Future applications of Carbon Nanotube reinforced Functionally Graded Composite Materials

Gururaja Udupa[1], S.Shrikantha rao [2], K.V.Gangadharan[3]

Mechanical Engineering, National Institute of Technology, Karnataka,Surathakal

[1]hiudupa@gmail.com,[2]ssrcsr@gmail.com,[3]kvganga@nitk.ac.in

***Abstract*—Future applications demand materials having extraordinary mechanical, thermal and chemical properties which must sustain the different environment conditions and in the same time available easily at reasonable prices. The carbon nanotubes(CNT) reinforced functionally graded composite materials(FGCM) is expected to be the new generation material having a wide range of unexplored potential applications in various technological areas such as aerospace, defence, energy, automobile, medicine, structural and chemical industry. They can be used as gas adsorbents, templates, actuators, catalyst supports, probes, chemical sensors, nanopipes, nano-reactors etc. This paper explores in detail the different possibilities of application of CNT reinforced functionally graded composites and manufacturing techniques, which raise the awareness on the promise of nanotechnology and the potential impact on aerospace industry as well as on other areas.**

***Keywords*— CNT, FGM, FGCM, Composite, Aerospace , Submarine, cutting tools.**

I. INTRODUCTION

Functionally graded materials (FGMs) are a new generation of engineered materials that are gaining interest in recent years. FGMs were initially designed as thermal barrier materials for aerospace structural applications and fusion reactors[1]. FGMs also found applications in structural components operating under extremely high-temperature environments [2]. As an example, FGMs based on ceramic reinforcement in metal matrix are able to withstand high-temperature environments due to better thermal resistance of ceramic constituents, while the metal constituents enhance their mechanical performance and reduce the possibility of catastrophic fracture. FGMs are the composite materials in which the content of reinforcement is gradually varied in some direction to achieve gradient in properties. Due to graded variation in the content of constituent materials, the properties of FGMs undergo appreciable and continuous change from one surface to another, thus eliminating interface problems and diminishing thermal stress concentrations. The application of the concept of FGMs to Metals Matrix Composites (MMCs) has led to the development of components designed with the purpose of employing selective reinforcement in certain regions where enhanced properties like Young's modulus, strength and /or wear resistance are required [3]. Since the documented discovery of carbon nanotubes (CNT) in 1991 by Iijima[4] and the realization of their unique physical, mechanical, thermal and electrical properties, many investigators[17-25] have endeavored to fabricate advanced CNT composite materials that exhibit one or more of these properties. A challenging issue presented in the technology is how to substantially enhance the performance of engaged materials and structures so as to strengthen their integrity, reliability and lower manufacture–operation–maintenance cost. FGM composite structures having excellent and unique mechanical properties offer a promising solution to this concern. High-performance materials are materials that provide specific performance advantages in comparison with the counterpart conventional materials. FGM shows various commercial applications, serving as an attractive candidate to realize current and future trends of new generation application requirements.

II. CHALLENGES FOR FGM RESEARCH AND DEVELOPMENT

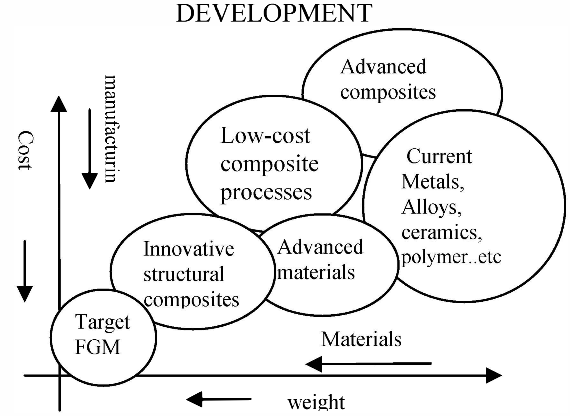


Fig.1 Future trends of material developments

The current focus of materials development activities for both composites and FGM includes: Improvements in material performance, ability to support optimized structural designs, continued lowering of manufacturing costs, and ability to perform reliably in service. In terms of automotive and airplane design drivers, there are significant cost and weight challenges for FGM composite materials as shown schematically in Figure1.The perception is that FGM composites have significant potential for performance and producibility improvements as they continue to mature technically. In addition as applications increase, their material costs are expected to be moderate[6-10].

