Chapter 13

Effect of Alloying Element on the Integrity and Functionality of Aluminium-Based Alloy

Ojo Sunday Isaac Fayomi,
Abimbola Patricia Idowu Popoola and
Nduka Ekene Udoye

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71399

Abstract

Aluminum alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base metal. Alloying elements are selected based on their individual properties as they impact on the structure and performance characteristics. The choice of this modifier affects the materials integrity in service resulting to improved corrosion, tribological and mechanical behavior. Hence, the need to understand typically the exact inoculants that could relatively impact on the low strength, unstable mechanical properties is envisage with the help of liquid stir casting technique. In this contribution, sufficient knowledge on Al alloy produced by stir casting will be reviewed with close attention on how the structural properties impact on the mechanical performance.

Keywords: aluminum alloy, alloying element, liquid stir casting technique, reinforcement

1. Introduction

The chemical composition consisting of an aluminum alloy is added to pure aluminum in order to improve its properties for the primary purpose of increasing the strength. The other elements such as iron, magnesium, manganese, zinc and silicon is added to build up 15% alloy by weight. If the aluminum is in molten form, the other elements is mixed with aluminum to produce the required alloy. [1]. Pure aluminum is not usually used for structural applications and that in order to produce aluminum that is of adequate strength for the manufacture of structural components, it is necessary to add other elements to the aluminum [1, 2]. The strength characteristic of aluminum (1xxx series) makes it a useful product for structural fabrication. The pure aluminum contains levels of impurities such as iron and silicon that enables it to respond to strain hardening even though 1xxx series is the same as pure aluminum [3]. To compare these alloys with other series aluminum alloys we observe it have a very low strength. The major properties considered when chosen these alloys for structural application is their superior corrosion resistance and their high electrical conductivity [4, 5].

The principal method of producing a selection of different materials that can be used in different structural application is the mixture of alloying elements with the aluminum itself. One can deduce that the different alloy element used to produce each of the alloy series from the seven selected aluminum alloy series. We studied the effects of these elements on aluminum [6]. **Table 1** shows the test result of different mechanical properties of alloys.

Alloy	**Temper**	**Proof stress 0.20% (MPa)**	**Tensile strength (MPa)**	**Shear strength (MPa)**	**Elongation A5 (%)**	**Elongation A50 (%)**	**Hardness Brinell HB**	**Hardness Vickers HV**	**Fatigue endurance limit (MPa)**
	H2	85	100	60	12		30	30	
AA1050A	H4	105	115	70	10	9	35	36	70
	H6	120	130	80	7		39		
	H8	140	150	85	6	5	43	44	100
	H9	170	180			3	48	51	
	0	35	80	50	42	38	21	20	50
	T3	290	365	220	15	15	95	100	250
	T4	270	350	210	18	18	90	95	250
AA2011	T6	300	395	235	12	12	110	115	250
	T8	315	420	250	13	12	115	120	250
	H2	115	135	80	11	11	40	40	
	H4	140	155	90	9	9	45	46	130
	H6	160	175	100	8	6	50	50	
	H8	180	200	110	6	6	55	55	150
	H9	210	240	125	4	3	65	70	
	0	45	105	70	29	25	29	29	100
	H2	240	330	185	17	16	90	95	280
	H4	275	360	200	16	14	100	105	280
AA3103	H6	305	380	210	10	9	105	110	
	H8	335	400	220	9	8	110	115	
	H9	370	420	230	5	5	115	120	
	0	145	300	175	23	22	70	75	250
	H2	165	210	125	14	14	60	65	
	H4	190	230	135	13	12	65	70	230
AA5083	H6	215	255	145	9	8	70	75	
	H8	240	280	155	8	7	80	80	250

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Alloy	Temper	Proof stress 0.20% (MPa)	Tensile strength (MPa)	Shear strength (MPa)	Elongation A5 (%)	Elongation A50 (%)	Hardness Brinell HB	Hardness Vickers HV	Fatigue endurance limit (MPa)
	H9	270	310	165	5	4	90	90	
	0	80	180	115	26	25	45	46	200
	H2	185	245	150	15	14	70	75	
	H4	215	270	160	14	12	75	80	250
AA6063	H6	245	290	170	10	9	80	85	
	H8	270	315	180	9	8	90	90	280
	H9	300	340	190	5	4	95	100	
	0	100	215	140	25	24	55	55	220
	0	50	100	70	27	26	25	85	110
	T1	90	150	95	26	24	45	45	150
	T4	90	160	110	21	21	50	50	150
	T5	175	215	135	14	13	60	65	150
AA5251	T6	210	245	150	14	12	75	80	150
	T8	240	260	155		9	80	85	
	0	60	130	85	27	26	35	35	120
	T1	170	260	155	24	24	70	75	200
AA6082	T4	170	260	170	19	19	70	75	200
	T5	275	325	195	11	11	90	95	210
	T6	310	340	210	11	11	95	100	210
	T6	240	290		8				
AA6262	T9	330	360		3				
	0	105	225	150		17	60	65	230
AA7075	T6	505	570	350	10	10	150	160	300
	T7	435	505	305	13	12	140	150	300

Table 1. Mechanical properties of different aluminum alloys [7].

