Manufacturing, Testing of Polymer Nanocomposite and Analysis of Tennis Racket Frame

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Abstract

The modern days, the game of tennis expects high levels of performance from every international tennis players. The performance of every tennis player based on the tennis racket and playing conditions. The evolution of the tennis racket, with respect to both design and materials (tennis racket strings and grips) developed lots of new tennis racket frames. The tennis racket required to change in recent years as a result of lightweight, stiffer rackets for better performance. The paper discusses the manufacturing, testing, structural and modal analysis of four ratios of Nylon6,6/MWNT new polymer nanocomposite material replacing excising composite materials to a tennis racket frame for better mechanical properties to enhanced performance of the tennis racket. Using universal testing machine test and calculate the various mechanical properties strength, modulus, impact, hardness, stiffness, toughness of the polymer nanocomposite. In the design, the tennis racket frame was designed of the shape, dimensions. After design part created the 3D model using by PRO/ENGINEER software. The 3D racket model can be export to ANSYS analysis software and incorporated with new polymer nanocomposite properties. The structural and model analysis was done.

Keywords: MWNT, nylon 6,6, tennis racket frame, PRO/ENGINEER, ANSYS

1. Introduction

When tennis was first invented, wooden rackets had always been used. The usage of wood rackets lasted for decades, until the 1970s. Thereafter metal tennis racket frames were introduced for the first time. These metal frames quickly replaced the old wooden frames, as many advantages could be spotted with such a change. Late 80's as manufacturers experimented with mixing different types and proportions of metals together to construct the frames, the racket frames became stronger, but also lighter. Most racket manufacturers mix graphite with another metal, such as titanium, to form composite metals.

Many of the racket frame made of Carbon fiber composite materials are stiffer and lighter in weight than most of the updated rackets. Increased stiffness reduces energy absorbed by the frame on ball contact and so increases applied ball velocity. New materials and technologies have been widely used. Today's tennis rackets are a showcase of high tech materials and engineering [1]. These arguments allow us to consider this field as the science of tennis racket. Nowadays tennis players are use the latest rackets of advance engineering materials for enhanced mechanical properties and lighter in aspect ratio of nanocomposite materials. At present various nanocomposite materials are in research work for replacement of existing material.

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Matthew Vokoun described in his work, the design aspects of tennis rackets the two main design aspects of tennis rackets, which are classified in external and internal design aspects. The external design aspects consist in strings, head size, and beam size. The internal design aspects are material type, weight, and balance [2, 3]. The strings characteristics such as elongation, tension, and pattern density are of great importance in stroke production. The head size provides the desired power: a larger head provides more power (longer head) or a better control (wider head). The beam size (racket's cross section) influences the racket's stiffness and power. Most modern racket frames are made from light-weight polymer nanocomposite allowing good frame flexibility, more power or more control, depending on the shots. Other important aspect refers to how racket’s weight and its distribution affect balance and control. New racket models are designed using computer-aided design which allows precise calculation of material rigidity and center of gravity. The trend today is toward lighter, bigger rackets, and these are viable because of advanced materials engineering [2]. Today's racket designs rely heavily on the engineering and scientific fields. For those who are interested in tennis, it is important to understand the modern design aspects of tennis rackets. This knowledge can be used by a tennis player to choose the best racket for him and to improve the tennis techniques. Understanding these design aspects is also important to anyone with an interest in modern technology [2, 3].

The Carbon nanotubes were first discovered by Iijima in 1991 [4, 5]. Carbon nanotubes are among the most amazing materials discovered in the 20^{th} century and probably the most highly cited name in scientific literature over the past two decades. Carbon Nanotubes are typically considered as molecular scale tubes of graphite carbon. Depending on numbers of carbon layers, they are categorized as single-walled and multi walled nanotubes. Rolling single layer of graphite is SWNT. Rolling two and more than two layers of graphite is called MWNT. Carbon Nanotubes show unique combinations of mechanical properties like stiffness, toughness, strength, thermal, physical & very high electrical conductivity. MWNTs with tensile strength up to 63 MPa, and with a high aspect ratio of 1,000 or higher are available [6-10] .Thermoplastic materials are those which get softened on the application of heat with or without pressure but they require cooling to set them to shape. Nylon 6,6 is one of the very important thermoplastic materials. It is made of hexamethylene diamine and adipic acid, which give nylon 6,6 a total of 12 carbon atoms. It is very tough, strong and rigid [11, 12].