III. CARBON NANOTUBE

The carbon nanotubes have very high stiffness and axial strength due to carbon–carbon sp^2 bonding. They are the best stiff material[23] having Young's modulus of 1.4 TPa and

ISBN: 978-81-909042-2-3 ©2012 IEEE

tensile strength well above 100 GPa. CNT are the best thermal conductors having thermal conductivity at least twice that of diamond and showing superconducting properties at low temperature. This shows Unique Electrical Properties such as extremely low electrical resistance and they can carry the highest current density measured as high as 10^9 A/cm^2. Comparison of Young's modulus of other reinforcing materials are shown in the table 1. Various techniques are being developed for the synthesis of carbon nanotubes. Some of the basic methods used are the carbon-arc discharge method, the laser ablation method, the chemical vapor deposition (CVD) method, the flame synthesis, and Smalley's high-pressure carbon monoxide (HIP-CO) process. To produce CNTs of desired characteristics in large quantities is still a challenging task for the scientists and engineers.

TABLE 1
COMPARISON OF YOUNG'S MODULUS

Sl.No	Reinforcing material	Young's modulus(Gpa)
1.	Carbon particle	50
2.	Aluminum	70
3.	Wrought iron	210
4.	Carbon fiber	250
5.	Silicon carbide	450
6.	Carbon Nanotube	1400

IV. CNT REINFORCED FGM COMPOSITES

CNT reinforced metal or ceramic matrix Functional graded composites exhibit continuous improvements in properties such as thermo mechanical, light weight, dimensional stability, barrier properties, flame retardancy, heat resistance and electrical conductivity[5-6]. These special properties give more challenging technology priorities in future days. Compared to metals these show better higher strength-to-density ratios, higher stiffness-to-density ratios, better fatigue and wear resistance, better elevated temperature properties(Higher strength-Lower creep rate). In contrast to composites materials, FG-composites have new unique properties like, ability to fabricate directional mechanical properties, higher temperature capability(Lower thermal expansion properties), excellent Fatigue and fracture resistance. Relatively immature technology development and present complex fabrication methods are the major draw backs. It is difficult to meet stringent dimensional stability requirements during gradation and results in higher cost of the product.

V. APPLICATION OF CNT IN FGM

Metal powders are used in the industry for diversity of products and applications. Traditional powder metallurgy is the process where the metal or alloy powder is compacted to a green body and then sintered to near net shape at elevated temperatures. The most important metal powders in use are: iron and steel, copper, aluminum, nickel, Molybdenum(Mo) , Tungsten(W), Tungsten cabide(WC), Tin(Sn) and their alloys. CNT reinforced metal matrix Functional graded-composites, due to their unique combination of hardness, toughness and strength, are universally used in cutting tools, drills, machining of wear resistant materials, mining and geothermal drilling. CNT reinforced Functional graded-composite materials have the ability to generate new features and perform new functions that are more efficient than larger structures and machines. Due to functional variation of FGM-materials, their physical/chemical properties (e.g. stability, hardness, conductivity, reactivity, optical sensitivity, melting point, etc.) can be manipulated to improve the overall properties of conventional materials[9-12].

