Mechanical Behavior of Particle Reinforcedaluminium Matrix Composites – A Review

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Abstract

Metal Matrix Composites (MMCs) with improved mechanical properties and their relatively reduced cost have made them attractive for wide range of applications like aerospace, automotive, sports and electronics industries. The advantages of particulate-reinforced composites over others are their formability with cost advantage. Further, they are inherent with heat and wear resistant properties. In general, the Al-MMCs are found to have higher elastic modulus, tensile and fatigue strength over monolithic alloys. It is evident that the structures and properties of the reinforcements control the mechanical properties of the composites. However, it is difficult to establish a direct relationship between mechanical properties of the composites, volume fraction, type of reinforcement and surface nature of reinforcements.

Keywords: Metal Matrix Composites (MMCs), Fabrication of Particulate Reinforced Metal Matrix Composites (PRMMCs), Hot Isostatic Pressing (HIP)

I. INTRODUCTION

Metal Matrix Composites (MMCs) with improved mechanical properties andtheir relatively reduced cost have made them attractive for wide range of applications like aerospace, automotive, sports and electronics industries [1]. More specifically, particulate MMCs(PMMCs) have been shown to offer improvements in strength, wear resistance, structural efficiency, reliability and control of physical properties such as density and coefficient of thermal expansion, improved wear behavior made them more efficient for various engineering applications in comparison to the un-reinforced matrix [2,3]. Aluminium and silicon carbide, for example, have very different mechanical properties: Young's moduli of 70 and 400 GPa, coefficients of thermal expansion of 24 x 10^{-6} and $4x10^{-6}$, and yield strengths of 35 and 600 MPa, respectively. By combining these materials, e.g. A6061/SiC/17p (T6 condition), an MMC with a Young's modulus of 96.6 GPa and a yield strength of 510 MPa can be produced [4].Al based composites are more oftenly used in aerospace industry and they are usually reinforced by Al_2O_3, SiC, C but SiO_2, B, BN, B4C, AlN and Gr etc. are also in use [5,6]. As proposed by the American Aluminum Association the AMCs should be designated by their constituents: accepted designation of the matrix / abbreviation of the reinforcement's designation / arrangement and volume fraction in % with symbol of type (shape) of reinforcement. For example, an aluminum alloy AA6061 reinforced by particulates of alumina, 22 % volume fraction, is designated as "AA6061/Al_2O_3/22p" [7]. Present study is focused upon AMMCs as these materials offer isotropic properties with an increase in strength and stiffness compared to unreinforced materials. One of the major challenges when processing MMCs is achieving a homogeneous distribution of reinforcement in the matrix as it has a strong impact on the properties and the quality of the material [4].

II.FABRICATION OF PARTICULATE REINFORCED METAL MATRIX COMPOSITES (PRMMCS)

A wide variety of fabrication techniques have been explored for metal matrix composites. These include liquid metallurgy methods, deposition of matrix from a semi-solid or vapor phase, and solid state consolidation [1,2]. Liquid phase processing has attractive economic aspects [4]. Chopped fibers, whiskers and particulates have been incorporated into molten matrix alloys. In some cases, pressure assistance has been used to infiltrate the reinforcement with the molten matrix. These methods result in microstructures dictated by the solidification of the molten metal. Achieving a homogeneous mixture can be difficult, particularly with fibers [4]. Powder Metallurgy is also extensively used to produce MMC. The important steps are; Blending of metallic powder with ceramic fibers or particulate, followed by cold compaction, canning, evacuation, degassing and a high temperature consolidation stage such as Hot Isostatic Pressing (HIP) or extrusion.

It has been realized that increasing number of reinforcements in MMCs can improve some mechanical properties, depends upon the nature of reinforcement or sometimes it reduces cost without altering the properties significantly, such type of combination is called a hybrid composite [8]. Hybrid MMCs are commonly produced by two basic manufacturing techniques namely casting and powder metallurgy with little changes in these two. Feng et al. [8]had fabricated the hybrid aluminum matrix composites reinforced with WO_3 particle sand ABO whiskers ($Al_{18}B_4O_{33}$ denoted by ABO) by a squeeze casting technique to improve some of mechanical properties of it. Ravindran et al. [9] had investigated and reported the improvement in tribological behavior of hybrid Al metal matrix composites over Al matrix, which were fabricated by the powder metallurgy process route. Suresha and Sridhara [10]had reported the improved wear resistance of Al-SiC-Gr composites fabricated by stir casting**.** The stir casting is having an edge over other composite fabrication techniques due to possibility of bulk size, simplicity of operation and reasonably good mechanical properties of fabricated MMCs [4].