Polymer/carbon nanotube composites have the potential to offer a vast improvement over current materials available today. Research scientists believe that the excellent physical, thermal and electrical properties of the carbon nanotubes (CNTs) can be realized at the macroscale by incorporating them into polymer matrices. Successful fabrication of such nanocomposites will lead to stronger and more conductive materials for advanced application (such as military and space). Examples include intelligent sensory materials in fabrics and films and strong, tough fibers for impact resistance. A polymer nanocomposite (PNC) is a two-phase material where one of the phases has at least one dimension in the nanometer range. PNCs can have enhanced mechanical and electrical properties in terms of their strength, weight, flame retardancy and electrical conductivity due to the very high surface/volume ratio of its reinforcements. The interfacial properties and the interfacial area have a crucial role to obtain good final properties in composites due to the nanosize of the fillers which provide them those above mentioned advance properties.

Today in sports equipment/automotive, aeronautics industry most, most common applied polymer nanocomposites are carbon nanotubes and nanoclay incorporated polymers. They are preferred due to their enhanced physical properties example. Light weight ratio, noise dampening, high impact strength, high strength to weight ratio, dimensional stability, long term durability, directional strength and etc., in addition to main constituents of composites, resins and reinforcements, use of additional fillers has become very common both for composites and nanocomposites. Fillers not only improve the mechanical properties and CNTs filler dispersion as well as interfacial interactions to be crucial for both incorporating CNTs into the resin and reaching enhanced mechanical properties in PNCs.

In this research, synthesizing various ratios of MWNTs with Nylon 6,6 and the study of improvements in mechanical properties of the polymer nanocomposites were attempted. Attempts were being made to use this material for making tennis racket frame. The tennis racket frame requires high stiffness, high impact strength, high tensile, flexural modulus, stiffness and less in weight. The racket 3D modeling was performed by using PRO/ENGINEER software. The 3D racket model can be export to ANSYS analysis software and structural analysis of the racket, especially the impact of tennis ball with string bed of the racket frame was performed.

2. Experimental

2.1. Materials and blend preparation

The Nylon 6,6 used in this study was obtained from DuPont India Pvt Ltd., under the trade name of Zytel 101L™. Nylon 6,6 has a melt flow index value of 11 g/10 min (275°C@ 0.325 kg) and melts at a temperature range between 260°C to 270°C. The Multiwall Carbon Nanotubes (MWNTs) were obtained from Sunnano, China with the purity of >95%, residue (after calculated) <5%, diameter of the MWNT being 10-30 nm. Prior to blending, Nylon 6,6 and Multiwall Carbon Nanotubes were dried at 80^0C in an oven for 12 hrs. Four ratios of polymer nanocomposites 0.15 wt% MWNT, 0.30 wt% MWNT, 0.45 wt% MWNT, and 0.60 wt% MWNT with Nylon 6,6, polymer nanocomposites were prepared by using Twin Screw Extruder Bersforft, FRG (L/D= 30, L=1 m) in the temperature range of 250-285^0C and at a screw speed of 150 rpm.

2.2. Manufacturing of nanocomposite and preparation of sample

After preparation of blend materials with various four ratios of polymer nanocomposite, was ready for synthesizing. Using Twin Screw Extruder starts the synthesis of each composition. Five heaters will set temperatures between 220^0C and 285^0C while constant temperature is maintained during the melting. Through the nozzle, the wire was drawn via water pool so that wire loses it is heat and starts cooling and the wire was cut into small granules. Using Injection moulding machine ,WINDSOR 130 Ton, India specimens of Virgin nylon 6,6 and Nylon 6,6/MWNT are prepared with of Tensile strength (ASTM D638), Flexural strength (ASTM D790), Impact strength (ASTM D256) and Hardness strength (ASTM D2240) as per ASTM standards.

