Investigation of Mechanical Behaviour of Aluminum, Iron and Zirconium Hybrid Composite Fabricated By Sand Casting Method

Kashif Faheem[1] Mohd Shahrukh[2] Dr. B.N. Tripathi[3] Mohd Aamir[4]
[1]Department of Civil Engineering [2,3,4]Department of Mechanical Engineering
[1]Zakir Husain College of Engineering and Technology (ZHCET), Aligarh Muslim University, Aligarh, India [2,3]Noida International University, Noida, India [4]Delhi Technical University, Delhi, India

Abstract— As composites play an important role in various industries including marine, aerospace and automotive applications. The main objective of this study is to investigate mechanical characteristics of Aluminium, iron and Zirconium metal matrix composites fabricated by using sand casting method as they are light in weight with improved mechanical properties such as hardness and toughness. This paper deal with experiment on aluminum composite in which different proportion of iron and zirconium were mixed in varying proportion for making samples. Three specimens each made were composed of Al + Fe and Al +Fe + Zr in which Fe and Zr composition was varied and mixed different composition at 20%, 30% and 40% respectively. The result shows that hardness and toughness will increase with the increase percentage of iron in aluminum and in case of iron and Zirconium, hardness will increase as the percentage of composition increase from 20% to 40% and toughness was reduce till 30% after further addition at 40% toughness was increased.

Keywords: Aluminum composite, sand casting, Mechanical properties, Metal Matrix Composite

I. INTRODUCTION

In the modern development world with the increase urbanisation and we need of find the way of development of advanced engineering materials for many engineering application. Metal matrix composites (MMC) are one of the most important ways to meet this demand. Composites are those materials which are made from two or more different type of material with improve properties such as hardness, toughness, light in weight, specific strength, specific modulus, damping capacities and better wear resistance compared to unreinforced alloys. Because of it combines the most favourable characteristics of its constituent while eliminating the least desirable characteristics [1]. Due to their superior properties, aluminum alloys are gradually being replaced by alumina matrix composites (AMCs) in the aerospace, nuclear and marine industries. Several scientists are researching the compositions, properties and uses of different composites all over the world. Composites technologies are used widely in the aerospace industry, automotive manufacturing and other technical applications including economical and environmental benefits [2]. Aluminum is the most commonly used metal in industry after iron, due to its mechanical properties such as good corrosion resistance, low density and excellent thermal conductivity [3]. It has high young's modulus as well as high hardness and has a melting point 600 ^{o} C. When the temperature increase, strength of the aluminum decreases but when an aluminum is mixed with the reinforcing material such as Zircon sand, Tungsten carbide (TC), Silicon carbide, alumina oxide(Al_2O_3) etc. It gets more toughened, strengthened and has posses good characteristic as they have been reinforced with TiB_2 particle [4].

Aluminum is one of the constituent of Aluminu matrix composite, and it forms a percolating network, also known as matrix phase. The other constituent usually non-metallic like SiC Al_2O_3 etc. is embedded into the aluminum and act as a reinforced material. These benefits of AMCs should be put with aluminum in order to improve the properties [5]. For example, by reinforcing with 60% continuous aluminum fiber. The elastic modulus of pure aluminum can be increased from 70Gpa to 240Gpa but on the other side reinforced with 60% of alumina fibre leads tom reduce the coefficient of expansion from 24ppm/^{o}C. Likewise, composites having wear resistance is equal to or greater than that of cast iron of process Al-9% Si-20 vol% SiC [6]. All the above examples show that, adding two or three appropriate reinforcements in a sufficient volume fraction will change several physical properties of an aluminum/aluminum alloy. Integration of nanometer-sized reinforcement particles will enhance the tribological and mechanical properties of metal matrix composites. Formation MMC must have uniform particle distribution in both the radial and axial directions. Density of composites increases as particle size and weight percentage increase, but porosity of composites increases as particle size and weight percentage decreases [7]. Depending on the reinforcing particles, many techniques such as sand casting, stir casting and pressure casting are used in the industry to manufacture metal matrix composites. A comparative study of different techniques used for fabrication aluminum matrix composites are shown in below table 1 [8].

