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Aluminium Based Metal Matrix Composites for Aerospace Application: A Literature Review

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Abstract: *Aerospace is a material intensive industry. Inadequacy of a single or a group of materials to fulfill all the stringent requirements of aerospace industry along with the dual demand of economy and performance have led the researchers to look for new material. Composite is the answer. Although aircraft utilizes numerous elements in their construction, the most important of these is aluminium because of its low density, good castability, high strength, corrosion resistant and good fatigue strength. However its usage is constrained due to its limited strength and hardness. To overcome this, aluminium is combined with various other elements. An example of this includes a family of materials known as aluminum metal matrix composites (Al-MMCs). Of all criteria of material selection for aerospace application, the most important is strength to weight ratio i.e. high specific modulus (E/ρ). Because of its high specific modulus, good mechanical and thermal properties aluminium based metal matrix composites are natural choice for aerospace applications.*
Keywords: *Metal Matrix Composite(MMC), Reaction at Interface, Wettability, Reinforcing Material, Grainsize, Hybrid Aluminium Composite*

I. Introduction

Composites are defined as materials with following criteria [1]
(a) Must be a combination of at least two chemically distinct materials with distinct interphase separating the constituents
(b) Must be combined three dimensionally
(c) Should be created to obtain properties which would not otherwise be achieved by any of the individual constituent.

Traditionally, aluminium and its alloys are being used for manufacturing various parts (specially aircraft structure) for aerospace application. some of the reasons being low density good castability, high strength, corrosion resistant and good fatigue strength.

However, aluminium based MMCs outsmart aluminum and its alloys in mechanical and thermal properties. Ceramics that are generally used for aluminum matrix are SiC, BN, graphite, flyash and rice husk ash (as a source of SiO_2), Si_3N_4, Al_2O3, B_4C and TiB_2. Primary aim of reinforcement is boosting of mechanical properties like strength, fracture toughness, creep strength, wearability, hardness and fatigue strength. Methods that are commonly used for fabrication and production of aluminum based MMCs are Powder Metallurgy, Stir Casting, Squeeze Casting, Rheocasting, Plasma Vapour Deposition and Infiltration Technique.

II. Factors Affecting Outcomes Of AL-MMCs

Factors affecting the outcome Al-MMCs are reaction at the interface, wettability, shape and size of reinforcing material volume fraction of reinforcing material and fabrication methods.

2.1 ReactionAt The Interface

It is always imperative that some degree of reaction takes place at the interface. It is Essential for developing strong interfacial bond which allows efficient transfer of load from matrix to reinforcing material
Reaction in AL/SIC MMC at interface is

$$4\,Al + 3\,SIC <-> AL_3C_4 + 3\,Si$$

The controlled reaction is good as AL_3C_4 layer at the interface improves offset yield strength, ultimate tensile strength, work hardening rate with a slight reduction in ductility [2] . On contrary if it is allowed to grow, the consequences are
(a) It deteriorate SiC reinforcement
(b) AL_3C_4 being brittle degrades mechanical properties of the composite
Method to avoid formation of $AL_3C_4$are
(a) Chemical coating of reinforcing material act as a barrier for reaction[2]
(b) In Squeeze casting method due to high rate of heat transfer and undercooling less time is available for reaction to take place [5]

(c) Addition of Si it shifts reaction to left side [10]

2.2 Wettability

It is the ability of liquid to wet the surface. It depends on surface tension of liquid. It is essential as it leads to a good interfacial bonding. Methods to enhance wettability are as mentioned below

(a) Addition of mg to molten Al matrix reduces surface tension of the matrix[2]
(b) heating of reinforcing material (contact angle for SiC at 900°C is 150 degree and at 1100 °C is 42 degree)[2]
(c) Chemical coating of reinforcing material (coating of SiC with Ni / chromium carbide[2])
(d) Application of pressure as in squeeze casting [5]
(e) Use of mechanical force such as steering[5]
(f) Use of ultrasonic energy to steer the melt [5,9]
(g) Addition of chemical that improves wettabiity (wettability of B_4C improved by adding K_2TiF_6 salt Al melt [8])

