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Study on Mechanical Behavior of Tungsten Carbide and Graphite Reinforced Aluminium Metal Matrix Composite

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Abstract : Composite materials made of reinforced aluminium metal matrix are extensively used in a range of sectors, including aerospace and automotive manufacture. We present and describe individual aluminium composites in this work. Aluminum alloy (AA 6061) is reinforced with tungsten carbide (WC) and graphite particles to fabricate the composite. Stir casting was used to create the composite material, which was characterized by its density, tensile strength, and hardness. The low cost and high efficiency of the stir casting process led to its selection. It can be seen that up to 6% graphite addition with the base alloy, void percentage is 1.18. However, up to 9% tungsten carbide addition with base alloy, it is 1.38%. This indicates uniform dispersion and good bonding between matrix and reinforcement. Tensile strength revealed that as the wt. % of graphite with base alloy increases the percentage of elongation increases up to 4% of graphite and upon increasing further the percentage of elongation decreases. Although the hardness property increases up to 4% graphite addition, it is observed that the material's hardness diminishes over 6% graphite. As a result, it can be inferred that the hardness of Al 6061 may be improved up to 4% graphite addition and is found to be optimal at this composition. In terms of mechanical characteristics, the Al/WC/graphite composites were found to be the improved manufactured composites, suggesting that they have significant structural ability.

1. INTRODUCTION

Materials are more deeply ingrained in our society than most would think. Historically, the capacity of individuals to manufacture and manage resources to meet their requirements has been inextricably linked to the growth and evolution of civilizations. Indeed, the amount of material development has been used to classify early civilizations. Only a few number of materials were available to the early people, all of which were found naturally: stone, wood, clay, skins, and so on. They eventually determined procedures for manufacturing materials with better properties than natural materials, such as ceramics and other materials. Additionally, it was found that heat treatments and the addition of other compounds might modify the qualities of a material. Materials usage was purely a selection process at this period, including selecting the optimal material for a specific application based on its properties from a restricted collection of materials [1]. Scientists did not fully comprehend the links between the structural parts of materials and their qualities until very recently. This expertise, gained over the last 60 years or more, has enabled them to create, to a considerable extent, material features. Metals, plastics, glass, and fibres are just a few of the tens of thousands of unique materials that have evolved with highly specialized properties to meet the demands of our contemporary and significant environment. The study of the relationship between material substance and characteristics is known as materials science. To generate a set of desired properties, materials engineers develop or engineer a material's structure. The arrangement of a material's interior components is frequently related to its structure. Subatomic structure is made up of electrons within atoms and their interactions with their nuclei. The arrangement of atoms and molecules at the atomic level is known as structure The word "microscopic" refers to that which is seen close under a microscope, which is the next higher structural domain and comprises huge groupings of atoms that are often agglomerated together. Subsequently, "macroscopic" structural components are those that can be seen with the naked eye [1].

2. LITERATURE REVIEW

Johny James S and et al [2] investigated the composite structure and the distribution of reinforced particles using optical microscopy. Vickers hardness measurement device was utilized to analyze the cast composite's hardness throughout the investigation. The use of SiC and TiB_2 reinforcement improves the hardness value. Increased reinforcing to 15% of total weight, on the other hand, leads in a reduction in hardness value. Mechanical testing is performed on tensile samples manufactured from cast composite specimens of varied compositions. Narender Panwar and et al employed scanning electron microscopy to verify the homogenous distribution of reinforcing particles and energy dispersive spectroscopy to demonstrate the presence of reinforcement with the Aluminium 6061 matrix [3]. With 6061Al as the matrix material, and Al_2O_3 as the reinforcement, Bharath V and et al [4] employed the stir casting method to create metal matrix composites. The reinforcement addition level is varied in steps of 3% wt. from 6 to 12% wt. Reinforcement particles were heated to 2000°C and then disseminated in three stages into the vortex of molten Al6061 alloy to improve wettability and distribution. AA 6061 composite materials with varying weight % of aluminium nitride