Method	Stir Casting	Squeeze Casting	Powder Metallurgy	Spray Casting
Cost	Least expensive	Moderate expensive	Expansive	Expansive
Range of shape and size	Wide range of shapes; Larger size; up to 500 kg	Limited by pre form shape up to 2cm height	Wide range; restricted size	Limited shape, large shape
Range of Vol. fraction	Up to 0.3	Up to 0.5	-	0.3-0.7
Damage to reinforcement	No damage	Severe damage	Reinforcement fracture	-

Table 1: parameters of different techniques used for fabrication AMCs

Sand casting is one of the oldest techniques; with atleast 2000 years of history and it has low cost with least damage. Sand casting was applied to aluminum as soon as the metal became accessible. Any aluminum alloy, including alloys that can show hot shortness in metal mould processes, may be cast in sand. Sand casting is divided into many types, which are normally determined by the form of binder used to tie the sand together [9]. Jenix et al., (2013) compared Al6063 with alumina and zircon sand in four separate volume fractions and observed that composites strengths for the mixture were higher (4+4)%. The Al-Cu alloy with alumina is subjected to abrasive wear [10]. Jeykrishna et al., fabricated the SiC metal matrix composites aluminum base using stir casting process and observed that the mechanical properties such as tensile strength and impact properties icrease because of silicon particle addition [11]. Rvikumar et al., fabricated Al metal matrix composites with the addition of different percentages of tungsten carbide (WC) particles including 2% , 4%, 6%, 8% and 10% by weight and investigated that mechanical properties of the composites, reporting reduction in impact strength and elongation with the addition of tungsten carbide (WC) reinforcement [12]. Vijay Ramnath et al., manufactured Al metal matrix composite by adding Carbon Nano tube particles and conclude that the added stiffness of the carbon nanotubes was not significantly improved but the compressive strength of the composite increased considerably. The composite have been to be prepared mainly using stir casting, and liitle or no work has been found to be prepared on strengthening tungsten carbide (WC) and zircon sand with different proportion to manufacture metal matrix composites, which has widely applied in aerospace and automotive engineering applications [13]. Halil karakoc et al. have examined the development by means of powder metallurgy of different composite materials. It introduces the latest method for optimizing hybrid composite mechanical properties (Al-SiC-B4C) developed with a powder extrusion technique. A16061 powders are used for reinforcement materials as matrix materials and B4C and SiC powders. Density, hardness and tensile strength of the composite are investigated. Moreover, analyse the surface fracture, microstructure, surface abrasion scanning electron microscopy (SEM0 are performed. At 12% SiC composite material produced the highest tensile strength. Because of the durability B4C and the strong adhesive properties of the matrix and SiC, the maximum wear resistance achieved with 9% B4C and 3% SiC tests [14].

According to the literature review and recent researches, intensive analysis was carried out to expose the mechanical properties of aluminium matrix composites reinforced with various reinforcing particles. Aluminium alloy is a possible matrix composite material in engineering application because of its good and strong surface finish, high corrosion resistance, and weldability. Studies in literature have shown that Zirconium has not been takes as reinforcement. Zirconium is normally used for resistant to corrosion by acids, alkalis and seawater, also used to make crucibles that will stand heat shock. It is also used for manufacture cutting tools (scissors and knives). In this study, we investigate the mechanical properties such as impact strength and hardness test of aluminium composite reinforced with iron and zirconium fabricated by sand casting method.

II. Material and Method

A. *Matrix Material*

The most widely used metal for metal matrix composite are magnesium, aluminium, titanium and their alloys too. The key reason for using aluminium as material matrix in the present study is due to its desired properties such as light weight, good strength and surface property and corrosion resistant. However, due to poor mechanical properties the wider use of aluminium is restricted. [15]

B. *Reinforced Material*

Al-Fe-Zr alloy was selected for the investigation. While selecting the reinforced material, mechanical, chemical and physical characteristic were considered. In recent studies, more focus was paid to particulate reinforced metal matrix composite. The probable reason is that good merchantability, improved physical and chemical properties, weight reduction and good workability are the advantages. In particulate-reinforced MMCs, the metal matrix and the reinforcing material share the load. In our study, Iron and Zirconium particulate were used due to its cost effectiveness and availability of material. There is no work available in previous study related to the use of zirconium with aluminium and iron composite. That is why, it is necessary to investigate the mechanical behaviour of the hybrid composite with the use of zirconium and iron both as reinforced material.

