MICROSTRUCTURE AND MECHANICAL PROPERTIES OF FLY ASH CENOSPHERES REINFORCED COPPER COMPOSITES PRODUCED BY POWDER METALLURGY ROUTE

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ABSTRACT

Fly ash cenospheres (FCs) was used as reinforcing filler in copper (Cu) matrix to develop lightweight metal matrix composites (FCs-Cu MMCs). FCs/Cu MMCs were successfully synthesized using powder metallurgy route. Experiments were conducted with various sintering temperatures (850 °C, 900 °C and 950 °C) for a holding time of 30 min, 60 min, and 90 min respectively. The influence of varying sintering temperature and holding time on microstructure, density, hardness and compression strength were measured according to ASTM standards. The results clearly demonstrated that the sintering parameters (temperature and holding time) influenced the mechanical properties. The results reveal that addition of FCs into Cu matrix led to the substantial improvement to the mechanical properties of the composites.

KEYWORDS: FCs/Cu MMCs; Powder metallurgy; Sintering; Mechanical properties

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INTRODUCTION

Fly ash is a waste product generated due to combustion of pulverized coal in coal fired thermal power plants. It has excellent physical, chemical, morphological, mineralogical properties and other characteristics such as thermal refractoriness, pozzolanic properties and low bulk density [1]. Fly ash cenospheres (FCs) are a naturally occurring by-product of the burning process at coal-fired power plants, and they have most of the same properties as manufactured hollow-sphere products. FCs are primarily used to reduce the weight of plastics, rubbers, resins, cements, etc. used extensively as filler lubricants in oil drilling operations. The compatibility of FCs with special cements and adhesives coating and composites for sports equipment's, insulation, automobile bodies, marine craft bodies, paints, and fire and heat protection devices have been well identified [2, 3].

In recent years, some researchers [4] attempted to use FCs as promising reinforcement to prepare porous and lightweight composite materials for high-temperature applications, due to their excellent high-temperature resistance and physical properties [4-10]. Rajan et al. [11] prepared fly ash for use as an effective reinforcement to improve the mechanical properties of Al-7Si-0.35Mg MMCs. Incorporation of flyash particles improves the wear resistance, damping properties, hardness and stiffness and reduces the density of Al alloys [12-16]. Some researchers recommended fly ash cenosphere particles for foam based applications [17, 18]. AA6061 aluminum alloy reinforced with FCs (1-2 µm particle size) composites synthesized using compo casting technique have shown hardness in the range of -80 to 112 corresponding to the wt. % of FCs in the range 4-12% and these composites have

exhibited ultimate tensile strengths of 130-240 MPa[19].

Copper metal particles have been generally utilized in engineering applications as a result of its high electrical and warm conductivity combined with good corrosion resistance and simplicity of fabrication [20]. Copper has wide assortment of utilizations, for example, electrical contacts in transfers, magnetrons in microwaves, electro-magnets, vacuum tubes, heat sinks, welding cathodes, semi-conductors, microchips, automobiles, and so on [21, 22]. Copper isn't considered as a decent material for auxiliary applications because of its poor mechanical properties particularly at elevated temperature [23]. In this way the analysts have been examining the impact of various approaches to improve its mechanical properties. The best strategy is making a Cu based composite by fortification expansion of an appropriate material [24]. Mahendra and Radhakrishna [25] synthesized Al-Cu alloy with fly ash and SiC reinforced hybrid MMCs and reported considerable improvement in the mechanical properties and wear resistance. Incorporation of alumina reinforcement in copper matrix leads to significant improvement in the tensile strength and hardness [26]. Copper-graphene MMCs exhibited excellent wear resistance due to higher hardness and excellent lubricating nature of graphene. Further, it is observed that porosity has a significant effect on the electrical conductivity [27]. Varol et al. manufactured multilayer graphene Cu nano composites by utilizing flake powder metallurgy and traditional sintering process. They found that the composite density decreased, improved hardness and electrical conductivity [28]. Zhang et al. examined the reinforcing impact of graphene nano platelets and diminished graphene oxide in Cu matrix through a modified molecular level blending process and plasma sintering process [29]. Allabergenov et al. [30] prepared Cu and Ni graphene nano layered composites with layer thickness of 70 nm and 100 nm for Cu-Gn and Ni-Gnnano composites respectively. The Cu-Gn and Ni-Gnnano composites displayed strength of 1.5 and 4 GPa individually. Xu et al. [31] considered the effect of sintering additives on mechanical properties, phase transformation and microstructure behavior of Si_3N_4 ceramic materials processed by microwave sintering.

