Production, Characterization & Analysis of A A 2024, Reinforced with Ternary Alloy

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Abstract— To produce composites with high strength and good ductility work has been carried out by maximizing a uniform and smooth interface for effective transfer of load and minimizing reinforcement agglomerations/cracking/pull outs. A stir cast route is a procedure by which the 14 mm Ø rods are prepared in a industrial furnace at 100^{0}C for 24 h. An increment of 62% is observed in mechanical behavior of alloy and composites by studying varying characteristics of resistivity, hardness and tensile stresses. An increment of about 5% and 15% of reinforcement contents enhance the mechanical properties such as young's modulus, yield strength and tensile strength.

Key words: Metal matrix composites, aluminum, copper, Tensile and shear behavior

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1 INTRODUCTION

A high specific strength, modulus and hardness properties metal with ceramic reinforcements are known as MMCS [1–3]. They are used in aerospace applications [4–9]. , compatibility between matrix and reinforcement and characterization are still the major problems in the manufacturing of these composites though they have many applications in many fields.To avoid these problems to we use metal–metal composite systems .The thought has been given by adhu et al. [10], to have the advantage of MMCs and metal–metal combination system has to be choosen .These alloy systems of thesecomposites with restricted solubility, termed as metal–metal composites. To have good compatibility between the matrix and the reinforcement, an established alloy system with proven application needs to be chosen, where the solvent acts as the matrix and the solute as the reinforcement. Solute dissolution needs to be controlled to have the reinforcement effect**.** Solute dissolution needs to be restricted/controlled to have the reinforce-ment effect. In the last few years, to reduce the wt. of components used in structural applications metal particle reinforced aluminium metal matrix composites(AMC's) have been developed. These compounds are also used in improving their mechanical and physical properties. Fabrication of composites having metals with limited mutual solubility can be produced, utilizing the properties of the alloy and the resulting composite.

With their high formability and low work hardening rates, these composites can be produced at low cost. In terms of applications, Al–Cu–Mg alloys shares a larger fraction of aluminium alloys due to their high specific mechanical properties and wide range of alloys and properties.

The basic idea of developing metal matrix composites is to derive high strength materials. Large number of products have been designed and manufactured for various applications. Many of the investigations have shown improved mechanical properties, but limited with low & poor ductility. In the present investigation, an attempt has been made to achieve a good combination of strength & ductility properties with composite.

2. EXPERIMENTAL DETAILS

2.1. Materials

2.1.1. Matrix material

In the present investigation AA 2024 was used as matrix material. The alloy is most widely used aluminium–copper alloys in forging as well as rivets for aircraft industry. This alloy has a higher tensile and yield strength with lower elongation

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Table 1

Chemical composition of AA 2024 alloy(wt%).

Cu	Mg	Si	Zn	Fe	Cr	Al
4.38	1.52	0.4	0.13	0.02	0.12	Balance

Table 2

Chemical composition of commercial AA 2024 alloy (wt.%).

Cu	Mg	Mn	Si	Zn	Cr	Pd	Bi	Al
4.3-4.5	1.3–1.5	0.5–0.6	<0.5	<0.5	<0.5	<0.5	<0.5	Bal.

Typical uses of this alloy are aircraft structures, rivets, hardware, truck wheels and screw machine products. This matrix alloy was chosen since it provides excellent combination of strength and damage tolerance at room as well as at elevated temperatures.AA 2024 alloy was prepared in the laboratory and the chemical composition of the same was shown in Table 1. The chemical composition of commercial AA2024 alloy (in wt.%) was given in Table 2. It shows that chemical composition of the alloy prepared was in tune with the commercial alloy AA 2024 alloy.

