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Research paper

A study to evaluate the Effect of Carburization on LM13 Aluminium alloy –Quartz Composites

Anupama A. Hiremath*

Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal-576104, India
**Email: anupama.hiremath@manipal.edu*

Abstract

Aluminum metal matrix composites have emerged as a new-class of lightweight, high-strength materials that are employed extensively in the automobile industries. Under such operating conditions, the material is constantly exposed to severe carbonaceous environment. The current paper investigates the effect of carburization on the chilled aluminium alloy reinforced with quartz particles. The composite is cast with the aid of mild steel, copper (metallic chills), silicon carbide and graphite (non-metallic) end chills by varying the weight percent quartz reinforcement. The variation in weight percent of reinforcement ranges from 5 to 15 percent with 5 percent increment in every iteration. Stir casting method of fabrication is employed to ensure even distribution of reinforcement within the matrix. The specimens are drawn from near chill end to evaluate the effect of chills on the soundness of the casting. The specimens are subjected to pack carburization for 60, 90 and 120 hours.

Keywords: Aluminium matrix composites, AlSi alloys, carburization, chills, quartz, stir casting

1. Introduction

Advancements in the field of metallurgy and materials have enabled researchers and metallurgists around the world to incorporate a wide-variety of reinforcements, both natural and synthetic into the base metal/alloy to come up with a new class of lightweight, high strength materials that have driven the technological advancements in the field of automobile and avionics. Amongst the various lightweight metals available, aluminium has garnered a lot of attention [1] owing to its easy availability and tailorable properties. A lot of research suggest the positive impact of adding single or multiple particulates as reinforcement to aluminium metal/alloy matrix that render the composite with excellent mechanical, thermal, electrical and tribological properties [2].

Due to wide spread application of aluminium matrix composites the focus now is onto bring down the cost of production of such materials through the incorporation of low-cost, easily available reinforcements along with an economical fabrication process suitable for mass production. This has prompted researchers to incorporate various industrial wastes as reinforcement and fabricate the composites through liquid processing methods such as stir casting [3].

Casting aluminium and its alloys pose challenges as aluminium tends to solidify over a broad range of temperature giving rise to smooth feeding of the melt [4]. This results in defective castings with pronounced porosity. This difficulty can be countered through employment of chills that help in rapid extraction of heat from the melt allowing directional solidification to set in [5]. In the present investigation measures have been taken to produce sound castings by the inclusion of suitable end chills made of metallic and non-metallic materials while the reinforcements are dispersed uniformly through stirring.

2. Materials

2.1. Matrix Material

Aluminium-silicon (AlSi) alloys have gained much importance as casting alloys with features such as unmatched castability yielding sound castings at a very economical price. These feature have rendered AlSi alloys the most preferred casting alloys in the field of automobiles [6]. LM13 is one such AlSi alloy that has excellent machinability owing to the presence of brittle silicon [7], good resistance to corrosion [8] and thermal stability. In the present work, LM13 is selected as matrix material. The composition of LM13 alloy is given in Table I.

Table1: Elemental composition of LM13

Elements	Weight Percent (Approx.)
Silicon	11.00
Nickel	1.50
Magnesium	1.0
Copper	1.0
Iron	0.8
Manganese	0.5
Aluminium	Balance

2.2. Quartz Reinforcement

Quartz which is pure or fused silica is a hard mineral that remains stable under varied conditions of temperature, pressure etc. and is available abundantly in the earth's crust [9]. Hence, quartz imparts required strength and hardness to the soft, ductile metals/alloys. Quartz reinforced metal matrix composites exhibit

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good resistance to corrosion and are chemically inert [10]. In this work quartz particles of 100 µm are incorporated as reinforcements. The mechanical properties of quartz are listed in Table II.

Table2: Mechanical properties of quartz

Mechanical properties	Values
Density	2.2 g/cm^3
Microhardness	8600-9800 N/mm^2
Tensile strength	50 N/mm^2 (Approx.)
Compressive strength	1150 N/mm^2 (Approx.)
Bending strength	67 N/mm^2 (Approx.)
Poisson's ratio	0.17
Torsional strength	30 N/mm^2 (Approx.)