In recent years, fly ash cenospheres (FCs) have been considered as a possible replacement for alumina/silica in the conventional and hybrid composites owing their light weight, low cost and high strength, and heat conductivity. In this regard, there are reports about development of load-bearing composites for automotive/electrical applications using FCs as reinforcement. However, limited research has been done in synthesis and characterization of MMCs involving FCs as reinforcement in copper matrix. In the light of the cited literature, this research work focuses on development of copper based MMCs with FCs as reinforcement using powder metallurgy technique. The effects of varying FCs wt. % (10, 20, 30, 40, and 50 by weight) on the density, microstructure, hardness, and compressive strength of copper MMCs are discussed.

MATERIALS AND METHODS

Materials

Different compositions of fine copper powder and fly ash cenospheres (FCs) were blended. Atomized pure copper metal powder of 99.5% purity with a particle size of ASTM 200 mesh ($45\mu\text{m}$) was obtained from M/s. Masil Scientific Products, Bengaluru. Fly as cenospheres was obtained from M/s. NTPC, Simhadri Thermal Power Station, India. Cenospheres with an average particle size of 25- $75\mu\text{m}$ has been used. Figure 1a and b shows the photograph of copper and FCs. Figure 2 shows the scanning electron microscopy (SEM) micrograph and EDAX of the FCs. It shows that the FCs was composed mainly of the three elements of the Si, Al, and O, and the few elements of Fe, Ca, Mg, and K (Table 1). Table 2 presents the physical properties of the FCs.

Table 1: Elemental Composition of FCs

Elements	Mg	Al	Si	K	Ca	Ti	Fe	O
Wt. %	0.55	6.99	28.37	0.91	1.29	0.83	1.41	49.65

Table 2: Physical Properties of FCs

FCs	Apparent density (g cm ⁻³)	Packing density (g cm ⁻³)	Density (g cm ⁻³)	Specific surface area cm ² g ⁻¹	Compression strength(MPa)
	0.336	0.41	0.78	2.52	6.0-8.0

Figure 1: Photographs of (a) Copper Particles, (b) Fly Ash Cenospheres.

Figure 2: Fly Ash Cenospheres (FCs): (a) SEM image, (b) EDAX.

Figure 3: XRD of: (a) Fly Ash Cenospheres, (b) Copper Particles.

X-Ray Diffraction Studies

Powder X-ray Diffraction (XRD) is one of the primary techniques used by mineralogists and solid state chemists to examine the physico-chemical make-up of unknown materials. XRD is an easy tool to determine the size and the shape of the unit cell for any compound. Powder Diffraction Methods is useful for Qualitative analysis (Phase Identification). Figure 3a shows the XRD pattern of the FCs. FCs consists of SiO₂ in amorphous and crystalline forms, Al₂O₃ and iron oxide. The mixture of glassy crystalline particles namely mullite, quartz and different oxides form FCs making it

heterogeneous. The XRD pattern indicates that the mineral phases in the fly ash consist of mainly mullite and quartz. In Figure 3a the broad hump, between $2\theta = 25^\circ$ and $2\theta = 30^\circ$, illustrates the amorphous phases in the FCs which contributes more than 50% of the total mass. Figure 3b shows the XRD pattern of the pure copper (Cu) powder.

Fabrication of Composites

Compositions with 10, 20, 30, 40 and 50 wt. % FCs and Cu powder were accurately weighed and mixed thoroughly using a pestle and mortar for 45 min to ensure uniform mixing. The blended powders were cold compacted using a closed cylindrical die in a hydraulic press with an axial pressure of 550 MPa. The cylindrical pellets fabricated had a diameter of 35 mm and height of 8 mm (Figure. 4). For easy ejection of the green compact from the die after compaction a small amount of zinc stearate powder was applied to the die wall and punch. The green compacts were sintered at 850°C, 900 °C and 950 °C in forming gas (95%N₂-5%H₂) by microwave sintering processes. Microwave sintering was performed in a 2.45 GHz, 1.1 kW microwave furnace (Figure. 5) with a heating rate of 32 °C/min and a holding time of 30 min, 60 min and 90 min. The samples were allowed to cool naturally in the furnace itself after the power was turned off. The sintered densities of the samples were determined using a method based on Archimedes principle. The densification parameter gives an insight to the degree of densification occurred during sintering process is expressed as shown in formula:

$$\text{Densification parameter} = \frac{(\text{sintered density} - \text{green density})}{(\text{theoretical density} - \text{green density})} \quad (1)$$

Figure 4: Fabricated FCs/Cu Composites: a)10,b)20,c)30,d)40,and e)50 wt. % of FCs.

