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Investigation on Properties of Reinforced Aluminium Matrix Composites – A Review

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***Abstract* - Aluminum Metal Matrix Composites (MMCs) sought over other conservative materials in the field of aerospace and automotive applications owing to their excellent improved properties. These materials are of much interest to the researchers from few decades. These composites initially replaced Cast Iron and Bronze alloys but owing to their poor wear and seizure resistance, they were subjected to many experiments and the wear behavior of these composites were explored to a maximum extent and were reported by number of research scholars for the past 20 years. In this paper an attempt has been made to consolidate some of the aspects of mechanical behavior of Al-MMCs and the prediction of the properties of Aluminum MMCs.**

Key Words - Al-MMCs, Density, Hardness, tensile strength.

I. INTRODUCTION

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. The composite generally has superior characteristics than those of each of the individual components.MMC is used for a wide range of applications as shown in Table 1.1.

Industrial Applications	**Components**
Aerospace	Struts, antennae.
Automobile	Piston crowns, engine block.
Electrical	Superconductors, contacts, filaments, electrodes.

Table 1.1 - Some applications of MMC [1]

Generally a composite material is composed of reinforcement (fibers, particles/ particulates, flakes, and/or fillers) embedded in a matrix (metals, polymers). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the mechanical properties of matrix. When designed properly, the new combined material exhibits better than would each individual material.

Mechanicalproperties of MMCs are directly related totheir microstructural features such as the reinforcement,matrix/reinforcement interfaces, dislocations, etc. GenerallyMMCs exhibit considerable increases in strengthand stiffness. However, they also have poor ductility,low values of fracture toughness and poor low-cyclefatigue properties [2–4].

Lloyd [5] reported that thedominant factor in controlling the elastic modulus is thevolume fraction of particles, and that it is relatively insensitiveto the particle size and distribution.

Interest on MMC has started in 1960s, which initiated from continuous reinforcementmaterial (e.g. tungsten and boron fibres) and aluminium or copper as the matrixelement. Somehow in the 1980s, the expansion of MMC production has led to thedevelopment of discontinuously reinforced MMC [6].

Many composite has been made over the periods of time to improve mechanical haracteristics of the material.this review paper is mainly focused on Al-Al_2O_3 Metal Matrix Composite (MMC) in which Al(Aluminium) matrix is reinforced by Al_2O_3Alumina.

II. BACKGROUND OF THE STUDY

Stir casting method is a relatively low cost liquid processing present to produce MMCand hence, this processing technique had been utilized in this study. Besides beingsimple, flexible, and attractive, as compared with other techniques, it also allows verylarge size components to be fabricated and is also applicable to large quantityproduction. Stir casting route also ensures that undamaged reinforcement materialsare attained. Moreover, this type of processing is now in commercial use for particulate Al-based composites [7] and the material produced is suitable for further operations, such as pressure die-casting [8]. There are several difficulties [9] in stir casting that areof concern, which are:

- porosity in the cast MMC,
- Difficulty in achieving a uniform distribution of the reinforcement material,
- Wettability between the two main substances, and
- Chemical reactions between the reinforcement material and matrix alloy.

III. LITERATURE SURVEY

In 1997, A.A Mazen and A.Y Ahmed manufactured a Metal matrix composites (MMC) using hot pressing followed by hot extrusion of aluminum (Al) powder reinforced by alumina (Al2O3) particles. Under tensile as well as compressive loads, a strength improvement of 64 to 100% compared to the matrix material strength was obtained.Under tensile loads, voids opened by decohesion between the matrix and reinforcement. Such behavior led to a decrease in strength properties of the MMC as a function of reinforcement volume fraction. [10]

In 2001, B.G. Park, A.G. Crosky and A.K. Hellier had gone through a systematic examination of the effect of particulate volume fraction on the mechanical properties of an Al2O3-Al MMC.The material used was a powder metallurgy processed AA 6061 matrix alloy reinforced with MICRAL-20TM, a polycrystalline microsphere reinforcement consisting of a mixture of alumina and mullite. The volume fraction of the reinforcement was varied systematically from 5 to 30% in 5% intervals. The powder metallurgy composites were extruded then heat treated to the T6 condition. Extruded liquid metallurgy processed AA 6061 was used to establish the properties of the unreinforced material.[11]

In 2003 , A. Daoud, T. El-Bitar, and A. Abd El-Azim had preparedAl5Mg alloy matrix composites reinforced with different percentages of Al2O3 (60 µm) or C (90 µm) particulates by Vortex Method.The composites were then subjected to hot or cold rolling with different reduction ratios. The microstructures of the rolled composites revealed that the matrix grains moved around the particulate causing deformation. The addition of either Al2O3 or C particulates into the matrix alloy increases the yield strength. However, the ultimate tensile strength and elongation of the composites are decreased in comparison with those of the matrix alloys.[12]