2.3. External End Chills

End chills are specific objects that are employed in casting for abstraction of heat from the molten melt at a faster rate, thereby allowing directional solidification of the melt within the mould cavity. Thus, employment of chills that are strategically placed within the mould cavity ensures the production of defect-free castings [11]. Copper and mild steel metallic end chills along with silicon carbide and graphite non-metallic chills are employed in the current research work. The selected chills are strategically placed within the mould cavity as illustrated in Fig.1.

Fig 1: End chill placement in the mould.

3. Methods

3.1. Casting

LM13 alloy ingots are melted in an electric furnace at a temperature of 750°C. Preheating of quartz reinforcement is carried out at a temperature of 350°C to ensure the absence of moisture and volatile matters. The reinforcement based on the required weight percentage is then poured into the molten LM13 alloy. The melt is then stirred thoroughly with the help of a motor-driven stirrer rotating at 500rpm for 600 seconds. Fig.2 depicts the stir casting setup employed for the present research work. The melt with dispersed reinforcement is then allowed to fill the sand mould cavity pre-inserted with end chills. Fig.3 illustrates the solidified castings within the mould cavity consisting of end chills placed within the mould cavity.

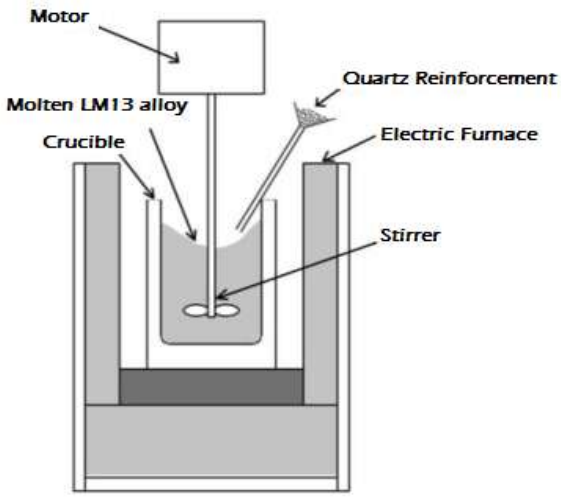


Fig 2: Stir casting setup.

Fig 3: Placement of end chills in the mould.

3.2. Carburization

Rectangular Specimens are obtained from the chill end of the casting and are subjected to pack carburization. The specimens are sandwiched between the layers of high carbon content coke powder inside a graphite crucible. The crucible is then closed with the help of clayey sand. The air-tight crucible is charged into an electric furnace. The specimens are held at 500°C for 60, 90 and 120 hours. Fig.4 illustrates the carburizing crucible with specimens immersed in coke powder. Fig.5 depicts specimens before and after carburization.

Fig 4: Specimens in coke powder.

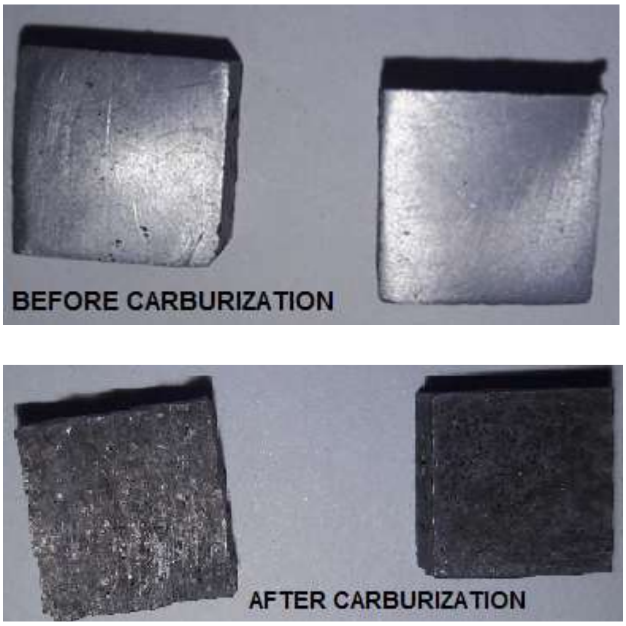


Fig5: Specimens before and after carburization.