Figure 5: Microwave Sintering Facility used in the Present Work.

The final fabricated FCs/Cu composites with reinforcement loading (10 to 50 wt. %) and theoretical density are given in the Table. 3.

Table 3: Details of FCs/Cu Composites Fabricated with Theoretical Densities

Sample Description	Sample Code	wt. % of FCs	Theoretical Density(g/cm ³)
10 wt. % FCs filled Copper	10 FCs/Cu	10	8.15
20 wt. % FCs filled Copper	20 FCs/Cu	20	7.33
30 wt. % FCs filled Copper	30 FCs/Cu	30	6.45
40 wt. % FCs filled Copper	40 FCs/Cu	40	5.70
50wt. % FCs filled Copper	50FCs/Cu	50	4.88

Testing of Composites

The apparent porosity (P_a) of the samples was calculated by water immersion method using Archimede's principle.

$$p_a(\%) = \frac{m_3 - m_1}{m_3 - m_2} \quad (2)$$

Where m_1 is the mass of a dried sample in air (g); m_2 is the mass of the saturated suspended weight of sample in water (g); m_3 is the mass of the sample saturated with water.

The fabricated composites density was measured by the Archimedes' method using ethanol as the liquid medium. The sample required size was cut, mounted, and finely polished (using 1 μ m diamond paste) for microstructural observations and hardness measurements. Microstructural observations of the polished surfaces were carried out by field emission scanning electron microscope (FESEM: Carl Zeiss, Germany). Microhardness was measured using Vickers hardness tester (HSV20, Shimadzu, Japan) with a diamond indenter pressed against the sample by applying a 4.9 N load for 15 seconds. For compressive strength measurement, the sample size of 4 mm $\times$ 4 mm $\times$ 8 mm was cut from the fabricated composite. Surfaces of the specimens were flattened, and the edges were chamfered using 600 grit SiC abrasive paper. Compression strength was measured using the universal testing machine (Instron UTM, UK) with 0.01 mm/s cross-head speed. Tests were carried out at room temperature.

RESULTS AND DISCUSSION

Effect of Process Parameters on Porosity

The porosity of FCs/Cu composites sintered using microwave furnace at 850°C and 900°C and 950 °C for soaking period of 30, 60 and 90 min are summarized in Table 4, 5 and 6 respectively. From the tables, it is obvious that the porosity of composites increased with the increase in FCs loading from 10 to 50 wt. % in copper matrix material.

From tables, it can be seen that, in each FCs/Cu composite, the microwave sintered temperature showed enhanced densification. The porosity of FCs/Cu composites sintered using microwave at 950 °C for holding time of 90 min appears to be on the lower side as compared to the other microwave sintered FCs/Cu composites. Furthermore, the porosity of the composites increased with the increase in FCs loading from 10 to 50 wt % of FCs. Also, from tables it can be noted that the microwave sintered samples showed porosity increase of 8% to 12% with increase of FCs from 10 wt % to 50 wt%. Samuels and Brandon [32] have also found increased density for alumina with sintering temperature difference of 300-400 °C.

Table 4: Porosity of FCs/Cu Composites at Different Sintering Temperatures (Holding Time 30 min)

Sintering at 850 °C			Sintering at 900 °C		Sintering at 950 °C	
Composites	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)
10 FCs/Cu	6.8	16.51	7.06	13.32	7.09	12.95
20 FCs/Cu	5.97	20.71	6.16	18.19	6.2	17.66
30 FCs/Cu	4.94	23.35	5.21	19.13	5.23	18.85
40 FCs/Cu	4.16	26.95	4.42	22.30	4.47	21.51
50 FCs/Cu	3.41	30.10	3.67	24.77	3.71	23.95

Table 5: Porosity of FCs/Cu Composites at Different Sintering Temperatures (Holding time 60 min)