2.1.2. Reinforcement material

Al–20Cu–10Mg alloy has been used as the reinforcement material in the present investigation, alloy powders were produced by filing techniques, where, fingersrotating on a lathe, were filed with speeds of rotation ranging between 800 and 290 rpm and files. Finer powders were obtained at high speed and with finer files. The average size found to be between 200 and 300 lm. Further ball milling in a conventional ball mill for 1 h, gave an average particle size of 125 lm with large fraction in _100, +120 mesh range. After thorough magnetization using a strong magnet, to remove the balls contamination, if any, the particulate material in the sieve range of _100 + 120 has been chosen for reinforcement purpose. Following Boltzmann's hypothesis on the relationship between entropy complexity [11], the configurational entropy change, DSconf, during the formation of a solid solution fromn elements with equimolar fractions, may be calculated from the following equation:

$$\triangle \mathbf{S}_{conf} = -R \ln(1/n) = R\ \mathrm{In}(n)$$

where R is the ideal gas constant. Entropy value of Al–20Cu–10Mg ternary alloy was calculated and found to be 5.55 J/mol K.

2.2. Fabrication and extrusion of composites

The composites were synthesized through stir casting route by dispersing high entropy alloy particulates (HEAp) of an average size of 125 lm as reinforcement with various weight fractions varying between 5% and 15% quickly and continuously to the vortex. At the end of the particulate addition, composites were cast into a cast iron cylindrical mould 60 mm Ø _ 90 mm length. Subsequently, billets were hot extruded to 14 mm Ø rods (extrusion ratio 18:1). All the extrudates were thoroughly homogenized with industrial furnace at 100 _C for 24 h.

2.3. Testing

Vickers hardness studies were carried out for the alloy and composites using vickers hardness tester (Lecco Vickers hardness tester, Model: LV 700, USA) with1 kg load. The indentation time for the hardness measurement was 15 s. An average of six readings was taken for each hardness value. Tensile strength of alloy and composites at room temperature was determined using INSTRON 500 kN UTM 8803J 5353, UK with an electronic extensometer as per ASTM E-8 standards.Online plotting of load versus extension was done continuously though a data acquisition system. Scanning electron microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) were carried out using SEM-Hitachi S-3400N – Japan and SEM–ZEISS SUPRA 55VP operated at 20 kV, in order to evaluate the morphological and chemical compositions observed. The X-ray diffraction (XRD) pattern of reinforcement material was carried out using RIGAKU, ULTIMA-IV H-12-JAPAN for identification of phases. The electrical resistivity was measured by using the four-probe technique.

2.4. Results and discussion

2.4.1. Metallographic studies

Fig. 1 shows the microstructure of the Al–20Cu–10Mg with uniform distribution of the inter dendritic regions (IDRs).

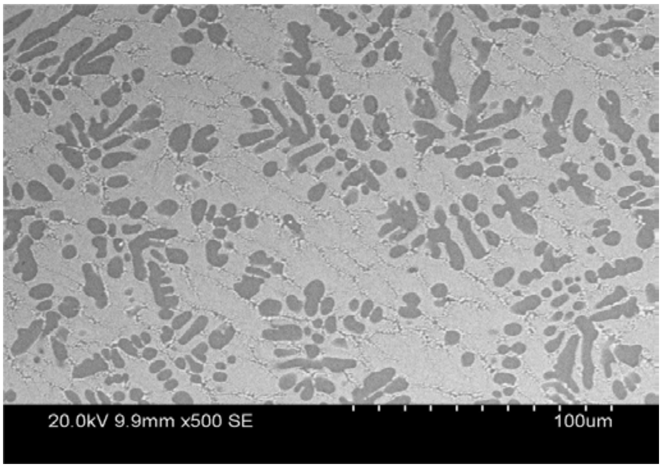


Fig. 1. SEM micrograph of Al–20Cu–10 Mg alloy.

