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Experimental Testing and Fabrication of Metal Matrix Composite for Automotive Applications

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Abstract: Cold compaction behaviour, hardness, and micro-structural behavior of aluminium–boron carbide composites with variable boron carbide content for several composite systems, including Al-5 percent B_4C, Al-10 percent B_4C, Al-15 percent B_4C, and Al-20 percent B_4C, were all evaluated. Powder metallurgy was used to create the particle reinforced composite, with aluminum particles measuring 75 microns and boron carbide particles measuring 150 microns. The compacts were made using a universal testing machine (UTM) with a 60-ton capacity and the appropriate punch and die set assembly. After the green compacts were prepared, they were sintered in an electric furnace at 550°C for 120 minutes. The compacts are then allowed to cool in the furnace to room temperature. Cold compaction and axial pressing were used to study densification tendencies. The link between applied pressure and density, as well as between applied pressure and relative density, was established. The percentage of B_4C reinforcement was used to boost the hardness and compressive strength of various composite samples. Scanning electron microscopy (SEM) images were used to investigate microstructural phenomena. The final solution was compared to that of Cam, an existing car component. It's made of a metal matrix composite of Al-SiC. Because the Al-B_4C composite has a lower density than the Al-SiC composite, it allows for the most weight reduction in the product. The samples' weights have been reduced, resulting in a higher strength-to-weight ratio. In both cases, the material cost evaluations were substantially identical. It's simple to automate the fabrication process.

Keywords: Cold Compaction Behavior, Metal Matrix, Green Compacts, Composite, Relative Density, Uniaxial Pressing

1. Introduction

The introduction of light-weight, corrosion- and fatigue-resistant composites was a major development that altered the usage of materials in a variety of applications. China and India have made remarkable progress in the field manufacturing composites, despite the obstacles and opportunities that lay ahead. Since the late 1970s, scientific discoveries in the field of metal matrix composites have piqued people's curiosity. A clear understanding of the relationship among the processing, structure and properties of composites had become increasing important today, because of this wider use over a range of critical application. The matrix material serves several functions which are vital to the performance of the composite material. These functions also depend upon the type of reinforcement such as dispersion, particulates, and whiskers, discontinuous fibers. The prominent metallic matrix include Aluminum and Aluminum base alloy, titanium base alloys, magnesium base alloys, super alloys, copper and beryllium.

Composite materials, polymers, and ceramics have dominated new materials for the past thirty years. Composite materials have gradually increased in volume and number of applications, relentlessly penetrating and winning new markets. Modern composite materials make up a large part of the engineered materials sector, with uses ranging from ordinary items to sophisticated specialized applications. While composites have previously demonstrated their value as weight-saving materials, the present difficulty is making them affordable.

Several unique production techniques are now used in the composite sector as a result of efforts to develop economically attractive composite components. It is self-evident, especially in the case of composites, that advancements in manufacturing technology are insufficient to overcome the cost barrier. For composites to compete with metals, an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management is required. The composites business is starting to grow [24, 9]. Composites are increasingly widely employed for seismic retrofitting and strengthening of existing structures, as well as for repairing damage caused by seismic activity. Unlike conventional materials (such as steel), the qualities of composite materials can be specified while structural considerations are taken into account. Material and structural design are both involved in the creation of a composite structural component. Under the supervision of the designer, composite qualities (such as stiffness and thermal expansion) can be adjusted continuously over a wide range of values. The properties of the finished product can be customized to practically any specific engineering requirement by carefully selecting the type of reinforcement.

Although composites will be the obvious choice in many cases, material selection in others will be influenced by factors such as working lifetime requirements, the number of items to be produced (run length), the complexity of the product shape, possible assembly cost reductions, and so on Composite structures have also routinely shown savings of at least 20% over metal counterparts, as well as lower operational and maintenance costs [1, 13, 18]. As more information about composite structure service life becomes available, it can be safely stated that they are durable, preserve dimensional integrity, resist fatigue loading, and are simple to maintain and repair. Composites will continue to find new uses, but the market's large-scale expansion will necessitate less expensive processing methods and the problem of recycling will have to be addressed.

