International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

A Survey of Al7075 Aluminium Metal Matrix Composites

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Abstract: ***A composite material is a combination of two or more chemically distinct and insoluble phases; its properties and structural performance are superior to those of the constituents acting independently. Metals and ceramics, as well, can be embedded with particles or fibers, to improve their properties; these combinations are known as Metal-Matrix composites. Aluminum 7075 alloy constitutes a very important engineering material widely employed in the aircraft and aerospace industry for the manufacturing of different parts and components. It is due to its high strength to density ratio that it a sought after metal matrix composite. In this paper we present a survey of Al 7075 Metal Matrix Composites.***

Keywords: Metal Matrix Composites (MMC's), Aluminium Metal Matrix, Beryl, Al7075, Aluminium alloy

1. Introduction

The effects of research in Aluminium based Metal Matrix Composites (MMC's) are far reaching these days. These composites find various applications in the automobile industry, the aerospace industry and in defence and marine engineering because of their high strength-to-weight ratio, high stiffness, hardness, wear resistance, high temperature resistance etc., compared to others. In metal matrix composites, extensive research work has been carried out on Al alloys. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together.

In structural applications, the matrix is usually a lighter metal such as aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common. The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMC's can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD). Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMC's usedboron filament as reinforcement. Discontinuous reinforcement uses whiskers, short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

Aluminium alloy 7075 is an aluminium alloy, with zinc as the primary alloying element. It is strong, with a strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. Its relatively high cost limits its use to applications where cheaper alloys are not suitable. 7075 aluminum alloy's composition roughly includes 5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and less than half a percent of silicon, iron, manganese, titanium, chromium, and other metals. It is produced in many tempers, some of which are 7075-0, 7075-T6, 7075-T651.

Aluminium Alloy 7075 offers the highest strength of the common screw machine alloys. The superior stress corrosion resistance of the T173 and T7351 tempers makes alloy 7075 a logical replacement for 2024, 2014 and 2017 in many of the most critical applications. The T6 and T651 tempers have fair machinability. Alloy 7075 is heavily utilized by the aircraft and ordnance industries because of its superior strength.

A few studies have been carried out on Al-beryl MMC's since the density of beryl is 2.71 g/cc which is almost equal to aluminum and hardness is ~1800 Hv. Most of work that has been carried out is on characterization of beryl particles. XRD, FTIR, EPR studies on beryl particles is also reported. The use of AlBeMet AM162, an aluminum–beryllium metal matrix composite, is an effective way to reduce the size and weight of many structural aerospace components that are currently made out of aluminum and titanium alloys.

For a MMC, large ceramic particles such as beryl, SiC,Al_2O_3, TiNand other ceramic particles are added and studied in detail. MMC's are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used inaluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compound Al_4C_3 on the surface of the fiber. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride.The aim of this paper is to survey the work done in the area of Al7075 MMC's.

2. Literature Survey

In [26], Zhao et.al. studied the microstructures and mechanical properties of equal-channel angular pressing (ECAP) processed and naturally aged ultrafine grained (UFG) and coarse grained (CG) Al7075 alloys and their evolutions during heat treatment. Their studies established that after the tests, natural aging, tensile yield strength, ultimate strength and micro hardness of UFG samples were higher by 103%, 35% and 48% respectively than those of the CG samples. Their studies show that severe plastic deformation has the potential to significantly improve the mechanical properties of age-hardening Al alloys.
In [17], the authors have investigated the microstructure and mechanical properties of GTAW and GMAW joints of AA7075 aluminium alloy. Welding of the AA7075 alloy is made using GTAW and GMAW with argon as a shielding gas.

In [8], JothiSudagar et.al. have investigated Dry sliding wear properties of a 7075-T6 Al alloy coated with Ni-P (h) in different pretreatment conditions. Dry sliding behavior of electroless nickel-phospurous (EN) coating of thickness ~35μm deposited on a 7075-T6 Al alloy was studied. Their results suggested that the wear behavior of EN mostly depended on the pretreatment conditions. Heat treatment at temperature of 400^{o}C can enhance the wear resistance properties for all types of pretreatment conditioned samples. Ni strike provided better interlocking adhesion between EN and Al and this pretreatment improved the wear, frictional and hardness behavior of the EN coatings on Al7075 substrate.

