Journal of Materials Science & Surface Engineering Vol. 4 (7), 2016, pp 483-487

Contents lists available at http://www.jmsse.org/

Journal of Materials Science & Surface Engineering

Enhanced Mechanical Properties of Al-6061 Metal Matrix Composites Reinforced with α-Al_2O_3 Nanoceramics

R.S. Raveendra[1], P.V. Krupakara[2], P.A. Prashanth[1*], B.M. Nagabhushana[3]

[1]*Research Center, Department of Chemistry Sai Vidya Institute of Technology, Bengaluru-560 064, India.*
[2]*Department of Chemistry, Adarsha Institute of Technology, Bengaluru-560 064, India.*
[3]*Department of Chemistry, M.S. Ramaiah Institute of Technology, Bengaluru-560 054, India.*

Article history

Received: 18-Oct-2016
Revised: 15-Nov-2016
Available online: 02-Dec-2016

Keywords:
α-Al_2O_3,
Al- 6061,
MMCs,
vortex,
Powder x-ray diffraction

Abstract

In the current article solution combustion synthesis method was used to prepare α-Al_2O_3 nanoceramics. Powder x-ray diffraction (PXRD) studies were done to study the phase formation and calculate crystallite size of α-Al_2O_3 nanoceramics. Transmission electron microscopy (TEM) was used to study the particle size of the nanopowder. The metal matrix composites (MMCs) were manufactured by liquid metallurgy technique using vortex method. Aluminium-6061 (Al-6061) alloy was used as matrix which is reinforced with 2, 4 and 6 weight percentage of α-Al_2O_3 nanoceramic powder. Scanning electron microscopy (SEM) analysis was used to study the distribution and homogeneity of the α-Al_2O_3 particles in the Al-6061 matrix. Results show that addition of α-Al_2O_3 nanoceramic powder as reinforcement has a drastic effect on the mechanical properties like hardness, compression strength and ultimate tensile strength (UTS) of the MMCs when compared with that of Al-6061 matrix. Further, the increased % age of α- Al_2O_3 nanoceramic powder contributed in increased hardness, compression strength and ultimate tensile strength the MMCs.

Introduction

In the current days aluminum alloys are preferred engineering material for automobile, aerospace and mineral processing industries for various high performing components that are being used for varieties of applications due to their excellent thermal conductivity properties. Among several series of aluminum alloys heat treatable Al-6061 and Al-7075 are much explored, among them Al-6061 alloy are highly corrosion resistant and are of excellent extricable in nature and exhibits moderate strength and finds much more applications in the fields of construction, automotive and marine applications. The MMCs formed out of aluminum alloys are of wide concern due to their high strength, fracture hardiness, wear resistance and stiffness. Further these MMCs are of superior in nature for elevated temperature application when reinforced with ceramic particle [1]. The use of Al-6061 MMCs has been limited in very specific applications such as aerospace and military weapon due to high processing cost. In the recent days, Al matrix composites have been used for the production of automotive parts such as engine piston, cylinder liner, brake disc/drum etc. [2]. Manufacturing techniques for Al-MMCs can be classified into three types such as (a) liquid state processing, (b) semisolid processing and (c) powder metallurgy [3, 4]. Particulate reinforced Al-MMCs can be processed more simply by the liquid state i.e. melt-stirring method. Melt stir casting is an attractive processing method since it is comparatively cheaper and offers a broad selection of materials and processing conditions. . Interest in MMCs for use in the aerospace and automotive industries, and other structural applications has increased over the past 20 years as a result of the availability of reasonably low-cost reinforcements and the development of various processing routes which result in reproducible microstructure and properties [5, 6]. It is anticipated that the strength of aluminum reinforced by ceramic nanoparticles would be improved significantly, while the ductility of the aluminum matrix is retained. At present, there are several production methods of MMCs, including in situ technique [7-9]. The case of escalation in particle reinforced metal matrix MMCs has been extensively researched in the long-ago; however no consent has been reached about its origin. Many dislocation models which were developed for dispersion or precipitation toughened alloys have been tailored and others particularly designed to account for strengthening in this class of materials [10, 11].

