A study on hardness and wear behavior of Al-Cu/B_4C composite by stir and squeeze casting with rolled composites

GN Lokesh[1*], S Shivakumar[2] and S Karunakara[3]

[1*]*Dept. of Mechanical Engineering, Presidency University, Itgalpura, Rajankunte, Yelahanka, Bengaluru, Karnataka*

[2]*Dept. of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, International Airport Road, Hunasamaranahalli, Yelahanka, Krishnadeveraya Nagar, Bengaluru, Karnataka*

[3]*Dept. of Mechanical Engineering, City Engineering College, Kanakapura Road, Doddakallasandra, Bikasipura, Bengaluru, Karnataka*

ABSTRACT

Keywords:
B_4C,
Stir Casting,
Squeeze Casting,
Hot rolling,
Wear

In the present investigation, the Al-Cu matrix reinforced by B_4C particulate was fabricated using stir casting and squeeze casting technique. The stir cast composites so produced were subjected to hot rolling for 40% reduction and the composites have been evaluated based on the investigation of mechanical properties. The wear tests were carried out using a pin on disc technique. Microstructure of the composites was observed by scanning electron microscope (SEM). The results show that the hardness and tensile strength increases with increase in percentage of B_4C by stir casting squeeze casting and rolled composites. But squeeze casting composites shows higher strength than stir casting and rolled composites show higher mechanical properties than both stir and squeeze cast composites. The test results showed that rolled specimens fabricated by stir casting technique have greater wear resistance than those fabricated by squeeze casting technique. Microstructure shows better bonding between matrix particle interface and no fracture observed in rolled composites.

1. Introduction

Aluminium-based alloys are widely used in the automotive and aerospace industries because of their low densities and good mechanical and tribological properties. However, the relatively poor seizure resistance of aluminium alloys has restricted their uses in such engineering applications [1]. The wear resistance of these alloys can be improved considerably by adding ceramic reinforcements into aluminium, leading to the formation of the metal-matrix composites (MMCs). Incorporation of ceramic reinforcements can result in a favorable combination of the high ductility and the high strength [2, 3]. The ceramic reinforcements generally can be in the form of particles, whiskers and fibers. Particulate reinforced MMCs appear to be the most popular choice because they can offer relative ease in processing, lower fabrication cost, and nearly isotropic properties in comparison to fibre-reinforced materials [4–8]. Materials possessing high wear resistance are associated with a stable tribolayer on the wearing surface and the formation of fine equiaxed wear debris [9]. Extensive review papers on the dry sliding wear characteristics of composites based on aluminium alloys have been presented by Sannino and Rack [10]. In their studies and discussions, the effect of reinforcement volume fraction, reinforcement size, sliding distance, applied load, sliding speed, hardness of the counter face and properties of the reinforcement phase which influence the dry sliding wear behavior of this group of composites are discussed in greater detail. Sliding wear rate and wear behavior were reported to be influenced by various wear parameters [11–14]. Lim et al. [15] studied the tribological properties of Al–Cu/SiC metal-matrix composites prepared using different processing routes. Many researchers have carried out research work on secondary process for the mechanisms of high temperature deformation of composites. Compared with some exclusive and costly methods such as forging, extrusion, rapid solidification, and equal channel angular pressing (ECAP), rolling process was a common way that can fabricate large dimensioning products [16-20].

*Corresponding author,
E-mail: dr.gnlokesh@gmail.com(GN Lokesh)

Table 1
Chemical composition of Al-Cu alloy.