Sintering at 850 °C			Sintering at 900 °C		Sintering at 950 °C	
Composites	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)
10 FC/Cu	6.91	15.16	7.15	12.21	7.38	9.3
20 FCs/Cu	5.98	18.41	6.25	14.73	6.49	11.45
30 FCs/Cu	5.05	21.64	5.40	16.21	5.62	12.80
40 FCs/Cu	4.27	25.02	4.51	20.71	4.82	15.36
50 FCs/Cu	3.52	27.85	3.76	22.93	3.97	18.58

Table 6: Porosity of FCs/Cu Composites at Different Sintering Temperatures (Holding time 90 min)

Sintering at 850°C			Sintering at 900°C		Sintering at 950°C	
Composites	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)	Actual density (ρ_a , g/cm ³)	Porosity (ϕ , %)
10FCs/Cu	7.21	11.47	7.45	8.53	7.671	5.8
20 FCs/Cu	6.28	14.32	6.55	10.64	6.781	7.4
30 FCs/Cu	5.35	16.98	5.702	11.54	5.912	8.26
40 FCs/Cu	4.57	19.75	4.815	15.45	5.115	10.18
50 FCs/Cu	3.82	21.7	4.06	16.78	4.262	12.64

The measured density of FCs reinforced Cu composites increases with increase in sintering temperature and decreased with increase in FCs for all composites. Further, it could be seen that the holding time has less influence in increasing the density of FCs/Cu composites when compared to the increase in sintering temperature (Tables 4-5).

Microstructure of the Composite Under Various Processing Conditions

To investigate the sintering development phase and microstructure, SEM micrographs of 50 wt. % FCs reinforced copper matrix composites examined at 850 °C, 900 °C, and 950 °C temperatures is shown in Figure 6. Figures 6a, b and c show the SEM images of the copper composite with 50 wt. % FCs loading under various sintering temperature viz., 850 °C, 900 °C and 950 °C respectively. Figure 9a shows the microstructure of the composite FCs/Cu with 50 wt. % loading sintered at 850 °C for a period of 90 minutes. Figure 6b clearly shows high porosity at 900 °C sintering. Figure 6c shows the increase in diffusion of copper matrix, reduction in porosity when compared to composite sintered at lower temperatures (Figures. 6a and b). It also indicates the formation of highly dense FCs-Cu composite. This dense phase has negligible amount of porosity. Further, the microstructure of the Cu-50 wt. % FCs composite sintered at 950°C for a period of 90 min results in the reduction of porosity (Figure. 6c).

Figure 6: Microwave Sintered Microstructure of 50 wt. % FCs/Cu Composite: (a) 850°C and 90min, (b) 900°C and 90min, (c) 950°C and 90min.

Effect of Process Parameters on Hardness

The hardness test results show that in general, the process parameters influence the hardness values of the composites studied. The variation in the microhardness of copper based MMCs reinforced with 10 to 50 wt. % FCs are shown in Figures 7a, b and c for different sintering temperatures and sintering time. The hardness of 10 wt. % FCs/Cu is about 189 (HV) and increased to 192, 198, 208 and 205 for 20, 30, 40 and 50 wt. % FCs reinforced copper composites. Further, the hardness increases marginally with increase in sintering temperature and sintering time (Figs. 7b and c) for all FCs/Cu composites. This could be due to the presence of hard FCs in the copper matrix. The hardness value does not change very much especially at 90 min sintering time (Fig. 7c) when compared to the hardness values of composites for sintering time of 60 min. (Fig. 7b). The hardness of FCs/Cu composites is almost same for 30 min and 90 min. sintering time, possibly due to long sintering time. Dinaharan et al. [33] characterized the fly ash reinforced MMCs based on aluminium alloy AA6061, magnesium alloy AZ31 and copper composites. These composites are synthesized using the novel and latest method friction stir processing (FSP). They found homogenous distribution of fly ash particles are observed in all the composites. The grains are refined remarkably in the composites due to dynamic recrystallization and pinning effect. The reinforcement of FA particles enhanced the microhardness of the composites [33]. As sintering temperature is increased, the two adjacent particles begin to form a good bond by diffusion in a solid-state bonding process [34], which results in increased surface hardness of the material. The present work hardness data are in consistent with the literature [33, 34]. In the present work, the change in hardness values could be due to the increase in brittleness caused by increased loading of FCs in the Cu matrix material. Figures 7a, b and c show the results of microhardness of FCs/Cu composite coupons. The microhardness increases with increase in FCs loading. It can also be seen from the figures that there is reduction in hardness for 10 wt. % FCs filled Cu composites and it could be due to more exposure of copper matrix phase during loading because of more copper diffusion during sintering process. The microhardness of 50 wt. % FCs/Cu is much higher than that of 10 wt. % FCs/Cu composites. For FCs/Cu with 50 wt. % loading, the hardness value increases with increasing sintering time. In FCs/Cu composites, higher hardness with increase in FCs loading is due to: (i) distribution of FCs particles in the pure Cu matrix as a hard phase. (ii) Refinement of grains in the composite surface, (iii) Quench hardening because of different thermal contraction between FCs particles and pure Cu matrix [35].

