FINITE ELEMENT MODELING & ANALYSIS OF NANO COMPOSITE AIRFOIL STRUCTURE

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ABSTRACT

An airfoil or aerofoil is the cross-sectional shape of a wing or blade of a turbine, rotor or propeller. An aerodynamic force is produced when an airfoil moves through a fluid. These forces are the very reason of lift produced in an aircraft or to produce a downward force on an automobile to improve traction. The efficiency of an airfoil is characterized mainly on its profile section and its aerodynamic design. In the present study a NACA 2412 AIRFOIL model is selected and analyzed. The material used for the analysis of airfoil is Nano composite, because of its unique and better mechanical properties than the conventional materials. Nano composites are the materials which consist of two or more constituents combined at a Nano scale regime in such a manner that it gives improved properties (such as elastic, damping, wear and corrosion resistant etc.) as compared to other conventional materials. In the present study, free vibration and static structural analyses are cared out in order to investigate the effect of carbon nanotube content on the static and dynamic responses of NACA 2412 aero foils.

The effective elastic properties of carbon Nano tube based Nano-composites are determined using Halpin Tsai model where carbon Nano tubes are assumed to be uniformly distributed and randomly oriented through the matrix. The properties thus obtained are used for further analysis. NACA 2412 airfoil profile was taken from readily available database and point clouds was imported to Solid works in order to make 3D model. The solid model thus generated used in ANSYS to perform free vibration analysis. To find the lift and drag forces that the airfoil generates are found from computational fluid dynamics module available in ANSYS work bench. Finally the calculated lift and drag forces are utilized to perform static structural analysis. Several parameters such as total deformation, equivalent stresses and shear stresses are measured for different carbon Nano tube content, airflow rate, and orientation of the airfoil. Increase in elastic properties is seen with increase in volume fraction of CNT in Nano composite. From the study it is also observed that the natural frequency on the Nano composite increases with increase in the percentage of carbon Nano tubes with a drastic decrease in deflection.

INTRODUCTION

In the earliest days, the only means of locomotion was by walk when man was in the early stages of development of his livelihood. Since then, man has achieved faster and more comfortable ways of travelling such as bikes, cars, trains and specially airplanes. From the day of its invention airplanes have been gone through many stages of advancement and today it is considered as one of the fastest option of transportation available. In World War II it had got the popularity as a modern war machine and had played an important role in the war. Popularity of airplanes in today's era has led to many innovative research and inventions to manufacture faster and more cost effective planes. The present study is all about to determine how to attain maximum performance from an airfoil section made up of Nano composite structure.

An airplane's airfoil is a cross-section of the wing which is somewhat similar to the cross section of wings of a bird. The main objective airfoil is to provide vertical lift to an aircraft during the take-off and when it is in flight. The airfoil structure also has a negative effect called Drag, which opposite to the forward motion of the airplane. The magnitude of lift required by a plane is decided according to the purpose for which it is to be used. The planes which are heavy and which are used to transfer heavier loads require more lift while plane used for lighter loads need less lift. Thus, airfoil section is designed depending on its weight and upon the use of airplane. Lift force thus produced acknowledges the vertical motion of the plane, which depends on the horizontal velocity of the aircraft. So, by calculating the coefficient of lift, the lift force can be determined. Once lift force and vertical acceleration is calculated the next step is to determine the horizontal velocity produced.

Aerodynamics is a field of science which focuses mainly on concentrating on the behavior of air movement, when associated with a solid model, such as turbine blade, propeller, airfoil etc. An aerodynamic energy is handled by the model based on airfoil when it travels through a fluid environment. The power produced during flight and which is perpendicular to the direction of movement is termed as lift. The force which acts opposite to the direction of travel is called drag. In designing of an airplane's wing these are the primary parameters to be considered. For a given magnitude of thrust the task of a designer is to minimize drag as much as possible and to maximize lift to increase its efficiency and reduce fuel consumption. The lift of an airfoil changes according to its approach and shape.

