MultiCraft

International Journal of Engineering, Science and Technology
Vol. 8, No. 1, 2016, pp. 57-63

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY

www.ijest-ng.com
www.ajol.info/index.php/ijest

Effect of alcoholic treated MWCNT on tensile behavior of epoxy composite

Hussain M. Tajammul[1], P.S. Shivakumar Gouda[2], I.G. Siddhalingeshwar[3]
Krishnaraja G. Kodancha[1*]

[1]*Department of Mechanical Engineering, B.V. Bhoomaraddi College of Engineering & Technology, Hubli, Karnataka, INDIA.*
[2]*Department of Mechanical Engineering, SDM College of Engineering & Technology, Dharwad, Karnataka, INDIA*
[3]*Department of Automobile Engineering, B.V.Bhoomaraddi College of Engineering & Technology, Hubli, Karnataka, INDIA*
[*]*Corresponding Author: e-mail: krishnaraja@bvb.edu,,Tel +91 98865 96953*

Abstract

In this work, the effect of alcoholic treatment of the multi-wall carbon nano-tube (MWCNT) on the mechanical properties of epoxy composites are investigated and compared. Nano-composites were developed by mixing 0.25%, 0.5% and 0.75wt% of MWCNT. Tensile strength, Young's modulus, and Elongation are found to be effectively improved with the addition of alcoholic functionalized MWCNT in epoxy matrix. Increased tensile strength and elastic modulus of epoxy composites loaded with the alcoholic functionalized MWCNT are observed through experimental studies. The results were compared with neat epoxy composite. These findings confirm that the improved dispersion and interfacial interaction in the composites arising from covalent bonds between the MWCNT and the epoxy matrix.

Keywords: MWCNT, tensile strength, alcoholic treatment, tensile modulus, epoxy

DOI: http://dx.doi.org/10.4314/ijest.v8i1.5

1. Introduction

Recently, the manufacturing, and application of polymer nano-composites have attracted attention and interest from both academics and industry. This is due to the reason that the addition of nano particles into composites does offer several advantages over general composites, with respect to higher stiffness, higher strength, and excellent chemical resistance, etc. There are several types of nano particles that are quite popular in nano-composites; these include nano-fibers, nano-tubes, metal nano-particles and nano-clay. Each of these fillers does have their own characteristic to improve the properties of composite materials. Mohapatra and Anand (2010) have studied on nano sized magnetite, which exhibits the excellent magnetic properties and used in the applications for biomedical purposes. Many researchers (Bai and Allaoui, 2003; Gojny *et al.,* 2005; Guo *et al.,* 2007; Yang *et al.,* 2007; Liu *et al.,* 2009; Spitalsky *et al.,* 2009) have studied Multi-Wall Carbon Nanotube (MWCNT) because of their inherent desirable mechanical properties and several other potential functional properties. MWCNT-filled polymer composites exhibits higher stiffness, higher strength, and better electrical conductivity even at low concentration of MWCNT's (Bai and Allaoui, 2003; Yang *et al.,* 2007; Gojny *et al.,* 2005; Guo *et al.,* 2007).

Epoxy/MWCNT composites have been extensively investigated due to their industrial and technological applications. The Nano-Composite of such kind is prepared by various means. Guo *et al.* (2007) have prepared these composites using melt mixing or solution mixing methods. A typical procedure for the preparation of composite by melt mixing method is as follows: MWCNTs are directly added to epoxy resin and then sonicated using an ultrasonic machine at an elevated temperature. Curing agent is added into the mixture and the mixture is degassed in a vacuum oven. Finally, mixture is injected into the sample moulds and is cured in an oven. Liu *et al.* (2009) have used solution mixing method and dispersed MWCNTs in alcohol by sonication. Epoxy resin is heated to elevated temperature then dispersed MWCNT are mixed with it. This mixture is mechanically stirred and sonicated in a water bath and hardener is added to it. The author have, reported that in MWCNT-reinforced epoxy composites using polyethylenimine as a dispersant. The covalently modified composites are 10,000 times more resistive than their noncovalent counterparts. Storage modulus of the composites containing covalently functionalized nanotubes is increased, relative to the noncovalent composites, due to the stronger polymer/nanotube interaction.