2.3. Mechanical testing

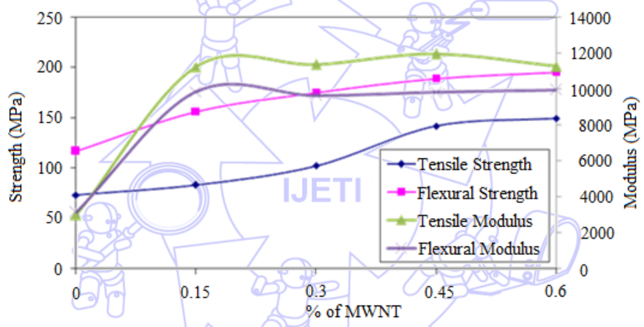
Specimens of Virgin nylon 6,6 and Nylon 6,6/MWNT were subjected to tensile test carried out as per ASTM D638 using Universal testing machine (UTM) Shimadzu Autograph (model AG 50kN ISD MS), Japan. A cross head speed of 50 mm/min and gauge length of 50 mm was used for carrying out the test. Specimens of virgin nylon 6,6 and Nylon 6,6/ MWNT were taken for flexural test under three points bending using the same universal testing machine (UTM) with ASTM D790 at a cross head speed of 1.3 mm/min and a span length of 50 mm. The Izod impact strength was determined with Tinius Olsen impact testing machine with specimen using notch cutter, cutting the specimen into 2.54 mm notch length, 45° notch angle at centre as per ASTM D 256. Hardness testing with the help of Duro hardness (Shore-D) with standard specimen ASTM D2240 was done. The test results were obtained by taking the average of five readings for each composition. For analyzing the mechanical properties test specimens were initially conditioned at 23+1°C and 55+2% RH. Five replicate specimens were used for each test and the data reported were the average of five tests. Corresponding standard deviations along with measurement uncertainty values for the experimental data showing the maximum standard deviation were also included.

3. Results and Discussion

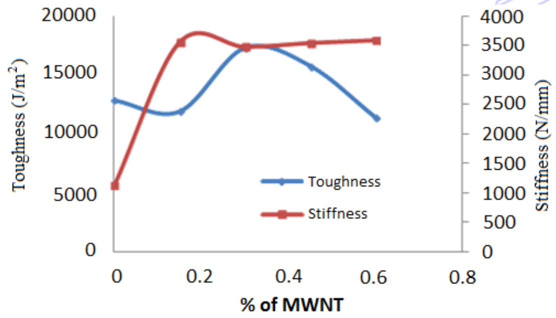
3.1. Measurement and mechanical characterization

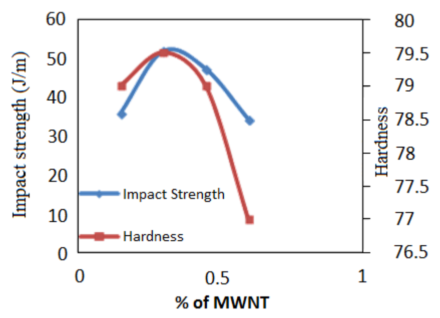
The Nylon 6,6 and Nylon 6,6/ MWNT nanocomposite with various ratios of MWNT like 0.15 wt%, 0.3 wt%, 0.45 wt% and 0.6 wt% were prepared. The Tensile strength, Flexural strength, Tensile strength and Flexural modulus of the nanocomposite increased with compared Virgin nylon 6,6. In that nanocomposite up to 0.6wt% multiwall carbon nanotube significant improvement of mechanical properties occurs. Fig. 1 (a), (b), (c) shows the values. The tensile modulus of the nanocomposite increases the value up to 0.45 wt% MWNT and then starts to reduce [13-16]. The average tensile strength, flexural strength and flexural modulus for 0.6 wt% structures are approximately 51%, 40%, and 69% respectively and are those of greater than virgin nylon 6,6. Peak value of tensile strength is 149.4 MPa, with flexural strength being 195.4 MPa and flexural modulus being 9951MPa. The average tensile modulus for 0.45 wt% structures is approximately 74% greater than virgin nylon 6,6. Peak value of tensile modulus is 11952 MPa .Impact strength and hardness 0.3 wt% structures are approximately 25% & 4% respectively and are greater than virgin nylon 6,6. The average stiffness value increases up to 3 times greater than the virgin nylon 6,6 and the peak value is 3582 N/mm. The average toughness optimized peak value is 17200 J/m^2. A slow decrease occurs with 0.6w% of tensile modulus dropping to 11233 MPa and 11258 MPa. But tensile strength, flexural strength and flexural modulus keep increasing MWNTs up to 0.6 wt% [17, 18].

