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Mechanical Properties of Stir-Casted Aluminum- 6061 Reinforced with Graphite and Boron Carbide

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Abstract

In recent years Al6061 alloy had increasing applications in all the areas due to its good formability, excellent properties and etc. By using Nano size B4C as size and graphite as reinforcements the fabrication process are done by Powder metallurgy process with overall 12 compositions primary and secondary specimens. Nano B4C is used as reinforcements from 3-15% with step of 3% as primary specimen and with addition of graphite of 3% in every reinforcement same manufactured. All specimens are manufactured by powder metallurgy technique and had a wide application. Hardness values are taken and each specimen is subjected to aging process. In aging process are subjected to 495°C and soaking for 2 to 10 hours. The cooling process can be done by in three medium water. In each case hardness values are taken with micro Vickers tests. All results are taken shows that increase in hardness with aging process. FESEM analysis is conducted to know the microstructure of composites.

Keywords: Al6061 Alloy, Powder Metallurgy Process FESEM Analysi

I. INTRODUCTION

Composites are materials made up of two or more distinct materials that are either physically or chemically different from each other. A composite typically consists of three main components: the matrix, the reinforcement, and the interface between them. The matrix is the continuous phase that holds the reinforcement in place, maintaining its predetermined orientation. Reinforcement, which is generally stronger than the matrix, is distributed within the matrix to enhance the overall properties of the composite. These two components are either chemically bonded or mechanically locked together. The characteristics of the composite are influenced by the properties of the matrix, the reinforcement, and the interface.

While the properties of the matrix material are modified during the composite manufacturing process, the properties of the reinforcement generally remain unchanged, except in cases where processing occurs at very high temperatures. Composites can be classified based on the type of matrix used, such as polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramic matrix composites (CMCs). They are also classified based on the type of reinforcement, which can include particle-reinforced composites, short fiber composites (such as whiskers), and continuous fiber composites (sheets). Reinforcement materials can be made of organic fibers, metallic fibers, ceramic fibers, or particles, while matrix materials can be polymers, metals and their alloys, glass, glass-ceramics, or ceramics.

Typically, the strength of the matrix is much lower than that of the fiber reinforcement. In PMCs, the matrices are often cross-linked thermoset polymers such as epoxy, polyester, and phenolic resins. Glass fiber-reinforced thermoset polymers offer a high strength-to-weight ratio, making them ideal for automotive components. Thermoplastic resins, such as polyethylene (PE), nylon, and PVC, are also commonly used in PMCs. In MMCs, lightweight metals like aluminum, titanium, and magnesium, along with their alloys, are commonly used as matrices. Aluminum is especially popular due to its excellent strength, toughness, and resistance to corrosion and abrasion. In CMCs, silicon carbide is frequently used for both the matrix and the reinforcement, though different forms of silicon carbide reinforcement are employed to achieve specific properties.

In particle-reinforced composites, the reinforcing particles can be ceramics, glass, metals, or amorphous materials. These composites typically exhibit a higher modulus than the matrix, but lower permeability and ductility, allowing them to withstand higher tensile, compressive, and shear stresses. Fiber-reinforced composites can be either short-fiber composites or continuous-fiber composites. Due to the strong covalent bonds along the fiber length, these composites have a higher modulus than their matrix, and the orientation of the fibers significantly affects the mechanical properties.

Apart from the matrix and reinforcement, the interface between these components also plays a crucial role in determining the properties of the composite. Since the matrix and reinforcement are not in thermodynamic equilibrium at the interface, a discontinuity in material parameters such as elastic modulus, strength, and chemical potential can occur. The interface facilitates smooth transitions in material properties, with gradual changes in these parameters over the thickness of the interface. Additionally, a chemical compound may form at the interface due to the discontinuity in chemical potential between the matrix and reinforcement. This interaction zone, with a specific desirable thickness, is important as long as it does not negatively affect the composite's overall properties.

II. LITERATURE REVIEW

Metal-matrix composites (MMCs), as described by K.K. Chawla, are engineered materials that combine a metal with other constituents, such as fibers, whiskers, or particles, to enhance properties that monolithic materials cannot achieve. Unlike conventional monolithic materials, MMCs offer improved combinations of strength, stiffness, and density. Through the careful design of reinforcement phases in a metal matrix, MMCs achieve outstanding properties such as high specific strength, specific modulus, elevated temperature strength, fatigue resistance, improved damping, and better electrical and thermal conductivities. These properties are tailored to meet specific engineering needs.