Similar results were observed by Spitalsky *et al. (*2009) for H_2O_2/NH_4OH mixture treated MWCNT/epoxy composites. Bai and Allaoui (2003) have reported that the effect of MWCNT length and aggregate size on the mechanical and electrical properties of epoxy/MWCNT composites. The insulator-to-conductor transition was found to occur at 0.5 wt. % of the as prepared MWCNTs. Yang *et al.* (2007) have prepared amide functionalized MWCNT/bisphenol-A epoxy resin/2-ethyl-4-methylimidazole composites. Transmission electron microscopy (TEM) showed that there was an organic thin layer on the MWCNT surface, which contributed to the homogenous dispersion of the MWCNTs in the epoxy matrix and to the improvement of the MWCNT-epoxy interfacial interaction. Thus the impact strength, bending strength, and thermal conductivity of the composites were enhanced. Similar results were observed by Gojny FH *et al.* (2005) for different types of nanofillers-reinforced epoxy nanocomposites. Guo *et al.* (2007) have fabricated epoxy/MWCNT nanocomposites using an ultra-sonication and cast moulding method. The tensile strength improved with the increase of MWCNT addition. In addition, the fracture strain was also distinctly enhanced, implying that MWCNT loading not only elevated the tensile strength of the epoxy matrix, but also increased the fracture toughness.

Gong *et al.*(2000) have investigated the effect of a non-ionic surfactant on the thermo-mechanical properties of epoxy/CNT composites. With the surfactant (C12EO8) as the processing aid, the addition of only 1 wt. % CNTs in the composite increases the glass transition temperature (T_g). Miyagawa and Drzal (2004) have reported on the thermo-physical properties and impact strength of diglycidyl ether of bisphenol F epoxy nanocomposites reinforced with fluorinated Single Wall Carbon Nanotubes (FSWCNTs). The T_g decreased approximately 30^oC with the addition of 0.2 wt. % FSWCNTs. Kim and Park (2010) have studied the effect of ammonized MWCNTs (NH-MWCNTs) on the mechanical interfacial properties of epoxy nanocomposites. The mechanical interfacial properties of the nanocomposites were remarkably improved with increase of the NH-MWCNT content. Similar results were observed by Jung *et al*. (2010) for amine epoxy adducts/thin MWCNT composite particles. Lee *et al.*(2009) have investigated the surface treatment effect of reinforcement filler on the dynamic mechanical properties of epoxy/MWCNT composites. The storage modulus of the epoxy/MWCNT composite was enhanced about 1.27 times through oxy fluorination of MWCNTs at 25^0C. As per the best knowledge of authors, earlier researchers have studied the effect of other organic solvents on MWCNTs. However, the effect of alcohol treated MWCNT's on the characteristics of composite are limited. In the present work an effort is made to study the effect of alcohol treated and un-treated MWCNT on the tensile properties of epoxy composites are investigated and results were comparedfor optimization.

2. Materials and methods

2.1 Materials

The present investigation has been carried out with MWCNT loaded in epoxy resin (LAPOX L-12) under room temperature with a curing hardener (K-6). All these polymer products were supplied by Atul India Pvt. Limited, Polymer Division, Gujarat, India. Senthil Saravanan *et.al.* (2010) have proposed a simplified arc discharge method for synthesis of MWCNTs. MWCNT used inthis work was research grade supplied by Sigma Aldrich, USA with a purity of 95%. The properties of Epoxy and MWCNT are tabulated in Table (1) and (2).

