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Synthesis, Testing of Nylon 6,6/Multi-wall Carbon Nanotube and Modeling, Analysis of Tennis Racket Frame and String

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Abstract: The tennis racket design had many improvements in last few years. The racket heads have grown larger, on frames that have become lighter. The racket frame and strings are of great importance for the player performance. The paper proposes synthesis and mechanical testing of Nylon6,6/MWNT newer nanocomposite material having a tennis racket frame , the strings made by nylon fiber , the creating model of tennis racket frame and applying newer material and analysis. The nanocomposite using Universal testing machine test the mechanical properties. The racket shape and dimensions can be established by the designer. The racket design was performed using CREO software. The racket model can be implemented in ANSYS analysis software in order to study the mechanical properties of the racket, especially the impact, vibration between tennis ball, string bed of the racket and transverse to frame.

Keywords: Carbon nanotube, Nylon6,6, properties, Tennis racket frame, CREO software.

1. Introduction

When tennis was first invented, wooden rackets had always been used. The usage of wood rackets lasted for decades, until the 1970s. In the 1970s, 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. Now day’s 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.

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 tubes were first discovered by Iijima in 1991[4-5]. Carbon nanotubes are among the most amazing materials discovered in the 20th 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 63MPa, 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. Nylon6,6 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]

In this research, synthesizing various ratios of MWNTs with Nylon 6,6 and the study of improvements in mechanical properties and characterization of the polymer nanocomposite are attempted. Attempts are 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. 3D model of the tennis racket frame and string bed was created by using CERO software and applying its newer material properties of analysis. Model analysis of the tennis racquet was done by the help of ANSYS software. Mathematical simulation can help in the evaluation of the effects of possible changes for tennis equipment requirement which can be adopted by the company in order to make tennis play more spectacular.

2. Experimental

2.1. Materials

The Nylon6,6 used in this study was obtained from DuPont India Pvt Ltd., under the trade name of Zytel 101L^{TM}. Nylon6,6 has a melt flow index value of 11g/10 min (275^{o}C@ 0.325 kg) and melts at a temperature range between 260^{o}C to 270^{o}C. The Multiwall Carbon Nanotubes (MWNTs) were obtained from Sunnano, China with the purity of >95%, residue (after calcinated) <5%, diameter of the MWNT being 10-30nm.

2.2. Preparation of the blends

Prior to blending, Nylon 6,6 and Multiwall Carbon Nanotubes were dried at 80^{0}C in an oven for 12 hrs. Nylon 6,6 composites were prepared by using Twin Screw Extruder Bersforft, FRG (L/D= 30, L=1m) in the temperature range of 250-285^{0}C and at a screw speed of 150 rpm

2.3. Synthesis

After preparation of blend materials with various four ratios of nanocomposite, it is ready for synthesizing. Using Twin Screw Extruder starts the synthesis of each composition. Five heaters will set temperatures between 220^{0}C and 285^{0}C while constant temperature is maintained during the melting. Through the nozzle the wire is drawn via water pool so that wire loses its heat and starts cooling and the wire is cut into small granules.

2.4. Sample Preparation

Using Injection moulding machine ,WINDSOR 130 Ton, India specimens of Virgin nylon6,6 and Nylon6,6/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.

