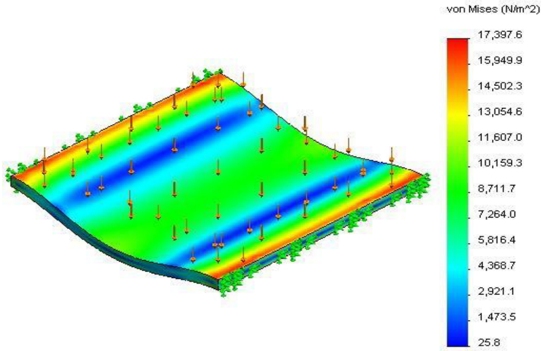
Fig. 3:. FGM plate model with boundary conditions

Two Side Fixed (As Shown)
Pressure at Top Surface = 100 N/m^2
Upper Surface temp 380 K & Lower surface temp 300 K (For Thermo Mechanical Analysis)

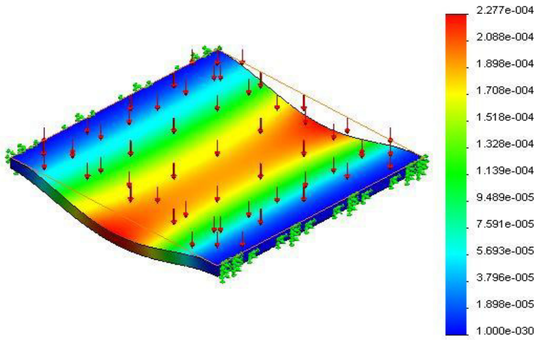
Results and Discussion

Mechanical and thermo mechanical analysis has been carried out. Stress, displacement have been captured using finite element analysis. Upper layer and lower layer stress and displacement are also calculated and compared in the results. Behaviour of FGM is also studied in this. Percentage variations in stress, strain and displacement have been calculated from the analysis.

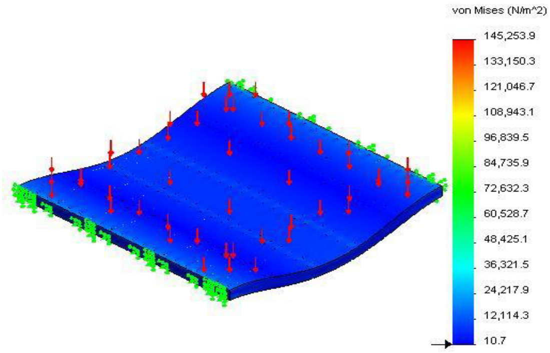
Mechanical Analysis Results and Discussion



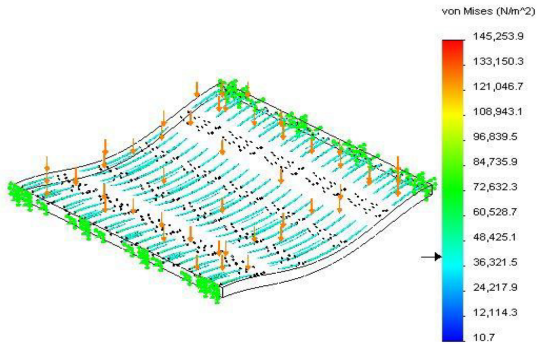
Von Mises Stress Plot for Al Nano Plate



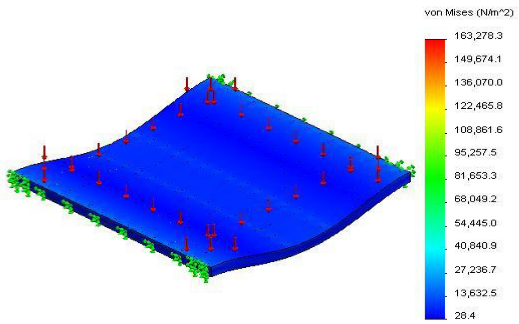
Displacement Plot for Al Nano Plate



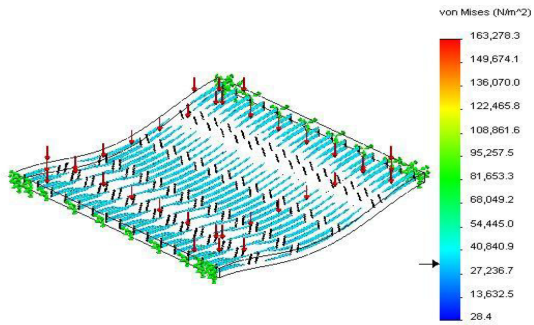
Von Mises Stress Plot for CNT FGM Nano Plate