Table 1: Physical Appearance and Properties of Epoxy

Lapox L12	Unit	Limiting Value
Appearance	-	Clear yellowish Viscous liquid
Viscosity at 25 °C	cPs	7000 to 15000
Gel time at 160 °C	Sec.	60 to 120(Resin Mix.)
Epoxy content	Eq/Kg	5.0 to 5.6
Epoxy Elevating Temp.(P.E.T)	°C	185 to 210

Table 2: Physical and Mechanical properties of MWCNT

Specifications	Dimensions
Diameter	10–30 (nm)
Length	1–2 (mm)
Purity	0.95 (%)
Surface area	350 (m^2/g)
Bulk density	0.05–0.17 (g/cm^3)
Density	1.8 (g/cm3)
Tensile strength	3500 (N/mm^2)
Length of fiber	5 (mm)
Fiber thickness	0.3(mm)

2.2 Preparation of epoxy/MWCNT composites

Nano-composites were developed by mixing 0.25%, 0.5% and 0.75wt**%** of MWCNT. Study has been made to find the effect of treated and un-treated ethanol on MWCNT. Henceforth, in the following section Type-I is used for un-treated ethanol of MWCNT and Type-II is used for with alcoholic treatment of MWCNT. The detailed procedure of the preparation of Type-I and Type-II composites are as follows:

Type-I

1. According to the dimension of mould the volume of the mould has been calculated, which is equal to the volume of composite (v_c)
2. Use theoretical equation $V_m + V_f = 1$, then obtain V_m, where V_m = volume fraction of matrix and V_f = volume fraction of fiber/filler, which is in our case =0%, 0.25%, 0.50% and 0.75 wt%. We have, $V_m = \frac{v_m}{vc}$; Obtain, v_m which is volume of matrix and get required mass of the matrix.
3. Calculated amount of Epoxy is heated to a temperature of 60^0C, such that semisolid form of epoxy is converted into the liquid form, at the same time put magnetic bid into liquid epoxy and stir it for 5 to 10 minutes until all bubbles present in epoxy will disappear.
4. After reaching the temperature of Epoxy to 60^0C, mix the required quantity of MWCNT and stir it using magnetic stirring thoroughly for five minutes; Keep the beaker into ultra sound sonication bath for 30 minutes to ensure homogeneity.
5. Add the hardener (10% of v_m)to mixer of Epoxy/MWCNT, and stir the mixture for three minutes and pour into the mould. Keep the mould at controlled temperature for about 24 hours.
6. Composites are manufactured using hand layup method of moulding. Specimens are machined as per ASTMD638Standarddimensions using constant speed electric cutter.

The detailed calculations involved in the preparation of the samples are shown in Table. 3. The sample preparation procedure along with the equipment is shown in Fig.1. The size of the mould, V_c = 170 x 180 x 4 = 122,400 mm^3.

Table. 3 Calculated values of different Weight of MWCNT

Weight Percentages of MWCNT	V_f	V_m	V_c	Weight of Epoxy	Weight of MWCNT
Plane Epoxy	0	1	1.224×10^{-5} m^3	145 gm	0
0.25**%** MWCNT	0.25%	99.75%	1.224×10^{-5} m^3	145gm	0.3625 gm
0.5% MWCNT	0.50%	99.50%	1.224×10^{-5} m^3	145gm	0.7250 gm
0.75% MWCNT	0.75%	99.25%	1.224×10^{-5} m^3	145gm	1.0875gm

Aluminum foiled mould | Heater used for the Experimentation | Chemical Balance | Ultrasound Sonication Bath | Composite slab

Fig. 1. Mould and Equipment used for fabrication of Nano-Composites

Type-II

The steps involved in fabrication of Type II specimen are same as Type-I preparation except in-place of plain MWCNT, a 10ml of ethanol is added into weighed MWCNT in glass spatula and subjected to sonication for 20 minutes and heat the sonicated mixture until ethanol is completely evaporated. But care should be taken that temperature should not exceed 75^0C. Finally**,** add alcoholic treated MWCNT into epoxy mixture and further follow the same steps of Type-I.

2.3 Tensile test

Tensile test is performed on Type-I and Type-II specimens to determine the elastic properties of the composite. The most commonly used specimen geometries are the dog-bone specimen and straight-sided specimen with end tabs. The tension test is performed by taking five samples as per ASTM D 638 with monotonic uniaxial tension at a strain rate of 2 mm/min under room temperature. The plot of stress versus strain, the values of yield stress, ultimate stress and percentage elongation were recorded.

3. Results and Discussions

Experiments have been carried out to characterize the candidate for Type-I and Type-II Composite material. The analysis of the results and the influence of alcoholic treatment on the properties of MWCNT epoxy composite are summarized under the following Section.

