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Mechanical Characteristics of Aluminum Metal Matrix Composite Fabricated by Powder Metallurgy: A Review

H. S. Kumaraswamy[1], V. Barath[2] and T. Krishna Rao[3]
[1]Research Scholar, [2]Assistant Professor
[1&2]BNM Institute of Technology, Bangalore, Karnataka, India
[3]Professor & Dean, Reva University, Bangalore, Karnataka, India
E-Mail: kumarhs89@gmail.com

Abstract **- The mechanical properties of composites are mainly depends on the distribution of reinforced particles into the matrix material. The distribution of particles plays a very important role while manufacturing the composite. To achieve good mechanical properties, uniform distribution of reinforcement into the matrix is very important, present review reveals one of the manufacturing methods to achieve uniform distribution of particle and to investigate the mechanical properties. There are several types of manufacturing methods are there for the composites , Powder metallurgy is one of the method to manufacture the composites, uniform mixing of particles can achieved by this technique and also the porosity is decreased in this technique but comparatively costlier than the stir casting technique. The present study also reveals a study on different mechanical & tribological characteristics of aluminum metal matrix composite reinforced with different material like silicon carbide, boron carbide, fly ash, tungsten carbide etc. manufactured by powder metallurgy technique.**
Keywords: **Aluminum metal matrix composite, Reinforcement, powder metallurgy**

I. INTRODUCTION

Composites means, advanced materials in which a reinforcement phase mixed in a matrix phase. The reinforcements are like it can be a particulate, short fiber, or continuous fiber. Generally there well-defined interface between the matrix phase and the reinforcement phases. Composites exhibit properties almost similar to that of the matrix and reinforcement properties. In metal matrix composites, for example, fibers reinforcement is generally added in a metal matrix phase. General reinforcements are like Al-Al_2O_3, Al-SiC, Ti-SiC, Mg-Al_2O_3, etc. the composites generally combines the properties of matrix and reinforcement together like ductility of the matrix material & stiffness of the reinforcement material . Aluminium metal matrix composite place a very important role in the transportation ,structural & aircraft application compare to other MMCs to develop light weight very high performance material because of its low density, high strength, wear resistance & good fatigue strength[2]. MMCs can be formed from solid and molten states into forging, extrusions, sheet and plate and casting. Conventional techniques such as casting, spraying and forging have problems, e.g., reinforcement segregation, unwanted interfacial chemical reactions, higher porosity and poor interfacial bonding. Alumina particles with high melting point, conventional melting and casting are not suitable for producing dispersion-strengthened Al composites [3, 4]. Alternatively, powder metallurgy ensures the fine alumina dispersoid is well distributed within the Al matrix, which eventually gives good final mechanical properties to the composite with sufficient physical properties. Mechanical alloying has also been to synthesize aluminum matrix composite (AMC). This method is relatively easy to produce composite powders with fine microstructure [5]. Mechanical alloying that is, a ball milling process where the powder particles are subjected to high energy impact have been recently used in the production of aluminum base matrix composite. MA enables a uniform distribution of the reinforcement particles into the aluminum matrix, the refining of the metal matrix and the fracturing of the hard reinforcement particles [6, 7].

II. POWDER METALLURGY

In a Powder metallurgy process, usually the powder of different size will be ball milled and sieve analysis will be done to get various grain sizes. Later the powder is mixed with some chemical agent called as binders and poured into the die which is designed according to our requirement, then mixed powder in the die will compacted using hydraulic press and after the compaction sintering will be done with different temperature to get the desired mechanical & tribological properties sometimes secondary operations like extrusion and rolling also will carried out to improve the properties.

