Experimental investigations on property evaluation of Al-alloy reinforced with nano ceramic particulates based metal matrix composites (NMMC's) subjected to forging

S Shivakumar[1*] and G Balakumar[2]

Department of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bangalore

ABSTRACT

This paper involves the Mechanical property Evaluation of Al- Alloy (T6-6061) reinforced with Nano Ceramic Particulates (ZrO_2) subjected to forging process. The standard Aluminum alloy ingots/blocks is melted and superheated in the electrical resistance furnace for about 8 hours at 750^0 C. The superheated melt was reinforced with zirconium dioxide particulates by varying weight percentages in 3, 6 and 9 percent. The molten metal mixture was poured in a metal die of cylindrical shape having dimensions 300mm X 20mm diameter and allowed to solidify at ambient temperature, the sample were subjected to hand forging process. The microstructural characterization of forged composite specimen exhibits more or less uniform distribution of ZrO_2 particulates. The grain structure with spherical morphology of secondary magnesium and silicon phase in the Aluminum matrix whereas the unforged composite sample indicates coarse with dendrite type morphology. The strength results in terms of forged composite specimen reveals significant improvement in the tensile strength over the unforged composite specimen due to refined grain structure. The hardness result also reveals significant improvement in the forged and reinforced samples over the matrix alloy.

Keywords:
Nanocomposite,
Solidification,
Critical Particle Size,
Strengthening,
Grain Refinement

1. Introduction

A Composite is a combination of two or more dissimilar materials having a distinct interface between them such that the properties of the resulting material are greater than the individual constituting components. Composite material is composed of two or more constituent phase i.e.: matrix phase and reinforcement phase. A Metal matrix composite is one of the types of composite in which the matrix phase is predominantly a metal or a metal alloy. The metal is the base material which constitutes the major part and the minor constituents are reinforcements that can be in the form of particles, continuous and discontinuous fibers. The MMC consists of superior properties such as high strength, high stiffness, and high electrical and thermal conductivity, greater resistance to corrosion, oxidation and wear comparable to base material. Aluminium is an ideal material to be selected as a matrix as it consists of desirable properties like abundance, low cost, low density, high strength-to-weight ratio, controlled co-efficient of thermal expansion, increased fatigue resistance and superior dimensional stability at elevated temperatures etc. Metal Matrix Composites (MMCs) are engineered combinations of two or more materials (one of which is a metal) where good properties were achieved by systematic combinations of different constituents. Conventional monolithic materials have limitations in respect to achievable combinations of strength, stiffness and density. Engineered MMCs consisting of continuous or discontinuous fibers, whiskers or particles in a metal achieve combinations of very high specific strength and specific modulus. Furthermore, systematic design and synthesis procedures allow unique combinations of engineering properties in composites like high elevated temperature strength, fatigue strength, damping property, electrical and thermal conductivities, friction coefficient, wear resistance and expansion coefficient.

*Corresponding author,
E-mail: hkumar.hiremath@gmail.com

Recently, nanotechnology has attracted the attention of many material scientists. Nano-metric particulates exhibit many attractive and special properties. Recent investigations find that the incorporation of Nano-particles into the aluminium matrix could enhance the hardness, the yield and ultimate tensile strength considerably, while the ductility is retained. The strength of composites is expected to be influenced by the dislocation density, dislocation-to-dislocation interaction and constraint of plastic flow due to the resistance offered by particles. It is reported that due to the stress, there is a possibility of increased dislocation density within the matrix which leads to local stress and increasing strength of the composite. Most studies so far are mainly concerned with the mechanical properties of the aluminium matrix composites reinforced with micrometric ceramic particulates. The present investigation is focused to fabricate aluminium matrix composite reinforced with varying Wt. % of nano-ZrO_2 particulates choosing die casting technique which remains an attractive choice among all the processing routes. It is also predicted that the aluminium alloys demand increased globally at an average rate of 20% every year. The composites thus obtained were hot extruded and characterized for their micro structural studies and sliding wear properties by varying the sliding speed, applied load and sliding distances. Particular emphasis is placed to study the effect of presence of nano-ZrO_2. It has been shown that enhanced as- cast properties of Al-Si alloys are obtained by treating the melt with Nano-sized particles Introducing ZrO_2 nanoparticles to the cast alloy in the semi-solid state with mechanical stirring has a beneficial effect on improving the strength–ductility relationship in these alloys. This is attributed to the modification of the dendritic columnar structure into a smaller and equated globular grain arrangement.