TABLE 2
APPLICATION OF FGM [7]

Major areas	Application
Automobiles	Combustion chambers (SiC-SiC), Engine cylinder liners (Al-SiC), CNG storage cylinders, Diesel Engine pistons (SiCw/Al-alloy), Brake rotors, Leaf springs (E-glass/epoxy), Drive shafts (Al-C), Flywheels, Racing car brakes (Al-SiC), Motorcycle drive sprocket, Pulleys, Torque converter reactor, Shock absorbers (SiCp/Al-alloy), Radiator end caps.
Sub-Marine	Propulsion shaft (Carbon and glass fibers), Cylindrical pressure hull (Graphite/Epoxy), Sonar domes (Glass/Epoxy), Composite piping system, Scuba diving cylinders (Al-SiC), Floats, Boat hulls.
Commercial and Industrial	Pressure vessels, Fuel tanks, Cutting tool inserts, Laptop cases, Wind turbine blades, Electric motors, Firefighting air bottles, Artificial ligaments, MRI scanner cryogenic tubes, Wheelchairs, Hip joint implants, Eyeglass frames, camera tripods, Musical instruments, Drilling tubes, Drilling motor shaft, Drill casing, Crane components, High pressure hydraulic pipe, X-ray tables, Heart valves, Helmets, Crucibles, Beams.
Aerospace equipment and structures	Rocket nozzle (TiAl-SiC fibers), Heat exchanger panels, Engine parts (Be-Al), Wind tunnel blades, Spacecraft truss structure, Reflectors, Solar panels, Camera housing, Hublle space telescope metering truss assembly, Turbine rotor, Turbine wheels (operating above 40,000 rpm), Nose caps and leading edge of missiles and Space shuttle.
Aerospace	Wings, Rotary launchers, Engine casing, Rings (Al_2O_3 /Al-alloy), Drive shaft, Propeller blades, Landing gear doors, Thrust reverser(Carbon/Bismaleimide), Helicopter components viz. Rotor drive shaft, Mast mount, Main rotor blades (Carbon/Epoxy).
Sports	Racing bicycle frame (SiCw/6061), Racing vehicle frame.

