Extracting of density and compression strength values of an Al-Wc MMC produced by sintering furnace

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Abstract—Aluminium (Al) alloy 6061 is one of the most extensively used of the 6000 series. Among the various useful alloys, aluminium alloy 6061 is typically characterized by properties such as fluidity, cast ability, corrosion resistance and high strength-weight ratio. Aluminium-based alloy MMCs has received increasing attention in recent decades as engineering applications. This alloy has been commonly used as a base metal for MMCs reinforced with a variety of fibres, particles and whiskers. Tungsten carbide (Wc) is approximately two times stiffer than steel, with a Young's modulus of approximately 550GPa, and is much denser than steel or titanium. Powder metallurgy is the process of blending fine powdered materials, compacting the same into a desired shape or form inside a mould followed by heating of the compacted powder in a controlled atmosphere, referred to as sintering to facilitate the formation of bonding of the powder particles to form the final part.

Sintering is the process of forming a solid mass of material by heat and/or pressure without melting it to the point of liquification. Sintering happens naturally in mineral deposits or as a manufacturing process used with metals, ceramics, plastics, and other materials. The atoms in the materials diffuse across the boundaries of the particles, fusing the particles together and creating one new solid piece. The Al-Wc MMC compacts are produced by using sintering furnace which is forwarded by the mixing of Al-Wc powders in V-blender, making of green compacts by hydraulic press. As the wt %of Wc is increased from 0 % to 9% weight as reinforcement in Al matrix, then compressive strength values are improved up to 6% of Wc, after that the compressive strength is gradually decreased at 9% weight of Wc. As increasing the weight percentage of the reinforcement Wc in the matrix, the density values also increased gradually)

IndexTerms: Sintering, Blending, Compacting, MMC

I. INTRODUCTION

In today's world almost all generic materials have been tried for various uses and their limitations have been met. But the never ending quest of civilization requires that materials qualify for harsher environments. One can create new materials with unique properties, which can be tailor-made and are different from their base ingredients. This concept holds true for a genre of materials called Composite materials where in, various types of matrices may be combined with reinforcements which contribute to the enhancement of the properties. Neither the matrices nor the reinforcements taken alone can stand up to the requirement, but the composite may be able to do so.

Aluminium alloys have found greater adoption as potential matrix materials in comparison with other alloys. And the 6xxx series of Aluminium alloys are coming into the picture very fast. The aerospace, automotive and utensil industries were the first reporting their use.

Tungsten carbide (chemical formula: WC) is a chemical compound (specifically, a carbide) containing equal parts of tungsten and carbon atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, cutting tools, abrasives, other tools and instruments, and jewelry.

When two or more materials are interspersed, there is always a contiguous region. Simply this may be the common boundary of the two phases concerned, in which case it is called an interface. A composite having a single interface is feasibly fabricated when the matrix and the reinforcement are perfectly compatible. On the other end, there may an altogether separate phase present between the matrix phase and the reinforcement phase. This intermediate phase is called an inter-phase. In case there is an inter-phase present, there are two interfaces, one defining the boundary between the matrix and the inter-phase, and the other between the inter-phase and the reinforcement. The strength of the composite in such a case is dependent upon the strength of the weaker of the two interfaces.

There are certain advantages of having a preferred inter-phase. Such a composite with an inter-phase is fabricated if the matrix and reinforcement are not chemically compatible or if the wettability of the pair is very poor. Such a composite is materialized, by introducing a third material that has good bonding properties, individually with the matrix and the reinforcement, which would not be possible otherwise. More or less, the strength of a composite is a function of the strength of its interface between the matrix and the reinforcement. The failure of a functional composite is essentially a result of the failure of the interface. Hence the strengthening mechanism is the most dominant parameter in successful fabrication of a high strength composite.