3.2. Essential mechanical properties of tennis racket frame



(a)





(b) (c)

Fig. 1 (a) Strength & modulus (b) Impact & hardness (c) Stiffness Vs toughness Vs% of MWNT

In the mechanical testing, tested and calculated the mechanical tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, Hardness, stiffness and toughness. All the properties are important but stiffness and impact strength is very important for functional tennis racket frame. When the ball hits on the tennis racket and returns the ball from the tennis racket, it required stiffness and impact strength. So the work involves the improvement of these properties at the same time rest of the properties optimized.

4. Design of the Tennis Racket

Specification: Head Ti 4700 Tennis racket. A racket design tries to find an ideal balance of playing characteristics. When a tennis racket is designed, some compromises must be accepted: power vs. control, comfort vs. feel, light weight/maneuverability vs. solid shot response and stability [1, 19]. Design of the tennis racket was focused on many items, such as: racket size (dimensions– length, width, and thickness), size and shape of the racket head, size and shape of the racket handle, frame and string materials, weight, centre of mass and inertial characteristics, etc. The racket design is performed using PRO/ENGINEER software suite multiplatform, one of the most used integrated CAD/CAM/CAE systems. PRO/ENGINEER offers one of the world's leading parametric solid modeling packages. Tennis racket designed was thought to be composed of two main components: racket frame and strings. All parts go through the same stages of design. Design stages used commands. As the first result, a sketch of the racket frame was obtained, using the Extrude-Swept Blend-Curve-Sweep. Next were realized holes into the racket frame for string fixing. There were used Hole command for the first hole and Pattern command to multiply the created hole. Racket frame is ellipse section. The holes made in the racket frame have diameter of 2 mm, string diameter is 1.3 mm and they are arranged on the racket frame periphery at 19 mm distance vertically and 16 mm horizontally. Using the software facilities, the mass centre was determined [20]. The figure 2 shows 3D model of the tennis racket.

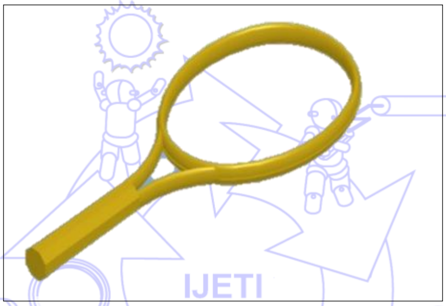


Fig. 2 3D model of the tennis racket

5. Analysis of Tennis Racket

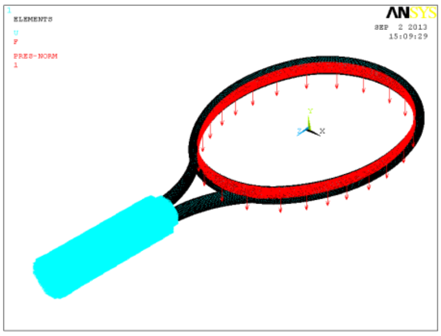
The racket model can be imported in finite element analysis software ANSYS 10.0 in order to simulate and analyze the mechanical characteristic of the racket, especially the impact between tennis ball and string bed of the racket and modal analyses were performed with the flexible racket models under different boundary conditions. Newer polymer nanocomposites material properties were taken for analyzing the tennis frame [21, 22].

