ABSTRACT

Powder metallurgy (PM) is the procedure of coalescing fine powder particle, compressing them into a preferred shape or dimension of the part or the product this process is known as compacting. followed by heating the compressed powders in a ascertained atmosphere to bond the powder material is called sintering. Generally the powder metallurgy contains four major basic steps: production of powders, blending of the powder, compacting and sintering. In this work a critical review has been done on the advance in manufacturing of composite material by powder metallurgy process.

Keywords: powder metallurgy (PM), compacting, sintering, composite material.

1. INTRODUCTION

Today’s one of the major production of various components and composite materials are manufacturing through the powder metallurgy methods. The development of the powder metallurgy was increased during the end of 20th century due to rapid growth of the new material processing technologies such as mechanical alloying, atomization, quick solidification powder [1][2]for the production of powder metallurgical product, hot and cold isostatic pressing (CIP and HIP) for the fabrication of the product[3][4]. The importance of powder metallurgy is growing interest due to it can produce very near net shapes of the product. The products which are manufacturing through PM are very much comparable with products which are made from the conventional methods. In PM not only metallic powdered products can be manufacture but also ceramic and polymers products can be produced. Further, the requirement of processing temperature is very less than the melting point of the constituent metals or powders. in addition the evolution of defects are also much less in PM as compared to other manufacturing techniques such as in casting and welding. From the above advance the power metallurgy has gaining lot of applications in the field of structural, aerospace and in general application such as in automobiles, house hold appliances, television, air conditioning and in industries applications. The most of the composites materials are manufactured by the powder metallurgical processes due to following advantages.

1) Products can be manufactured by high amount of the reinforcing phases attributing to high stiffness and extremely low thermal expansion.

2) As the PM is carried in the solid state condition, reduces the possible reaction rate of the ceramic reinforcements with the metal matrix, in turn this will decreases the risk of the brittleness in the interphase boundaries.

These following advantages made PM ease in manufacturing various products.

1. POWDER METALLURGY PROCESS

Powder metallurgy process includes several steps such as powder production and selecting the mould composition, mixing the powders, forming, compacting and finally sintering. Figure 1 illustrate the various functions involving in the PM processes. The raw powders are prepared through various techniques such as atomization, splat cooling, Thermal spraying, high velocity oxy-fuel, plasma
spraying, reaction process, exothermic dispersion, machining, ball milling etc[5].

Then the powders are mixed or blended in required quantities with the help of techniques like Turbula™ mixing unit or a V-shaped mixer, ultrasonic stirring method of the powder compounding within an solvent made from alcoholic based [6][7]. Figure 2 show the various blending equipments.

![Blending Equipment Diagram](image)

**Figure 2.** (a) rotation in a drum; (b) rotation in a double-cone container; (c) agitation in a screw mixer; and (d) stirring in a blade mixer.

Powder compaction is followed after the powder blending. The powder compaction is done to produce a desired shape by pre-prepared set of punch and die setup. usually these compaction die and punches are prepared by steel or cemented carbide material. The blended powders are poured into the die and the compression load acting on the punch makes the powder to compact. the compaction can be done through the following processes: (1) Hot compaction: Employing high temperature and directly pressure - in this method further sintering is not necessary; (2) Cold compaction: Only pressure applied at room temperature- additional sintering process is required. Figure 3. Illustrate the sequence of compaction technique. The extent or degree of compaction has a greater influence on the mechanical properties of the final PM sample.

![Compaction Process Diagram](image)

**Figure 3.** Illustrating the die compaction.

The prepared cold compaction is called "Green compact" is further sintered in the controlled atmosphere and with controlled heating rate. Along, with the rate of heating rate, sintering is done in the permutation of environmental conditions such as pressure, temperature, sintering time. further, the sintering done is protective atmosphere such as in vacuum, nitrogen or under hydrogen atmosphere (reductive). during heating the loose individual powder particle are joined or bounded to produce the structural solid part with desire shape and desired mechanical properties. In sintering process all the porosity is lost and densification of the powder will take place. During this process, the green compact is consolidated forming its microstructure and final shape. The sintering process determines by many factors such as temperature, time, atmosphere, green compacted pressure, sintering pressure, powder particle shape and size. Figure 4 gives the illustration of the sintering process. Out of the above parameters the sintering time plays a vital role in attributing the PM products properties.

![Sintering Process Diagram](image)

**Figure 4.** Illustrating the sintering process: a) particles in contact, b) formation of necks, grain boundaries and pore, c) final sintered geometry.

