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Mechanical Properties of Aluminum MetalMatrix Composites - A Review

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***Abstract* – Current engineering applications require materials that are stronger, lighter and less expensive. Metal Matrix Composites (MMCs) are used for structural, electrical, thermal, tribological and environmental applications. Development of hybrid metal matrix composites has become an important area of research interest in Material Science. The research works on hybrid composite material containing Aluminum alloy as matrix and SiC, B4C, Alumina, TiO2, Gr etc., as reinforcements with varying weight percentages are considered for the review. This review also aims at studying the effect of reinforcement on mechanical properties of aluminum matrix composite with cryogenic treatment.**

Key Words: Aluminum Metal Matrix Composites (AMMCs), Metal Matrix Composites (MMCs), Cryogenic treatment, Reinforcements.

1. INTRODUCTION

Composite materials gained importance because of their enhanced properties compared to alloys. Today composites are well occupied in the field of automotive, aeronautical and spacecraft's industry. Composite materials are present generation materials which are developed to meet the demands of fast-growing requirements of industry and market. The present investigation is concentrated on Aluminium Metal Matrix Composites (AMMCs). In AMMCs, the major phase of aluminium alloy act as matrix phase and another phase act as reinforcement phase which tightly binded the matrix phase, basically they are ceramic, non-metallic carbides or cemented carbide materials like alumina, SiC, B4C, Gr, CO etc., The major advantages of AMMCs compared to unreinforced materials are greater strength, improved stiffness, reduced weight, improved high temperature properties, improved abrasion and wear resistance as well as improved damping capabilities. Cryo treatment has successfully proved that it has improved material characteristics of MMC. This is possible by changes in the Microstructural of the material by change in the crystal structure with fine grains and it converts the chemical composition of the material by deep cryo treatment [-196^{o}C].

2. Mechanical properties of AMMCs

The essence of research works concerning with the various properties of composite materials for different reinforcement materials with varied proportions along with cryogenic treatment are discussed in this section.

2.1 Tensile strength of AMMCs

The specimen fabricated by stir casting equipment which yields maximum tensile strength at 15% SiC reinforcement, then decreases from 15% till 30% SiC reinforcements [1]. Stir casting and lost wax casting technique was used to fabricate the composites which show a significant improvement in the yield and ultimate tensile strengths of the composite with increasing the SiC content and/or decreasing the particle size of the reinforcement. [3,4,6,19,30,35]. The ultimate tensile strength was decreased by 5.88% by the addition of gr reinforcement in steps of 3% which varied from 0% to 12%. . This is due to the detrimental effect of Al4C3 at the interface of the graphite and the Al matrix [2, 5]. Tensile properties improvement has been observed for cryo treated specimens. The cryotreated Al 6061+5%SiC+2%Gr composite has shown optimum value. As the percentage of Gr increases above 2% decrease in tensile strength has been observed [7].The SiC varies from 2.5 % to 10% and Gr varies from 1% to 4% in four equal proportions. The cryotreated Al6061 reinforced with 2% Gr and Al6061 reinforced with 7.5% Sic has maximum value of tensile strength compared to untreated specimens [8]. Addition of SiC in Aluminum metal matrix above 10% leads to decrease in tensile strength and elongation which was fabricated by stir casting technique [9]. Tensile strength of prepared Al6061 hybrid composites is higher when

compared to base Al 6061 composite. Addition of 6% SiC and Gr varies from 3% to 9% increases the tensile strength considerably with respect to base matrix Al6061 [10]. The composite specimen was prepared with 66 grams (3.3%) of SiC, 66 grams (3.3%) of graphite and 2000 grams of Aluminium. The results indicate an improved tensile strength of around 9% compared to base Al alloy [11]. The tensile strength and yielding strength of the Al-4.5% Cu alloy increased with the addition of 6 wt. % of SiC and Graphite particulates [12]. Al–SiC and Al–Gr composites required for the investigation are fabricated by stir casting. Al-SiC and Al-Gr composite shows considerable improvement in tensile strength compared to base Al 6063 alloy.. The Al-SiC exhibits higher tensile strength compared to Al-Gr composite [13]. The tensile strength of Al-Si alloy, Al-Si-Gr (3%) and Al-Si-Cu (2%) decreases were decreasing with increase in temperature from room temperature to 3000C [14]. The tensile strength will be the optimum at Al (90%) - Gr (2%) - SiC (2%) - B4C (6%) combination which was fabricated by stir casting method with a stirring speed of 450 rpm, stirring time 0f 5 min and preheat temperature of 4800C [15]. Fabrication of Al6061 hybrid composite reinforced with 6 wt.% of SiC and varying steps of graphite by 3 wt.%, 6 wt.%, and 9 wt.%. The tensile strength increases with the increase in Gr particulates with the influence of SiC particulates [16]. The Al6061 (95%) - SiC (3%) - TiB2 (2%) will exhibit higher tensile strength than Al6061 (90%) -