Cu	Mg	Zn	Fe	Si	Mn	Sn	Pb	Cr	Ni	Ti
4.45	3.14	0.50	0.20	0.08	0.01	0.009	0.006	0.002	0.001	0.001

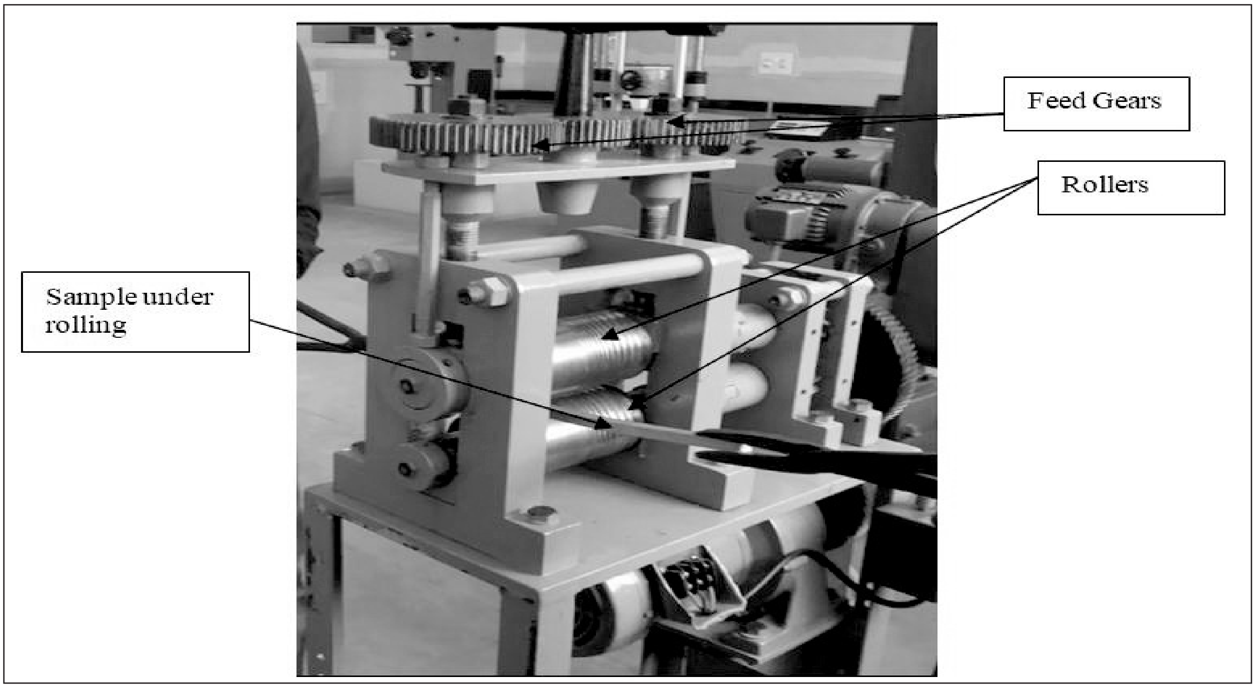


Fig. 1. Rolling of composite in a rolling mill.

In the present study an attempt has been made to stir and squeeze cast Al-Cu alloy reinforced B_4C with different weight percentage. The hardness and wear behavior of composites were investigated. The stir cast blanks were subjected to hot rolling process for reduction. Microphotographs were taken by SEM after wear to know the distribution and fracture of reinforcements.

2. Experimental Work

Fabrication of composite by stir casting (vortex method) and squeeze casting technique has been used to fabricate composite. The Al-Cu alloy is used as matrix and B_4C is used as reinforcements. The chemical composition of the matrix alloy is shown in Table 1.

In vortex technique, the matrix alloy was cut to small pieces and then charged into crucible furnace of 3 kW power where it is heated to a superheat of 740°C. Then the melt is stirred using mechanical stirrer. The B_4C particles with as size ranging between 15-20µm were preheated to 210°C for two hours to remove moisture. After the Al-Cu alloy was fully melted, solid dry hexachloroethane degassing tablet was added to reduce the porosity. The stirrer was lowered into the melt slowly to stir the molten metal at the speed of 450 rpm. Various stirrer speeds, tilt angles and movement of stirrer from top to bottom in the crucible were used to obtain vortex strong enough to disperse the reinforcements into the melt. The preheated B_4C particles with different weight percentage of 2%, 4%, 6%, 8% and 10wt% were added to the vortex between liquidus and solidus temperatures at the rate of 25g/min during the stirring time with Mg (0.6wt %) were also added to ensure good wettability of particles. When the addition of B_4C particulate was completed, stirring of the mixture was continued for another 5 minutes and then the mixture was poured at 720°C into the prepared steel die. The cast was withdrawn from the mold after complete solidification and then the required specimens were taken for investigation.