III. PARTICLE REINFORCED ALBUMINIMETRY COMPOSITES (PRAMCS)

The Aluminium Matrix Composites (AMCs are categorized into four categories namely Particle-reinforced AMCs, Whisker-or short fibre-reinforced AMCs, Continuous fibre-reinforced AMCs (CFAMCs), and Mono filament-reinforced AMCs. The advantages of particulate-reinforced composites over others are their formability with cost advantage [12]. Further, they are inherent with heat and wear resistant properties. Among the variants of reinforcements, the low aspect ratio particle reinforcements are of much significant in imparting the hardness of the material in which they are dispersed (the hardness of fiber reinforced MMC < whisker reinforced MMC < particle dispersed MMC) [13,14]. The PRAMCs composites are designed with equiaxed ceramic reinforcements of an aspect ratio less than about 5. The mechanical properties of composite materials reinforced with ceramic particles depend on the matrix properties, mutual wettability at interphase, and the amount of reinforcing phase and the diameter of the reinforcing particles. In these type of composites, ceramic reinforcements like Al_2O_3, SiC or TiB_2 (oxides or carbides or borides) are used and present in low volume fraction (up to 30%) in case of structural and wear resistance applications. The coating of reinforcements with Ni [15] and Cu [16], also leads to good quality interface characteristics. The fabrication for these types of MMCs is done preferably by powder metallurgy routes or liquid state (stir casting, infiltration and *in-situ*) processes. These composites are isotropic in nature and can be subjected to a variety of secondary forming operations including extrusion, rolling and forging. Hybrid PAMCs essentially contain more than one type of reinforcement for example, mixture of particle and whisker, or mixture of fibre and particle or mixture of hard and soft reinforcements.

IV. MECHANICAL PROPERTIES OF PRAMCS

Mechanical properties of metal matrix composites (MMCs) are essentially functions of the manufacturing processes. In general, the PRAMCs are found to have higher elastic modulus, tensile and fatigue strength over monolithic alloys. Particle reinforced composites possess better plastic forming capability than that of whisker or fiber reinforced composites [12]. Moreover, these composites exhibit excellent heat and wear resistances due to the superior hardness and heat resistance characteristics of the particles that are dispersed in the matrix [17]. Among many ceramic materials, SiC and Al_2O_3 are widely in use, due to their favorable combination of density, hardness and cost effectiveness [18, 19, 20]. The factors such as the porosity of the matrix, volume fraction of the reinforcement and their distribution, agglomeration or sedimentation of particles and particle size, dross and porosities influence the mechanical behavior of the fabricated PMMC. Improving mechanical properties suchas tensile strength, hardness, Young's modulus, creep resistance, and fatigue resistance, is usually the major concern while developing a composite material. According to [14,21] it is difficult to relation between mechanical properties of the composites, volume fraction, type of reinforcement and surface nature of reinforcements. But the reduced size of the reinforcement particles to be effective in improving the strength of the fabricated MMCs as reported by Ma et al. [22].

The resistance to indentation or scratch is termed as hardness. The micro-hardness is a direct, simple and easy method of measuring the interface bonding strength between the matrix and reinforcement [23]. Howell et al. [24] and Vencl et al.[25], reasoned the improvement of the hardness of the composites to the increased particle volume fraction. Unlu [26] studied the properties of Al based Al_2O_3 and SiC particle reinforced composite materials and found that mechanical properties like hardness of the composites significantly improved by the use of reinforcements . Wu [27] and Deuis [28] attributed this increase in hardness to the decreased particle size and increased specific surface of the reinforcement for a given volume fraction.