3.1 Tensile behavior

Tensile test were conducted in accordance with ASTM D 638 for five specimens in each compositions of prepared composite. The dimensions of the test specimens were 165 mm in length, 13 mm in width and 3.5 mm in thickness respectively. A total of 35 specimens were tested at a cross-head speed of 2 mm / min under room temperature. The Fig. 2 and 3 shows stress versus strain plots for Type-I and Type-II oftreated and un-treated MWCNT epoxy composite samples.

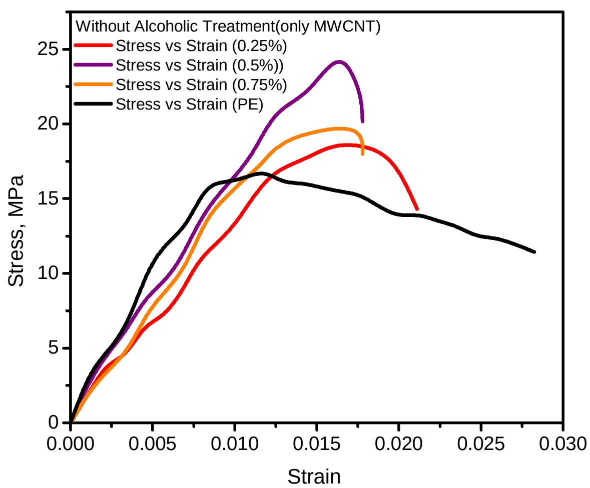

Fig. 2: Stress strain behavior of Epoxy/MWCNT without ethanol treatment

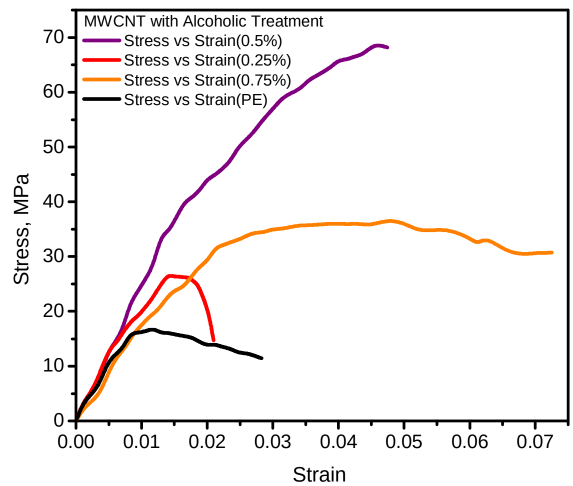

Fig. 3: Stress strain behavior of Epoxy/MWCNT with Ethanol treatment

Tensile behaviour in terms of stress versus strain for ethanol treated and un-treated MWCNT with varying weight percent are shown in Fig. (2) and (3). At low value of stress the elongation is high in Plane Epoxy(PE) samples shown in Fig.2 as compared to 0.25%,0.5% and 0.75wt % un treated MWCNT epoxy composites (Type-I). There will be similar value of Young's modulus with higher value of stress in case of 0.5wt% and 0.75wt % loaded MWCNT un-treated epoxy composite samples has been observed. This behaviour indicates the samples loaded with MWCNT withstand higher loads as compared to plane epoxy composite samples. Among type-I, the specimens loaded with 0.5wt % MWCNT gives better tensile strength and stiffness.The low stress with low elongation has been observed in Fig.3 for plane epoxy and 0.25wt% loaded with treated MWCNT composite samples.The samples loaded with 0.5wt% treated MWCNT have higher value of tensile strength and stiffness as compared to 0.75wt% treated MWCNT composite samples has been observed but these strength and stiffness enhancement still higher than the plane epoxy and 0.25wt% loaded with treated MWCNT composites. In type II specimens also the tensile strength and stiffness has been observed better in case of 0.5wt% of MWCNT.

