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RESEARCH ARTICLE

INVESTIGATION OF PRODUCTION PARAMETERS FOR FUNCTIONALLY GRADED Al-Al_2O_3 and Cu-Steatite

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ABSTRACT

In this study, determined amount of powder (Al-Al2O3 and Cu-Steatite) by weight are mixed homogeneously with 3-D shaker and then pressed to obtain FGM. Mixture ratios by weight vary from 80 % Al - 20 % Al_2O_3 to 20 % Al - 80 % Al2O3. Same mixture ratios are also prepaired for Cu-Steatite. For both of the mixtures, maximum ratio of metal (Aluminum and Copper) stay in the core while maximum ratio of ceramics (Al2O3 and Steatite) at the outer. Powder mixtures are passed through Hall funnel and appearant densities of them are calculated. Appearant density of Al-Al2O3 mixtures varies from 1.184 gr/cm3 to 1.344 gr/cm3 while it varies from 1.04 gr/cm3 to 2.352 gr/cm3 for Cu-Steatite mixtures. Aluminum tubes at successive diameters are placed into the cylindirical die of 32 mm diameter to seperate the different regions in the die before pressing. Each layer between the tubes corresponce to a different ratio of homogeneous mixture. Zinc stearate lubricant at the amount of 1% of each mixture by weight is added into each mixture before pressing. Pressing pressure varies from 700 MPa to 750 MPa. FGM specimen prepared from Al-Al_2O_3 mixture is sintered at 630 0C for 90 min and the one from Cu-Steatite 1030 0C for 60 min.

Keywords: *Functionally graded materials, Powder Mettalurgy, Sintering*

1. INTRODUCTION

The concept of FGM was first mentioned in 1984 for a science project. In this project, a combination of materials has been used for creating a thermal barrier with enduring a surface temperature of 2000 K and a temperature gradient of 1000 K across a 10 mm section.

FGM aims to make a composite material by varying the microstructure from one material to another material with a specific gradient in order to have the best of both materials. Both strengths of the material may be used to avoid corrosion, fatigue, fracture, and stress corrosion cracking when considering thermal, corrosive resistance or malleability and toughness.

Powder metallurgy is widely used to produce FGMs. Some of the material couples to produce FGM by means of the powder metallurgy are ZrO2-Ni, Hydroxyapatite-Ti (biomaterial), ZrO_2-NiCr, Ti-ZrO_2, Al_2O_3-Ti_3SiC_2, Mullite/Mo, SiC/C, Al-SiC and Ni-Al_2O_3. In this study, Al-Al_2O_3 and Cu-Steatite couples are used to produce FGM by means of the powder metallurgy. Powder metallurgical processing is one of method for manufacturing of FGM [1]. This method required by powder metallurgical (PM) processing involves rapid solidification that offers unique advantages for the ductility of the material. For example, segregation in the powdered material can be minimized, very fine grains can be produced, and solid solubility of alloying elements can be increased [1-3]. Biomaterial implants [4], thermal barriers [5], energy conversion materials [6], cutting and rock drilling tools [7], mechanical elements as gears, and optical and optoelectronic materials [8] are some of the fields for application. FGM development procedures also include powder metallurgy (PM), centrifugal casting, thermal or plasma spraying, electrochemical processing, and chemical vapor deposition (CVD) and physical vapor deposition (PVD). Cast blanking, frictional mixing machining (FSP) and laser-controlled web formation are state-of-the-art processes to produce such hybrid material. FGMs have a growing role due to their custom-made properties and the lack of well-defined restrictions or interfaces among their different sections unlike conventional composites. As a result of the high sectional laminar stresses in classical composites, the layers split, leading to the breakdown of the load transfer mechanism between the matrix and the reinforcement, loss of rigidity and structural integrity, which ultimately leads to failure. functionality and structure. FGM has a good opportunity for diminishing mechanical and thermal stress concentrations in several structural materials to develop specific tools [9]. For example, the optimized formation gradient of a cutting tool can increase tool life and abrasion resistance [10]. Likewise, dental implants are improved by optimized constituent gradients and gradient thicknesses in terms of implant duration and convenience [11].

