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Mechanical Behaviours of Heat Treated Aluminum/Alumina MMCs

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ABSTRACT: The mechanical properties such as hardness, ultimate tensile strength, ductility and compressive strength of Ascast and heat treated aluminum and aluminum/ Al_2O_3 metal matrix composites (MMCs) are measured using Brinell Hardness Tester and Universal Testing Machine. The MMCs were prepared by liquid metallurgy technique for varying percentages of reinforcement in steps of 0, 5, 10, 15 and 20% by weight. The hardness, UTS and Young's modulus increases considerably with an increase in heat treatment and addition of Al_2O_3 particulates. But, the ductility decreases drastically with an increase in Al_2O_3 content and when the duration of heat treatment was increased, it was found that the ductility is increased by a small amount. As the alumina content increases, the compressive strength of the composite material increases and also increases with aging time.

KEYWORDS: Al_2O_3 , MMCs, heat treatment, hardness, UTS, ductility, compressive strength

I. INTRODUCTION

Metal Matrix Composites (MMCs) are the advanced materials, which combine two or more different physical materials, stronger than monolithic materials, and designed for specific applications, with least negative properties. MMCs find many applications such as structural, electrical-electronics, thermo-mechanical, wear-tribological, and environmental applications [1]. The resulting MMCs have a balance of structural, thermal, and other properties that are superior to conventional materials [2]. Due to their significant properties, there is a sharp global demand for MMCs from automotive, electrical/electronics, high-temperature applications, and even aerospace industries to push the world composites market in future years [3, 4]. On the other hand, Al MMCs are a family of materials whose stiffness, strength, density, thermal, and electrical properties can be tailored [6, 7]. The properties of Al MMCs depend on the type of matrix alloy, reinforcement type, and the weight % of reinforcement, size, and shape of reinforcement, reinforcement location, and method of fabrication of MMCs [8]. Al MMCs offer a lower cost over the other matrix-based MMCs. MMCs also offer good thermal conductivity, high specific shear strength, wear-abrasion resistance, higher operating temperature, and flammability and corrosion resistance. Al composites found many applications such as automotive components, machinery components, electronic substrates, etc. [9].

II. LITERATURE SURVEY

Aluminum MMCs offer investigators, many added benefits as they are particularly suited for applications requiring high specific strength at elevated temperatures, good structural rigidity, dimensional stability [21] and low Coefficient of Thermal Expansion (CTE) [22]. The residual stresses would introduce some undesirable effects on the physical and thermal properties of the composites. Several publications on experimental works of thermal stresses have been found in the literature [23-25]. MMCs are potential materials for technological applications because they exhibit higher stiffness [5-7], lower thermal expansion [8, 9], lower thermal conductivity [10, 11], better damping properties [12, 13], higher hardness [14], and higher wear and corrosion resistance [15] than conventional alloys. MMCs are increasingly being used in many engineering applications, in products such as automobile parts (i.e. Piston liners, clutches, pulleys, etc.), aircraft components, sports goods, etc.

III. EXPERIMENTAL PROCEDURE

The matrix used in the present study was Al6061 alloy because of its superior properties like fluidity, corrosion resistance, reasonable strength, improved mechanical properties, excellent casting properties and heat treatability. Alumina (Al_2O_3) particulates of 30-50 μm of 99% purity were used for the present study. The alumina reinforcement was increased in the steps of 5 wt.% from 0 wt.% to 20 wt.%. The MMCs were prepared by liquid metallurgy technique for varying percentages of reinforcement in steps of 0, 5, 10, 15 and 20% by weight.

A. HARDNESS TEST

The hardness values of both Al alloy and Al composites were measured using Brinell hardness tester. The ASTM E10-10 standard was used for measuring the hardness of the composites. The dimension of ball indenter was 2.5 mm, and a load of 31.25 kg was applied on the specimens of diameter 30 mm and thickness 6 mm for 30 seconds for measuring the hardness of Al alloy and Al composites with different weight percentages of alumina.