1.1. General Objective

The automotive industries are mainly depends upon the metal matrix composite in the recent days. Due to the Metal matrix composites are having excellent material properties. Consequently the experimental testing and fabrication of metal matrix composite for automotive applications is very much essential.

1.2. Specific Objective

The aluminum and boron carbide as reinforcement content are the new combination of mmc by powder metallurgy route in various percentages. From the sample evaluate the various testing and mechanical properties to compare the results with the existing mmc to provide the valuable results, suggestions to the industrial applications.

2. Composite Material

On a macroscopic scale, a typical composite material is a system of materials made up of two or more constituents (mixed and bonded). A composite material, in general, is made up of reinforcement (fibers, particles, flakes, and/or fillers) contained in a matrix (polymers, metals, or ceramics) [2, 9, 10, 13].

The reinforcement holds the matrix in place to construct the desired shape, while the reinforcement improves the matrix's overall mechanical qualities [11, 9]. When properly developed, the new composite material has more strength than the individual materials.

2.1. Metal Matrix Composite

In general, metal matrix composites have at least two components: one is the metal matrix, and the other is reinforcement. Metal Matrix Composites (MMCs) have gotten a lot of press in recent decades as engineering materials [15, 12]. By incorporating a ceramic reinforcement into a metal matrix, a composite material with an appealing mix of physical and mechanical qualities that monolithic alloys cannot match is created. The structure and features of this reinforcement-metal interface govern the mechanical properties of MMCs to a great extent.

A strong interface is thought to allow load to be transferred and distributed from the matrix to the reinforcement, resulting in greater elastic modulus and strength. Aluminium and aluminium alloy composites reinforced with ceramic particles have received a lot of attention in recent years. A composite material is one that has two or more physically and chemically different phases [2, 8, 15, 24]. The composite generally has superior characteristics than those of each of the individual components. Usually the reinforcing component is distributed in the continuous or matrix component. In MMCs, the reinforcement usually takes the form of particles, whiskers, short fibers, or continuous fibers [16, 9, 21]. Metal composite materials have found application in many areas of daily life for quite some time. Often it is not realized that the application makes use of composite materials.

For many researchers, the terms "metal matrix composites" and "light metal matrix composites" are interchangeable (MMCs). In recent decades, significant progress has been made in the creation of light metal matrix composites, allowing them to be integrated into the most critical applications. MMCs have been employed commercially in traffic engineering, particularly in the automotive sector; in fiber reinforced pistons and aluminum crank cases with enhanced cylinder surfaces, as well as particle strengthened brake disks. The features of MMCs can be designed into the material or custom-made, depending on the application, opening up endless opportunities for current material research and development [6, 23].

Metal matrix composites, as a result of this capability, fulfill all of the designer's desires. If the property profile of conventional materials either does not meet the increased standards of specific demands, or if the property profile of conventional materials does not meet the increased standards of specific demands, this material group becomes interesting for use as constructional and functional materials [14, 17].

2.2. Formulation of the Problems

A survey of the literature has indicated that to produce powder metallurgy compacts of very high density, by hot or cold forming techniques were used. The densification and mechanical properties of the powder metallurgy compacts also increase compared to the cast or wrought products. The mode through which a very high density is achieved also plays a role in the improvement of mechanical properties. Compacting and sintering process has been developed to eliminate the residual porosities and to achieve densification [5, 13, 17, 22]. Powder forging is generally done in confined dies, which assures full densification and eliminates flash formation. Careful selection of the process parameters and successful implementation would lead to a sound metallurgical structure of the compact. Large amount of work has been done in the areas of the powder perform of aluminum as a matrix materials. Though the automotive industry has recognized the need for material substitution. Metal matrix composites offer outstanding properties for a number of automotive components. The cam was already made by Al-SiC composite by powder metallurgy route. These findings are compared to those of the current study as an Al-B_4C composite material. We identified the Aluminium-Boron carbide metal matrix composite material as a feasible replacement material for a current automotive application based on the preceding literature review. The metal matrix composite, on the other hand, was made with aluminium as the matrix material and Boron carbide as the reinforcing content, utilizing powder metallurgy (cold uniaxial pressing) [6, 15, 21]. The goal of this study is to look into the densification, mechanical characteristics, and microstructural behaviour in greater depth.