Since better results have been observed for the addition of 0.5wt %MWCNT in epoxy, hence comparison has been made to understand this enhancement with plane epoxy and ethanol treated and un-treated composites samples are shown in Fig 4. It has been evidenced that there will be increase in the value of yield strength by 65% for un-treated ethanol epoxy composite samples. The reason behind this increase in the value of yield strength has been explained in below paragraph. The Young's modulus, Yield strength, Ultimate strength and percentage elongation for without ethanol treated MWCNT for various composition specimens tested are tabulated in Table 4.

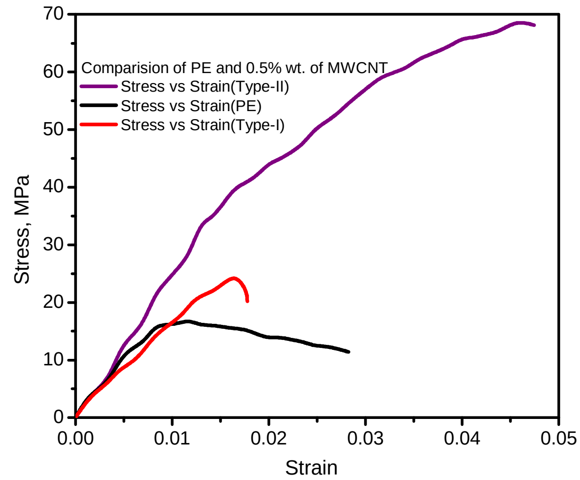

Fig. 4: Stress strain behavior of Epoxy 0.5%wt MWCNT for Type-I and Type-II along with Plane Epoxy

Table 4: Elastic properties of specimens without ethanol treated MWCNT

Composition	Young's Modulus (MPa)	Yield Strength (MPa)	%Elongation
Pure Epoxy	1892	16.30	15.00
Epoxy/0.25% MWCNT	1300	15.87	18.98
Epoxy/0.50% MWCNT	1597	22.54	13.55
Epoxy/0.75% MWCNT	1574	15.75	07.89

The Young's Modulus, Yield strength, Ultimate strength and % Elongation for without ethanol treated MWCNT for various compositions based on mean values of specimens tested were tabulated in Table 5.

Table 5. Elastic properties of specimens with ethanol treated MWCNT

Composition	Young's Modulus (MPa)	Yield Strength (MPa)	Elongation (%)
Pure Epoxy	1892	16.30	15.00
Epoxy/0.25% MWCNT	1872	26.60	07.69
Epoxy/0.50% MWCNT	1941	58.67	07.89
Epoxy/0.75% MWCNT	1433	36.00	07.69

The probable reason may be due to change in the morphology and microstructure of multi-walled carbon nano-tubes (MWCNTs) when treated with ethanol. According to Guojun Yu*et.al* 2006, the etching by OH radicals and deposition of C radicals on the carbon nano-tubes were considered to be responsible for the modification of the MWCNT structures and the formation of new carbon nanostructures. After ethanol treatment the nano-tube surface become rough and a large number of nano-lumps are formed on the surface. The SEM images of MWCNTs, before treatment and after treatment were shown in the work of Guojun Yu*et.al* 2006. Three chemical equations were proposed to demonstrate the decomposition of ethanol and etching reaction of MWCNTs by OH radicals, which are in agreement with the discussion in Maruyama *et al.* (2002).

$$C_2H_5OH \xrightarrow{\Delta} C_2H_5^{\bullet} + OH^{\bullet} \quad (1)$$

$$C_2H_5^{\bullet} \xrightarrow{\Delta} C^{\bullet}_{n(n=1\text{-}2)} + H^{\bullet} \quad (2)$$

$$OH^{\bullet} + C^{\bullet}\ (MWCNT) \xrightarrow{\Delta} CO_{(g)} + H_{2(g)} \tag{3}$$

The CO gas can further react with OH radicals to produce CO_2 gas (Zen *et al*., 1999; Brenninkmeijer *et al.*, 1999)

$$CO_{(g)} + {}^{\bullet} \xleftrightarrow{\Delta} CO^{\bullet} \tag{4}$$

$$CO^{\bullet} + OH^{\bullet} \xrightarrow{\Delta} CO_{2(g)} + H^{\bullet} \tag{5}$$

This etching of ethanol may be going to enhance the cross linking reaction of Epoxy and Hardener, hence the homogeneity of MWCNT dispersion is increasing which is going to enhance the tensile property of Epoxy/MWCNT composite.