T.W. Clyne and P.J. Withers also emphasize that MMCs consist of fibers, whiskers, or particles embedded in a metal matrix. These reinforcements enhance the matrix's properties, leading to performance characteristics that are not attainable in pure metals. According to P. Rohatgi, the modern composites differ from traditional ones like cast iron or aluminum-silicon alloys because their design is less restricted by thermodynamic phase diagrams. This allows more flexibility in the size, shape, and volume fraction of ceramic phases within the metal.

I.A. Ibrahim et al. point out that modern composites are non-equilibrium materials that combine metals and ceramics. This lack of thermodynamic constraints permits the design of composites with fewer limitations regarding volume percentages and reinforcement shapes. As S. Ray mentions, MMCs are attractive because they enable the creation of materials that combine properties unattainable in monolithic materials, such as enhanced strength, reduced weight, better wear resistance, higher modulus, controlled thermal expansion, and improved fatigue resistance.

The development of MMC fabrication technology has advanced significantly, as highlighted by S.V. Prasad and R. Asthana. Key innovations in fabrication techniques include powder metallurgy and liquid metallurgy processes. Among the liquid metallurgy techniques are methods such as unidirectional solidification to produce directionally aligned MMCs, as well as casting techniques like compo-casting, squeeze casting, spray casting, and pressure infiltration. Liquid metallurgy methods are generally the least expensive, while multi-step diffusion bonding methods tend to be more costly.

Graphite, as described by B.P. Krishnan et al., is a soft, grayish-black substance commonly known as black lead or plumbago. It is made of crystallized carbon atoms arranged in flat hexagonal planes. The unique crystal structure of graphite, with free electrons between the planes, allows it to be a good conductor of electricity. This structure also makes graphite slippery and useful as a lubricant. Graphite's properties include a specific gravity of 2.3, high thermal and electrical conductivity, and stability at high temperatures. It is also slightly more chemically reactive than diamond.

These combined properties make graphite an essential material in a variety of applications, from writing instruments to high-performance electrical components.

III. PROBLEM DESCRIPTION

Normally copper (Cu) and its alloys have played a vital role as additives to non-asbestos friction materials (FMs). Their main functions include; increasing thermal conductivity, to act as a solid lubricant at high temperature. Environmental concerns in most of the advanced countries have resulted in legislation to gradually phase out. Thus, the FM industry is facing a challenge to replace Cu and its alloys in FMs with additives that will match the desired performance. Composite material brake pads are the one of the main applications of the aerospace and automobile industries. Because of their less weight, high strength to weight ratio, lighter weight, lower cost, good behavior and less corrosive properties. Auto parts workers have a mild risk of copper exposure when they move or come into contact with new brake pads that contain copper, while workers in brake pad plants are also presented with copper free brake pads and to make the material with equal strength to the copper brake pads and to give better performance.

IV. EXPERIMENTAL WORK

Powder metallurgy technique was used here because of its various advantages like less time simple fabricating technique, less cost of production, simple technique. Here the fabrication was carried out by two stages of Non-hybrid composites and hybrid composites. In the both types Al6061 was taken as the base material (matrix material), B4C and Graphite was taken as the reinforcement material. Al6061 was taken in 50 µm, Graphite was taken 100 µm, and B4C was taken in form of Nano size of 100 nm and all those materials was received from Material Suppliers. The preparation of composites was started by measuring the powder which could do by the simple balance of accuracy of 0.001 g. The preparations of 12 different compositions are done fo r the non–hybrid and hybrid composites. Type 6061 aluminum is of the 6xxx aluminum alloys, which entails those mixtures which use magnesium and silicon as the primary alloying elements. The second digit indicates the degree of impurity control for the base aluminum. When this second digit is a "0", it indicates that the bulk of the alloy is commercial aluminum containing its existing impurity levels, and no special care is needed to tighten controls. The third and fourth digits are simply designators for individual alloys (note that this is not the case with 1xxx aluminum alloys). The nominal composition of type 6061 aluminum is 97.9% Al,

0.6% Si, 1.0%Mg, 0.2%Cr, and 0.28% Cu. The density of 6061 aluminum alloy is 2.7 g/cm^3(0.0975 lb/in^3). 6061 aluminum alloy is heat treatable, easily formed, weld-able, and is good at resisting corrosion.