J.R.Cho and J.Tinseley [12], in their studies, express material properties in terms of the volume fractions of the ceramic and metal components in the composition. In this study, FGM is considered as a multilayered composite structure. Each layer is assumed to be isotropic so that stress and strain components are calculated as shown below:

$$\sigma = V_s\sigma_s + V_m\sigma_m$$
$$\varepsilon = V_s\varepsilon_s + V_m\varepsilon_m$$

Where;
V_s : Volume fraction of the ceramic, V_m : Volume fraction of the metal
σ_s : Stress of the ceramic , σ_m : Stress of the metal
ε_s : Strain of the ceramic , ε_m : Strain of the metal

So, modulus of elasticity of the FGM is determined as shown below [13]:

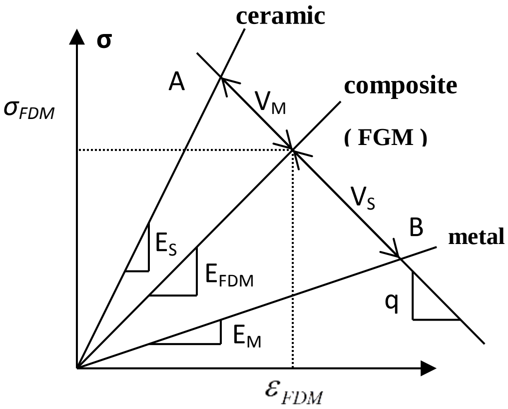


Figure 1. Stress-Strain relationship in FGM due to volume fractions.

As shown in the figure;

$q = (\sigma_A - \sigma_B)/(\varepsilon_A - \varepsilon_B)$

Values of q are determined experimentally for various volume fractions. So that, modulus of elasticity is calculated along the FGM layers in the material. Modulus of elasticity is defined in terms of q, V_m, V_s, E_m and E_s due to the experimental results.

2. EXPERIMENTAL METHOD

Materials:

Production of the FGM is achieved by using metal and ceramic powders. Properties of these powders are tabulated in Table 1. Metal powder is composed from aluminum and copper whereas ceramic powder is composed from aluminum oxide and steatite.

Table 1. Powders used to produce FGM.

Powder Material	Al	Al_2O_3	Cu	Steatite
Density (g/cm^3)	2.7	3.89	8.96	2.7
Melting Temperature (^{0}C)	660	2054	1084	1450
Mean Particle Size (µm)	60	12.15	72	15.12

Particle Sizer:

Particle size is determined by means of the Malvern Mastersizer Laser Particle Sizer Unit in the powder metallurgy laboratory of Gazi University, Department of Mechanical Engineering. This unit contains a laser beam source to emit monochrome, intensive and parallel beams, in addition to the beam expander, measurement chamber, Fourier lense and detector. Mechanical shaker, centrifugal pump and ultrasonic energy application facilities are available in the sample preparing unit. Ultrasonic energy is applied to dissipate the lumps. Mechanical mixer is used to make the suspension stay homogenous during analyzing. Finally centrifugal pump is used to make the suspension be sprayed towards the laser beam. The sample in the reservoir, prepared with one liter of water, is maintained to circulate continuously in front of the laser beams. Laser beams which collide with the particles refract with definite angles, pass through the Fourier lens and then land on the detector. These beams which land on the detector are digitized by means of an analog-digital converter. Then these converted data are entered into the computer. Refracting angles of the beams help to calculate the particle size besides intensity of the beams help to calculate the particle percentage by volume. A general view and installation of the "particle sizer" is shown in figure 2.

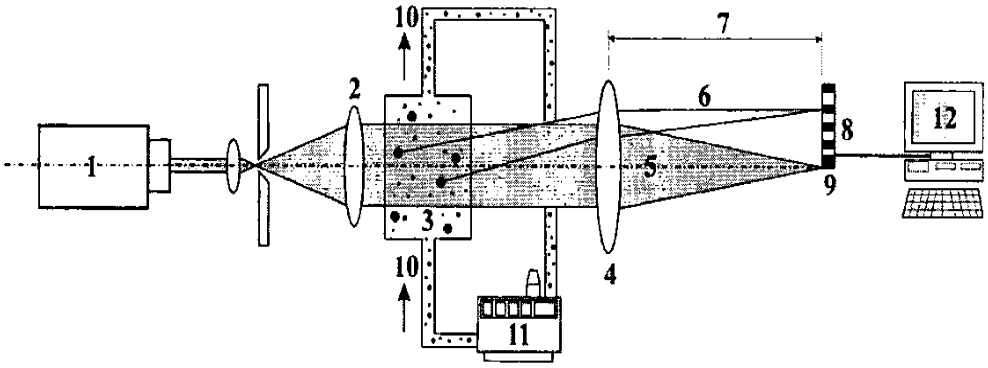


Figure 2. Installation of Particle Sizer. (1. Laser beam source, 2. Beam expander, 3. Measurement chamber, 4. Fourier lens, 5. Laser beam cluster which didn't collide with any particle, 6. Refracted beams which collided with the same-sized particles, 7. Lens focus length, 8. Detector, 9. Central detector, 10. Suspension flow direction, 11. Sample preparing unit (reservoir), 12. Computer.