MMCs reinforced with nanoceramic particles, whiskers have received increasing attention due to their potentially high fracture hardness and strength [12-16]. Particle reinforced Al-MMCs find potential applications in several thermal environments, especially in the automobile engine parts such as drive shafts, cylinders, pistons and brake rotors and in space applications [17]. With the exemption of noble metals, no metal and alloy is stable in air at room temperature which tends to form oxides. The majority of the metals in the solid or liquid state are morphologically unstable in air at any temperature. A research relating to the temperature profiles of the piston area in a diesel engine has revealed that the temperature can reach as high as 200-600 ºC in certain regions of the piston [18]. As the piston and cylinder areas are exposed to high temperature environment, the MMCs used here should have sufficient stability as well as good mechanical and chemical strength (oxidation).

Corresponding author. Tel. (080) 28468196
E-mail address: prsnthmysore@gmail.com

Objective of this work is to prepare the MMCs of Al-6061 reinforced with α-Al_2O_3 nanoceramics powder and study of its mechanical behaviour.

Experimental

All the chemicals and reagents used in this study were of analytical grade. Commercially pure aluminium nitrate ($Al(NO_3)_3$ 9.H_2O, 99% Merck), urea ($CO(NH_2)_2$ 99% Merck) were used. Al-6061 alloy which is available commercially and exhibits excellent casting properties and reasonable strength, was used as base alloy. This alloy is best suited for mass production of lightweight metal casting. The chemical composition of Al- 6061matrix is given in table 1.

Table 1: The chemical composition of Al- 6061

Mg	Si	Fe	CU	Ti	Pb	Zn	Mn	Sn	Ni	Al
0.8-1.5	10-12	1	0.7-1.5	0.2	0.1	0.5	0.5	0.1	1.5	Bal

The reinforcement selected is α-Al_2O_3 nanoceramic particles prepared synthetically in the lab.

Synthesis of α-Al_2O_3 nanoceramics

α-Al_2O_3 nanoceramic powder was prepared by solution combustion method [19-22]. Aluminium nitrate and urea was used as oxidizer and fuel respectively, precursor mixture was stirred well for about 20 min with distilled water, then it was introduced into the preheated muffle furnace at 500 ˚C (±10 ˚C). Entire mixture catches fire, burned and transformed into a white crystalline powder in very short period of 5 min. The overall reaction can be written as,

$$2Al(NO_3)_3 + 3CO(NH_2)_2 \rightarrow Al_2O_3 + 6H_2O + 6N_2 + 3CO_2 \qquad (1)$$

Characterizations of α-Al_2O_3 nanoceramics and MMCs

Powder X- ray diffraction patterns was recorded on a Shimadzu XRD-700 X-ray Diffractometer with CuKα radiation with diffraction angle range 2θ = 20º to 80º operating at 40 kV and 30 mA. HR-TEM analysis was performed on a Hitachi H-8100 (accelerating voltage up to 200 KV, LaB6 Filament). SEM performed on a ZEISS ULTRA 55 scanning electron microscope.

MMCs preparation

The liquid metallurgy route using vortex technique is employed to prepare the MMCs. A mechanical stirrer was used to create the vortex. The reinforcement material used was α-Al_2O_3 nanoceramic powder. The weight percentage of nanoceramic powder used was 2, 4 and 6 weight percentages in steps of 2%. Addition of nanoceramic into the molten Al-6061 matrix melt was carried out by creating a vortex in the melt using a mechanical stainless steel stirrer coated with alumina (to prevent migration of ferrous ions from the stirrer material to the Al alloy). The stirrer was rotated at a speed of 450 rpm in order to create the necessary vortex. The α-Al_2O_3 nanoceramic powder was pre heated to 450 ºC and added in to the vortex of liquid melt at a rate of 120 g/min. The MMCs melt was thoroughly stirred and subsequently degasified by the addition of degassifier. Castings were produced in permanent moulds in the form of cylindrical rods. (Diameter 30 mm and length 150 mm). The castings of MMCs were subjected to machining in CNC lathe to get the specimens for mechanical properties. The matrix alloy was also casted under identical conditions and machined for comparison.