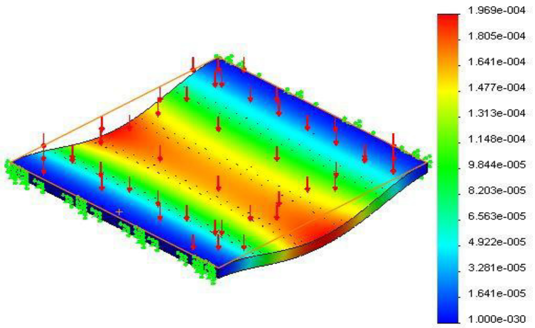
Detailed Von Mises Stress Plot for CNT FGM Nano Plate



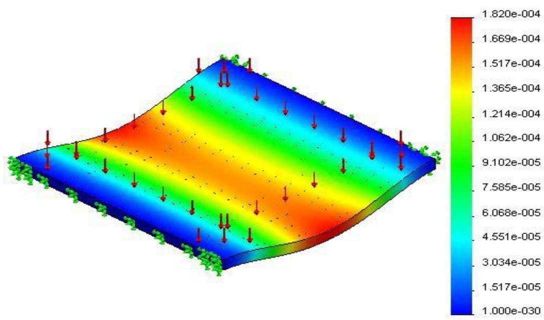
Von Mises Stress Plot for CNT Composite Nano Plate



Detailed Von Mises Stress Plot for CNT CompositeNano Plate



Displacement Plot for CNT FGM Nano Plate



Displacement Plot for CNT Composite Nano Plate

Fig. 4:. Mechanical Analysis Results

In FGM and composite, maximum stresses are much higher compare to Al plate and in composite max stress is slightly higher compare to FGM. At upper surface Average stress is reduced more compare to lower surfaces in FGM, compare to Al plate and reduced more in composite plate.

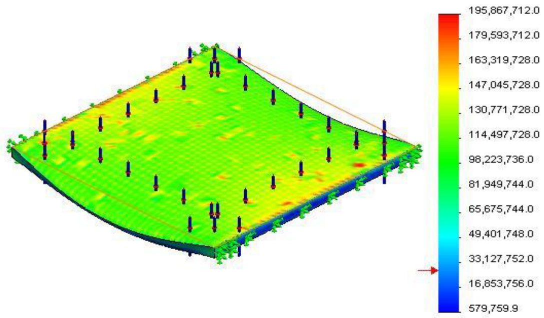
It may be because CNT is stronger than Al, so in combination it will offer more resistance to applied load. There is sudden property variation at CNT Al contact area, so it may be because of stress concentration at that area.

Max displacement of FGM plate, max displacement and average displacement in upper and lower surface in FGM is reduced around 14%. compare to Al plate. In case of composite, max displacement of FGM plate, max displacement and average displacement in upper and lower surface in FGM is reduced around 20%. compare to Al plate.

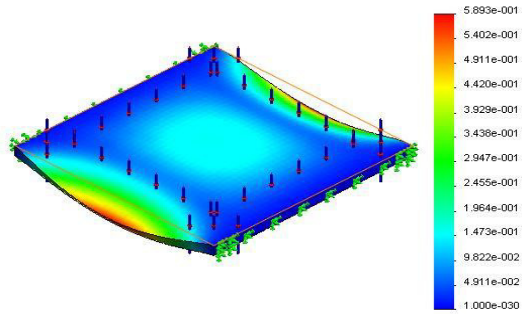
In composite, CNTs are distributed uniformally 1% along the thickness, while in FGM, lower two layer have 0.5% and 0% CNTs, So it may be reason of above.

From the result it can be concluded that in mechanical loading, CNT reinforced FGM plate is much stronger than Al plate, while slightly weaker compare to CNT reinforced composite plate.

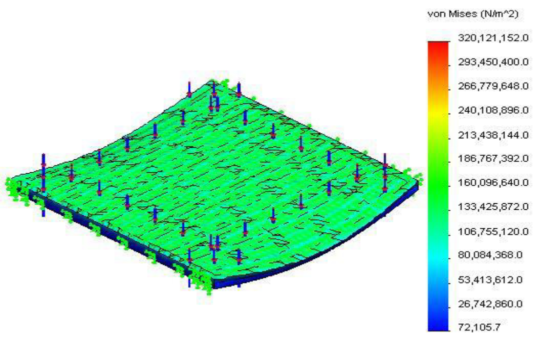
Thermo - Mechanical Analysis Results and Discussion