II. LITERATURE SURVEY

[1] S Jerry Andrews Fabian1 stated that there is a huge demand for Aluminium matrix based composites (AMC) as they offer high specific strength and wear resistance as compared to pure Aluminium. In this study the

densification effect of tungsten carbide (WC) particulate reinforcement in the Aluminium (Al) matrix was investigated. The Al composite was prepared by P/M process with tungsten carbide particulate of 2.5%, 5%, 7.5% and 10% on mass fraction basis. The preforms were prepared for the aspect ratios of 0.5, 0.75 and 1.0.

The theoretical density of the preforms was calculated using rule of mixture. Compaction was carried out in UTM machine by applying load of 80 to 98KN. The preforms were sintered at 640OC for 60 minutes in a muffle furnace. The densities of the sintered samples were measured using Archimedes principle. The measured values were plotted for unreinforced Aluminium and the composite preforms.

The experiment indicated that increase in WC particulate increases density of the preforms and a relative density of 93.73% are achievable. For aspect ratio 0.5 the progress in densification is linear indicating further densification is possible with addition of WCp more than 10%.

[2] C.Padmavathi1, D.Agarwal2, et al., presented a paper on MICROWAVE SINTERING OF ALUMINUM ALLOYS Until 2000 almost all research in the microwave sintering area was confined to non-metallic materials. However, after the first report by Penn State in 19991 on full sintering of steel powders in microwave, now in the last few years there has been increasing interest in applying microwave energy for processing of variety of metallic materials.

The present study is an extension of this work and relates to the sintering behaviour of aluminium alloy powders. Blended 2712 (Al-Cu-Mg-Si-Sn) and 6711 (Al-Mg-Si- Cu) alloy powders were consolidated by microwave sintering through temperature range of 570 to 630 °C for 1 hr in vacuum, nitrogen, argon and hydrogen atmospheres.

The influence of sintering temperature and atmosphere on densification response were investigated in comparison with conventional sintered parts. Microwave sintering enhanced the densification response in shorter times and lower sintering temperature in turn leading to better properties.

III. POWDER METALLURGY

ThePowder metallurgy is the process whereby metallic shapes are manufactured from metallic powders. The process involves the manufacture of metallic powders and the subsequent welding of these powders into a solid from of the required shape. In powder metallurgy. The metal or alloy is solid at the very start of manipulation and remains completely sold during the manipulation process.

Power metallurgy is becoming an increasingly important tool in the fabrication of many products. Powdered metal techniques are invaluable in the manufacture of parts from refractory materials of materials which are extremely difficult to work or machine e.g sintered carbides etc.. Powder metallurgy is the process of blending fine powdered materials, compacting the same into a desired shape or form inside a mould followed by heating of the compacted powder in a controlled atmosphere, referred to as sintering to facilitate the formation of bonding of the powder particles to form the final part. Thus, the powder metallurgy process generally consists of four basic steps

(1) Powder manufacture,

(2) Blending of powders,

(3) Compacting of powders in a mould or die, and

(4) Compacting is generally performed at room temperature and at high pressure.

Sintering is usually done at elevated temperature and at atmospheric pressure. Often, compacting and sintering are combined. Optional secondary processing often follows to obtain special properties or enhanced dimensional precision. Powder Metallurgy route is very suitable for parts that are required to be manufactured from a single or multiple materials (in powder form) with very high strength and melting temperature that pose challenge for the application of casting or deformation processes.

Characteristics of metal powder :The performance of metal powders during processing and the properties of powder metallurgy are dependent upon the characteristics of the metal powders that are used. Following are the important characteristics of metal powders (a) Particle shape (b) Particle size. (c) Particle size distribution. (d) Flow rate (e) Compressibility (f) Apparent density (g) Purity.

IV. METAL MATRIX COMPOSITES (MMCS)

MMC are increasingly becoming attractive materials for advanced aerospace applications because their properties can be tailored through the addition of selected reinforcements. In particular, particulate reinforced MMCs have recently found special interest because of their specific strength and specific stiffness at room or elevated temperatures. It is well known that the elastic properties of metal matrix composites are strongly influenced by micro structural parameters of the reinforcement such as shape, size, orientation, distribution and volume fraction.