4. Conclusions

Adding Carbon Nano materials in polymer composites has attracted attention and interest from both academics and industry. This is due to the reason that addition of Nano materials into composites does offer higher stiffness, higher strength, excellent chemical resistance etc. over conventional polymer composites. In this study the Nano composites samples were successfully processed and developed using hand layup method of manufacturing. Samples loaded with MWCNT withstand higher loads as compared to plane epoxy composite samples.The samples loaded with 0.5wt% treated MWCNT have higher value of tensile strength and stiffness as compared to 0.25%wt and 0.75wt% treated MWCNT composite samples. Yield strength and Young's modulus were increased by17.7% to 65% for 0.5wt% treated MWCNT compared to untreated composite samples. Since most of the Nano composites materials can find their use in aerospace, surgical and automotive engineering. Due to the high diversity, properties, and advantages of Nano particles in polymer composite-based applications have been envisioned to be practical application in near feature. These Nano materials in composites coupled with affordable cost will soon be seen in the global market.

References

Bai JB, Allaoui A., 2003.Effect of the length and the aggregate size of MWNTs on the improvement efficiency of the mechanical and electrical properties of nanocomposites--experimental investigation. *Composite Part A: Applied Science and Manufacturing*, Vol.34, p.689.

Brenninkmeijer CAM, Rckmann T, Braunlich M, Jockel P, Bergamaschi P.,1999. Review of progress in isotope studies of atmospheric carbonmonoxide. *Chemosphere: Global Change Sci*;Vol.1(1–3), p.33–52.

Gojny FH, Wichmann MHG, Fiedler B, Schulte K.2005. Influence of different carbon nanotubes on the mechanical properties of epoxy matrix composites - A comparative study. *Composites Science and Technology*, Vol.65, p.2300

Gong X, Liu J, Baskaran S, Voise RD, Young JS. 2000. Surfactant-assisted processing of carbon nanotube/polymer composites. *Chemistry of Materials*, Vol.12, p.1049.

Guo P, Chen X, Gao X, Song H, Shen H. 2007. Fabrication and mechanical properties of well-dispersed multiwalled carbon nanotubes/epoxy composites. *Composites Science and Technology*, Vol.67, p.3331.

Jung HT, Cho Y, Kim T, Kim TA, Park M. 2010. Preparation of amine-epoxy adducts (AEA)/thin multiwalled carbon nanotubes (TWCNTs) composite particles using dry processes. *Carbon Letters*, Vol.11, p.107.

Kim KS, Park SJ. 2010. Influence of surface treatment of multi-walled carbon nanotubes on interfacial interaction of nanocomposites. *Carbon Letters*, Vol.11, p.102

Lee YS, Im JS, Yun SM, Nho YC, Kang PH, Jin H. 2009. X-ray photoelectron spectroscopic analysis of modified MWCNT and dynamic mechanical properties of e-beam cured epoxy resins with the MWCNT. *Carbon Letters*, Vol.10, p.314

Liu L, Etika KC, Liao KS, Hess LA, Bergbreiter DE, Grunlan JC. 2009. Comparison of covalently and non covalently functionalized carbon nanotubes in epoxy. *Macromolecular Rapid Communications*, Vol.30, p.627.

Maruyama S, Kojima R, Miyauchi Y, Chiashi S, Kohno M.2002. Low temperature synthesis of high-purity single-walled carbon nanotubes from alcohol. *Chemical Physics Letters*. Vol.360(3–4), p.229–34.

Miyagawa H, Drzal LT. 2004. Thermo-physical and impact properties of epoxy nanocomposites reinforced by single-wall carbon nanotubes. *Polymer*, Vol.45, p.5163.

Mohapatra M. and Anand S., 2010. Synthesis and applications of nano-structured iron oxides/hydroxides – A review *International Journal of Engineering, Science and Technology*, Vol.2, p. 127-146.

