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Mechanical Behaviors of Ceramic Particulate Reinforced Aluminium Metal Matrix Composites – A Review

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Abstract - *This review paper is broadly focused on the effect of the different ceramic particulates (SiC, B_4C and Al_2O_3) on the mechanical properties of the Al and Al alloy. Ceramic Particulate Reinforced Aluminium Metal Matrix Composites (PRAMMCs) provide improved properties i.e. improved hardness, improved strength to weight ratio, tensile & compressive strength, creep & fatigue resistance etc. as compared to conventional Al and Al alloy. Aluminium Metal Matrix Composites (AMMCs) are preferred to use in aerospace, automobile, sports, marine application etc due to its lightweight and high strength property. This manuscript reported the pioneering work of most of the researchers in the field of mechanical characterizations of ceramic PRAMMCs. The effects of weight or volume percentages and particles size of the reinforcement on the properties of AMMCs are discussed in this article.*

Key Words: Al_2O_3, B_4C, Composite, Density, Hardness, MMC, SiC, Tensile strength.

1. INTRODUCTION

The composite materials are composed of two or more materials in macroscopic level [1]. It has two chemically non-reactive phases namely reinforcing phase and matrix phase. The reinforcing phase always embedded in the matrix phase and distributes the load with reinforcing phase. Particles (nano or micro size), fibers (uni-directional or bi-directional) or flakes are used for reinforcing phase and polymers, metals or ceramics are used for matrix phase. The matrix phase of the composite material is generally ductile as compared to the reinforcing phase. [2]. Based on the types of the reinforcement composites are classified as: Particulate Composites (composed of particles), Fibrous Composites (composed of fibers), and Laminate Composites (composed of laminates). The composites materials are applicable in many areas due to its advantageous properties over conventional materials [3], [4]. In particulate metal matrix composite, the reinforcing phase is particles (mostly ceramic particles) and the matrix phase is metal. Al and its alloys are mainly used for developing metal matrix composite. Al metal matrix composites have wide range of application i.e. aerospace, biotechnology, automotive and sports industries etc. [5]–[8]. Aluminium and its alloy based Metal Matrix Composites (MMCs) are "engineered materials" for automobile, aerospace etc. due to its lightweight property with good strength. The addition of ceramic particles i.e. SiC, B_4C Al_2O_3 etc. can enhanced the mechanical as well as tribological properties of the base Al or its alloy matrix. Over the last decade, low-cost particulate reinforcements i.e. SiC, $A1_2O_3$ have been used to reduce the cost of Al or Al alloy MMCs [9]. In particulate reinforced AMMCs rolling, forging and extrusion are applicable and they give isotropic property in nature and it is also recyclable [6], [10], [11]. The detailed survey on mechanical behavior of different ceramic particulate reinforced AMMCs are explained in this paper.