C. *Reinforced Process*

In this study we use sand casting method. First, the aluminium was heated and melted in a graphite cruciable to a temperature about 700 ºC for our analysis of the stir casting process. The iron powder was then poured into the same cruciable as molten aluminium, and the temperature was raised to 1000 ºC. Figure 2 depicts the sand casting technique used to make the composite. To make rectangular form specimens, the optimal weight percentages of Fe and Zr were placed one by one in percentages of 20%, 30% and 40% to fabricate three samples of each for Al+Fe and Al+Fe+Zr. The total weight of composite was 14g, with different amounts of Fe and Zr in each sample. The Fe content of the three Al+Fe composite samples varies from 2.8gm for sample 1, 4.2gm for sample 2, and 5.6gm for sample 3. Similarly, three samples were made whose composition was taken for the hybrid composite of Al+Fe+Zr, with a total weight of 14gm. In the Al+Fe+Zr composite, the percentage of Zr varies in tghe same way that of Fe in Al+Fe composite. Both the Al+Fe and Al+Fe+Zr mixture were stirred continuously for a period of time at about 200-1000 rpm, followed by sand casting for final specimen preparation. The complete procedure from raw material to the testing shown in figure 1 below

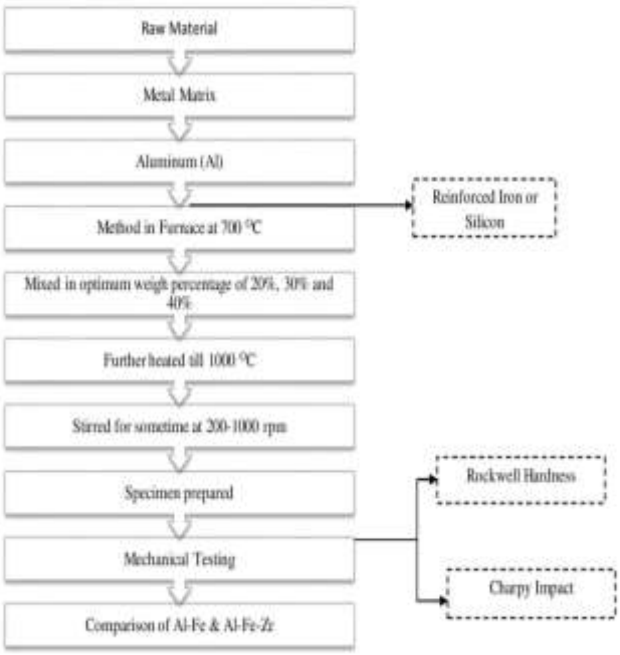

Fig. 1: Shows the procedure of preparing and testing of samples

Fig. 2: Graphite cruciable in sand casting process

Fig. 3: Al+Fe and Al+Fe+Zr samples after testing

III. Experimental Setup

In this study, two tests were conducted such as hardness and toughness tests. The Rockwell hardness test for measuring hardness and the charpy impact test for measuring composite toughness were used in this study.

A. Rockwell hardness test

Hardness is defined as the material's resistance to abrasion, scratching and cutting and it shows clear indication of strength. The Rockwell hardness test is used to determine the hardness of sample by measuring the extent of an indenter's penetration into the specimen under tests. A specified force is mechanically applied to the piece in all hardness testing, which varies in size and shape according to their tests. In Rockwell hardness test (figure), specimens were tested on B scale. As an indenter steel balls were used of having diameter 1/16 inch in the hardness test. To begin, a 10kgf minor load was applied to create a zero position to counter act the effects of surface finish. Then a major load of 60kgf was applied for 10 seconds before being released and the hardness value was calculated from the dial indicator's final position. The hardness value was calculated using an average of three hardness readings. Below Table 1 shows the hardness result and a graph for the hardness number of three specimens is plotted. (See in figure 4)

