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On studies of Powder Metallurgy as an effective method for Processing Metal Matrix Composites

KEYWORDS: Metal Matrix composites, Powder Metallurgy, stir cast method, reinforcing element, wear resistance

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ABSTRACT this paper deal with a study of research going in the area of composite materials, especially metal matrix composites (MMC), as compared to Polymer based composites; MMC possesses higher strength, stiffness and at the same time they can be developed as wear resistant material document. Also it has been reported from many research studies that MMC does have better creep resistance and thermal management. case studies has been included in this paper to demonstrate the research work being carried.

I. INTRODUCTION

It is being fact and observation that metal matrix composites (MMCs) is a upcoming newer family of such materials which are replacing conventional, materials, specially in the automobile, sporting goods, aviation and recreation industries.

Compared to monolithic metals, MMCs have:

- Higher strength-to-density ratios
- Higher stiffness-to-density ratios
- Better fatigue resistance
- Better elevated temperature properties
- Higher strength
- Lower creep rate
- Lower coefficients of thermal expansion
- Better wear resistance

The advantages of MMCs over polymer matrix composites are:

- Higher temperature capability
- Fire resistance
- Higher transverse stiffness and strength
- No moisture absorption
- Higher electrical and thermal conductivities
- Better radiation resistance
- Fabric ability of whisker and particulate-reinforced

MMCs with Conventional metalworking equipment.

Some of the disadvantages of MMCs compared to monolithic metals and polymer matrix composites are:

- Higher cost of some material systems.
- Relatively immature technology
- Complex fabrication methods for fiber-reinforced systems (except for casting).
- Limited service experience

Fabrication Method of MMC

There are many processes available to fabricate MMCs; they can be classified in: solid-state, liquid-state and deposition processes.

Solid state processing includes following methods

- Powder blending and consolidation.
- Diffusion bonding
- Physical vapour deposition:

While liquid state processing include following methods

- Stir casting:
- Infiltration process:
- Spray deposition:
- In-situ processing (reactive processing):

In deposition processes, droplets of molten metal are sprayed together with the reinforcing phase and collected on a substrate where the metal solidification is completed. This technique has the main advantage that the matrix microstructure exhibits very fine grain sizes and low segregation, but has several drawbacks: the technique can only be used with discontinuous reinforcements, the costs are high, and the products are limited to the simple shapes that by obtained by extrusion, rolling or forging.

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II. METAL MATRIX COMPOSITES – A WIDE SPECTRUM

MMC in general consist of at least two components: one is the metal matrix and second is the reinforcement. It has been found from many research studies and other available literature that aluminium, copper, titanium cobalt, iron and silicon are the some materials which can be used as a matrix material for MMCs. While silicon carbide, aluminium oxide, lignite fly ash and graphite in power form and fibre form are being used as a reinforcing elements. MMC reinforcement can be generally divided into five major categories: continuous fibre, discontinuous fibres, whiskers, wires and particulate. Out of available matrix material aluminium is most preferred and used material as a matrix metal. Titanium based MMC are also being the second preferred MMC as powder metallurgy makes the processing of titanium quiet easy and properties can be tailored. Both of these metals have comparatively low specific gravities and are available in a variety of alloy form.

Aluminium and its alloys have the most attention as matrix material for MMCs and the most common reinforcement is SiC. MMC engine applications are produced and used for automobile engine cylinders die-cast from carbon fibre-aluminium-Al2O3 material. The titanium alloys that are most useful in MMCs are , alloys and metastable alloys. These titanium alloys have higher tensile strength-to-weight ratios as well as better strength retentions at 400- 500° C than those of aluminium alloy. Titanium MMCs are used in applications where performance is demanded without regard to cost-effectiveness. This is where one obtains high-temperature performance unattainable with conventional materials.[4]

