Influence of Heat Treatment on Mechanical Characteristics of Al7075/Al₂O₃/TiC Hybrid Metal Matrix Composite

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ABSTRACT: The present paper deals with the study and characterization of the physical and mechanical behaviors of Al-7075/ Al₂O₃ / TiC hybrid metal matrix composite (HMMC) materials. The assimilation of dual particles like self-lubricated ceramic particles (Al₂O₃) along with hard particles (TiC) in the Al-7075 matrix is done using liquid stir casting method. The hybrid composite is produced with varying weight percentages of (8, 6, 4, 2, 0) Al₂O₃ and TiC (0, 2, 4, 6, 8) particulates. The produced Al HMMC materials are subjected to heat treatment (T6). The behavior of properties like density, hardness, impact and tensile strengths are analyzed based on experimentation. The obtained properties of cast Al-7075 HMMC materials are compared with heat treated Al-7075 composite materials. The dispersion of TiC hard particles in ductile Al-7075 matrix, predominates Al₂O₃ in improving mechanical properties because of its superior properties.

Keywords: Hybrid Metal Matrix Composite, Al-7075, Al₂O₃, TiC, T6 Solution heat treatment.

1. INTRODUCTION

The Aluminum metal matrix composite (AMMC) materials are low in density, good in castability, dimensionally stable and they exhibit excellent mechanical properties, tribological behavior, thermodynamic stability and high strength to weight ratio¹,². Among various Al-alloys, Al-7075 is strong and it has good fatigue strength. Compared to other Al alloys, the 7075-aluminum alloy is most preferably used for aircraft structural fittings³. Demand for further advanced materials, researches focused on the development of hybrid metal matrix composites. It consists of two different materials reinforced in the metal matrix. The comprehensive reports show improved properties of a hybrid than single reinforced metal matrix composites⁴,⁵. As a comparison with metal matrix composites, less literature is available with Aluminum HMMCs. Different Al alloys are combined with commonly used hard reinforcement particles like SiC, Al₂O₃, B₄C, Cr₃C₂, TiB₂, TiC in addition to RHA, beryl, fly ash, zirconia, graphite, MgO etc⁶,⁷. These reinforcements improve mechanical properties in the composites⁸. Among various reinforcements, TiC was preferred more due to better properties at high temperatures⁹,¹⁰. The discontinuous composites are fabricated using cost-effective stir casting technology⁴. From the literature studies, it was identified that most of the composites are produced with a simple stir casting method which is more cost effective and used for mass production¹¹. This casting technique avoids damage to reinforcement particles compared to other techniques¹². The composites produced by stir casting illustrate better dispersion of particulates, good wettability between the materials and reduced porosity¹³. The Al-7075/ TiC MMCs are used as advanced materials in aircraft applications. The addition of hard filler material TiC up to 8% in weight with the Al-7075 matrix alloy through stir casting strengthened the mechanical properties and tribological behavior in comparison with untreated Al-7075 alloy.
Researches preferred TiC as reinforcement material at ageing temperatures due to the elevated modulus of elasticity, low chemical reactivity, hardness and wettability. The improvement in properties of Al/TiC metal matrix composites is due to better TiC particle bonding with Aluminum matrix compared with other reinforcements.

The Al-7075/Al2O3 matrix composite also has exhibited excellent mechanical and tribological properties compared to the base Al alloy. The priority for Al2O3 as reinforcement particles is due to its high thermal stability and good electrical conductivity along with hardness. The results show an increase in wear resistance and a decrease in the coefficient of friction by the addition of Al2O3 with Al-7075 alloy. The tensile strength, hardness, and thermal properties show superior results at 10% reinforcement of Al2O3 with Al-7075alloy.

From the Literature study, it is found that researchers worked on Al-7075 with Al2O3 and also Al-7075 with TiC combinations as single and hybrid composite materials and gained advantages by improving mechanical properties. The present work is an attempt to combine the advantages of both Al2O3 and TiC with Al-7075 alloy. The novelty of current work is to prepare hybrid metal matrix composite materials by Al-7075 as base metal and Al2O3 and TiC as reinforcements and the physical and mechanical properties are investigated. Also, the effect of heat treatment on the composite material is studied.

2. EXPERIMENTATION

The Al matrix alloy is reinforced with dual Al2O3 and TiC with variations in weight to percentage ratios. The hybrid metal matrix composite is produced using a liquid stir casting method. This investigation is to study and characterize the influence of heat treatment on physical properties like microstructure and mechanical characteristics like hardness, tensile and impact strength of Al-7075/Al2O3/TiC composite materials.