V. EXPERIMENTAL SETUP

Aluminium-based MMCs have received increasing attention in recent decades as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys.

Al 6061: Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities. The powder form of the Al 6061 is shown in the below figure

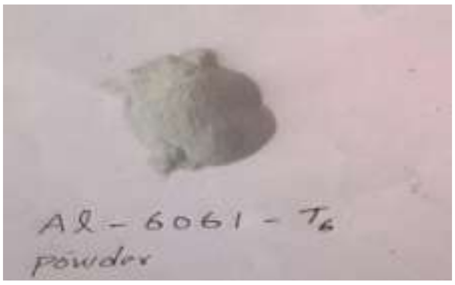


Fig 1: Al-6061-T6 powdwer

Al 6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S," it was developed in

1935. It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use. It is commonly available in pre-tempered grades such as 6061-O (annealed) and tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061T651 (solutionized, stress-relieved stretched and artificially aged).

Tungsten carbide (chemical formula: WC) is a chemical compound (specifically, a carbide) containing equal parts of tungsten and carbon atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, cutting tools, abrasives, armourpiercing rounds, other tools and instruments, and jewellery.

Fig 2: Wc-Tungsten carbide powder

Tungsten carbide is approximately two times stiffer than steel, with a Young's modulus of approximately 550GPa, and is much denser than steel or titanium. It is comparable with corundum (α-Al_2O_3), sapphire and ruby in hardness and can only be polished and finished with abrasives of superior hardness such as cubic boron nitride and diamond, in the form of powder, wheels, and compounds.

a) Industrial mixers and blenders are used to mix two or more materials in large quantities. Batch mixers operate a single batch at a time while continuous mixers operate continuously. Mixers can also be rated for pressure and vacuum and come in many different types of mixing motions for various types of materials. The needed mixing force, material properties, desired output, pressure, and mixing speed are used to select an industrial mixer or blender. The detailed components of v-blender is shown in the below figure.

Fig 3: V-blender

Mixing devices can be classified into two groups with respect to segregation: segregating mixers—which have mainly diffusive mechanisms, encouraging the movement of individual particles, making segregation more significant, non-impeller type mixers tend to be of this type. Less segregating mixers—have mainly convective mixing mechanisms. These are typically impeller types in which blades, screws, ploughs, etc. sweep groups of particles through the mixing zone. Mixing devices are chosen according to the material mixed; therefore, it is important to know the particle size as well as their flow properties

V-Blenders are very popular in a wide variety of industries. The blending performance of this type of blender has shadowed many of the members in the blender family. They offer both short blending times and efficient blending. The blend is achieved by the constant dividing and intermeshing of particle movement provided by two connected cylinders.

b) Binder: A binder is any material or substance that holds or draws other materials together to form a cohesive whole mechanically, chemically, or as an adhesive. Often materials labeled as binders in different proportions or uses can have their roles reversed with what they are binding. An example is straw helping to mechanically bind clay together as in the building material cob, and clay as an adhesive helping to bind straw together as in a natural insulation.

Fig4: wax binder

Al 6061 metal was taken in the form of metal powder with the uniform grain size as a major constituent, similarly to that tungsten carbide is also taken in the form of metal powders with the uniform grain size of 5 microns.

Based on the weight of the compact the reinforcement matrix powders are taken separately in to a bowl. After making the v-blender ready to operate then along with the powders some amount of aluminium and carbide made balls as shown in the figure are to be added in to the powder compositions. Along with this some amount of wax binders are taken to bind the metal powders together in v- blender to make the powders mix homogeneously in the entire blender by the rotary action of the equipment. This process of mixing is to be carried out for 24 hours continuously.

