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Mechanical and Thermal Properties of Aluminum Metal Matrix Composites - A Review

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ABSTRACT

Aluminium metal matrix composites (AMMCs) have been suitable materials for multiple devices because of its excellent physical and structural characteristics. These AMMCs have been attaining public adoption for applications of industrial, aeronautics, heavy equipment's owing to its key features. The current research dealt with study of effect on aluminium matrix alloy with adding reinforcement like fly-ash, Sic, Al_2O_3, Graphite, B_4C, Cubic boron nitride (CBN) etc. to aluminium in multiple percentages. Every reinforcement had its own individual characteristics that enhances the base aluminium characteristics when added. By adding these types of reinforcement to metal base led to enhancement the properties like wear resistance, stiffness, creep, tensile strength, fatigue, toughness, thermal conductivity, hardness in comparison with traditional materials of engineering. This paper gives detailed information about the impact of incorporation of various reinforcements in matrix illustrating its benefits and drawbacks. Extensive understanding of properties were given to have general survey of MMCs, and the greater results could be used to much farther develop the AMMCs.

Keywords: Aluminum Metal Matrix Composites; Mechanical Properties; Thermal Properties

1. Introduction

Metal matrix Composites (MMCs) are the material of composites with a minimum of two components, one should essentially be a metal, another one could be a different metal like compound or ceramics. They were formed by distributing the reinforcement materials within the matrix. By the introduction of reinforcements like B_4C, Sic, Al_2O_3 to matrix alloy, much useful Properties of alloy matrix like Hardness, thermal Conductivity, strength, wear-rate and so on would be enhanced. Composite’s properties rely upon the properties of component phases, its relative quantity, distributed phase geometry in addition to the Particle’s shape, size and alignment of matrix[1]

In our daily life, AMMC’s have found many applications. AMMCs were Composites that only use aluminium as the matrix and incorporate a few reinforced components into the Matrix. There are a few benefits when using the reinforced AMMCs in the comparison with unreinforced products such as low thermal-expansion Coefficient (CTE), improved stiffness, greater Hardness and Strength, light weight, high-specific modulus, enhanced damping capabilities, enhanced wear-resistance and greater thermal Conductivity (TC).The Matrix may include reinforcing elements in a manner of continuous fibers, particulates or monofilaments. These have been using in the fields of industrial goods, automotive and aeronautics applications [1]. The reinforcement particulates must be robust, flexible and anti-reactive in the specified operating temperature. Sic, Al_2O_3, graphite, Cubic boron Nitride (CBN) are commonly Used as reinforcements.

In order to gain the optimum Properties selection of good reinforcement and the Matrix materials were not only sufficient, Processing method additionally plays a significant role. There are different techniques available to produce AMMCs like Powder Metallurgy, squeeze casting, stir Casting, Chemical vapour Deposition, Pressure Infiltration etc. Among these manufacturing techniques stir Casting was the prevalent technique which has been using by many investigators because it is cost-effective, standardized Matrix material reinforcement dispersion can be obtain and samples which are generated by this process have greater Hardness and refined microstructure-grains than other techniques. Skibo et.al [2] noted that the Cost for preparing AMMCs is approximately one-third to half that of other techniques and that price of high-volume manufacturing will be reduced to one-tenth.

2. Mechanical Properties

The mechanical Properties of MMCs are necessary to describe the Composite material’s behaviour. Tensile strength, Stiffness, Hardness, wear resistance, toughness were few of the significant mechanical properties assessed. These mechanical properties play a key role to characterize the behaviour of composites. By adding greater Strength, greater-modulus refractory particulates to a highly ductile Matrix material gives a new product which has mechanical Properties were in between reinforcement and metal matrix. Metals had a beneficial Properties like ductile, greater temperature resistance, immense strength but typically can have poor stiffness, while ceramic materials have greater stiffness and strength, although brittle. By combining both will get a new product which has stiff, immense strength and greater temperature resistance.

AMMCs have different positive impact on Mechanical Properties those are important in several current applications. Experiments on the mechanical Properties try to create the research on Composite materials in exhaustive. The different mechanical Properties that are regarded as follows in this review.

2.1 Hardness

Hardness is the material's ability to resist scratching (abrasion). It is also defined as the material's capacity to cut different metal. It encompasses other different Properties like Machinability, Deformation, Scratching, wear-resistance and so on. Processes that enhance a material's hardness also enhance its tensile Strength but at the same moment reduce the material's Toughness as it gets further brittle.