Densification depends on the pore closure which in turn depends on the following:

1) Initial perform geometry
2) Composition of the sample
3) Uniform Compaction load
4) Frictional constraints during forming operations
5) Mode of deformation.

3. Methodology of the Study

3.1. Structure of Methodology

1) Literature Review
2) Selection of Materials
3) Data collection and optimizing the process parameters
4) Design of Experimental setup
5) Design analysis
6) Fabrication of components.

3.2. Selection of Fabrication Route

The selection of the production route was based on the following basis.

1) The method of fabrication of parts is simple and flexible
2) Good dimensional control
3) The products are competitive in comparison to other similar products from conventional material and techniques.

3.3. Materials and Alloy Composition

The low density Boron carbide is reinforced with aluminum matrix material and to the following compositions was investigated by powder metallurgy route [2, 5, 7, 13, 19].

1) Al - 95% + B_4C-5%
2) Al - 90% + B_4C-10%
3) Al - 85% + B_4C-15%
4) Al - 80% + B_4C-20%.

3.4. Experimental Approach

The above considerations and the literature survey the following experimental approach was adapted.

I. Preparation of the powder blends corresponding to the various composition by using pot mill.
II. Preparation of the green compacts for the above mentioned alloy composition by using punch and die set assembly.
III. Sintering at a temperature of 540°C for a period of two hours by using furnace.

4. Result and Discussion

Taking into consideration the compaction of the system considered for analysis various plots have been drawn to arrive the relevant relations like density, relative density and applied pressure which could assist in describing the compaction mechanism. Similarly the fabrication route characteristic relations like porosity, density value before and after sintering were drawn with the reinforcement content weight percentages. The micro structural studies were also made by using scanning electron microscope (SEM) images.

4.1. Apparent Density for Pure Aluminum & Boron Carbide

The apparent density of a powder is defined as the mass per unit volume of loose or unpacked powder. Pure aluminum has low apparent density value when compared to the boron carbide. It represents the adding B_4C with aluminum then the apparent density will increase.

4.2. Tap Density for Pure Aluminum & Boron Carbide

Because there were more pores in the aluminum powder at the beginning, the tap density was very low. The porosity and height of the powder are reduced when the number of taps is increased. Densification is rising, as evidenced by this. As the number of taps was increased, the densification of the powder increased as well. The powder height does not decrease after some tapping, and it remains constant. When compared to boron carbide powder, the tap density of aluminum powder is low. It means that when the proportion of boron carbide content in aluminum grows, the tap density increases as well.

4.3. Compressibility Data for the Various Samples

The Figure 1 shows the compressibility data for various samples. In this figure shows while increasing the load, the density of the compact was increased. Because at initial stage more quantity porous present in powder. While increasing the load porosity of the powder and also height of the powder were reduced. The height of green compact was reduced then automatically corresponding volume reduced. Then density value was increased.

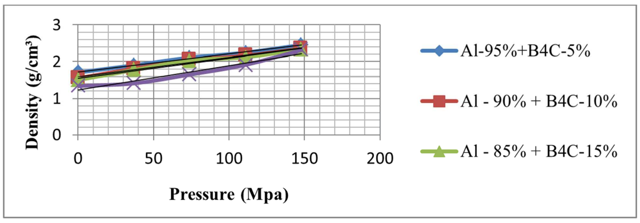

Figure 1. *The variation of density value with respect to applied pressure for various sample.*

Figure 2 depicts the relative density fluctuation in tones in relation to the applied stress. For each sample, the load value was gradually increased. When the applied load is raised, the corresponding relative density value rises as well. However, the addition of reinforcement (B_4C particles) enhanced the maximum relative density reached, which was thereafter gradually lowered. Particle size, shape, porosity or density, hardness surface characteristics, chemical compositions, and other factors all influence compressibility.

