A Review on Mechanical Behaviour of Aluminium Reinforced Composites

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Abstract. Aluminium Matrix Composites (AMC) finds applications in automobiles and aerospace fields as they bear better mechanical and physical properties. Compared to available traditional materials these composites are found to have improved wear, tensile and other similar properties due to the addition of reinforcements to the matrix. The property of base alloy gets improved when it gets mixed up with different reinforcements having various properties. The effects of addition of various reinforcements on aluminium alloy were given overview in this paper. It has been noted after review that fabricated composites yield better results if they are free from agglomeration, have uniform distribution of matrix and reinforcement and ensure better bonding of fiber with matrix. It is obvious from investigations that the life and behaviour of composites are superior for Aluminium matrix composites than that of the traditionally available materials. The studies show that because of reinforcement addition the mechanical properties of the AMC will have an average improvement of at least around 10% approximately while comparing with base material alone.

Keywords: Aluminium, Composites, Stir casting, Mechanical Properties, Wear

1. Introduction

Various methods are available for fabrication of composite materials and a researcher can select one among them depending on type of matrix and reinforcement chosen. Production methods are categorized into three namely solid, liquid and semi-solid phases of fabrication [1]. Stir casting, compo casting, rheocasting and liquid infiltration are some of the liquid processing techniques available [2]. Out of various fabrication methods available, one of the less expensive methods is the stir casting method. Hence, it is used for bulk production of composites. Many researchers earlier have used stir casting technique and found to have improved wear and mechanical properties in the composites fabricated [3]. Melt stirring process is successful in achieving better bonding of matrix and particle, easy in controlling the structure of matrix, applicable for mass production, flexible, simple and inexpensive. On the other hand, non uniform distribution of reinforcement with matrix material and poor wettability are the quite common problems faced in stir casted Aluminium Matrix Composites (AMC).

In order to overcome problems related with stir casting, few techniques were followed by the researchers. Wettability of reinforcement can be improved by pre heating of reinforcement particles before introducing into the molten metal melt. This method helps in adsorption of gases from the
reinforcement surface [4]. Reinforcement particles, if injected with the help of inert carrier into metal melt will result in homogeneous distribution of particles into the melt [5]. Wettability of reinforcement particle is found better with the three step stir casting method followed in the newly designed equipment by Sajjadi et al [6].

Combining harder ceramic reinforcements with metallic matrix results in metal matrix composite (MMC). Less production cost and improved properties of Aluminium composites make them best suited for marine and aerospace applications [7]. They are also used in pistons, cylinder liners and brake rotors [8]. Properties like low density, ductility and formability of aluminium and its alloys make them to choose as matrix material for MMC. The performance of composite material depends mainly on its microstructure. Distribution of reinforcement in the alloy, fibre or particulate size and shape are some other essential parameters to be noted on which physical property of the resulting composite depends [9].

For application of the fabricated composites in various areas, proper choice of matrix and reinforcement will play a prominent role. Reinforcements such as SiC, Al₂O₃, B₄C and TiB₂ are widely used in Aluminium composites as reinforcements [10].

Most of the studies on casting analyse the mechanical properties like hardness, tensile, wear and similar other properties and evaluate the microstructure of the resulting specimens. Whereas Finite Element Analysis (FEA) [11], Response Surface Methodology (RSM) and Artificial Neural Networking (ANN) [12] are the methods used for analysing the performance of welded specimens. Behaviour of AMC on using different reinforcements were discussed and reviewed.

2. Effect of SiC on AMC

Rajesh Kumar Bhushan [13] used stir casting method and provided 5, 10 and 15 wt% SiC with size of the particle from 10 to 40 μm to AA 7075 to produce AMC. Scanning electron microscopy (SEM) and energy – dispersive X-ray analysis (EDAX) tests were conducted for examining the samples and studied the interaction and distribution of SiC particles with of matrix. Hardness of samples increased with increasing SiC reinforcement from 5% to 15%. Composite sample with 10% SiC exhibited maximum tensile properties.