Cemented carbide and aluminium balls are neatly cleaned with water and rub those wet balls with the help of a clean and fresh cloth. After that these balls have to keep under the sun in order to make the moister content evaporate from the balls, so that the balls are ready to use for mixing of powders. Because of the presence of this kind of balls in the mixer/blender powders can mix properly in a way that the powders grains can separate and by the revolving action of mixtures/blenders the powder will be mixed homogeneously in the blenders

Fig5 : Al and Wc balls used for mixing

So that by having some angular construction of the blender vessel these powders which are packed in the small boxes are mixed homogeneously. Based on these reinforcements the powders are taken in separate boxes by providing coded label on the top of the boxes.

Fig6: packed powders for mixing in V- blender

Compositions of wc with al 6061is taken as follows and shown in below fig.

Fig7:different compositions of Al-Wc

AL 100% & WC 0% is A0 AL 94% & WC 6% is A2
AL 97% & WC 3% is A1 AL 91% & WC 9% is A3

In the batch A0 the al6061 is taken as 100% in weight with no addition of Wc.
In the batch, A1 the al is taken as 97% and Wc is taken as 3% in weight.
In the batch A2 the al is taken as 94% and Wc is taken as 6% in weight.
In the batch A3 the al is taken as 91% and Wc is taken as 9% in weight

c) Process of powder pressing

Initially powders are taken out from the blender and placed them separately to one another. Based on the reinforcement compositions and size of the compact, the powders are taken accurately that too by taking in to the account of no. of compacts to be produced. By following the sequential steps of process as shown in the below pressed compacts can be obtained.

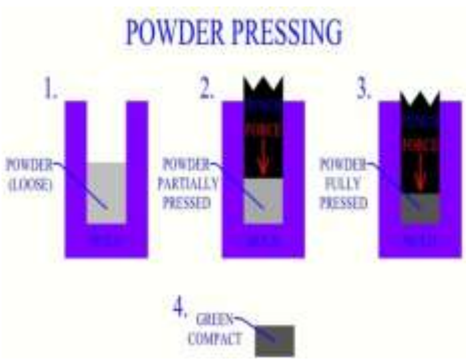


Fig8: compact making process

In this process, 15 grams of powder is to be taken for making of each compact in a batch, so that 5 compacts are to be produced for the experimental process in each batch like that 4 batches in each 5 compacts. By this totally 20 compacts are produced. The powder is taken and poured in to the dies and a punch is placed on the die which is filled with the powder. The entire die and punch arrangement is to be placed in the hydraulic pressing machine table.

Fig9: dies used to prepare compacts

By doing like this the final shape and size of the green compact is obtained in cylindrical shape and sizes are as follows.
Diameter d=2.687 cm and,
Height h=1.5 49cm.

d) Sintering

Sintering is the process of forming a solid mass of material by heat and/or pressure without melting it to the point of liquefaction. Sintering happens naturally in mineral deposits or as a manufacturing process used with metals, ceramics, plastics, and other materials. The atoms in the materials diffuse across the boundaries of the particles, fusing the particles together and creating one new solid piece.

This Sintering refers to the heating of the compacted powder perform to a specific temperature (below the melting temperature of the principle powder particles while well above the temperature that would allow diffusion between the neighbouring particles). Sintering facilitates the bonding action between the individual powder particles and increase in the strength of the final part by using the vacuum sintering furnace as shown in fig 6.1. The heating process must be carried out in a controlled, inert or reducing atmosphere or in vacuum for very critical parts to prevent oxidation.

Prior to the sintering process, the compacted powder perform is brittle and confirm to very low green strength. The nature and strength of the bond between the particles depends on the mechanism of diffusion and plastic flow of the powder particles, and evaporation of volatile material from the in the compacted preform. Bonding among the powder particles takes places in three stages:
(1) Melting of minor constituents in the powder particles,
(2) Diffusion between the powder particles, and
(3) Mechanical bonding.