The significance of three important deep drawing process parameters namely blank temperature, die arc radius and punch velocity on the deep drawing characteristics of Al7075 sheet were determined in [22]. The methodology in this paper involved a combination of finite element techniques along with Taguchi analysis. Simulations were carried out as per orthogonal array using DEFORM 2D software. The study established that the blank temperature has the greatest influence on the formability of Al material followed by punch velocity and die arc radius.

In [21], the effect of surface hardening by Shot Peening on fatigue properties of high strength Al7075-T651 alloy is investigated. The authors show an increase of fatigue strength after Shot Peening treatment due to the compressive residual stress ability to influence fatigue crack nucleation.

Machinability is considered as a system property that includes both the process and the material. Various factors such as hardness, ductility, surface tensions, alloying elements within the structure and heat treatment to which the material is exposed have influence on the machinability of a material. Hasan Kaya et.al. in [7] have analyzed the effect of aging on the machinability of AA7075 aluminium alloy using the single point turning method. In their analysis, the alloy samples were aged at 180^{o}C for 1, 6, 12 and 24 hours. The machinability tests were conducted at various cutting speeds and the resulting sample surface roughness, cutting forces and thermal changes occurring on the cutting tool were analyzed according to the cutting speed. The tests also involved unaged samples. Their results showed that depending on the aging time, the hardness measurement taken from the aged samples increased the hardness between the intervals of 102 to 211 (HV). The temperature of different types of chips which were observed with thermal camera during machining of the unaged and aged samples were found to vary between 52^{o}C to 92^{o}C.

H.B.Bhaskar and Abdul Sharief in [2] have investigated the Tribological properties of Al 2024 alloy. Al2024-beryl composites were fabricated by liquid metallurgy route by varying the weight percentage of reinforcement from 0 to 10 wt.% in steps of 2 wt.%. Dry sliding wear tests were conducted to test the wear behavior of Al2024 alloy its composites. Their results indicated that the wear rates of the composite was lower than half of the matrix alloy and friction coefficient was minimum when compared to monolithic alloy. Further beryl particles as reinforcement improved Tribological characteristics.
The process of factorial design of elements have been demonstrated in [9] to predict the hardness behavior of forged composites. The components produced by stir casting and forging of Al7075/Al_2O_3 composites are shown to possess almost two times the average hardness as compared to those obtained by their monolithic matrix based counter parts. Their study shows that parts possessing maximum micro hardness of 140VHN can be produced using 15% by weight of 60μm diameter Al_2O_3 at forging temperature of 425^{o}C and a reduction in area of 55% after forging. The model proposed in this paper can be used to produce Al7075/Al_2O_3 composites of desired micro hardness and to predict the hardness of composites.

In [10], Karthigeyan et.al. Al7075 alloy composites containing different volume fraction of short basalt fiber are developed using the stir casting process. The experimental strength values of the composites are compared with the theoretical values in this paper. The results suggested that the experimental values best suited the theoretical values owing to the random distribution of basalt fibers in the Al7075 matrix.

The effects of load and sliding speed on the friction coefficient and wear properties of pin of Al7075-Fly Ash composite material on Pin on Disc apparatus was investigated in [4] by Deepak Singla and Mediratta. Their experiments indicated that composites with fly ash as reinforcement in Al7075 optimizes the different physical and mechanical properties of the composite.

The mechanical properties of TiB_2 reinforced Al7075 MMC material was studied in [14]. Aluminium MMC's containing Titanium-boride are developed using liquid metallurgy technique. The composites were prepared with Al-10%Ti and Al-3%B master alloys as reinforcement. Microstructure test and grain size tests were conducted to find uniform distribution of TiB_2 particles in the matrix material. Micro hardness test confirmed the fact that this composite is much harder than the matrix alloy. Tensile strength increased in the

MMC but the ductility of the MMC decreased in respect of the ductility of the matrix material. TiB_2 particle peaks were observed in the X-ray diffraction test, Grain size test indicated the initiation of heterogeneous nucleation in the composite mixture, homogeneous distribution of TiB_2 particles were observed in the Optical micrographs and the presence of TiB_2particles indicated a grain refinement.