2.5. Mechanical testing

Specimens of Virgin nylon6,6 and Nylon6,6/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 50mm/min and gauge length of 50mm was used for carrying out the test. Specimens of Virgin nylon6,6 and Nylon6,6/ MWNT were taken for flexural test under three point 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 50mm. 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^{o} 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 Nylon6,6 and Nylon6,6/ MWNT Nanocomposite with various ratios of MWNT like 0.15w%,0.3w%,0.45w% and 0.6w% were prepared. The Tensile strength, Flexural strength, Tensile strength and Flexural modulus of the nanocomposite increased with compared Virgin nylon6,6. In that nanocomposite up to 0.6w% multiwall carbon nanotube significant improvement of mechanical properties occurs. Fig.1 (a), c),(d) shows the values. The tensile modulus of the nanocomposite increases the value up to 0.45w% 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 nylon6,6. Peak value of tensile strength is 149.4 MPa, with flexural strength being 195.4MPa and flexural modulus being 9951MPa. The average tensile modulus for 0.45 wt% structures is approximately 74% greater than Virgin nylon6,6. Peak value of tensile modulus is 11952 MPa .Impact strength and hardness 0.3w% structures are approximately 25% & 4% respectively and are greater than virgin nylon6,6. The average stiffness value increases up to 3 times greater than the virgin nylon6,6 and the peak value is 3582 N/mm. The average toughness optimized peak value is 17200J/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 0.6w%.[17-18]

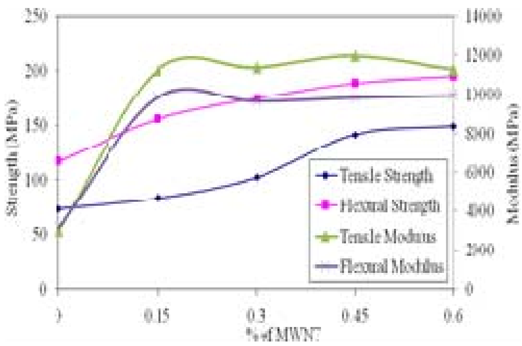
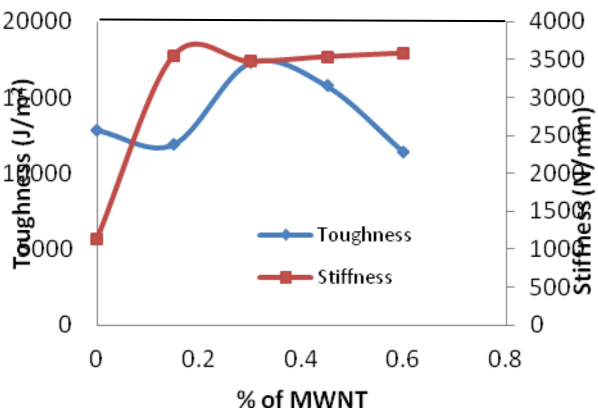


Fig.1a Strength & Modulus Vs % of MWNT



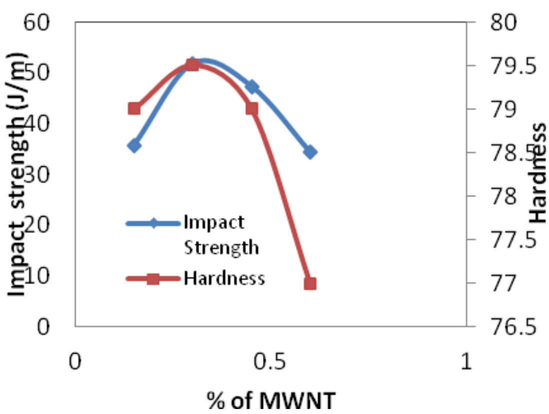


Fig.1b Impact & Hardness Vs % of MWNT Fig.1c.Stiffness Vs Toughness % of MWNT

4. Design of the tennis racket

Specification: HEAD Ti 4700 Tennis racket. A racquet 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 racquet was focused on many items, such as: racket size (dimensions– length, width, and thickness), size and shape of the racquet 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 CREO software suite multiplatform, one of the most used integrated CAD/CAM/CAE systems. CREO 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 a 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 placing. 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 2mm, 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 2a. and 2b show 2D diagram and 3D model of the tennis racket.

