Study on Mechanical Behaviour of AA2014 Aluminium Alloy Blended with Cobalt (Co) and Iron Oxide (Fe_2O_3)

T Anand[1*], *K* Ragupathy[2], *M.*Arun [3] and *G* Prabaharan[4]

[1*,2,3]Agni College of Technology,Thalambur, Chennai – 600 130, India
[4]S.A.Engineering College, Poonamalle - Avadi Road, Chennai – 600 077, India

Abstract. In order to increase system efficiency, lightweight materials are crucial in the automotive and aerospace sectors. In this work, iron oxide (Fe_2O_3) and cobalt (Co) were used as reinforcements, with aluminium alloy AA2014 serving as the matrix material. The metal matrix composites were made using the stir casting technique. The proportions of iron oxide and cobalt utilised as reinforcement in the composites were 2.5 wt % and 5 wt %, respectively. On the composite specimen created in accordance with ASTM E8, E9, and E23 standards, the mechanical properties of tensile, flexural, and impact strength were investigated. Investigations were also done on the hardness of the composites. The morphology of the composites was examined using an optical microscope.

1 Introduction

Since composite materials contain a number of distinctive properties not present in typical ordinary materials, they are desirable in many industrial applications. The volume-to-weight ratio is one such important characteristic that the automotive, aerospace, and other industries find particularly attractive [1].

Researchers are drawn to aluminium metal matrix composites because of their low weight and great strength, which reduces the amount of material and energy needed. Some important elements to take into account include the size of the reinforcement particles and their properties. These days, reinforcements made of bio-ceramics are also employed. The mechanical and tribological properties of aluminium alloy composites reinforced with bio-ceramics were examined by V. Bhuvaneswari et al. The mechanical and tribological properties of seashell powder reinforced with AA2219 alloy were improved by 3 wt% [2].

According to studies, stir casting is mostly utilised to create Al-based MMC. Utilizing a two-stage stir casting procedure, Cast A 356 alloy reinforced with 4 weight percent graphite (Gr) and 12 weight percent boron carbide (B4C) was created. The hardness and

* Corresponding author: anand.tvel@gmail.com

tensile characteristics were improved by the homogeneous distribution of B4C and Gr; however the density was lowered upon adding the reinforcement [3]. The mechanical characteristics and microstructure of the stir-cast and campo-cast A356 aluminium alloy/Al2O3 composites were compared by Seyed Abdolkarim Saiiadi et al [4].

With the examination of the structure and attributes of fine fly ash particle reinforced Al-7Si-0.35Mg alloy composites, the impact of three distinct stir casting processes is assessed. Evaluations of liquid metal stir casting, modified compo casting, compo casting (semi solid processing), and modified compo casting followed by squeeze casting techniques were among them, the latter produced composites with well-dispersed fly ash particles that were largely agglomeration and porosity free. Liquid metal stir cast composites exhibit greater interfacial interactions between the fly ash particle and matrix that result in the development of Mg Al_2O_4 spinel and iron intermetallics than compo cast composites [5].

The three main drawbacks of stir casting include porosities in composites during fabrication, the wettability of ceramic particles with molten metals, and poor distribution of the reinforcing particles known as agglomerations in the metal matrix. The main goal of many studies is to improve the parameters of stir casting for Ceramic-Metals Matrix Composites (CMMCs). The factors influencing the uniform dispersion of reinforcements, porosities in composites during the manufacturing process, and the mechanical characteristics of the ceramic metal matrix composites were thoroughly examined when talking about the stir casting procedure.[6,7].

Since the matrix and reinforcing components are in varying phases, achieving homogeneous metal matrix composites poses challenges. Although there has been a significant increase in interest in the topic, the title "Particulate Metal Matrix Composites" does not adequately describe all of its diverse aspects. In this study, the mechanical characteristics of metal matrix composites made of aluminium alloy are examined. Iron oxide and cobalt were used as reinforcements, and AA 2014 aluminium alloy was used as the matrix.

2 Materials and Experimentation

2.1 Material

The matrix material chosen was AA 2014 aluminium alloy, which is primarily employed in the construction of truck frames and aircraft constructions. The material was purchased in an ingot form. The AA 2014 alloy has a density, poisson's ratio, and melting point of 2.82 g/cm^3, 0.33, and 515^0 C. Table 1 lists the chemical composition of the AA 2014 alloy used in this investigation. The reinforcements employed were iron oxide (Fe_2O_3), a reddish-brown solid powder with a density of 5.23 g/cm^3, and cobalt (Co), a ferromagnetic, silver-white lustrous element with a density of 8.9 g/cm^3 and a poisson's ratio of 0.31. Cobalt has the ability to withstand wear and corrosion.