Leading edge: The edge of the airfoil which faces the direction of travel of the plane is called as leading edge. This edge cuts the air in such a way that the air gets deflected in two directions, along the upper surface and lower surface. Generally the velocity of air along the upper surface is more than the velocity of air along the lower surface.

Trailing edge: The edge where the airfoil section ends is called as trailing edge. It is located at the back of airfoil and generally its shape is pointed in nature.

Chord line: Chord line may be defined as the line which joins the trailing edge and the leading edge. This line bisects equally the airfoil section into two halves in case of a symmetric airfoil.

Angle of attack: The angle made by the chord line with the direction of motion is known as angle of attack. By changing the angle of attack we can observe a considerable changes in lift and drag, hence it is an important parameter to be considered while designing the airfoil.

Chamber line: It may be defined as a line which joins leading edge to the trailing edge and divides the airfoil section into two equal halves.

LITERATURE REVIEW

Lu [1] investigated using an empirical force constant model the elastic properties of carbon nanotubes and Nano ropes. It was found that the elastic moduli of single and multiwall nanotubes are insensitive to structural variables such as helicity, radius and the number of walls**.** Gultop [2] determined the impact perspective degree on Airfoil performance. The main reason for this study was to find out the conditions where the ripple conditions can be avoided throughout wind tunnel tests. This resulted increase in the aero elastic insecurities at Mach number 0.55, which came out to be higher than the wind tunnel Mach number of velocity of 0.3. Goel [3] used Quansi – 3D analysis codes to devise a method of optimization of Turbine Airfoil. In his paper the complexity of 3D modeling is solved by modeling it in multiple 2D airfoil sections and then joining them in radial direction using first and second order polynomials which leads to no roughness in the radial direction. Prabhakar [4] analyzed the NACA 4412 airfoil profile and studied its profile for consideration of an airplane wing .The NACA 4412 airfoil was created using CATIA V5 and analysis was carried out in ANSYS 13.0 FLUENT software at an inlet speed of 340.29 m/sec for different angles of attack of 0˚, 6, 12 and 16˚. Standard k-ε turbulence model was assumed for

Airflow. Fluctuations of dynamic pressure and static pressure are presented graphically in form of filled contour. Habali and saleh [5] discussed a selection procedure for airfoil section and aerodynamic design of a rotor blade. They used Glass Fiber Reinforced Plastic for designing the rotor blade and conducted a static proof load test to determine the load carrying capacity. Feistauer et al [6] presented a brief study on numerical simulation of interaction of two dimensional incompressible viscous fluids and vibration analysis of airfoil with large amplitude. Gharali and Johnson [7] used ANSYS Fluent 12.1 to stimulate numerically flow of an oscillating free stream over a stationary S809 airfoil. A comparison study is performed in this study to choose the model. Several simulations were conducted based on different Reynolds numbers from 0.026 to 18. Qu et al [8] carried out a numerical simulation on the landing process of a NACA 4412 airfoil considering the influence of dynamic ground effect (DGE). Murugan et al [9] studied variable camber morphing airfoil incorporating compliant ribs and flexible composite skins. A hierarchical modeling framework is utilized in this study to decouple the compliant ribs and airfoil skin. Koziel and Leifsson [10] presented an automated low-fidelity model selection procedure is presented. A comparison study is carried out in this paper to compare the standard and proposed approach within the scope of aerodynamic design of transonic airfoil. Huang et al [11] conducted a research on plunging motion, varying pitching, and varying incoming flow for NACA 0012 airfoil section. This study mainly concentrates on observing the real characteristics and response of airfoil of rotor blades in unsteady flow field.

Li et al [12] successfully fabricated the interlinear reinforced and toughened CFRP composites in which MWNTs-EP/PSF (polysulfone) hybrid Nano fibers with preferred orientation were directly electrospun onto the carbon fiber/prepegs.