In squeeze cast technique, a special die set of 50 mm inside diameter, 100 mm outside diameter and 200 mm height provided with a punch of 50 mm diameter. The die set was manufactured from tool steel material. The die walls were coated by graphite to inhibit sticking of ingot to the walls. After through mixing of matrix and reinforcements, the melt was poured into preheated die cavity and solidification was carried out with a squeeze pressure of 110MPa for a period between 120 and 180 seconds [21]. A gradually increasing pressure was applied to the aggregate through the punch. The maximum applied pressure was maintained constant till completion of solidification. The stir cast samples were hot rolled with a temperature of 410°C and the thickness reduction of 0.25mm per each cycle into different final reductions of 40% with intermediate heat treating process. The laboratory rolling mill with a loading capacity of 15 tons is used for rolling the samples with no lubrications shown in Fig. 1. The roll diameter was 85mm and roller speed was set to 30rpm. Hardness measurements were performed using a Brinnel hardness tester with a load of 10kgf as per ASTM-E10-01. Wear test was carried out using a computerized pin on a disc wear testing machine under ambient temperature conditions on specimens for normal load of 10N and for a constant track velocity of 4 m/sec. A hardened steel disc (60 HRc) was used as the counter body. The duration of the test was fixed to 30 minutes. For each experiment, a new pin and a new disc were used. Before the tests were conducted, both the pin and disc were degreased, cleaned and dried with acetone. The wear tracks on the specimen were observed under a SEM to examine the effect of the percentage of particulate on the wear behavior of the composites.

3. Results and Discussion

3.1. Hardness

The dispersion of B_4C particles enhances the hardness, as particles are harder than Al alloy; the materials render their inherent property of hardness to the soft matrix. The peak hardness of 143BHN was found to be for an addition of 10 wt.% B_4C particles in stir cast condition shown in Fig. 2. The squeeze cast composites having 2wt.% B_4C was found to be 10% more harder than the corresponding stir casting. However, the peak hardness observed for addition of 10 wt.% B_4C particles in both the cases and squeeze cast composite is 16% higher than stir cast composite. The hardness of Al-Cu/ B_4C composites after hot rolling was found to increase gradually with an increase in the extent of reduction during rolling. This increase was observed from 108 for base alloy to 183BHN for 10 wt.% B_4C reinforcement which is attributed primarily to the refined grain structure of matrix, presence of harder B_4C and harder $CuAl_2$ phase in the matrix, and also the higher constraint to the localized matrix deformation during indentation as a result of the presence of reinforcement.