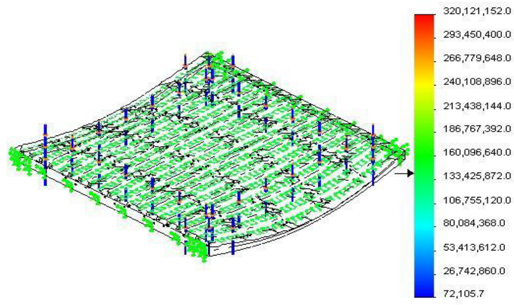
Von Mises Stress Plot for Al Nano Plate



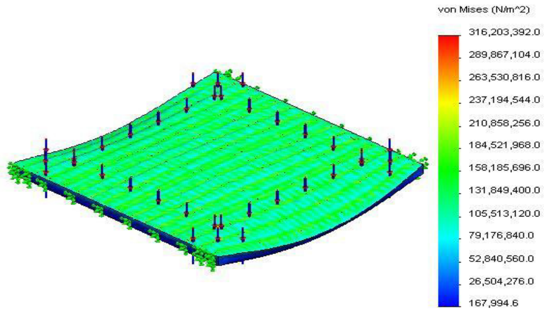
Displacement Plot for Al Nano Plate



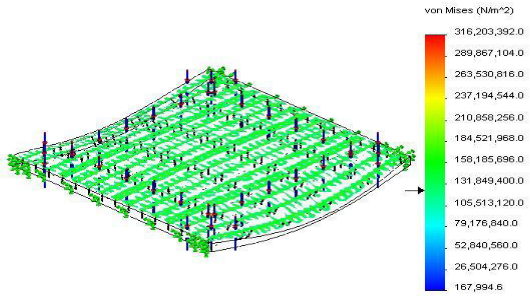
Von Mises Stress Plot for CNT FGM Nano Plate



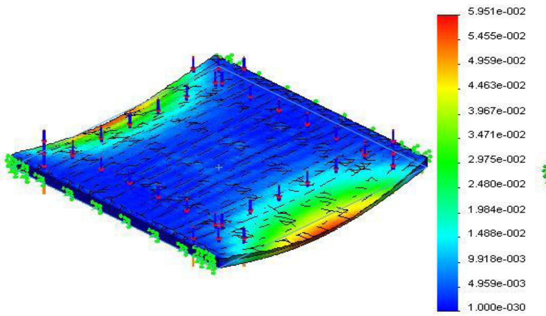
Detailed Von Mises Stress Plot for CNT FGM Nano Plate



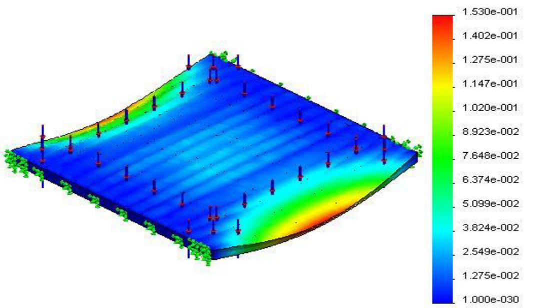
Von Mises Stress Plot for CNT Composite Nano Plate



Detailed Von Mises Stress Plot for CNT Composite Nano Plate



Displacement Plot for CNT FGM Nano Plate



Displacement Plot for CNT Composite Nano Plate

Fig. 5:. Thermo Mechanical Analysis Results

In thermo mechanical loading Al plate, composite and FGM stresses have more stresses than mechanical loading, due to thermal loading is also added in this. Max stresses are higher in FGM and composite compare to Al plate. Max stress in FGM is slightly more compare to composite.

Max stresses are observed at CNT and upper surface of plate, where maximum temperature is applied. It may be because CNT is more stronger than Al and max thermal stresses at upper surface due to higher temprature, so in combination it will offer more resistance to applied load. And there is sudden property variation at CNT Al joining area, so it may be because of stress concentration at that area.

Max displacement of FGM plate, max displacement in upper and lower surface in FGM is reduced around 90%. compare to Al plate. In case of composite, max displacement of FGM plate, max displacement in upper and lower surface in FGM is reduced around 74%. compare to Al plate.

It may be because CNT provides more thermal strength, and FGM has more numbers of CNTs at its upper surface where higher temperature is applied.

From the result it can be concluded that in thermo mechanical loading, CNT reinforced FGM plate is much stronger than Al plate and slightly stronger than CNT reinforced composite plate.

Conclusion

From the above mechanical and thermo mechanical analysis, It was observe that CNT reinforced FGM plate and CNT reinforced composite is much stronger than Al plate. So It can conclude that CNT plays an important role in increasing property of the CNT reinforced material.

In thermo mechanical loading, CNT reinforced FGM is slightly stronger to CNT reinforced composite too. So it is well suited to application, where thermo mechanical loading are there. That is why CNT reinforced FGM is having most of its application in aerospace field.

In mechanical loading, CNT reinforced FGM is slightly weaker compare to CNT reinforced composite. So where high strength is required, CNT reinforced composite is most suitable, but where moderate strength is required CNT reinforced FGM is suitable there.

Further study can be done to see the effect of CNT orientation on CNT reinforced FGM, which is also going to play an important role in its strength.

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