The facture toughness was attained a maximum at 10 wt% MWNTs-EP loading and then decreases. With increased MWNTs-EP loading the flexural properties and interlaminar shear strength of composite are improved. Shokrieh and Rafiee [13] developed a stochastic multi-scale modeling technique to estimate the mechanical effective properties of carbon nanotube rein forced polymers. A full range multi scale technique is implemented to consider parameters of nano, micro, meso and macro-scales and developed full stochastic integrated modeling procedure. It has been proved that mean values can be replaced with that of random distribution of carbon nanotube length and volume fractions. Rafiee et al [14] studied the nonlinear free vibration of carbon nanotubes/fiber/polymer composite multiscale plates with surface-bonded piezoelectric actuators. First order shear deformation theory (FSDT) and von karman geometrical nonlinearity are used as the governing equations for the piezoelectric nanotubes/polymer/fiber multiscale laminated composite plates. Modeling is accomplished using the Halpin-Tsai equations and fiber micromechanics in hierarchy to predict the effective properties of the hybrid composite. Sharma and Shukla [15] discussed the dispersion of carbon nanotube and effect of functionalization on the effective properties of multiscale carbon epoxy composites. Young's modulus, inter-laminar shear strength and flexural modulus increased by 51.46%, 39.62% and 38.04%, respectively with the addition of CNTs(1.0wt%) in the resin. Halpin-Tsai equations and micromechanics modeling were used to evaluate the bulk properties of multiscale composites. Halpin and Kardos [16] developed the micromechanics relationships for semi-crystalline polymers, which formed the operational base for the composite analysis. Ramakrishna et al [17] investigated the tensile modulus of two sets of electrospun fibers: nylon-6 and montmorillonite (MMT) reinforced nylon-6.

METHODOLOGY

Geometry Formation

In the present study a NACA 2412 airfoil model is selected with suitable grid points and dimensions. From the airfoil database the airfoil coordinates are obtained in Dat file format which is to be imported to Microsoft excel. These points or coordinates are then imported to Solidworks to create a profile of the airfoil. If the dimensions of the coordinates are in millimeter then it is to be scaled properly to evaluate in meter units. Figure 3.2 shows the profile of NACA 2412 model after drawing the spline over the specified grid points and importing it to Ansys workspace. The 2D profile is then extruded to form a 3D solid model and upon which CFD and modal analysis is carried out.

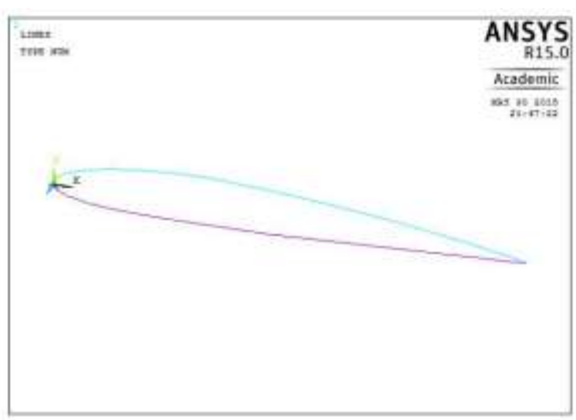

Figure: Profile of NACA 2412 airfoil model

Meshing

The next step of analysis of airfoil is to generate mesh on its surface. In Mesh section of Ansys, small grids are generated with nodes. Ansys provides options to make grids in the workspace as per our needs, we can select either the whole geometry at once and can specify which type of element it is and the spacing in between two grids or we can select the growth ratios on each surface. The size of grids can be set as coarse grid, medium grids or fine grids. In the present study we have chosen medium grids to have better results. The mesh contains 14045 numbers of nodes and 2432 number of elements. Meshing divides the enclosed area or volume into numerous numbers of small grids which helps us to analyze the working phenomenon and evaluate the results accurately. The values of any parameter at the nodes are found out to give exact condition of the parameter during the simulation part.