Specimen preparation

The test specimens were prepared by machining from the cylindrical bar castings. The samples for tensile test, each specimen having 10 mm dia x 50 mm gauge length in size, specimen for compression strength and hardness 20 mm length x 20 mm dia were machined according to BS: 18: 1962 test standards [23].

Characterization of MMCs

SEM micrographs for all the MMCs products were performed on a ZEISS ULTRA 55 scanning electron microscope.

Results and Discussion

PXRD studies α-Al_2O_3

The formation of nanocrystalline phase of the combustion derived α-Al_2O_3 was confirmed by PXRD measurements. The PXRD of α-Al_2O_3 powder show the crystalline nature having rhombohedral structure (matched with ICDD card number 46-1212 with space group R-3c (No-167)), and cell parameters a = 4.7587 Å, b = 4.7587 Å, c = 12.9929 Å. All the diffraction peaks can be indexed to (0 1 2), (1 0 4), (1 1 0), (0 0 6) (1 1 3), (2 0 2), (0 2 4), (1 1 6), (2 1 1), (1 2 2), (0 1 8), (2 1 4), (3 0 0), (1 2 5) and (2 0 8) reflections. The broadening of the reflections clearly indicates the inherent nature of nanocrystals. Figure 1 shows the powder X-ray diffraction patterns of α-Al_2O_3 nanoceramics. The crystallite size is calculated from the full width at half maximum (FWHM (β)) of the diffraction peaks using Debye- Scherer's method [24] using the following equation,

$$d = \frac{k\lambda}{\beta \cos\theta} \qquad (2)$$

Where 'd' is the average crystalline size, 'λ' is the X-ray wavelength, 'k' is Scherer's constant (0.92), 'β' is the full width at half maximum (FWHM) intensity of a Bragg reflection excluding instrumental broadening and 'θ' is the Bragg's angle. The calculated average crystallite size of the product is found in the range of 20-25 nm.

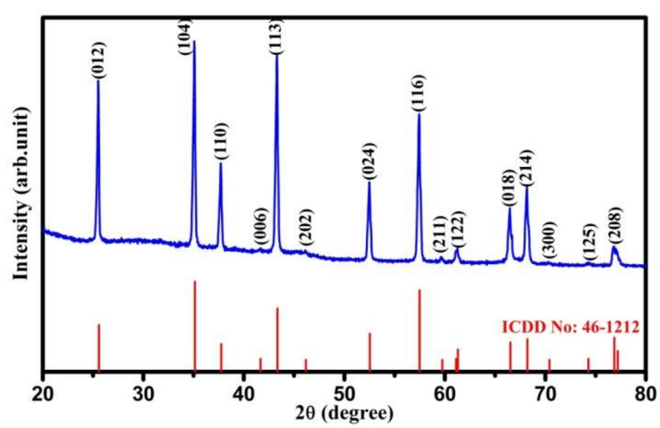

Figure 1: PXRD patterns of α-Al_2O_3 nanoceramics

Morphological analysis

Figure 2(a-b) shows SEM micrographs of α-Al_2O_3 nanoceramic powder. It revealed that the morphology of the nanoceramic was a nonspherical shape i.e. flakes like and has uniform size and distribution [22]. The proof for the crystallinity of the nanoceramic was obtained by TEM investigations. TEM micrographs of α-Al_2O_3 nanoceramic (Figure 3(a-b)) shows that the particles obtained are in nano range and have highly crystalline and average particle size ~ 20 nm.

Figures 4(a-d) shows the SEM micrographs of Al-6061 matrix and MMCs with reinforcement of α-Al_2O_3 ranging from 2 to 6 weight percentage respectively. From the micrographs it is clearly observed that the reinforcement of α-Al_2O_3 have been distributed uniformly throughout the matrix. Further also found that there are many big size cracks, grooves and voids present on the surfaces of MMCs. It may be due to the trapping of air bubbles during casting of sample.