2. Literature Review

Prantik Mukhopadhyay [1] has carried out intensive investigation on the latest knowledge available from various sources on alloy design, industrial processing, development of properties and potential use of Al 6061 alloys. The strength to weight ratio offered by Al alloy and their enhanced mechanical properties have become crucial criteria for their use in light weight military vehicles, rockers, missiles, aircrafts and cars, used for both defence and civil purpose. The chill cast alloy working like fabrication process and hardening heat treatment are the foci of review through designation section also contains designations of cast alloys to provide the reader a broad overview on designation.

N. Rajesh [2] has investigated on the recent studies in al MMC composites. Aluminium MMC are very promising material featuring for physical and mechanical properties very different from those the metal matrix composites. The Nano particle can enhance the properties of the base material in terms of were resistance ,damping properties and mechanical properties like tensile strength, hardness, wear and fatigue were analysed ZrO_2 Nano particles reinforced al Nano composites can find its applications in automotive components like piston, cylinder liners and connecting rods.

G Venkateshwarlu [3] carried out investigations on evaluation of mechanical properties of Aluminium alloy 6061. The general manufacturing objective during the fabrication of automotive, structural and aerospace components, particularly through flow forming process is to achieve predefined product quality characteristics and mechanical properties with process cost and time constraints. The current state of the economy and the consequent market pressure has forced vehicle manufacturers to simultaneously reduce operating expenses along with further improving product quality. With light weight and high performance characteristics Aluminium alloy acts as an important material in defence and aerospace applications. The Mechanical Properties of Aluminium Alloy 6061 were evaluated and compression test was conducted on the material under annealed condition. Aluminium alloys have attractive properties of high corrosion resistance and excellent machining properties. The micro hardness, microstructure and mechanical properties like hardness, ultimate tensile strength, yield strength, Strength Coefficient (K), Strain hardening coefficient (n) and % reduction at fracture of Aluminium Alloy 6061 were evaluated before the flow forming process, so that these values can be compared after flow forming process. It was observed that Manganese content which controlled the grain structure was slightly high, which results in superior strength. From the microstructure it was revealed that the grain size was uniformly distributed in all the directions.

B. Vijaya Ramnath [4] investigated on Aluminium metal matrix composites. Aluminium matrix composites (AMCs) are potential materials for various applications due to their good physical

Table 1
Chemical composition of aluminum alloy 6061.

Element	Al	Mg	Si	Fe	Cu	Zn	Mn	Cr	Tt	other
Wt %	96.50	0.986	0.562	0.532	0.236	0.202	0.102	0.04	0.15	0.864

and mechanical properties. The addition of reinforcements into the metallic matrix improves the stillness, specific strength, wear, creep and fatigue properties compared to the conventional engineering material. The effect of addition on different reinforcements in aluminium alloy highlighting their merits and demerits, major issues like agglomerating phenomenon, fibre-matrix bonding and the problems related to distribution of particles are discussed in this paper. Effect of different reinforcement on AMCs on the mechanical properties like tensile strength, strain, hardness, wears and fatigue is also discussed in detail.