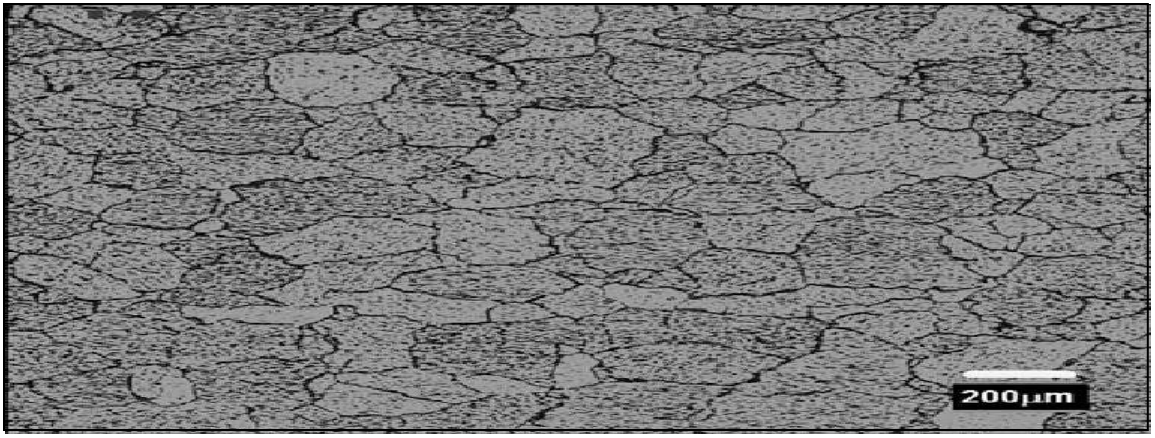

Fig. 4.1:

A. SEM Structure of Aluminium 6061

The mechanical properties of 6061 aluminum alloy differ based on how it is heat treated, or made stronger using the tempering process. To simplify this article, the strength values for this alloy will be taken from T6 tempered 6061 aluminum alloy (6061-T6), which is a common temper for aluminum plate and bar stock. Its modulus of elasticity is 68.9 GPa (10,000 ksi) and its shear modulus is 26 GPa (3770 ksi). These values measure the alloy's stiffness, or resistance to deformation. Generally, this alloy is easy to join via welding and readily deforms into most desired shapes, making it a versatile manufacturing material. Two important factors when considering mechanical properties are yield strength and ultimate strength. The yield strength describes the maximum amount of stress needed to elastically deform the part in a given loading arrangement (tension, compression, twisting, etc.). The ultimate strength, on the other hand, describes the maximum amount of stress a material can withstand before fracturing (undergoing plastic or permanent deformation). For static applications, the yield strength is the more important design constraint as per industry standard design practices; however, the ultimate strength can be useful for certain applications that call for it. 6061 aluminum alloy has a yield tensile strength of 276 MPa (40000 psi), and an ultimate tensile strength of 310 MPa (45000 psi).Shear strength is the ability of a material to resist being sheared by opposing forces along a plane, just as a scissor cuts through paper. As the two scissor blades close, their opposing forces act on the cross sectional plane of the paper and cause it to fail "in shear". This value is useful in torsional applications (shafts, bars etc.), where twisting can cause this kind of shearing stress on a material.

Table - 4.1

Properties of Aluminum 6061

MECHANICAL PROPERTIES	*METRIC*	*PSI*
Ultimate Tensile Strength	*310MPa*	*45000 psi*
Tensile Yield Strength	*276MPa*	*40000 psi*
Shear Strength	*207MPa*	*30000 psi*
Fatigue Strength	*96.5MPa*	*14000 psi*
Modulus of Elasticity	*68.9GPa*	*10000 psi*
Shear Modulus	*26 GPa*	*3770 psi*

The shear strength of 6061 aluminum alloy is 207 MPa (30000 psi). Fatigue strength is the ability of a material to resist breaking under cyclical loading, where a small load is repeatedly imparted on the material over time. This value is useful for applications where a part is subject to repetitive loading cycles such as vehicle axles or pistons. The fatigue strength of 6061 aluminum alloy is