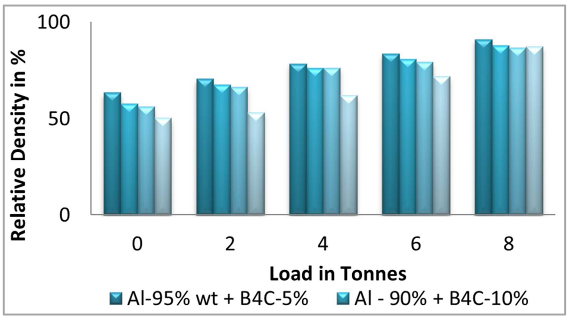

Figure 2. *The variation of Relative Density value with respect to applied load for various sample.*

4.4. Sintering Effect

A powder compact is heated to 70-80 percent of the melting point temperature of the primary aluminium component in a controlled environment.

Densification of the powder happens as pores are removed, resulting in a sintered product with greater mechanical strength. Sintering of powder involves the formation and growth of bonds between powder particles at their points of contact, as well as the movement of grain boundaries created at the linkages [1, 11, 19, 16]. As a result, the pores between the particles have been periodized, and small pores have been eliminated (and possibly the growth of larger pores).

Porosity reduced and shrinkage rose as the sintering temperature climbed. During sintering, particles create bonds with one another, and the number of particle bonds grows as the temperature rises [17, 19, 22]. The small variation in the density value before and after sintering which was clearly shown in Figure 3 the small increments in the density value in each sample due to pore reduction and shrinkage effects occur during and after sintering. The density of the Al-B_4C composite in the green and the sintered conditions were determined.

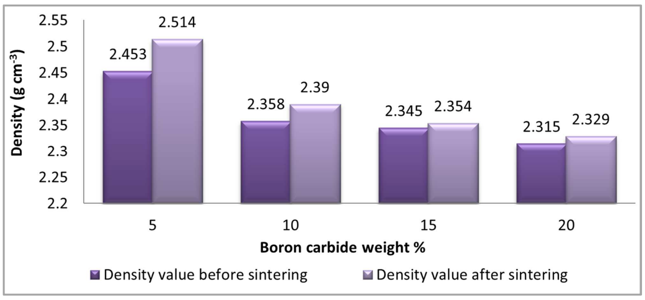

Figure 3. *The density value variation before and after sintering.*

4.5. Porosity of the Various Samples

Figure 4 shows the porosity range in percentage before and after sintering. The porosity was increases with increase in wt % of (B_4C) reinforcement content. The porosity percentage was higher value in before sintering stage. After sintering there was a small percentage of reduction in the porosity values. It reduced due to pores reduction, good bonding, and shrinkage effect.

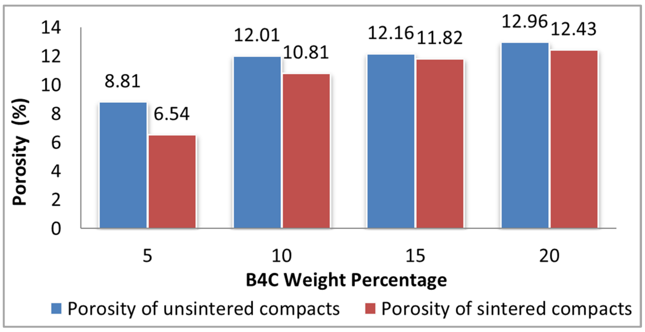

Figure 4. *The Porosity (%) of various samples before and after sintering.*

4.6. Compressive Strength

The compressive strength of the composite material were gradually increases relatively the percentage of increment in the reinforcement content. The maximum reinforced composite yield a higher compressive strength value. This test was performed on sintered compacts, after sintering its densification increases by eliminating pores and a sintered product of increased mechanical strength is formed.

4.7. Hardness Value

The hardness values evaluation of the aluminum composite material which was presented in table. In Figure 5 shows the relationship between hardness value and weight percentage of Boron carbide reinforcement content. The hardness values were gradually increasing according to the percentage of increment in the reinforcement. The increase in hardness was related to the higher densification of the B_4C particles forming a well inter connected network structure leads to a higher strength. From these evaluation 20% reinforced B_4C sample yield a higher hardness value.