2.1 Preparation of Al-7075/Al2O3/TiC hybrid composite specimens

The raw Al-7075 received in the form of 160mm cylindrical rods with 20mm diameter. The average particle size of Al2O3 is 40-50microns and TiC is 44microns. The elemental composition of the Al-7075 alloy has mentioned in the table 1. Weight percentage ratio of Al2O3 & TiC is mentioned in table 2.

| Sl. No | Sample Name | Percentages of samples          |
|--------|-------------|---------------------------------|
| 1      | Sample 1    | Pure Al-7075                    |
| 2      | Sample 2    | 92% Al 7075 + 8% Al2O3 + 0% TiC |
| 3      | Sample 3    | 92% Al 7075 + 6% Al2O3 + 2% TiC |
| 4      | Sample 4    | 92% Al 7075 + 4% Al2O3 + 4% TiC |
| 5      | Sample 5    | 92% Al 7075 + 2% Al2O3 + 6% TiC |
| 6      | Sample 6    | 92% Al 7075 + 0% Al2O3 + 8% TiC |

Table 1: Elemental Composition of Al-7075

| Element | Al | Si  | Cu  | Fe  | Zn  | Mg  | Ti  | Cr  |
|---------|----|-----|-----|-----|-----|-----|-----|-----|
| Weight %|    | Base|     |     |     |     |     |     |
|         | 0.20| 1.71| 0.23| 5.29| 2.46| 0.54| 2.21|
Stir Casting

In the stir casting process, Al-7075 was melted in a graphite crucible at a temperature of 700°C for 20 minutes. In the intermediate time reinforcement particulates are preheated in another furnace to a temperature of 300°C for 1hr. The preheating of matrix and reinforcement materials before mixing them helps in removing the moisture content and trapped air in between the particles to avoid agglomeration. When the temperature of the melt has crossed the pouring temperature, the stirrer which was already preheated, is introduced into the melt. A brisk stirring of the melt was started and parallelly the preheated Al₂O₃ and TiC particles are poured into the melt at a rate of 10g/ min. The mixture is stirred at 600rpm for 20 min using graphite impeller and the temperature was maintained at 700°C. A degassing tablet is used to remove the impurities. To improve the wettability of molten aluminum to mix with solid reinforcement particles, a small quantity of magnesium as a catalyst is added. Later the molten mixture is poured into the preheated die and allowed for natural cooling at room temperature. The same process was carried out for the preparation of 2 sets of 6 specimens with different weights to percentage ratios of Al₂O₃ and TiC particles. One set of specimens is used to study the properties before heat treatment while the other set for comparison. The experimental set-up of stir casting is shown in figure 1.

![Experimental set-up of stir casting](image)

2.2 Solution Heat Treatment

The Al-7075 HMMC specimens are subjected to T6 tempering (solution heat treated and artificially aged). For the tempering treatment, the specimen materials are heated in a furnace to a temperature value of 478°C for 1 hr and immediately quenched in the water for cooling purposes. Later aging of the specimens is done by heating in a furnace at a temperature of 127°C for 24 hrs. The specimens are cooled by natural air at room temperature. The effect of solution heat treatment, quenching and age hardening processes on the mechanical properties of Al-7075 HMMC are investigated.

3. Physical and Mechanical Tests

3.1 Density and Porosity

The density is determined to analyze the effect of Al₂O₃-TiC Wt% propositions in Al-7075 hybrid composites. The theoretical density was calculated by using the formula rule of the mixture and experimental density was measured by volume of water displacement.

3.2 Metallographic Test

The test pieces are sectioned to a convenient size from the casted specimen and are mounted in an epoxy material to facilitate handling during grinding and polishing steps. Grinding is done by grazing the surface of specimens under a series of operations using gradually finer abrasive grits. Grit sizes ranging from 100 to 1200 mesh are used. For fine finish grit sizes of 1/0, 2/0, 3/0 and 4/0 are also used. The persistence of grinding is actually to eradicate the oxide layer or uneven surfaces that might have occurred during the last segmenting operation.
Polishing is the final phase of a surface to get the flat, free from scratches and mirror-like appearance. A velvet cloth is lapped over the disc of polishing machine and Al₂O₃ paste is used as a finishing agent. The disc is rotated with an electric motor and the specimen is held on the disc by hand. Once the mirror finish is obtained, Keller’s (composition) reagent is used to etch the samples for microscopic study. The specimens are now examined under an optical microscope to study the microscopic structure of the Al-7075/ Al₂O₃/TiC hybrid composite samples.