96.5 Mpa (14000 psi), which is calculated using 500,000,000 cycles of continuous, cyclical loading below the yield point. Natural graphite is a mineral composed of graphitic carbon. It varies considerably in crystallinity. Most of the commercial (natural) graphite's are mined, and typically contain other minerals. After graphite is mined, it usually requires a considerable amount of mineral processing like froth flotation to concentrate the graphite. Natural graphite is an excellent conductor of heat and electricity, stable over a broad range of temperatures, and a highly refractory material with a high melting point of 3650 °C. Crystalline Graphite. It is said that crystalline vein graphite came from crude oil deposits that have transformed into graphite through time, temperature, and pressure. Vein graphite fissures typically measure between 1 cm and 1 m in thickness and usually have a purity of more than 90%. Amorphous graphite is the least graphitic among the natural graphite's. However, the term "amorphous" is incorrect as the material is still crystalline. Amorphous graphite can be found as minute particles in beds of monomorphic rocks such as coal, slate, or shale deposits. The graphite content varies from 25% to 85% according to the geological environment. Synthetic graphite can be produced from coke and pitch. This graphite is not as crystalline as natural graphite; it is likely to have higher purity. Pure carbon produced from coal tar pitch and calcined petroleum coke in an electric furnace. The second is synthetic graphite, produced by heating calcined petroleum pitch to 2800 °C. Essentially, synthetic graphite has higher electrical resistance and porosity, and lower density. Its enhanced porosity makes it unsuitable for refractory applications. Synthetic graphite contains mainly graphitic carbon that has been attained by graphitization, heat treatment of non-graphitic carbon, or chemical vapor deposition from hydrocarbons at temperatures over 2100 K.Boron Carbide (B_4C) is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It is the hardest material produced in tonnage quantities. Originally discovered in mid-19th century as a by-product in the production of metal borides, boron carbide was only studied in detail since 1930.Boron carbide powder is mainly produced by reacting carbon with B_2O_3 in an electric arc furnace, through carbon thermal reduction or by gas phase reactions. For commercial use B_4C powders usually need to be milled and purified to remove metallic impurities.