B. TENSILE TEST

Tensile tests were conducted as per the ASTM E8 standard. Specimen dimensions were 8.9 mm diameter and 76 mm gauge length. The tensile properties of the materials viz, ultimate strength and ductility were evaluated using a standard 40 Ton capacity servo hydraulic universal testing machine (model UTM ZD40). The test specimens after failure are as shown in Fig. 1.



Fig. 1. Tensile test specimens

C. COMPRESSION TEST

The developed composites were subjected to compression test as per the ASTM E9 standard by using 40 Ton UTM. The specimen dimensions used for compression tests were diameter 12 mm and length 20 mm. Four specimens for each sample were tested, and an average value is reported. The compression test specimens before and after the tests are as shown in Fig. 2 & Fig. 3.



Fig. 2. Compression test specimens before test



Fig. 3. Compression test specimens after test

IV. RESULTS & DISCUSSIONS

A. HARDNESS RESULTS

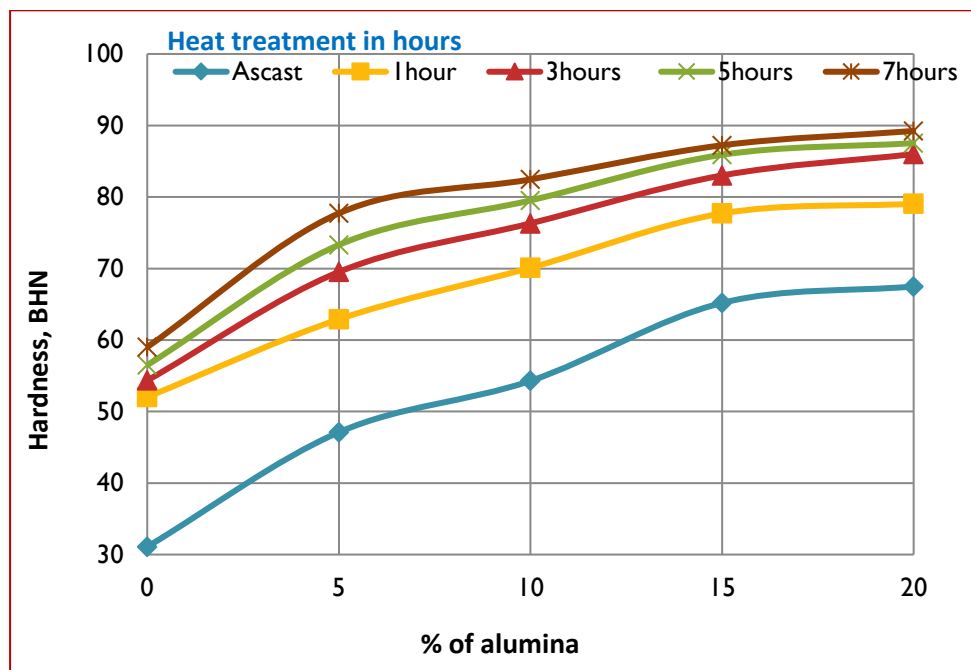


Fig. 4. Effect of heat treatment and Al_2O_3 on the hardness of $\text{Al}/\text{Al}_2\text{O}_3$ composites and Al alloy

The results of the hardness tests of heat treated alloy as well as the composites containing 0, 5, 10, 15 and 20 wt.% Al_2O_3 particulate by weight are represented graphically and are shown in Fig. 4. It has been reported previously [18] that the addition of alumina particulate brings about a considerable increase in hardness of the composite. Changing the solution treatment temperature [19] does not influence the accelerated aging response observed for the composites. The increase in hardness is to be expected because alumina particulates are very hard which acts as a barrier to the movement of dislocations within the matrix and exhibit greater resistance to indentation of the hardness tester. The addition of alumina has increased hardness of the composite by 1.51 to 2.17 times for 20 wt.% alumina composites compared to 0 wt.% alumina and also hardness has increased with heat treatment by 32% to 89% for 7 hours of heat treatment compared to the as-cast alloy. It was found that the hardness was maximum with 20 wt.% alumina content and 7 hours of heat treatment and increased by 2.87 times the hardness of the as-cast Al alloy with 0 wt.% alumina.