4. Results

4.1. Carbon Deposition

The effect of carburization is done through weight analysis. The amount of weight gained or lost by the carburized specimens indicate the deposition of carbon in and over the material due to carburization. Fig.6, Fig.7 and Fig.8 depict the weight of carburized specimen (rounded off to the nearest whole number) before and after carburization carried out for 60, 90 and 120 hours respectively.

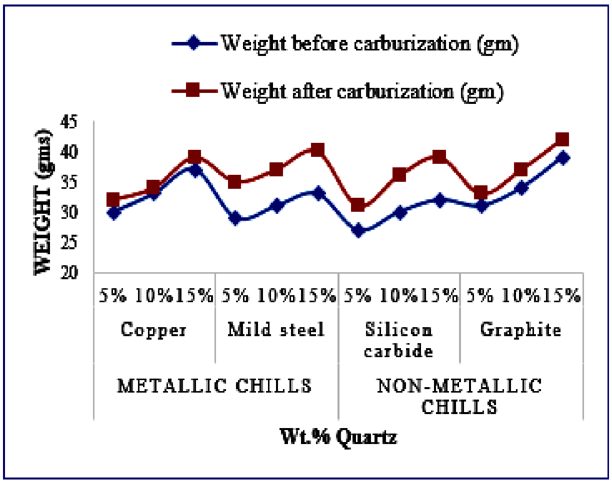


Fig6: Specimen weight before and after carburization carried out for 60 hours.

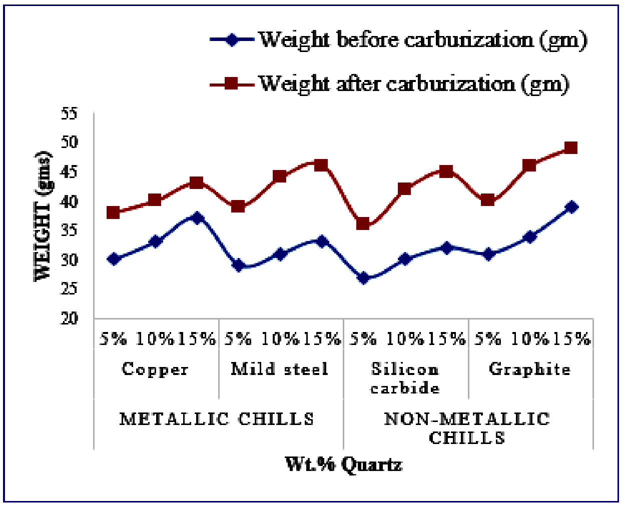


Fig7: Specimen weight before and after carburization carried out for 90 hours.

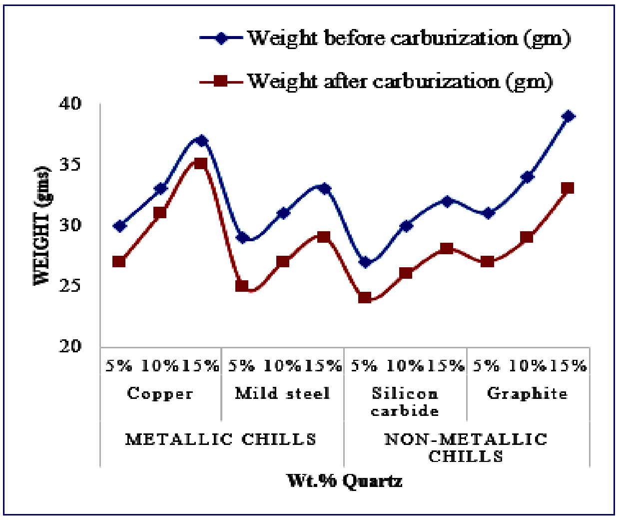
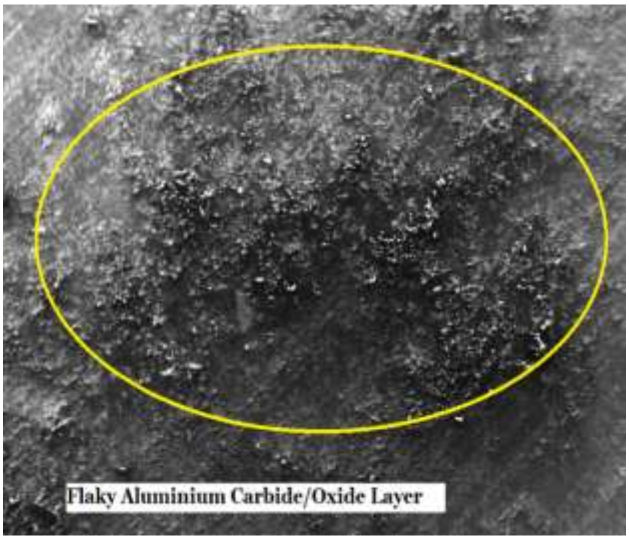