6. Finite Element Analysis of Tennis Racket

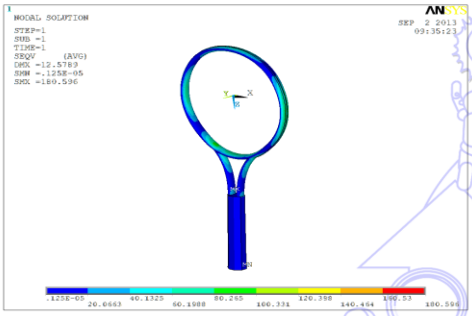
6.1. Structural analysis

Using SOLID186 is a higher order 3-D 20-node solid element of meshing the tennis racket 3D model for structural analysis. It is well suited to modeling irregular meshes (such as those produced by various CAD/CAM systems). The model will be constrained at the handle location in all DOFs. A pressure distribution of -1MPa along the inside edge of the ellipsoidal face will be applied to simulate the racket strings 32 forces of magnitude (32x 15.625 N –z direction) will be distributed over the head of the racket frame to represent the string-distributed forces on the racket frame as impact force 500 N (distributes 32 forces= 500/32=15.625 N). The first load case with only pressure distribution applied and Simulate. Second load case with both pressure and force applied and simulate. Both the cases, pressure distribution and pressure distribution with load applied plot analysis results of 0.45 wt% MWNT and 0.6 wt% MWNT. Actual volume of the tennis racket 668.228 mm^3 and mass of the nylon 6,6 racket frame is 715 grams and mass of the nanocomposite tennis racket frame 742 grams.

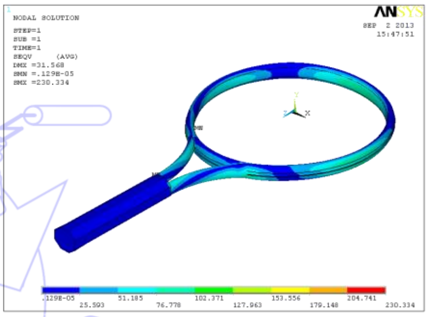
The details report of the stress analysis of the tennis racket frame structural. In the finite element analysis given the load and pressure distribution on the racket frames and plots the graphs and recorded the stress values. Nanocomposite 0.45 wt% MWNT tennis racket frame having betterment stress value is 230 MPa and moderate deflection value. The 0.45 wt% MWNT having better strength, modulus, and impact and moderate stress value suits for making a wide range tennis racket frame and also use other sport equipments golf bat, ho-ckey stick etc., Fig. 3 (a) - (e) show the stress and deflection of nanocomposite.



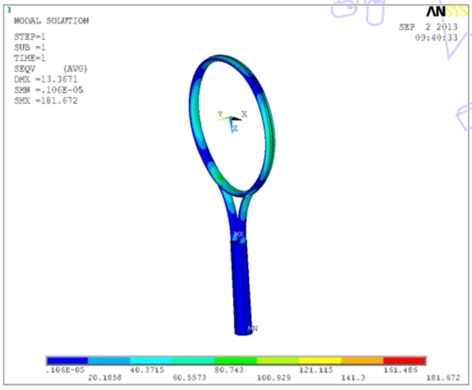
(a) Boundary conditions 32x15.625N–z direction