(AlN) and zirconium-boride (ZrB_2) reinforcements were explored by N. Mathan Kumar and colleagues [5]. In situ stir casting was used to mix various reinforcement percentages with the matrix, such as 0, 3, 6, 9, and 12 wt %, respectively. The sliding wear characteristics of silicon carbide with boron carbide reinforcement produced by stir casting were studied by Hussein Alrobei and et al [6]. As compared to AA6061, AA6061 reinforced with silicon carbide, and AA6061 reinforced with boron carbide, the latter two metal composites had a consistent and higher hardness. Analysis of variance (ANOVA) and response plots are used to investigate the influence of control parameters on output variables. At a 200-minute ageing time, a 27 percent increase in hardness value for B_4C reinforced composite material was observed. Additionally, as compared to monolithic AA6061, the wear rate of B4C reinforced composite material is four times lower. The optimized parameters, agglomeration-free particle distribution, and homogeneous particle size are all factors that contribute to these improvements. Ajith G. Joshi and et al [7] investigated the wear behavior of aluminum-based composites reinforced with hard ceramics such as Silicon carbide particle (SiC) and graphite (Gr). Taguchi's L27 orthogonal array is used in their study to conduct experiments and investigate the effect of parameters on material wear behavior. K. Sekar and et al [8] used stir casting and other forming processes to fabricate AA2017+ B_4C+Gr Composites with various weight percentages of B_4C and constant Graphite. In comparison to the base alloy, the composite's compression value improved from 445MPa to 689MPa, with a constant 1% wt. Graphite and 0.5, 1, 1.5, and 2% wt. B_4C. The signal to noise ratio of Taguchi analysis shows that increasing the weight percent of reinforcement particle lowers the wear rate with applied load and sliding velocity. Elango M. and et al [9] investigated the impact of adding graphite to Al/SiC composites made by stir casting. Cutting speed (48.76%) is the critical factor influencing surface roughness in their study based on ANOVA analysis. Grey Relational analysis is used to increase Material Removal Rate and surface roughness at the same time. The Taguchi method was used to predict roughness values, and the predicted values were compared to experimental findings. Roughness values are reduced as a result of the element chips generated during machining. Nagender Kumar Chandla and et al [10] fabricated a low-cost, lightweight metal matrix composite employing Al6061 as the matrix material and alumina (Al_2O_3) and bagasse ash as reinforcing components using the stir casting process. In comparison to a single reinforced metal matrix composite, the produced hybrid reinforced metal matrix composite shown considerable increases in mechanical parameters such as tensile strength, hardness, and compressive strength.

3. MATERIALS SELECTION

In this work, aluminium alloy (Al6061) is used as base material, while tungsten carbide & Graphite is used as reinforcement. Tungsten carbide, graphite, and Al6061 aluminium alloy have densities of 15.63, 2.26, and 2.7 g/cm3 correspondingly. For Al+WC, tungsten carbide is varied in percentages of 3, 6, 9, and 12 % by weight, while graphite is changed in percentages of 2, 4, 6, and 8 by weight for Al+C. Stir casting is one of the most productive and cost-effective manufacturing processes for creating aluminium matrix composites suitable for a broad variety of processing conditions. The fabricated samples of metal matrix composite are subjected to evaluation of different mechanical behaviors by conducting tests such as density, tensile, hardness. The samples prepared for the tests are based on ASTM standards. The evaluation of mechanical properties is carried out for individual MMC.

4. SPECIMENS PREPARATION

The next sections discuss the characteristics of the materials used and the procedures used to fabricate and test individual MMCs in the present experiments.

4.1 Composite Preparation

The matrix material used for this investigation is Al6061 alloy, which is obtained in the form of ingots from Material Supplier Mysuru. Tungsten Carbide (WC) with particle sizes ranging from 0.15 to 50 µm and Graphite (Gr) with particle sizes ranging from 15µm were chosen as reinforcing materials and were obtained from Supervac Industries.

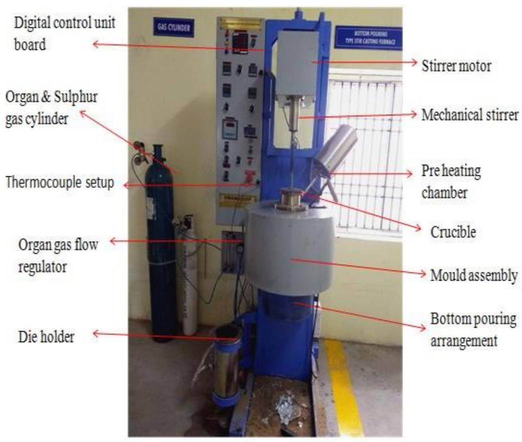


FIGURE 1. Stir Casting Setup

An 8500°C graphite crucible is used to melt aluminium metal matrix in a stir casting process described in fig. 1. At the same time, a 4000°C preheating step removes moisture from the tungsten carbide particles/graphite, which is then mechanically combined with the molten melt using an automated stirrer [11-13]. The tungsten carbide particles/graphite are uniformly scattered in the aluminium alloy matrix by swirling for 5 minutes at a speed of 500 rpm. A split-type die is used to pour the molten composite material and solidify it at room temperature. In this process Al6061 bars are cut into small ingots using a chisel and hammer. For each experiment, 1.5kg of Al-6061 ingots were weighed on a weighing scale and placed in a clay graphite crucible, which was then placed in the electrical resistance furnace. At a temperature of 800ºC, the ingots were melted for 5 to 6 hours.