The strength of SiC, Al_2O_3, TiC [29], and TiB2 particulate reinforced Al-MMCs is found to increase at the cost of reduced ductility, increasing the volume percentage of ceramic phase and by decreasing the size of the reinforcement in the composite [22,29,30]. Ribs et. Al [31] observed that, elastic modulus, microscopic yield and tensile strength of the alloy increases with the increase in volume fraction of the SiC reinforcement coupled with lower ductility. YuXiao-Dong et al. experimented on Aluminium matrix composites reinforced with SiC with higher volume fraction of about 50% and various particle size 10, 28, 40 and 63μm and concluded that bending strength increases with increasing volume fraction and decreasing particle size but fracture toughness increases with increasing particle size [32]. Veereshkumar et al. investigated the mechanical properties of Al6061-Al2O3 and Al7075- SiC composites and reported that brinnel hardness of the composites were found to be increased with increase in filler content in the composites, the dispersion of Al2O3 in Al6061 and SiC in Al7075 alloy confirmed enhancement of the mechanical properties [33].J.R. Gomes et al. investigated that SiC reinforced Aluminiumalloys are widely used because of their effective combination of density, hardness and strength. The SiC reinforced aluminium MMCs exhibits significant increase in elastic modulus, hardness, tensile strength and wear characteristic [34]. A.M.S. Hamouda et al. experimented on the processing and characterization of SiO_{2p} reinforced Al-Si alloy matrix. From the experiment it was observed that with the increased addition of SiO_{2p} there is a decrease in tensile strength and modulus of elasticity in Al-Si alloy [35].

The fatigue behavior of MMCs is very important for many engineering applications involving cyclic or dynamic loading. Many researchers have reported the presence of particulate reinforcement's results in the development of localized stresses from constraints in matrix deformation around the reinforcing particles[36, 37, 38]. The highly localized stresses contribute to the observed work-hardening behavior of the composites. The concentration of the localized stresses results from constraints in matrix deformation that occur because of the significant difference in elastic modulus of the constituents of the composite, i.e. the discontinuous particulate-reinforcement and continuous phases and the continuous Aluminium alloy metal matrix. The fatigue resistance of particulate MMCs depends on a variety of factors, including reinforcement particle volume fraction, particle size, matrix microstructure, the presence of inclusions or defects that arise from processing, and testing environment[39].Creep behavior in particulate reinforced MMCs is characterized by a progressively increasing creep rate (tertiary creep) over most of the creep life. In general, the addition of a high stiffness reinforcement greatly increases the creep resistance over the unreinforced alloy.[40,41] .

Ductility is one of the important aspects in the mechanical properties of composites. The tensile elongation decreases rapidly with the addition of reinforcing particles and with increased aging time in the heat treatable alloys. Lee et al. have examined the tensile properties and microstructures of AA6061/SiCp composites fabricated by the pressure less infiltration method under a nitrogen atmosphere [41]. They reported that reaction products (Al_4C_3) which were formed at the interface between SiCp and Al alloy matrix as a result of the in situ reaction has significant effect on the ductility rather than strength.

A need is felt to produce high quality and low-cost reinforcements from industrial wastes and by-products. Mahendra et al. investigated the properties of Al-4.5% Cu alloy composite with fly ash as reinforcement. They reported the increase in hardness, tensile strength, compression strength and impact strength with increase in the fly ash content [42]. Sudarshan and Surrapa studied characterization of A356 Alfly ash particle composites with fly ash particles of narrow range (53-106μm) and wide size range(0.5-400 μm) and reported that addition of fly ash lead to increase in hardness, elastic modulus and 0.2% proof stress [43]. They also concluded that composites with narrow size range fly ash particle exhibit superior mechanical properties compared to composites with wide size range fly ash particles.

V. CONCLUSIONS

An optimized combination of surface and bulk mechanical properties may be achieved, if PRAMCs are processed with a controlled gradient of reinforcing particles and also by adopting a better method of manufacturing. The pretreatment of reinforcement particle significantly improves the wettability and prevents the serious interfacial reaction between reinforcement and matrix. There is no clear relation between mechanical properties of the composites, volume fraction, type of reinforcement and surface nature of reinforcements, the reduced size of the reinforcement particles is believed to be effective in improving the strength of the composites. The hardness of the composites was reviewed and on conclusion, it is discovered that as the reinforcement contents increased in the matrix material, the hardness of the composites also increased. It is evident that the structures and properties of the reinforcements control the mechanical properties of the composites. Secondary processing is an important issue in PRAMCs. Work must be initiated to develop simple and affordable joining techniques for PRAMCs. Development of less expensive tools for machining and cutting PRAMCs is of great necessity.

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