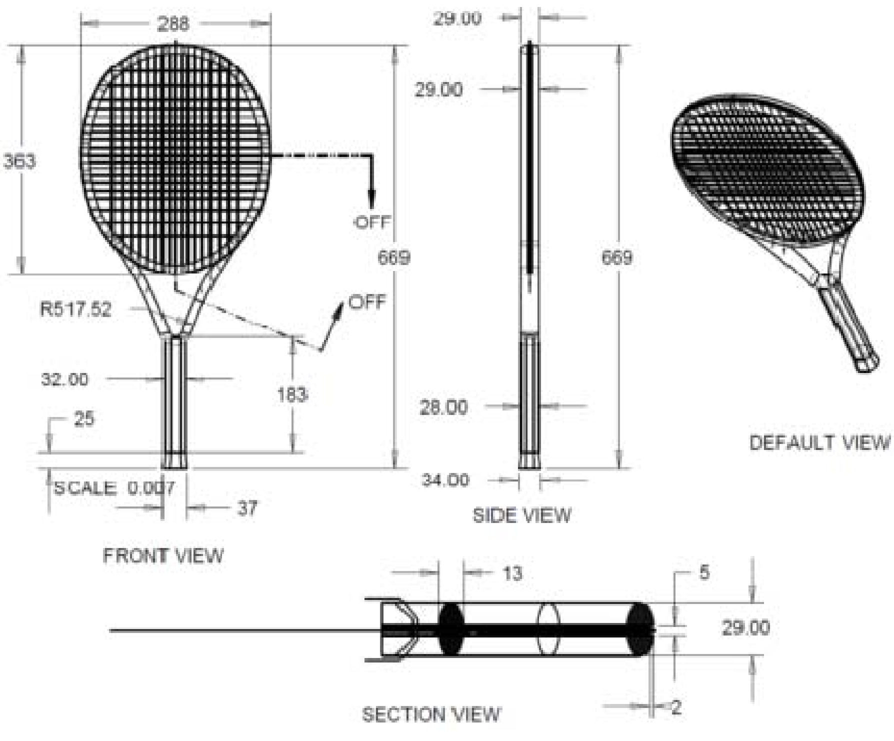


Fig. 2a. 2D Diagram of the tennis racket

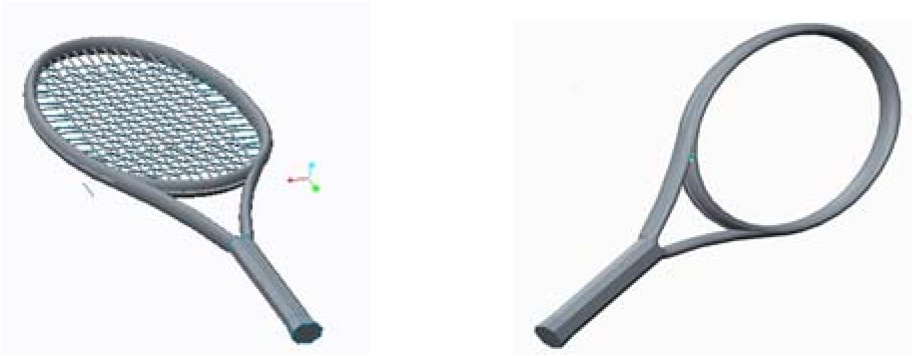


Fig. 2b. Model of the tennis racket (with string and without string)

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]
Due to their low weight and high mechanical strength, nanocomposite fibers are preferred, more and more, for making a wide range of parts for aerospace, automobile industry, and sport equipments golf bat, hockey stick, badminton and very much suited to tennis racket

6. Conclusion

The average tensile strength, flexural strength, flexural modulus and tensile modulus for 0.6 w% and 0.45w% structures increase. Impact strength 0.3w% increases and stats decrease occurs with 0.6w% of tensile modulus dropping. But tensile strength, flexural strength and flexural modulus keep increasing MWNTs up to 0.6w%. The average stiffness increases and the toughness start reducing. So the 0.6W% and 0.3W% nanocomposite replaces existing composite materials in application with better efficiency. In the tennis racket modeling applied nanocomposite properties and analysis is done. It is showing the very good performance. It has absorbed shock and vibration and less in weight compared with existing tennis racket frame material.

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