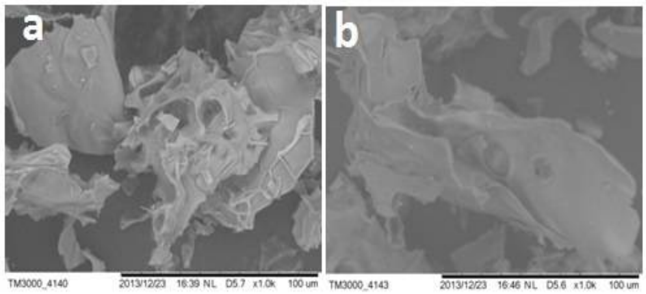

Figure 2: (a-b): SEM micrographs of α-Al_2O_3 nanoceramics

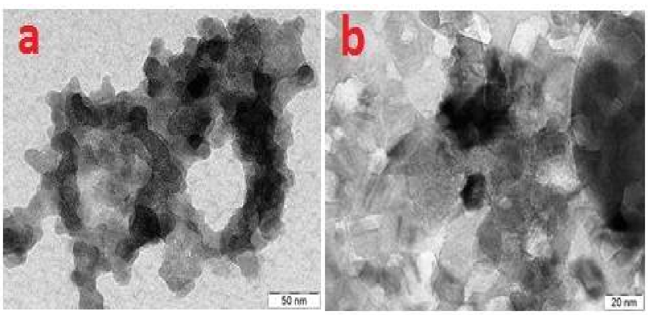

Figure 3: (a-b): TEM micrographs of α-Al_2O_3 nanoceramics at different magnifications

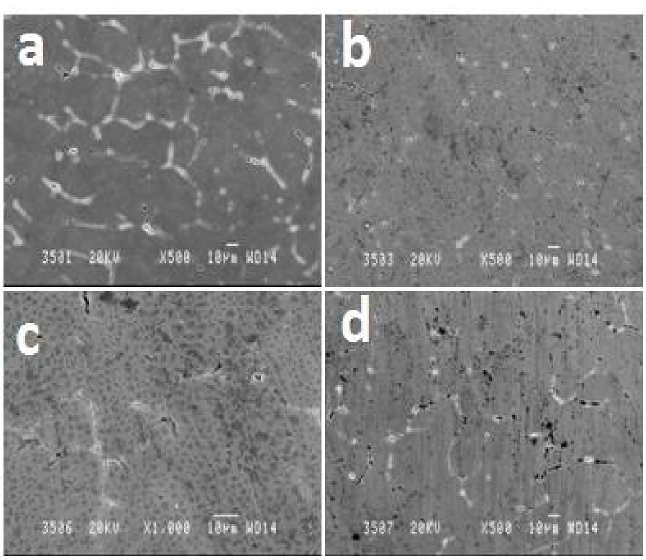

Figure 4: a) SEM micrograph of matrix, b) SEM micrograph of 2% MMCs, c) SEM micrograph of 4% MMCs and d) SEM micrograph of 6% MMCs)

Mechanical properties

Tensile tests were conducted at room temperature using 1175 model Instron universal testing machine at a cross load speed of 0.5 mm per minute. Hardness tests were conducted in accordance with ASTM E-10 using a Brinell Hardness Tester with a ball indenter of 5 mm diameter and 500 kg load. Compression property was measured using an 1175 V model of Instron UTM at a crushed speed of 0.2 mm/minute.