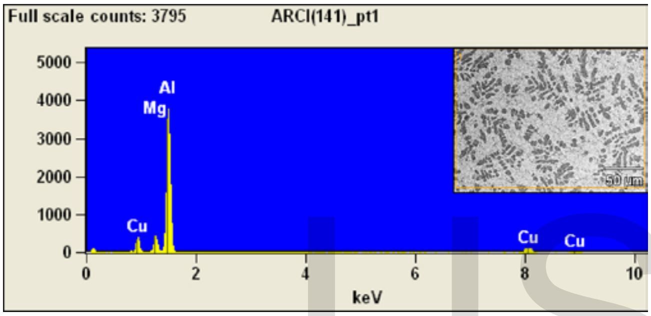
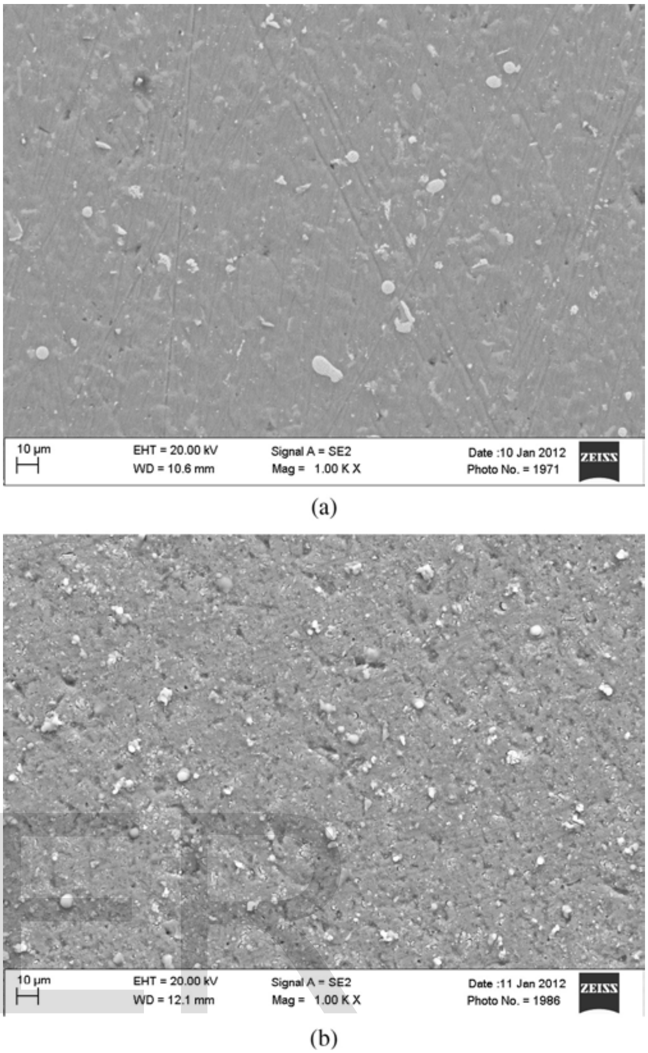


Fig. 2. EDX patterns of Al–20Cu–10Mg showing uniform composition of alloy.

Fig. 2 shows the EDX pattern of Al–20Cu–10Mg alloy. It was evident from the figure that Al, Cu and Mg peaks were observed in the EDS analysis. No oxygen peaks were observed in the alloy area, confirm that the prepared alloy does not contain any additional contamination from the atmosphere.



(a)

(b)