SiC (5%) - TiB2 (5%) [17]. Al 6061 +10% alumina and fly-ash, Al 6061 +15% alumina and fly-ash and Al 6061 +20%alumina and fly-ash are fabricated by using stir casting. The tensile strength increases with increasing % of alumina and fly-ash [18]. The matrix alloy 7072 exhibits lower ductility than the matrix alloy 6063. Adding of 5 wt. % TiO2 to the aluminum matrix and addition of 2 or 4 wt. % Gr to the Al-TiO2 composite increased the tensile strength [20]. The results showed that the yield stress, tensile strength and the modulus of elasticity were increased by 11%, 51%, and 51% respectively for 4% wt. reinforcement of boron carbide [21]. Increasing the content of graphite within the aluminum boron carbide matrix results in significant decrease in ductility and ultimate tensile strength [22]. Increase in the yield strength and ultimate tensile strength takes place with the increase in rice husk and SiC content. The strength improvement of hybrid composites can be attributed to the increase in the dislocation density [23]. With the addition of SiC (5%) + Flyash (5%) and SiC (5%) + Basalt (5%) to the base Al6082 alloy, the tensile strength increases [24]. For longer time and with higher speed it is recommended that the composite with 10 % Cu, for short run applications composite with 15 % Cu is the best and for structural applications the composite with 20 % Cu may be considered [25]. Addition of SiC particulates up to 20% has resulted in increased tensile strength with maximum value being at 15% of SiC as well as its addition yields weight reduction by a factor two [26]. Addition of Al2O3 has resulted in application of higher stress to initiate plastic deformation in matrix alloy of AA6061 composite [27]. Mechanical properties of the specimens shown increase up to 20% reinforcement of SiC beyond that no improvement found [28]. Tensile properties after mixing of Al2O3 and Graphite particulates are higher than Al6061 alloy [29,31,36]. Al6061/Al6063-wt. 15%/20% SiC exhibited higher UTS compared to unreinforced alloy [32,33]. The AlSiC rod can sustain axial stress of 23% over Von Mises yield stress in constant angle of twist tests, when the plastic strain was of the order of elastic strain [34].

2.2 Hardness of AMMCs

The material became harder due to increasing proportions of SiC results to decrease in elongation % of AlSiC metal matrix composites [1,4,6,9,24,28,32]. The hardness of the nano composites continuously decreases with the addition of graphite [2,5,22] but addition of boron carbide will contribute to increase in hardness to the base Al alloy. The low aspect ratio particle reinforcements are of much significant in imparting the hardness of the material than the other types of reinforcements. The higher hardness is due to the particulate reinforcements like SiC, Al_2O_3 and aluminide [9,37]. This is as shown in figure 1 and 2 [37]. The hardness of Al-SiC composite is greater than that of Al-Gr composite because of high hardness of SiC [13,38]. Hardness of hydrid composites (Al-SiC-Gr) shows significant improvement due to uniform distribution of reinforcement [11,39]. The hardness of the Al-4.5% Cu alloy increased with the addition of 6 wt. % of SiC and Graphite particulates [12], Also, 5 wt.% SiC and 15 wt.% Copper will have increased hardness value [25]. Addition of boron carbide to Al-SiC improves the hardness of the hybrid composite [15]. Adding Gr above 3% to the Al-SiC/Alalloy will decrease the value of hardness [16,29]. On addition of SiC and TiB2 to the Al6061 matrix, hardness value increases by considerable amount [17].

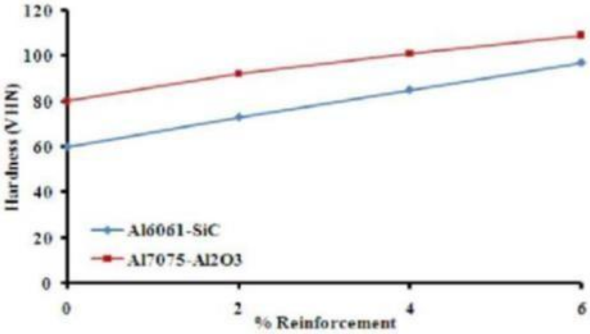

Fig. 1. Variation of Vicker's Hardness of Al6061-SiC and Al7075-Al2O3 composites [37]