Turbula Shaker:

Shaking process is achieved in the Powder Metallurgy Laboratory of Mechanical Engineering Department of Gazi University by means of a three dimensional shaker which is called "Turbula Shaker". Powders with definite percentages (Table 2) are shaked in a dry medium during approximately 45 minutes and it is observed that this period is sufficient for a homogenous mixture.

Table 2. Powder percentages used for FGM.

Mixture Numbers	Mixture Percentages by weight			
	Al	Al_2O_3	Cu	Steatit
1	80	20	80	20
2	60	40	60	40
3	20	80	20	80

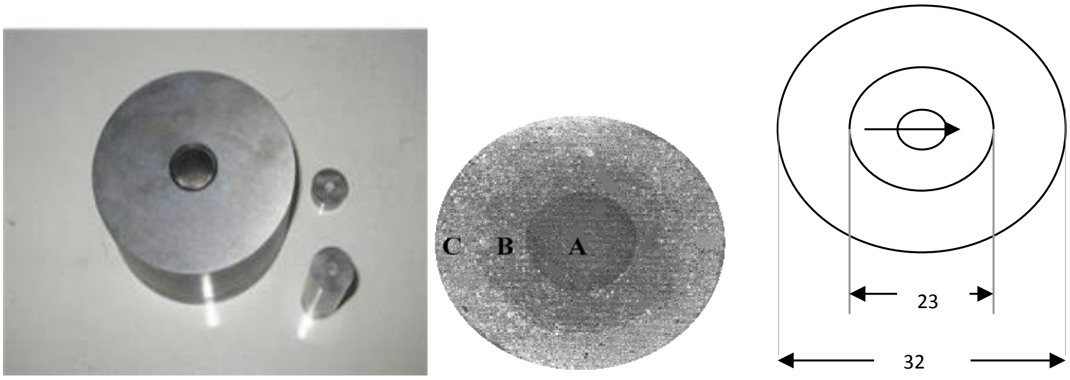
Hall Funel:

Mixture powders are passed through hall funel and apparent densities are determined. The powders which pass through the holes diameter of 1 inch, flow into the cylinder that has a volume of 25 cm^3. Apparent density is calculated by means of the fraction of the weight of the powder mixture to the volume. It is observed that apparent density varies between 1.184-1.344 gr/cm^3 for Al_2O_3-Al and 1.04-

2.352 gr/cm^3 for Cu-Steatite. Increasing of ceramic content decreases the apparent density of both mixtures.

Molding:

Pressing of the powders are achieved by means of “Dartec Tensile Testing Machine” which has a capacity of 60 tons. The powders are pressed between the loads of 570-600 kN. Applied pressures are between 709.1 MPa for Al_2O_3-Al and 746.42 MPa for Cu-Steatite. Zinc stearate lubricant at the amount of 1% of each mixture by weight is added into each mixture before pressing in order to minimize the friction. Two hollow cylinders each of which has a thickness of 1 mm are placed into the die in order to create three cylindirical regions and powder mixtures are poured into the each region. The diameters of these hollow cylinders are 23 mm and 9 mm whereas the diameter of the die is 32 mm which consists of upper and lower punches. Into the outer region of the die, Al_2O_3-Al powder mixture 80% by weight is poured and then into the inner regions 40% and 20% by weight of the same mixture respectively. Similarly for the Cu-Steatite, into the outer region Cu-Steatite powder mixture 80% by weight is poured and then into the inner regions 60% and 20% by weight of the same mixture respectively. Pressing pressure and the amount of powder to be poured into the die are determined due to the apparent density of the powder mixture. The die, upper and lower punches are shown in the figure 3a besides the regions are shown schematically in the figure 3b.



(a) (b) (c)

Figure 3. (a) The die, upper and lower punches (b) Schematical regions (c) FGM.

Sintering Properties:

Sintering temperature for Al_2O_3-Al is 630 ^{0}C where sintering period is 90 min. This temperature is above the sintering temperature but below the melting temperature of aliminum. Sintering temperature for Cu-Steatite is 1030 ^{0}C where sintering period is 60 min. Similarly, this temperature is above the sintering temperature but below the melting temperature of copper. Applied pressure for Al_2O_3-Al is 709.1 MPa whereas 746.42 MPa for Cu-Steatite. Sintering graph is given in figure 4 for both materials. In figüre 5 and 6 raw and sintered views of Cu-Steatite are given.