Fig. 4: Rockwell Hardnes testing machine

B. Charpy Impact Test

The charpy test is the standard test for determining impact energy. This provides information about the material's properties during fracturing. A pendulum like arm is swung down motion to impact with the test material. The amount of energy required to fracture the sample is recorded. Charpy device consist of the specimen, anvils on which the specimen is supported freely, and a pendulum with affixed mass attached to rotating arm pinned to the instrument body. The pendulum falls in a circular path, striking the test specimen in the center of the span, transmitting kinetic energy to it and the amount of energy required to fracture the sample is recorded. (Figure) Shows the charpy impact testing machine used investigating the toughness. The charpy test was used to determine the hardness of the samples made of Al+Fe and Al+Fe+Zr. We took the three sample of each composite. The amount of energy absorbed in splitting the specimen is estimated in joules, which indicate the test material's notch toughness. The three Al+Fe and Al+Fe+Zr specimen are measured at room temperature, the results are shown in Table 2 and the average is calculated. The measurement machine used to measure the toughness in this study as seen in figure 5.

Fig. 5: Charpy Impact testing machine

IV. RESULT AND DISCUSSION

The material Al+Fe is mixed by percentage by weight with a composite of 20%, 30% and 40% and the total weight of sample is 14gm by weight. Three samples were made by these composite using sand casting methods and Hardness is tested on Rockwell hardness testing machine and Toughness test on charpy impact testing machine. The composition and result shown in table 2 below

By using sand casting method three samples were prepared of Al+Fe composite and tested on Rockwell hardness testing machine for hardness and Charpy impact testing machine for toughness and the result are shown table 2 and variation of hardness and toughness of samples with varying composition 20%, 30% and 40% shown in figure 1 and 2.

Material	Weight (gram)	Rockwell Hardness test	Charpy impact test
Al+Fe	2.8	B 7	18
	4.2	B 9	18.2
	5.6	B 25	18.6

Table 2: Observation and composition of hardness and Toughness result in Al+Fe composite

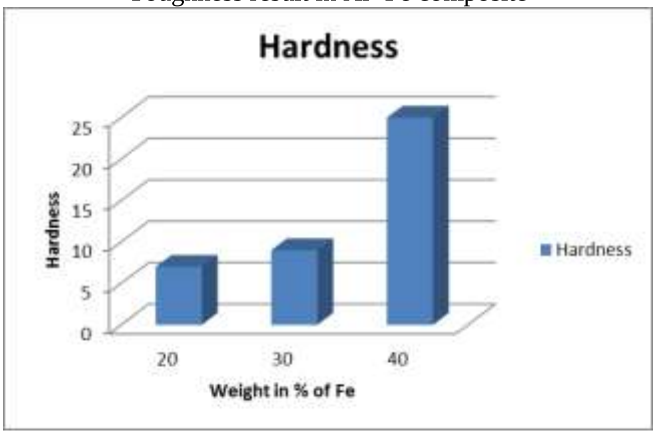

Fig. 6: Behaviour of the Al-Fe hybrid composition hardness with varying Fe composition

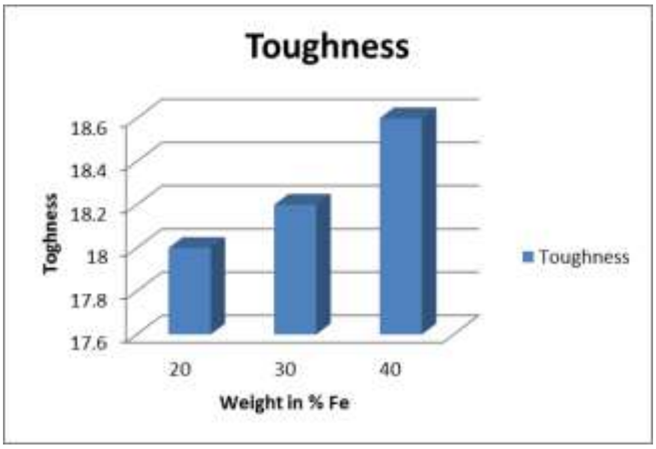

Fig. 7: Behaviour of the Al-Fe hybrid composite on toughness with varying Fe composition

Figure 6 and 7 shows that mechanical behaviour (hardness and toughness) of AMC (Al+Fe) with varying proportion of iron that at 20% HRB value found 18, at 30% the HRB value is 18.2 and at 40% HRB value is 18.6. Figure 1 and 2 also shows that as the percentage of iron in matrix was increased both the hardness and toughness increased. The varying percentage composition is taken on the X-axis and Hardness and Toughness value were taken on the Y-axis.