Also it is studied by nikilesh chawla [2] that High strength-to-weight ratios, enhanced mechanical and thermal properties, and tailor-ability make metal matrix composites (MMCs) very attractive for automotive applications. Particle-reinforced MMCs, such as SiC particles in an aluminium alloy matrix, are particularly attractive because of their lower cost, relative isotropy, and ease of fabrication relative to their continuous-fibre reinforced counter parts.]An important application for Al/SiC composites is in the connecting rod, which requires high fatigue resistance at temperatures as

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high as 150°C (300°F). A lighter connecting rod would provide a 12 to 20% reduction in secondary shaking force, a 0.5 to 1% improvement in fuel economy (with lightweight piston and pin), a 15 to 20% increase in peak RPM, lower bearing width (package improvement), and better bearing and crankshaft durability.[2]

At Hindustan Aeronautic Limited research was also undertaken for the development of aluminium based MMC, which shows the significance of MMC as far as structural components are concerned. Also HAL along with Defence Metallurgical Research Laboratory has developed Metallo-ceramic composites Break Pads for passenger/military and fighter aircrafts successfully. This brings a cost reduction of 58% as these brake pad materials were used to be imported from Boeing Corporation.[3]

III. POWDER METALLURGY FOR PROCESSING OF METAL MATRIX COMPOSITES

Powder Metallurgy (P/M) is a well known and established process of producing special components like self lubricating bearing and bushed, and also for processing the materials which are difficult to process by other conventional processes. Transportation and automotive industries are the major sectors which uses a large chunk of part and components made from powder metallurgy. P/M is a material processing technology to create new materials and parts by diffusing metal powders as raw ingredients through the sintering process. Applications of P/M may be found in making of structural parts, Tribological parts such as high contact pressure bearings, heat and wear resisting parts, Magnetic parts and other next generation high performance parts. [5]The features of P/M can be seen in following areas.

1. Alloys can be created from high melting point metals including Tungsten, Molybdenum and tantalum.
2. Metal /non metal composite materials as represented by cemented carbide, cermets and friction materials can be created.
3. Composite of metals that do not dissolve into each other such as high thermal conducting materials (W-Cu, Mo-Cu) High density alloy and electric contact materials (Ag-Cu, Cr-Cu) can be created.
4. Porous materials such as oil-impregnated bearing and filters can be created.
5.P/M has excellent economic efficiency because product can be formed by pressing powders in moulding tools.

Fig 1 shows a Rotor core for motor of a Hybrid Electrical Vehicle (HEV) produced from P/M in which diffusion bonding is achieved by sintering. Its outer circumferences use a sintered magnetic core material made of pure iron. The interior requires a high degree of strength because motor torque is directly transmitted to the shaft. It is composed of Fe-Ni-Cu-C based material, and is combined into a single body by diffusion bonding at sintering.

Fig1: Rotor core for motor of HEV by diffusion bonding at sintering.

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The entire document should be in Times New Roman or Times font. Type 3 fonts must not be used. Other font types may be used if needed for special purposes.

Recommended font sizes are shown in Table 1.

A. Advantages of P/M for MMC fabrication

Itself powder metallurgy has so many advantages to list but here author would like to highlight following points as advantages of P/M process for MMC fabrication.

- It allows good combinations of metals and non metals.
- No material is wasted as scarp or chips.
- Processing of carbides is possible.
- It prevents or avoids segregation effects.
- It also avoids brittle reaction products formation which normally happens in liquid state processing of MMC.
- After development this method does not require highly skilled manpower to handle the process.
- Tooling can be effectively and easily developed.

B Demerits of P/M for MMC fabrication

- Raw material in powder form is costly.
- Capital cost may be high as for compaction high capacity press tools are required.
- Porosity can be a difficult issue to handle.
- Post processing is always required.