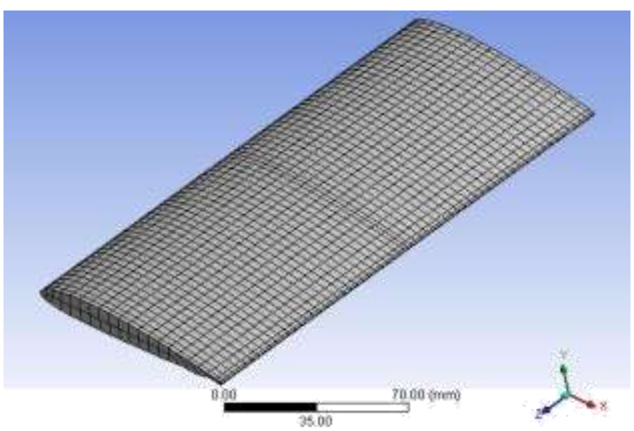

Figure: 3D Meshed model of airfoil

Setup and Solution

After the completion of formation of grid on the surface the data is saved and the mesh window is closed. The setup bar in the Ansys-fluent window is selected next where the meshed geometry is automatically imported for further analysis. The inlet and outlet sections are defined by selecting create named selection by selecting the surface of the model. The model used for the test the viscous laminar model to simulate the aerodynamic environment.

The cell zone condition in the interior of the body is defined to be as air with density of 1.225 kg/m^3 and viscosity of 0.0000178 kg/m-s. Inlet velocity of air is specified in the boundary where the velocity value is defined to be 133 m/s. The gauge pressure is specified to zero at the outlet by default and no slip boundary condition for the wall is defined. After defining all the input data the calculation is performed with 300 numbers of iterations. When the calculation is completed the contours of velocity and pressure profiles of inlet, outlet and wall can be obtained by selecting the contour tab. Results are obtained in the form of lift force and drag force. These forces are used in further static structural analysis.

In the static structural analysis the lift and drag forces obtained by the above method is acted upon the wing model as pressure forces. Here we are interested to calculate the total deformation, shear stress, stress intensity, and equivalent stress, which is also known as Von-mises stress. One end of the wing is fixed as the boundary condition. The lift force acts in an upward direction tending the wing to lift upwards and the drag acts perpendicular to the trailing edge along the direction opposite to the motion of airfoil. In this analysis the properties of nano composite at various CNT percentages is incorporated in the airfoil model.

RESULTS AND DISCUSSION

Material Modeling

The elastic properties of nano composite are determined from the above different methodology. A Matlab program is used to formulate the above stated equations and the results thus obtained are plotted to compare the properties obtained from different methods. The result obtained is in good agreement with the paper used as reference for this study. The elastic properties obtained from Halpin-Tsai method are found to be higher than that of elastic properties obtained from Mori Tanaka method which is obvious as referred to some published literature. A plot has been presented below showing variation of Young's modulus obtained from both Halpin-Tsai and Mori Tanaka method with different percentage of volume fraction of CNTs.

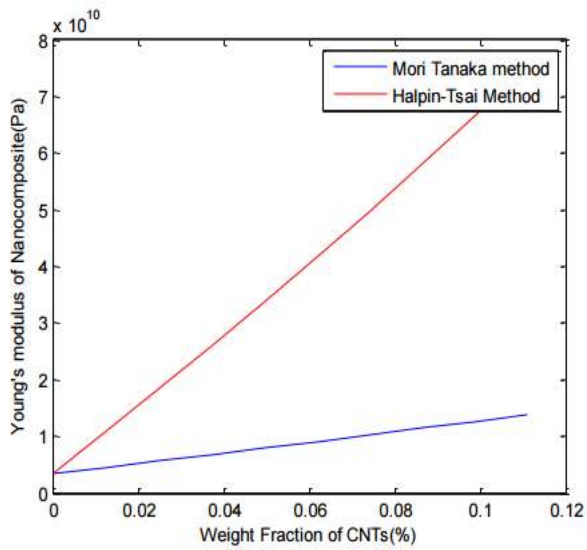

Figure: Variation of Young's modulus with different percentage of carbon nanotube

Figure shows the variation of Young's modulus with different percentages of CNTs. It is found that with increase in the percentage of CNTs in the nanocomposite there is gradual increase in the eastic properties of the nanocomposite thereby improving the mechanical strength of the material. The elastic properties obtained from material modeling of nanocomposite is found to vary with increase in volume fraction of CNTs. Incorporating the novel properties of nanocomposite into the solid airfoil model CFD analysis is carried out in Ansys-fluent workspace. The cruising speed of an airplane i.e. 133 m/s is defined as the velocity of flow of air over the airfoil surface. Then lift and drag coefficient for various angle of attack of the airfoil is calculated in the CFD analysis which is tabulated below.