Shanmuga Sundaram et.al [3] has proposed that the study of the impact of Particulate types and extrusion on Al2014/Si_3N_4, Al2014/Sic and Al2014 matrix material. From hardness test, there is an enhancement of 23% and 42% was noticed in Al-Sic Composite material in As-Cast and Extruded situations compared to matrix material. The general reason for enhancement of hardness of a matrix material was owing to the introducing hard ceramic particulates to the highly ductile and smooth metal matrix. Likewise, there is an enhancement of 35% and 31% was witnessed in Al/Si_3N_4Compared to matrix material. This was owed to the existence of strong ceramic particulates that prevent the matrix dislocation motion that causes a matrix to harden. Singla.et.al [4] has noted that the peak Hardness 45.5 BHN has achieved in Al/SiC composite material with weight proportion of 25%. Song et.al [5] found Hardness Values are enhanced with rise in ageing temperature and peak hardness value acquired at temperature 150°C to 200°C and also noted that the 2014 Al composites are very hard in Compared to 6061Al. By rising the ageing temperature to 250°C, there is considerable loss in hardness values for all Composites was noted. Vanarotti et.al [6] observed with increment of wt.% of Sic in Al 356, the BHN was increased. Fang et.al [7] noted that, due to few reaction contaminations and greater porosity problems, in-situ Al composites had poor Vickers hardness. Biswas and Jairam [8] revealed that porosity has been the key factor effecting Sic and Al_2O_3 reinforced Al composite's hardness. Bansal and saini [9] Al 359 MMC's hardness reinforced with Sic is so much greater than the Al 359-Graphite's hardness. Good Gr/Sic bonding enables the material to resist greater loads.

Mali et.al [10] explored few Properties on Al 356 alloy with alumina and fly-ash as reinforcement with different percentages. It had been noted that composite's hardness raised to 94 BHN till 12% and subsequently reduced owing to Porosity. Raao et.al [11] examined Vickers Hardness of Al/Zn/Mg (Al7009) and Sic reinforced Al/Zn/Mg (Al7009) enhanced with the heat treatment and as well with the increment of Sic percentage in the alloy matrix.(Kumar and Bhushan) noticed 10.48% rise in hardness with an increment of 5-15% Sic reinforcement in Al 7075 alloy.Purohit and deshamanya [12] found Al7075/Al_2O_3 composite's hardness reduced as reinforcement size increased owing to a greater size of grains resulting in a less dense dispersion of Al_2O_3 Particles in Al Matrix. Initially, the composite's hardness is revealed to be decreased with arise in the reinforcement proportion. Indeed, the hardness was enhanced significantly after approximately 8% of the reinforcement added and a peak hardness value 140 BHN for a Composite material comprising 15% Al_2O_3 was noted. As reinforcement quantity rises, the reinforcement-matrix ratio may become richer, resulting in enhanced Composites hardness.

It is obvious that by above discourse that Silicon Carbide (Sic) plays a significant role within enhancing the composite's hardness. The best range displaying the greatest results at the weight proportion of 25%. If we rise wt.% of Sic beyond 25% then it results in reduction of hardness values because the greater wt.% of Sic particulates began to settle in melt of aluminium. Introducing different reinforcements shows rise in hardness, but they were restricted to some range and after that they will tend to reduce.

2.2 Tensile Strength

Tensile strength was a material's capacity to loads of tensile (stretching) without material being in the tension. D. sujan et.al [13] discovered that, AMMCs with Al_2O_3 as a reinforcement had a greater density values Compared to AMMCs with Sic as a reinforcement, since Al_2O_3 density value was greater than the Sic density. It is also discovered that Tensile strength and Hardness of Al/Sic greater in comparison with Al/Al_2O_3 Composites. The reinforcing particulates serves as a strengthening substance that enables close the pores in Matrix alloy, establishing a greater contact between matrix particulates. Rahman and rashed et.al [14] reported peak Tensile strength Value obtained at 20 wt.% of Sic incorporated within matrix alloy. The general reason for rise in Tensile strength is owing to the shifting of tensile load to the heavily attached Sic reinforcement which mostly increases the density of dislocation and therefore results in refining impact of grain. The results indicated from tensile test on 6061 Al which was reinforced with graphite had greater tensile strength Compared to Sic reinforced 6061 Al. This was all because of graphite filler's greater strength. Strangely, the Tensile strength stayed same at 12wt.% owing to inadequate graphite wetting.