1.1. Principal effects of alloying elements in aluminum

1.1.1. Unalloyed aluminium 1xxx series

This alloy consists of 99% of aluminum in high purity.

Properties of aluminum 1xxx series

- Perfect corrosion resistance.
- Effective workability.
- High thermal and electrical conductivity.

Uses of Aluminum 1xxx series

- Transmission of electricity or power grid.
- To connect natural grid across the country [8, 9].

1350 alloy designation is for electrical applications while 1100 alloy designation is for food packaging trays. The most common applications for the 1xxx series alloys are aluminum foil, electrical buss bars, metallizing wire and chemical tanks and piping systems [10].

1.1.2. Copper (Cu) 2xxx

The alloy of aluminum and copper consist of 2–10% of copper with other traces of elements. **Figures 1–3** are the SEM micrograph of the different quantity of Fe 0.53 in Cu sample.

Uses of copper

- It provides strength and facilitates precipitation hardening.
- It reduces ductility and corrosion resistance.
- It contains highest strength heat treatable aluminum alloys.
- It is applied in aerospace, military vehicles and rocket fins [11, 13].

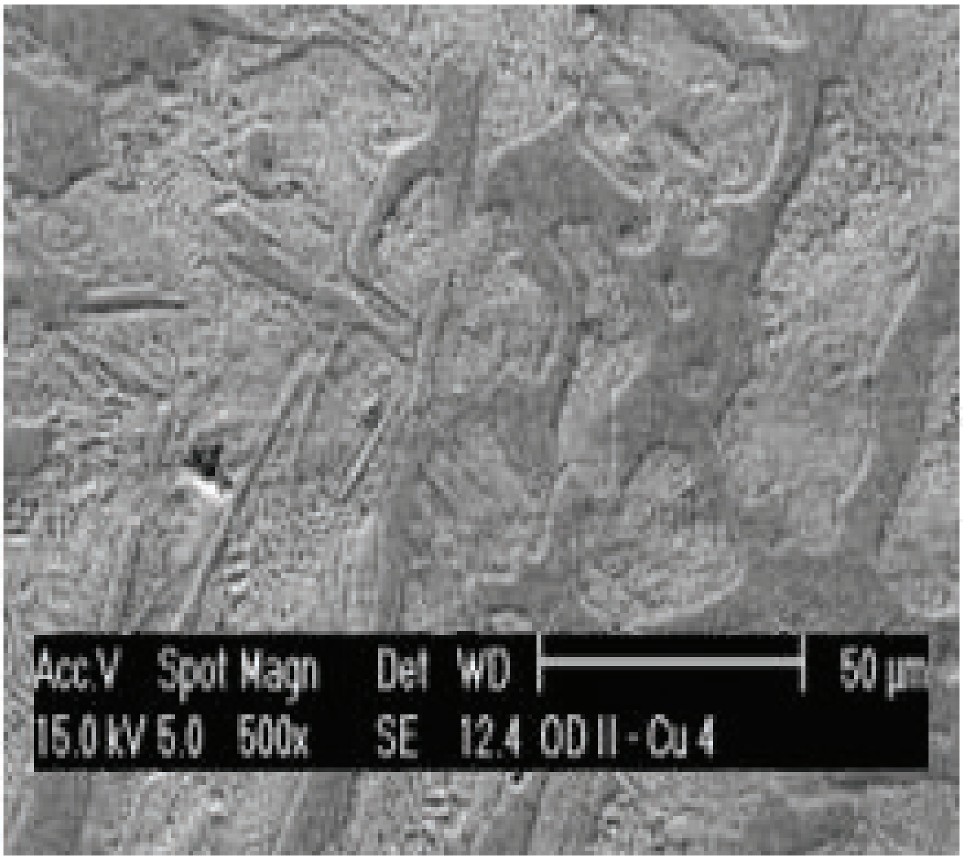

Figure 1. SEM micrograph of the Fe 0.53 Cu sample (×500).