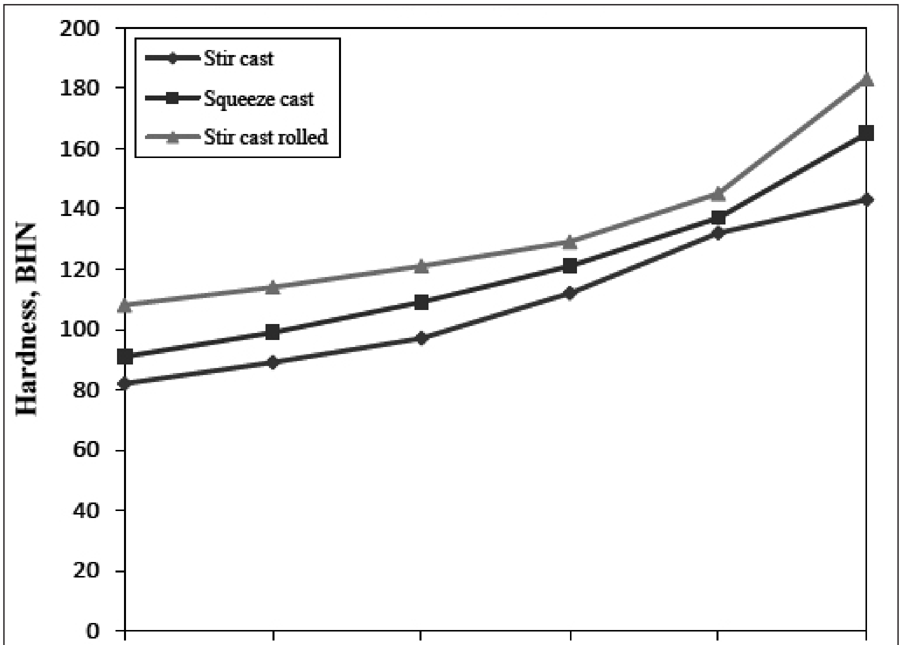


Fig. 2. Variation of hardness with varying B_4C particle content.

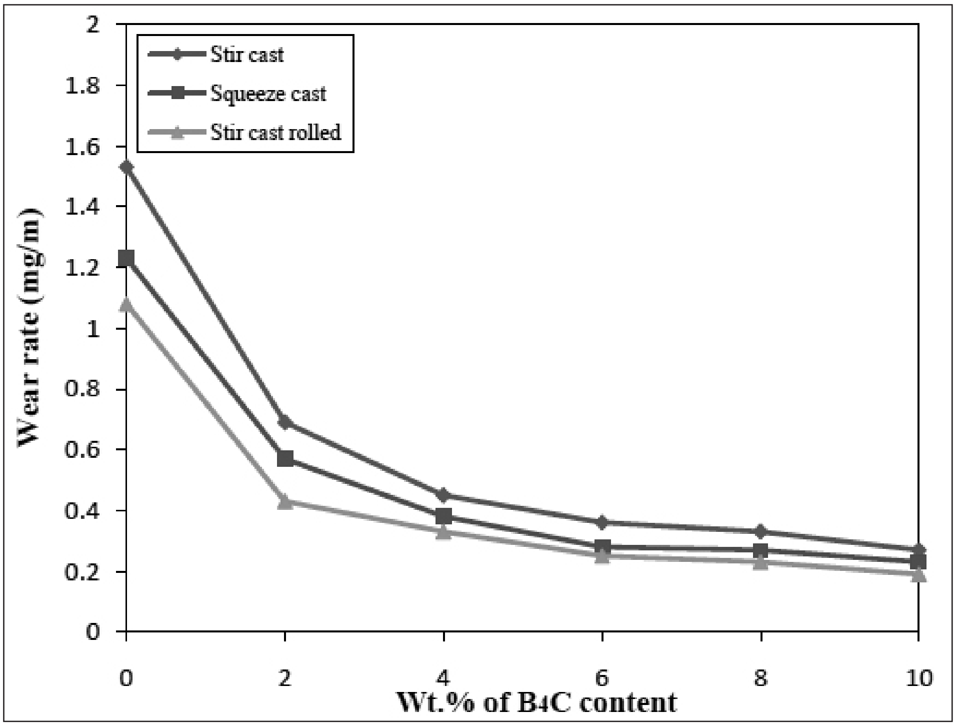


Fig. 3. Wear rate with varying B_4C particle content.

3.2. Wear test

The stir, squeeze and rolled composites were machined to a diameter of 8mm with height of 30mm for perfect match in the wear testing specimen holder (separate arrangement) for the wear study. The test report of dry sliding wear of both stir cast and squeeze cast composites of different weight percentage particles is indicated in Fig. 3. It is observed that the both stir and squeeze cast composites shows peak strength at 30 minute duration. Hence the wear studies of this composite are presented here. The wear rate is decreased with increasing wt.% of B_4C in both stir and squeeze casting for 10 wt.% of B_4C. The squeeze cast composite showed decreases of 15% lesser wear weight loss compared to stir cast composite for highest reinforcements. It may be attributed to hardness of the material a dominating factor affecting the wear resistance. The decrease in wear weight loss may also be attributed to higher load bearing capacity of hard reinforcing material. It is evident that rolled composites show lesser wear weight loss when compare to stir and squeeze cast composites for the same duration in all the composites. This is due to the increase of hardness of the respective composites with the extent of rolling and also the abrasive nature of B_4C particles. The finer dispersion of the fragmented particles strengthens the composite. Since the average particlesize of B_4C lies in the range 15-20µm,the extent of particles pulled out from the surface was smaller. With increase in reduction, the amount of particle present strengthens the matrix and hence more wear resistance is observed in rolled composites.