B. ULTIMATE TENSILE STRENGTH

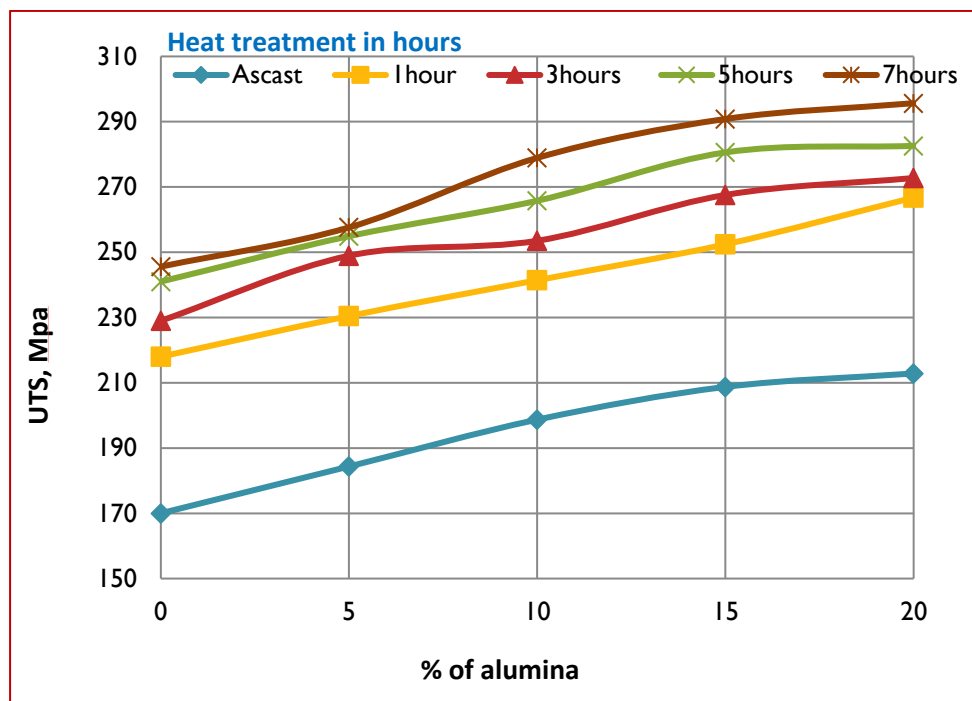


Fig. 5. Effect of heat treatment and Al_2O_3 on the UTS of Al/ Al_2O_3 composites and Al alloy

Fig. 5 shows the effect of heat treatment and Al_2O_3 on UTS of Al MMCs consisting of different weight percentage of Al_2O_3 particulates. Various researchers found [16, 17] remarkable improvements in both UTS and Young's modulus ranging 50-100% by incorporation of reinforcement. In a present investigation with heat treatment and the addition of alumina reinforcement, it was found to increase UTS and Young's modulus substantially. As more Al_2O_3 was added, the inter-particulate distance between hard Al_2O_3 decreased thereby causing an increase in the dislocation pile-up. It can be seen that as the alumina content increases, the UTS of the composite material increases by 17% to 25% for 20 wt.% alumina content compared to 0 wt.% alumina, and also, the UTS increases with heat treatment by 38% to 44% for 7 hours of heat treatment compared to the as-cast alloy. It was found that the UTS was maximum with 20 wt.% alumina content and 7 hours of heat treatment and increased by 74% compared to as-cast Al alloy with 0 wt.% alumina.