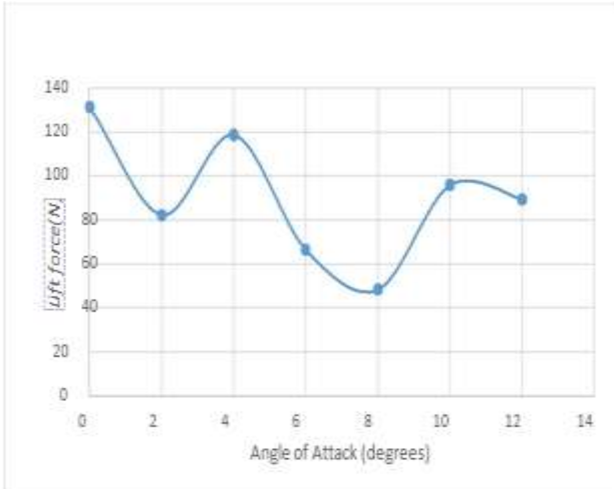

Figure: Plot between Lift force and Angle of Attack.

From the above tabulation and graphical representation of variation of lift and drag forces with that of different angle of attack we can conclude that lift force increases with increase in angle of attack. The same effect is observed in case of drag. It has been observed in this analysis that after a particular angle of attack the lift and drag force is found to decrease. This angle is known as stall angle of attack. Drag force is an unwanted force and should be avoided as much as possible but it is also seen that there is a gradual increase in drag coefficient which is not favorable from the aerodynamic point of view. Pressure and velocity contours on the airfoil model are obtained and are shown as below:

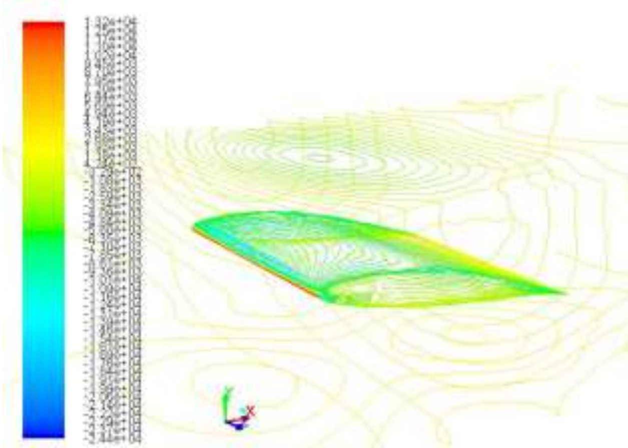

Figure: Pressure contours on the airfoil model

Figure shows the pressure contour of the airfoil model where the red zone indicates high pressure zone and the blue zone indicates low pressure zone. As it can be seen that on the upper portion of the airfoil there are some blue zones which indicates that there is low pressure in that region which is the cause to produce the necessary lift force on the airfoil.

Modal Analysis

In the modal analysis of the airfoil the different modes of vibration is determined and observed. It is noticed in this study that the natural frequency of the airfoil made up of nano composite material increases with increase in volume fraction percentage of CNTs. Below is the tabulation of data observed during the experiment representing the first, second and third natural frequency for different volume fraction of CNTs.