3.3. Microstructure

Fig. 4. (a, b and c) shows that the presence of grooves of varying sizes was observed frequently on the worn surface. The worn debris particles are likely to act as third body abrasive particles. The B_4C particles trapped between the specimen and counter face cause microploughing on the contact surface of the composite both in stir and squeeze casting. The wearing surface is characterized by a significant transfer of material between the sliding surfaces. The B_4C could be dispersed inside the matrix alloy with better bonding due to which the wear resistance occurred. More debris can be seen in the tracks of stir and squeeze cast composite in Fig. 4a and 4b, while in Fig. 4c shows uniform wear track with reasonably lower debris. The lower wear weight loss of rolled sample may be due to the fact that the material is denser, better interfacial bond between the particle and the matrix than in the stir cast samples, reducing the possibility of particle pull out which may result in higher wear. Also it is observed

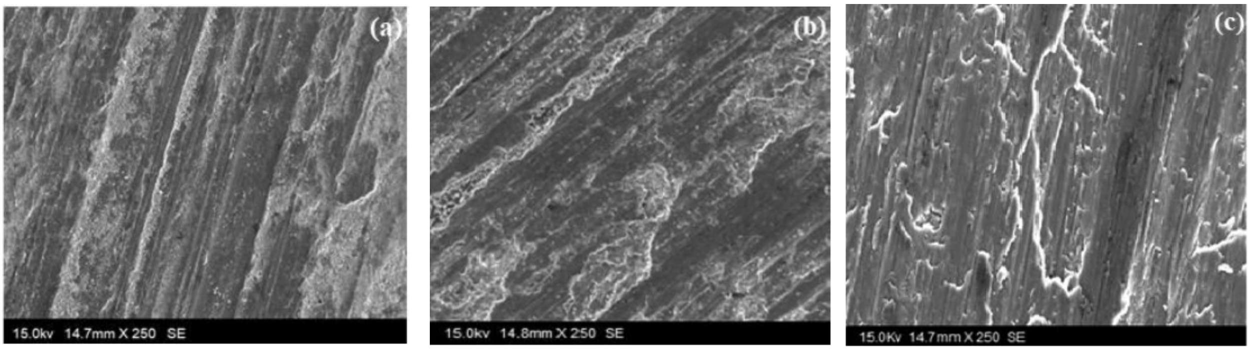


Fig. 4. SEM micrographs of worn surfaces of Al-Cu-10wt.% B_4C (a) stir cast (b)squeeze cast (c) stir cast rolled.

that the rolled composite reinforced up to 10wt.% B_4C for a load of 10N, there is no fracture initiation at matrix particle interface.

4. Conclusion

Effect of stir cast with rolling and squeeze cast in addition of reinforcements on mechanical properties of B_4C in Al-Cu matrix have been investigated in this paper. The test results showed that the B_4C particles up to 10% by weight can be successfully added to Al-Cu alloy by both stir and squeeze casting and hot rolled to 40% reduction without edge crack. The hardness increases with an increase of B_4C particulates. The squeeze cast composites exhibit 16% higher hardness for 10wt.% B_4C composite when compared to corresponding stir cast composites. But the rolling composites exhibit better mechanical properties when compared to squeeze cast composites. The rolled composites manifest higher wear resistance as compared to both vortex and squeeze cast composites Microphotographs of rolled composites shows better bonding between matrix and reinforcement with no fracture observed at matrix particle interface after 40% reduction. Overall, Al-Cu alloy may be considered as a suitable matrix for the development of B_4C reinforced aluminium based composites by secondary process such as rolling.

