ISSN (e): 2250 – 3005 || Volume, 08 || Issue, 07|| July – 2018 ||
International Journal of Computational Engineering Research (IJCER)

Design and fabrication of Aluminium/Alumina advanced composites using Powder Metallurgy route

Aravind Tripathy[1], Rahul Prajapati[2], Prasant Kumar Sahu[3]
[1,3]Assistant Professor, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar
[2] Assistant Professor, Department of Mechanical Engineering, Gandhi Engineering College, Bhubaneswar

Abstract— *Engineered materials are in demand today owing to their superior mechanical properties with Al-Al2O3 combination being one of the most popular pair in which Al is the matrix and Al2O3 being the reinforcing agent. Present work revolves around the fabrication and characterization of Al/Al2O3 composites with a varying range of Al2O3 starting with 0% and goes up to 40% in steps of 10% each. These composites were fabricated using a uniaxial hot press under* 10^{-5} *mbar vacuum pressure and a sintering temperature of 400 °C, 3 ton load under a two hour experimental condition. It was observed during characterization that the relative density of the advanced composite increased with the rise in sintering temperature and the density range changed quasi continuously from* $2.665x10^3\ Kg/m^3$ *to* $2.709\ x10^3\ Kg/m^3$*. At the same time the micro hardness obtained at the top layer (100% Al) was 35.2 HV which gradually increased to 75HV at the layer comprising of 40% Al2O3 as reinforcement. This Advanced Composite can be a good substitute for light weight –high strength material with better wear resisting characteristics at elevated temperatures. These advanced composite are also popularly called as Functionally Graded Composite or simply functionally graded materials.*
Keywords—*Advanced Composites, powder metallurgy, hot pressing, layered structures, functionally graded materials.*

I. INTRODUCTION

Automobile and aerospace sectors are evolving very fast with passage of time, hence need for new engineered materials is also growing very fast focusing on superior properties such as higher strength, low specific weight, better temperature resistance, environment friendly, better recyclability and so on. Among the various types of composites Al-Al2O3 composites are the most successful metal-matrix composites [1]. The need for such advanced composites is to balance the demand of extreme environments and complex thermo mechanical loading on the work front. Materials like light weight alloys (Al, Ti, Mg), copper alloys, steel or cast iron were tried unsuccessfully for above applications. Metal – Ceramic composites which offer a great deal of advantages over the above list of materials could just be the answer to above challenges [2]. Al/Al_2O_3 are a class of composites which exhibit characteristics like high strength-to-weight ratio, good castability and better tribological properties in comparison to unreinforced alloys[3]. MMCs comprise of light weight metals like Al or Mg reinforced with ceramic materials like Al2O3 or SiC in the form of particulates or fibres [6]. Higher specific strength and stiffness, higher operating temperature and greater wear resistance, are the hall mark of MMCs. Also the opportunities to tailor these properties for a particular application give them the added advantage over unreinforced metals [7].Functionally Graded (FG) Material has compositional and micro structural gradient along its thickness direction and was developed as an answer to delaminating failures in laminated composites. FG Materials exhibit flexibility in terms of functional behavior of a single material as on one side it may exhibit metal like properties on the other side it will exhibit high temperature withstanding characteristics. Scholars have applied the best methods or combination of several methods depending on the characteristics of the constituent materials to successfully fabricate these FG Materials [5]. Figure 1 below depicts the FG Material concept in a very clear manner.

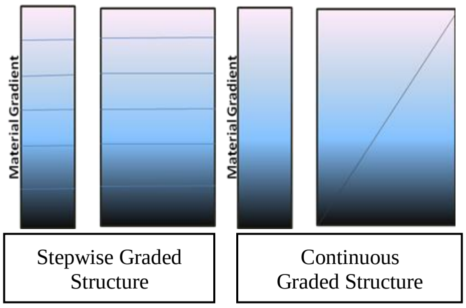

Fig.1. Representation of Functionally Graded Material

These days, researchers acknowledge the importance of innovative materials in the use for economic and environmental reasons [6]. These engineered materials are designed for an intended function, and the material properties are tailored by a spatial gradation in structure and /or composition. FGMs exist in nature too. Like many other man-made materials, FGMs occurring in nature such as bamboo have been in use for thousands of years for decoration and construction works [8]. The scientific term "functionally graded material" was first introduced in the year 1984 by the Japanese researchers while developing thermal barrier materials [9]. There has been a plethora of research and publications in this area in the last three decades. A great deal of detailed study of different fabrication processes, huge amount of research investments and support by different industries and large scale production of FGMs lead to a rise in popularity as well as application of these engineered materials in comparison to conventional materials. Powder Metallurgy process is one such most popular process in the field of FGM fabrication.