VI. PROCESSING TECHNIQES

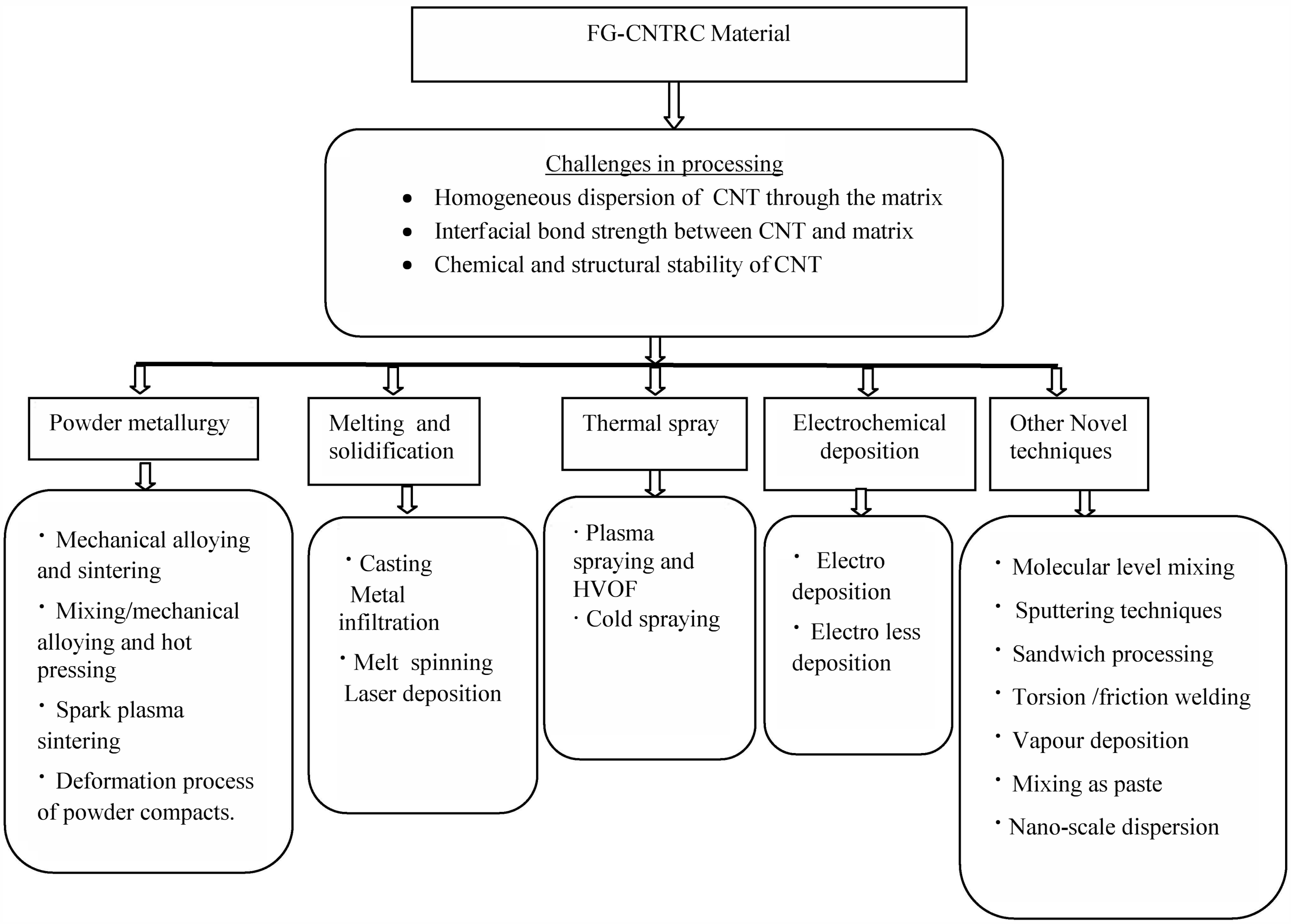
Functionally graded carbon nanotube reinforced (FG-CNTRC) composites are prepared through a variety of processing techniques, table 3 shows the various processes that have been adopted for synthesis of CNT-reinforced FG-composites.

ISBN: 978-81-909042-2-3 ©2012 IEEE

Powder metallurgy is the most popular and widely applied technique for preparing CNT Reinforced FG composites[7]. Electrodeposition and electroless deposition are the second most important techniques for deposition of thin coatings of Metal matrix-CNT composites as well as for deposition of metals on to CNTs. For low-melting-point metals such as Mg and bulk metallic glasses, melting and solidification is a viable route. Apart from these techniques, scattered efforts have been made on indigenous methods for preparing Metal matrix-CNT composites. Following subsections show different processing techniques.

TABLE 3

PROCESSING TECHNIQUES



VI. CASE STUDIES

The FGM technology[13-15] offers a great potential in creating next generation technological revolution. Of particular interest in the field of biotechnology and nanotechnology. In the field of materials science, we may see a paradigm shift from the traditional materials role of developing metals, polymers, ceramics, and composites to a revolutionary role of developing nanostructured, functionalized, self-assembling, and selfhealing materials. Looking into the future, the theoretical potential of these revolutionary classes of new materials will create breakthroughs that will enable technology developments that are barely imaginable today. In the aerospace field, these new technologies may make space travel routine and enable human exploration of space beyond our current practical limitation of low Earth orbit. Imagine the possibilities if there was a material to replace aluminum that is in an order of magnitude stiffer and two orders of magnitude stronger! Dramatic breakthroughs in manipulating matter will be required to develop this technology. Perhaps the most exciting outcome will be the realization of self-assembling, self-repairing, adaptive, intelligent, multifunctional materials. The key to realizing this dream may be the development of the molecular assemblers, perhaps approaching the versatility of the DNA molecule, so that matter may be manipulated as an atom at a time. Material systems based on carbon nanotubes are a