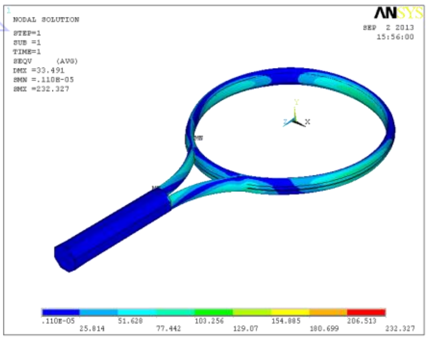
(b) 0.45 wt% MWNT force-stress



(c) 0.45 wt% MWNT Pressure & force-stress



(d) 0.6 wt% MWNT pressure-stress

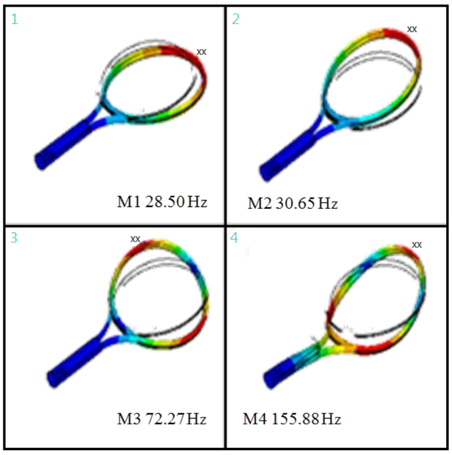


(e) 0.6 wt% MWNT pressure & force-stress

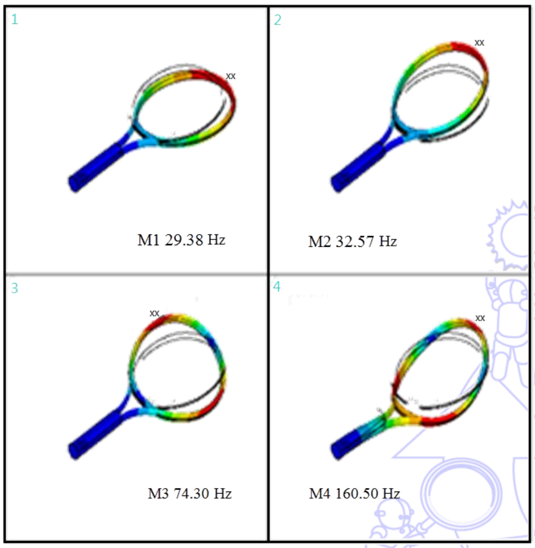
Fig. 3 boundary conditions & stress values of nanocomposites

6.2. Modal analysis

The vibration characteristics (natural frequencies and mode shapes) of a tennis racket structure was analysis used the modal analysis. Modal analysis in the ANSYS, Inc. family of products is a linear analysis, any nonlinearity, such as plasticity and contact (gap) elements, are ignored even if they are defined. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.



(a)



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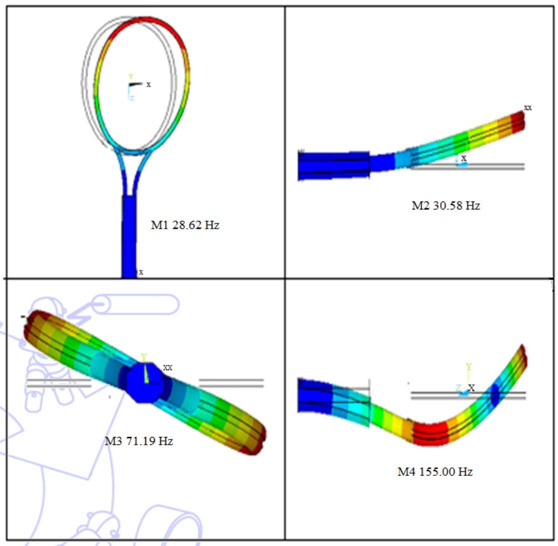

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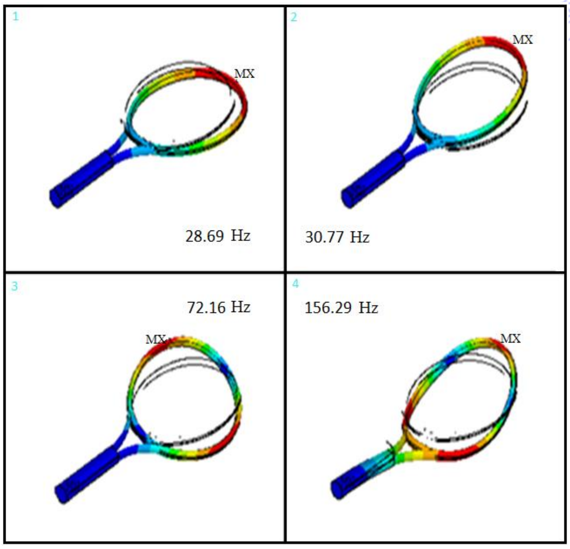