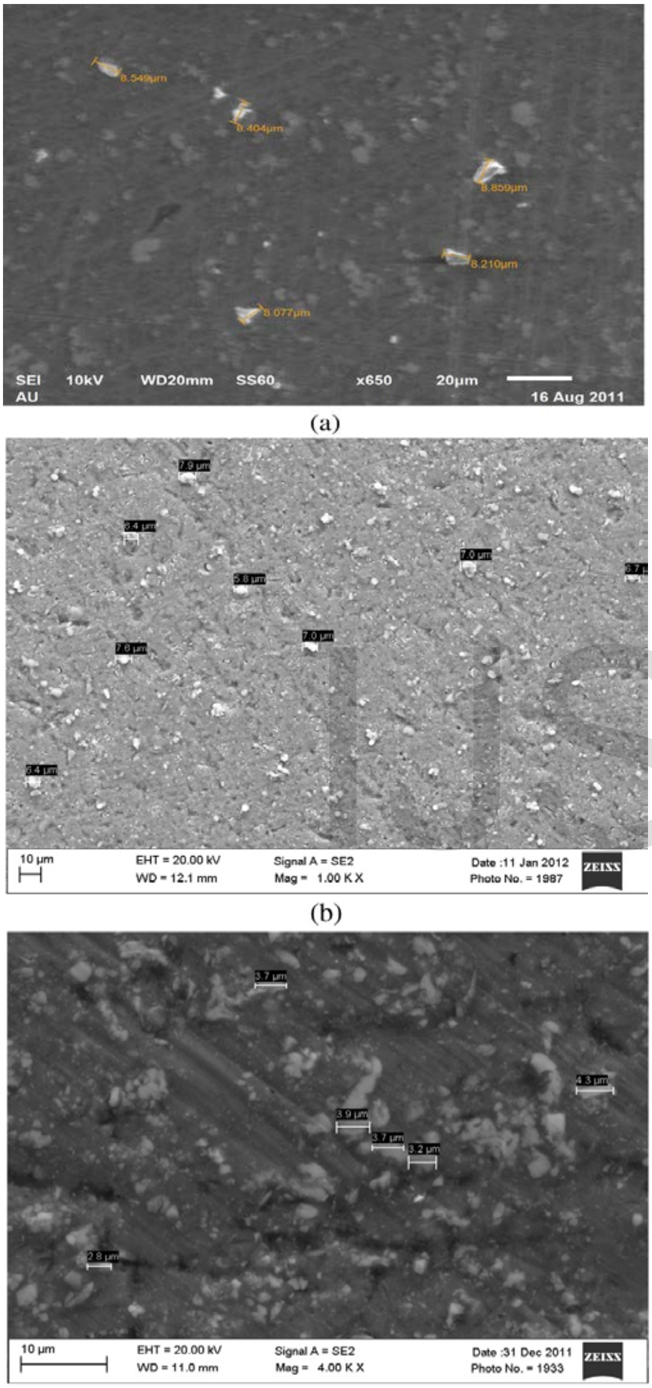
Fig. 3. SEM Image of (a) AA 2024-5% and (b) AA 2024-10% HEAp composites.

2.4.2. Mechanical properties

Fig. 3 shows the SEM images of the composites with 5% & 10% reinforcements. Structure shows the uniform distribution of the particulates. Though all the composites were prepared with particulate material of 125 lm size, the average particle size of the resultant composite found to be decreasing with increasing reinforcement content, Fig. 4. Since particulate addition times in composite making increases with increasing weight fraction, interface dissolution increases with time. This has resulted in the decrease of particle size, Fig. 5.

2.4.3 Hardness studies.

Fig. 6 shows the effect of reinforcement content on the hardness of the composites. Hardness increases with the increase of the amount of reinforcement contents.



(a)

(b)

(c)

Fig. 4. SEM images of (a) AA 2024-5%, (b) AA 2024-10% and (c) AA 2024-15% HEAp composites.

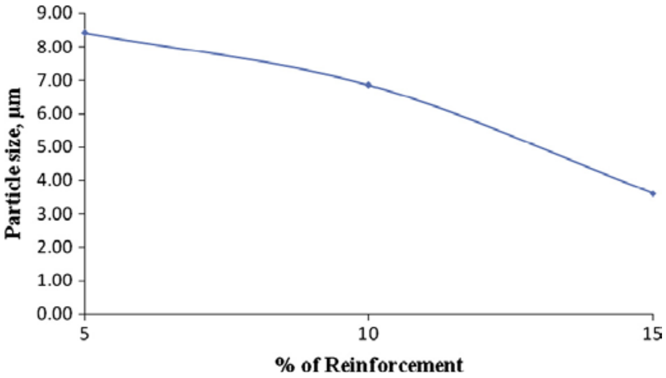


Fig 5. Effect of reinforcement on particle size.

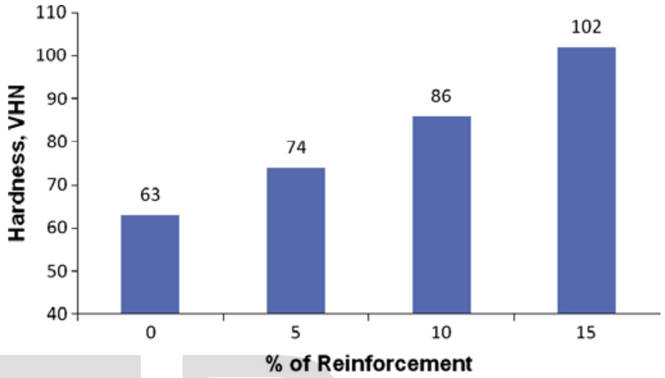


Fig. 6. Hardness variations of composites.