Fig8: Specimen weight before and after carburization carried out for 120 hours.

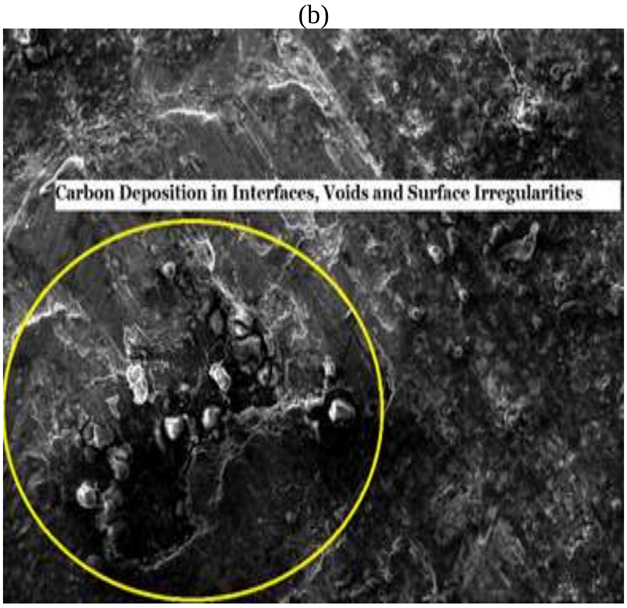
4.2.SEM Analysis

SEM analysis is carried out to investigate the carbon activity at/near the material surface after carburization. Fig.9 illustrates the SEM images obtained for the cast LM13-quartz composites after carburization.

(a)



(b)

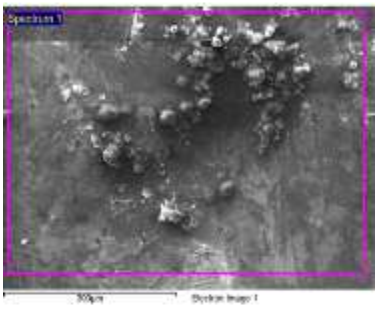


(c)

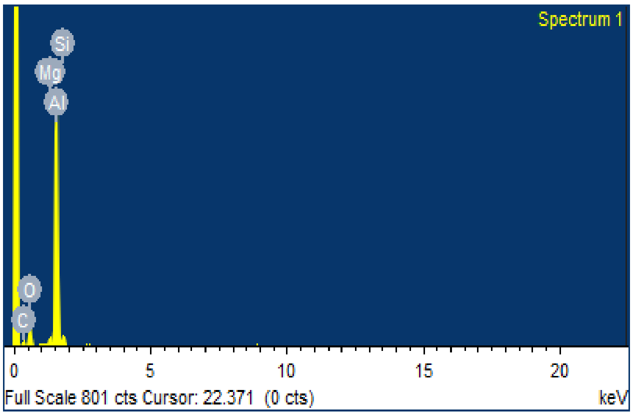
Fig9: (a),(b) and (c): SEM images illustrating carbon deposition.

4.3.EDX Analysis

EDX analysis is carried out to confirm the formation of aluminium oxide layer over the cast surface after carburization. EDX analysis also throws the light on the relationship of the quantity of the oxide layer formation with the duration of carburization. Fig.10 and Fig.11 depicts the EDX for cast specimens carburized for 60 and 90 hours respectively.

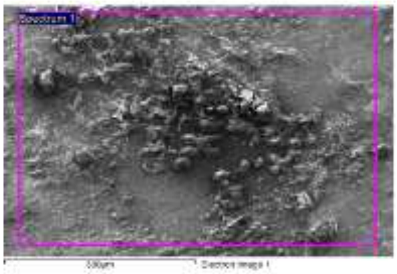


(a)



(b)

Fig10: EDX for specimen carburized for 60 hours; (a) SEM of the oxide layer; (b) EDX.