Acknowledgement

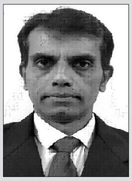
The authors express their sincere thanks to Presidency University, City Engineering College and Sir M. Visvesvaraya Institute of Technology, Bengaluru, for providing facilities to conduct research. In addition, Authors are grateful to NIT, Calicut, for providing laboratory facility for getting SEM photographs.

Reference

1. Baradeswaran, A; Elaya Perumal A: Influence of B_4C on the tribological and mechanical properties of Al 7075–B_4C composites, 'Composites: Part -B', vol. 54, 2013, 146 - 152
2. Gowri Shankar, MC; Manjunath Shettar; Sharma, SS; Achutha, Kini; Jayashree: Enhancement in hardness and influence of artificial aging on stir cast Al6061-B_4C and Al6061-SiC Composites, 'Materials Today: Proceedings', vol. 5, no. 1: Part 3, 2018, 2435 - 2443.
3. Amir Pakdel; Agnieszka Witecka; Gaulthier Rydzek; Dayangku Noorfazidah Awang, Shri; Valeria, Nicolosi: A comprehensive analysis of extrusion behavior, microstructural evolution, and mechanical properties of 6063 Al–B_4C composites produced by semisolid stir casting, 'Materials Science and Engineering: A', vol. 721, no. 4, April 2018, 28 - 37.
4. Liu, Zhang; Zhi, Wang; Qinggang, Li; Junyan Wu; Xin, Zhou: Microtopography and mechanical properties of vacuum hot pressing Al/B_4C composites. Ceramics International', vol. 44, no. 3, 15 February 2018, 3048-3055.
5. Basavarajappa, S; Chandramohan, G; Subramanian, R; Chandrasekar, A: Dry sliding wear behaviour of Al2219/SiC metal matrix, 'Materials Science-Poland', vol. 24, no. 2/1, 2006, 357–366.
6. SM Seyed Reihani: Processing of squeeze cast Al6061–30 vol % SiC composites and their characterization, 'Materials and Design', vol. 27, no. 3, 2006, 216–222.
7. Sahin, Y; Özdin, K: A model for the abrasive wear behaviour of aluminium based composites, 'Materials and Design', vol. 29, 2008, 728–733.
8. Das, S; Mondal, DP; Sawla, S; Ramakrishnan, N: Synergic effect of reinforcement and heat treatment on the two body abrasive wear of an Al–Si alloy under varying loads and abrasive sizes, 'Wear', vol. 264, 2008, 47–59.
9. Ma, T; Yamaura, H; Koss, DA; Voigt, RC: Dry sliding wear behavior of cast SiC-reinforced Al MMCs, 'Materials Science and Engineering A' vol. 360, 2003, 116-125.
10. Sannino, AP; Rack, HJ: Dry sliding wear of discontinuously reinforced aluminum composites:

review and discussion, 'Wear', vol. 189, no. 1/2, 1995, 1–19.