Similar behaviour has been reported by Kumar et al. [12] in a study on Al7075 - Al2O3 metal matrix composites concluded that hardness of the composites increased with increased filler content. Howell et al. [13] and Vencl et al. [14] reasoned the improvement of the hardness of the composites to the increased particle volume fraction. Wu and Li [15] and Deuis et al. [16] attributed this increase in hardness to the decreased particle size and increased specific surface of the reinforcement for a given volume fraction. Kim et al. [17] reasoned the increase in hardness of the composites to the increased strain energy at the periphery of particles dispersed in the matrix. Deuis et al. concluded that the increase in the hardness of the composites containing hard ceramic particles not only depends on the size of reinforcement but also on the structure of the composite and good interface bonding. Babu Rao et al. [18] reported the hardness improvement in aluminium alloys by incorporating flyash as reinforcement from 5 to 15 wt.%. This could be due to the presence of fly ash particulates which consists of majority of the alumina and silica which are hard in nature.

An increment of 62% in hardness has been observed. The increase may be attributed to the reinforcement effect, refined grain size of the matrix, interparticle distance, interfacial bond between reinforcement and matrix, restricted dislocation mobility [19], enhanced dislocation density [19], and higher constraint to the localized matrix deformation during indentation as a result of the presence of reinforcement & particle solubility in the matrix.

Fig. 7 shows the relation between the reinforcement content and the surface area to the volume ratio of the particulates measured. The decrease in particle size with increasing reinforcement content enhances the surface area to the volume ratio of the resultant reinforcement, Fig. 8. This further enhances the bonding between the matrix and the reinforcement.

Fig. 9 reports the comparison between the theoretical and measured values of hardness of the investigated composites. Measured values found to be more compared to the projected values by the rule of mixtures, this could be due to refined grain size of the matrix, restricted dislocation mobility, enhanced dislocation density, and constrain to the localized matrix deformation during indentation as a result of the presence of reinforcement.

The cumulative effect of all the above mechanisms, stimulate the hardness to higher values. Compared to the linear path of rule of mixture (ROM), the measured values took an exponential path, Fig. 9.

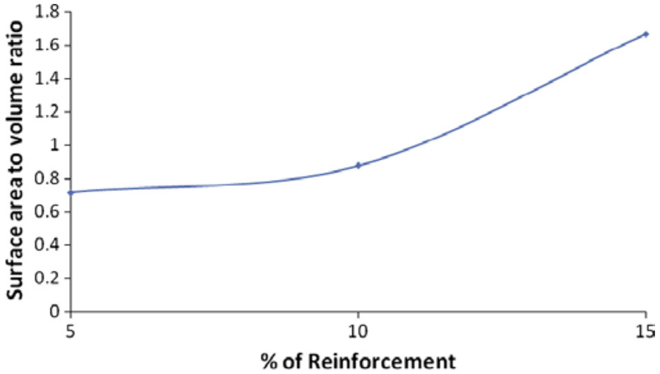


Fig. 7. Effect of reinforcement on surface area to volume ratio.

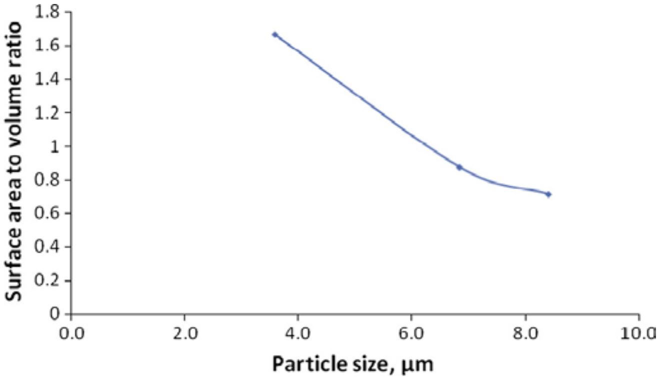


Fig. 8. Particle size vs. surface area to volume ratio.