2.3 Distribution Of Reinforcing Material

Homogeneous distribution of reinforcing materials enhances mechanical properties. Methods to avoid agglomeration/clustering during addition of reinforcing materials are as given below. (it is needed as it deteriorates mechanical properties of Al-MMCs.)

a) Addition of reinforcing material when melt is in semi-solid state (Rheocasting)[3]
b) Steer casting and then use of secondary processing method like extrusion[4]
c) Squeeze casting method[5]
d) Powder metallurgy route of processing[6] Use of ultrasonic vibration[9]
e) Double steering method[10,11]
f) Two steps addition of reinforcing material[8]

2.4 Strengthening Mechanism

Reinforcing material impedes dislocation movement thereby strengthening the metal matrix. Parameters affecting dislocation inhibiting mechanism are

(a) Mean free path in the matrix M_{fp}
(b) Separation distance between particles D_p

Relationship between these parameters and particle diameter 'd' and volume fraction v_f are

$$M_{fp}=2d/3v_p(1-v_p)$$
$$D_p=2d/3v_p(1-v_p)$$

For a dislocation to pass through a dispersion of fixed particle, the applied stress must be sufficient to bend the dislocation into semicircular loop whose radius is given as

$$R=G_m\, b/2\tau_i$$

Relation between shear stress to distort dislocation into loop, τ_i and interparticle spacing, D_p

$$\tau_i=G_m b/ D_p$$
$$D_p=2R$$

2.5 Grain Size And Reinforcing Particle Size

Smaller size particle provides more interfacial area that serves as nucleation site for grain formation. It provides constrains to grain growth during cooling, thus refining grain size. The rate of solidification affects grain size as given by relation[5]

$$D= K/R^a$$

d=grain size, k=constant depending on types of composite(range form 0.34-.39)

Thermal mismatch between metal matrix and reinforcement leads (CTE for Al=$21.4*10^{-6}$ and Sic= $4.3*10^{-6}$) generation of dislocation at interface as given by Taya and Aersanault model [11]

$$\rho=B\varepsilon V_r/bd(1-v_r)$$

B=costant, ε=thermal strain, $V_{r=}$ volume fraction, b=burger vector, d=grain size

Contribution to strengthening due differential CTE is given by [11]

$$\sigma_t=\alpha Gb(\rho)^{0.5}$$

Hall Petchequationgives Relation between grain size of metal matrix and yield stress

$$\sigma_o= \sigma_i+k/d^{0.5}$$

σ_t- yield stress, σ_i- friction stress, k- locking parameter, d- grain diameter

2.6 Fabrication Methods

Comparison between three main fabrication methods along with their attributes are given in table below

Attributes	**Steer Casting [2,3,4]**	**Squeeze casting[5]**	**Powder metallurgy[6,7]**
Distribution of reinforcing material	Problem of settling down during solidification leading to inhomogeneous distribution	Homogeneous distribution	Homogeneous distribution
Volume fraction of reinforcing material	Up to 20% possible after that segregation and cluster formation	Up to 30 % possible	Even beyond 30 % possible
Interfacial bonding	Difficult in forming interfacial bonding	Strong	strong
Wetability	Problematic	Good	Better than other methods
Mechanical properties	good	Better than steer casting	Best result achievable
Grain size of matrix)	coarse	Fine	Can be tailored as per requirement by mechanical alloying