The Al+Fe+Zr hybrid composite was made by sanding in the same way as the Al=Fe composite but with different Zr compositions in the sample at 20%, 30% and 40% by weight in the Al+Fe composite. The hybrid composite had a total weight of 14 grams. The composition and the result showed in table 3 and in figure 8 and 9. In addition, figure 10 shows an overall comparison of the mechanical properties of the Al+Fe and Al+Fe+Zr composites, especially hardness and toughness.

Material	Weight (gram)	Rockwell hardness test	Charpy impact test
Al+Fe+Zr	2.8	B 60.3	17.4
	4.2	B 65	16.2
	5.6	B 70	18

Table 3: Observation for Hardness and Toughness result in Al-Fe-Br hybrid composite with varying Br composition

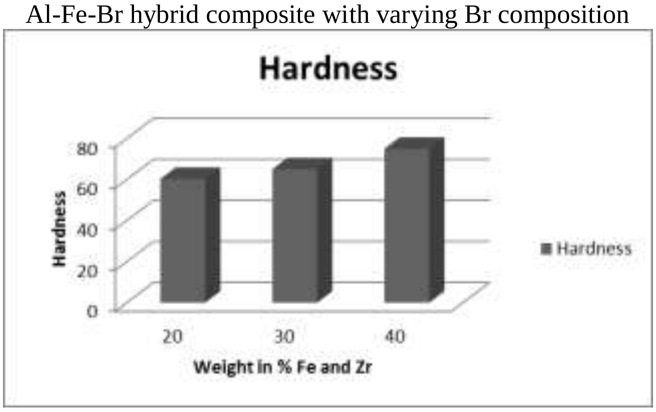

Fig. 8: Behaviour of Al+Fe+Zr hybrid composite on hardness with varying Iron and Zirconium composition

Fig. 9: Behaviour of Al+Fe+Zr hybrid composite on toughness with varying composition of Fe and Zirconium

Figure 3 and 4 shows the mechanical behaviour (hardness and toughness) of the AMC (Al+Fe+Zr) with varying proportion of Fe and Zr. We can see that in figure 3 that when the percentage of Fe and Zr increases in the matrix, hardness is increased from 20% to 40%. In figure 4 shows that when the percentage of iron and zirconium increases toughness get decreases till 30% composition and then increases at 40% composition.

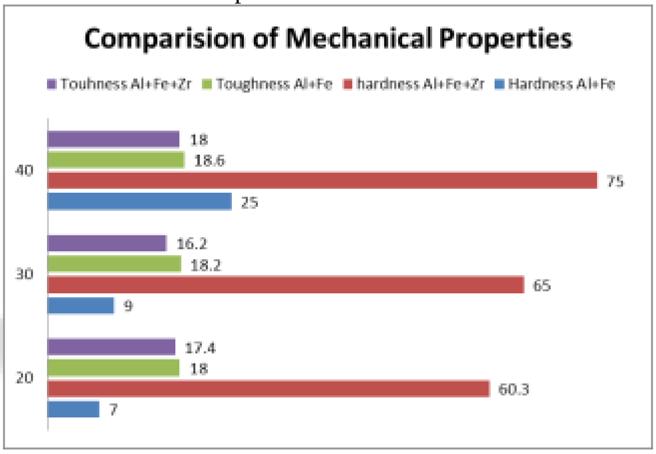

Fig. 10: Comparison of mechanical properties of hybrid composite material at a glance

V. CONCLUSION

From this study, we examined the effect of Iron(Fe) and Zirconium(Zr) on the mechanical properties i.e. hardness and toughness of the composites from this analysis of Al+Fe and Al+Fe+Zr composite. The Rockwell hardness and Charpy impact test was used to determine the hardness and toughness of the samples respectively by using sand casting method. The following conclusions are inferred:

- The hardness increases with the increase in percentage of Iron(Fe) in the Al+Fe composite from 20% to 40% and further increase when the percentage of iron increases. The toughness also increases as the percentage of iron increases.
- In case of Al+Fe+Zr composite, as the percentage of iron and zirconium increases in the composition hardness get increased but the toughness decreases as the percentage of iron and zirconium increases till 30%, after further addition from 30% to 40% toughness got increased.
- The mechanical alloying of the metal alloying of the metal result in improvement of hardness of hardness and

toughness in Al+Fe composite with 20% to 40% composition by weight.