Table 1. Chemical composition of AA2014 Aluminium alloy

Al (%)	Cu (%)	Si (%)	Mg (%)	Cr (%)	Mn (%)
93.2	4.35	0.95	0.6	0.2	0.7

2.2 Fabrication of composites

The ratios of reinforcements used to develop the AA 2014 Aluminium alloy Composites are listed in Table 2.

Table 2. Proportions of AA2014 Aluminium alloy composites

Composites	AA 2014 (%)	Iron Oxide (Fe_2O_3) (%)	Cobalt (Co) (%)
S1	100	-	-
S2	97.5	2.5	-
S3	95	5	-
S4	95	2.5	2.5
S5	90	5	5

Stir casting was used to create the composites made from the AA 2014 Aluminum alloy. It was done using stir casting machinery with a maximum temperature of 1000^0C and a capacity of 2 Kg. The apparatus includes an immersion-type mould pre heater with a 450°C maximum temperature. Also used was an automatic stirrer with a speed range of 300 to 1200 rpm. In order to avoid porosity, which is a significant issue in the casting process, the mould was preheated. Preheating releases the gases that were trapped in the slurry before they could enter the mould. For 60 minutes, the preheating operation was conducted at 450^0C [8].

Fig. 1. Stir casting technique

The additional support to get rid of any moisture, iron oxide and cobalt was additionally warmed for 45 minutes at 450^0C. The furnace was stacked with the AA2014 Aluminum Alloy ingots, and the temperature was steadily raised. Cobalt and iron oxide metal powder were manually added after the ingots had begun melting and reached a semi-solid state. To guarantee homogenous mixing, the reinforcement and matrix material were mixed using an automated stirrer at a 400-rpm speed. Figure 1 shows the stir casting method used in this work.

2.3 Mechanical Properties

The specimens were prepared as per the ASTM standards. The specimens for tensile, flexural and impact strength were prepared as per ASTM E8, E9 and E23 standards. Tensile and flexural strength tests were conducted using the TINIUS OLSEN H10KT dual column universal testing machine, which has a 10 kN frame capacity. The machine has the following measurements: 1600 mm (H), 650 mm (W), and 450 mm (D). The testing speed range is 0.001 to 1000 mm/min, and the maximum crosshead travel is 1100 mm. The impact strength was measured using Tinius Olsen's pendulum impact tester, which has a maximum speed of 5.47 m/s and a lowest speed of 0.13 m/s.

3 Results and Discussion

The mechanical characteristics of AA2014 mixed with cobalt and iron oxide are shown in Table 3. The composites' tensile, flexural, and impact strengths are shown and compared with those of pure AA2014. The Composites' hardness is also determined and compared. When compared to pure AA2014, the tensile strength and hardness of the AA2014 composite with 5 wt% of iron oxide increased to 48.14% and 19.38%, respectively. With the addition of iron oxide and cobalt at a 5 wt% each, AA2014 composites improved their flexural and impact strength.

Table 3. Mechanical properties of AA2014 Aluminium alloy and its composites

Specimen	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (Nm)	Percentage of Elongation (%)	Hardness (HV)
S1	222.50	128.40	6.1	10.8	113.5
S2	272.80	106.52	5.2	8.2	127.2
S3	329.62	97.33	4.6	6.5	135.5
S4	253.25	126.82	5.8	9.9	118.8
S5	302.72	140.48	7.4	11.3	121.4

Figures 2, 3, 4 and 5 show the tensile strength of AA2014 aluminium alloy with cobalt and iron oxide reinforcement. Compared to AA2014, iron oxide is a tougher substance. The stiffness of the composite material is improved, which increases the flexural strength and hardness of the composites when iron oxide as the reinforcement is added to the matrix material AA2014 in the range of 2.5 wt% and 5 wt%. While the impact strength and flexural strength both decreased by the same percentage. The cobalt reinforcement cobalt was added to the composite in the range 2.5 wt% and 5 wt%. It moderates the hardness of the composites due to which the composites became soft, increasing the flexural and impact strength of the material [9, 10].

