International Journal of Engineering Applied Sciences and Technology, 2021
Vol. 6, Issue 5, ISSN No. 2455-2143, Pages 226-230
Published Online September 2021 in IJEAST (http://www.ijeast.com)

INVESTIGATION ON PREPARATION, CHARACTERIZATION AND PROPERTY EVALUATION OF FGM AL-SI ALLOY CASTINGS PRODUCED BY CAST-DECANT-CAST (CDC) PROCESS

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Abstract— Aim of this research paper is to study the microstructural behavior and mechanical properties of Functionally Gradient (FG) layer of Al-Si alloy castings produced by CDC process. The effect of decantation time on the thickness of functionally gradient castings of Al-4.5 wt % Si alloy as an inner layer and Al-Si alloy with 12.5 wt %Si as outer layers was studied by CDC process. The three different combinations of FGM castings were characterized for microstructural and wear behavior using metallurgical characterization and mechanical testing. From the microstructural and wear behavior of FGM casting at outer layer, FG layer and inner layer, it is observed that the FG layer of FGM casting showed very wear resistance compared to other two layers in the FGM casting.

*Keywords— **FGM casting, CDC process, characterization***

I. INTRODUCTION

Functionally graded materials (FGMs) are a new generation of engineered materials whose compositions are designed to change continuously within the solid. The graded transition in composition across an interface of two materials (for instance, metal and ceramics or polymer) can essentially reduce the thermal stresses and stress concentration at intersection with free surfaces [1]. In fact, the interface bonding is much improved by providing smooth composition variation when traversing the interface. FGMs are potential materials for applications involving severe thermal gradients varying from thermal structures in advanced air craft and aerospace engines to computer circuit boards [2].

Among FGMs, Al based FGMs have been reported to possess high wear resistance and lower friction with increasing the volume fraction of the hard particles. Compared to ceramic reinforcements, aluminides in Al based FGMs as wear resistant reinforcement has some advantages [3]. There are various processing methods available for fabricating functionally graded composite material. These methods include centrifugal method, Powder metallurgy, Diffusion bonding, CVD, CVI, PVD, Spray deposition, Laser deposition, Directional solidification, Infiltration, Settling, Sol-gel method, Electro Deposition and Electro less plating. Each process has its own advantages and disadvantages [4-8]. The CDC process has been adapted to a number of conventional casting methods, including several gravity and low pressure casting technologies. The low pressure technique for the CDC process is based on an extension of low pressure permanent mold casting, which allows FGM casting in a closed mold by means of closed mold by means of counter-gravity filling to avoid melt turbulence [9]. Though FGM's have superior properties, it is having difficult in production by conventional fabrication techniques such as centrifugal casting, powder metallurgy and it is due to controlling the concentration of elements in the component. In contrast to this problem, the cast decant-cast (CDC) process provides an alternative method to produce FGM's with lowest cost and superior properties. The main aim of the work is to produce functionally graded Si particles across the interface between high Si alloy (Al-12.5 wt Si alloy) and low Si alloy (Al-4.5wt % Si alloy) by CDC method. The process is carried out to FGM casting with different decantation time. The FGM samples are characterized for microstructural behavior and wear behavior using optical microscopy, SEM and Mechanical tests.

II. EXPERIMENTAL WORK

Master alloy of Al-Si alloys with 4.5 wt % Si and 12.5 wt % Si were used for preparation of FGM casting by CDC process. These master alloys were melted at 750ºC in an electrical resistance melting furnace and poured into a metallic mould having decantation facility in CDC process. Then the liquid metal was held for a few seconds in the mould until to obtain a required thickness and un-solidified metal was decanted. The effect of decantation time on a desired wall thickness of the first layer was optimized by trial and error method. After optimizing the required thickness of the FG layer, the liquid metal of core alloy (Al-4.5wt % Si) was poured into the cup of outer layer alloy in the mould and allowed the liquid metal solidify. Then the solidified casting was prepared for microstructural analysis and mechanical tests.

III. Results and Discussion

Decantation time on thickness of FG layer in FGM castings

Liquid metal of outer alloy (Al-12.5 wt % Si) was poured into a metal mold. Then the liquid metal was allowed to solidify for different time intervals ranging from 5 seconds to 20 seconds by increment of 5 seconds. Based on the decantation times, the thickness of outer alloy obtained for the FGM castings is shown in Table 1. The photographs of outer layer FGM castings for corresponding decantation time are shown in Figure 1.