References

[1] Miracle, D.B. and Donaldson, S.L., 2001. Introduction to composites. *ASM handbook*, *21*, pp.3-17.
[2] Ozben, T., Kilickap, E. and Cakır, O., 2008. Investigation of mechanical and machinability properties of SiC particle reinforced Al-MMC. *Journal of materials processing technology*, *198*(1-3), pp.220-225.
[3] Bobić, B., S. Mitrović, M. Babić, and I. Bobić. "Corrosion of metal-matrix composites with aluminium alloy substrate." *Tribology in industry* 32, no. 1 (2010): 3-11.
[4] Ramnath, B. Vijaya, J. Jeykrishnan, S. Akilesh, B. Saravanan, and V. Krishna Vivek. "Investigation of Micro-structure and Mechanical Behaviour of Aluminum-Zircon Sand-Tungsten Carbide Metal Matrix Composites." *Materials Today: Proceedings* 5, no. 11 (2018): 25553-25561.
[5] Surappa, M. K. "Aluminium matrix composites: Challenges and opportunities." *Sadhana* 28, no. 1-2 (2003): 319-334.
[6] Bhandare, Rajeshkumar Gangaram, and Parshuram M. Sonawane. "Preparation of aluminium matrix composite by using stir casting method." *International Journal of Engineering and Advanced Technology (IJEAT)* 3, no. 3 (2013): 61-65.
[7] Fatile, Oluwagbenga Babajide, Joshua Ifedayo Akinruli, and Anthony Akpofure Amori. "Microstructure and mechanical behaviour of stir-cast Al-Mg-Sl alloy matrix hybrid composite reinforced with corn cob ash and silicon carbide." *International Journal of Engineering and Technology Innovation* 4, no. 4 (2014): 251.
[8] Wahab, M. N., A. R. Daud, and M. J. Ghazali. "Preparation and characterization of stir cast-aluminum nitride reinforced aluminum metal matrix composites." *International journal of mechanical and materials engineering* 4, no. 2 (2009): 115-117.
[9] Hawaldar, Nishant, and Jing Zhang. "A comparative study of fabrication of sand casting mold using additive manufacturing and conventional process." *The International Journal of Advanced Manufacturing Technology* 97, no. 1 (2018): 1037-1045.
[10] Rino, J. Jenix, D. Sivalingappa, Halesh Koti, and V. Daniel Jebin. "Properties of Al6063 MMC reinforced with zircon sand and alumina." *IOSR Journal of Mechanical and Civil Engineering* 5, no. 5 (2013): 72-77.
[11] Jeykrishnan, J., B. Vijaya Ramnath, X. Hervin Savariraj, R. David Prakash, VR Dhinesh Rajan, and D. Dinesh Kumar. "Investigation on tensile and impact behavior of aluminum base silicon carbide metal matrix composites." *Indian journal of science and technology* 9, no. 37 (2016): 1-4.
[12] Ravikumar, K., K. Kiran, and V. S. Sreebalaji. "Characterization of mechanical properties of aluminium/tungsten carbide composites." *Measurement* 102 (2017): 142-149.
[13] Ramnath, B. Vijaya, C. Elanchezhian, M. Jaivignesh, S. Rajesh, C. Parswajinan, and A. Siddique Ahmed Ghias. "Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites." *Materials & Design* 58 (2014): 332-338.
[14] Halil, Karakoç, Ovalı İsmail, Dündar Sibel, and Çıtak Ramazan. "Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy." *Journal of Materials Research and Technology* 8, no. 6 (2019): 5348-5361.
[15] Suresh, P., P. Arunagiri, and AP Arun Pravin. "Experimental analysis of aluminium alloy LM25 with carbon in composite material." *Materials Today: Proceedings* 33 (2020): 7-12.