4.8. Microstructural Behavior

The microstructure of sintered Al matrix material with 10% and 20% B_4C reinforcement is shown in the figure.

The presence of B_4C reinforcement (white contrast particle) in the aluminium matrix composite is depicted in the SEM image. In both samples, uniform particle distributions were attained, as indicated in the Figures 1 to 10. In some sections of the microstructure, pore flaws were produced. Good bonding between the matrix and reinforced materials was obtained, as illustrated in the figure.

4.9. Comparison of Various Properties of Al-B_4C & Al-SiC, Composite [3, 12, 15, 20]

1) The various properties of fabricated composite namely, green compact density, sintered density, porosity before and after sintering and compressive strength were measured and their variation with reinforcement content were compared and presented in the table.
2) The Al-B_4C composite were higher compressive strength values, when compared to the Al-SiC composite, so it provides an increased life cycle of the product.
3) The Al-B_4C composite has low density value when compared to the Al-SiC composite, so it provides maximum weight reduction in the product [5, 8].
4) The reduction in the weight of the samples provides a higher strength to weight ratio.
5) The cost evaluations of the materials were nearly same in both the case.
6) The fabrication route was easy to automate for mass production.
7) The good dimensional control was achieved in this powder metallurgy route.
8) These factors were clearly shows that the Al-B_4C as a better replacement of cam made by Al-SiC composite.

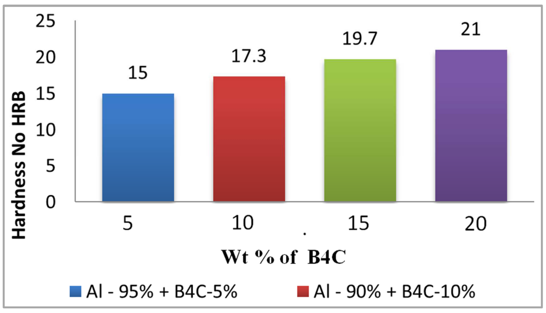

Figure 5. *Hardness values variation with respect to weight percentage of B_4C.*

Comparison of Various Properties of Al-B_4C & Al-Sic Composite.