Powder metallurgy: In powder metallurgy, four basic steps are followed which are mixing, stacking, pressing and sintering as explained in the flow chart (Fig.2). Mixing is *Powder preparation*, (precise weighing and blend the powder and ensure proper dispersion of each of them in the mixture which will significantly affect the structural properties), stacking is putting the powder in the die, pressing is applying the load through the punch to give shape to the material and in order to provide strength and integrity to the powder compact, controlled heating of the powder compact is facilitated and is known as sintering. Sintering temperature is usually below the melting point of the major constituent of the powder mix [5, 10]. PM is an appropriate technology for both ultrafine composite as well as FGM-fabrication and is widely being used too.

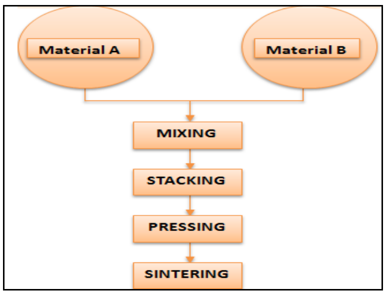

Fig. 2 Powder Metallurgy Process

II. METHODOLOGY

The starting materials were Alumina (Al_2O_3) powder, (Alfa-Aesar. <1µm, purity 99.99%, density: 3.965g/cc) and Al metal powder, (High-media, <40µm, with impurities such as Iron (Fe):0.5%, Heavy Metals (As Pb):0.03%).

Mechanical Milling: Powders of Aluminium and Alumina were weighed as per the volume fraction constituting each individual sample or layer (for FGM) and were then homogeneously mixed by using planetary ball mill (Retsch PM 400). Primarily the techniques are about proper volume fractions of the matrix and reinforcement materials that were taken for mechanical milling in order to homogenize the mixture. Phase analysis of the milled powders were done using powder diffraction technique with the help of X'Pert PRO PAN Analytical's materials research Diffractometer (λ=1.54184Å).

Experimental Method: Measured quantity of the powder was taken in the die. Consolidation of powder to produce samples was done using Hot Uniaxial Vacuum Press at 400^0C and with dwell time of 5 minutes at the vacuum pressure of 10^{-5} mbar with heating rate 25 °C/min. The samples were tested for density, hardness and microstructure in order to find an optimum balance between matrix and reinforcement with best characteristic for a low weight high strength composite with many other added characteristics. The pictures below show the raw samples after being taken out of the die. After fabrication of pellet samples (Fig. 3) and density measurements, samples were ground and polished (mirror finished), followed by cloth polishing up to 0.1 µm with diamond paste and mounted for characterization studies as shown in Fig.4.

Testing: All necessary tests are carried out sequentially to ascertain the characteristics of the prepared sample before necessary trial is carried out for proving the material manufactured for a particular cause.

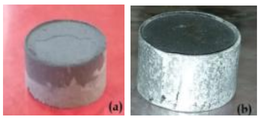

Fig3: FGM samples

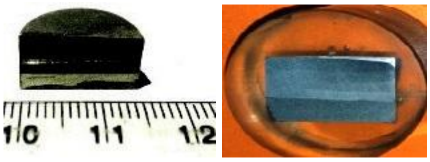

Fig4. FGM Samples for hardness measurement.

III. RESULTS AND DISCUSSION

A. XRD Analysis: XRD patterns of the selected layers are shown (Fig. 5) in different colors to distinguish the pattern of each layer. The pattern shows only Al and Al_2O_3 peaks which indicate that there is no new phase formation during milling process. All the patterns look identical, only difference in the intensity is observed as expected due to difference in the composition of the layers. The patterns also shows little broadening of the peaks due to fine size of the particles.

B. Density Measurement: At different volume fractions of the reinforcing material, the density was measured using Archimedes' principle in distilled water setup. Theoretical and actual density of the FGM samples, the data and plot are explained (Fig.6) for comparison. As the sintering temperature was raised densification increased as shown in Fig.6.

C. Hardness measurements: The effect of Al_2O_3 particulate reinforcement on the hardness variations of the different ultrafine composite samples and different layers of the FGM sample is shown in Figs. 8 and 9 respectively. It is found that there is sudden rise in hardness by nearly 33% in the 2^{nd} layer with respect to that of 1^{st} layer (pure Al) and thereafter the average hardness increased by 11% increase in hardness is the result of strong interfacial bonding between Al matrix and Al_2O_3 particulates.