Shanmuga Sundaram et.al [3] has proposed that there is 11% and 33% yield strength enhanced within the composites of Al/Si_3N_4 and Al/Sic Compared to base matrix metal. The general reason for enhancement of composite's strength is owing to increasing density of dislocation that was due to incorporation of ceramic particulates such as Si_3N_4 and Sic. The greater CTE difference between Sic and aluminium causes the rising of density dislocation and it was also noted that the composites Al/Sic displayed better properties Comparison with Al/Si_3N_4. Kumar et.al [15] has observed from Al 6061 reinforced with three variation of fly-ash 10%, 15%, 20 wt.% and mentioned that there is increment of tensile strength because fly ash had a greater strength. But the Tensile strength property was diminished when the reinforcement added beyond 15 wt.%. the principal reason for diminishing the Tensile strength is owing to the poor wettability. It was also noted that the UTS enhanced to 192 MPa. Kanagaraj and kumar et.al [16] evident that UTS was enhanced with incorporation 17 wt.% alumina but there was no obvious change with the graphite reinforcement. This may owe to the thermal mismatch that tries to be the primary driving force to raise matrix's dislocation density. Vinitha and motgi [17] observed from their research that Al 7075/Sic/fly ash MMCs has greater strength than Al 7075/redmud/Sic composites. Muruganandan et.al [18] mentioned that there is 32% enhancement of Tensile strength in Al 7075/Tic/fly ashMMCs in Compared to matrix alloy. This was owing to fly-ash hardened the matrix material. Onel and cocen [19] evident that the Values of tensile and yield strength were enhanced until Sic of 17 vol.% in as-Cast situations and after that the values were decreased. These values enhanced for extruded specimens by 40% and consistently enhanced with vol.% of reinforcement. Yilmaz and kalkanil [20] noticed from T6 heat treated and as-Cast silicon Carbide reinforced 7075 Al tensile test results and mentioned that 10 wt.% Sic heat-treated composite had greater tensile strength in comparison with as-Cast reinforced Al 7075.

From above discussion, both Graphite and Sic were prolific reinforcements in the field of tensile strength. Another reinforcement alumina demonstrates nice outcomes as well, but there was not much talk about it. The incorporation of different reinforcements like fly-ash and red-mud also helped to raise tensile strength values until certain limit but after that rapidly diminished.

2.3 Ductility

Ductility was the measure of the Capacity of material to deform plastically when put under tensile stress that surpass its yield strength without splintering. Greater ductility shows that the material is more suitable for deformation and does not shatter. Whereas less ductility shows the substances was brittle and breaks before it deforms through a tensile load. Ductility relies mainly on the structure of crystalline substances, Chemical composition of substances and temperature at where ductility was evaluated.

Onel and cocen [19] has reported that with the raise in Sic vol.%, diminished ductility of as-cast MMC sand also noticed that there is enhancement of ductility by the implementation of extrusion. Srivastan and Prakash et.al [21] observed elongation %, decrease in area %, reduction of tensile ductility by raising reinforcement. Study of fractography disclosed that existence of brittle and tough Sic within the ductile and smooth alloy matrix triggered fine micro-cracks to be begun at less stress values. The micro-cracks grew quickly, leading to macroscopic deficiency and less tensile ductility. Xu et.al noted Al 359 which was reinforced with as-Cast Sic composite's ductility enhanced significantly through Hot iso-static Pressing (HIP) but still yield stress dropped considerably. The decrease of inner defects owing to HIP therapy was the principal reason for ductility enhancement. In terms of ductility and strength, the hot iso-static pressed and T6 heat-treatment samples were good than as-Cast samples. Garg and Ravesh et.al [22] mentioned there was diminish in ductility and increment in Tensile strength values with raise in Sic wt.% within Al 6061/fly ash/Sic composites.

2.4 Toughness

Toughness is a material's potential to withstand cracking. If a substance breaks down, it was brittle. If it was doesn't break when undergoing an impact load, it was tough. Md. Habidur et.al [1] noticed from with raising Sic reinforcement in Al MMCs, Hardness, porosity Tensile Strength and wear-resistance enhanced but toughness has decreased. Ravesh and Grag [22] mentioned toughness of Al 6061/fly ash/Sic was enhanced with the increment of reinforcement. This is owing to sufficient reinforcement distribution within alloy matrix and there was greater bond between reinforcement and base metal. The peak toughness 7.8 acquired at the composite comprising 5 wt.% fly-ash and Sic 10 wt.%.Aluko and Alaneme [23] revealed from Circumferential notch tensile test that fracture- toughness is enhanced with the raising vol.% of SiC or else with the help of ageing treatment. Park et.al [24] mentioned that toughness value has diminished with raising 5 to 30vol.% of Al_2O_3 reinforcement. The principal reason for this is owing to reduction in spacing among nucleated micro-voids of inter-particulates. Alaname et.al [25] disclosed that BLA and Sic reinforced Al/Mg/Si composite's fracture-toughness is enhanced as BLA proportion raised. This is because raising existence of silica which was smooth than Sic. The hybrid composite's fracture toughness found to be inferior than single reinforcement which has 10 wt.% Sic in aluminium.