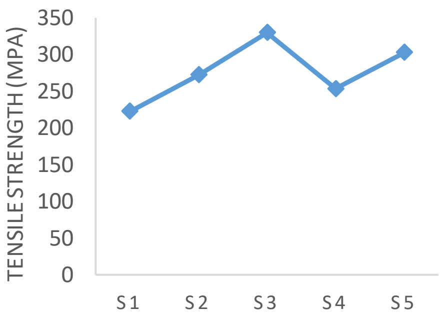


Fig. 2. Tensile strength of AA2014 Aluminium alloy and its composites.

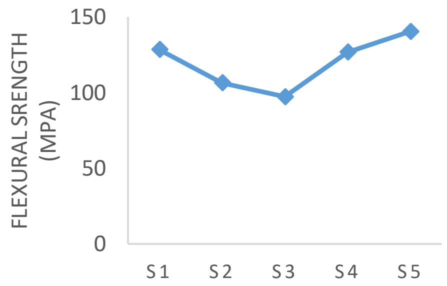


Fig. 3. Flexural strength of AA2014 Aluminium alloy and its composites.

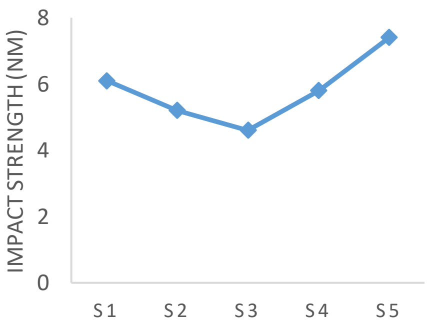


Fig. 4. Impact strength of AA2014 Aluminium alloy and its composites.

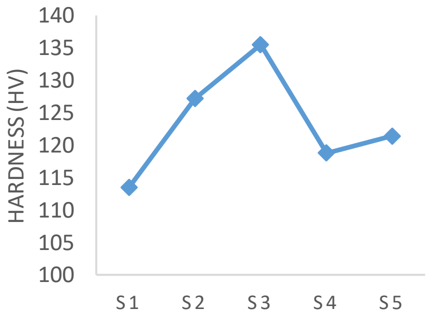


Fig. 5. Hardness of AA2014 Aluminium alloy and its composites.

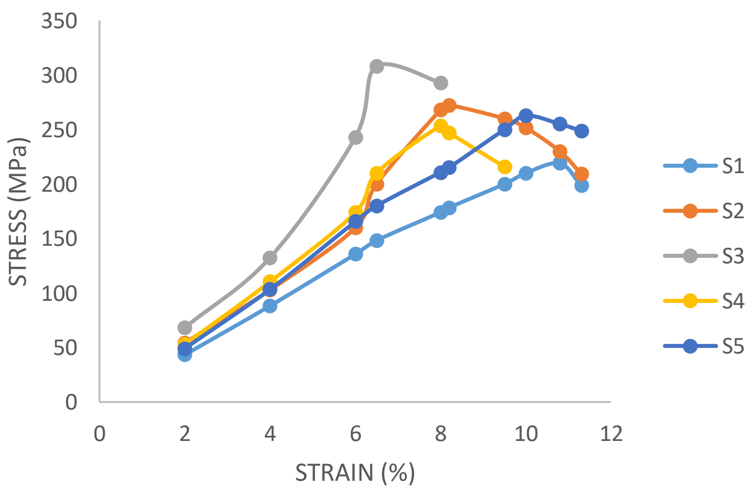
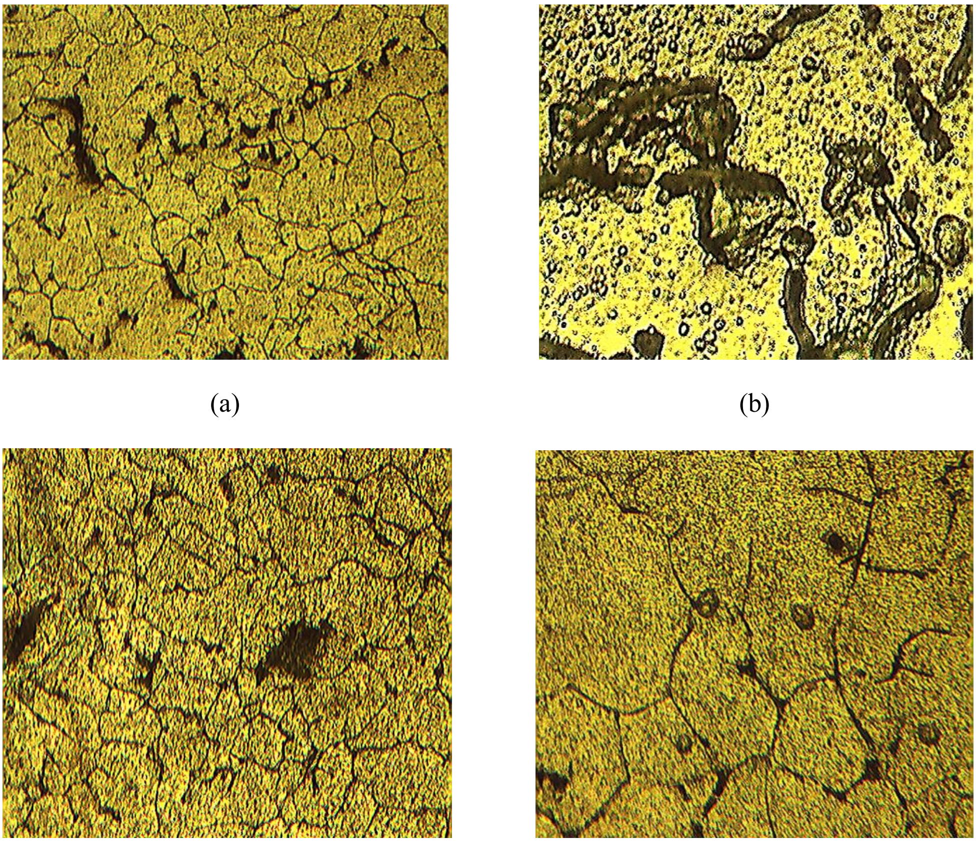