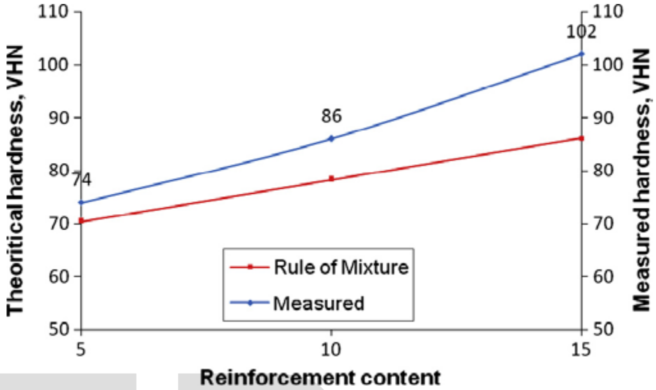


Fig. 9. Rule of mixture.

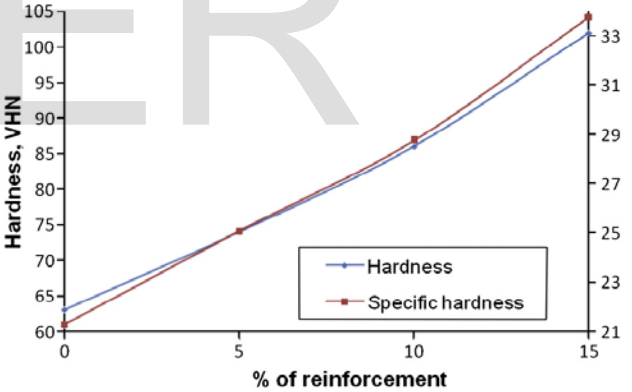


Fig. 10. Effect of reinforcement content on specific hardness.

Table 3
Summary of yield strength, UTS, and modulus of composites.

Composite	Yield strength (MPa)	Ultimate tensile strength (UTS) MPa	Young's modulus (GPa)	% Elongation
AA 2024 alloy	207.13	330.07	78.14	16.53
5% composite	311.3	401.14	87.75	12.58
10% composite	380.41	493.71	94.86	10.85
15% composite	405.78	563.65	102.69	8.64

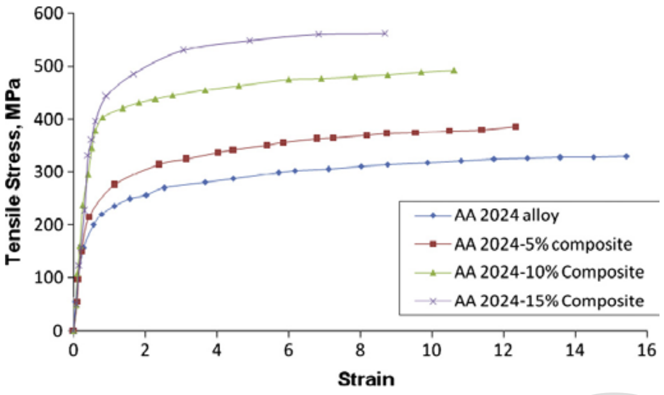


Fig. 11. Tensile strength vs. tensile strain of alloy and composites.

Since density plays an important in the selection of material, a comparison has been made between the specific hardness and measured hardness of the matrix material and the composites against their increasing weight fraction, Fig. 10. Though alloy shows lower specific hardness compared to the measured hardness, reinforcing the matrix with the particulate material enhances the specific hardness of the resultant composite right from the lower weight percentages of reinforcements itself. And the specific hardness found to be increasing with reinforcement content.

2.4.4 Tensile behaviour.

Table 3 shows the tensile behaviour of the alloy and the composites with reinforcements between 5% and 15%. Composites show improved strength properties compared to the base matrix. Increased reinforcement content enhances the strength properties further, Fig. 11. The tensile properties of composites found to be increasing with reinforcement content of the composites.