In [12], the influence of microstructure and tensile properties in specimens of ultrafine grained materials processed by equal channel angular extrusion (ECAE) is investigated. This study by the authors show that severe plastic deformation has potential to significantly improve the mechanical properties of aluminium alloys. Static annealing experiments were conducted on the samples. Microstructure evaluation during repetitive ECAE of Al7075 with $\phi=120^o$ die and outer arc with $\psi=50^o$are evaluated using optical microscopy.

Benachour et.al. Investigated fatigue crack initiation 7075 T6 and 7075 T71 aluminium alloys under constant amplitude loading in [1]. The investigation involved local strain approach at the notch and a single edge notch tensile specimen with semicircular notch was used. Their results indicated that fatigue life initiation was affected by notch geometry and mean stress.

Fabrication and characterization of Al7075 alloy reinforced with SiC particulates is studied by the authors Rajesh Kumar Bhushan, Sudhir Kumar and S. Das in [13]. The investigation involves fabrication using stir cast method of the alloys AA7075 and AA7075/SiCp (20-40 μm). The characterizations of composites of different weight fractions of reinforcement materials (10% and 15%) were carried out by SEM, EDAX, XRD, DTA and EMPA analysis. It was observed that alloying of Al matrix with 2.52 wt% Mg and its segregation at the interfaces was effective in restricting the formation of Al_4C_3 at the interfaces during casting. Oxidation of SiC has prevented or restricted chemical reaction at interfaces. Enhancement of wetting between the molten alloy and reinforcement was observed due to the well stirred matrix and reinforcement. SEM examination showed that the distribution of reinforcement particles is homogeneous. The XRD pattern indicated no peaks of Al_4C_3. EPMA analysis indicated aluminium as the main constituent and the coarse particles contained the alloying element of Zn, Mg and Cu and microstructures of Al7075 alloy, AA7075-10 wt%SiCp (20-40 μm) and AA7075-15 wt% SiCp (20-40 μm).

In [25], Yazdian et.al. have investigated the fabrication and precipitation hardening characterization of nanostructure Al7075 alloy. In their experiment, the Al7075 alloy is milled up to 15 h and then hot pressed. The milled and hot pressed samples are characterized by XRD, TEM, SEM and DTA. Their results indicated that after 15 h of milling, the alloying elements are dissolved in the Al matrix and a supersaturated solid solution with average crystallite size of 30±5 nm is obtained. Hot pressing the powder samples at 500^{o}C under 400 MPa resulted in a fully dense bulk nanostructure Al7075 alloy. The hardness value of the consolidated sample increased from 165 HV to 240 HV after appropriate hardening.

Gurvishal Singh et.al. in [6] provided an approach to improve the wear rate of aluminium based metal using red mud, SiC and Al_2O_3 MMC's. They conclude that red mud, the waste generated from alumina production can be successfully used as a reinforcing material to produce MMC's and can replace other expensive reinforcement materials like SiC and Al_2O_3.

The effects of short basalt fiber reinforcement on the mechanical properties of case Al7075 alloy composites containing short basalt fiber of content ranging from 2.5% to 10% by weight in steps of 2.5% and fabricated using compo-casting technique was studied by EzhilVannan and Paul Vizhian in [5]. The study revealed that as the short basalt fiber content was increased, there were significant increases in the ultimate tensile strength, hardness, compressive strength and Young's modulus accompanied by a reduction in its ductility. The microstructure and facture studies using OM and SEM carried out were used to establish the relationships between the quality of the fiber/aluminium interface bond and the mechanical properties of composites.

Fabrication, Surface Morphology and Corrosion investigation of Al7075/Al_2O_3 matrix composite in sea water and industrial environment was presented by VigneshShanbagh et.al. in [24]. The corrosion behavior of base Al7075 alloy and Al7075 reinforced with 10% wt and 15% wt of Al_2O_3 fabricated by stir casting method is studied. Metallographic study of composite was carried out using optical microscope, XRD, SEM with EDX. The results showed that Al7075/Al_2O_3 corroded more in sea water environment than in industrial environment. By correlating density measurement, Tafel plots, SEM Micrograph, the authors concluded that as reinforcement increases, interface bond between matrix and reinforcement reduces. Consequently, porosity increases and corrosion rate increases.