The time, temperature and the furnace atmosphere are the three critical factors that control the sintering process. Sintering process enhances the density of the final part by filling up the incipient holes and increasing the area of contact among the powder particles in the compact perform.

After being compacted in to a briquette having the shape of the finished work piece, the cold –welded

aggregate of metal particles heated in a furnace to a temperature close to the melting point of the base metal which goes in to the mixture. This is carried out in controlled atmosphere furnaces.
It may also be carried out under protective gas normally hydrogen or in a vacuum if the material tends to react with the protective gas, the heating causes the metal particle to sinter, that is, a portion of them partially melt and so that by doing cement the remaining particles together in a cellular structure. From the economic point of view, the sintering time should be long enough to obtain the required properties in the work piece.

This experiment has been done on the low vacuumed sintering equipment.

Fig10: low vacuum sintering furnace.

e) Vacuum furnace

A vacuum furnace is a type of furnace that can heat materials, typically metals, to very high temperatures and carry out processes such as brazing, sintering and heat treatment with high consistency and low contamination.
In a vacuum furnace the product in the furnace is surrounded by a vacuum. The absence of air or other gases prevents heat transfer with the product through convection and removes a source of contamination.
Some of the benefits of a vacuum furnace are
Uniform temperatures in the range 1100–1500°C (2000–2800°F), Temperature can be controlled within a small area, Low contamination of the product by carbon, oxygen and other gases, Quick cooling (quenching) of product, The process can be computer controlled to ensure metallurgical repeatability.

Heating metals to high temperatures normally causes rapid oxidation, which is undesirable. A vacuum furnace removes the oxygen and prevents this from happening. Sintering is performed to achieve all possible final strength and hardness needed in the finished product. The three most important variables governing the sintering process are temperature, time, and sintering atmosphere. The work dimensions change during sintering. Such changes may be either a shrinkage or growth. Grain growth changes are shown in the below figure

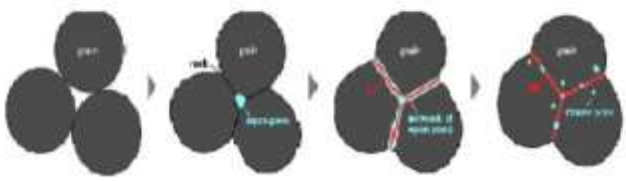


Fig11: stages of grain growth and formation of new boundaries.

Before going to start the sintering process the entire set up have to check with no leakages in air compressors, pressure gauges, over all water control systems and temperature control systems. After the checking up, the machinery has to start to make warm in ideal condition so that it is ready to provide set of instructions by coding a program on a monitoring display screen. Working of sintering furnace is shown in the above the figure

Fig12: Compacting in sintering furnace

After completion of the compacting process those green compacts are to be taken in to the tray by developing a code on each and every compact. In this experiment, I have taken coding on totally 20 compacts in 4 batches like

A0 (A0-1, A0-2, A0-3, A0-4,)
A1 (A1-1, A1-2, A1-3, A1-4,)
A2 (A2-1, A2-2, A2-3, A2-4,)
A3 (A3-1, A3-2, A3-3, A3-4,)

Like this batches and coding are taken for the experimental work.

- Over all sintering time is 3hours This sintering process is carried out in five stages
- Initial sintering temperature is programmed up to in 30min of time.
- Soaking time for 30 min.
- Gradually increase the sintering temperature up to in 30min of time.
- Again, soaking for 30 min.
- Finally allow the sintered specimens to gain room temperature for 1 hour.