Akash.M [5] earned out intensive investigations on Aluminium alloy 6061, Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. Aluminium in its purest form is too soft and reactive to be of structural use. However, its alloys such as 6061 alloy, makes it structurally stronger. In the present investigation typical commercial grade A1 6061 alloy obtained from leading professional environments would be the test materials for Investigations. The alloy has been subjected to solution zing treatment at a temperature of 54°C for 2 hours followed by quenching in water. The quenched specimens are subjected to artificial ageing. Micro structural studies were carried out to understand nature of structure. Tensile test, wear test and hardness tests have been conducted on the specimens subjected to heat treatment. It has been observed under identical heat treatment conditions adopted; A1 6061- subjected to heat treatment under specific conditions exhibited a significant improvement in hardness when compared with A1 6061 before heat treatment.

Dhamesh M. Patoliya [6] studied on the Preparation and Characterization of Zirconium Dioxide Reinforced Aluminium Metal Matrix Composites. The study deals with the investigation of effect of reinforcement (Zirconium dioxide) particles on mechanical properties of aluminium alloy composites, fabricated by stir casting method. The MMC's specimens were prepared by varying weight fraction of the reinforced particles as 0 wt.%, 2.5 wt.%, 5 wt.% and 7.5wt.% and keeping all other parameters constant. The microstructure and mechanical properties of fabricated MMC's were analysed. Micro structural studies of the MMC's reveal a uniform distribution of zirconium dioxide (ZrO_2) particles in the matrix. The mechanical properties like hardness, tensile strength and impact strength were improved with the increase in weight fraction of zirconium dioxide particles in the aluminium matrix. It was observed that the elongation decrease with increase weight fraction of zirconium dioxide particles in the aluminium matrix.

Table 2
Chemical composition zirconium dioxide powder.

Element	ZrO_2	SiO_2	TiO_2	Fe_2O_3	other
Wt %	99.5	0.10	0.007	0.002	0.39

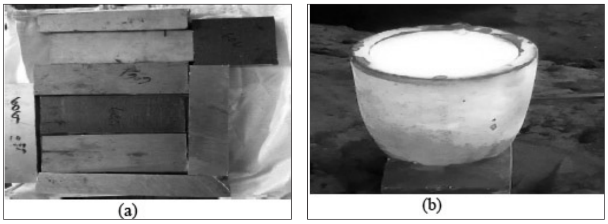


Fig. 1. (a) Aluminum cubes/blocks
(b) Molten metal in graphite crucible.

3. Materials and Experimental Procedure

The matrix material utilized in the experimental study is an aluminium alloy 6061 whose chemical composition are as shown in Table 1.

The reinforced material used in experimental investigation is zirconium dioxide powder whose chemical Composition is listed in Table 2.

4. Methodology and Testing

1. Melting of aluminium alloy cubes (Fig 1a) in graphite crucible (Fig 1b) (using muffle furnace (melting up to 550-650°c for 6-8 hrs).
2. Preheating of reinforcement (ZrO_2) separately in furnace up to 600°C.

3. Mixing of reinforcement to the molten metal using mechanical stirrer using stir casting process. (Fig 2).
4. The Reinforcement treated melt is poured into the molten melt and agitated by using a stirrer for about 5 minutes.
5. Slag was removed from the melt. The reinforcement treated mixture was then poured into a metal die of our desired dimension and allowed to solidify at ambient temperature.

Fig. 2. Stir casting process.

6. The developed composites are subjected to hand forging.
7. Micro structural studies are carried out to reveal the effect of weight percentage additions of Nano ZrO_2 and the effect of chills on the composite. Polished and etched specimens are observed using OLYMPUS Microscope BX51M with Clemex Image Analyser. Morphology test to reveal size and distribution of particulate Zircon is carried out.
8. Testing the specimens to American Foundry men Society (AFS) for ultimate tensile strength (UTS), Compressive strength, percentage elongation and hardness (BHN) are carried out in order to investigate the Zircon additions effect. In order to understand the fracture type and interfacial deformation.