Abhijit et al [14] evaluated wear behaviour of Al7075 composite reinforced with SiC particles. 20 μm grain sized SiC particles at 0, 3, 6 and 9% are used for fabricating components by stir casting route. Uniform particulate mixing was observed using X-Ray Diffraction method. Wear tests were performed on all samples with a constant load of 30 N, stable sliding distance of 2000 m and varying sliding velocity as 1, 2, 3 and 4 m/s. Friction between disc and pin resulted in decrease in COF and increase in wear rate. Minimum material removal was achieved in worn out surface Al7075 composite pin having 9% of SiC.

Anshuman et al [15] used ultrasonic stir casting method for fabricating Al-SiC composites with 0, 3, 5, 8 and 10 weight % of SiC particles. Probe was used for 5 minutes in order to disperse the reinforcement properly in the melt. Tensile, compressive, hardness and density tests were conducted. All the properties were found to be increasing with increasing wt% of SiC.

Soundararajan et al [16] mixed 20wt% SiC to A356 alloy to make AMC. They used three different methods of casting namely gravity die cast, stir cast and stir cum squeeze casting techniques to make composites. Hardness, tensile and wear tests were conducted for samples produced by three different methods and the surface morphology were analysed for the casted and worn out samples. Compared to the other two casted samples squeeze cum stir casted samples exhibited better properties.

Sonagiri Suresh et al [17] manufactured nano composite using Aluminium 7075with SiC particle measuring 50 nm. 1, 2, 3 and 4 wt.% of SiC particles are used for preparation of composite specimens. Wear test with 20, 30 and 40 N loads using round pin on a steel disc and Micro hardness test were conducted. Micro structures were examined on the worn out surfaces. In comparison to the base metal the nano composites exhibited better wear and hardness properties.

Juwen Zhu et al [18] achieved uniform distribution in SiCnp/Al6082 AMC fabricated through combined squeeze and stir casting method. Yield strength, ultimate tensile strength and elongation of SiCnp/Al6082 AMC were examined and found to be increasing than that of matrix material alone. The compactness and grain refinement improved for the stir casted SiCnp/Al6082 composites.

Jaya Prasad Vanam et al [19] studied the effect of mechanical, microstructure and wear properties of Al5083-SiC composite. Stir casting process is used for preparing AMC with SiC wt% as 3, 5 and 7. With normal loads as 10, 20 and 30 N, pin on disc wear test was conducted. Having 3.14 m/s as sliding velocity and 942 m as sliding distance tribological behaviour was evaluated. Wear mechanisms of the worn out surfaces were analysed on the worn out specimens using optical microscope. Micro hardness number and tensile strength of the samples was measured using micro hardness and tensile tests. SEM and XRD
analysis were done and the microstructures were observed. Superior tribological properties were noticed with increased addition of particles of SiC.

Karthikeyan et al [20] discussed about the behaviour of wear on Al6063/SiC composite having 5, 7 and 9 vol.% of SiC manufactured through stir casting technique. 10 N load and 500 m sliding distance were set as parameters for conducting wear test. Wear loss increased on increasing sliding velocity and it decreased on increasing reinforcement amount.

Pawar et al [21] studied the outcome of addition of 2.5%, 5%, 7.5% and 10% mass ratio of SiC composite into Aluminium matrix using stir casting technique. Microstructure and hardness tests were conducted and suggested that the composites are used as replacements for gears made of conventional materials. Table 1 given below shows the properties of composites made with SiC reinforcements.

