Abstract

This paper deals with the comparison studies on mechanical properties for cleaner energy like microwave heat treatment and conventional heat treatment of Al (6061) -B₄C composite. Aluminium Metal Matrix Composites (MMC) are fabricated through two step stir casting method. Fabricated composites were subjected to microwave and conventional heat treatment for enhancing the mechanical properties. Energy efficient microwave heat treatment has produced comparable mechanical properties with conventional heat treatment. Machinability characteristics of microwave heat treated and non-heat treated composites were evaluated using a lathe tool dynamometer. Machined surfaces were analyzed by SEM and surface roughness meter.

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1. Introduction

Composite materials are a result of the continuous attempts to develop new engineering materials with low weight to strength ratios and improved properties. Among the advanced composite materials, particulate reinforced metal matrix composites (MMCs) are finding increased applications due to their favourable mechanical properties such as improved strength, stiffness and increased wear resistance over unreinforced alloys. In particular, these composites show enhanced properties compared to unreinforced alloys.

Metal matrix composites consists of a metallic alloy matrix typically reinforced with a ceramic phase in the form of particles, platelets, whiskers, short fibers, and continuously aligned fibers. Aluminium metal matrix
composites (Al MMCs) offer a combination of (a) higher stiffness-to-density ratio, (b) better elevated temperature properties and (c) improved wear resistance. These Al-MMCs have become the necessary materials in various engineering applications like aerospace, marine and automobile product applications such as engine piston, cylinder liner, brake disc/drum etc. [1].

Aluminium metal matrix reinforced with Boron Carbide (B₄C) is a novel composite, which is used in automotive industries (ex. Brake pads and brake rotor) due to high wear resistance, high strength to weight ratio, elevated temperature toughness and high stiffness. B₄C is also used in the nuclear industry [2] as radioactivity containment vessels and control rod fixture, since B₄C is a neutron absorber, also high-temperature thermoelectricity conversion [3,4] and ballistic protections [5]. Boron carbide is an attractive reinforcement for aluminium and its alloys. It shows many of the mechanical and physical properties required of an effective reinforcement, in particular high stiffness 445 GPa, and hardness 3700 HV. These factors, combined with a density, 2.51 g cm⁻³, less than that of solid aluminium, 2.7 g cm⁻³, indicate that large specific property improvements are possible and specific properties will improve with increasing particle addition. The small density difference between B₄C and molten Al means that particle sedimentation rates are low, minimizing settling problems observed during solidification processing. A clear interfacial reaction product was found at Al–SiC interface for composites processed for long periods, while no reaction product was observed at Al–B₄C [6]. Heat treatment is a process utilized to change certain characteristics of metals and alloys in order to make them more suitable for a particular kind of application. It can greatly influence physical and mechanical properties such as strength, hardness, ductility, toughness and wear resistance of the resulting composite [7].

Heat treatment is often associated with increasing the strength of the material, but it can also be used to alter certain manufacturability objectives such as to improve machining, and to improve formability. Conventionally processed or cast products exhibited higher porosity and coarser microstructure [8]. It affects the physical and mechanical properties of products. Microwave heating overcomes the negative effects of conventional processing.

Microwave post heat treatment of the components is a newer technique employed in this study. In microwave sintering, heat is generated internally within the material and the sample becomes the source of heat [9]. In the conventional heat treating process, energy is transferred to the material from the surface of the material whereas in microwave heating, the energy is directly delivered to the material through the molecular interaction with the electromagnetic field [10]. Microwave heating process improves the product uniformity by way of providing unique microstructure and properties as a result of selective heating. Microwave post-heat treatment enhances the properties of WC inserts [11]. And it is the efficient process when compared to conventional heat treatment process. Compared with microwave post heat treatment, the power consumed and time taken to achieve the specified temperature is high in the conventional heat treatment. Improved mechanical and machining properties can be achieved in microwave heat treatment within a short period of time with lower power consumption.