11. Radhika, N; Raghu, R: Development of functionally graded aluminium composites using centrifugal casting and influence of reinforcements on mechanical and wear properties, 'Transactions of Nonferrous Metals Society of China', vol. 26, no. 4, April 2016, 905-916
12. Shipway, PH; Kennedy, AR; Wilkes, AJ: Sliding wear behaviour of aluminium-based metal matrix composites produced by a novel liquid route, 'Wear', vol. 216, no. 2, 1998, 160–171.
13. Korkut, MH: Effect of particulate reinforcement on wear behaviour of aluminium matrix composites, 'Materials Science and Technology', vol. 20, no.1, 2004, 73–81.
14. Venkataraman, B; Sundararajan, G: Correlation between the characteristics of the mechanically mixed layer and wear behaviour of aluminium, Al-7075 alloy and Al-MMCs, 'Wear', vol. 245, no. 1/2, 2000, 22–38.
15. Lim, SC; Gupta, M; Ren, L; Kwok, JKM: Tribological properties of Al-Cu/SiCp metal matrix composites fabricated using the rheocasting technique 'J. of Materials Processing Technology', vol. 89/90, 1999, 591-596.
16. Khodabakhshi, F; Gerlich, AP; Worswick, M: Fabrication and characterization of a high strength ultra-fine grained metal-matrix AA8006-B_4C layered nanocomposite by a novel accumulative fold-forging (AFF) process, 'Materials & Design', vol. 157, 5 Nov 2018, 211-226.
17. Morteza Alizadeh; Mostafa Alizadeh; Rasool amini: Structural and mechanical properties of al/b4c composites fabricated by wet attrition milling and hot extrusion 'Journal of Materials Science & Technology', vol. 29, no. 8, August 2013, 725-730.
18. Shujin Liang, Hongfei Sun, Zuyan Liu, Erde wang: Structural and mechanical properties of Al/B_4C composites fabricated by wet attrition milling and hot extrusion, 'Journal of Alloys and Compounds', vol. 472, 2009, 127-132.
19. Morris, DG; Munoz-Morris, MA; The effectiveness of equal channel angular pressing and rod rolling for refining microstructures and obtaining high strength in a Cu–Fe composite, 'Materials Science and Engg', A 528, 2011, 6293-6302.
20. Smallman, RE; Harris, IR; Duggan, MA: 'Microstructure and materials processing, 'Journal of Materials Processing Technology', vol. 63, 1997, 18-29.
21. Lokesh, GN; Ramachandra, M; Mahendra, KV; Sreenith, T: Characterization of Al-Cu alloy reinforced fly ash metal matrix composites by squeeze casting method, 'International Journal of Engineering Science and Technology, vol. 5, no. 4, 2013,71-79 ◘



Dr. G N lokesh Associate Professor in Mechanical Engineering Dept, Presidency University, Bengaluru. He graduated in Mechanical Engineering from Dayananda Sagar College of Engineering, Bengaluru and M. Tech. in Production Engineering from UBDT College of Engineering, Davangere. He was awarded Ph.D in the year 2017 by Visvesvaraya Technological University, Belgaum. He is having teaching experience of more than 19 years. He is member of BOE/BOS at VTU and he was also worked in Karnataka State Road Transport Corporation and worked on problem solving in fuel injectors at Divisional workshop, Tumkur. He has published more than 30 technical papers in international journals and conferences. His specialization includes CAD/CAM, TQM, Non Traditional Machining, Non Destructive Testing and Hybrid composites for its secondary process. (E-mail: dr.gnlokesh@gmail.com)

S Shivakumar Assistant Professor, Dept of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bengaluru. He graduated in 2001 and obtained his post graduation in 2006, He is persuing his research under the guidance of Dr. G. Balakumar. He has 15 years of teaching experience and published 6 National papers & 2 International papers. His area of interest includes design engineering, mechanics of materials, design of machine elements, control engineering, hydraulics and pneumatics, computer aided engineering drawing, theory of elasticity, theory of plasticity kinematics of machines, robotics, elements of mechanical engineering. (E-mail: hkumar.hiremath@gmail.com)

Dr. S Karunakara presently Professor and Head of the Department of Mechanical Engineering, at City Engineering College, Bengaluru. He has graduated in Mechanical Engineering from Dayananda Sagar College of Engineering, Bangalore and M. Tech from M S Ramaiah Institute of Technology. He was awarded Ph.D in the year 2018 by Visvesvaraya Technological University, Belgaum. He is having more than 18 years of teaching experience. He was an entrepreneur and manufactured components for L&T, and many Foundry companies. He has published more than 10 technical papers in international journals and Conferences and his specialization includes powder metallurgy, material science and thermal properties of metal matrix composites for automobile applications. (E-mail: karunakara.74@gmail.com)