In 2004, Yung-Chang Kang, Sammy Lap-Ip Chan has found that the hardness and tensile behaviors of aluminum matrix composites reinforced with nanometric Al2O3 particulate increaseswith the volume fraction of the reinforcement. Above 4 vol.% of Al2O3, however, the strengthening effect leveled off because of the clustering of Al2O3. The main strengthening mechanismwas Orowan strengthening of effective nano-Al2O3 particles evenly distributed inthe matrix. The major strength mechanism was the Orowan strengthening by these particulates. However, as the particulate volume fraction increased, the extent of agglomerations of the particulates increased. When nano-particle content in the composites exceeded 4 vol.%, the agglomerations reduce the amount of 'effective' nano-particulates available, and the particle strengthening effect diminishes.[13]

IV. PROPERTIES OF COMPOSITE MATERIALS

From the nature of the composites, theirproperties can be predicted and the factors such as intrinsic properties, structural arrangement and the interaction between the constituents are of much importance. The intrinsic properties of constituents determine the general order of properties that the composite will display. The interaction of constituents results in a new set of properties. The shape and size of the individual constituents, their structural arrangement and distribution . The factors that determine properties of composites arevolume fraction, microstructure, homogeneity and isotropy of the system and these are stronglyinfluenced by proportions and properties of the matrix and the reinforcement. The propertiessuch as the Young's modulus, shear modulus, Poisson's ratio, coefficient of friction andcoefficient of thermal expansion are predicted in terms of the properties andthe most commonly used approach is based on the assumption that each

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phase component issubjected to either iso-stress or iso-strain condition.

PROPERTIES OF COMPOSITES

Density

Density is the physical property that reflects the characteristics of composites. In a composite, the proportions of the matrix and r reinforcement are expressed either as the weight fraction (*w*),which is relevant to fabrication, or the volume fraction (*v*), which is commonly used in propertycalculations. By relating weight and volume fractions via density (Á), the following expression isobtained (m stands for matrix and for reinforcement material):

$$\rho_c = \rho_r v_r + \rho_m v_m$$

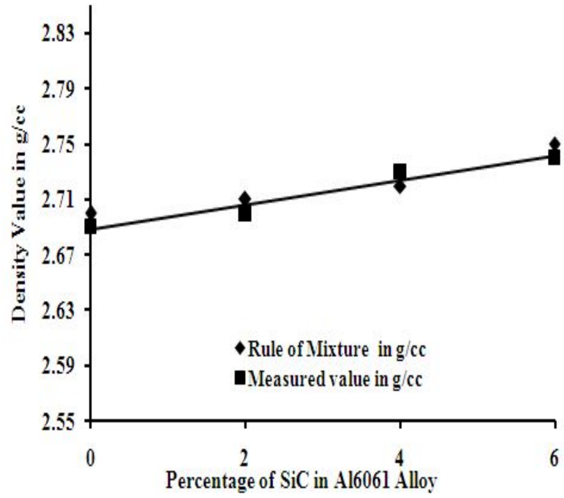
The above expression can be generalized and its general form is known as law of mixture and is as follows:

$$X_c = X_m v_m + X_p v_p$$

Experimentally, the density of a composite is obtained by displacement techniques [17] using a physical balance with density measuring kit as per ASTM: D 792-66 test methodThe results of the several investigations [19-21] regarding the density of the Al2O3/ SiC particle reinforced Al6061 and other aluminum alloys can be summarized as follows: the reinforcements Al2O3 and SiC enhance the density of the base alloy when they are added to the base alloy to form the composite. Moreover, the theoretical density values match with the measured density values of these composites..

Further, the density can also be calculated from apparent density values (sample mass and dimensions)and porosity [18]. Further, Miyajima et.al. [22] reported that the density of Al2024-SiC particle composites is greater than that of Al2024-SiC whisker reinforced composites for the same amount of volume fraction. From the above the increase in density can be reasoned to the fact that the ceramic particles possess higher density.

Additionally, the above discussions can be reasoned to the fact that the ceramic particles possess higher density. The Al6061- SiC and Al7075-Al2O3 particulate reinforced composites were developed by liquid metallurgy technique (stir casting route). The cast alloy and composite specimens were subjected to density test by two methods, i.e. weight to volume ratio and another being the rule of mixture, the obtained results are shown in the Figures 1 and 2.[15]



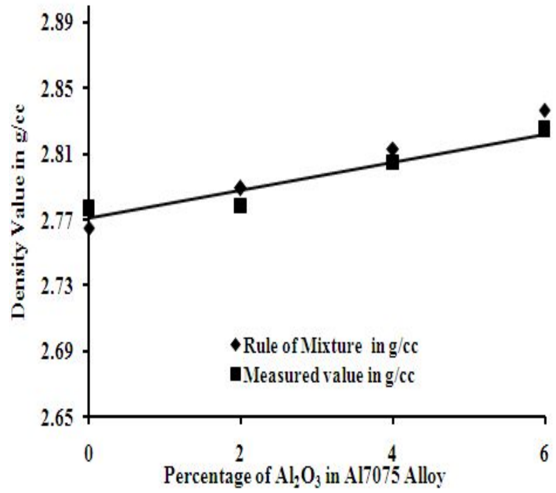


Figure 4.1 - Theoretical and Experimental Density of Al6061-SiC Composites and Al7075-Al2O3 Composites.