Ultimate tensile strength

Figure 5: (a) specimen of compression strength and hardness test, (b) specimen of ultimate tensile strength tests

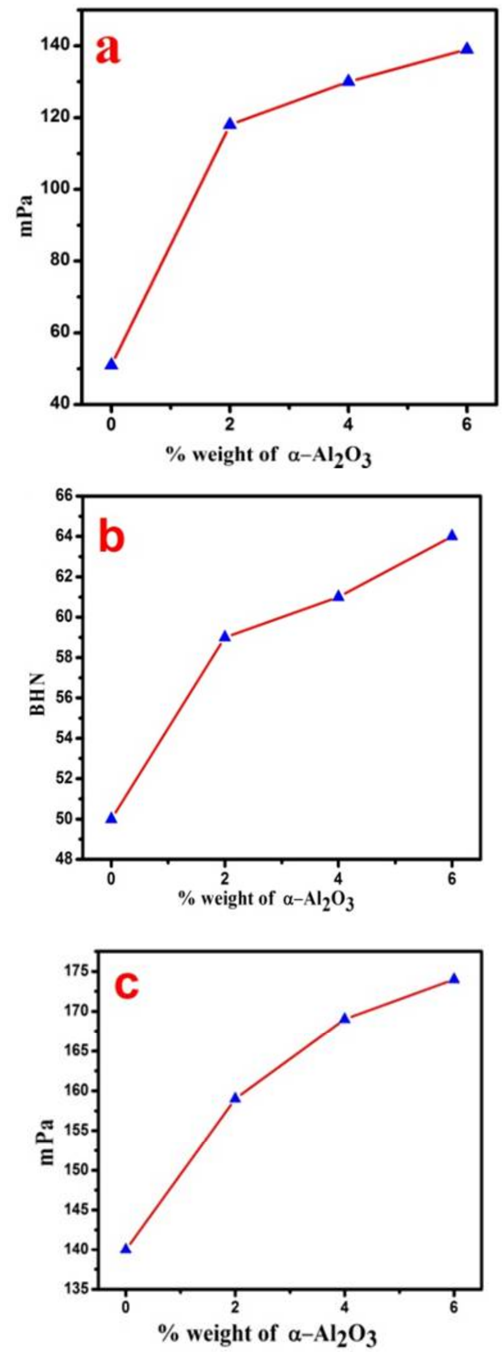

Figure 6: (a) Plot of ultimate tensile strength, (b) Plot of hardness, (c) Plot of compression strength

Figure 6a shows the variation of ultimate tensile strength with respect to reinforcement of α-Al_2O_3 nanoceramic**s.** Specimen for ultimate tensile strength tests used is shown in the figure 5(b). It explains that the UTS of the MMCs material is more as compared to the Al-6061 matrix. Without the reinforcement the UTS of the matrix was only 51mPa, when the 2 weight percentage of reinforcement was added the UTS of the MMCs has been raised to 118 mPa. UTS was increases 139 mPa when the amount of reinforcement is 6 weight percentage. It may be due to the fact that Al_2O_3 nanoceramic reinforcement exhibits a good bonding with Al-6061 alloy and also with each other which helps in withstanding more load as compared to Al-6061 matrix alone [25].

Hardness

The variation of Brinell hardness values of MMCs of Al-6061 is plotted in Fig. 6b. Six specimens for each MMCs and matrix have been tested and average was calculated. The specimen used for hardness test is shown in the figure 5(a). For each MMCs material hardness increases with increase in weight percentage of α-Al_2O_3 nanoceramic powder in the Al-6061 matrix. It can also be seen from the figure that the hardness of matrix without the reinforcement was only 50 BHN. This rises to 64 BHN when the quantity of reinforcement was 6 weight percentage. The increase in hardness is probably attributed to the fact that the hard nanoceramic powder act as barriers to the movement of the dislocations within the matrix [26, 27]. Resistance to the indentation carried out by means of Brinell hardness test against an increase of α-Al_2O_3 nanoceramic content shows a substantial improvement for a larger percentage of reinforcement addition. Since the resistance to indentation is a measure of the ability of the material to bear static loads, abrasion, surface deformation etc. It is clear with a hardness number in a higher plane as a mark of improvement in material property to this criterion.