5. Experimental Results

5.1 Microstructure analysis

Microstructure analysis of the developed composite forged specimens are discussed in

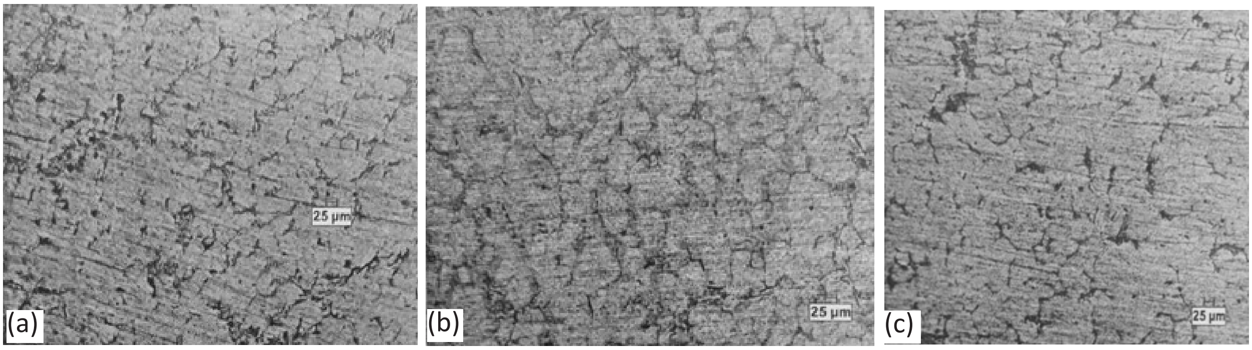


Fig. 3. (a) optical micrograph (100X) of Al 6061, 0wt. % ZrO_2 (b) optical micrograph (100X) of Al 6061, 3wt. % ZrO_2(c) optical micrograph (100X) of Al 6061, 6wt. % ZrO_2.

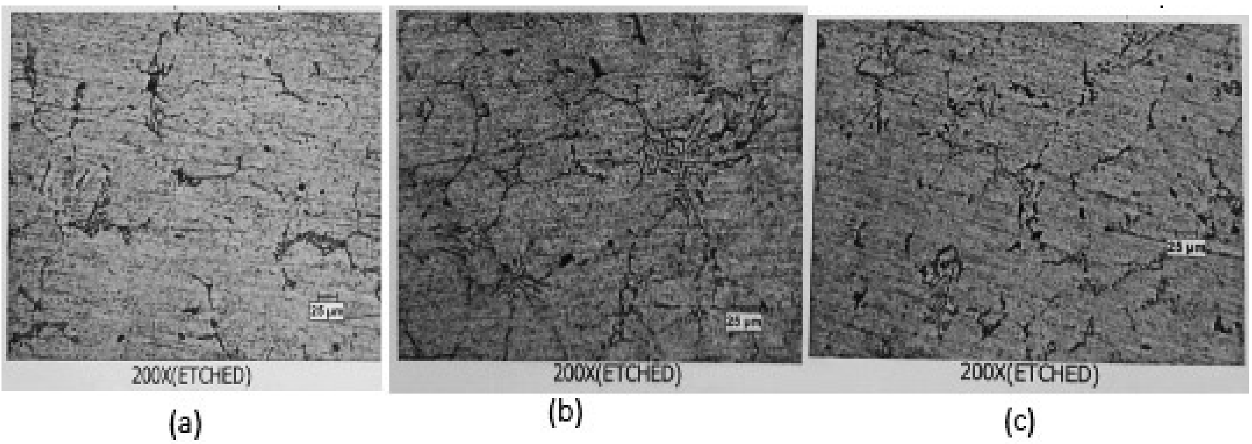


Fig. 4. (a) optical micrograph (200X) of Al 6061, 0wt. % ZrO_2 (b) optical micrograph (200X) of Al 6061, 3wt. % ZrO_2(c) optical micrograph (200X) of Al 6061, 6wt. % ZrO_2.