### Table 1. Properties of composites made with SiC reinforcements

| Matrix material | Reinforcement | Wt.% or Vol.% of reinforcement | Reinforcement particle size | Manufacturing method | Properties Obtained | References |
|----------------|---------------|--------------------------------|----------------------------|----------------------|---------------------|------------|
| AA7075SiC      | 5, 10 and 15 wt.% | 10-20 μm, 20-40 μm | Stir casting | Maximum Tensile strength 272 MPa | Maximum Hardness 118 BHN | [13]       |
| Al5083 SiC     | 0, 3, 5, 8 and 10 wt.% | - | Stir casting (Ultrasonic assisted) | 254.9 MPa | 88.8 BHN | [15]       |
| A356 SiC       | 20 wt.% | 45 μm | Stir casting | 331 ± 4.50 Mpa | 950 ± 3.80 MPa | [16]       |
| Al7075 SiC     | 1, 2, 3 and 4 wt.% | 50 nm | Stir casting | - | 90 to 110 HV | [17]       |
| Al6082 SiC     | 1 wt.% | 50 nm | Stir casting | 344.21 Mpa | - | [18]       |
| Al5083 SiC     | 3, 5 and 7 wt.% | - | Stir casting | 226 MPa | 112 HV | [19]       |
| Al SiC         | 2.5, 5, 7.5 and 10 wt.% | - | Stir casting | - | 60.3 BHN | [21]       |

3. Effect of B4C on AMC

Suresh Gudipudi et al [22] used ultrasonic supported stir casting technique to overcome problems related to distribution, wetting and incorporation on increase of reinforcement in AA6061-B4C composite. 2, 4, 5, 6 and 8 wt.% of reinforcements were used to make composites. Among the various wt.% of reinforcements used AA6061-4wt.%B4C exhibited better microstructural, compressive and hardness behaviour.

Chandrasheker et al [23] made an attempt through electromagnetic stir casting method in synthesising Al7050/B4C AMC with 3, 6 and 9 wt.% of B4C particles. Hardness of the composites was found to be increasing on rising wt% of reinforcement. Tensile strength of composites increased until adding of reinforcement up to 6%. Further addition of reinforcement resulted in formation of clusters and decreased the tensile strength. Microstructure analysis helped to check uniformity on reinforcement distribution.

Radhika et al [24] made a comparative study to analyse the friction and wear behaviour of as-cast, A359/10 wt% B4C composite (heat treated (HT) Functionally Graded (FG) ) and A359/6 wt% B4C (homogeneous) composite made of gravity casting and horizontal centrifugal technique. FG composites were found to have reinforcement particles in a decreasing grade and homogeneous composites observed uniform reinforcement throughout, when analysed using metallographic test. Mechanical properties like tensile and micro hardness are superior for FG composites. Wear resistance is superior for HT FG composite. Wear mechanism were studied using morphological analysis.

Yu Li et al [25] studied the effect of AA6061–31%B4C composite made through stir casting technique. Scanning electronic microscope (SEM) and X-ray diffraction (XRD) tests were done and the
uniform distribution of reinforcements was conformed. Tensile strength of AA6061−31%B4C composites was found to be superior to that of AA1100−31%B4C composite.

Siddhartha Prabhakar et al [26] investigated the tribological behavior of Al/5 wt.% B4C composite made of stir casting route. Microstructure tests confirmed even distribution of reinforcement particles with matrix. Wear tests by Taguchi technique were done with wear load of 10, 20 and 30 N, velocity of 1, 2 and 3 m/s and sliding distance of 1000, 1500 and 2000 m, optimum parameters were found. Co-efficient of friction and wear rate decreased with distance and velocity increased with load. Wear mechanism was analysed using Scanning Electron Microscope. Table 2 given below shows the properties of composites made with B4C reinforcements.

| Matrix material | Reinforcement | Wt.% or Vol.% of reinforcement | Reinforcement particle size | Manufacturing method | Properties Obtained | References |
|-----------------|---------------|-------------------------------|-----------------------------|----------------------|---------------------|------------|
| AA6061 B4C      | 2, 4, 5, 6 and 8 wt.% | 30 μm | Stir casting (Ultrasonic assisted) | ~220 MPa | 36.5 BHN | 56.01HV | [22] |
| Al7050 B4C      | 3, 6 and 9 wt.% | - | Electromagnetic stir casting | 153 MPa | 84.27 HV | [23] |
| A359 B4C        | 10 wt.% | 18 μm | Centrifugal and gravity casting | 239 MPa | 161.8 HV | [24] |
| AA6061 B4C      | 31 wt.% | 23 μm | Stir casting | 340 MPa | - | [25] |