3.3 Hardness Test:

The Vickers hardness tester is used to evaluate hardness values for Al-7075/ Al₂O₃/TiC hybrid composite materials. A load of 150kg is applied over the specimen for 15 seconds. Four values at different locations on each specimen are taken and the average is considered for evaluation.

3.4 Impact Test:

As per ASTM A370 standards specimens are prepared. The impact load in terms of Joules is noted from the scale. The energy absorbed area and impact resistance are calculated based on the impact load.

3.5 Tensile Test:

The tensile test is conducted on the Tensometer. The specimens are prepared as per ASTM E8 standards. The tensile strength is assessed at crosshead speed of 0.3 mm/min. The true displacement–load curves are obtained.

4. RESULTS AND DISCUSSIONS

4.1 Density and Porosity

The percentage of porosity obtained from theoretical and experimental densities mentioned are shown in table 3.

| Sl. No. | Reinforcement Compositions | Theoretical Density(g/cm³) | Experimental Density(g/cm³) | Percentage Porosity |
|--------|---------------------------|----------------------------|-----------------------------|---------------------|
| 1      | Sample 1                  | 2.81                       | 2.79                        | 0.07                |
| 2      | Sample 2                  | 2.9                        | 2.83                        | 2.47                |
| 3      | Sample 3                  | 2.92                       | 2.86                        | 2.09                |
| 4      | Sample 4                  | 2.94                       | 2.89                        | 1.73                |
| 5      | Sample 5                  | 2.96                       | 2.91                        | 1.71                |
| 6      | Sample 6                  | 2.98                       | 2.94                        | 1.36                |
Figure 2: Graphical representation of theoretical & experimental densities with different compositions of Al-7075/Al₂O₃/TiC hybrid composites

Figure 2 indicate that the values of density are varying linearly. The density increased with an increase in TiC along with a decrease of Al₂O₃ particles in the composition. The porosity levels are within the limits (3%). The porosity is less and does not affect the mechanical behaviors of Al-7075/Al₂O₃/TiC hybrid composite materials. The casted aluminum hybrid matrix composites are acceptable using stir casting technique.

4.2 Microscopic Images

Figure 3: Microscopic image of Al-7075 with 2% Al₂O₃ and 6% TiC composite before heat treatment at 200X

Figure 4: Microscopic image of Al-7075 with 2% Al₂O₃ and 6% TiC composite after heat treatment at 200X

Figure 3 demonstrates the distribution of Al₂O₃ and TiC particles in the Al-7075 matrix. It has evident that there are no voids, cracks or dendrites in Al7075 HMMC material. After completion of heat treatment, due to the formation of grain boundaries, the movement of grains was restricted. Such restriction is essential for increment in the strength of composite. Comparison of figure 3, figure 4 shows a fine dispersion of reinforcements into the Al matrix with the impact of heat treatment (T6). The fine dispersion of reinforcements improves the mechanical properties of Al HMMC.
4.3 Hardness

Figure 5 shows a comparison in hardness value before and after the heat treatment of Al-7075 HMMC materials. The characteristics and functionality of a material especially depends on the material hardness. The hardness of a material increase resistance to plastic deformation and wear resistance. The Al-7075 hybrid composite specimens are subjected to Vicker’s test and an optimized weight percentage of reinforcement is analyzed. Also, the heat treatment influence on the specimens has examined.

![Figure 5: Comparison of hardness values before and after heat treatment on Al-7075/Al₂O₃/TiC hybrid composites](image)

From figure 5, the sample composition with 8% Al₂O₃ and 0% TiC achieved high hardness value than pure Al-7075 material because of presence of hard ceramic particles (Al₂O₃). The TiC hard particles (%) improved hardness in the Al composite than Al₂O₃. Also, the uniformly distributed reinforced particulates in Al matrix improved the hardness as the load is shared by matrix and the hard particles. A rise in hardness is observed for the Al-7075 cast condition from 110 to 132 VHN. The specimens are subjected to solution and age heat treatment. From figure 5 it is noticed that the hardness has increased after heat treatment process.

The hardness value of heat-treated specimens increased from 125 to 154 VHN due to refinement of grains. The maximum hardness is obtained at 8% of TiC and 0% of the Al₂O₃ composition. Figure 5 shows the overall improvement in hardness for aged Al-7075/ Al₂O₃/TiC composite specimens than the cast condition composites. Hardness is improved by 40% after heat treatment.