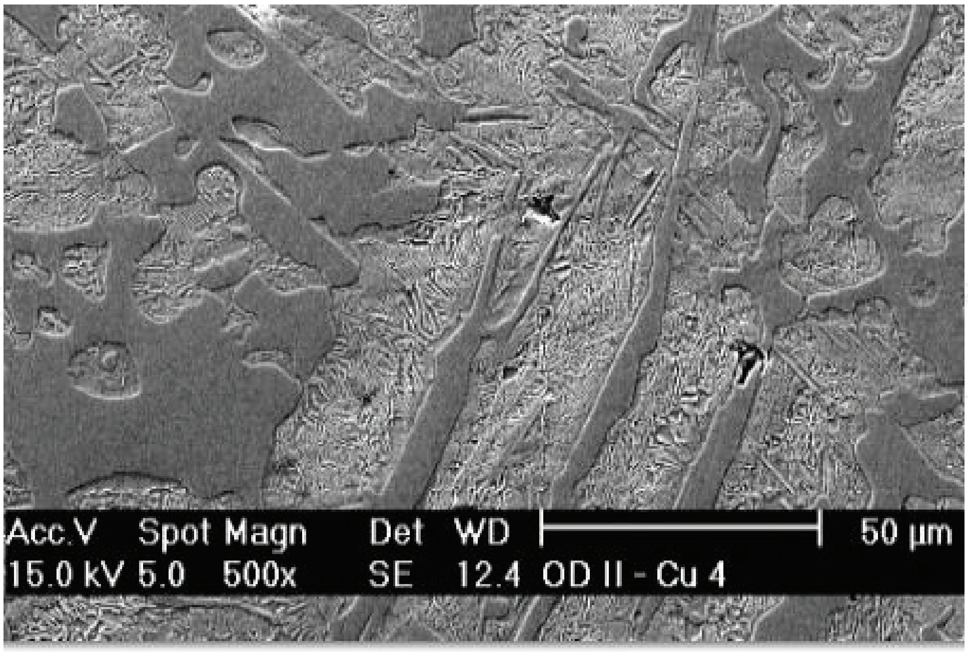

Figure 2. SEM micrograph of the Fe 0.21 Cu sample (×500) [11].

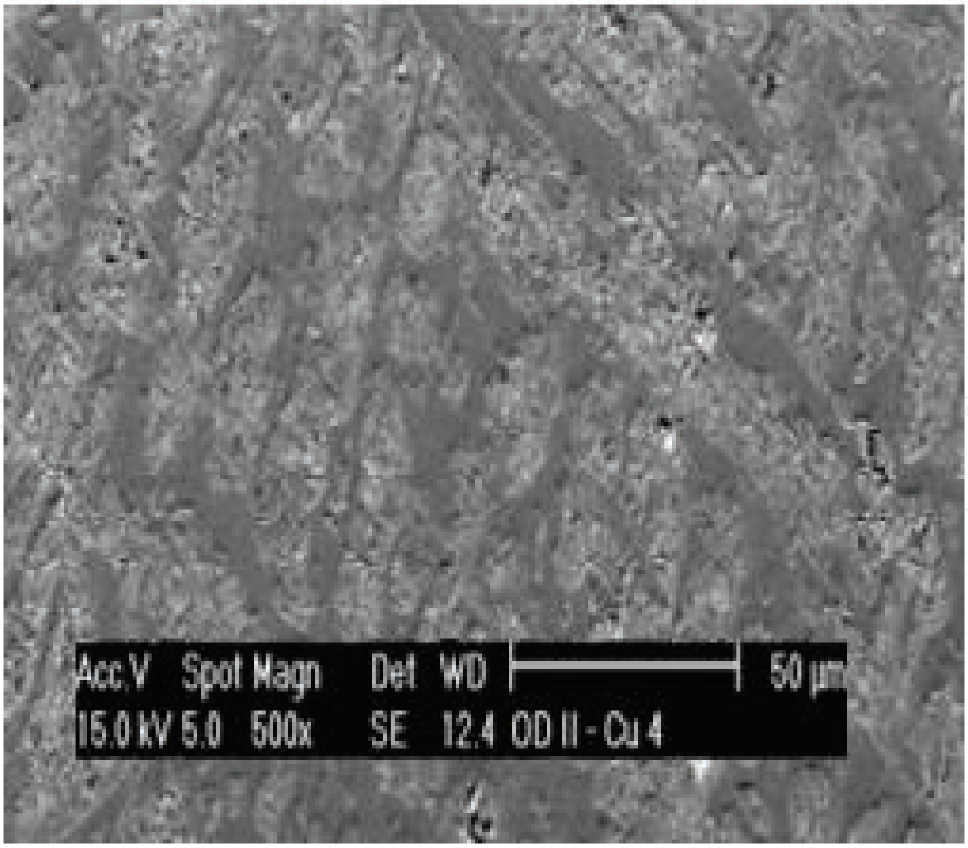

Figure 3. SEM micrograph of the control sample of Fe in Cu (×500) [12].