M.G. Ananda Kumar *et al.*, Reveals that, Atomized Aluminum metal powder of 99.5% purity with a particle size of about ASTM 200 mesh (75 µm) obtained from M/s. NICE Chemicals make laboratory reagent powder was used for the matrix. Cenosphere was obtained from fly-ash received from M/s. NTPC Simhadri Thermal Power Station, India. Cenospheres were harvested from the fly ash through a process which involved ash slurry preparation, stirring and dispersion of slurry. The agitated slurry was then allowed to settle to a standstill. Later, the light weight floating material of the ash comprising mainly of cenospheres was removed and dried. The dried material was then sieved to remove cenospheres of various size fractions. Cenospheres with an average particle size of 10- 100 µm has been used Six composite mixes of Aluminum powder and Cenospheres were prepared. The composite powders were thoroughly mixed with dextrin solution, which was used as a binder to aid pressing the mix powder in the die and also to impart green strength. The mixing was carried out in a laboratory mechanical mixer for about 10 minutes to achieve homogeneity. The composite mixes were pressed into round pellets of diameter 40 mm x 7 mm height size, at a load of 25 kN in a hydraulic press.

Two sets of composite pellets were Prepared, one set of pellets to be sintered in Microwave and the other set through conventional resistance heating One set of pellets was sintered at a temperature of 665 ±50C which is near about the liquidus temperature of Aluminum, make Microwave Sintering Facility operating at 1.1 kW power and microwave frequency of 2.45 GHz. This multimode microwave unit was operated at power level of 100 % with programmable controls. The sintering cycle time comprised of 90 minutes for sintering from room temperature to 6700C temperature which included soaking/ dwell time of 42 minutes. The rate of heating was 120C per minute for attaining the temperature of 6650C and the pellets were soaked at this temperature for 42 minutes. Silicon Carbide crucible, a microwave susceptor, was used to hold the sample in the microwave sintering unit to aid sintering. The 2nd set of pellets was sintered conventionally in a muffle type resistance furnace heated with kanthal element, to a temperature of 6700C and the sintering duration was 8 hours. [16].

III. MECHANICAL PROPERTIES

Aykut Canakci, Temel Varol and Saban Ertok. "The effect of mechanical alloying on Al2o3 distribution and properties of Al_2O_3 particle reinforced Al-MMCs" Sci Eng Composite Material 19 (2012): 227–235 [2].The authors used Al as a matrix & Al_2O_3 as a reinforcement with an average powder particle size of 377µ m and a theoretical density of 2.708 g/cm 3 were used as the matrix material and Al_2O_3 particles with an average particle size of 13 µ m and a density of 3.95 g/cm 3 were used as the reinforcements to characterize the mechanical properties fabricated by powder metallurgy. They found that hardness value increased by increasing the milling time & the percentage of reinforcement. the addition of hard reinforcement in the case of composite powder showed great influence on the morphological and microstructure characteristics of MMCs.

Amal E. Nassar, Eman E. Nassar "Properties of aluminum matrix Nano composites prepared by powder metallurgy processing" Journal of King Saud University – Engineering Sciences (2015) [3].The authors has taken Pure aluminum Nano composite which is reinforced with Nano titanium dioxide was produced By powder metallurgy route technique to characterize the mechanical & tribological properties. The authors reveal that as the percentage of reinforcement increases there is increase in the percentage of ultimate tensile strength & yield strength of composites. Because of harder nano particle as the percentage of reinforcement increases there is increase in the wear resistance and also increase in the hardness level.

Mehdi Rahimiana, Naser Ehsania, Nader Parvinb, Hamid reza Baharvandic, "The effect of particle size, sintering temperature and sintering time on the properties of Al–Al_2O_3 composites, made by powder metallurgy" Journal of Materials Processing Technology 209 (2009) 5387–5393[3].

The author used Al– Al_2O_3 as a matrix & reinforcement to investigate the effect of alumina particle size; sintering temperature and sintering time on the properties of Al–Al_2O_3 composite fabricated by powder metallurgy, the average particle size of alumina were 3, 12 and 48 µm. Sintering temperature and time were in the range of 500–600 ◦C for 30–90 min. the authors found that larger the particle size of Al_2O_3 rise in the density however, the relative density is reduced. This is because the density of alumina (3.97 g/cm3) is higher than aluminum (2.7 g/cm3).