ISBN: 978-81-909042-2-3 ©2012 IEEE

particularly attractive new class of materials. Carbon nanotubes are cylindrical molecules composed of carbon atoms in a regular hexagonal arrangement, closed on both ends by hemispherical endcaps. On the basis of computer simulations and limited actual experimental data [21-25], some specific forms of carbon nanotubes appear to possess extraordinary mechanical, thermal, and electrical properties. If the properties of carbon nanotubes observed at the molecular level can be translated into useful macro-scale materials, the potential benefits to the aerospace industry include applications to vehicle structures, propulsion systems, thermal management, energy storage, electronic and computing, sensors and devices. Systems analysis studies [30] were conducted to quantify some of these benefits in specific applications of interest.

A. Benefits to aerospace structures

Fig.2 passenger aeroplane
[Courtesy: defenceaviation.com]

Material systems based on carbon nanotubes are a particularly attractive new class of Materials. On the basis of computer simulations and limited actual experimental data [16-27], some specific forms of carbon nanotubes appear to possess extraordinary mechanical, thermal, and electrical properties. The theoretical properties of the nanotube reinforced composite were used in a simple, systems analysis model [30] of a reusable launch vehicle shown in Figure 3. Huge reductions in weight were achieved during analysis. The results shown assume that the wings, body, and cryogenic propellant tanks are replaced with CNT reinforced FG- composites. Simplifying assumptions were made regarding design issues such as the amount of minimum gage structure and applications of stiffness versus strength critical design criteria. An aircraft engine application was also analyzed [30]. A typical gas turbine engine for a 300 passenger aircraft, was selected as the current baseline for the analysis. The low temperature applications were based on the use of carbon nanotube fibre reinforced polymer (NtFRP) composites for the nacelle, fan, low-pressure compressor components (blades, stator vanes, case, and ducts), and the bypass ducts. The high temperature applications were based on the use of carbon nanotube reinforced Functionally graded ceramic matrix composites for the high-pressure compressor, combustor, turbine components (blades, stator vanes, case, and ducts), and the nozzles. Significant weight savings benefits may also be achieved by designing spacecraft using FG-composites. These components comprise about 40% of the gross weight of the baseline spacecraft.

B. Materials for Propulsion Systems Components

Second and third generation propulsion system concepts under development for reusable launch vehicles (RLV) are illustrated in Figure 3. Properties of advanced metallic and non-metallic material systems were surveyed. In the long-term, CNT ceramic matrix composites and nanostructured FGM metals offer significant property improvements over the current baseline materials[15].

Fig.3 Reusable launch vehicle
[Courtesy: defenceaviation.com]

C. Advanced, Low cost FGM composite Trunk for the Universal Modular Submarine Mast

FGM Composite construction is now the material of choice for sonar domes on surface ships and submarines[5]. The domes provide a smooth flow around sonar transducers and protect the transducers from impact damage. Domes on submarines are truly massive structures that measure almost 34 feet across and weigh over 43,000 pounds, as they are built to match the hulls cross section shape. The domes are water-filled, so they are not subjected to the tremendous compressive loads that the pressure hull sees. Even so, demanding performance requirements are imposed on submarine bow dome structures. The domes must have a high degree of acoustic transparency. To avoid signal distortion, stiffeners are undesirable. Early sonar domes were made with polyester resin and alternate plies of woven roving and mat E-glass. Minimizing void content was also paramount, both to improve acoustic transparency and overall part strength. The current level of Navy Submarine logistics requires a broad reduction in subsystems weight. Excessive weight promotes roll instability and reduce submarine maneuverability.

