CFD Simulation of Centrifugal Casting of Al-SiC FGM for the Application of Brake Rotor Disc

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Abstract — *A Functionally graded material (FGM) is a suitable candidate for manufacturing automobile brake rotor discs. This paper discusses the simulation of centrifugal casting process to manufacture aluminium-silicon carbide FGM disc in ANSYS Fluent. The work consists of simulating an experimental work of horizontal centrifugal casting to test the software, and a simulation of vertical centrifugal casting process. The simulation results were analysed and maximum volume fraction of SiC in the component was found to be 51.47% at a radial distance of 9mm from the outer surface.*

Keywords — *Functionally graded materials, Centrifugal casting, Numerical simulation.*

I. Introduction

A functionally graded material is a class of advanced composite distinguished by its composition. It is a two component composite, for example, metal-ceramic or metal-metal, with its composition gradually changing from one component to the other within the bulk. This enables to completely utilize the required properties of both the components. For example, the refractoriness of ceramic part and the toughness of metal part. This feature makes the FGM tailor made for numerous applications. Seashells, human bones and teeth are considered as some naturally occurring examples of FGM [1]. Some of the main applications of functionally graded materials are rocket heat shields, heat exchanger tubes, wear resistant linings, bullet proof vests, automobile engine cylinder pistons and so on.

The work discussed in this paper takes interest in the application of FGM as a brake rotor disc. Currently, the brake rotor discs are made of conventional materials like cast iron. The material considered in this study consists of aluminium as the metal and silicon carbide as the ceramic reinforcement. The advantages of FGM over cast iron are discussed in the later section. The friction between the braking pads and the rotor disc causes the moving object to stop. This generates high amount of heat and results in the wear of the rotor disc. It is proved that wear resistance of aluminium alloys can be improved by adding ceramic particles such as silicon carbide to the matrix alloy [2].

Vertical centrifugal casting is considered as an efficient method in manufacturing FGM discs commercially. For the centrifugal casting process, the mix of molten aluminium and silicon carbide powder is poured into the pre-heated rotating mould. The silicon carbide powder travels up to the outer surface under the action of centrifugal force. The accumulation of silicon carbide powder near the outer periphery of the disc provides the required strength and wear resistance in that area.

The simulation is carried out in ANSYS Fluent to understand the distribution and volume fraction of silicon carbide in the metal after the solidification.

II. Literature Review

Centrifugal casting is considered as the most suitable manufacturing method to produce functionally graded materials commercially. Experimental studies by Manoj Singla et al. [3] reported that stir casting helps to obtain uniform dispersion of the silicon carbide particles in molten aluminium. D. Brabazon et al. [4] studied the effect of stirring and concluded that stirring at 200rpm gives uniform suspension of the particles in the melt. G. Chirita et al. [5] compared the mechanical properties of FGMs that were produced by centrifugal casting process and gravity casting method. The component casted by centrifugal casting showed increased rupture strength of about 35%. The Young modulus and fatigue life also showed an increase of about 18% and 1.5% respectively. The experiment conducted by X. Huang et al. [6] concluded that centrifugal casting can be used as an effective method to manufacture pistons. Al-Si based composite was fabricated with silicon carbide particles reinforced at the piston head. 800rpm was found as a reasonable parameter as the rotational speed of the mould. Madhusudhan et al. [7] determined the effects of pouring temperature and wall temperature and rotational speed of the mould in the solidification rate by conducting experiment. The casted component showed harder metal and fine grains at 800rpm compared to that at lower mould rotation speeds. The rate of solidification was found to be about 3^0C/s for mould rotation speed of 400rpm.

The property of wear behaviour in the application of brake discs is most vital. The friction and sliding wear behaviour of Al-Si alloy composites have been an area of interest for a number of researchers. Particle-reinforced metal matrix composites have been used in brake and piston components in automobile and aircraft's over the last decade owing to their attractive friction and wear properties [8]. A.K. Telang et al. in their review concluded the following [9]:

- The coefficient of friction of FGM is about 30% more than that of cast iron.

