Mechanical Behavior of Aluminium-6061 Reinforced with Boron - Carbide and Graphite Synthesized by Stir Casting

Muthiah A
Department of Mechanical Engineering
P.S.R.Engineering College, Sivakasi, India

UmaRajeshwaran G.M
Department of Mechanical Engineering
P.S.R.Engineering College, Sivakasi, India

Ravikumar K
Department of Mechanical Engineering
P.S.R.Engineering College, Sivakasi, India

Kanagaraj.C
Department of Mechanical Engineering
P.S.R.Engineering College, Sivakasi, India

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 Analysis

I. Introduction

Composites consist of two or more physically and/or chemically distinct materials. There are three components of a composite i.e., matrix, reinforcement, and the interface between matrix and reinforcement. A matrix is a continuous phase of composites and serves to hold the reinforcements in predetermined orientation. Reinforcement is a stronger material distributed within the matrix. Matrix and reinforcements are chemically bonded or mechanically locked together. Matrix, reinforcements, and the interface determine the characteristics of a composite. While the characteristics of a matrix material are changed in the composite making process, those of reinforcing materials remain the same except in rare instances of processing at very high temperature. Composites are classified based on the types of matrix and reinforcements. Composites are classified as polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramics matrix composites (CMCs) based on the type of matrix. Depending on the types of reinforcements, composites include particle reinforced composites, short fiber composites (whisker), and continuous fiber composites (sheet). The materials for reinforcements can be organic fibers, metallic fibers, ceramic fibers, and particles. The materials for matrices can be polymers, metal and its alloys, glasses, glass-ceramics, ceramics. Usually, the strength of a matrix is considerably less than that of fiber reinforcement. In PMCs, matrices are mostly cross-linked thermoset polymers (epoxy, polyester, phenolic). Glass fiber-reinforced thermoset polymers have high strength and stiffness to weight ratio, thus they are usually used in automotive components. Other matrices in PMCs include thermoplastic resins (PE, Nylon, PVC …). In MMCs, light metals like aluminum, titanium and magnesium, and their alloys are usually used as matrices. Aluminum is most commonly used due to its excellent strength, toughness, and resistance to corrosion and abrasion. In CMCs, silicon carbides are regularly used for both matrices and reinforcements. However, the silicon carbide reinforcements are of multiple forms to achieve preferred properties. In particle reinforced composites, particles can be ceramics, glasses, metal, and/or amorphous materials. While the modulus of a composite is higher than that of its matrix, the permeability and ductility are lower. Therefore, particle reinforced composites can sustain higher tensile, compressive and shear stresses. Fiber reinforced composites consist of short fiber composites and continuous fiber composites. The modulus of a composite of this type is higher than that of a matrix because of the strong covalent bonds along the fiber length. The orientation of the fibers relative to one another has significant impact on the mechanical properties of the composite. In addition to matrix and reinforcements, the interfaces also play an important role in the properties of composites. As matrix and reinforcements are not in thermodynamic equilibrium at the interface, a discontinuity of one or more material parameters (elastic moduli, strength, and chemical potential) occurs. The interfaces create a medium for the transitions and avoid a jump in material parameters between matrix and reinforcements, the transitions gradually take place over the thickness of the interface. In addition, there is a chemical compound formed from the matrix materials and reinforcing materials at the interface due to the discontinuity in chemical potential. This chemical compound forms an interaction zone of which a certain thickness is desirable as long as it does not affect the properties of a composite.

