ABSTRACT

In recent years, the demand for Functionally Gradient Materials (FGM) has been increasing for a number of engineering applications due to their useful properties. The FGM alloys are the new kind of composite materials having a progressive change in composition and microstructure across the cross section. This microstructure produces a wide variation in their properties. The FGM alloys are used for applications where the interesting properties like wear resistance, strength and toughness are of importance. Presently, the components of multilayered alloys consisting of wear resistant material in the outer and tough material in the core with gradient in properties can be produced by Powder Metallurgy routes and centrifugal processes. However these processes are having some limitations with respect to the processing capabilities and the geometrical complexity.

To overcome these problems, a novel Cast–Decant-Cast (CDC) process is being adapted. This process is very simple and industrially feasible for development of FGM castings consisting of multi-layered alloys with gradient chemical compositions. The basic principle of CDC process involves pouring the first alloy into a cylindrical mold, after the first has alloy solidified for a desired thickness against the mold walls decantation of un-solidified liquid and subsequently pouring the second alloy at a suitable superheated temperature into the same cylindrical mold, in such a way that the first alloy gets partially re-melted forming a functionally gradient material between the two layers. The CDC process has been developed recently from the conventional casting methods in combination with gravity die casting and low pressure die casting. In this research, an in-house CDC equipment was

designed and locally fabricated to produce FGM castings containing bi-metallic alloys or multi-layered alloys.

The present research work is reported in two parts: Part I deals with the results of FGM castings of Al-Si alloy with four different combinations of Si content using metal mold. The part II deals with the results of the FGM castings of Al-Si alloy at different Si content using sand mold. These four combinations of FGM castings were produced by CDC process in metal and sand mold separately. The compositions of these Al-Si alloy FGM castings are as follows: the FGM 1 is of Al-4.5 wt % Si (low Si) as the outer layer and pure Al as the inner layer. The FGM 2 casting is of Al-7.5 wt % Si (medium Si) as the outer layer and pure Al as the inner layer. The FGM 3 is of Al-12.5 wt %Si (high Si) as the outer layer and pure Al as the inner layer. For the FGM 4 casting, the outer layer (contained) is of Al-12.5 wt % Si and the inner layer is of Al-4.5 wt % Si. All the four FGM castings were characterized for studying the microstructure, mechanical and corrosion resistance by (i) optical microscopy, (ii) SEM with EDS, (iii) hardness testing, (iv) wear testing and (v) corrosion tests.

The micrographs of the outer layer in FGM 1, FGM 2, FGM 3 and FGM 4 castings showed fine equiaxed grains with a uniform distribution of Si particles in the α-Al eutectic matrix. The FG layer of these castings shows a uniform metallic bonding free from porosity, delamination of foreign particles in the surface of the FG layer. The gradient of Si particles in all the four FGM castings was clearly observed by EDS analysis. The average size of Si particles observed in FG layer of all the four FGM castings was about 12 to 20 µm in diameter. The hardness values of the four FGM castings produced by CDC process in metal mold and sand mold showed significant variations in the outer layer, the FG layer and the inner layer. The hardness of FG layer gradually decreased with distance from the interface of the outer layer towards the inner layer. However, the hardness of the outer layer and inner layer in all the FGM castings was uniform throughout the cross section.

The results of wear test of the FGM castings at the outer layer, FG layer and inner layer showed that the wear resistance of outer layer markedly high compared to the inner layer, whereas it was almost equal in the FG layer under the same conditions in the pin-on-disc machine. In fact, at higher sliding distance, the wear resistance of the FG layer was found to be better than the outer layer in the FGM castings. This result is due to the presence of uniform distribution of Si particles in the FG layer. Out of these four combinations of FGM castings, FGM 4 casting showed improved wear resistance as compared to other FGM 1, FGM 2, and FGM 3 castings. The SEM micrographs of worn surfaces in the outer layer, FG layer and inner layer exhibited a combination of adhesive and abrasive wear in all the four FGM castings produced by the CDC process in metal and sand molds. The depth of scoring is higher in the inner layer as compared to the outer layer and FG layers in all the FGM castings.

From the corrosion results of all the FGM castings, it was found that the corrosion rate of the inner layer (with respect to Si content) was much lower as compared to the outer layer and the FG layer of the same FGM castings. The results indicated that the corrosion resistance of the FGM castings decreased with increase in Si content. The corrosion rate of the FG layer in all the four FGM castings was relatively lower than that of the outer layer while almost equal to that of inner layer. This improved corrosion resistance of the FG layer in FGM castings can be attributed to the presence of the modified morphology of the Si particles.

The overall summary of the present research work is as follows: The CDC equipment was designed and successfully fabricated locally for the present research work. The FGM castings of pure Al and Al-Si alloys with different combinations of Si content were successfully produced. The results showed that the thickness of FG layer in FGM castings prepared by CDC process can be easily controlled by adjusting the decantation time in the CDC process. A maximum thickness of the FG layer in FGM castings plays a significant role in enhancement of the mechanical properties and the corrosion resistance of the castings. The FGM castings with combinations low Si and high Si Al-Si alloys showed better wear resistance and corrosion resistance as compared to FGM castings using combinations of pure Al and Al-Si alloys.