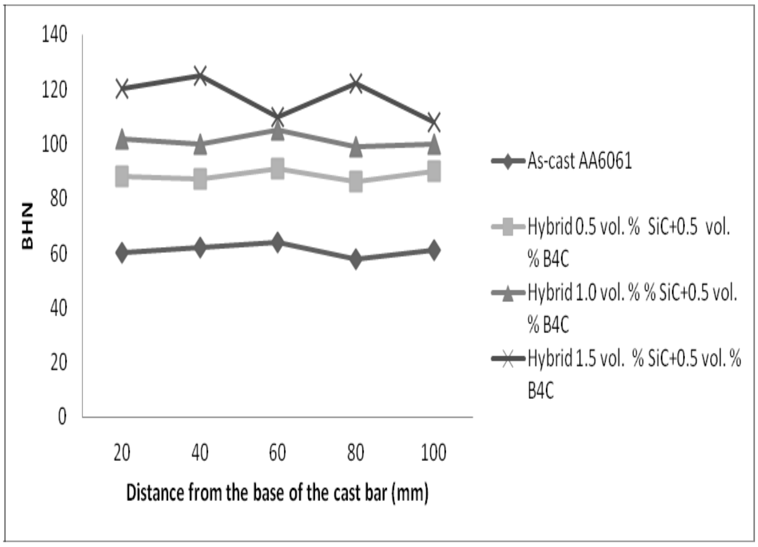

Figure1 BHN Distribution of Unreinforced and Hybrid Composite[9]

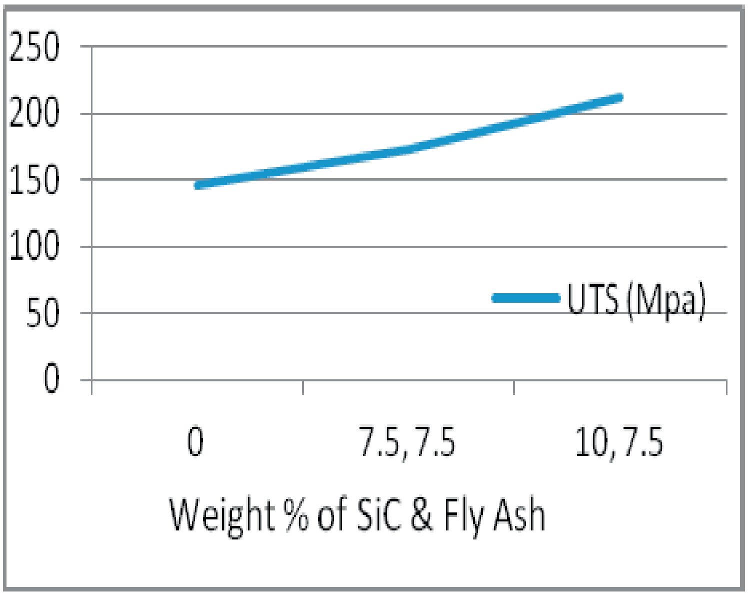

Figure2: Effect of Weight % of SiC& Fly Ash on UTS [10]

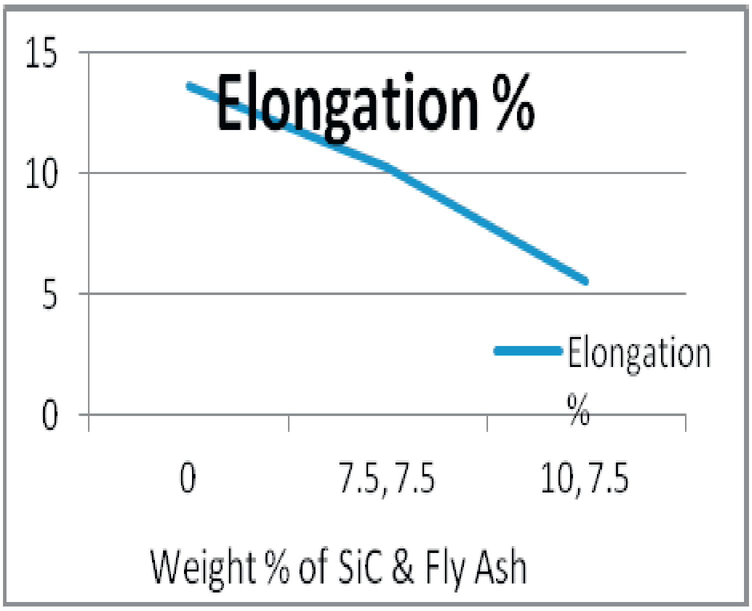

Figure 3: Effect of Weight % of SiC& Fly Ash on Elongation[10]