4.4 Impact test

Table 4 shows the influence of heat treatment on impact load and figure 6 represents impact resistance before and after heat treatment on Al-7075/ Al₂O₃/TiC hybrid specimens.
Table 4: Comparison of Heat Treatment on Impact Load

| S. No | Samples  | Before Heat Treatment | After Heat Treatment |
|-------|----------|-----------------------|----------------------|
|       |          | Impact Load (N)       | Energy absorbed (J/cm²) | Impact Load (N) | Energy absorbed (J/cm²) |
| 1     | Sample1  | 5                     | 0.472                | 6               | 0.51                |
| 2     | Sample2  | 6                     | 0.519                | 7               | 0.54                |
| 3     | Sample3  | 7                     | 0.543                | 8               | 0.58                |
| 4     | Sample4  | 9                     | 0.628                | 11              | 0.69                |
| 5     | Sample5  | 10                    | 0.615                | 12              | 0.68                |
| 6     | Sample6  | 9                     | 0.602                | 11              | 0.69                |

Figure 6: Comparison of Heat Treatment on Impact Resistance

The table 4 indicates a rise in impact energy for the Al 7075 cast condition. The cause might be due to the high toughness of Al₂O₃ and TiC and load distribution capacity of TiC particles that restrict crack or fracture propagation in the Al matrix. Thereby, impact strength is improved. From figure 6 it is observed that at 2% Al₂O₃ and 6% TiC, the maximum impact strength is obtained. But, the increase in TiC percentage increases brittleness and decrease the impact strength at 8% TiC composition.

Figure 6 reveals that the impact resistance has been increased by 65% in aged specimens when compared with cast samples. The heat treatment may cause fine dispersion of reinforcements (Al₂O₃ and TiC) in the Al matrix. This fine dispersion improves bonding strength and the specimens can withstand the impact loads. The Al-7075 reinforced with 2% Al₂O₃ and 6% TiC specimens exhibited more impact strength.

4.5 Tensile strength

The table 5 exhibits the results of the tensile tests conducted on the samples prepared as per the standards and heat treated.
Table 5: Percentage Elongation and Tensile Strength before and after T6 heat treatment

| Sl. No. | Samples | % Elongation Before T6 Heat Treatment | % Elongation After T6 Heat Treatment | Tensile Strength (Mpa) Before T6 Heat Treatment | Tensile Strength (Mpa) After T6 Heat Treatment |
|---------|---------|-------------------------------------|-------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1       | Sample1 | 9.32                                | 7.13                                | 314.6                                         | 336.4                                         |
| 2       | Sample2 | 8.75                                | 6.78                                | 352.1                                         | 376.2                                         |
| 3       | Sample3 | 8.42                                | 6.51                                | 365.8                                         | 391.8                                         |
| 4       | Sample4 | 8.13                                | 6.12                                | 391.3                                         | 419.6                                         |
| 5       | Sample5 | 8.05                                | 5.92                                | 415.7                                         | 437.2                                         |
| 6       | Sample6 | 7.52                                | 5.21                                | 390.4                                         | 428.6                                         |

Figure 7: Graphical representation of tensile strength with different compositions of Al-7075/Al2O3/TiC hybrid composites

From Table 5, it is evident that the tensile strength at 2% Al2O3 and 6% TiC composition is maximum. The ductility is percentage elongation obtained from a tensile test. Thereby brittleness is increased and the tensile strength is decreased when the samples have 8% of TiC since the reduction in percentage elongation of material reduces ductility due to percentage increase in TiC hard particles. The heat-treated specimens (Figure 7) exhibit greater tensile strength compared to cast Al alloy specimens. The cause may be with increase in strengthening property by the dispersion of filler materials like Al2O3 and TiC. The percentage of TiC hard particles reinforced into a soft matrix alloy increases the tensile strength called as direct strengthening.27 The tensile strength increased by 38% further with T6 solution heat treatment. The heat treatment may cause thermal mismatch between matrix alloy and reinforced particles. This increases dislocation densities around reinforcement particles. The hard particles Al2O3/TiC restrict dislocation movement and increase tensile strength called as indirect strengthening, called Orowan mechanism.28
5. CONCLUSIONS

The mechanical properties of Al-7075 HMMC materials have been considerably improved by adding Al$_2$O$_3$ and TiC as reinforcement. The improvement in properties is further enhanced with the combination of solution and ageing heat treatments. The study of microscopic images revealed the fine distribution of particles by the effect of T6 heat treatment than cast Al-7075 composites. The sample 6 with Al-7075 and 8 % TiC, 0% Al$_2$O$_3$ results in high hardness and sample 5 with 2% Al$_2$O$_3$ and 6% TiC resulted in high impact and tensile strength. The hardness increased by 40%, impact strength by 65% and tensile strength increased by 38% for reinforced and T6 heat treated Al-7075 composites.

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