The lower relative density of the composite can be attributed to the reduction in compressibility when hard Al_2O_3 particles are added to aluminum powder. For the sintering temperature 600 ◦C shows the maximum density 99.95%. for particle size 3µm sintered at 600 ◦C for 45 min shows the highest hardness of 76 HB ,

Further increase in sintering time to 90 min results in a reduction in hardness to 59 HB. The finer the particle size of alumina, the greater the compressive strength and elongation. The highest strength was 318MPa, for the composite containing an average particle size of 3 µm and sintered at 600 ◦C for 45 min. Further increase in sintering time has an adverse effect on the strength. Extended sintering times and also the use of fine alumina in Al–Al_2O_3 composite results in higher elongations. Maximum elongation was observed to be 61.8% in samples containing the average particle size of 3 µm.

P. Ravindran, K. Manisekar, P. Rathika , P. Narayanasamy "Tribological properties of powder metallurgy – Processed aluminium self-lubricating hybrid composites with SiC additions" Materials and Design 45 (2013) 561–570[4].

The authors has taken Aluminum2024 as a matrix material & graphite & Silicon carbide as a reinforcement to fabricate hybrid composite by powder metallurgy & to investigate the tribological & mechanical properties under dry sliding condition. The authors reveals that incorporation of graphite into Al 2024 will increase the wear resistance further its increased by adding SiC. If the percentage of SiC increases the co-efficient of friction also get increases and also wear debris become smaller as the amount of SiC addition increases. Hardness will increase by increasing the percentage of SiC but the density level will also increase.

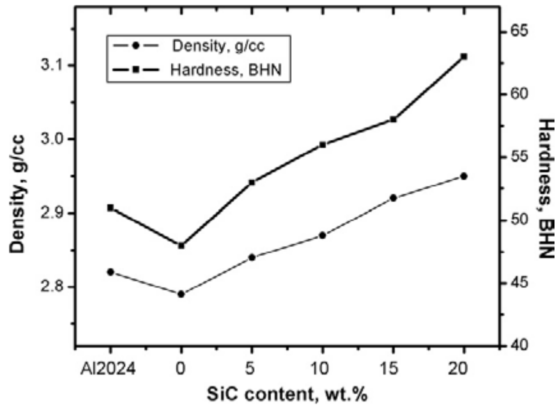

Fig. 1 Variation of density and hardness of hybrid composites with different weight percentage of SiC

A. Azimi, H. Fallahdoost, O. Nejadseyfi "Microstructure, mechanical and tribological behavior of hot-pressed mechanically alloyed Al–Zn–Mg–Cu powders" Materials and Design 75 (2015) 1–8. The authors had taken Al-Zn-Mg-Cu-Zr with a chemical composition similar to Al7050 [5].

They reveals that effect of milling time on the microstructure, density, and mechanical characteristic like hardness, compression strength & wear resistance for a sample size 10mm dia & length 15mm were prepared with 15:1 ball powder ratio with a rotation speed of 250rpm, hot pressing technique was done on the composite under 500Mpa pressure for 30 min at 400 degree C for 30 min. Increasing the micro hardness value and compressive strength with declined rate was due to crystallite refinement. Moreover, there were both negative and positive effects of increasing milling time on mechanical alloying. Developing porosities deteriorated strength and on the other hand, reducing crystallite size improved the mechanical properties.