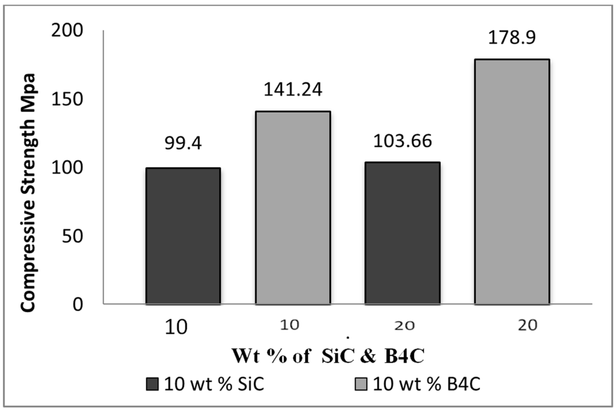

Figure 6. *Compressive strength of Al-SiC & Al-B_4C Composite.*

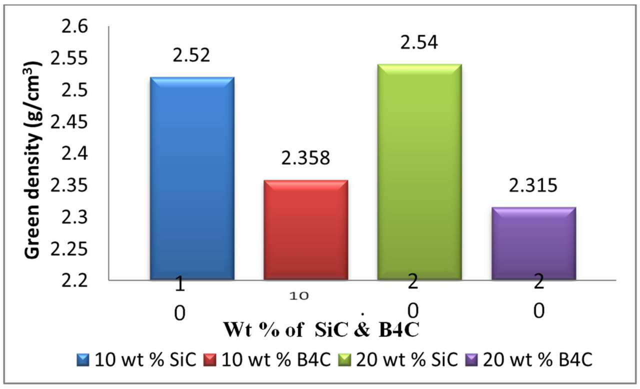

Figure 7. *Green Compact density of Al-SiC & Al-B_4C composite.*

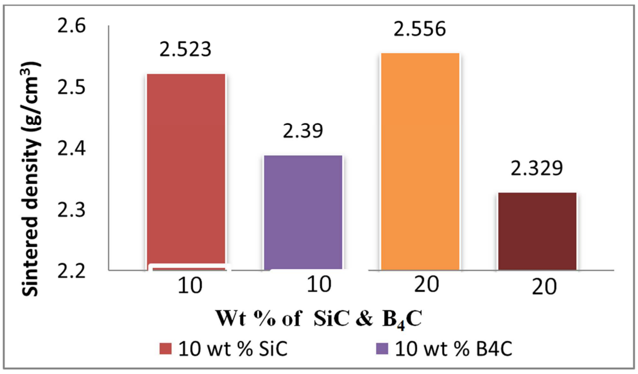

Figure 8. *Sintered density of Al-SiC & Al-B_4C composite.*

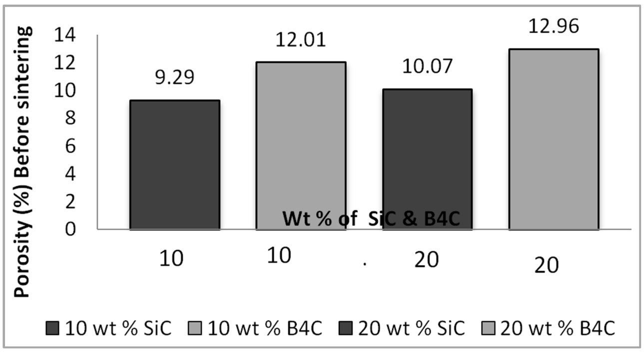

Figure 9. *Porosity % of Al-SiC & Al-B_4C composites before Sintering.*

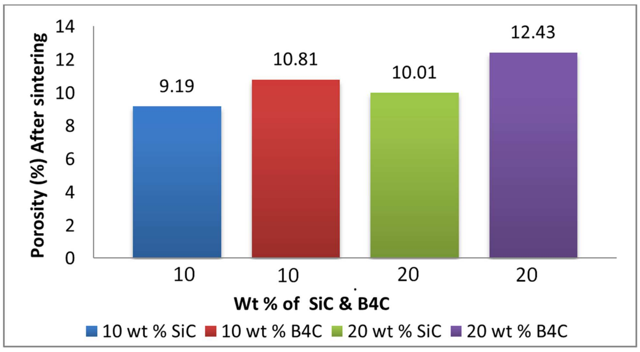

Figure 10. *Porosity % of Al-SiC & Al-B_4C composites After Sintering.*

5. Conclusion

Based on a literature survey and experimental investigation, the study has been developed and various findings have been made. The main purpose of the study was to show the following investigations. Using the powder metallurgy approach, the experiment for cold compaction of aluminium as a matrix and boron carbide content reinforcement was successfully completed. The reinforcing weight percentage in the composite can range from 5% to 20%, and it plays an important role in the powder consolidated Al-B_4C metal matrix composite. Pore reduction and shrinkage effects occur during and after sintering due to B_4C's low density. According to the proportion of reinforcement augmentation, the hardness values continuously increase. The B_4C sample with 20% reinforcement has a higher hardness value. Through this method of production, the microstructure observation from SEM images reveals a uniform distribution and good bonding between the matrix and reinforcement particles. When compared to the Al-SiC composite, the Al-B_4C composite has greater compressive strength values. Because the Al-B_4C composite has a lower density than the Al-SiC composite, it allows for the greatest weight reduction in the application. In both cases, the material cost evaluations are substantially identical. For mass production, the fabrication route is simple to automate. The Al-B_4C composite material is a good alternative for an Al-SiC composite cam in an existing vehicle application.

6. Recommendations

The Al-B_4C Metal matrix composite is a new innovative material for different percentages of composition. It will provide better mechanical and material properties in the metal matrix composite. It provides a good replacement for the existing composite material made up of Al-SiC metal matrix composites.

Appendix

Sintered Specimen for Various Sample Pieces.

Figure 11. *Sintered Specimen for Various Sample Pieces (Top Orientation).*

Figure 12. *Sintered Specimen for Various Sample Pieces (front orientation).*

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