2. Experimental Details

2.1. Preparation of Composites

Boron Carbide is used as reinforcement in aluminium alloy (6061) [12]. B₄C particles of 25 μm size were used in this study. Two step stir casting method was used to fabricate the Al-B₄C. Aluminium alloy was melted up to 700°C. Varying volume % (5, 10 & 15%) of reinforcement (B₄C) was added to this molten Al-6061 alloy. Then allowed to cool to solidus temperature and stirred at 120 rpm carefully. In this way 100% of the B₄C particles were transferred to the metal. Then stirred composite material is heated to 670°C and transferred to metal mould. Composites were cast into a cylindrical rod in required diameter and length.

2.2. Heat Treatment

The purpose of the heat treatment over the composite is to improve the composite characteristics economically. Choosing a process in heat treatment, the sample composite of Al-B₄C (10%) was tested in both
conventional as well as in microwave oven separately. 850W Microwave oven and 1450W muffle furnace were used to heat treat the Al 6061-B₄C (10%). In order to obtain T6 property of Al-6061 alloy, solution heat treatment was done over the material and it was heated up-to 520°C in muffle furnace as well as microwave oven. After reaching required temperature, the composite material was maintained for definite holding time at 520°C. The better heat treatment process was chosen based on the mechanical properties and time consumption.

2.3. Microscopic Examination

The heat treated composites were polished according to standard metallographic procedures, etched with Keller’s reagent and observed in Scanning Electron Microscope.

2.4. Mechanical Properties

The hardness tests for the Al-B₄C(5, 10 & 15%) composites was carried out using Rockwell Hardness machine at load of 100kgf, Scale-B, Indenter-Tungsten Carbide Ball 1/16". As well as, to find the impact strength of Al-B₄C (5, 10 & 15%) composite, Izod test was done. The hardness & impact tests were carried out on both the heat treated & non heat treated composite material.

2.5. Machining Characteristics

In the machining aspects, the main object of this work is to evaluate the cutting force with depth of cut, speed and feed for the heat treated and non heat treated Al-B₄C (5, 10 & 15%). The presence of hard ceramic particles in the composites makes them extremely difficult to machine and it leads to rapid tool wear. Cutting force was estimated in using a lathe tool dynamometer and cutting tool used as K-Type Carbide. The roughness is measured using a Surfcorder. Standard: ISO 1999, Profile: R, Cut-off length: 0.8mm, Number of samples: 6, Speed: 0.50 mm/s. Machined surfaces of heat treated and non heat treated materials were analyzed using a SEM (Scanning Electron Microscope).

3. Results & Discussion

3.1. Heat Treatment

For casting the composite, double stir casting method was successfully used and the composites were fabricated into required sizes and shapes. After fabrication of rod, it was allowed for heat treatment. The two heat treatment process results were compared. In order to obtain the T6 property of the material, the solution heat treatment process was carried out. Fig.1 clearly shows the time and temperature history curve. In the conventional heating process, the longer time (208 minute) is required to heat up to 520°C, as shown in Fig.1. Whereas, in microwave heat treatment process only 15 minutes is required to reach 520°C. It is understood that microwave heating is faster which resulted in finer microstructure. The rate of cooling of conventionally heated composite is ch lower than microwave heat treated composite.

Fig.2 (a) shows the conventional heating over the composites. In the conventional heating process, the heat is transferred to the composite through conduction, convection and radiation. The heat is slowly transferred from the surface of the composite to inner core of the composite material. Fig. 2(a) clearly shows that the centre core (yellow colour) temperature of the composite is lower than the outer surface. It requires longer time for homogenization of the microstructure. Consequently it leads to coarser microstructure. Fig.2 (b) shows microwave heat treated composite material. The heat is delivered directly to the B₄C particles through molecular interaction with the electromagnetic field. Primarily, the reinforcement particles & porosity in the casting were directly coupled with microwaves. Also, reinforcement of boron carbide has high absorbing capacity of microwaves, subsequently heat is transferred in and around to the aluminium matrix. Simultaneously, SiC susceptor radiates the heat to the aluminium matrix material. The combined heating of composite leads to faster heating. Finally the required temperature is reached within shorter period of time. No heat energy was lost during the microwave heating process as the sample itself is made to be the source of heating whereas in conventional heating the surroundings is also heated up.
3.2. Mechanical Characteristics

The hardness and impact strengths are presented in Table.1 for the both microwave and conventional heat treatment processes.