Rohatgi et al. [21] reports that the increases in tensile elastic modulus with increase in volume percent (3–10) of fly ash. The tensile deformation and fracture behaviour of the aluminium alloy 6061 reinforced with SiC has been investigated by Lloyd [22] and reported the elastic modulus of discontinuously reinforced composites is expected to be a function of the volume fraction of reinforcement, the aspect ratio of the reinforcement and the ability to transfer load to the reinforcement through the interface. Manoharan and Lewandowski [23] studied the effects of systematic changes in reinforcement size and matrix microstructure on the crack initiation and growth toughness of a 7091 aluminum alloy reinforced with SiC particulates. The addition of the SiC leads to an improvement in both the yield and ultimate tensile strength of the material.

Singh and Lewandowski [24] studied the effects of heat-treatment, matrix microstructure, and reinforcement size on the evolution of damage, in the form of SiCp cracking, during uniaxial tension testing of an aluminum-alloy based composite and reported that, the evolution of SiCp fracture is very dependent on particulate size, matrix aging condition, and matrix-reinforcement interfacial regions. Mcfranels [25] investigated SiC whisker and particle reinforcement in several different alloy matrices and reported up to a 60% increase in yield and ultimate tensile strengths, depending on the volume fraction of reinforcement, the type of alloy, and the matrix alloy temper.

Aghajanian et al. [26] have studied the Al2O3 particle reinforced Al MMCs, with varying particulate volume percentages, and report improvement in elastic modulus, tensile strength, compressive strength with increase in reinforcement content. Composites behave normally up to the yield point under both tensile and compressive loads. However, compression samples (52vol.% Al2O3 reinforced Al–10 Mg MMC) were able to accommodate far more strain before failing than tensile samples.

Sudarshan and Surappa [27] reported that the ductility of the composite decreased with the increase in weight fraction of the fly ash. This is due to the hardness of the fly ash particles or clustering of the particles. The various factors including particle size, weight percent of reinforcement affect the percent elongation of the composites even in defect free composites. Lorca and Gonzalez [28] proposed that at the initial stages of plastic deformation the increase in load carried by the particles is mainly due to the progressive strain hardening of the surrounding matrix, which is relatively ductile. As the matrix strain hardening capacity is saturated relaxation of stresses from fractured particles result in the stress transfer to nearby particles causing greater particle fracture. They further inferred that the final fracture of the composites takes place by a ductile mechanism involving the nucleation and growth of voids in the matrix, which contributes to the fina coalescence of the larger voids originating around broken particle.

Al-Dheylan et al. [29], reported that, The yield strength, UTS and Young's modulus of composites increased with the increase in volume fraction of the reinforcement, while the ductility decreased. Due to the constraints imposed on the deformation caused by the presence of the hard and brittle Al2O3 particles in the soft and ductile 6061 Al alloy matrix higher applied stress is required to initiate plastic deformation in the matrix. This in turn results in the increase in the elastic modulus and strength of the composite.

With increasing weight percentage of the reinforcement more load was transferred to the reinforcement resulting in a higher ultimate tensile strength values. The increase in work hardening rate with increase in reinforcement content enhanced the modulus values. Since both the matrix and reinforcement used were of similar nature of the materials, the good compatibility between them offered lower rate of resistance towards deformation resulting decelerated increase in modulus values. Yield strength shows a similar trend as that of tensile strength depicting an increase of 95%, while compared to 70% increase of that of ultimate tensile strength.

As reported by several authors, there was only a 50% drop in % elongation compared with the matrix material. The drop in ductility is due to the increased resistance offered by the reinforcement and the intermetallics present at the matrix-reinforcement interface as explained in earlier paragraphs. Composite with 15% reinforcement has shown 8.6% ductility which is quit high compared to any of the metal matrix composites reported.

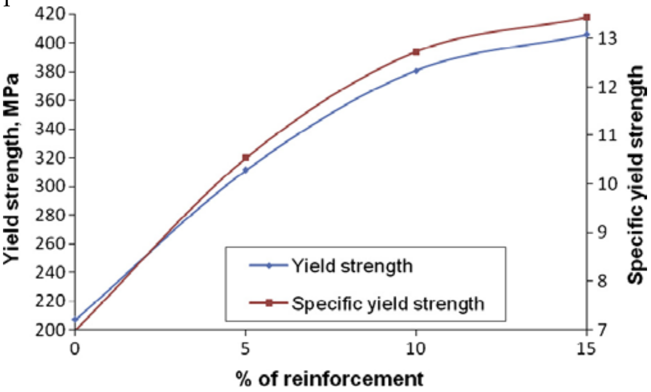


Fig. 12. Effect of reinforcement content on specific yield strength.