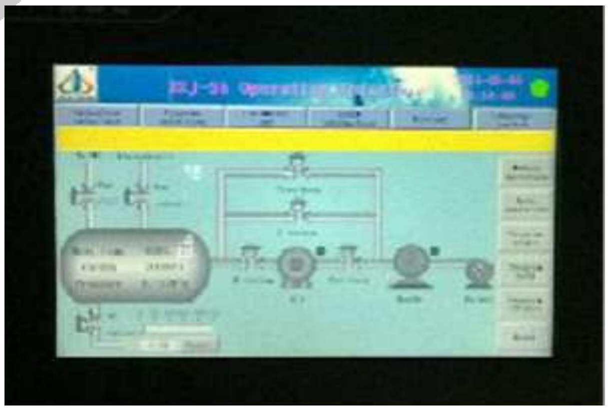


Fig 13: low vacuum sintering furnace condition before operation

The complete internal working conditions of the low vacuum sintering machine are visible in the computerized display screen with advanced screen touch feature in order to make the system as compact as possible.

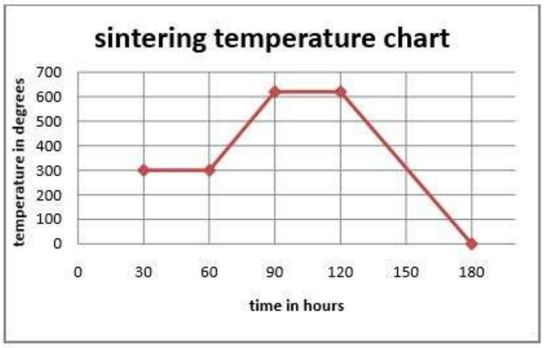
At the time of sintering process entire furnace working conditions are shown in below figure. The pressure of the low vacuum sintering is about -97.0 kpa. The current required to heat the furnace is 250 amps. The voltage required to heat the furnace is 20kw

Fig14: low vacuum sintering furnace condition at the time of operation

Finally the sintered compacts are obtained with high strength and good surface finish and those specimens are shown in below figure

Fig15: finally obtained sintered specimens

Initially temperature is starting from the c then gradually increased to 300deg c for 30min in step 1 then maintain that 300deg c for another 30min for soaking in step 2 after that again gradually increase the temperature of the furnace to 620c for 30min in step3 after that maintain that 620c for another 30min for soaking in step 4. Finally stop the increment of the temperature and allow the compacts to reach the room temperature in the furnace for 1hr



Graph1: Sintering temperature

CONCLUSIONS

Density conclusion

By observing the density results it is clear that for batch A0 i.e.100% of Al 6061 after performing sintering process those specimens got the density value as .

So that by adding the Wc reinforcement in Al matrix it is clear that the density values are improved to say than Al 6061.

As increasing the weight percentage of the reinforcement in the matrix, the density values also increased gradually.

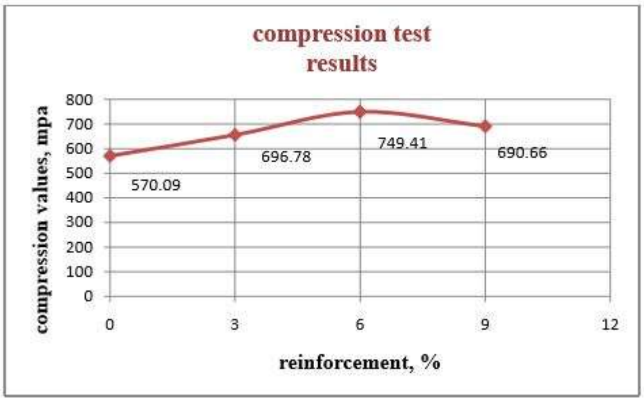
Graph2: Density results

Compression conclusion

The compressive strength of the composites is higher than that of the base alloy. It can be observed that with increase in Wc content the composites compressive strength is also increased.

While taking 100% Al6061 t6 we get the compression value as 570.09Mpa. The compressive strength value is improved up to 6 % wt of Wc, after that the compressive strength is gradually decreased at 9 % of Wc.

While taking 94% of Al and 6% of Wc we get the compression value is further increased as 749.41Mpa.



Graph3: Compression results

Future scope

Based on this experimental work I can suggest that there may be chance to get much better results by choosing this Wc reinforcement as a nano-level along with Al 6061 powder

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