Table 1.1 Thickness of outer layer and FG layer in FGM castings in metal mold

Type of mould	Decantation time (in seconds)	Thickness of outer layer (in mm)	Thickness of FG layer (in µm)
metal mould	5	3.0	12
	10	6.0	27
	15	12.0	45
	20	16.0	67
	25	Fully solidified	-

It is observed that the thickness of the outer layer increases with increasing decantation time as is evident from the photographs of the FGM castings (Figure 1). The liquid metal solidified completely after 20 seconds of decantation time leaving no cavity for filling up the second alloy in this casting. Hence, it is noted that the decantation time cannot be maintained beyond this time interval according to the present CDC casting set-up

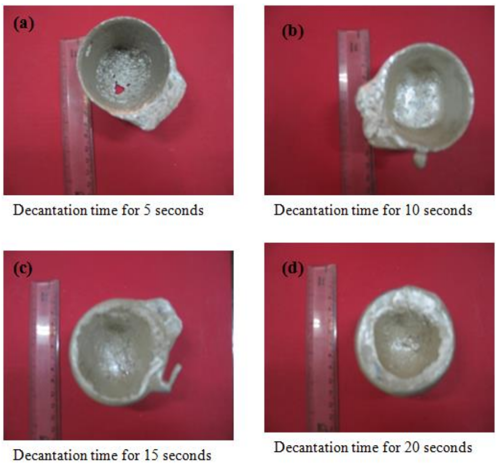


Figure 1: Effect of decantation time on thickness of outer layer of FGM castings

From this study, the sample of 12 mm wall thickness for decantation time of 15 seconds was used for producing FGM casting because it showed adequate thickness to withstand the liquid metal of second alloy in the subsequent process. The internal cavity formed around the outer layer of this alloy casting was filled with pure Al to have a gradient of Si content across the outer layer to the core. The thickness of functionally gradient layer this casting was measured by optical microscope at lower magnifications. It is observed that the FGM layer was found to be about 60 mµ in thickness across the surface the casting. The FGM casting produced by CDC process was characterized for microstructural investigation and wear behavior evaluation.

3.2 Microstructural Investigation

3.2.1 Optical microscopy

Figure2 represents the optical micrographs of (a) outer layer, (b) FG layer and (c) inner layer in FGM casting. The outer layer of FGM casting reveals unmodified Si particles in the matrix of Al eutectic. The Si particles are found to be more uniform distribution and acicular in shape, as similar to microstructure of Al alloy produced by high pressure die casting process. In general, hypoeutectic Al-Si alloy (Al-4.5 wt % Si alloy) has shown Si particles in acicular shape Si particles in the eutectic α-Al matrix resulting low hardness [10]. This result is clearly evidenced from the optical microstructure of outer layer of FGM 1 casting (Figure 2.1a).

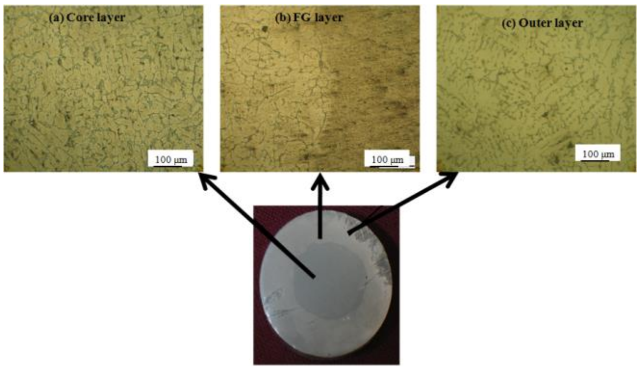
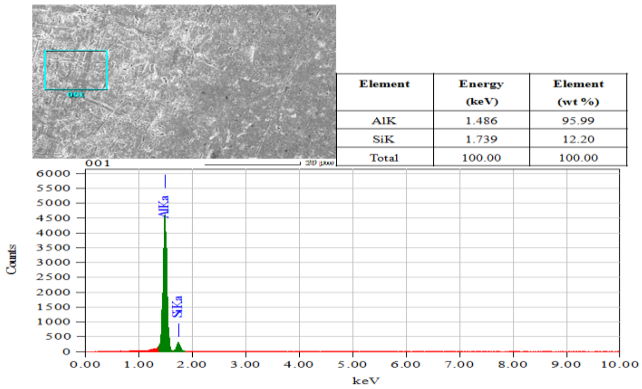
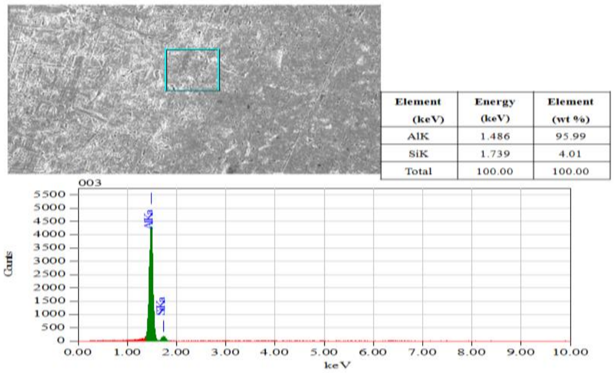


Figure 2.1 Optical microstructures of (a) outer region, (b) FG layer and (c) inner layer FGM 1 casting.