4. Effect of Al2O3 on AMC

Mohanavel et al [27] produced AA6082 matrix composite reinforced with alumina particles of size 50 nm with the help of stir casting route. The volume fractions of reinforcement added vary from 0 to 3% in steps of 1 to produce AMC. SEM analysis was conducted to check microscopic behaviour and dispersion of reinforcement particles with matrix and is found to be homogeneous. Mechanical properties like hardness and tensile strength of composites were compared with base metal and were found to be increasing with increased addition of alumina into the matrix because of better binding between alloy and reinforcement.

Abhishek Kumar et al [28] discussed about the mechanical properties and microstructural behaviour of A359/Al2O3 composites fabricated using electromagnetic stir casting method. 30μm sized 2, 4, 6 and 8 wt.% of Al2O3 were used as reinforcements in making AMC. Hardness, tensile and microstructure analysis were done on the composite samples. Increase in weight fraction of reinforcement increased the hardness and tensile strength of composites. Casted MMC results in lesser grain size and better matrix reinforcement bonding because of electromagnetic stirring action.

Abdullah Dhayea Assi [29] investigated the effect of Al2O3 nanoparticle addition into AA6082-T6 matrix. Experiments were conducted on AMC made with nano Al2O3 reinforcements having varying weight fractions ranging from 5 to 30 in steps of 5 fabricated through Stir Casting Technique (SCT). Tensile strength, density and hardness of samples were found increasing on increasing the amount of reinforcement whereas the Young’s modulus and yield strength decreased on increasing reinforcement amount.

Prakash et al [30] investigated the performance of various feeding techniques of stir casted Al70705-Al2O3 nano composites. SEM micrographs revealed the sample’s porosity, particle agglomeration and bonding between ceramic interface and matrix. Mechanical properties like yield strength, micro hardness and ultimate tensile strength were measured and homogeneous reinforcement particle distribution yielded increasing results for composites than that of alloy alone.

Hanuna Haritsa et al [31] investigated the behaviour of A356 composite reinforced with Al2O3. Reinforcement added varied from 2 to 15 vol.% and composite specimens were made through stir casting method. Magnesium has been added to improve the wettability of reinforcement. Die was preheated to 800°C before introducing the molten metal into it. Agglomeration and porosity made the composite
specimens to result in less tensile strength than that of alloy alone. Even though, hardness of the composite was better than that of base material.

Islam et al [32] studied the result of nano- Al₂O₃ addition with A356 matrix composite made of stir casting method. 0.1 to 1.2 volume fraction of reinforcement is used as reinforcement. 10% of magnesium is added as wetting agent during fabrication. Agglomeration of reinforcement reduced the tensile strength of the resulting samples. Hardness of the composite was found to have an increasing value. Table 3 given below shows the properties of composites made with Al₂O₃ reinforcements.

Table 3. Properties of composites made with Al₂O₃ reinforcements

| Matrix material | Reinforcement | Wt.% or Vol.% of reinforcement | Reinforcement particle size | Manufacturing method | Properties Obtained | References |
|-----------------|---------------|--------------------------------|----------------------------|----------------------|---------------------|------------|
| A359 Al₂O₃      | 2, 4, 6 and 8 wt.% | 30 μm                          | Electromagnetic stir casting | 148.7 MPa            | 72.8 HRC            | [28]       |
| AA6082 Al₂O₃   | 5, 10, 15, 20, 25 and 30 wt.% | 20 - 40 nm                    | Stir casting                | 340 MPa              | 92 BHN              | [29]       |
| Al7075 Al₂O₃   | 2.5 wt.%      | 50 nm                          | Stir casting                | 387 MPa              | 878.6 HRC           | [30]       |
| A356 Al₂O₃     | 2, 5, 8, 10 and 15 vol.% | -                              | Stir casting                | 131.55 MPa           | 37.43 HRB           | [31]       |
| A356 Al₂O₃₉ap  | 0.1, 0.2, 0.5, 1, 1.2 vol.% | 80 nm                          | Stir casting                | 164 MPa              | 47 BHN              | [32]       |