5. RESULT AND DISCUSSION

5.1 Density Distribution of Al+Gr and Al+WC Composite

The distribution of fragments in MMC is associated to the density distribution. The density of MMC is evaluated by taking small samples at the top of the MMC. With a 0.0001g precision digital scale, weight and volume measurements are used to determine the actual density of specimens. Based on the Archimedes principle (ASTM D792), the empirical density of the composite is determined [14]. The effect of reinforcement addition on theoretical and experimental density is graphically depicted in fig. 2.

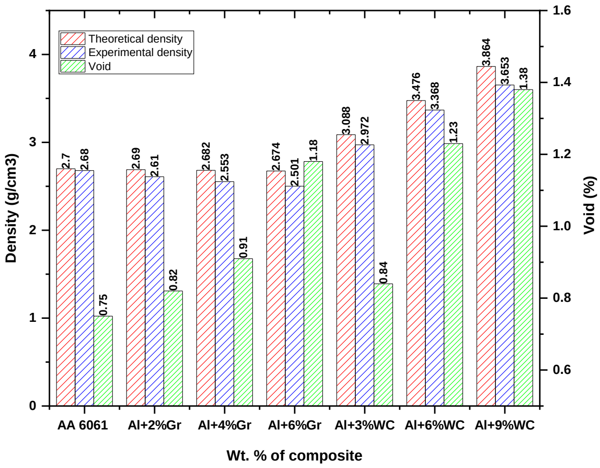


FIGURE 2. Density with Wt % of Composite

Void indicates the percentage of error between theoretical and experimental densities.It can be noted that the percentage of error has increased with the addition of reinforcement such as graphite with base alloy and tungsten carbide with base alloy. It can be seen that up to 6% graphite addition with the base alloy, void percentage is 1.18. However, up to 9% tungsten carbide addition with base alloy, it is 1.38%. This indicates uniform dispersion and good bonding between matrix and reinforcement [15]. The voids formed are due to porosity, a common defect found in casting process.

5.2 Tensile Test

The specimens prepared as per ASTM E8-04 [16] standard are used to evaluate the tensile properties of Al+Gr and Al+WC composition MMC and the test is carried out in computerized universal testing machine (UTM).

FIGURE 3. Tensile fractured specimens

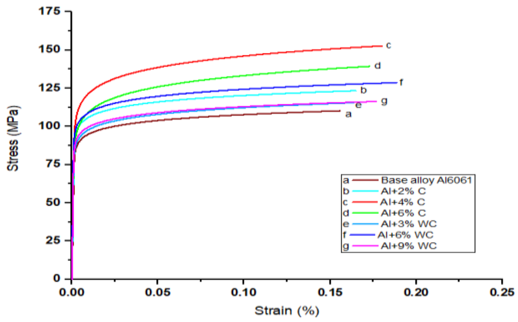
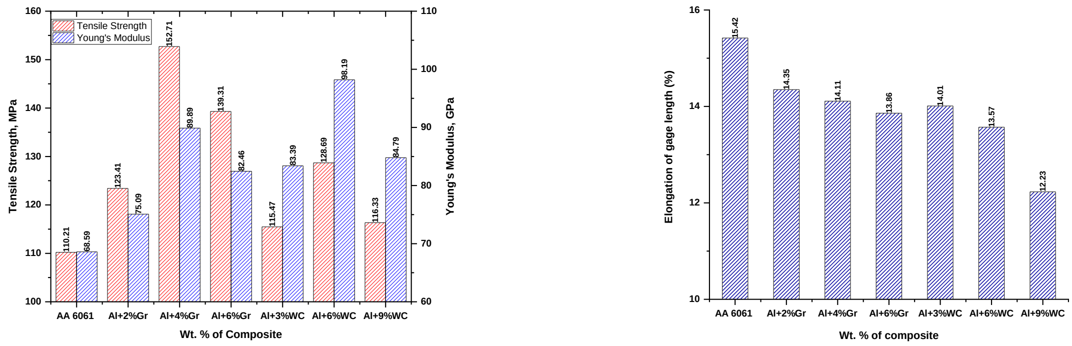