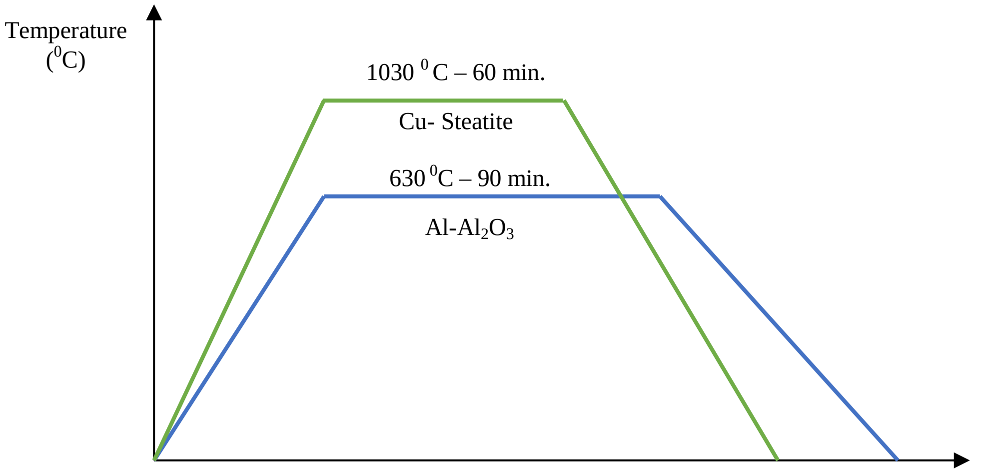
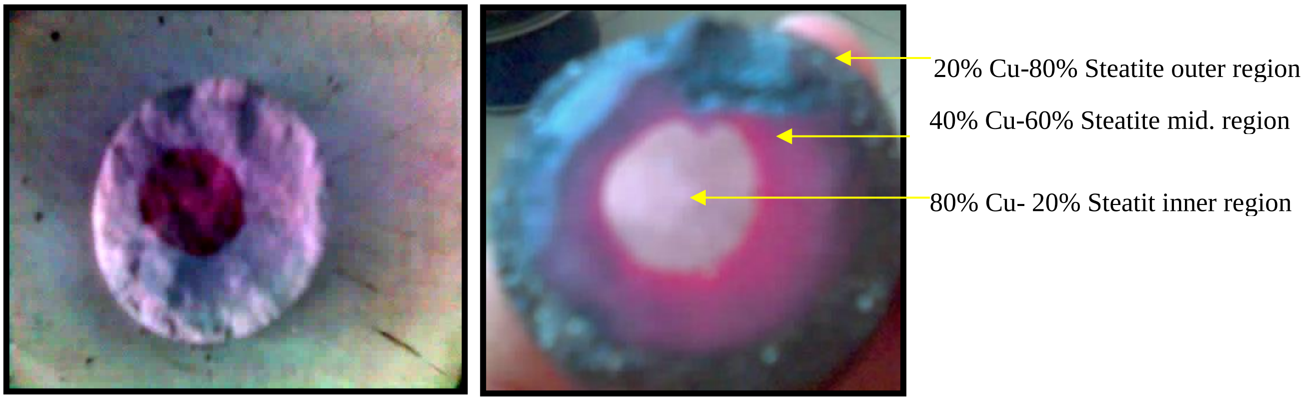


Figure 4. Sintering graph for Al_2O_3-Al and Cu-Steatite.



(a) (b)

Figure 5. (a) Sintering Cu-Steatite FGM (b) Sintering Cu-Steatite FGM.

3. RESULTS and DISCUSSION

It is observed that Cu-Steatite specimen has higher strength than the raw material. However some cracks are visible around the specimen. Sintering conditions must be improved in order to avoid from the cracks. Strength of the pressed Al-Al_2O_3 specimen increases after sintering but not as much as the increase of the Cu-Steatite specimen. Appropriate sintering conditions must be determined by means of DSC and sintering must be achieved under a protective atmosphere. Apparent densities of both mixtures decrease when ceramic content increases. Appearant density of Al-Al_2O_3 mixtures varies from 1.184 gr/cm^3 to 1.344 gr/cm^3 while it varies from 1.04 gr/cm^3 to 2.352 gr/cm^3 for Cu-Steatite mixtures depending on the mixture pertentages. Powders are pressed between the loads of 570-600 kN. Pressing pressure is 709.1 MPa for Al_2O_3-Al where 746.42 MPa for Cu-Steatite.

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The article is not relevant

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