Fig. 6. Stress – Strain curves of AA2014 Aluminium alloy and its composites.

Figure 6 depicts the stress-strain behaviour of AA2014 and its composites with 2.5 and 5 weight % of iron oxide and cobalt. Within the elastic limit, the stress value grows linearly; however once above that point, the strain increases quickly for a small stress value. As compared to pure AA2014, the stress-strain behaviour of AA2014 composites including 2.5 and 5 wt% iron oxide and cobalt was quite similar. Along with the improvement in the stress-strain relationship, the percentage of elongation was also improved [11]. The percentage of elongation is lowered when iron oxide is added to pure AA2014 because it reduces deformability, whereas the percentage of elongation is increased when cobalt is added as reinforcement because it promotes deformability [12, 13].



(a) (b)

(c) (d)

Fig. 7. Optical microscope images of Aluminium alloy AA2014 with (a) 2.5 wt. % of Iron oxide (b) 5 wt. % of Iron oxide (c) 2.5 wt. % of Iron oxide and Cobalt, each (d) 5 wt. % of Iron oxide and Cobalt, each

Figure 7 demonstrates the strong contact between the reinforcement and the matrix material created by the addition of cobalt and iron oxide particles to Pure AA2014 alloy [14]. Cobalt particles and Fe_2O_3 clusters can both be seen in the microstructure. The AA2014 alloy's as-cast microstructure shows several dispersed compounds in the grain boundary [15]. Five weight percent of the AA2014 matrix is covered in a uniform distribution of Fe_2O_3 and cobalt particles. Fe_2O_3, which was used in this study and has a tetragonal structure, tends to restructure into a monoclinic structure as it cools. This transition consequently results in volumetric expansion, which may facilitate in the filling of the defects. The reinforcements' and AA2014 matrix's strong interaction significantly improved interfacial adhesion and dispersion. As a result, the mechanical characteristics of the composites might be enhanced [16, 17].

4 Conclusion

The mechanical characteristics of AA2014 aluminium alloy reinforced with 2.5 and 5 weight percent of iron oxide and cobalt were investigated, and the results were compared with those of virgin aluminium alloy. In the composite of AA2014 with 5 wt.% iron oxide, the tensile strength and hardness were improved. The flexural strength and impact strength of the AA2014 composite with 5 wt.% iron oxide and 5 weight percent cobalt were improved. Using an optical microscope to examine the microstructure revealed that the inclusion of reinforcement iron oxide and cobalt contributed to the strengthening of the composites, improving their characteristics.