II. LITERATURE REVIEW

K.K. Chawla Metal-matrix composites (MMCs) are engineered combinations of two or more materials (one of which is a metal) where tailored properties are achieved by systematic combinations of different constituents. Conventional monolithic materials have limitations in respect to achievable combinations of strength, stiffness and density. Engineered MMCs consisting of continuous or discontinuous fibres, whiskers, or particles in a metal achieve combinations of very high specific strength and specific modulus. Furthermore, systematic design and synthesis procedures allow unique combinations of engineering properties in composites like high elevated temperature strength, fatigue strength, damping property, electrical and thermal conductivities, friction coefficient, wear resistance and expansion coefficient. T.W. Clyne and P.J. Withers Structurally, MMCs consist of continuous or discontinuous fibers, whiskers, or particles in an alloy matrix which reinforce the matrix or provide it with requisite properties not achievable in monolithic alloys. P. Rohatgi .In a broader sense, cast composites, where the volume and shape of phase is governed by phase diagrams, for example, cast iron and aluminum-silicon alloys, have been produced by foundries for a long time. The modern composites differ in the sense that any selected volume, shape and size properties in composites like high elevated temperature of reinforcement can be artificially introduced in the matrix. I.A. Ibrahim et al.. The modem composites are non-equilibrium combinations of metals and ceramics, where there are fewer thermodynamic restrictions on the relative volume percentages, shapes and size of ceramic phases. S. Ray [5]. Composite materials are attractive since they offer the possibility of attaining property combinations which are not obtained in monolithic materials and which can result in a number of significant service benefits. These could include increased strength, decreased weight, higher service temperature, improved wear resistance, higher elastic modulus, controlled coefficients of thermal expansion and improved fatigue properties. S.V. Prasad and R. Asthana. The quest for improved performance has resulted in a number of developments in the area of MMC fabrication technology .These includes both the preparation of the reinforcing phases and the development of fabrication techniques. A number of composite fabrication techniques have been developed that can be placed into four broad categories. These are powder metallurgical techniques, liquid metallurgy. The liquid metallurgy techniques include unidirectional solidifications to produce directionally aligned MMCs, suspension of reinforcement in melts followed by solidification, compo casting, squeeze casting, spray casting, and pressure infiltration. The liquid metallurgy techniques are the least expensive of all, and the multi-step diffusion bonding techniques may be the most expensive. B.P. Krishnan et al.Graphite is a soft grayish-black greasy substance. The word graphite comes from a Greek word meaning 'to write'. The lead in our writing pencils is graphite mixed with clay. Graphite is also known as black lead or plumb ago. Graphite is also crystallized carbon. The carbon atoms of graphite form a crystal pattern that differs from that of the carbon atoms in diamond. In graphite, the carbon atoms are arranged in flat planes of hexagonal rings stacked on one another. This free electron accounts for the electrical conductivity of graphite. The lack of carbon-carbon bonding between adjacent planes enables them to slide over each other making graphite soft, slippery and useful as a lubricant. The presence of free electrons makes graphite a good conductor of electricity and it is used to make electrodes. S. Biswas et al..Graphite has the following properties. (i) Graphite is a soft, slippery, grayish-black substance. It has a metallic luster and is opaque to light. (ii)Specific gravity of graphite is 2.3. (iii)Graphite is a good conductor of heat and electricity. (iv)Although graphite is a very stable allotrope of carbon but at a very high temperature it can be transformed into artificial diamond. (v)Chemically, graphite is slightly more reactive than diamond.

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 for 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.

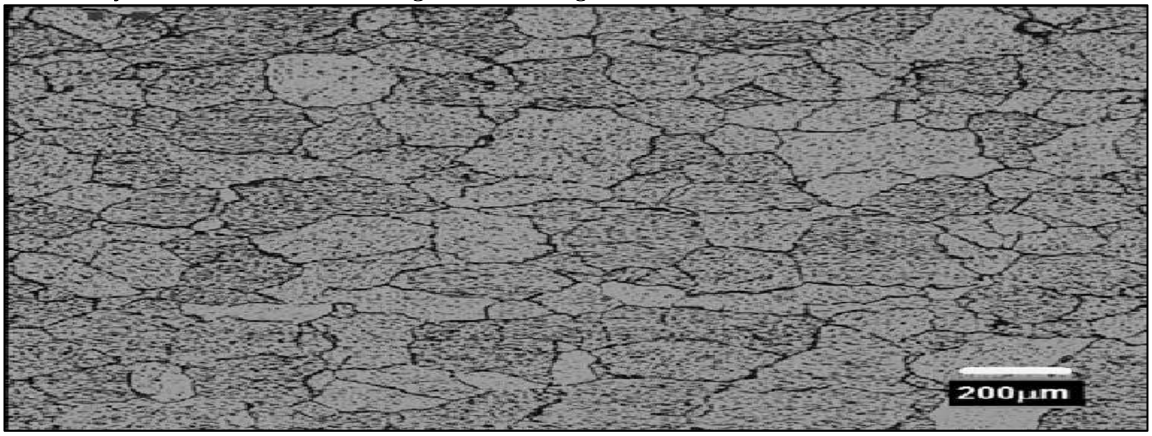

Fig. 4.1:

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.