IV. CASE STUDIES IN METAL MATRIX COMPOSITE PROCESSING THROUGH POWDER METALLURGY

CASE STUDY-I: Here some cases have been presented and discussed to highlight the production of metal matrix composites and related issues. Case Study –I: [6] Here in this experimental study powders of atomized aluminium (Al), deoxidized iron (Fe), and electrolytic copper (Cu) were taken and thoroughly mixed together. The average size of powder was about 98 μm. This powder mix was compacted in simple cylindrical die. The compaction characteristics of the powder mix having two elements were examined. Fig 2 shows the two layered green compacts which were produced. Fig 3a and fig 3b shows the variation of relative density against compacting pressure for Al-Fe and Al-Cu combination. It is seen that the relative density of the two layered green compact increases with increasing compacting pressure and the calculated values were found in good agreement with the experimental value.

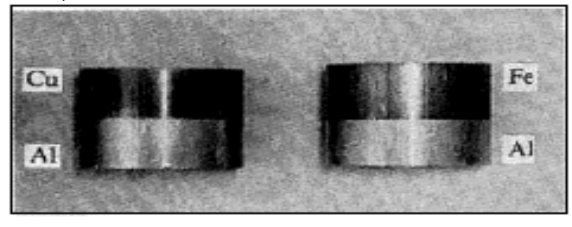

Fig2: Examples of two layered composite green compact. [6]

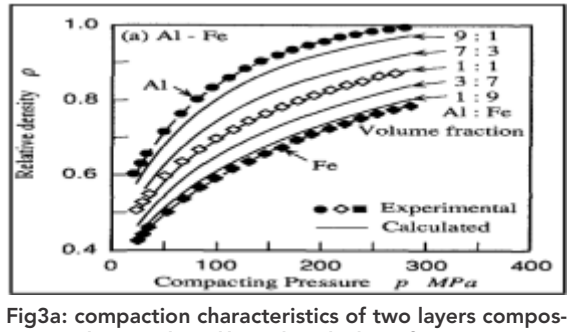

Fig3a: compaction characteristics of two layers composite Powders predicted based on the law of mixture [6]

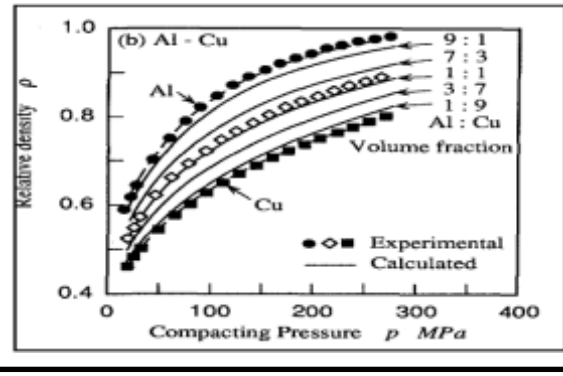

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Fig3b: compaction characteristics of Al-Cu base MMC green compact [6]

A.Density change of mixed composite green compacts with sintering.[6]

In the processing of powder materials, the green compacts are sintered to decrease the porosity and subsequently to increase the density. It is observed that the increase in density can depend on the type of powders used, sintering conditions and time as well. Here in this experiment inert atmosphere were produced by the use of argon gas. However is a matter of fact that for a green compact made from mixed campsite powder , the density change is not only affected by the sintering conditions but also by the combination and volume fraction of the composite powders. Here in this study Al-Cu mix was sintered at 803 K(530° C) and Cu-Fe mix was sintered 1273 K(1000° C) 60 minutes in the inert atmosphere of argon gas,

Figure 4 shows that density of composites is always higher than that of green compact for Cu-Fe mixture but figure 5 shows that for Al-Cu combination it was observed that density of the sintered part becomes smaller than that of green compact. The reason behind the decreased density in sintered part is because of volume expansion due to appearance of eutectic during the sintering. Also Al-Cu composite having equal proportions were found having several internal pores.