(a)

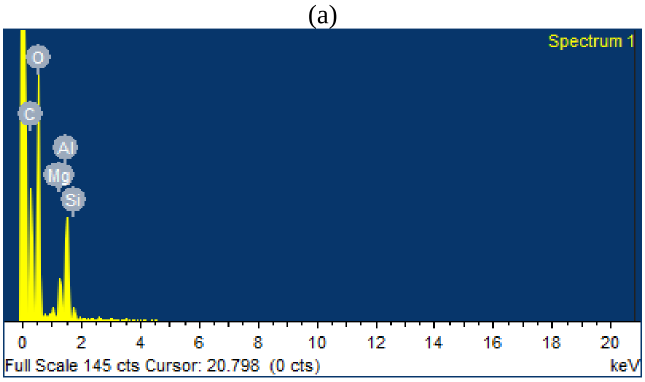


Fig11: EDX for specimen carburized for 90 hours; (a) SEM of the oxide layer; (b) EDX

5. Discussions

Aluminium and its alloy tend to be non-reactive to carburization as they have a tendency to react with carbon and form a superficial layer of either aluminium carbide or aluminium oxide. These hard and brittle layers of carbide and oxide prevent further entry of carbon within the material thus immunizing the material from the effects of carburization. However, at extreme operating conditions where the activities of carbon at/near the material surface is highly pronounced, then under such situations carbon tend to penetrate the carbide or oxide layers and get embedded within the microstructure of the material.

Analysis of the obtained result indicate that there is weight gain for specimens after carburization carried out for 60 and 90 hours respectively. This gain in weight is mainly due to the localized deposition of carbon in-between the intricate interfacial regions present between the matrix and the reinforcing particle. The carbon deposition also happens in the voids and surface irregularities present in the cast material as depicted in Fig.9. But, further extension of carburizing time beyond 90 hours to 120 hours result in the weight loss for carburized specimen as shown in Fig. 8. This is due to the fact that the aluminium carbide/oxide

layer formed is flaky and brittle in nature. Prolonged heating time results in the disintegration of any such layers formed on the surface resulting in loss of material from the cast specimens.
Fig.10 and Fig.11 indicates the EDX analysis which confirms the presence of carbon and aluminium oxide layer after carburization on the cast specimens. The EDX analysis clearly tells that the formation of aluminium oxide layer is directly dependent on the length of carburizing duration. The aluminium oxide layer formed is more in quantity for specimen carburized for 90 hours (Fig.11) as compared to the specimen carburized for 60 hours (Fig.10).
Further analysis of the obtained result indicate that the selected chill material also bears a relationship with the weight gain/loss associated with the carburized specimen. Carburized specimens cast with the help of metallic end chills result in lesser weigh gain/loss after carburization as opposed to those cast with the aid of non-metallic end chills. This is mainly due to the fact that metallic chills possess higher volumetric heat capacities that aid in quicker heat abstraction from the melt during solidification. This ensures denser castings with less defects. Hence, metallic chills are preferred over non-metallic chills for obtaining good quality castings.

6. Conclusions

The following conclusions can be drawn from the foregone discussions:

- Carburization of LM13-quartz composite leads to the formation of brittle aluminium oxide layer over the surface which prevents the seepage of carbon atoms into the microstructure of the composite material.
- However, in extreme carbonaceous environments, the carbon tends to seep into the material and tends to get deposited in the interfacial regions, voids and other surface irregularities.
- The formation of brittle oxide layer as well as the surface deposition of the carbon leads to increase in weight of the carburized specimens.
- The weight gain due to carburization is directly proportional to the carburizing time up to 90 hours. The specimens carburized for 120 hours depicted a loss of weight.
- The loss of weight of carburized specimen subjected to carburization for 120 hours is mainly due to the disintegration of oxide layer resulting in the loss of aluminium from the composites.
- The employment of metallic end chills help in obtaining denser, good quality specimens that are immune to the severe effects of carburization.

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