2. **CU-GRAPHITE MMC FABRICATION BY PM METHOD.**

Copper MMC with coated and un coated Ni reinforcement has superior mechanical properties such as Yield and compression strengths due to good adhesion between Cu-matrix and Ni reinforcement. The higher relative density and low porosity was observed due to good bonding between the matrix and...
reinforcement. In addition to that the coated reinforcement has superior properties than the uncoated one [5][6]. Furthermore, it was observed that the same wear mechanisms exhibit by Cu-coated and uncoated graphite composites attributing to oxidation induced delamination, high strained delaminating, and sub-surface delamination [7]. D. H. He et al. observed that the Carbon Composite Materials (CGCMs) has increases the wear resistance by acting as the self - lubricating material and render protection to contact wire. Further, exhibits special mechanism for good conductor of electricity[8]. X.C. Ma et al [9]studied on the sliding wear behavior of copper– graphite composite material for use in maglev transportation system and observed that the increasing normal stress and electrical current increased the wear loss. Also, observed that the electrical erosion wear, Adhesive wear and abrasive wear are the dominant wear mechanisms during the electrical sliding wear processes. The mechanical properties such as tensile strength, micro hardness of the hybrid composite are higher as compared to the copper matrix. The increase in mechanical properties were attributed to the increase in the reinforcement particles in the powder however the ductility was observed to decrease [10]. A. Yeoh et al. observed that the expansion of the cylindrical specimens in the lateral and longitudinal directions was increased. The composites with the 50 vol. % copper-50 vol. % graphite shown higher expansion due to spheroidization- resulting of non-wetting between copper and graphite [11]. The hybrid composites of copper -graphite were successfully sintered utilizing microwave hybrid heating without any defects. It was observed that round and fine pores with fine microstructure were formed due to the microwave heating. This has been improved the efficiency of the composite [12]. The mechanical properties such as hardness wear rate , coefficient of friction of the hybrid composite made form TiC and graphite acting as reinforcement in copper matrix has increases with increase in reinforcement content. Coefficient of friction of hybrid composites is decreased with increase in % graphite reinforcement [13]. The compressive strength was increased with increase in strain rate from $10^{-4}$ s$^{-1}$ to $10^{-2}$ s$^{-1}$ of the copper nano-composite further, the wear rate of the composite increased with increasing applied sliding speeds or applied loads the above study was made by A. Fathy et al. [14]. Copper (Cu)/ Graphene Nanao Sheet (GNS) composites were manufactured by employing the PM technology. It was observed that the compressive strengths very improved with inclusion of 0.2% GNS. About 10% increase in the compressive stress was observed as compared to the un-reinforced copper PM sample due to good bonding and uniform distribution of GNS with Cu [15]. The PM composite comprising different content of yttrium were produced with optimized cold-press forming and hot-press forming respectively. The inclusion of yttrium observed to improve the oxidation resistance and hardness of the copper appreciably and has a negative effect on the conductivity. Further, it was observed that the hot-press forming resulted in better properties than cold-press forming [16]. The mechanical and thermal properties of copper -aluminum alloys with additional of silver prepared by powder metallurgy was investigated by Gohar et al.[17]. The outcome of this work indicate that existence of silver in Cu-Al alloy furnished better hardness up-to 3%Ag and compression strength increases up to 2%Ag in Cu-10 wt. It is observed that both thermal diffusivity and thermal conductivity increased with the increase of Ag contents in the alloys attributing to higher conductive behavior of silver.

3. ALUMINUM MMC FABRICATION BY PM METHOD.

The MMC's was manufactured from Al matrix and SiC as the reinforcement by Chennakeshava et al., in his study, observed that the particle reinforced with 20% SiC in MMC resulted highest modulus of elasticity of 68 GPa as compared to other combinations in their study [18]. The effect of varying weight fraction of SiC in Al matrix was studied by singla. The SiC composition was varied about 5%, 10%, 15%, 20%, 25%, 30% respectively in the Al MMC's. In their study it was observed that the hardness of about 45.5 BHN with an impact strength of 36 Nm at 25% weight fraction was reported. In the work of abdullah, reported the hardness values of 78 and 82 BHN with 5 and 10% B$_4$C respectively [20]. In order to have a good bonding between the reinforcement and the matrix, Mg added as a binder. This binder act a good bonding medium among the SiC and the Al matrix and enhances the mechanical properties [21]. Hybrid Al MMCs was fabricated with SiC and graphite powders followed by forging and reported that hardness has been improved of about 83 BHN [22]. Ibrahim et al.,[23] studied Sinterability and characterization of aluminum PM alloy with Si and Mg powders. In this work, sintering has performed at various temperature ranging from 610 to 640 °C and reported that 98% theoretical density was attained this
was attributed to the good sintering response. Also, it was found that mechanical properties such as hardness, tensile strength, yield strength values acquired were close to the actual alloy. Apart from all the mechanical properties, the study of the tribological property for the PM MMC’s is also important to study. It was observed that increasing the amount of the ceramic particle enhances the tribological properties of the matrix alloy [24][25]. This attribute to the hard particulates resist the wear action of abrasion and give protection to the surface. The reinforcement powders will improve the yield strength and the UTS when studies done with reinforced with various particulates such as SiC, Al₂O₃, silica sand, boron, TiC, MgO and Si₃N₄[26]. The grain refinement is also an important factor for evaluating the mechanical properties. Mazahery et al., [27] studied the grain refined strengthening effect of the TiO₂ particles. This particle act as catalyst for heterogeneous nucleation in the matrix and this phenomenon will increase with increase in volume fraction. Al nano composite was produced with the TiO as reinforcement. It was observed that the tensile strength, hardness, and density showed that the porosity and the tensile strength of composites increased with an increase in volume fraction of nanoparticles; however ductility of aluminum was decreased further the composite has superior wear resistance compared to alloy [28]. The porous aluminum mechanical property may be altered by including reinforcements into the matrix. Dukhan et al. [11] employed polypropylene polymer to give interpenetrating phases in an aluminum foam to make composites with a high flexible strengthen. The test results of flexural strength and modulus revealed that the combination of the polymer and metal foams produced stiffer materials than either one of the two components.

The aim of the present review is to render insight on the processing of these advanced powder metallurgy materials giving their prospective relevance in the applications in the field of aerospace, civil and structural industries.

4. CONCLUSIONS

This paper has dealt with the importance and application of powder metallurgy products in the field of aerospace and other important structural applications. Also, this paper gives a review on the powder metallurgical composites of Cu- Carbon and Aluminum PM products.

REFERENCES