It can be observed from Table.1 comparable results were obtained from both the processes. It is understood that microwave heat treatment process is relatively better than conventional heat treatment process in terms of time and power consumption. Hence microwave heat treatment process is adopted for different composition of the composites.
Fig. 3 shows the hardness of microwave heat treated and un-treated composites. It can be seen that the addition of B₄C particles improves the mechanical properties of the resulting composite. It is observed that by increasing the percentage of B₄C in Al matrix, hardness of the composite increases.

![Fig.3. Hardness of Al in 5, 10 &15% of B₄C](image)

Table 1: Hardness and Impact strength of Al-B₄C (10%)

<table>
<thead>
<tr>
<th>Heat Treatment</th>
<th>Hardness (HRC)</th>
<th>Impact Strength (J/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional process</td>
<td>67</td>
<td>0.14</td>
</tr>
<tr>
<td>Microwave Oven</td>
<td>63</td>
<td>0.16</td>
</tr>
</tbody>
</table>

3.3. Machining Characteristics

The cutting force is evaluated under different speeds, at a constant feed rate of 0.14 mm/rev, a depth of cut of 0.6 mm, and a length of turning of 70 mm. Fig. 5 shows the influence of the cutting speed with different volume percentage of reinforcement on cutting force. It is observed that increasing in ceramic reinforcement in Al matrix increased the cutting force due to increase in hardness of the composite. It is evident from Fig.3; the hardness of the composites is increased with increasing hard reinforcements. It can be observed that the increase in cutting speed will reduce the chip tool contact length therefore cutting force is reduced.

Fig. 6 shows the effect of different feed rate on cutting force, which is examined by considering a constant speed of 13.19 m/min, a depth of cut of 0.6 mm, and length of continuous turning of 70 mm. Fig. 5 shows that the cutting force was increased when increasing the feed rate. At constant speed and depth of cut, an increase in feed rate causes excessive friction between the tool and work piece, which increases the cutting force.

Fig. 7 shows the influence of the depth of cut on cutting force in turning of Al-B₄C. The effect of an increase in reinforcement is tested under different depths of cut at a constant feed rate of 0.14 mm/rev, cutting speed of 13.19 m/min and a length of machining of 70 mm.
3.4. Surface Roughness

Surface Roughness (Ra) was evaluated in machined composite materials, using surface roughness tester (Surfocorder SE1200). The 5, 10 & 15% of B₄C with Al, microwave heat-treated and non heat treated composite were machined at constant speed (14m/min), constant feed (0.14mm/rev) and constant depth of cut (0.4mm). From Fig.8, high surface roughness was observed in the non heat treated composite material. Microwave heat treated material gives a good surface finish after machining.
The machined surface was analysed through SEM. Fig.9 (a) & (b) shows the SEM image of non heat treated Al-B4C. In this image, the wider plastically deformed grooves were present in the machined surface. Fig.10 shows that the SEM image of microwave oven heat treated Al-B4C. In this image, better surface can be observed with slim grooves due to improved interfacial strength between reinforcement particles and metal matrix.

4. Conclusions

- Energy saving heat treatment process was carried out using microwave oven.
- Comparable mechanical properties were obtained in both conventional & microwave heat treatment processes.
- Time consumption is very less in microwave heat treatment and it is a cleaner energy process.
- The non heat treated composite material of Al-B4C is less hard than the heat treated one.
- The hardness of the composite is increased while adding the B4C reinforcement to the Aluminium matrix.
- At high cutting speed, machining will minimize chip tool contact length & build-up edge formation, which reduces the cutting force. As such, cutting force is high when machining with a higher depth of cut and increased feed rate.
- Microwave heat treated composites exhibited finer microstructure in machining compared with non heat treated composite material
- Surface roughness is reduced in heat treated samples when compared with non heat treated material.

5. Acknowledgment

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6. References