FIGURE 4. Effect of reinforcements on stress-strain curve

By varying the graphite content in the aluminium alloy by 2% by weight, it is possible to observe that the tensile strength improves up to 4% graphite reinforcement with base metal but decreases to 6% graphite reinforcement with base metal. As a consequence, it can be shown that adding 4% graphite by weight to Al 6061 alloy results in a significant improvement in Tensile Strength. Pillai [17] reported comparable findings, and these results are consistent with them. Fig. 4 depicts the effect of stress-strain parameters on the composite. Fig. 5 (a) depicts the effects of reinforcements on tensile properties. The strength of the composite increases with an increase in tungsten carbide up to 6% by weight and subsequently declines with additional increases in tungsten carbide. This is due to insufficient bonding between the matrix and the reinforcing components. As the particle load increases, the interspatial space between the hard WC particulates decreases, causing an increase in dislocation pile-up [18]. When compared to the base aluminium alloy, the tensile strength is improved by 19.52% and the yield strength is by 17.2%. The hard tungsten carbide may be responsible for the increase in tensile and yield strength.



(a) **(b)**

FIGURE 5. (a) Effect of reinforcements on Tensile Properties of composite (b) Percentage Elongation vs Wt % of composite

Fig. 5 (b) represents the effect of composite on percentage of elongation in the gage length. It can be observed that as the wt. % of graphite with base alloy increases the percentage of elongation increases up to 4% of graphite and upon increasing further the percentage of elongation decreases. Also, the percentage of elongation increases with the increase in wt. % of tungsten carbide up to 4%. The elongation percentage decreases when the weight percent of Al+WC reinforcement is increased, indicating that the soft and ductile matrix is transiting into a moderately brittle material with the increase in addition of reinforcement [19].

5.3 Hardness Test

The composite sample is subjected to a hardness test in order to identify and validate the homogenous distribution of reinforcement particles in the Al matrix at various reinforcement weight percent. The Vickers hardness tests are used to determine the composites' hardness. On the specimens, the micro-hardness of advanced MMCs and the matrix alloy is measured using a digital Vickers hardness tester in accordance with ASTM E384 [20].

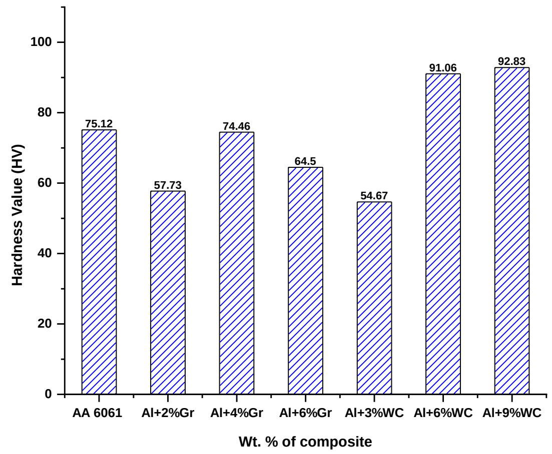


FIGURE 6. Hardness Values vs Wt% of Composite

According to the mechanical test findings, the variation in hardness of specimens with various compositions exhibits the same behavior as the variation in tensile strength for these compositions. As demonstrated in fig. 6, graphite reinforcement in certain weight fractions increases the hardness of base metal Al 6061 up to an optimal level. Hardness increases up to 4 percent graphite reinforcement in Al 6061 but declines below 6 percent when more graphite weight is added. As a result, it is possible to deduce that the hardness of Al 6061 may be improved up to 4% graphite addition by weight and is stated to be maximal at this composition. The metal's hardness decreases beyond this point [21]. The hardness of composites increases as the amount of tungsten carbide particles in the aluminium matrix increases. Reinforcing material Tungsten Carbide resists indentation and thus the hardness is enhanced fairly. Tungsten carbide's ability to withstand greater loads from the base metal is another contributing factor to its increased hardness.

6. CONCLUSION

The following conclusions were reached after using the Stir casting process to investigate the mechanical behavior of tungsten carbide and graphite reinforced aluminium metal matrix composites:

- Stir casting procedures were used to effectively produce cast Al6061-Gr-WC composites.
- It can be seen that up to 6% graphite addition with the base alloy, void percentage is 1.18. However, up to 9% tungsten carbide addition with base alloy, it is 1.38%. This indicates uniform dispersion and good bonding between matrix and reinforcement.
- The tensile strengthobserved that as the wt. % of graphite with base alloy increases the percentage of elongation increases up to 4% of graphite and upon increasing further the percentage of elongation decreases.
- The hardness of the metal increases up to 4% graphite reinforcement; however, at 6% graphite weight, the hardness of the metal diminishes. As a result, it is possible to deduce that the hardness of Al 6061 may be improved up to 4% graphite addition by weight and is stated to be maximal at this composition.

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