2. SiC PARTICULATE REINFORCED AMMC

Cocen and Onel [12] have investigated the ductility and strength of extruded SiC PRAMMCs. In this work Al-5Si-0.2Mg reinforced with 9, 13, 17, 22 and 26 vol. % of SiC particulates (15-30μm particle size). The composites are fabricated by melt stirring technique and extruded at 500˚C at an extrusion ratio of 10:1. By the application of extrusion; disappear the cluster of SiC particles, reduce the porosity to very low levels and the yield strength & the tensile strength values are improved by approximately 40%. The yield strength and tensile strength of the as-cast composites increase with the volume fraction of SiC particulate upto 17% and then decrease with further additions of reinforcement. In extruded composite, the yield and tensile strength increase continuously with the volume fraction of reinforcement. The ductility of the as-cast composites is decreased with the increasing amounts of SiC particulate, but by the application of extrusion, a substantial improvement in ductility is obtained. The high reinforcement extruded composites samples exhibited better ductility levels than the forged samples and this observation is explained during extrusion process by the reduction in reinforcement particle size, the absence of particle de-cohesion, and the improvement of particle-matrix interfacial bond. Sahin [13] has studied about the preparation and analysis of mechanical properties of SiC particulate reinforced AMMCs. He developed composites by AA2014 reinforced with SiC particulate (10 and 20 wt. % and size of 29μm, 45μm and 110μm) from squeeze casting technique. They analysed the effect on density, porosity and hardness. To minimize porosity of the AMMCs, 3000kg of force by the hydraulic press was applied for 7min mechanically before taken from the mould and then the mould was taken from the press to cool down for 20 min approx. He observed the density decreased with decreasing particle sizes, but porosity and hardness decreased considerably with increasing particle size. Hardness, porosity and density of composites are increases when wt. % of reinforcement increases. The homogenous distribution of SiC particles are obtained in the composite with particle size of 110μm when compared with another particle size (45μm and 29μm) reinforced composites, some agglomeration is observed when particle size is less than 110μm. The functionally graded centrifugal cast Al-SiC particulate MMCs manufactured and characterized by El-Galy et al. [14]. SiC particulate with different weight fractions (0%, 2.5%, 5%, 7.5%, 10% and 15%) and three different particle sizes of 16μm, 23μm and 500μm have investigated. Three rotational speeds of 800, 900 or 1000 rpm and two controlled linear speeds of 16 or 28 mm/s have been used for feeding the metal along the tube axis. The cast tubes have SiC particles concentrations and hardness in the outer zone reach its maximum value and followed by a gradual decrease in concentrations and hardness in the direction of inner diameter. With increase in weight fraction of SiC particulate, proportionally increase in outer zone hardness and beyond 10 wt. % SiC particulate the increasing rate is decreases slightly. When increasing the weight fraction of SiC particulate then increase in tensile strength but ductility decreases. They found that the ultimate tensile strength is proportional to the percentage of SiC particulate and inversely proportional to the size of the particles. The tensile strength is increases linear up to 10 wt. % SiC particulate and the increase rate is lower afterwards up to 15 wt. % SiC particulate. In the range 7.5-10 wt. % SiC particulate, maximum improvement of wear resistance could be achieved. The wear resistance of the 23μm particles size SiC particulate reinforced AMMC shows that the highest wear resistance is achieved at outer zones in all investigated tubes. Ozden et al. [15] have investigated the impact behavior at different temperature i.e. -176˚C, 21˚C, 100˚C, 200˚C and 300˚C of aluminium alloy (2124, 5083 and 6063 Al alloy) with SiC particulate (167μm and 511μm) reinforced MMCs with hot extrusion ratio of 13.63:1 and 19.63:1. They observed SiC particulate as reinforcement in a ductile matrix of Al alloys decreased the impact toughness of matrix. The impact toughness of the composites slightly improved with increased particle size and the hot extrusion ratio, but artificial ageing decreased the impact toughness of all unreinforced alloys and the composites. Clustering or agglomeration of particles observed in AA6063 and AA2124 MMCs. The test temperature were not affected the impact behavior of unreinforced AA5083 and AA5083-SiC particulate composite. Around 100˚C, the impact strength of the composites based on AA2124 and AA6063 alloys are decrease. Meena et al. [16] have analysed the mechanical properties of the developed Al/SiC MMCs by stir casting process in which AA6063 reinforced with SiC particulate (weight fraction of 5, 10, 15 and 20%) with mesh size of 220, 300 and 400. They observed proportionality limit, upper & lower yield point, ultimate tensile strength, breaking strength, hardness and density increases with the increase in reinforced particulate size (220 mesh, 300 mesh, 400 mesh) and weight fraction (5%, 10%, 15% and 20%) of SiC particles, but % elongation & % reduction in area decreases with the increase in reinforced particulate size and weight fraction of SiC particulate. Impact strength decreases with the increase in reinforced particulate size and increases with the increase in weight fraction of SiC particulate. Patel et al. [17] have investigated the Brinell hardness and impact toughness of the $Al5Mg5Zn/3WO_3$ MMC (produced by stir casting processing route) after replacing the Zn content present in the developed composite into SiC particulates and they analysed the hardness is improved but impact toughness is decreases. Patel et al. [18] also gives a review on SiC PRAMMC, according to this review article nano SiC particulate reinforced Al MMCs have high tensile strength as compared to micro SiC reinforced Al MMCs.