C. DUCTILITY

Fig. 6 shows the effect of heat treatment and Al_2O_3 on the ductility of composites containing various amounts of alumina particles. The ductility had decreased drastically with an increase in Al_2O_3 content by 2 to 3 times for 20 wt.% of alumina composites compared to Al alloy and when the duration of heat treatment was increased, it was found that ductility has increased by 17 to 73% for 7 hours of heat treatment compared to as-cast alloy. All these results are in close agreement with many previous researchers [20], who believe that the ductility of discontinuous reinforced MMCs decreases with increase in reinforcement content. The particulate reinforcement induces stress sites and also a large

difference in elastic behavior between matrix and reinforcement. Heat treatment seems to increase ductility with the increase in heat treatment time, which is due to the fine dispersion of precipitate clusters formed during quenching.

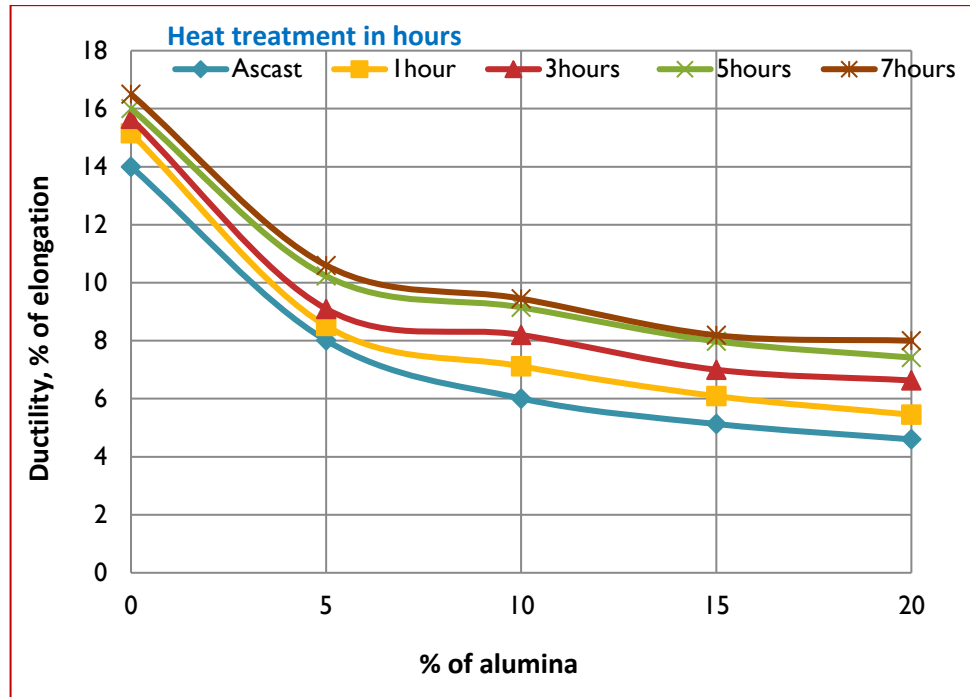


Fig. 6. Effect of heat treatment and Al_2O_3 on the ductility of Al/ Al_2O_3 composite and Al alloy