Figure 7: Hardness of FCs/Cu Composites at Different Sintering Temperatures: (a) Sintering Time 30min, (b) Sintering Time 60min, (c) Sintering Time 90min.

Effect of Sintering Temperature on Compression Strength

Figures 8a, b and c present the compressive strength of 10-50 wt. % FCs reinforced Cu composites sintered at 850 °C, 900 °C, and 950 °C for holding time of 30 min, 60 min, and 90 min, respectively. All composites under investigation are found to withstand higher stresses and the increasing trend is not consistent with FCs loading. The higher compressive strength of composites is due to the presence of hard FCs. Composite with 10 wt. % FCs has the highest compression strength (538 MPa) (Fig. 8c).

Figure 8: Compression Strength of FCs/Cu Composites at Different Sintering Temperatures: (a) Sintering Time 30min, (b) Sintering Time 60min, (c) Sintering Time 90min.

Uniform dispersion of FCs and good interfacial strength between FCs and matrix could be the reason to withstand maximum compressive stress among all the composite coupons. The compressive strength of composites is found in the order of coupons 10FCs/Cu > 20FCs/Cu > 30FCs/Cu > 40FCs/Cu > 50FCs/Cu which is inversely proportional to the amount of FCs in copper matrix.

Compression strength of composites with increasing sintering temperature and time are shown in Fig. 8a, b and c. Results show that the compressive strength gradually increased with sintering temperature increasing from 850 °C to 900 °C, but thereafter the strength significantly increased as sintering temperature increased 950 °C. Figs. 8a-c show that the 10 wt. % FCs reinforced Cu composites sintered at 950 °C displayed higher compressive strength of 538 MPa. The results also demonstrated that the FCs reinforced Cu composites possessed excellent compressive strength at 950 °C which may be attributed to the good adhesion between FCs and the Cu matrix, in addition to the lower density and lower porosity.

CONCLUSIONS

In this experimental investigation, microstructure and mechanical properties of FCs/Cu composites were investigated. The following conclusions can be made:

- The existence of FCs in copper matrix composites produced by powder metallurgy route results in significant refinement of the surrounding matrix material, which becomes more strong with increasing FCs loading. The structure of copper matrix areas near the FCs are more polished than those areas left from the FCs.
- The measured density decreases with increase in FCs loading and the porosity percentage increases with increase in FCs loading. This decreased density could be attributed to an increase in the porosity percentage with increasing FCs loading in the copper matrix. Further, the increase in sintering temperature and holding time decreased the porosity of the composites.
- The FCs/Cu composite with 50 wt. % loading respond to sintering temperature as well as sintering time, in a manner similar to that of the other FCs/Cu composites; the sintering temperature of 950 °C and sintering time of 60 min required to reach the peak hardness (about 231 Hv) in the pure copper matrix.
- The addition of FCs into copper matrix decreases the compressive strength of the composite, but increasing the sintering temperature and holding time increased the compressive strength of the FCs/Cu composites. The compressive strength of 10 wt. % FCs/Cu composite shows a peak and then decreases for the composites with filler loading greater than 20 wt. %. This is attributed to the presence of FCs with uniform dispersion and improved interfacial adhesion between filler and copper matrix material.