2.5 Wear resistance

Wear rate is the volume loss per unit distance. Shanmuga Sundaram et.al [3] had manufactured Al7075-SiC Composite. By using pin-disc test, elaborated sliding-speed and differing load on wear rate. At 1 m/sec sliding-velocity and 20 N load, the composite material which was precipitated heat-treated (6 hrs T6 aged) displayed greater wear-resistance and also elaborated that by doubling load there was 26% enhancement wear rate and by raising sliding velocity there was 21% wear enhancement and also clarified that Irrespective of load and velocity heat-treated composite's wear resistance enhanced by ageing. Saini and bansal et.al [9] explained Al 359/graphite/Sic wear behaviour and results had shown reinforced matrix's wear resistance raised with conditions of sliding distance, loading and greater sliding-speed and also mentioned that graphite diminishes wear- resistance at greater loading than Sic because it has extreme lubricant property. From SEM analysis concluded that Al 359/Sic surface had big sized cracks, voids, groove sand also confirmed that these were viewed very fine within Al/graphite/Sic than Al/Sic composites.

Natarajan et.al [26] et.al linked 356 Al/Sic 25 composite's wear properties with gray cast-iron sliding material towards the friction material of the automotive. It has been discovered that the composite's wear resistance was greater than standard gray cast-iron and was very appropriate for Brake drum material. Even so due to existence of hard particulates of Sic, it won't be taken for lining components. MahaJan et.al [27] and thirumalai et.al [28] taken reinforcements of B_4C and Tic and revealed that till some wt.% the wear-resistance was raised. Manikandan et.al [29] explained Al 7075/B_4C, Al 7075/Sic and Al 7075/Al_2O_3 composite's wear characteristics with differing sliding distance and load by test performing on pin-disc and mentioned that due to hardness and heat-resistance of B_4C, the Al 7075/B_4C composite had disclosed better wear-resistance In compared to others. Muthu et.al [30] discovered 7075 Al-fly-ash 5%- Sic 3% dry sliding properties and noted that there is diminishing wear-rate and enhanced density when Sic incorporated to 7075 Al. both properties were diminished in fly-ash context and also noted with increasing sliding speed 2 m/sec to 3 m/sec wear-rate and includes specific wear-rate both enhanced and after reduced at m/sec.

Abouelmagd [31] examined AMMCs wear behaviour and hot-deformation which were generated by powder-metallurgy method and disclosed that compressive strength, hardness enhanced with raising introduction of Al_4C_3, Al_2O_3 reinforcement to alloy matrix. In the context of Al/Al_4C_3, there was enhancement of wear-resistance. Kumar et.al [32] enhanced the effectiveness of 2024 Al/Sic nano particulates by the incorporation of nano particulates of Graphite and mentioned that wear-resistance enhanced by Sic incorporation but with graphite particulates incorporation furthermore enhanced and there was good bond within composites which was revealed by XRD analyser. Rahman and Rashed [14] noticed from his research that mass loss for Al/Sic was lower in compared to aluminium which was in pure form. This is owing to softness of Pure Al. it gets easily got worn while doing tensile test. These attached Sic safeguard the alloy matrix against more wear. At Sic 20 wt.% the peak wear-resistance was attained.

From literature-survey, it is clearly understanding that with adding Graphite, Sic wear-resistance could enhanced. The MMCs were guarded with Sic which were predominant on external substances layer and also if the MMCs are conducted at grater load, the particulates of Graphite tend to diminish the rate of wear.

3. Thermal Properties of MMCs

The material's thermal Properties were those features which are associated with its heat Conductivity. In another sentences, when heat moves through it, substances possesses these properties. Thermal-resistivity or conductivity, Thermal-expansion Coefficient, thermal-diffusivity and specific-heat Capacity were few of essential properties of thermal. The evaluation and characterization of this kind of Properties plays crucial role. The investigation and observation of thermal Properties are conducted at elevated temperature, room-temperature too.