Table: Variation of natural frequency with different carbon nano tube percentage

Percentage of carbon Nanotube (%)	Density(kg/m^3)	First Natural Frequency(Hz)	Second Natural Frequency(Hz)	Third Natural Frequency(Hz)
0	1200	2.4231	8.6659	15.404
0.0111	1201.7	2.808	10.043	17.851
0.0222	1203.3	3.1465	11.253	20.003
0.0333	1205	3.4527	12.348	21.949
0.0444	1206.7	3.7344	13.356	23.740
0.0556	1208.3	3.9967	14.294	25.407
0.0667	1210	4.2426	15.173	26.970
0.0778	1211.7	4.4758	16.007	28.453
0.0889	1213.3	4.6987	16.804	29.870
0.1	1215	4.7730	17.056	31.127

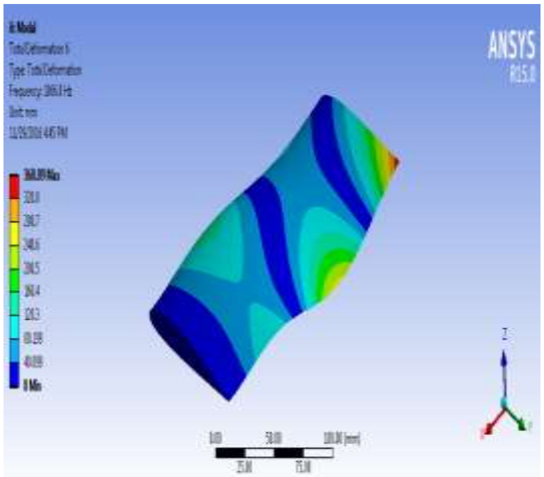

Fig: Sixth mode shape of the airfoil model

Static Structural Analysis

In the following section we will discuss the results obtained from the static structural analysis. Here the material properties of nano composite are incorporated in the solid airfoil model to carry out the analysis. The model is then acted by the lift and drag forces as pressure forces along upward direction and along direction opposite to the direction of motion respectively. In this analysis we are concentrating to determine the total deformation, shear stress, shear intensity and equivalent stress, also known as von-mises stress. In the table below the maximum value of all these parameters for a particular orientation of airfoil is shown in a tabular form.

Table: Maximum values obtained of total deformation and various stresses on the airfoil.

Total deformation(mm)	0.05596
Equivalent stress(MPa)	0.57592
Shear stress(MPa)	0.023453
Stress intensity(MPa)	0.61288

Following figures are the various contours of the above mentioned stresses and deflection.