D. COMPRESSION STRENGTH

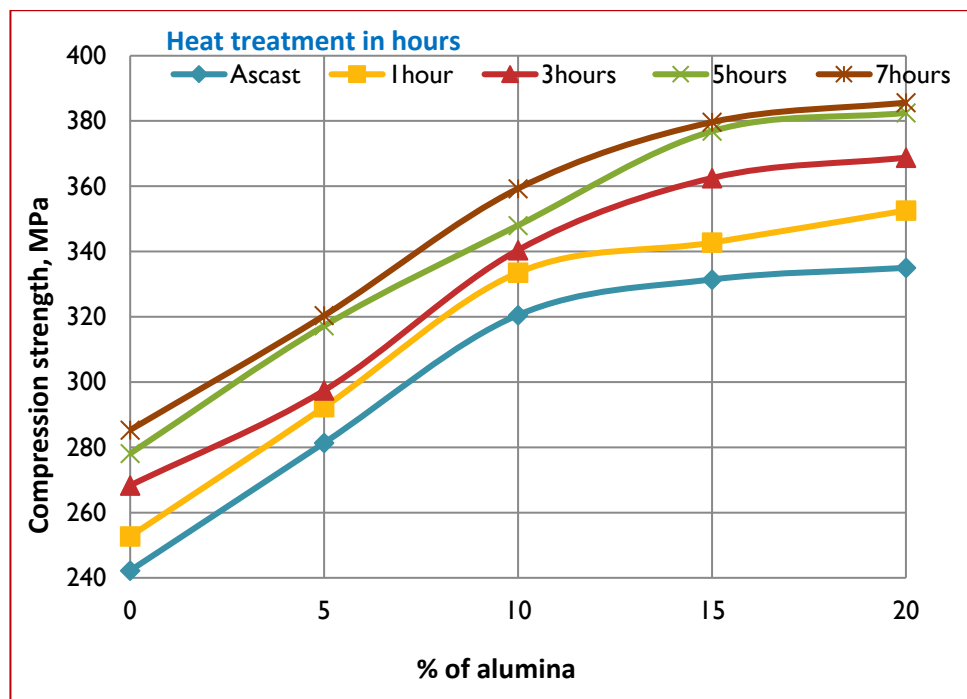


Fig. 7 shows the effect of heat treatment and Al_2O_3 content on the compression strength of Al/ Al_2O_3 MMCs consisting different weight percentage of Al_2O_3 particles. It can be seen that as the alumina content increases, the compression

strength of the composite material increases monotonically by 35% to 39% for 20 wt.% of alumina composites compared to Al alloy and also the compression strength has increased with heat treatment duration by 12% to 18% for 7 hours of heat treatment compared to as-cast alloy. The compression strength was maximum with 20 wt.% alumina content and 7 hours of heat treatment and has increased by 59% compared to as-cast Al alloy with 0 wt.% alumina. In the present investigation, four heat treatment conditions, namely 1, 3, 5 and 7 hours were selected to study the compression behavior for Al/Al₂O₃ MMCs consisting different weight percentage of Al₂O₃ particles.

V. CONCLUSION

Based on this study, the following conclusions have arrived.

- The hardness increases considerably with an increase in heat treatment and addition of Al₂O₃ particulates. The addition of alumina has increased the hardness of the composite by 1.51 to 2.17 times and also hardness has increased with heat treatment by 32% to 89%. It was found that the hardness was maximum with 20 wt.% alumina and 7 hours of heat treatment and increased by 2.87 times the hardness of the as-cast Al alloy with 0 wt.% alumina.
- UTS and young's modulus have increased considerably with an increase in heat treatment and addition of Al₂O₃ particulates. It can be seen that as the alumina content increases, the UTS of the composite material increases by 17% to 25%, and the UTS increases with heat treatment by 38% to 44%. As Al₂O₃ particle content was increased from 0 to 20% in steps of 5% by weight, an improvement in Young's modulus of 24% was observed.
- The ductility decreases drastically with an increase in Al₂O₃ content and when the duration of heat treatment was increased, it was found that the ductility is increased by a small amount. The ductility has decreased with an increase in Al₂O₃ content by 2 to 3 times and when the duration of heat treatment was increased, it was found that the ductility has increased by 17% to 73%.
- As the alumina content increases, the compressive strength of the composite material increases and also increases with aging time. It can be seen that as the alumina content increases, the compression strength of the composite material increases by 35% to 39% and also the compression strength has increased with heat treatment duration by 12% to 18%. The compression strength was maximum with 20 wt.% alumina content and 7 hours of heat treatment and was increased by 59% compared to as-cast Al alloy with 0 wt.% alumina.

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