3. Al_2O_3 PARTICULATE REINFORCED AMMC

Kandpal et al. [19] have fabricated the AA6061-Al_2O_3 MMCs by using stir casting route and characterized their mechanical properties. They use 5, 10, 15 and 20 wt.% Al_2O_3 to reinforced the Al alloy matrix and found that the micro hardness, tensile strength are increase with increase in alumina content in matrix. The ductility is decrease with increase in wt. % of alumina in AA6061 matrix. Arunachalam et al. [20] have developed AMMCs by using squize casting method. They used AA7075 as the matrix material and 2.5 wt. % alumina as reinforcement. They investigated hardness and compressive strength of the MMC and find these properties are improved significantly as compared to unreinforced AA7075. Sharifitabar et al. [21] have fabricated the AA5052/Al_2O_3 nano ceramic particulate reinforced composite by following the friction stir processing route. Effects of different FSP pass on microstructures and mechanical properties of AA5052/Al_2O_3 (particle size of 50nm) surface composites were investigated by them. More uniform dispersion of Al_2O_3 nanoparticles were obtained by increasing the number of FSP passes. Due to FSP, the grains in the stir zone were refined. They observed that when increase in FSP passes from one to three then samples elongation are improved. The tensile strength and elongation of base material were improved to 118% and 165% respectively. The tribological properties of aluminium-clay composites for brake disc rotor applications have investigated by Agbeleye et al. [22]. The AA6063-clay composites with 5, 10, 15, 20, 25 and 30 wt. % of clay particles of grain size of 250 μm were developed through stir casting route. With the 15-25 wt. % clay addition in AA6063 composites were similar to conventional semi-metallic brake pad in terms of wear and friction properties. They found that the mechanical properties, wear resistance and COF of the AA6063 improved with the addition of clay particles.

4. B_4C PARTICULATE REINFORCED AMMC

LM6 Al-B_4C composites are fabricated by Rao and Padmanabhan [23] by using stir casting process and they observed that the distribution of the B_4C particulate in the matrix phase is uniform. They found that the hardness and ultimate compression strength of the composites increased and density was decreased with increasing the amount of the B_4C particulate in the matrix phase. Nagaral et al. [24] have also studied on 3 wt. % and 9 wt. % of B_4C particulate reinforced AA7025 composites. They also used liquid stir casting process to fabricate the composites. They found that the tensile strength of composites are increased with increasing the wt.% of B_4C particulate in the AA7025 matrix but percentage elongation of the composite decreases with increasing of B_4C particulate in the Al matrix. By the use of stir casting process, Al-Mg-B_4C (3 and 7 wt. %) PRAMMCs are prepared and characterized by Marimuthu and Berchmans [25]. They also observed the hardness and tensile strength of the composite increases with increase in the wt. % B_4C particulate in alloy matrix. The effect of particles size on the abrasive wear and hardness of B_4C particulate reinforced AMMCs are evaluated by Nieto et al. [26]. They used three different particle size of B_4C particulates i.e. micrometric B_4C particulate (μB_4C), submicron B_4C particulate ($s\mu B_4C$) and nano-metric B_4C particulate (nB_4C) to reinforce the AA5083. They found larger B_4C particulate reinforcements negating the benefit of higher hardness because they are prone to particle pull-out. The AA5083+nB_4C composite has superior wear resistance because it has high hardness and greater interfacial area, which hindered pull-out of nano-B_4C particles. It enhances hardness by 56% and abrasive wear resistance by 7% as compared to AA5083. The effect of nano and micro particle size of B_4C particulate on mechanical properties of Al-B_4C particulate reinforced (0-10 wt. %) MMC are analysed by Harichandran and Selvakumar. In this analysis composites were fabricated by stir and ultrasonic cavitation-assisted casting process. They analysed the tensile strength, impact energy, wear resistance and ductility of nano B_4C particulate reinforced composite is greater than the micro B_4C particulate reinforced composite. They noted that the ductility and the strength of nano particulate MMCs are decrease beyond the 6 wt. % due to agglomeration of particles and porosity in the composite.

5. CONCLUSIONS

This review article is mainly focused on the mechanical characterization of the different ceramic particulates (SiC, B_4C and Al_2O_3) reinforced AMMCs. From the previous work on this field by many researchers following points may be concluded:

- When the SiC particulate weight percentage in the Al or Al alloy matrix increases then density, porosity, hardness and tensile strength of the composites are increase but ductility, % elongation and impact toughness of the composites are decrease.
- When the particle size of the SiC particulates in the Al or Al alloy matrix is increases then upper & lower yield strength, ultimate tensile strength, breaking strength, hardness, impact toughness and density of the composites are improved.
- By the application of extrusion mechanical properties of SiC particulate reinforced AMMCs can be improved.
- When the weight percentage of Al_2O_3 particulates in the Al or Al alloy matrix increases then hardness, tensile strength and compressive strength of the composites are increase but ductility of the composite decreases.
- When the weight percentage of B_4C particulates in the Al or Al alloy matrix increases then hardness, tensile strength and compressive strength of the composites are increase but density and % elongation of the composite decrease.

Nano particle size ceramic reinforcement highly improved the mechanical properties of the PRAMMCs as compared to the micro particle size ceramic reinforced PRAMMCs.

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