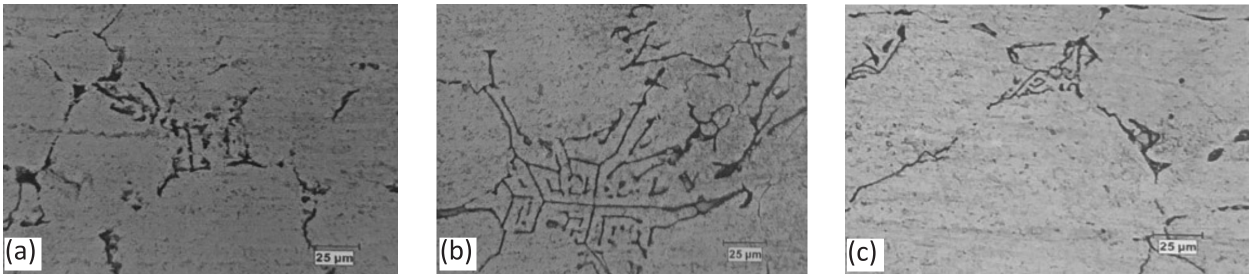
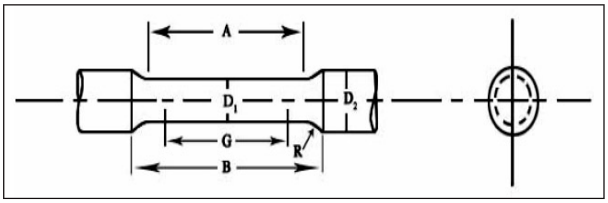
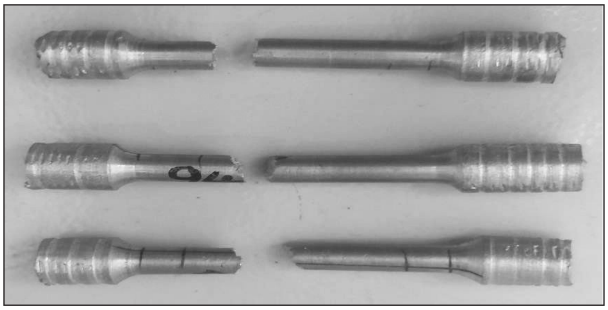


Fig. 5. (a) optical micrograph (500X) of Al 6061, 0wt. % ZrO_2 (b) optical micrograph (500X) of Al 6061, 3wt. % ZrO_2(c) optical micrograph (500X) of Al 6061, 6wt. % ZrO_2.



(a) Standard test specimen (ASTM E8).



(b)Tensile specimens after testing.

Fig. 6. Tensile specimens

Table 3
Tensile property of specimens.

Sample	CS Area (mm^2)	Peak Load (KN)	% Elongation
Al 6061	62.91	7.17	2.4
Al+3wt.% ZrO_2	63.01	7.70	6.4
Al+6wt.% ZrO_2	63.76	8.23	8.5

terms of distribution of reinforcement, grain refinement and grain morphology. They are further compared with microstructure of the base alloy. The microstructures of base alloy and developed composites (0wt. %, 3wt% & 6wt. % ZrO_2 reinforcement additions) with 100X, 200X, and 500X are shown in the Figure 3 (a, b, c), Figure 4 (a, b, c) and Figure 5 (a, b, c) respectively. The size of the secondary phase approximately measured from the micron scale reveal 3 to 25um

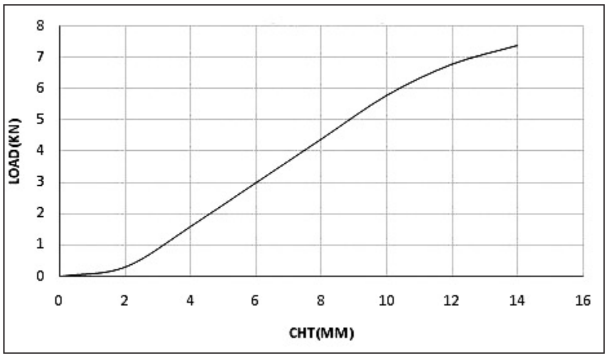


Fig. 7. Load v/s elongation for composite with 3% wt. ZrO_2.