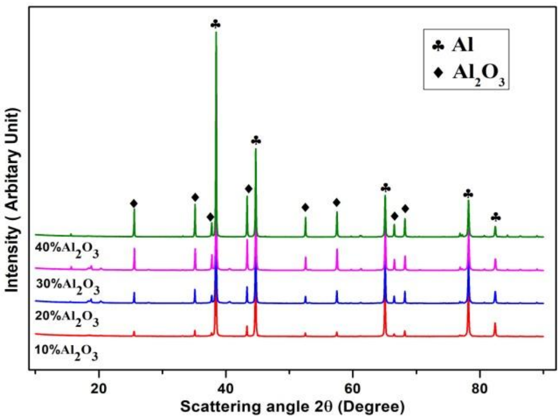

Fig.5. XRD Analysis of powders after milling.

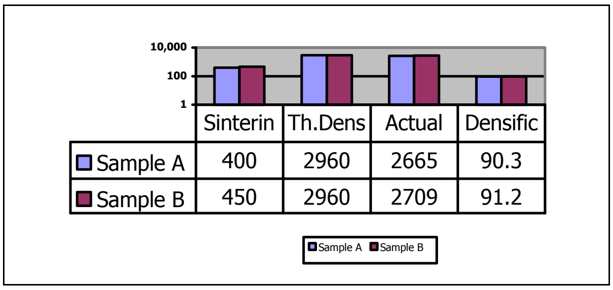

Fig.6. Densification plot for different FGM samples sintered at 400°C and 450°C.

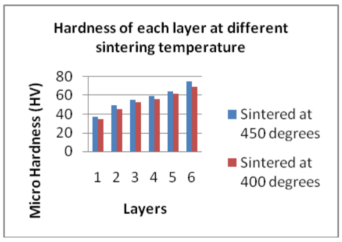

Fig. 7 Hardness of FGM sample at each layer.

IV. CONCLUSIONS

Functionally Graded Composite samples with more than 90% density were fabricated with desired composition ratios. The hardness of each layer in the sample showed different values and it increases with increased percentage of Al_2O_3 in the sample. This confirms the final product is as per the layered composite design. The fabrication process using PM (powder metallurgy) route coupled with hot pressing method was thus validated.

REFERENCES

[1]. Dinesh Kumar Koli, Geeta Agnihotri, Rajesh Purohit, “Properties and characterization of Al-Al2O3 Composites Processed by Casting and Powder Metallurgy Routes (Review)”, IJLTET; pp486-496, Vol.2, Issue 4, July 2013.

[2]. Kaczmar J W, Pietrzak K, Włosinski W. The production and application of metal matrix composite materials. J Mater Process Technol; 106:58–67, 2000.

[3]. Hunt Jr WH, Miracle DB. Automotive applications of metal matrix composites in: Miracle DB; Donaldson SL,(Ed), ASM handbook, vol. 21: composites, ASM International pp. 1029–32, 2001.

[4]. Miracle DB. Metal matrix composites – from science to technological significance. Compos Sci Technol; 65:2526–40, 2005.

[5]. A Tripathy, S.K.Sarangi, R.K.Panda, “Fabrication of functionally graded composite material using powder metallurgy route: an overview”, IJMPERD, Vol. 7, Issue 6, 135-146, Dec 2017.

[6]. Lannutti JJ (1994), “Functionally graded materials: Properties, potential and design guidelines”, Compos. Eng. 4(1):81-94.

[7]. Chawla KK. Composites materials. 3rd ed. New York: Springer; [Chapter 4 Metal Matrix Composites, https://www.princeton.edu/~ota/ disk2 /1988 /8801/ 880107 .PDF], 2012.

[8]. Emilio Carlos Nelli Silva, Matthew C. Walters, Glaucio H. Paulino, “Modeling bamboo as a functionally graded material: lessons for the analysis of affordable materials”, J Mater Sci, 41:6991–7004, 2006.

[9]. M. Yamanoushi, M. Koizumi, T. Hiraii, and I. Shiota, Eds., Proceedings of the 1st International Symposium on Functionally Gradient Materials, Sendai, Japan, 1990.

[10]. Rajat Gupta, Rohit Kumar, A.K. Chaubey, Shailesh Kanpara and S.S. Khirwadkar, “Mechanical and microstructural characterization of W–Cu FGM fabricated by one-step sintering method through PM route”, IOP Conf. Series: Materials Science and Engineering 338 (2018) 012042 doi:10.1088/1757-899X/338/1/012042.