Fig.4 Submarine

ISBN: 978-81-909042-2-3 ©2012 IEEE

[Courtesy: defenceaviation.com]

Reducing installation weight is critical since many new system, and their associated mass, are added to the platform over its lifetime. Furthermore cost reduction is critical for submarine manufacturers as global competition for this market has become more intense. The role in this cost and weight reduction scheme is to produce a light weight FGM composite UMM(Universal Modular Mast) guide trunk at reduced cost as compared to the current metal baseline by utilization of pultrusion processing. The UMM is an integrated system for housing, erecting, and supporting submarine mast mounted antennas and sensors. The FGM composite guide trunk offers up to a 60% weight savings and estimated 30% cost savings compared to current stainless steel trunk. Other application of FGM composites on submarines focused on developing an advanced Autonomous Underwater Vehicle (AUV) designed to operate at a depth of 20,000 feet.

D. Defence application

Defence applications such as fighter jets, helicopters, defence tanks, weapons and armor suits demand extremely light, robust and cost effective materials[13-15]. CNT reinforced FGM materials show more thermal stability and mechanical properties such as adhesion resistance, flexural strength, toughness and hardness. This exhibits the great advantage of FGM in military application. The use of advanced composites started in 1959 with the development of Optimum Pitch Blade for the XCH-47 twin rotor helicopter of Vertol Aircraft Corporation[13]. The good damping properties of CNT reinforced composites and thermal, chemical resistance influenced to manufacture various parts, which include main & tail rotor blades, stabilizers and fuselage portions. On focusing at weight reduction and good structural properties, the FGM nano composites are the best replacement for composites. Weight reduction for present and future Army systems is critical to rapid deployment of military contingencies. Ultralight weapon platforms will be the expectation of next generation battlefield. Also the lightweight metallic, ceramic, and polymeric composites for armor and armaments and barrier materials for chemical-biological protection in military applications focus on utilization of CNT reinforced FGM composites. Which typically consists of a hard frontal surface and a softer backing. The hard frontal materials are typically CNT reinforced ceramics FGM or hardened metallics. Aluminum and fiber-reinforced polymer FGM composites are commonly used for backing the harder frontal materials. The purpose of the hard surface is to blunt and to induce a destructive shock wave on to the projectile upon impact.

E. FGM metal cutting tools

The thermal stress concentration and vibration near the tip shank interface cause unexpected tool failure, due to the sharp discontinuity in thermo mechanical properties near the tip-shank interface. Based on the FGM concept, the graded region is inserted between tip and shank as shown in fig 5 in order to relax the stress concentration near the tip-shank interface, in which the material composition becomes identical with shank at the graded-shank interface and tip at the other interface. This is the basic concept of functionally graded cutting tool.

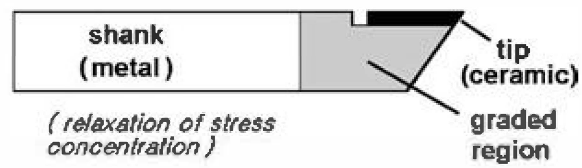


Fig.5 FGM type Cutting Tool

F. Other applications

Potential applications of FGM are both diverse and numerous. Some Special Problems and Examples of Applications of FGM [31] that have recently been reported include the following:

1.CNT reinforced functionally graded prosthesis joint increasing adhesive strength and reducing pain.

2.CNT reinforced functionally graded polyester-calcium phosphate materials for bone replacement with a controllable in vitro polyester degradation rate

3.CNT reinforced functionally graded TBCs for combustion chambers .

4. CNT reinforced functionally graded piezoelectric actuators.

5.CNT reinforced functionally graded reactor shield in nuclear reactors to reduce chemical corrosion and thermal stress.

6. CNT reinforced functionally graded tools and dies will enable better thermal management, possess better wear resistance, reduce scrap, and improve process productivity. FGMs also find application as furnace liners and thermal shielding elements in microelectronics.