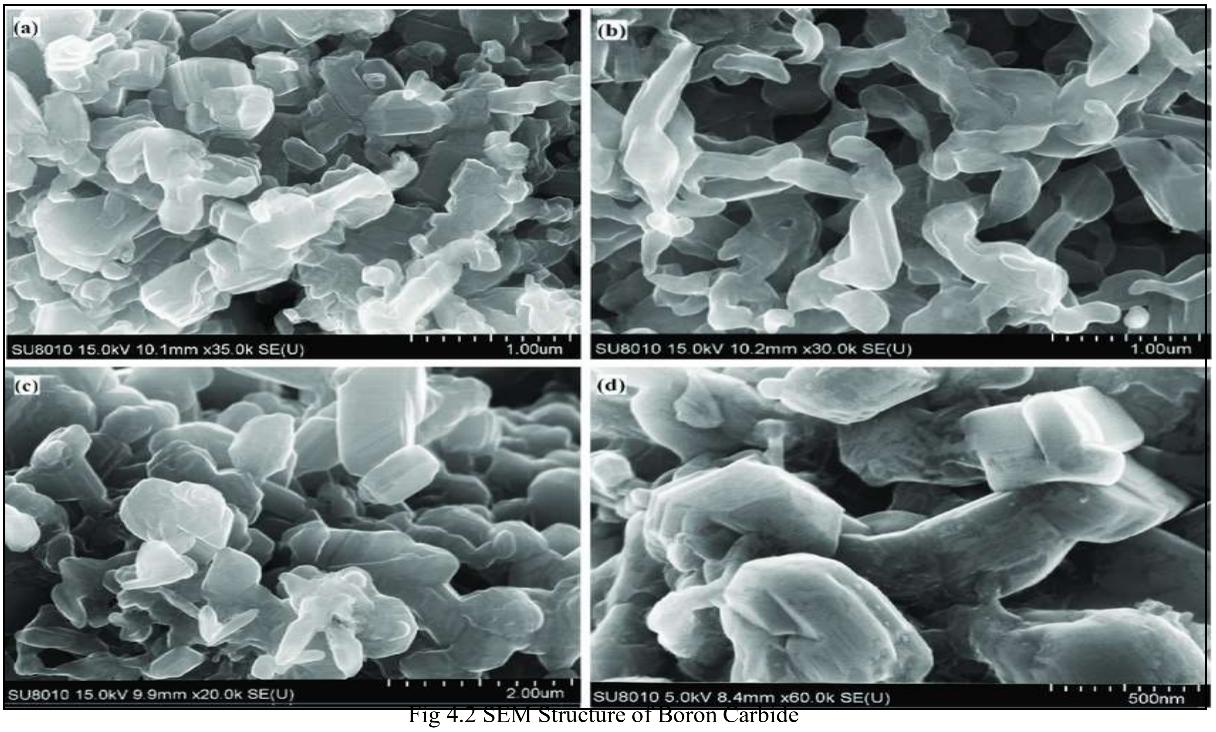

Fig 4.2 SEM Structure of Boron Carbide

Table - 4.2

Properties of Boron Carbide

PROPERTIES	*VALUES*
Density (g.cm^{-3})	*2.52*
Melting Point (°C)	*2445*
Hardness (Knoop 100 g) (kg.mm^{-2})	*2900 – 3580*
Fracture Toughness (MPa.m$^{-½}$)	*2.9 - 3.7*
Young's Modulus (GPa)	*450 – 470*
Electrical Conductivity (at 25 °C) (S)	*140*
Thermal Conductivity (at 25 °C) (W/m.K)	*30 – 42*
Thermal Expansion Co-eff. x10^{-6} (°C)	*5*
Thermal neutron capture cross section (barn)	*600*

V. RESULT AND DICUSSION

Powder metallurgy technique was used here because of its various advantages like less time simple fabricating technique, less cost of production, simple technique. Here the fabrication was carried out by two stages of Non-hybrid composites and hybrid composites. In the both types Al6061 was taken as the base material (matrix material), B4C and Graphite was taken as the reinforcement material. Al6061 was taken in 50 µm, Graphite was taken 100 µm, and B4C was taken in form of Nano size of 100 nm and all those materials was received from Material Suppliers. Friction stir welding of aluminum alloy 6061-T6 plate was carried out using the parameter values and thee hardness test were investigated. From the experiments it was observed that the hardness values in the welding zone is having 91% of the base metal hardness value. Using method, the combination of the parameters for the better hardness is identified as follows Tool rotational speed 450 rpm. Welding speed 20 mm/min, Dwell time 1.5 min, Tool tilt angle 0 degree. The preparation of composites was started by measuring the powder which could do by the simple balance of accuracy of 0.001 g. The preparations of 12 different compositions are done for the non–hybrid and hybrid composites. The distribution of particles plays a vital role in the composite properties. For making the properties homogeneous though out it sections can be done by the proper mixing of reinforcements and base metal only. This can be done by using high speed ball milling machine of speed 400 rpm for the time of 30 minutes. The powders to balls ratio is followed by 10:1. These process was carried out at inert gas (organ) conditions. Scanning electron microscope (SEM) is one the type of electron micro scope which scans the sample with focused beam of elections. SEM can gives the information about sample contains with less than 1 Nanometer accuracy. By using compression testing machine pellets are manufactured by the applied pressure of 400 Mpa. In ctm load applied is slowly progressive load and at the load is maintained for time of 45 s. Separate die are manufactured with diameter of 15 mm and length of 60 mm. The size obtained pillets are 15 mm diameter and length of 35 mm. By filling the die with blended powders and placed in the cut for applying load. The load applied is very slow manner and after reaching the required level there will be maintaining of load at that high pressure for time of 45s.Sintering process makes the pellets into specimens for the testing purpose. This can be done by using muffle furnace of capacity 1500°C. All the pellets are placed in muffle furnace for sintering purpose at temperature of 600°C for the time of 3 hours. By the successful manufacturing and sintering of specimens and conducting both density and harness testing of components subjected to heat treatment process. The heat treatment procedure is done by the heating in muffle furnace. The total procedure consists two stages of operation in the first stage the specimens are subjected to around 490°C for 3 hours that is followed by quenching in the water. In the second stage process of specimens is subjected to natural aging process for the time of 18 hour to be became uniform grain growth of materials uniform by furnace cooling.

VI. CONCLUSION

The ultimate tensile strength of a material is an intensive property, meaning its value is independent of the size of the test specimen. However, factors such as specimen preparation, the presence of surface defects, and the temperature of both the material and the testing environment can influence the tensile strength. Hardness, on the other hand, refers to a material's resistance to localized plastic deformation caused by mechanical indentation or abrasion. Materials like metals are typically harder than plastics or wood. Macroscopic hardness is generally associated with strong intermolecular bonds, but the behavior of solid materials under force is complex. As a result, different methods are used to measure hardness, including scratch hardness, indentation hardness, and rebound hardness.

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