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AUTHOR PROFILE

Dr. Aravindrao M. Yadwad, Professor in the Department of Mechanical Engineering & Dean (Student Welfare), NIE, Mysuru. Obtained Ph.D, M. Tech degrees from Visvesvaraya Technological University, Belagavi and MBA, PGDHRM from Karnataka State Open University-Mysuru and B.E. from Kuvempu University. Having around 22 years of experience in Teaching, Research and Administration. I also served as Member of Academic Council [AC] during 2013-2015 and Deputy Dean [AA] during 2016-2019 for NIE, Mysuru. Under GoK deputation, I served the newly started Government Engineering College, as the HOD at Haveri during 2009-2010 and Chamarajanagar during 2007- 2009. My research interests are in the field of Production/Management/Energy Engineering and published more than 32 research papers in National and International Journals and Conferences. Guided more than 20 UG and PG students and actively involved in Research. Five PhD Scholars are pursuing their doctoral studies under my supervision in the field of engineering and management studies from VTU-Belagavi. One research scholar has been awarded the doctoral degree(PhD). My research interests are mostly networking with research institutions like UBDT,BEC, BMS, AIT,MCE, GECs, CPRI, NAL, HAL, GT&TC, NDRF, JNTU(H/A), Apex Professional University(AP), NITs(K/W/P/T), etc. My contributions in this field has been recognized and I have been made member to various scientific and technical committees for FIE, MISTE., ASME., MCI., C.Engg.

Dr. S. Seetharamu Former Director of CPRI, Bangalore, received his M.E. and Ph.D. degrees in Mechanical Engineering from the Indian Institute of Science, Bangalore and joined CPRI in 1985 after working in M/s. Best & Compton Engineering Ltd., for 3 years. He currently holds the position of Director in CPRI. He has also served as teaching faculty at Toyohashi University of Technology, Japan. His areas of interest include Materials Science & Engineering, remaining life assessment of power plant components and energy technologies linked to Energy Efficiency and Environmental Engineering aspects.

The technical contributions of Dr. S. Seetharamu, are given below:-

- Workshops – cum – Conferences conducted / coordinated: 42
- Patents: 26 (Granted 3 and in process 23)
- Membership in National Committees: 6
- Worked as Chief Vigilance Officer for 3 years in CPRI
- No. of Ph.D Candidates: 18 (Awarded 10 and in progress 8)
- Research papers : Reviewed journal publications: 105
- Conferences/Seminars & invited papers: 224

Further, Dr. S. Seetharamu, has also received many meritorious awards starting from FAA Jasadanwala award for the ME thesis (IISc.1976) and also worked as a Jury Member in many award committees. He is also heading the Journal Committee, member convenor of the IPR Committee of CPRI and High Level Committee for Centre for Collaborative & Advanced Research in CPRI.

Dr. Mahesh G. Emmi completed his B Tech in Mechanical Engineering from Uty BDT College of Engineering. He undertook his Masters from Indian Institute of Technology, Kharagpur in Materials Science & Engineering. He undertook his Masters Research work at Institute For Complex Materials, Dresden (Germany) on Nano composite Magnetic Materials. He received Institute Silver Medal during his Masters at Kharagpur and Jagmohan Singh Memorial award for the best M Tech project in the Institute for the year 2008. He has completed his Doctoral thesis on Simulation Modeling and Performance Evaluation of Cogeneration Plant.

He is presently tenanted the appointment of Head Of Faculty of Management Studies and Advanced Technologies at Air Force Technical College, Bangalore. He has been with the Indian Air Force and as an Aeronautical Engineer for the past 23 years and is qualified on various State of Art Systems and Platforms. He has been trained abroad on various systems and has contributed towards Make in India.

His areas of interest include Gas Turbine Research, Contemporary and Emerging Aviation Technologies, Nano composite Magnetic Materials, Bulk Metallic Glasses, Simulation Modeling, Renewable Energy, Composite Materials Research and Characterisation etc.

Mr. Pragnya Pradeep, M.Tech, [Phd] research scholar at NIE research centre affiliated to VTU, Belgaum worked as Senior Research Fellow in Central Power Research Institute, Bangalore from October 2014 to 2018. Worked as Assistant Professor at Mechanical Department, Navodaya Institute of Technology, Raichur from August 2013 to September 2014 and Bharat Ratna Indira Gandhi College of Engineering, Solapur, Maharastra from August 2012 to September 2013. Worked as a Graduate Apprenticeship Trainee in BEL Bangalore, Production Planning and Control Dept., since December 2008 to December 2009. Published papers in Journals like Taylor and Francis group, International Journal of Engineering Research and Development and TEST Presented Paper in International Conference held at DTU, New Delhi. Participated in workshop “Power Crisis and Disaster Management” Held at Central Power Research Institute Bangalore, 2016. Attended in National Seminars/ Conferences/workshops etc.