VII. CONCLUSION

FGM belongs to novel material category and offers fundamentally new capabilities to use it at large scale. FGM technology has the potential to drastically redefine the methods used for developing lighter, stronger, and high-performance structures and processes with unique and non-traditional properties. FGM-composites often lead to a reduction in weight and costs and are more environmental friendly. For these reasons the popularity of these composites is increasing in world market and already a significant amount of scientific knowledge is generated. Numerous scientific and engineering breakthroughs will be required to develop the technology required in long-term goals. Critical technologies include advanced vehicle

ISBN: 978-81-909042-2-3 ©2012 IEEE

primary and secondary structure, radiation protection, propulsion and power systems, fuel storage, electronic devices, sensors, science and medical diagnostic instruments expects FGM kind of advanced materials with revolutionary new capabilities.

REFERENCES

[1] Pindera, M.-J., Arnold, S. M, Aboudi, J, and Hui, D., "Use of Composites in Functionally Graded Materials," Composites Eng. **4**, pp. 1–145, 1994.

[2] Pindera, M.-J., Aboudi, J, Arnold, S. M, and Jones, W. F., "Use of Composites in Multi-Phased and Functionally Graded Materials," Composites Eng., **5**, pp. 743–974, 1995.

[3] Markworth, A. J., Ramesh, K. S., and Parks, W. P., "Review: Modeling Studies Applied to Functionally Graded Materials," J. Mater. Sci., 30, pp. 2183–2193, 1995.

[4] IIJIMA S. Helical microtubes of graphitic carbon[J]. Nature, 354: 56-58, 1991.

[5] Pindera, M.-J., Aboudi, J, Glaeser, A. M., and Arnold, S. M, "Use of Composites in Multi-Phased and Functionally Graded Materials," Composites, Part B 28, pp. 1–175,1997.

[6] Suresh, S., and Mortensen, A., "Fundamentals of Functionally Graded Materials", IOM Communications, London, 1998.

[7] Miyamoto, Y., Kaysser, W. A., Rabin, B. H., Kawasaki, A., and Ford, R. G.," functionally Graded Materials: Design, Processing and Applications", Kluwer Academic, Dordrecht, 1999 .

[8] Paulino, G. H., Jin, Z. H., and Dodds, R. H., Jr, "Failure of Functionally Graded Materials," Comprehensive Structural Integrity, B. Karihallo and, W. G. Knauss, eds., Elsevier Science, New York, Vol. 2, Chap. 13, pp. 607–644, 2003.

[9] Noda, N., "Thermal Stresses in Functionally Graded Material," J. Therm. Stresses, 22, pp. 477–512,1999.

[10] Functionally Graded Materials VIII (FGM2004), Proceedings of the Eighth International Symposium on Multifunctional and Functionally Graded Materials, Materials Science Forum, Vols. 492–493, O. Van der Biest, M. Gasik, and J. Vleugels eds., Trans Tech Publications Ltd, Uetikon-Zuerich, Switzerland.

[11] Birman, V., "Stability of Functionally Graded Hybrid Composite Plates," Composites Eng., **5**, pp. 913–921,1995.

[12] Birman, V., "Stability of Functionally Graded Shape Memory Alloy Sandwich Panels," Smart Mater. Struct., 6, pp. 278–286,1997.

[13] Kaysser, W. A., and Ilschner, B., "FGM Research Activities in Europe," MRS Bull., 20, pp. 22–26, 1995.

[14] Cho, J. R., and Ha, D. Y., "Averaging and Finite Element Discretization aproaches in the Numerical Analysis of Functionally Graded Materials," Mater. Sci. Eng., A, 302, 187–196,2001.

[15] Yin, H. M., Paulino, G. H., Buttlar, W. G., and Sun, L. Z., "Effective Thermal Conductivity of Two-Phase Functionally Graded Particulate Composites," J. Appl. Phys., 98-6, p. 063704, 2005.

[16] Liu, G. R., Han, X., Xu, Y. G., and Lam, K. Y., "Material Characterization of Functionally Graded Materials by Means of Elastic Waves and a Progressive-Learning Neural Network," Compos. Sci. Technol., 61, pp. 1401– 1411, 2001.