The wear rates and coefficient of friction were reduced significantly with declined rate by increasing the milling time. Furthermore, changing wear parameters such as increasing applied load and wear velocity do not have any detrimental effect on the wear properties of samples after 40 or 50 h milling in contrast with samples milled for about 20 or 30 h. Observation of the worn surfaces of the samples suggested that the dominant wear mechanisms were abrasion, adhesion and delimitation in samples with shorter milling times (20 and 30 h). Smoother abrasion mechanisms with insignificant signs of other mechanisms for longer milled samples (40 and 50 h) were observed. [5] K. Kanthavel, K.R. Sumesh , P. Saravanakumar "Study of tribological properties on Al/ Al_2O_3/MoS_2 hybrid composite processed by powder metallurgy" Alexandria Engineering Journal (2016) 55, 13–17. The author has considered aluminum as a matrix composite and MoS_2 (5%) Al_2O_3 (%) as a reinforcement to study the wear properties of the composites, the authors reveals that aluminium composite has significant improvements in tribological properties with a combination of 5% alumina (Al_2O_3) and 5% molybdenum disulphide (MoS_2). The sliding distance of 1000 m and sliding speed of 1.5 m/s with applied load of 5 N results in minimum wear loss of 0.0102 g and coefficient of friction as 0.117. The authors also reveals that further addition of 10% MoS_2 in the hybrid composite does not help to improve the tribological property.[6] Hossein Abdizadeh , Reza Ebrahimifard, Mohammad Amin Baghchesara "Investigation of microstructure and mechanical properties of nano MgO reinforced Al composites manufactured by stir casting and powder metallurgy methods: A comparative study" Composites: Part B 56 (2014) 217–221. The authors has taken Aluminium as a matrix & Mgo as a reinforcement with a percentage of 1.5, 2.5, 5 fabricated by both stir casting & powder metallurgy technique to characterize the mechanical properties. The author found that the level of porosity was more with the powder metallurgy component than the stir casting technique which makes the density more in case of stir casting technique. When the percentage of reinforcement increases, the density also increases in both the technique but comparatively stir casting has more hardness than the powder metallurgy. Compressive strength values of casting composites were higher than sintered samples which were majorly due to the more homogeneity of Al matrix, less porosity portions, and better wettability of MgO nanoparticles in casting method. [7] Temel Varol , Aykut Canakci a, Sukru Ozsahin, "Artificial neural network modeling to effect of reinforcement properties on the physical and mechanical properties of Al2024–B4C composites produced by powder metallurgy" Composites: Part B 54 (2013) 224–233.

The author used Al2024 matrix & B4C (boron carbide) as a reinforcement with a varying percentage. Artificial neural network (ANN) approach was used for the prediction of effect of Physical and mechanical properties of Al2024–B4C composites produced by powder metallurgy. The author used 5, 10, 15 wt% of B4C reinforcement size of 49 μm & 5 μm & matrix as a Al2024 with a size of 75 μm , the author reveals that The density decreased by increasing the percentage of reinforcement moreover the relative density is decreased by decreasing the particle size 5 μm. The BHN increased by increasing the percentage of reinforcement, for the small particle size the hardness is more than the larger particle size.

The strengthening of composites was improved with the increasing milling time (from 1 h to 5 h), and then decreased with further increasing the milling time. The results of tensile strength measurements reveals that after 5 h milling process steady state was achieved at 10 wt.% B4C. The tensile strength of composites with reinforced fine B4C particles increased by 20% compared to the unreinforced Al2024 alloy for 5 h of milling. 5 h of milling and 10 wt. % B4C composite was suggested and other milling times (5 h < milling time and milling time > 5 h) and B4C content were not recommended for manufacturing of B4C reinforced MMCs. [9] Mohamed A. Taha, Nahed A. El-Mahallawy, Ahmed M. El-Sabbagh, "Some experimental data on workability of aluminium particulate-reinforced metal matrix composites” journal of materials processing technology 202 (2008) 380–385.author has taken Al as a matrix material with a powder size of 60 µm & SiC as a reinforcement with a percentage of 5,10,15% fabricated by Powder metallurgy technique to examine the workability by upsetting test & the author concluded that the workability index of APMMC decreases when the percentage of reinforcement increases.[11] M.Ramachandra, A. Abhishek, P. Siddeshwar, V. Bharathi, Hardness and Wear Resistance of ZrO_2 Nano Particle Reinforced Al Nanocomposites Produced by Powder Metallurgy, Procedia Materials Science 10 (2015) 212 – 219. The authors have taken aluminium as a matrix and Zirconium dioxide (ZrO_2) Nano Particle as reinforcement. The authors reveal that if the percentage of reinforcement increases there is increase in the hardness level and also the wear properties increases when the percentage of reinforcement increases.