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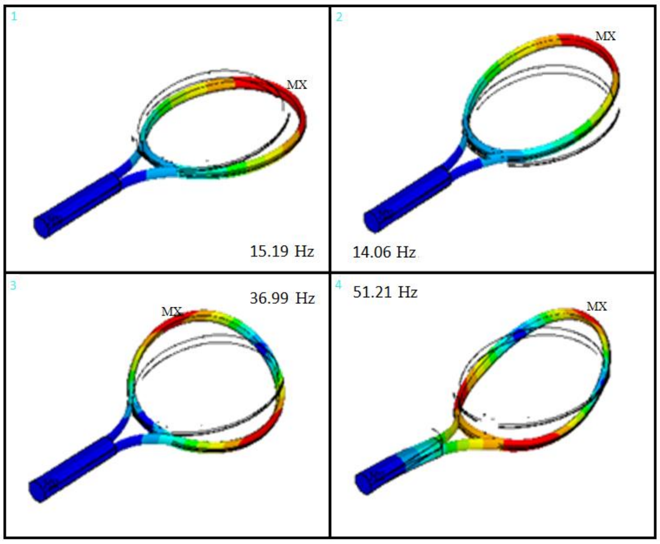

(e)

Fig. 4 Four modes (a) 0.6 wt% MWNT (b) 0.45 wt% MWNT (c) 0.15 wt% MWNT (d) 0.3 wt% MWNT (e) Nylon 6,6

The analysis type and options apply loads, specify load step options, and begin the finite element solution for the natural frequencies, select from among several mode-extraction methods: Block Lanczos, Supernode, PCG Lanczos, reduced, unsymmetrical, damped, and QR damped. The damped and QR damped methods allow you to include damping in the structure. The QR damped method also allows for unsymmetrical damping and stiffness matrices.

Build the model for a modal analysis was chosen 3-D Structural Solid-Solid 45 element used and meshed after that applied Loads, Obtained the Solution and applied boundary conditions and solved. Vibration analysis was done for four ratios of the polymer nanocomposites. Among 0.45 wt% MWNT and 0.6 w% MWNT polymer nanocomposite show the optimize natural frequency with other mechanical properties. The figure 4(a), (b) show four various modes of 0.45 wt% MWNT and 0.6 wt% MWNT polymer nanocomposite**.** The natural frequency in Hz listed of the various four modes of four ratio's of nanocomposites in the table 1.

Table 1 Natural frequency of various modes of nanocomposite

Modes/Polymer Nanocomposite	1 in Hz	2 in Hz	3 in Hz	4 in Hz
Nylon 6,6	15.19	16.06	39.99	51.21
0.15 wt% MWNT	28.623	30.576	71.193	155.00
0.30 wt% MWNT	28.690	30.774	72.157	156.29
0.45 wt% MWNT	29.381	31.574	74.300	160.50
0.60 wt% MWNT	28.498	30.651	72.263	155.88

0.45 wt% MWNT polymer nanocomposites show optimize natural frequency fourth mode 160.50 Hz for tennis racket frame and of various playing conditions, it was absorbed and reduced the vibration transverse to the through player hands through tennis racket handle [23].

7. Conclusions

The new polymer nanocomposite four ratio's of nylon 6,6/MWNT was manufactured and tested properties. 0.45 wt% MWNT polymer nanocomposite produced the best optimized results. It shown optimized strength, modulus both (tensile and flexural). The stiffness, impact value was increased, so the 0.45 wt% MWNT nanocomposite improved properties than existing composite materials. The tennis racket 3D model incorporated 0.45 wt% MWNT polymer nanocomposite properties and structural, modal analysis was done. It was shown the best stress value and it was improved better performance of the tennis racket. The natural frequency in Hz of the tennis racket of various four modes was done and shown best natural frequency. The polymer nanocomposite improved stiffness, less in weight and stored vibration & shock. Less amount shock transverse to the racket handle, so it was replaced existing composite materials to tennis racket frame.

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