FGM ROTATING DISC FABRICATE BY Al/Al2O3

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ABSTRACT
Our aim of is to develop a processing method for a rotating disc made of functionally graded materials (FGM), by stacking the shurry, layer by layer in a radial direction. A three-layer functionally graded material of Al/Al2O3 is fabricated with compositions of 10, 20, 30 vol.% Al2O3. The ceramic composition increases from the discs inner (centre) to the outer. The combination of these materials can offer the ability to withstand high temperature conditions whilst maintaining strength in extreme environments. In this paper we present a method of fabricating a disc made of Al/Al2O3 functionally graded materials (FGM), using a powder metallurgy manufacturing process.

KEYWORDS
Scanning Electron Microscopy, Functionally graded materials, aluminium, alumina, rotating disc, electrophoretic

I. INTRODUCTION
Research on new material concepts to meet the requirements of extreme environments has received worldwide attention in this challenging era. Conventional materials that have been developed may face failure under severe paradigm [19]; therefore, materials with unique characteristics need to be derived. Functionally graded materials (FGMs) have been introduced and defined in various aspects like Koizumi 1997 [10], Kawasaki and Watanabe, 1997 [9], Song et al., 2007 [14] and Sun et al., 2008 [15]. Feng et al. (2005) [5] defined FGM as a composite material consisting of two or more phases in which the volume fractions of the constituents change, so that the composition, microstructure and properties vary gradually along one direction. The novel concept of FGM is essential in many fields, including: aerospace, automotive, medical, electronic industry, energy industry, etc.

A rotating disc is an essential component in many engineering applications, such as: turbine rotors, gears, internal combustion engines, turbojet engines, ship propellers, etc. In some applications, there is a possibility that external heat transmits to the shaft and from it to the bearings, causing adverse effects on its function and efficiency [1]. Normally, rotating discs are fabricated using a single metal or alloy. However, some components cannot withstand extreme mechanical loadings. Furthermore, for some specific applications, such as in high temperature environments, the components have a tendency to fail and cause the discs to crack. Therefore, the concept of an FGM rotating disc, along with a method of its production, was necessary in order to meet this functional performance requirement.

A number of FGM production methods, such as combustion synthesis [3], electrophoretic deposition [13], centrifugal methods [17], plasma spraying, laser cladding and powder metallurgy [19] have been successfully developed and reported in recent publications. Among these, the method of powder metallurgy is one of the most viable routes for FGM, in which the composition and microstructure variations, as well as shape forming, can be easily controlled for a wide range of applications [9] [7]. Researchers have developed a variety of material combinations by using powder metallurgy techniques to fabricate FGM products. Some examples include: ZrO2-NiCr FGMs [19], Al2O3-Al2TiO5 FGMs [11] [12], Al-Al2O3 FGMs [16], Al-SiC FGMs [2], p-Pb1-xSnxTe FGMs [6]. This study presents an FGM rotating disc made by combining Al and Al2O3 powders.

II. PROCESSING METHOD
This section details the fabrication of the FGM rotating disc using the method of powder metallurgy. The development of the manufacturing process begins with the stage of designing the rotating disc and continues up to the characterization of samples by scanning electron microscopy (SEM). Figure 1 illustrates a flow chart of the proposed fabrication process of the FGM rotating disc.
**Design concept of rotating disc**

The disc is designed in three circular layers each with a different compositional ratio determined by volume percentage, as shown in Figure 2. The three layers form rings with proportions consisting of 90, 80, 70 vol.% Al from the inner (centre) to the outer of the disc. Al powder (99.7% purity, particle size: 63µm) and Al₂O₃ powder (99.7% purity, particle size: 0.7µm) were used as the starting materials. The disc is designed to have a 42 mm diameter for the first layer, 83 mm for the second and 103 mm for the third with all layers 10 mm in depth.

**Mixing Process**

The starting powders were mixed in different ratios by using a VT-V Powder Mixer. A special bottle was filled and mixed mechanically in order to facilitate a uniform distribution of the Al/Al₂O₃ powder particles. The mixing was performed with a speed of rotation of 100 rpm for a minimum of 1 hr.

**Stacking Process**

The inner die, made of material 718, was sprayed with heavy-duty silicone lubricant to ease the discharging process of green compact. A few marks were made on the surface of the bottom base by following the diameter of the two aluminium thin-walled cylinders. The diameters of the cylinder reflect the diameters of layers 1 and 2, which are 42 and 83 mm, respectively. The two cylinders were positioned on the marked points and four pins were used to ensure the cylinders did not move during the stacking of the slurry. The mixtures were sequentially stacked in the die, layer by layer, in a radial direction starting from layer 3 to layer 1. To maintain the correct compositional distribution and to level the height of the mixture among the three layers in the die, a cylindrical rod is used to tap mixtures with low pressure. After levelling the layers, the stacking powders were closed with the top base and the punch. This process is presented schematically in Figure4.
Compaction
After the stacking process, the mixed powders were pressed into shapes in the die. The compacted product is called the green component. The purpose of this step is to obtain the required shape, density and particle-to-particle contact, as well as to make the part sufficiently strong. The equipment used was a manual press gang Coleman machine and the pressure exerted on the stacked powders was 44.8 MPa with a holding time of 1 hr.

Sintering Process
The green component was heated in a furnace at a temperature slightly below the lower melting point of the two materials. For the present disc, the melting point of Aluminium (660 °C) is lower than that of alumina (1600 °C). Therefore, the discs must not be heated above 660 °C. The actual temperature used was 640 °C with a holding time of 2 hrs. The heating rate was 5 deg/min, taking 2 hrs 8 mins to reach the highest temperature. Then, the product is cooled to room temperature.

III. RESULTS
The successfully fabricated green component of FGM is shown in Figure 4. It can be seen that the clear circular shape boundary exists on the surface of the rotating disc that divides the region of the ring portion. The bonding of the materials appears to be sound and it can hold its structure perfectly, even when lifted roughly in this state. This confirms that the final product (after sintering) is able to withstand the high stress of centrifugal forces during operation, without breaking at the interlayer of the materials.

The study of densification of the sintered FGM disc has been conducted using the water-immersion technique. The density of the Al/Al₂O₃ FGM disc increases with an increase of the Al₂O₃ content, which changes gradually from 2.437 × 10³ kg/m³ to 2.6978 × 10³ kg/m³ from the inner to the outer of the rotating disc. However, the real density value of the Al/Al₂O₃ FGM disc was 2.599 × 10³ kg/m³. The results show that the trend of density increase when the Al₂O₃ content increases, acts in accordance with the findings of Deng et al. [4] but the value obtained is lower [16].

In order to obtain the highest density in each layer of the Al/Al₂O₃ FGM disc, pressure sintering, such as hot-pressing or hot isostatic pressing, may be a more effective method to use, as these processes can enhance the densification of the metal/ceramic FGM, as well as reduce unavoidable porosity. Nevertheless, this work is just the beginning in Malaysia and improvements will guarantee the ability...
to triumph in the future.

CONCLUSION AND FUTURE SCOPE

The Al/Al2O3 system of functionally graded materials (FGMs) with various Al2O3 fractions has been successfully fabricated by using a powder metallurgy process. A three-layer functionally graded material of Al/Al2O3 was fabricated using Al and Al2O3 powders, in compositions of 10, 20, 30 vol. % Al2O3. A method of fabrication of FGM rotating discs with layers, arranged layer by layer along a radial direction from the inner of the disc (centre) to the outer, was developed and can be applied in producing other FGM-based products.

REFERENCES