3.2.2 SEM analysis with EDS

The EDS analysis was carried out on the FGM casting at different location to measure the variations of Si content. The outer layer and the inner layer of the FGM casting were made with known composition and it was further confirmed by EDS analysis as shown in Figure 2 and Figure 3, Figure 4 and Figure 5.





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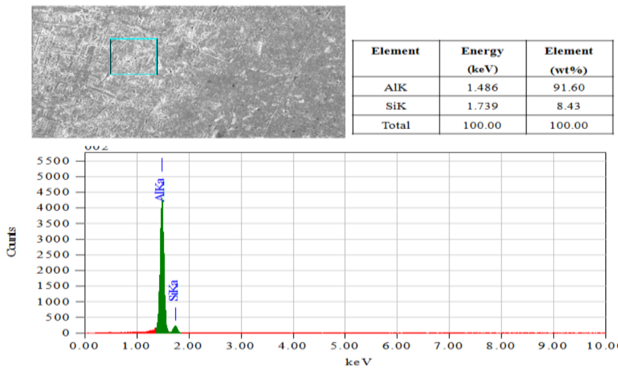
However, the composition of the FG layer formed at the interface between outer and inner layers is unknown. Amount of Si content present in the FG layer of FGM casting is measured using EDS analysis and its result is shown in Fig.3



As is seen from Figure 3.2, the Si content is found to be about 8.3 wt %. This result indicates that the concentration of Si content decreases with distance from the interface of the outer layer. It can also be understood that the CDC process is a most viably efficient process to produce FGM castings as compared to other manufacturing processes such as centrifugal casting and P/M routes. The size and distribution of Si particles present in the FG layer of FGM casting. The size and distribution of Si particles present in the FG layer of FGM casting was evaluated by SEM analysis and its micrographs of FG layer of these castings are shown in Figure.

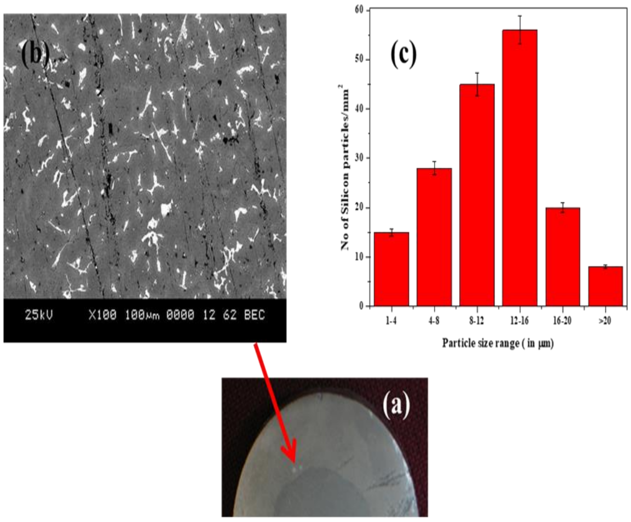


Figure 6: (a) FGM casting, (b) SEM micrograph of FG layer and (c) distribution of Si particles in the FG layer.

The SEM micrographs also revealed the shape of Si particles obtained in the FG layer of all the four FGM castings. The Si particles with fibrous and irregular shapes were seen in FGM 1 casting (Figure 6), whereas almost the irregular or needle like shape of Si particles was observed in outer layer of FGM casting. It is clear that as weight percentage of Si content increases the morphology of Si particles in Al matrix is altered from fibrous shape to needle like or irregular shapes. The SEM results are in good agreement with the findings of various researchers [12], who reported the change in morphology of Si particles with increasing Si content. The irregular shape of unmodified Si particles confirms to be independent from the solidification rate [13].

3.2.3 Wear tests

Wear behaviour of FGM casting at three locations like core layer, FG layer and outer layer studied by pin-on-disc test method. The wear characteristics such as wear volume and wear rate were studied as a function of sliding distance from 5 km to 25 km and the wear test results for the FGM samples are shown in Table 4.1. Since the amount of Si particles in the outer layer of FGM casting is higher, the wear volume and wear rate were found to be lower compared with inner layer of FGM casting. The wear volume and wear rate of FG layer in FGM casting is observed very close to that of outer layer of FGM casting, the wear volume and wear of these three layers are shown in Figure 7.