3.1 Coefficient of Thermal Expansion (CTE)

CTE is described as Change within dimensions of material accompanying with alteration in the temperature. D. Sujan et.al [13] has proposed values of CTE were shortened as reinforcement proportion raising.CTE monitors a variation in fractional quantity per degree of temperature variation. In automobile applications temperature variation occur so that less CTE substances recommended. S. Cem okumus et.al [33] has proposed there was reduction of CTE by raising Graphite with 45 and 53 µm grain size of Sic and also Proposed that values of CTE raised with increment of temperature and when temperature goes 200 to 250°C beyond it got reached to saturation relies on proportion of Graphite. The grater the proportion of graphite, reduced the Temperature of saturation and raising proportion of graphite had led un the refining of grain for eutectic-silicon, aluminium as well that is why it has given less CTE. In addition to, incorporation of much proportion of graphite given the dimension stability for MMCs. Arpon et.al [34] has investigated the evaluation of CTE within 50 to 300°C and revealed that the CTE was varied with temperature change and reduced with raising vol.% of reinforcement. Manivinan et.al [35] has reported by adding Carbon boron nitride (CBN) contents in matrix metal, there is a decrease in thermal-contact resistance i.e. it reduces CTE which was in turn, improvises the substance thermal diffusivity and conductivity.

S.A Mohan Krishna et.al [36] revealed that CTE of 6061 Al/Gr/Sic hybrid MMCs reduced with raising addition of Graphite, Sic in equal proportion and CTE values were raised with increment of temperature till 300°C. The general reason for reduction of CTE is owing to the less CTE values for graphite and Sic in comparison to aluminium-base matrix material.

3.2 Thermal Conductivity (TC)

Thermal conductivity (TC) was the material's property that depicts the capacity for heat conductivity. It may describe as heat-transfer rate by unit material's thickness per unit area per unit difference of temperature. One of the main compensations of aluminium is its TC is approximately thrice to steel. It allows Aluminium was a significant substance in applications of cooling or heating such as heat exchangers.

S. Cem okumus et.al [33] has proposed that, as the amount of graphite content increasing in Al matrix, TC values were shortened and raising test temperature resulted in gradual reduce in TC values but also stated that by decreasing grain size of SiC particles, there is a decrease of TC because reducing SiC's particulate size, the interface characteristics among Sic and matrix Al could ascribed. Manivinan et.al [35] has investigated on 6061 Al/CBN, 6061 Al/Sic and 6061 Al/Al_2O_3 MMCs. From this, it is observed that Cubic boron nitride (CBN) contents in the Al matrix have tremendous raise in both TC and heat transfer coefficient than Al/SiC, Al/Al_2O_3 fillers. Krishna et.al [37] researched on 6061 Al/Gr/Sic MMCs with help of software ANSYS and disclosed that reduction in TC due to graphite incorporation. S.A Mohan Krishna et.al [36] mentioned that TC values were reduced with raising incorporation of graphite, Sic in equal proportion within 6061 Al and concluded that there is no enhancement of TC of AMMCs by using graphite and Sic as reinforcements and also mentioned that only single Sic reinforcement may enhance the TC of AMMCs. The reason for reduction in TC values may attributed to less TC values for reinforcement particulates.

4. Conclusion

The intention of this review is to possess a broader view on aluminium various grades and selecting the perfect combination of the distinctive parameters taken into account.

- The Values of Hardness improved as SiC reinforcement rises but values were reduced as graphite content rises. The 359 Al/Sic MMCs hardness was greater Compared to 359 Al/Gr MMCs. This is owing to graphite softness and lubricant properties.
- The peak Hardness values are attained at the 25 wt.% SiC.

- Al/SiC MMCs displayed greater tensile strength, hardness in comparison with Al/Si_3N_4 and Al/Al_2O_3 MMCs and the peak tensile strength Values are obtained at 20 wt.% of Sic.
- Ductility values were reduced as increasing Sic reinforcement. In the context of fly-ash, it reduces significantly until 10 wt.% of reinforcement.
- For the MMCs which are reinforced with fly-ash 5 wt.% and Sic 10 wt.% acquired the greatest toughness value 7.8.
- The hybrid Al/Si/Mg hybrid MMCs had a greater fracture toughness than single reinforcement of Al/10 wt.% Sic MMCs.
- The CTE values are raised as the increasing temperature and also values of CTE were gradually reduced as the incorporation of graphite, Sic reinforcement increased. By adding Carbon boron nitride (CBN) contents in matrix metal, there is decrease in thermal contact resistance i.e. it reduces the CTE value which was in turn, improvise the substance's thermal diffusivity and conductivity.
- As amount of graphite content increases, TC values were shortened and also raising test temperature resulted in a continuous reduction in TC values.
- By reducing Sic grain size, there is a decrease in TC because reducing SiC grain size outcomes in wider area of surface among SiC and Al matrix.

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