- Thermal conductivity of FGM tends to be about three times higher than that of cast iron.
- When compared to an equivalent cast iron component, the weight of FGM disc is found to be 60% lesser.
- Thermal diffusivity of FGM is observed to be four times higher than that of cast iron.

All these advantages make a functionally graded material the best alternative over cast iron for the application of brake rotor disc. The objective of this study is to model an Al-SiC brake disc and to simulate its vertical centrifugal casting process. The maximum concentration of SiC particles in the bulk is expected to fall near the area of contact of brake shoe and disc.

III. COMPUTATIONAL MODELLING AND SIMULATION

In this study, two works are carried out. The first work is the numerical simulation of an experimental study conducted by T.P.D. Rajan et al. [10]. The volume fraction of silicon carbide radially inward from the outer edge of the cylindrically cast component was observed in their study. An attempt is made to simulate this casting process and to obtain the same result using ANSYS Fluent software. Reproducing this experimental result could prove the accuracy of the software.

The second work is to simulate the vertical centrifugal casting process of Al-SiC FGM disc. The disc modelled in this study has a diameter of 222mm. The brake shoe size is assumed to be 40mm. The maximum SiC accumulation is expected to show up within the bulk between 71mm from the centre of the disc till the outer periphery to ensure improved mechanical properties.

A. Simulation of experimental study

T.P.D. Rajan et al. fabricated a functionally graded cylindrical casting by horizontal centrifugal casting technique. The cylinder manufactured by them was 380mm in length and 120mm in diameter with wall thickness being 16mm.

A two dimensional model of the cross section of this cylindrical casting is created in ANSYS Fluent. Grid convergence index (GCI) studies according to Ismail B. Celik [11] are carried out to obtain the effective meshing for the model. The GCI is found to be less than 5% as required. Orthogonal meshing with 143126 nodes and 143089 elements is created. The minimum orthogonal quality of the mesh is found to be 0.3714 and the element face size is 0.20mm.

Pressure based solver is used to carry out the simulation. Multiphase volume-of-fluid model is selected and solidification model is also selected with mushy zone parameter set as the default value of 100000. Aluminium (liquid) is set as the primary phase and silicon carbide (powder) is set as the secondary phase. The boundary condition for outer wall is given as a rotating wall with a speed of 115.19rad/s. For the calculation of energy, second order upwind scheme is used. 15% volume fraction of silicon carbide is patched in the entire area.

The simulation is carried out and the simulated result of volume fraction of silicon carbide along the radial distance is found to be in accordance with the experimental result. Fig.1 shows the experimental result and the simulated result with a small difference between the curves.

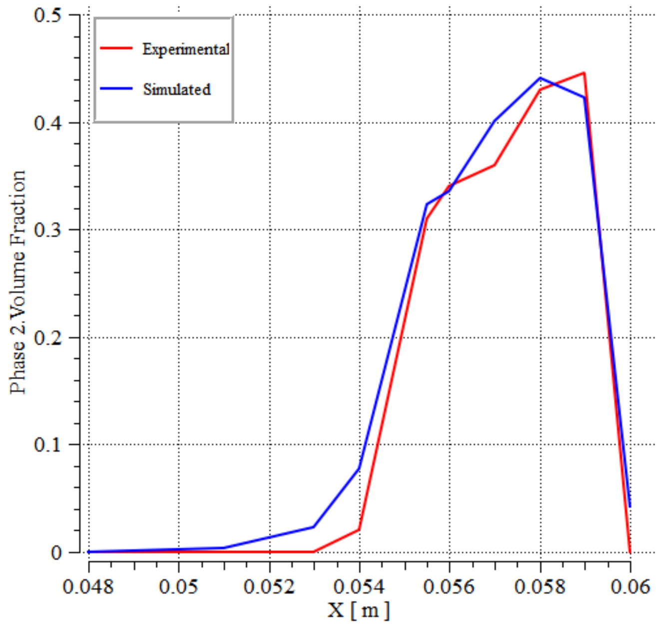

Fig. 1 A comparison of SiC volume fraction between experimental result and simulated result.