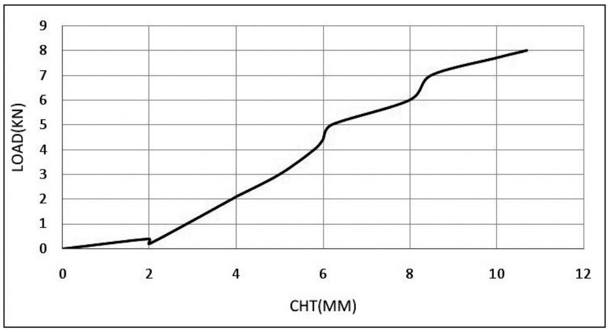


Fig. 8. Load v/s Elongation for composite with 6% wt. ZrO_2.

in the case of developed and forged specimens. The refinement in the grain size is primarily attributed to presence of flake sized reinforcement particulates which acts as multiple nuclei sites during solidification process and also effect of recrystallization process taking place during hot forging process. No porosity is absorbed in the forged sample.

5.2 Tensile test

1. The standard test specimen (Fig 6a) for tensile strength are prepared in accordance with ASTM standards (EM8) with standard dimensions of G- Gauge Length = 45mm, D1- Diameter of gauge = 8.95mm, R- Radius of fillet =8mm, D2- Diameter of initial gauge

length=16mm, A- Length of Radius = 53mm for the developed composited and base alloy. The tensile test is conducted in the standard computer interfaced Universal Testing Machine.

2. The test involved crosshead speed set at 2 mm/min till rupture of the specimen. During the tests, the loading elongation data was recorded by the computer interfaced with the UTM. The specimens for the tensile test are as shown in the Fig.6b.

The results of tensile test conducted at ambient temperature on the developed forged specimens are as shown in the Table 3. The comparative plots of engineering stress-strain diagrams are shown in the Figure 7 and 8. It is observed from the results that the UTS and young's modulus of developed forged specimens exhibits higher strength values in comparison with base material. The percentage increase in strength in developed forged composite (3wt %) exhibit 6.4%. The percentage increase in strength is developed forged composite (6wt %) exhibit 8.5%. The enhancement in the tensile strength is due to the presence of ZrO_2 ceramic particles which acts as obstacles against deformation and increases dislocation density in the material and also due to grain refinement as observed in the microstructure. As the weight percentage of ZrO_2 increases there is significant increase in tensile strength.

6. Conclusion

Synthesis of Aluminium 6061 alloy based composites (MMCs) was successfully accomplished. This technique reveals the following: Microstructural analysis showed fine grain refinement, fairly uniform distribution of reinforcement with no porosity. Mechanical characterization revealed significant improvement in strength. The developed forged specimens reveals significant improvement in the strength properties along enhanced ductility, which can be primarily attributed to refined grain structure achieved through forging process and presence of reinforcement and its increasing weight percentage in the matrix alloy.

Acknowledegment

We gratefully thank the Visvesvaraya Technological University, Jnana Sangama, Belagavi for financial support extended to this research work.