M.G.Ananda Kumara, S.Seetharamua,Jagannath Nayak, L.N.Satapathy A Study on Thermal Behavior of Aluminum Cenosphere Powder Metallurgy Composites Sintered in Microwave. Procedia Materials Science 5 (2014) 1066 – 1074. The author has taken aluminium as a matrix and Cenospheres varying from 10 to 50 vol. % as reinforcement. The authors reveal that Microwave sintering is rapid, economical and fast. The microwave sintered samples show better thermal properties like co-efficient of thermal expansion, thermal shock resistance than the conventionally sintered ones. This is attributed to the fine microstructure and the relative phases that are developed in the microwave sintered product which enhances the properties of the composite including thermal properties. Microwave sintering also aids in achieving properties such as high compressive yield strength and reduced porosity. The composite mix and the amount of cenospheres that can be loaded into the matrix needs to be optimized to design product with desired thermal and mechanical properties[12],which are cheap, economical, through microwave sintering.

P. Rama Murty Rajua, S. Rajesha, K. Sita Rama Rajua, V. Ramachandra Raju. “Effect of reinforcement of nano Al_2O_3 on mechanical properties of Al2024 NMMCs” Materials Today: Proceedings 2 (2015) 3712 – 3717 [11].

The author used Al 2024 as a matrix & nano Al_2O_3 as reinforcement material with a percentage range of 0-2 by varying 0.5% for each trail fabricated by powder metallurgy & stir casting technique. The author reveals that if the percentage of reinforcement increases hardness also increased similarly if the percentage of reinforcement increases the tensile strength is increase up to 1.5% of Al_2O_3 thereafter tensile strength will decrease.

F. Erdemir, A. Canakci, T. Varol, “Micro structural characterization and mechanical properties of functionally graded Al2024/Sic composites prepared by powder metallurgy techniques” Trans. Nonferrous Met. Soc. China 25(2015) 3569−3577.The author used Al 2024 as a matrix material & Sic as reinforcement with 30%-60% percentage fabricated by powder metallurgy technique containing cold pressing followed by hot sintering process [13]. Author used Al 2024 powder (54 µm) & Sic powder with 30%, 40%, 50%& 60% blended in ball mill. Finally author reveals that if the content of SiC increases up to 40% the micro hardness will increase (maximum) there after micro hardness value will decreased with a percentage of 50 & 60% of SiC. Because of increasing the percentage of SiC porosity will increase again it causes decreasing in the bending strength with a SiC percentage of 50-60%, but in the range of 40% SiC the maximum bending strength was noted, hence bending strength will increase by increasing the percentage of SiC up to 40% thereafter its keep decreasing.

IV. CONCLUSION

1. Powder metallurgy ensures the fine alumina dispersion is well distributed within the Al matrix, which eventually gives good final mechanical properties to the composite with sufficient physical properties
2. Aluminium composite has significant improvements in tribological properties with a combination of 5% alumina (Al_2O_3) and 5% molybdenum disulphide (MoS_2).
3. Al 2024 powder (54 µm) & Sic powder with 30%, 40%, 50%& 60% blended in ball mill. If the content of SiC increases up to 40% the micro hardness will increase (maximum) there after micro hardness value will decreased with a percentage of 50 & 60% of SiC. Because of increasing the percentage of SiC porosity will increase again it causes decreasing in the bending strength with a SiC percentage of 50-60%, but in the range of 40% SiC the maximum bending strength was noted, hence bending strength will increase by increasing the percentage of SiC up to 40% thereafter its keep decreasing
4. Al 2024 as a matrix & nano Al_2O_3 as reinforcement material with a percentage range of 0-2 by varying 0.5% for each trail fabricated by powder metallurgy & stir casting technique. Found that if the percentage of reinforcement increases hardness also increased similarly if the percentage of reinforcement increases the tensile strength is increase up to 1.5% of Al_2O_3 thereafter tensile strength will decrease.
5. Pure aluminum Nano composite which is reinforced with Nano titanium dioxide it’s been observed as the percentage of reinforcement increases there is increase in the percentage of ultimate tensile strength & yield strength of composites. Because of harder nano particle as the percentage of reinforcement increases there is increase in the wear resistance and also increase in the hardness level.

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