SenthilSaravanan M.S., KumareshBabu S.P., Sivaprasad K., Jagannatham M., 2010. Techno-economics of carbon nanotubes produced by open air arc discharge method. *International Journal of Engineering, Science and Technology*, Vol. 2, p. 100-108.

Spitalsky Z, Krontiras CA, Georga SN, Galiotis C.2009. Effect of oxidation treatment of multiwalled carbon nanotubes on the mechanical and electrical properties of their epoxy composites. *Composites Part A: Applied Science and Manufacturing*, Vol.40, p.778.

Yang M, Gao Y, Li H, Adronov A. 2007.Functionalization of multiwalled carbon nanotubes with polyamide 6 by anionic ring-opening polymerization. *Carbon*, Vol. 45, p.2327.

Zen JQ, Zang JC. 1999. Simulation study of the initial microkinetics of water-gas shift reaction. *Journal of Molecular Catalysts* Vol.13, p.132–6.

Biographical notes

Tajammul Hussain Mysore.,obtained his B.E. Mechanical Engineering from B.V.Bhoomaraddi College of Engineering affiliated to Visvesvaraya Technical University Belgaum Karnataka India in 2013.Presently he is pursuing his master's degree in Machine Design course, Department of Mechanical Engineering, B.V.Bhoomaraddi College of Engineering Hubli,Karnataka, India. During Pre University College he had won Marathon Mathematics Award. Recently he has registered for two patents under Indian patent office. He has two conference papers in his credit.

Dr. P.S. Shivakumar Gouda is currently working as Assistant Professor in Mechanical Engineering Department and Deputy Dean Industry Institute SDM College of Engineering and Technology, Dharwad, Karnataka India. He holds his Ph.D, M.Tech in Machine Design and B.E in Mechanical Engineering from Visvesvaraya Technological University, Belgaum, India, in 2014, 2005 and 2003 respectively. Shivakumar Gouda is an outstanding Teacher, Researcher who rendered more than 12 Years of his Distinguished Service in SDM College of Engineering and Technology, Dharwad, Karnataka India. Dr. Shivakumar is a researcher of repute and has more than 20 Scientific Papers in National and International Peer Reviewed Journals and conference proceedings to his credit. His work is Indexed and Cited in Various Peer Reviewed Journals. He has successfully Guided 15 Students for M.Tech Degree and 4 Students are working at present for their M.Tech Degree and one student for PhD degree. He is recipient of "Young Scientist Award" by Swadeshi VijananaAndolana, Bangalore in 2006. His Academic Excellence has been recognized by Commonwealth Scholarship and Fellowship Commission, United Kingdom and awarded Commonwealth fellowship for the year 2012-2013. Under this fellowship he had visited University of Bristol UK for the period of one year for his collaborative research work. He has travelled countries like, Germany, Belgium, France, and Portugal for presenting research papers in conferences. He is Member of Professional bodies namely Life Member of ISTE, MIE, and International Association of Engineers (IAENG).

Dr. I.G. Siddhalingeshwar obtained his undergraduate and master's degree in Mechanical Engineering from B.V.B. College of Engineering and Technology, Hubli, Karnataka, and then, he joined as a faculty in the Department of Automobile Engineering in the same institute. In the year August 2011 he obtained doctoral degree from Department of Metallurgical and materials Engineering, IIT, Kharagpur. The author is presently working as a faculty and also as Faculty Coordinator, Academics at B.V.B. College of Engg. & Tech., Hubli, Karnataka. The author's research interest is in the area of Deformation processing of metal matrix composites and has nearly 20 publications in International Journals and conferences.

Dr. Krishnraja G. Kodancha, obtained M. Tech.in Design Engineering from Indian Institute of Technology, Chennai, India in 2002 and Ph. D from Visvesvaraya Technological University, Belgaum, Karnataka, India in 2012. He has more than 21 years of teaching and research experience and has several technical papers to his credit. He is presently working as Professor and Coordinator, M.Tech, Machine Design, in the Department of Mechanical Engineering, BVB College of Engineering. His research interests include stress analysis and fracture mechanics.

Received May 2015
Accepted December 2015
Final acceptance in revised form December 2015