Compression strength

Figure 6c shows the variation of the compression tests with respect increase in the percentage of α-Al_2O_3 nanoceramics content in the aluminium matrix. Specimen used for compression strength test is shown in the figure 5(a). A close study of the plot indicates that the compression strength increases with the addition of α-Al_2O_3 nanoceramics in the matrix. Compression strength increases from 140 to 174 mPa when the weight percentage of reinforcement increases from 0 to 6. The increase in compression strength of MMCs can be attributed to decrease in inter particle spacing between α-Al_2O_3 nanoceramics**,** since nanoceramics is much harder than the matrix. The hard ceramic particles resist deformation stress whilst increasing composite strength of the composite [28].

Conclusions

The important conclusion of the studies on mechanical properties of Al-6061α-Al_2O_3 nanoceramics reinforced Al-6061 MMCs is as follows.

Solution combustion synthesis method was used to prepare α-Al_2O_3 nanoceramic powder. All the PXRD peaks are well matched with ICDD card number 46-1212. The results of PXRD also show that nanoceramic powder is in well crystalline nature. Liquid metallurgy route using vortex technique is employed to prepare Al-6061 MMCs material. The morphological studies revealed the uniform distribution of the ceramic particles in the matrix. Hardness of the MMCs found increased with increase in weight percentage of α-Al_2O_3 nanoceramics. The ultimate tensile strength of the MMCs are found higher than that of base matrix and the compression strength also increases with increase in α-Al_2O_3 nanoceramics. From the studies in overall it can be concluded that Al-6061 MMCs exhibits superior mechanical properties.

Acknowledgments

Authors R.S. Raveendra and P.A. Prashanth thank the Principal and Management of Sai Vidya Institute of Technology for the continuous support of research work, P.V. Krupakara thanks the Principal and Management of Adarsha Institute of Technology for the encouragement towards the publication of this article.

References

1. G. B. Veeresh Kumar, C. S. P. Rao, N. Selvaraj, M. S. Bhagyashekar, Studies on Al-6061-SiC and Al7075-Al_2O_3, Metal Matrix Composites, J. Minerals Mater Charact. Engg. 9 (2010) .43-55.
2. K.M. Shorowordia, T. Laoui, A.S.M.A. Haseeb, J.P. Celis, L. Froyen, Microstructure and interface characteristics of B4C, SiC and Al_2O_3 reinforced Al matrix composites s: a comparative study, J. Mater Process. Technol. 142 (2003) 738–743.
3. M.J. Kozack, S.C. Khatri, J.E. Alison, M.G. Baber, in: S. Suresh. (Eds.), Fundamentals of composites, Butterworth-Heinemann, Boston, MA, 1993, pp. 297–326.
4. T.S. Srivatsan, I.A. Ibrahim, F.A. Mohamed, E.J. Lavernia, Processing techniques for particulate-reinforced aluminium metal matrix composites, J. Mater. Sci. 26 (1991) 5965–5978.
5. S.C. Tjong, Z.Y. Ma, Microstructural and mechanical characteristics of in situ metal matrix composites, Mater. Sci. Engg: R. 29 (2000) 49-113.
6. T.W. Chow, A. Kelly, A. Okura, Fibre-reinforced metal-matrix composites, composites. 16 (1986) 187-206.
7. J.P. Tu, N.Y. Wang, Y.Z. Yang, W.X. Qi, F. Liu, X.B. Zhang, Preparation and properties of TiB_2 nanoparticle, reinforced copper matrix composites by in situ processing. Mater. Lett. 52 (2002) 448–452.
8. Y.T. Zhao, S.L. Zhang, G. Chen, X.N. Cheng, C.Q. Wang, in situ (Al_2O_3+Al_3Zr) np/Al nanocomposites synthesized by magneto-chemical melt reaction, Compos. Sci Technol. 68 (2008) 1463–1470.
9. A. Mazahery, M. Ostadshabani, Investigation on mechanical properties of nano-Al_2O_3-reinforced aluminum matrix composites, J. Compos. Mater. 45 (2011) 2579–2586.
10. R.J. Arsenault, N. Shi, Dislocation generation due to differences between the coefficients of thermal expansion, Mater. Sci. Eng. 81 (1986) 175-181.
11. M. Kouzeli A. Mortensen, Size dependent strengthening in particle reinforced aluminium, Acta Mater. 50 (2002) 39–51.
12. S. Elomari, R. Boukhili, M.D. Skibo, Dynamic mechanical analysis of prestrained Al_2O_3/Al metal-matrix composites, J. Mater. Sci. 30 (1995) 3037-3044.
13. J.N. Fridlymander, The textbook of metal matrix composites, Chapman and Hall, Oxford, 1995, p. 15.
14. H. Jones, C.A. Lavender, M.T. Smith, Yield strength-fracture toughness relationships in metal matrix composites, Scripta Metall. 21 (1987) 1565-1570.
15. B.M. Girish, R. Kamath, B.M. Satish, Fractography, Fluidity, and Tensile Properties of Aluminum/Hematite Particulate composites. J. Mater. Eng. Perform. 8 (1999) 309-314.
16. E.A Feest, Metal matrix composites for industrial application, Mater. Des. 7 (1986) 58-64.
17. J. E. Allison, G.S. Cole, Metal-matrix composites in the automotive industry: Opportunities and challenges J. Metals. 45 (1993) 19-24.
18. R.R Bowles, D.L. Macini, M.W. Toaz, Advanced composites - The Latest Developments in: Peter Beardmore, Carl F. Johnson, Advanced composites, ASTM International, Michigan, 1990, pp.21.
19. T. Mimani, K.C. Patil, solution combustion synthesis of nanoscale oxides and their MMCs, mater. Phys. Mech. 4 (2001) 134-137.
20. R. S. Raveendra, P. A. Prashanth, R. Hari Krishna, N. P. Bhagya, B. M. Nagabhushana, H. Raja Naika, K. Lingaraju, H. Nagabhushana, B. Daruka Prasad, Synthesis, structural characterization of nano $ZnTiO_3$ ceramic: An effective azo dye adsorbent and antibacterial agent, J. Asian Ceram. Soc. 2 (2014) 357–365.
21. P. A. Prashanth, R. S. Raveendra, R. H. Krishna, N. P. Bhagya, S. Ananda, B. M. Nagabhushana, K. Lingaraju, H. R. Naika,