Rajesha et.al. in [15] have studied recast layers and surface roughness on Al7075 MMC during EDM machining. Optimization of process parameters to minimize surface roughness of the rapidly resolidified layer of Al7075 MMC which machining using EDM process is carried out using Taguchi techniques.

Corrosion studies on friction welded dissimilar aluminium alloys of AA7075 and AA6061-T6 were carried out in [16] by Satish and Sheshagiri Rao. Their experiments indicated that the parental metal wrought aluminium alloy corroded at a higher rate than the corresponding friction welded region of joints. The corrosion current and corrosion rate was found to be higher for the AA7075-T6 side compared toi the AA-6061-T6 side. The minimum and maximum corrosion rate varied from 1.91 to 5.74 mm/year in different regions. The results were validated by a microstructure study by optical microscopy of the weld joints.

In [11] Madhusudhan et.al. haveanalysed the near optimal process parameters speed, feed and axial force of friction stir welding of dissimilar aluminium alloys AA6262 and AA7075. The authors conducted confirmation experiments to validate the optimized parameters in the analysis.

In [20], Song et.al. studied the temperature induced work softening in Be/Al composites. The Be/Al composites exhibited a normal work hardening behavior at room temperature but flow softening occurred at 232°C and above. Work softening behavior was observed in Be/Al composites at elevated temperatures. Alloy 562 exhibited a pronounced softening behavior after yielding, while alloy 162 was work hardened slightly in the early stage of deformation and its stress/strain curve was leveled off later. Reinforcement particle size plays an important part in the observed work softening. The smaller the particle size, the more pronounced is the softening behavior. Particle rearrangement and interfacial sliding are the primary causes for the observed work softening of the Be/Al composites. Increasing temperature and decreasing particle size intensify work-softening behavior.

The synthesis of Al-TiN (10, 20, 30 wt. %) composites by using microwave radiation was studied by Venkateswarlu et.al. in [23]. During analysis, Al and TiN powders were sintered for various times. The results showed that an optimum microwave sintering time of 2 min was essential for synthesis of Al-TiN MMC's. Moreover, microwave sintering is more economical than other conventional sintering methods. SiCsusceptor was used during microwave sintering which was responsible for an efficient way of supply of heat to the samples. Increasing TiN content in Al-TiN MMC's from 10 to 30 wt. % showed superior hardness and wear resistance properties as compared to Al-TiN composites prepared by hot pressing.

Bodhak et.al. in [3] synthesized mullite using microwave sintering process. Alumina and Zircon were sintered under microwave assisted reactive method. The results obtained showed that a high-sintering temperature of 16000^{o}C for ~20 min was sufficient for sintering purpose.

Soon-Jik Hong et.al. [18,19] synthesized Al 2024 –SiC MMC by centrifugal atomization, hot extruded to investigate the effect of clustering on the mechanical properties. Fracture toughness and tension tests were conducted on specimens reinforced with different volume fractions of SiC. Their results show that by optimizing the volume fraction of the reinforcement and the clusters, high strength and reasonably good fracture toughness values could be obtained. For the Al 2024-SiC system, the optimum values appear to be 5-7 vol. % SiC, with a cluster volume of about 15-20%. Processing methods that produce microstructures with a more uniform distribution of reinforcements could potentially result in composites with improved mechanical properties.

3. Conclusions

The exhaustive literature provided in the previous section highlights the properties of Al7075 MMC's along with various other MMC's. The methodologies suggested by the authors give an insight into the advancements made in the area of composites. It can be observed that Al-Al_2O_3, Al-SiC composites can be successfully fabricated by Liquid metallurgy vortex route technique and Powder metallurgy route. In the liquid metallurgy vortex route technique, the percentage of reinforcements used is varied from 5-wt% to 15-wt%. The experiments have shown that mechanical and wear properties have increased significantly. The use of ceramic materials likeberyl $Be_3Al_2Si_6O_{18,}$ Silicon carbide SiC etc., as a reinforcement for the matrix Al7075 in various proportions can lead to more effective MMC's which exhibit improved mechanical and Tribological properties.

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