From the above figures, it can be observed that the density of the composite is higher than the base matrix. Also, the density of the composites increased with increase in filler content. Further, the theoretical and experimental density values are in line with each other. The increase in density of composites can be attributed to higher density of reinforcement particles.

Tensile strength

From the application point of view, the mechanical properties of the composites are of enormous

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importance. An optimized combination of surface and bulk mechanical properties may be achieved, if Al-MMCs are processed with a measured gradient of reinforcing particles and also by accepting a better method of manufacturing [23, 24]. Although there is no clear relation between mechanical properties of the composites, volume fraction,surface nature of reinforcements [25] and type of reinforcement [18,22] the reduced size of the reinforcement particles [27] is believed to be effective in improving the strength of the composites.

Further, the improved interface strength and better dispersion of the particles in the matrix can also be achieved by preheating the reinforcements [26]. In case of heat treatable Al-alloys and their composites, the yield strength of composites increase after heat treatment [28] by reducing the cracking propensity [33] . The composites, before fabrication process, are heat treated to an under aged condition as the materials can be shaped more easily and after manufacture, these materials are heat treated to the peak aged condition so as to provide improved mechanical properties [29]. When these reinforcements are combined with Al-MMCs, the resulting material exhibits important increase in its elastic modulus, hardness and strength [30].

Hardness

The resistance to indentation or scratch is termed as hardness. Among various instruments for measurement of hardness, Brinell's and Vicker's hardness testers are significant. Theoretically, the rule of mixture of the type for composites [35] helps in approximating the hardness values. 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 [22]. The contributions of several investigators regarding the effect of reinforcement on hardness of the composites are summarized as follows;

The particulate reinforcements such as SiC, Al2O3 . The coating of reinforcements with Ni [38] and Cu [26], also leads to quality boundary characteristics and hence contribute in improving hardness. TiC when dispersed in Al matrix, increases the hardness to weight ratio.Lloyd et.al. [39] explored the significance of hard ceramic particles in increasing the bulk hardness of Al-MMCs. Howell et.al. [40] and Vencl et.al.[32], reasoned the improvement of the hardness of the composites to the increased particle volume fraction. Wu [41] and Deuis [42] attributed this increase in hardness to the decreased particle size and increased specific surface of the reinforcement for a given volume fraction. Sug Won Kima et.al. [21] rational the increase in hardness of the composites to the increased strain energy at the periphery of particles discrete 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 [42].

The micro-hardness is a direct, simple and easy method of measuring the interface bonding strength between the matrix and reinforcement [43]. Subramanian [31] combined Silicon in Al- alloys and concluded that the higher wt.% of Si improves the hardness of the composites. The heat- treated alloy and composite exhibits better hardness [33,34].

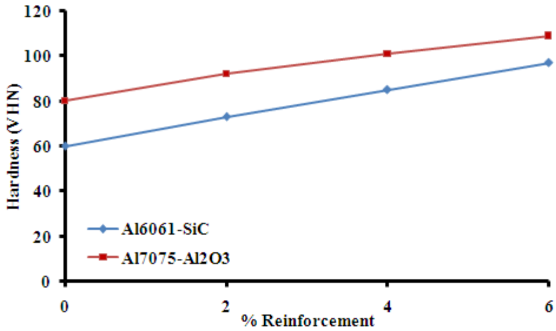

Figure 4.2 - Variation of Vicker's Hardness of Al6061-SiC and Al7075-Al2O3 Composites.

Variation of Brinell's Hardness of Al6061-Al2O3 and Al7075-SiC Composites.

The composites developed (as explained above) were subjected to hardness test using the Vicker's and Brinell's hardness testing machines. From the Figures 3 and 4, it can be observed that the hardness of composites were greater than that of its base alloy[15]. Further, the hardness of the composite is found to increase with increased filler content.

V. CONCLUSION

This review presents the views, experimental results obtained and conclusions made over the years by numerous investigators in the field of reinforced Al-MMCs. A significantamount of interest in Al-MMCs evinced by researchers from academics and industries hashelped in conduction of various studies and has enriched our knowledge about the physical and mechanical properties.

- 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. The mechanical properties were studied with respect to strength. It isevident that properties of the reinforcements control the mechanicalproperties of the composites. The reported works regarding the variations of thecompression strength of ceramic filled aluminum composites are meager. Further, the tests conducted to determine the same specified the increased hardness with increased reinforcement contents when comparedwith the base matrix.

- It has been studied that the density of the composites increases with theinclusion of the hard ceramic reinforcement into the matrix material. In view of the above conclusions on density, experiments were perform on the Al6061-SiC and Al7075-Al2O3 to determine the density by weight to volume ratio. Theexperimental and theoretical densities of the composites were create to be in line with eachother. There is an increase in the density of the composites compared to the base matrix.

- Finally there is an enormous potential, scope and opportunities for the researchers, in the fieldof estimate of mechanical properties of the particulate reinforced metalmatrix composites by using soft computing techniques.

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