Synthesis, characterizations, antibacterial and photoluminescence studies of solution combustion-derived α-Al_2O_3 nanoceramic, J. Asian Ceram. Soc. 3 (2015) 345-351.

22. R. S. Raveendra, P. A. Prashanth, B. M. Nagabhushana, Study on the effect of fuels on phase formation and morphology of combustion derived α-Al_2O_3 and NiO nanomaterials, Adv. Mater. Lett. 7 (2016) 216-220.
23. Vinitha, B. S. Motgi, Evaluation of Mechanical Properties of Al 7075 Alloy, Flyash, SiC and Red mud Reinforced Metal Matrix composites, Inter. J. Sci. Research. Develop. 2 (2014) 190-193.
24. P. Klug, L.E, Alexander, X-ray Diffraction Procedure. Wiley, New York 1954.
25. S. Bansal, J. S. Saini, Mechanical and Wear Properties of SiC/Graphite Reinforced Al359 Alloy-based Metal Matrix Composite, Def. Sci. J. 65 (2015) 330-338.
26. S. E. Vannan, S. P. Vizhian, Microstructure and Mechanical Properties of as Cast Aluminium Alloy 7075/Basalt Dispersed Metal Matrix Composites, J. Minerals Mater Charact. Engg. 2 (2014) 182-193.
27. H.X. Zhu, S.K. Liu, Mechanical Properties of Squeeze Cast Zinc Alloy Matrix Composites Containing α- Alumina Fibers, Composites. 24 (1993) 437- 442.
28. K. P. Gowda, J. N. Prakash, S. Gowda, B. S. Babu, Effect of Particulate Reinforcement on the Mechanical Properties of Al2024-WC MMCs, J. Minerals Mater Charact. Engg.3 (2015) 469-476.