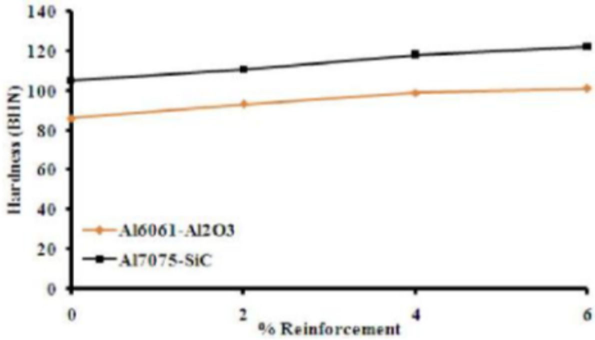

Figure 2. Variation of Brinell's Hardness of Al6061-Al2O3 and Al7075-SiC Composites [37]

2.3 Wear strength of AMMCs

A Pin-On-Disc wear testing machine to check the wear rate. Wear rate reduces significantly in the composites due to the increasing proportions of SiC reinforcement till 15% [6]. The wear behavior on Pin-on-disc wear setup shown reduction in mass loss and wear rate due to the presence of SiC, Gr [11,13,29,35,50]. The addition of SiC (5%) + Flyash (5%) and SiC (5%) + Basalt (5%) to the base Al6082 alloy decreases the wear [24]. For longer time and with higher speed it is recommended that the composite with 10 % Cu, for short run applications composite with 15 % Cu is the best and for structural applications the composite with 20 % Cu may be considered [25]. Wear resistance properties are higher in case of composites compared to unreinforced 6061Al matrix. The graphite varied as 3%, 6% and 9%, alumina is maintained 10% as constant [29]. The composite shows better dry abrasive wear resistance when Aluminium reinforced with SiC and MWCNT [40]. The addition of fly ash up to certain level (20%) and graphite (4%) reinforcement to the base Al alloy decreases the specific wear rate [41]. The optimum conditions for wear volume loss of MMCs tested are observed at 5 wt % reinforcement of Gr with contact stress of 0.4 MPa and 1.6 MPa, sliding distance of 300 m and 1800 m, sliding velocity of 2 m/s and 0.5 m/s respectively [42]. Results showed that sliding distance is the most influential factor and load is the factor which affects the wear least. The Al6082/Gr composites were successfully fabricated by stir casting process and the wear resistance of composite has been improved as compared to conventional AA6082 matrix [43]. Increase in percentage of TiC from 2% to 10% to AA7075 matrix material, decreases the volume loss and coefficient of friction [44]. Alumina (Al2O3), Silicon Carbide (SiC) and Hybrid (Al2O3+SiC) reinforced with

Aluminum alloy (AL7075) will show improved wear resistant which will be used for automobile parts like disc brake, piston, cylinder liner, drive shaft etc. [45]. The addition of reinforcement particles B4C and MoS2 to the base Al 2219 alloy reduces the specific wear rate of composites [46]. The study reveals that the addition of Gr will enhance the wear properties of Al/SiC/Gr hybrid composites under optimum conditions [48]. The results indicate that 5% B4C reinforced with Al-Gr MMC is better applicable than the other B4C reinforced (2.5% and 7.5%) due to their superior characterization [49].

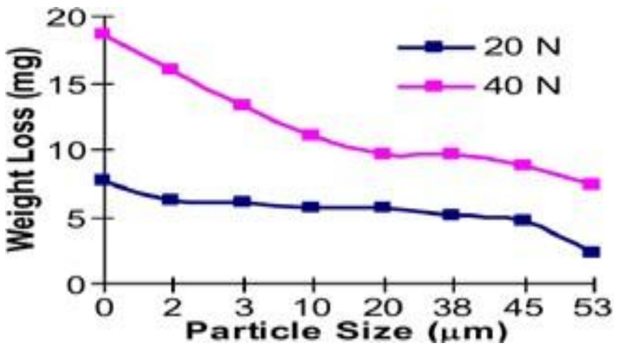

Fig.3. Weight loss values of different Al2O3/ SiC MMCs [47]

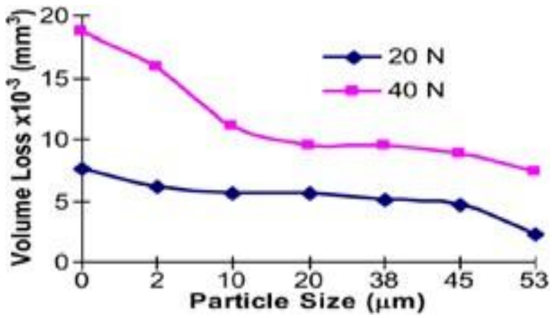

Fig.4. Cumulative volume loss values of different Al2O3/SiC MMCs [47]