[17] Han Y, Elliott J., "Molecular dynamics simulations of the elastic properties polymer/carbon nanotube composites". Comput Mater Sci;39:315–23, 2007,.

[18] Shen HS," Nonlinear bending of functionally graded carbon nanotubereinforced composite plates in thermal environments". Compos Struct;91:9–19, 2009.

[19] Halicioglu, T.,"Stress Calculations for Carbon Nanotubes," *Thin Solid Films*, Vol. 312, , pp11-14, 1998.

[20] Hernandez, E., and Goze, C.,"Elastic Properties of Single-Walled Nanotubes," *Applied Physics* A, Vol. 68, pp. 287-292, 1998.

[21] Lu, J. P.,"Elastic Properties of Carbon Nanotubes and Nanoropes," *Physical Review Letters*, Vol. 79, No. 7, pp. 1297-1300, 1997 .

[22]. Sinnott, S. B., Shenderova, O. A., White, C. T., and Brenner, D. W.,"Mechanical Properties of Nanotubule Fibers and Composites Determined From Theoretical Calculations and Simulations," *Carbon*, Vol. 36, Nos. 1-2, pp. 1-9, 1998 .

[23] Treacy, M. J., and Ebberse, W., "Exceptionally High Young's Modulus Observed for Individual Carbon Nanotubes," *Nature*, Vol. 381, pp. 678, 1996.

[24] Wong, E. W., and Sheehan, P. E., "Nanobeam Mechanics: Elasticity, Strength, and Toughness of Nanorods and Nanotubes," *Science*, Vol. 277, 1997, pp. 1971-1975.

[25] Yao, N., and Lordi, V.,"Young's Modulus of Single Walled Carbon Nanotubes," *Journal of Applied Physics*, Vol. 84, No. 4, pp. 1939-1943, 1998.

[26] Yu, M.-F., Lourie, O., Dyer, M. J., Moloni, K., Kelly, T. F., and Ruoff, R. S.,"Strength and Breaking Mechanism of Multiwalled Carbon Nanotubes under Tensile Load," *Science Magazine*, Vol. 287, No. 5453, pp. 637-640, 2000.

[27] Srivastrava, D., Menon, M., and Cho, K., "Nanoplasticity of Single-Wall Carbon Nanotubes Under Uniaxial Compression," *Physical Review Letters*, Vol. 83, pp. 2973,1999 .

[28] Mintmire, J. W., and White, C. T., "Electronic and Structural Properties of Carbon Nanotubes," *Carbon*, Vol. 33, pp. 893, 1995.

[29] Tersoff, J., and Ruoff, R. S.,"Structural Properties of a Carbon-Nanotube Crystal," *Physical Review Letters,* Vol. 73, pp. 676, 1994.

[30] Talay, T., Cerro, J., Lepsch, R., Gelhausen, P., and Guynn, M. "Systems Analysis of Nanotube Technology", published in the Nanotube Technology Assessment, National Aeronautics and Space Administration, Office of AeroSpace Technology, Washington, D. C., August 16, 2000.

[31] Schiller, C., Siedler, M., Peters, F., and Epple, M., "Functionally Graded Materials of Biodegradable Polyesters and Bone-Like Calcium Phosphates for Bone Replacement," Functionally Graded Materials 2000, Proceedings of the Sixth International symposium on Functionally Graded Materials, The American Ceramic Society, Westerville, OH, pp. 97– 108,2000.

First Author

Gururaja Udupa is currently a Research scholar in Mechanical Engineering Department at National Institute of Technology Karnataka. He obtained Bachelor of Engineering degree in Mechanical Engineering from P.E.S Institute of Technology, Mandya in the year 2001 and M.Tech from NITK surahtkal in the year 2006. His area of research is Manufacturing Technology and material sciences. He has two (2) international and national conferences papers and one (1) international journal paper. He is also interested in the use of visualization tools in various applications.

ISBN: 978-81-909042-2-3 ©2012 IEEE