B. Impact on hardness.[6]

The two kinds of composites were examined for micro-Vickers Hardness after sintering, in order to evaluate the effect of volume fraction of mixed powder and sintering temperature on the hardness of the sintered composite parts. It was found that for (20% Al-80%Cu), the hardness was constant regardless the sintering temperature. However for (80% Al-20% Cu) and (50%Al-50%Cu) sintered parts the hardness which was observed was remarkably high e.g. in one of the case i.e. (50%Al-50%Cu) sintered part it was 600 which is roughly 15 to 20 times higher than the sintered pure copper and aluminium. This may attributed to the appearance of eutectic during the sintering process.

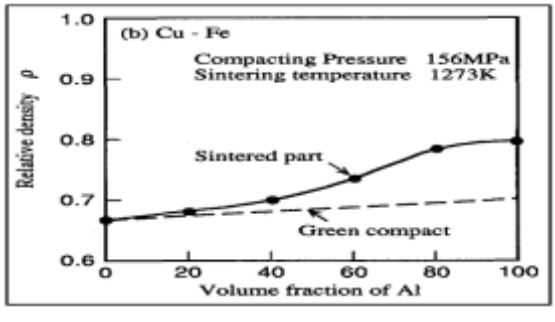

Fig 4: Variation of density of green compact with sintering-Mix-1 [6]

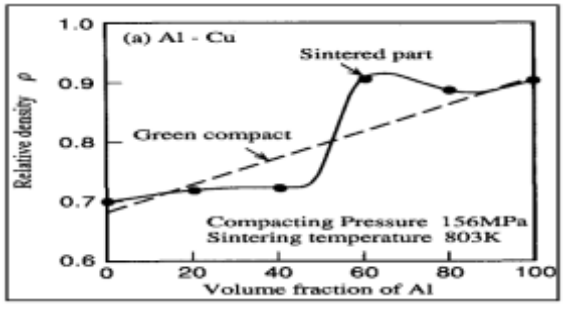

Fig 5: Variation of density of green compact with sintering-Mix-2 [6]

V. EXPERIMENTAL WORK BEING DONE BY THE AUTHOR

At Nirma University under the scheme of minor research projects author is doing experiments in synthesis of Aluminium based Metal Matrix Composites (MMC) through powder metallurgy process. The main objectives of this minor research project are as follows,

- Synthesis of Al- based MMC
- Investigation of their mechanical properties.
- Testing of MMC for wear resistance.

To carry out the work fine aluminium powder has been obtained from a specialized industry called "ANAL Aluminium "from SANAND District Ahmedabad. Silicon Carbide and Aluminium oxide of different grit like 400, 600, 800, 1000 and 1200 have been procured. Cylindrical die with a bore of 25 mm with punch has been fabricated. Both punch and die have been hardened too. The reason behind keeping the bore diameter as 25 mm is that for checking of wear resistance a pin on disk type arrangement has been developed which can accommodate a cylindrical ingot of 25mm diameter. This device can be mounted on tool post of lathe machine and the reference disk disc after mounting on chuck can be rotated at different speed using gear box of lathe. Author intends to apply conventional powder metallurgy and hot pressing technique to produce MMC.Following Figure shows the Dies and punch being used for experimentation.

Fig 9: Die and Punch for P/M Process (1) is a oil hardened die and

(2) Is a die hardened through liquid nitriding.

A mounting press is being used for preparing the cylindrical ingots of 25 mm diameter and 40 mm height. Pressure of 350 kg/cm2 is being applied during compaction. Fig 10 shows the specimen containing 90% aluminium and 10 % SiC (1000 grit). Both the ingredients are mixed thoroughly and heated to a temperature of 600°C and then compacted into the cylindrical die. Further this specimen shall be tested for their mechanical properties and wear resistance.

Fig 10: Samples developed through P/M Process (90% Al-10% SiC)

VI. CONCLUSIONS

In this paper a basic study of Metal Matrix Composites (MMC) has been presented where their advantages and limitations has been presented. Also this paper aims to seek the Powder metallurgy as a one of the effective process to develop MMC; also an attempt has been made to introduce to the experimental cum research work being done by the author at Nirma University.

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