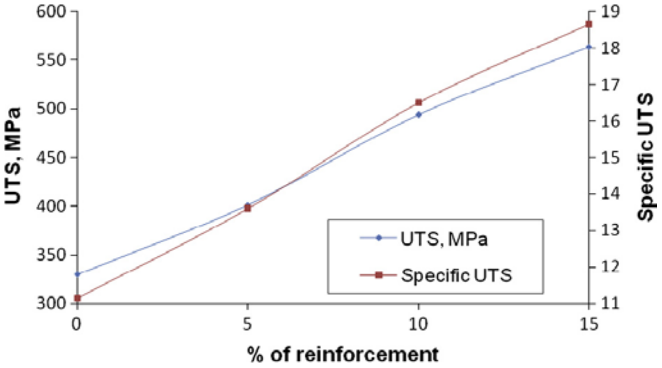


Fig. 13. Effect of reinforcement content on specific ultimate tensile strength.

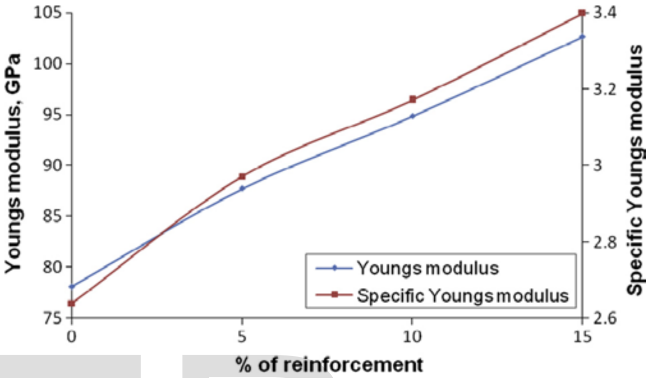


Fig. 14. Effect of reinforcement content on specific Young's modulus.

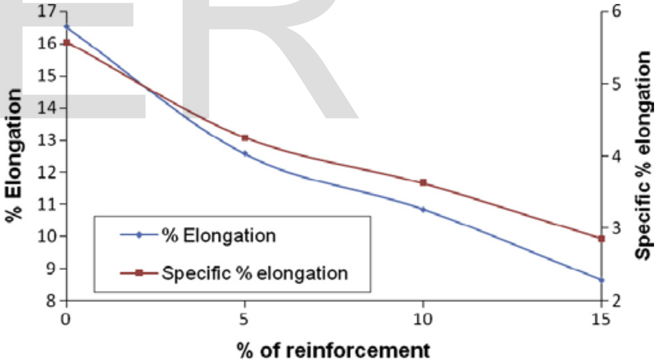


Fig. 15. Effect of reinforcement content on specific % elongation

The specific properties of the ultimate tensile strength, yield strength, Young's modulus and ductility have been shown from Figs. 12–15. In all the cases compositing has shown improved specific properties compared to the alloy. Similarly, the specific property interms of ductility has been proved better compared to that ofmatrix alloy.

3. CONCLUSIONS

The commercial alloys features are tuned with the AA2024 alloy prepared in the lab.The fabrication procresses for metal-metal composites ofAA2024 is reinforced with high entropy alloy particulate is successful. Increased reinforcement contents enhance all the mechanical properties such as yield strength, tensile strength and Young’s modulus of elasticity . Specific hardness of the resultant metal–metal composites is much superior to conventional MMCs. The decrease in particle size with increasing reinforcement content enhances the surface area to volume ratio of the resultant particulates. Direct hot extrusion produced resultant composites.

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Fig. 12. Effect of reinforcement content on specific yield strength.
Fig. 13. Effect of reinforcement content on specific ultimate tensile strength.
Fig. 14. Effect of reinforcement content on specific Young’s modulus.
Fig. 15. Effect of reinforcement content on specific % elongation.
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