7. References

1. Pratik Mukhopadhyay: Alloy Designation, processing, and use of AA6XXX Series Aluminium Alloys, February 2012.
2. Rajesh, N and Dr. Yohan, M: Recent Studies in aluminum metal Matrix Nano Composites (AMMNCS) - Review, vol. 7, no. 6, November-December 2016, 618-623.
3. Venkateshwarlu, G; Prasad, AMK and Ramesh Kumar, K: Evaluation of Mechanical Properties of Aluminum Alloy AA6061, 'International Journal of Current Engineering and Technology' February 2014, 295-297.
4. Vijay Ramanth, B; C Elanchezhian; Annamalai, RM; Aravind, S; Sri Ananda Atreya, T; Vignesh, V and Subramanian, C: Aluminum Metal Matrix Composites-A Review, 'Rev. Adv. Mater. Sci'., vol. 38, 2014, 55-60.
5. Akash, M; Mani, N; Prajwal, S; Prasanna Kumar, H; Shivakumar, P; Microstructural Charecterization and Mechanical Properteis of Al 6061 subjected to heat treatment Under T6 Conditions, ' International Research Journal of Engineering and Technology (IRJET)', vol. 3, no. 5, May 2016, 3169-3172.
6. Dharmesh M Patoliya; Sunil Sharma; Preparation and Charecterization of Zirconium Dioxide reinforced with Aluminum Metal Matrix Composites, 'International Journal of Innovative Research in Science, Engineering and Technology', vol. 4, no. 5, May 2015, 3315-3321.
7. Rajput, V; Gautam, RK; Tyagi, R: Tribological Behaviour of Al Based Self Lubricating Composites, 'Proceedings of Malaysian Intl. Tribology Conference, Nov 2015, 108-110.
8. Ray, N and Karketta, DK: Some studies on Aluminium Matrix In-Situ Composites produced by stir casting method, 'Material Science', 2010.
9. Alavudeen, A; Venkateshwaran, N; Winowlin Jappes, JT: A Textbook of Engineering Materials and Metallurgy, Laxmi Publication, New Delhi, 2006.
10. Park, BG; Crosky, AG; Hellier, AK: Composites: Part B: Engineering, vol. 39 (7-8), Oct - Dec 2008, 1270-1279.
11. Anderson PRG; ARA McLelland and Ward, PJ: Thixofrming of Aluminum- based Metal Matrix Composite system, SAE 940812 Technical Paper.

12. Sherman, Andrew M and Phillip S Sklad: Collaborative Development of Light Weight Metal and Alloys for Automotive Applications", SAE Transactions, vol. 111, 2002, 744 - 749.
13. Archard, FJ: Contact and rubbing of flat surfaces, 'J. Appl. Physics, vol. 24, 981-988, 1953.
14. Alpas, AT; Zhang, J: Effect of microstructure (particulate size and volume fraction) and counterface material on the sliding wear resistance of particulate - reinforced aluminum matrix composites: 'Metallurgical and Materials Transaction A, May 1994, vol.25 (5), 969-983.
15. Zhang, J and Alpas, AT: Wear Regimes and transition in Al203 particulate-reinforced aluminum alloys, 'Materials Science and Engineering: A', vol. 161, no. 2, April 1993, Pages 273-284.
16. Asthana, R; Tewari, SN: The engulfment of foreign particles by a freezing interface, 'Journal of Materials Science', October 1993, vol. 28, no. 20, 5414–5425 ◘

S Shivakumar is presently working as Assistant Professor in the Department of Mechanical Engineering at Sir M. Visvesvaraya Institute of Technology, Bengaluru. He graduated in the year 2001 and obtained post-graduation in the year 2006, he is currently pursuing his research under the guidance of Dr. G. Balakumar. He has 15 year of industrial experience and 15 years of teaching experience, he has successfully published 6 National and 2 International papers. His area of research interest is Design Engineering. He was also guided by Mr. Armugaswamy, the former Joint Director, CMTI, Bengaluru during his M. Tech project.

Dr. G Balakumar is working as Associate Professor in the Department of Mechanical Engineering at Sir M Visvesvaraya Institute of Technology, Hunasamaranahalli, Bengluru North-562157. Having 19 years of teaching experience till date and obtained PhD in the field of Nano-Metal matrix composites from Jawaharlal Nehru Technological University, Andra Pradesh in 2015. Published Fifteen research paper in International Journals & five National Journals. Presently guiding five research scholars registered under Visvesvaraya Technological University Belagavi.
(E-mail: drgbalakumar_mech@sirmvit.edu)