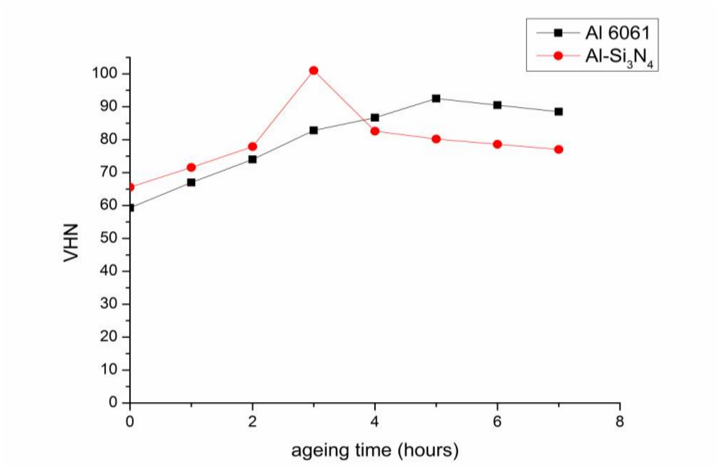

Figure 4: Ageing Behavior of Al6061 and Al-Si_3N_4composite[12]

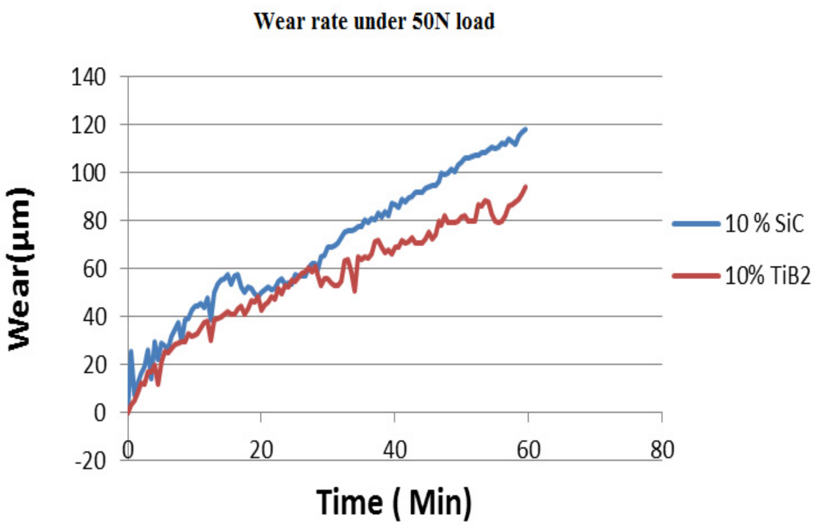

Figure 5: wearability of Al Composites Reinforced with SiC&TiB_2[13]

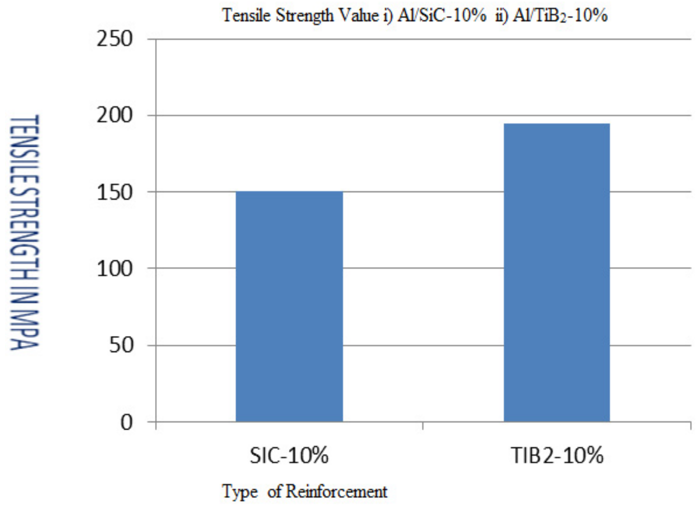

Figure 6: Tensile strength of Al Composites Reinforced with SiC&TiB_2[13]