References

1. Divya Chandra, Nadhi Ram Chauhan. Hardness and Roughness Evaluation of Developed Al Metal Matrix Composites using Stir Casting Method. Materials Today Proceedings, Volume **25**, Part 4, pages 872 – 876, (2020)
2. V.Bhuvaneswaria, L. Rajesjhkumar, D.Balaji, R.Saravanakumar. Study of Mechanical and Tribological Properties of Bio-Ceramics reinforced Al Alloy Composites. Solid State Technology. Vol **63**, No.5 (2020)
3. Pankaj R Jadhav, B.R.Sridhar, Madeva Nagared, Jayasheel L.Harti. Mechanical Behaviour and fractography of graphite and boron carbide particulates reinforced A356 alloy hybrid metal matrix composites. Advanced Composites Hybrid Materials **3**, 114 – 119 (2020)
4. Seyed Abdolkarim Saijadi, M.Torabi Pairizi. Comparison of microstructure and mechanical properties of A356 aluminium alloy / Al_2O_3 composites fabricated stir and campo-casting process. Materials & Design. **34**, 106 – 111, (2012)
5. T.P.D. Rajan, R M Pillai, B C Pai, K G Satyanarayana, P K Rohatgi. Fabrication and Characterization of Al – 7Si – 0.35 Mg / Fly ash Metal Matrix Composites Processed by Different Stir Casting Routes. Composite Science and Technology. **67** (15-16), 3369 – 3377, 2007
6. Malek Ali. Review of Stir Casting Technique and Technical Challenges for Ceramic Reinforcement Particulate Aluminium Matrix Composites. Journal of Silicate Based and Composite Materials.Volume **72**, Issue 6, May (2020).
7. Susanta KP, Subhranshu C, Amitava BM, Debdulal D 2016 A simple stir casting technique for the preparation of in situ Fe-aluminides reinforced Al-matrix composites. Perspectives in Science. Volume **8**, 529—532, (2016)
8. Fathy A, El-Kady O, Moustafa MM Mohammed. Effect of iron addition on microstructure, mechanical and magnetic properties of Al-matrix composite produced by powder metallurgy route Trans. Nonferrous Met. Soc. China **25,** 46−53, (2015)
9. Subramanya RP, Arun KS, Mervin AH, Shrikantha SR. Microstructure and mechanical properties of rutile-reinforced AA6061 matrix composites produced via stir casting process Trans. Nonferrous Met. Soc. China, **29** 2229−2236, (2019)
10. Sivananthan S, Ravi K, Samson Jerold Samuel C. Effect of SiC particles reinforcement on mechanical properties of aluminium 6061 alloy processed using stir casting route Materials Today: Proceedings. **21**, 968-970, (2020)

11. Nagendra KM, Manish M, Srivastava AK, Dwivedi SP, kumar A, Chauhan S. Investigation of mechanical properties of Al 6061/SiC composite prepared through stir casting technique Materials Today: Proceedings **25** 755-758, (2020)
12. Sarkari Khorrami M, Samadi S, Janghorban Z, Movahedi M. In-situ aluminum matrix composite produced by friction stir processing using Fe particles Mater Sci Eng A. **641**, 380– 390, (2015)
13. Wang MM and Apelian D. Aluminium die casting alloys: alloy composition, microstructure, and properties-performance relationships Int. Mater. Rev. **40** 225–252, (1995)
14. Mikhaylov VI, Maslennikova TP, Ugolkov VL, Krivoshapkin PV. Hydrothermal synthesis, characterization and sorption properties of Al/Fe oxide–oxyhydroxide composite powders. Advanced Powder Technology. **27**, 756-764, (2016)
15. Yang X, Rujuan S, Ni S, Song M, Xiao D. Fabrication, microstructure and mechanical properties of Al–Fe intermetallic particle reinforced Al-based composites. Journal of Alloys and Compounds. **618**, 537–544, (2015)
16. A.V. Pozdniakov, A. Lotfy, A. Qadir, E. Shalaby, M.G. Khomutov, A.Y. Churyumov, V.S. Zolotorevskiy. Development of Al-5Cu/B4C composites with low coefficient of thermal expansion for automotive application. Mater. Sci. Eng., A, **688** pp. 1-8, 10.1016/j.msea.2017.01.075, (2017)
17. H. sheng Chen, W. xian Wang, H. Hui Nie, J. Zhou, Y. li Li, P. Zhang. Microstructure and mechanical properties of B4C/6061Al laminar composites fabricated by power metallurgy. Vacuum, **143**, pp. 363-37010.1016/j.vacuum.2017.06.009, (2017)