Table 4.1: The results of pin-on disc abrasive wear test for FGM 1 casting

Region of CDC alloy	Sliding distance (km)	Mass loss (g)	Wear volume (mm^3)	Wear rate (mm^3/m x10^{-7})
Outer region	5	0.0031	0.005	4.52
	10	0.0120	0.004	4.82
	15	0.0210	0.008	6.25
	20	0.0380	0.014	7.72
	25	0.0621	0.023	9.40
FGM region	5	0.0030	0.001	3.41
	10	0.0128	0.004	4.93
	15	0.0218	0.008	7.14
	20	0.0424	0.015	8.10
	25	0.0519	0.019	8.20
Core region	5	0.0041	0.001	24.12
	10	0.079	0.029	28.53
	15	0.142	0.052	34.52
	20	0.209	0.077	39.52
	25	0.269	0.101	40.10

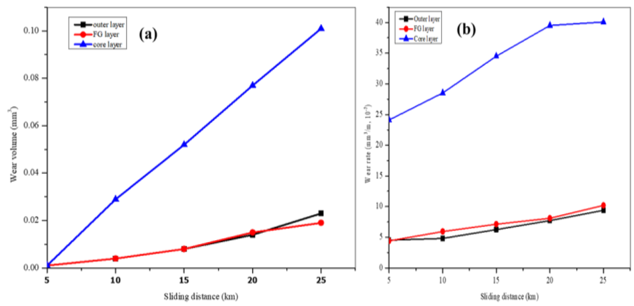


Figure 7: Wear behaviour of FGM casting: (a) Sliding distance versus wear volume and (b) sliding distance versus wear rate

3.2.4 SEM analysis for worn out surfaces

Figure 8 shows the SEM images of wear samples of FGM casting at outer layer, FG layer and inner layer in sliding of 25 km.

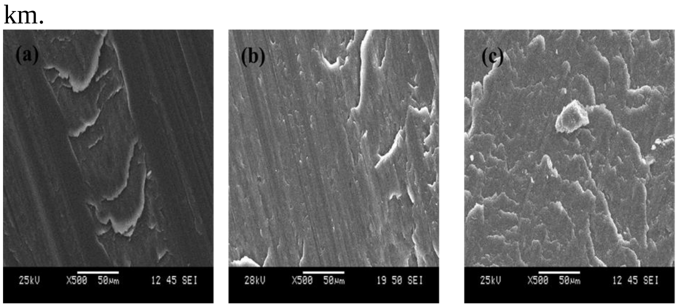


Figure 8: SEM micrographs of worn-out surfaces of FGM samples (a) outer layer, (b) FG layer and (c) inner layer at sliding distance of 25 km

From the SEM images of wear test samples for FGM casting at outer layer, FG layer and inner layer, it is found a clear cohesive and decohesive boding in the worn out surfaces of wear samples. The cohesive wear is associated with adhesion wear phenomena and decohesive wear is associated with abrasive wear phenomena [13]. Many past research work reported that the crack propagation was considered to be the important wear rate controlling factor. The cracks were primarily initiated at the interface of particles and matrix or by fracture of the particles. For crack nucleation at interface between particles and matrix, the following conditions have to be satisfied [14]

(i) Tensile stress across the interface should exceed the interfacial bond strength

(ii) Elastic strain energy released upon de-cohesion of the interface should be sufficient to account for the interface energy of the crack created.

Argon (ref) suggested that for Si particles to be a important factor in the formation of a void or micro-cracks, the particles diameter should be in excesses of 2.5 µm in order to satisfy the energy condition. For good wear resistance, large volume fractions of very small coherent Si particles are desired for Al-Si alloys [15].

IV. CONCLUSION

- Using CDC process, FG layer was successfully produced with required thickness in the FGM casting of 12 wt % Si in the outer layer and 4.5 wt % Si in the inner layer.
- The FG layer is clearly distinguished at the interfaces between outer layer and inner layer in the FGM casting. It was also noticed that the interface of FG layer is having very good metallurgical bonding.
- SEM micrograph showed a gradual transition of Si content from outer layer to inner layer in the FGM casting.
- The wear behavior of FG layer in the FGM casting was found to be as good as that of outer layer. This confirms that FGM casting of Al-Si alloy with different concentration of Si content produced by CDC process is capable of having very good wear resistance.

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