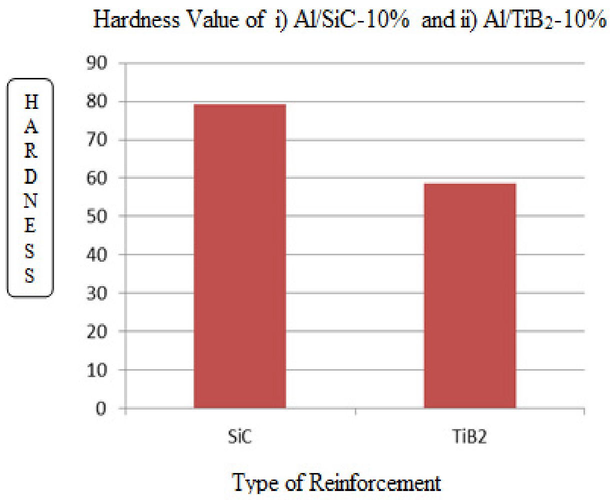

Figure 7: harndness value of Al Composites Reinforced with SiC&TiB_2[13]

III. Hybrid Aluminium Composite

When more than one reinforcements are added to optimize the properties (mechanicalthermal, electrical etc), it is called hybrid composite. Literature survey on some of the Al hybrid MMCs are as tabled below

Hybrid AMC	**Authors**	**Method**	**Findings**
Al/B_4C (0.5vol%) /SiC(0.5,1%1.5 %)nanoparticles	Poovazhagan L et all [9]	Ultrasonic cavitation method	Increase in hardness, tensile strength, High dislocation density due to thermal mismatch, Grain size refinement, Optimum value achieved at 1vol % and 0.5vol % B_4C
Al/SiC(7.5,10 wt%)/FlyAsh(7.5wt%)	David Raja Sevlam j. et all [10]	Stir casting method	Decrease density, increase hardness, wear resistance and stiffness , High dislocation density due to thermal mismatch,Grain size refinement
Hybrid AMC	**Authors**	**Method**	**Findings**
Al/x%SiC/x%RHA (x=2,4,6,8 wt%)	Dora Sivaprasad et all [11]	Double stir casting	Precipitation kinetics accelerated leading to reduction in time for getting optimum hardness through ageing Decrease in density, increase in yield strength and UTS,Grain size refinement
Al/Al_2O_3(0.5wt%) /B_4C (0%,3%,5%wt)	T Harprasad et all [14]	Stir Casting	Wear characteristics of hybrid composite is better than singular reinforced composite,Increasing wear resistance with increasing % of B_4C

IV. Conclusion

Selection of exact material in aviation industry is role specific however certain properties such as high specific modulus, good fatigue performance, and high wear and corrosion resistant are seen as universal requirements. Al/ SIC MMC looks promising. The main reasons for its considerations are

a) Good strength to weight ratio
b) Good ductility
c) High tensile strength (AL – 89.6 n/mm^2 , AL/SIC- 265 n/mm^2)
d) Good corrosion and wear resistant
e) Good thermal stability

From literature, it seems that composite can be manufactured by either solid or liquid phase methods. But for effective results, factors such as interface reaction, volume fraction of reinforcing material, type of reinforcing material and its distribution in the matrix must be taken into consideration during design, material selection and fabrication process. With the right selection made, it is genuinely believed that Al-MMCs have tremendous potential for application in aerospace industry.

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