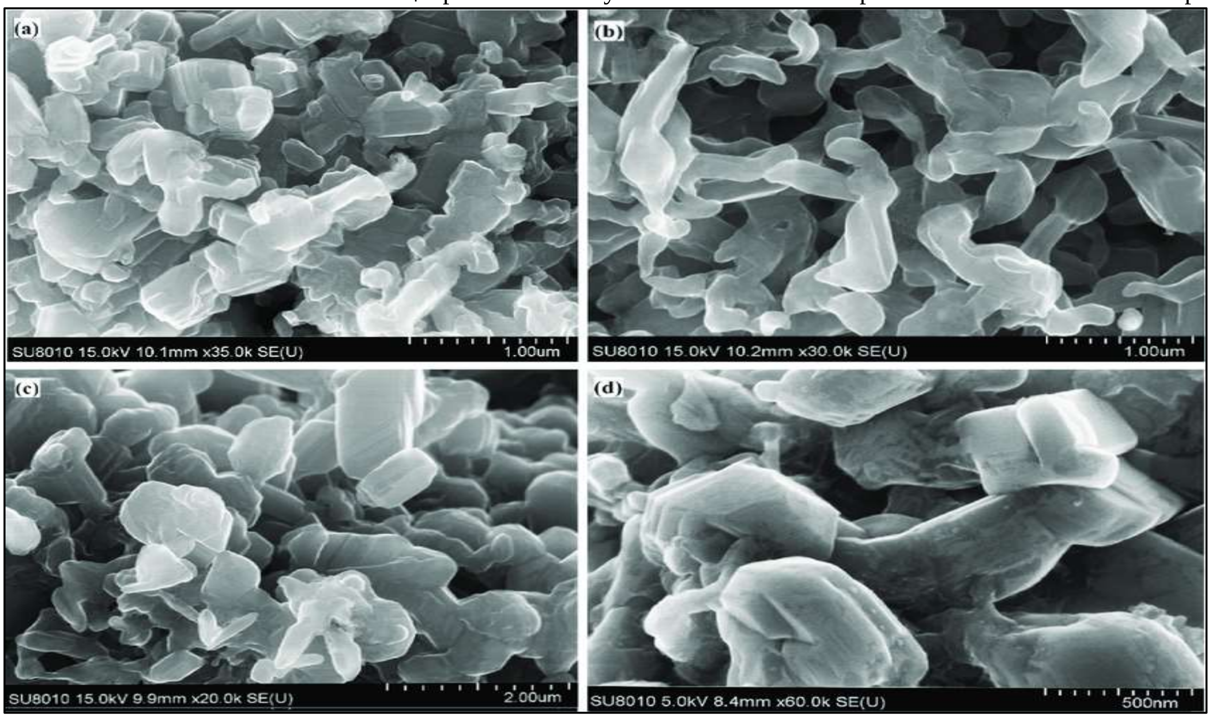

Fig 4.2 SEM Structure of Boron Carbide

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; therefore, its value does not depend on the size of the test specimen. However, depending on the material, it may be dependent on other factors, such as the preparation of the specimen, the presence or otherwise of surface defects, and the temperature of the test environment and material. Hardness is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion. Some materials (e.g. metals) are harder than others (e.g. plastics, wood). Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: scratch hardness, indentation hardness, and rebound hardness.

Reference

[1] Telang.A.K, Rehman.A,(2015)“Alternate materials in automobile brake disc applications with empasis on AL composites – a technical Review”.
[2] Maleque,S.Dyuti (2015),”Material selection method in design of automotive brake disc”
[3] Aranganathan.N, Bijwe Jayashree (2016) “Development of copper – free Eco-friendly Brake – Friction Material using Novel Ingredients”.
[4] Brijendra Gupta, Ashish jashvantlal modi (2015),"Review of Automotive brake friction materials” International Journal of Advance Engineering and Research Development, vol 2
[5] Nagesh.S.N, Siddaraju.C,(2014)“Characterization of brake pads by variation in composition of friction materials”.
[6] F.H.Latif, El-Sayed M.sherif, (2012) “ Effects of sintering temperature and graphene addition on the Mechanical properties of aluminium”.
[7] AjithGopinath et al, (2014), “ Exprimental Investigastions on Mechanical Properties of Jute Fiber Reinforced Composites with Polyster and Epoxy Resin Matrices, Procedia Engineering”.
[8] S.Goussous, W,Xu,X,Wu,K,Xia, (2010) “ Composites science and technology 69”.
[9] Tej singh, Amar patnaik, Ranchan chauhan (2015), “Assesement of braking performance of lapnius – wollastonaite fibre reinfored friction composite materials”.
[10] Minyang Hao, Ruiying Luo Wei yang (2014), “Effect of fiber-tyes on the braking performances of carbon/carbon composites”.