This difference reflects the error in the simulation result. Since we are not interested in the micro level change, this difference can be neglected. Thus the solidification and melting model of ANSYS Fluent proves to give satisfactory results.

B. Simulation of vertical centrifugal casting

The disc modelled for the simulation of vertical centrifugal casting has a radius of 111mm. The brake shoe is assumed to have a width of 40mm. So the area of contact of the shoe and the disc is between 71mm and 111mm from the disc's centre. This portion should accumulate maximum amount of silicon carbide particles inside the bulk to impart the required improved properties.

A two dimensional model of the disc is created in ANSYS Fluent. GCI is found to be less than 5%. Orthogonal meshing with 284404 nodes and 283730 elements is created. Minimum orthogonal quality of the mesh is found to be 0.3611 and the element face size is 0.42mm.

The basic properties of aluminium and silicon carbide are available in the fluent database. All other settings are similar to the previous simulation except for the mould rotation speed and SiC volume fraction. The mould rotation speed is set to 83.77rad/s and 10% volume fraction of silicon carbide is patched in the entire area.

The simulation is carried out and the SiC volume fraction curve is obtained as shown in Fig.2.

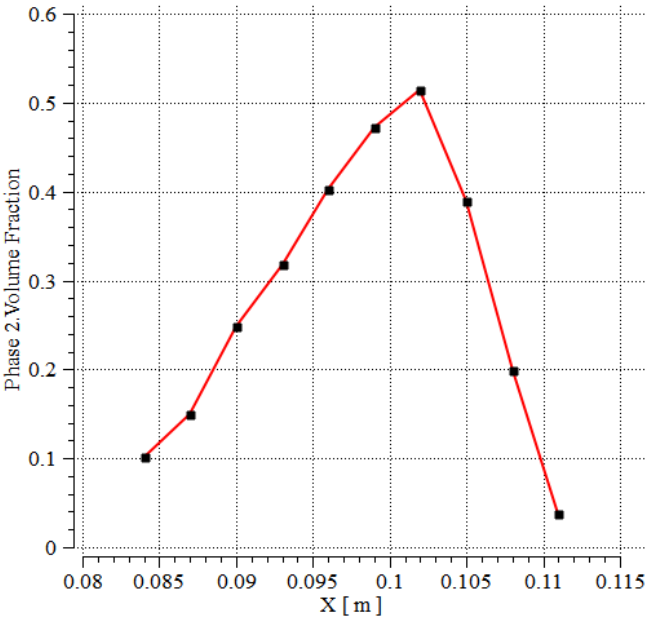

Fig. 2 The curve showing SiC volume fraction along the radius of the disc.

The maximum volume fraction of silicon carbide is 51.47% and is observed at 102mm from the centre of the disc. As evident from the figure, the maximum concentration of SiC particles is observed between 80mm from the centre to the outer periphery. This area of the disc experiences the maximum wear and tear during the braking process. The reinforcement of silicon carbide in aluminium matrix will provide the necessary strength at that region.

IV. Conclusions

Functionally graded materials are an emerging class of advanced composites that has numerous applications in many fields. These can be substituted instead of cast iron for the manufacture of brake rotor discs. Vertical centrifugal casting technique is considered as an effective method of producing FGM discs. The simulation of casting process helps to visualize the progress of solidification of the molten metal and to avoid the need of time consuming and costly experimental procedures. In this paper, the vertical centrifugal casting of Al-SiC FGM is carried out in ANSYS Fluent to obtain the volume fraction of silicon carbide along the radial distance of the disc. The maximum concentration of SiC particles in the bulk are observed around the area of contact of the disc and the brake shoe. The simulation carried out in this study uses a two dimensional model. An analysis of a three dimensional model with the effect of gravitational force could probably produce better results. Thus vertical centrifugal casting technique would prove to be an easy and economical way to produce FGM brake rotor discs.

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