2.4 AMMCs subjected to cryogenic treatment

The tensile, hardness of the Al6061 alloy reinforced with B4C and Gr shows marginal improvement after cryogenic treatment, but impact strength decreases [50]. The hardness of the LM25/SiC composites improves showed after the cryogenic treatment at -1960C due to the coarse eutectic β phase present in the matrix as compared with cast samples. Deep cryogenic treatment of 0.2 wt. % Al2O3 showed great value of yield strength compared to other alloys [53]. Increasing cryogenic cycles will decrease the creep compliance as the matrix of the composite became brittle after cryogenic cycled [54]. The microstructure and hardness of the AL6061-Al2O3 metal matrix composites improves on effect of cryogenic treatment. Also, varying cryogenic treatment duration in hours increases the hardness is shown in figure 5 [55]. The Ultimate tensile strength, yield strength and compressive strength increases with increasing wt. % of reinforcement for the MMCs for the same cryogenic condition. The application of cryo treatment has increased the hardness further due to the presence of coarse eutectic β phase [56]. The results revealed that cryogenic treatment improves the wear resistant and hardness of Al6061/SiC/TiO2 hybrid composites [57]. The experimental results show that Compression Strengths increases as the duration of cryogenic treatment increases, but as the percentage of Copper increases in the Alloy the Compression Strength increases to some extent and then decreases [58]. The tensile strength increases and compressive strength, toughness & hardness of AlSi10Mg alloy increased drastically after cryogenic treatment. Ductile to brittle transition in between 12 hour to 24 hour cryogenic treatment takes place which was mainly due to the precipitation of second phase particles [59]. A marginal improvement in the mechanical properties was observed after cryogenic treatment for most of the alloys.

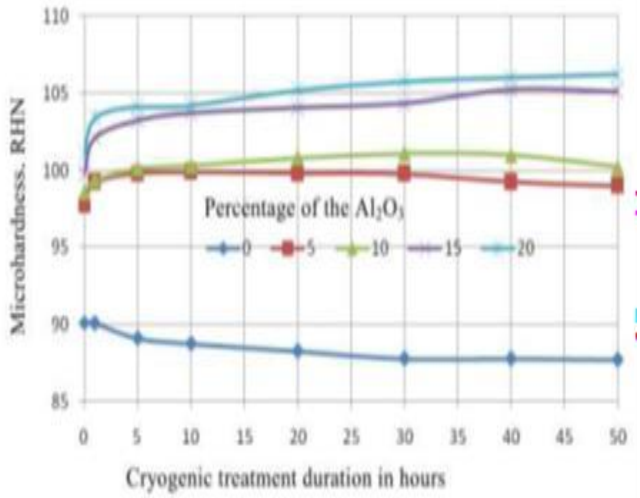

Fig.5. Effect of cryogenic treatment duration on microhardness of the Al and Al /Al_2O_3

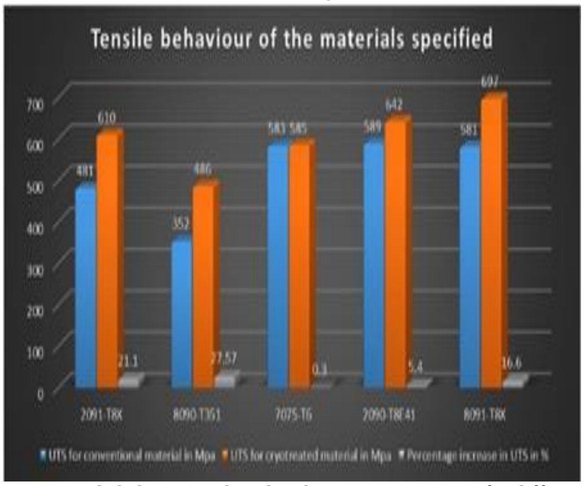

Fig.6. Tensile behavior with and without cryo Treatment for different materials [60]

CONCLUSION

The review of investigations reveals that various parameters like Fabrication method, Microstructure and different combinations of reinforcements will lead to the several conclusions on the Hybrid Aluminum Metal Matrix Composites (HAMMCs). Firstly, the microstructures of the HAMMCs fabricated by stir casting method have been found to be stable with uniformed distribution of reinforcing particles. Consequently, the HAMMCs can be fabricated with different combinations of reinforcements to achieve desirable mechanical properties. The composition and type of the

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reinforcements control the mechanical properties of the HAMMCs with respect to the strength. It has also been observed from the literature that the reinforcements like SiC, alumina, Gr, B4C can be combined with complementary reinforcements to obtain desirable properties for the composite. Also, from the review it is seen that the effect of cryogenic treatment will enhance the mechanical properties like Tensile strength, hardness and Wear resistance of HAMMCs. The study reveals that the HAMMCs can be considered as a replacement for conventional materials in recent advanced applications. The present review confirms that the utilization of HAMMCs in various structural, electrical, thermal, tribological and environmental applications seems to be feasible.

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