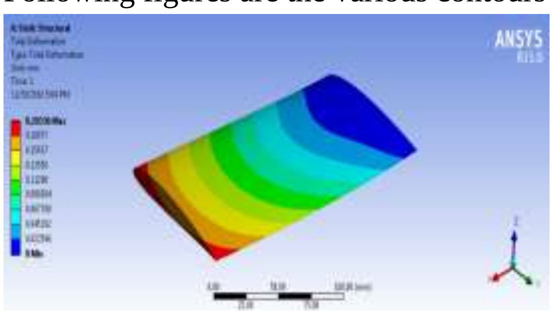

Fig: Total deformation of the airfoil model

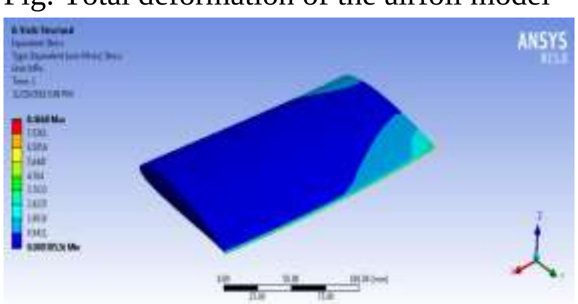

Fig: Equivalent (von-mises) stress distribution of the airfoil model

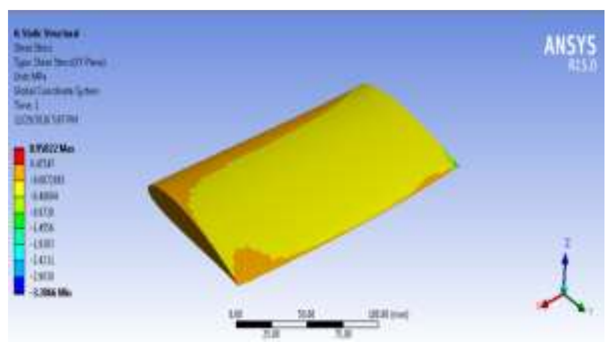

Fig: Shear stress distribution of the airfoil model

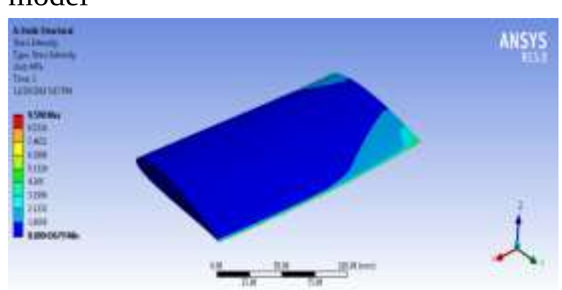

Fig: Stress intensity distribution of the airfoil model

Below Table represents the variation of deformation along the three axes individually by varying the orientation of the airfoil and also by varying the CNT volume fraction. From the results obtained it is observed that by increasing the CNTs volume fraction in the nanocomposite the deformation along all the axes gets reduced by some amount. It means that by adding more amount of CNT we are improving the properties of nanocomposite.

Table: Variation of deformation along the three axes of the airfoil model with varying percentage of CNTs.

Orientation of airfoil section(degrees)	Percentage volume fraction of CNTs (%)	Density(kg/m^3)	Deformation along x axis (mm)	Deformation along y axis (mm)	Deformation along z axis (mm)
2	0.0111	1201.7	8.657	3.04	3.329
2	0.0333	1205	5.994	4.91	5.43
2	0.0556	1208.3	4.79	5.16	1.516
4	0.0111	1201.7	8.118	3.15	5.615
4	0.0333	1205	5.345	9.85	6.942
4	0.0556	1208.3	4.052	9.15	2.644
6	0.0111	1201.7	9.961	8.93	7.74
6	0.0333	1205	6.487	2.91	8.348
6	0.0556	1208.3	4.889	8.92	3.693

CONCLUSION

In this study, material modelling of nano composites is performed to determine the effective properties of nano composites by using the Halpin-Tsai method. A matlab program was used to evaluate the elastic properties of the nano composite and the determined values are in good agreement with the values of the referred literatures. Then an investigation of the NACA 2412 airfoil model made up of nano composite material is performed and analysed. The airfoil model is then subjected to CFD analysis where the aim is to determine the different forces acting on an airfoil model when it is operational in its working environment. Lift and drag are the two forces acting on the airfoil model and due to these forces an airplane gets its required lift. These forces are computed with the help of modeling software Ansys-Fluent. Lift and drag for various angle of attack is computed and plotted which shows an increase in lift and drag forces as the angle of attack increases. Free vibration analysis of the selected airfoil model is performed by developing a model using Ansys (APDL) workspace. Different mode shapes are obtained in this analysis with different frequency. At last using the lift and drag forces obtained from the CFD analysis static structural analysis is performed to determine total deformation, shear stress, equivalent stress and stress intensity. Here in this study it is shown that the proposed method successfully simulates the flow around a conventional wing. The method employed here is under the same conditions as those used by various authors and the comparison results are found to be satisfactory.

The main conclusions that can be drawn are:

- With increase of percentage of volume fraction of CNTs the elastic properties of nano composite increases.
- Natural frequency of nano composite increases with increase in percentage of volume fraction of CNTs.
- Total deflection of the model decreases with increase of percentage of volume fraction of CNTs.
- Lift and drag forces of the airfoil section increases with increase in angle of attack.
- Static structural analysis is carried out with satisfactory results.

FUTURE SCOPE

Above study is an approach which can be applied to solve problems which are more complex in nature. Below are some problems on which future analysis can be carried out.

- Two way fluid structure interaction analysis of airfoil structure can be performed to get better simulation of aerodynamic environment.
- Transient analysis coupled with static structural.
- Thermal analysis
- Incorporating ribs instead of solid material and carrying out the above analysis.
- Considering damping of carbon nanotubes.

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