5. Effect of TiB₂ on AMC

Pazhouhanfar et al [33] reported the effect of addition of 3 6 and 9 wt.% of TiB₂ reinforcement addition into Al matrix during manufacture of composite employing stir casting method and studied mechanical properties, microstructure and fracture surface of tensile specimens. Stirring speed, duration and preheating temperatures were optimized initially before manufacture of composites. Reinforcement pre heating and K₂TiF₆ addition during casting process improved the wettability and matrix reinforcement bonding of the composite, which was revealed during SEM analysis. Uniform reinforcement distribution was found during SEM analysis. Tensile test results were found to be increasing with increasing addition of volume fraction of reinforcement.

Semegn Cheneke et al [34] characterized and investigated the mechanical properties and microstructure of AA2024-TiB₂ composite made of stir rheocast method. 2, 4 and 6 wt.% of reinforcements were used for making composite with working temperature kept as 640ºC. Field Emission SEM analysis confirmed even distribution of reinforcements in matrix. Agglomeration of reinforcements was found on composites having 6wt.% of TiB₂. Hardness and tensile strength of composite specimens were compared with liquid cast samples and found better. Dimples and voids present in fractography analysis confirmed the ductile fracture of test specimens.

Fei Chen et al [35] discussed the effect of mechanical stirring of Al-TiB₂ composites using stir casting technique. The study is quite different from others. Instead of mixing the reinforcement directly into the metal melt, K₂TiF₆ and KBF₄ salts were added resulting in formation and uniform distribution of TiB₂ by chemical reaction. Optimized processing parameters were used and the microstructure and mechanical properties were evaluated. The novel method exhibited improved ductility in addition to increased yield and tensile strengths.

Loganathan et al [36] employed two step stir casting process to produce Al7075-TiB₂ composite with 5, 10 and 15 wt.% of reinforcement. Hardness, tensile, density and impact tests were performed to examine the mechanical properties of the composite. SEM and XRD tests were employed to observe the factography of the composite specimens. Grain refinements were seen from those observations on addition TiB₂ which lead to improved mechanical properties of composite. Load bearing capacity of the composite increased because of better matrix reinforcement bonding. Table 4 given below shows the properties of composites made with TiB₂ reinforcements.
Table 4. Properties of composites made with TiB₂ reinforcements

| Matrix material | Reinforcement | Wt.% or Vol.% of reinforcement | Reinforcement particle size | Manufacturing method | Properties Obtained | References |
|-----------------|---------------|------------------------------|-----------------------------|----------------------|---------------------|------------|
| Al6061          | TiB₂          | 3, 6 and 9 wt.%              | 2 to 10 μm                  | Stir casting         | ~260 MPa ~150 (HV 0.25) | [33]       |
| Al              | TiB₂          | 1, 4 and 7 wt.%              | -                           | Stir casting         | 104.4 ± 2.4 MPa 24.4 ± 0.3 BHN | [35]       |
| AA7075          | TiB₂          | 5, 10 and 15 wt.%            | 25 μm                       | Stir casting         | ~220 MPa 152 HV     | [36]       |

6. Conclusion

It is evident from the reviewed researches that:
- Aluminium composites are finding applications in aerospace and automobile fields and are capable of replacing the conventional materials.
- Adding 10-20μm SiC of 10wt.% with AA7075 increase tensile strength upto 9.67%. 10.48% of increment in hardness can be seen because of addition of 15% of SiC.
- Heat Treated (HT) Functionally Graded (FG) composites exhibit better mechanical and wear behaviour than as-cast samples.
- Wettability between matrix and reinforcement can be improved by adding magnesium and K₂TiF₆ into the metal melt in the casting process.
- Preheating of reinforcements before introducing it into molten metal improves the matrix reinforcement bonding and load carrying capacity of the composites increases if better matrix reinforcement bonding is achieved.

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