1.1.3. Manganese (Mn) 3xxx

The alloy of manganese and aluminum results to improvement in strain hardening and strengthening but does not reduce ductility or corrosion resistance. It retains strength when used on non-heat treatable materials. The uses of 3xxx series alloys are cooking utensils, radiators, evaporators, heat exchangers and associated piping systems [14]. **Figure 4** is the SEM micrograph of manganese in iron and EDX of manganese ferrite (Mn-Fe_2O_4) powder prepared by hydrothermal route.

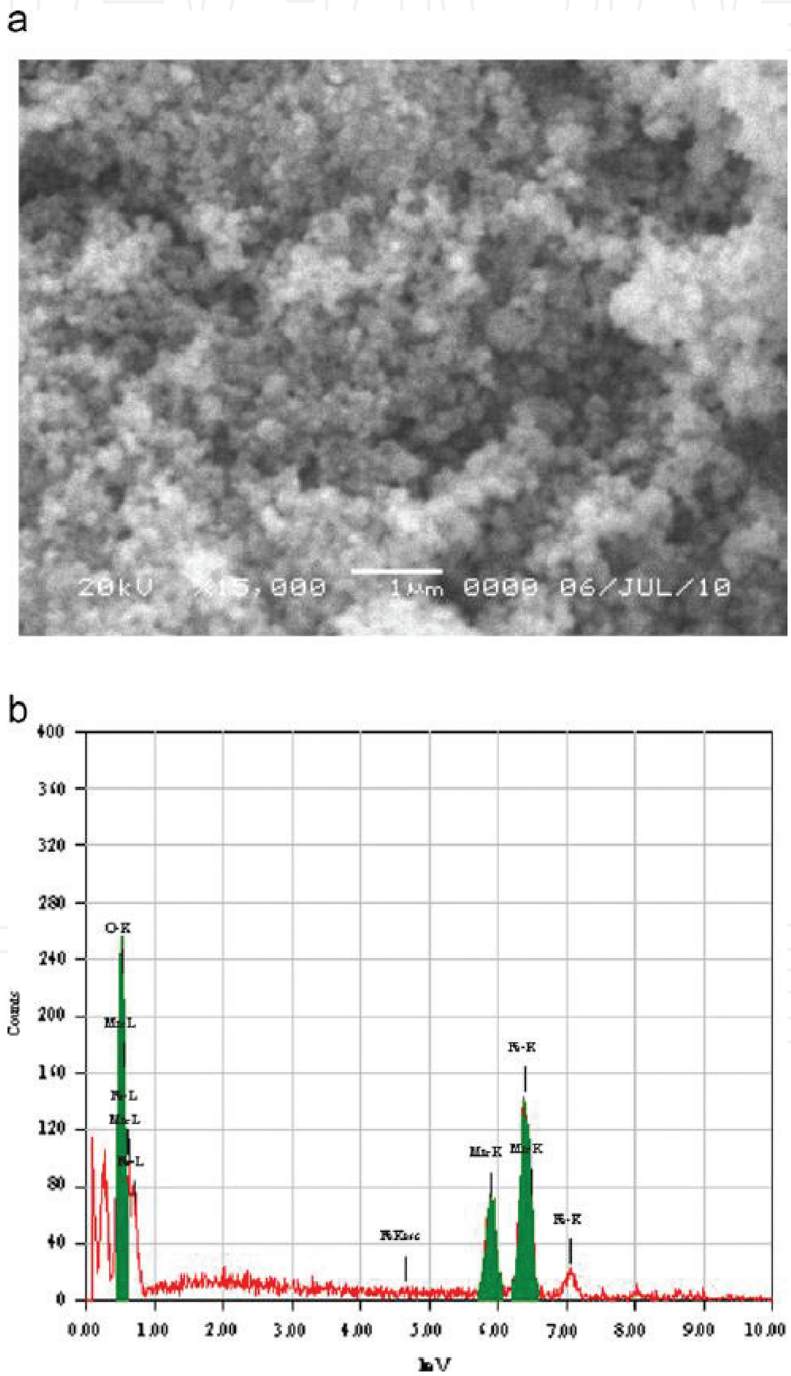

Figure 4. (a) SEM micrograph and (b) EDX of manganese ferrite (Mn-Fe_2O_4) powder prepared by hydrothermal route [15].

1.1.4. Silicon (Si) 4xxx

The alloy of silicon and aluminum reduces the melting point of temperature and enhances fluidity. **Figure 5** is the SEM micrograph of cast aluminum-silicon alloys.

Uses of silicon

- It produces a non-heat-treatable alloy.
- Silicon with magnesium produces a precipitation hardening heat-treatable alloy.
- Alloy of silicon and aluminum are used for the manufacturing of castings [17].
- They are also used as filler wires for fusion welding.

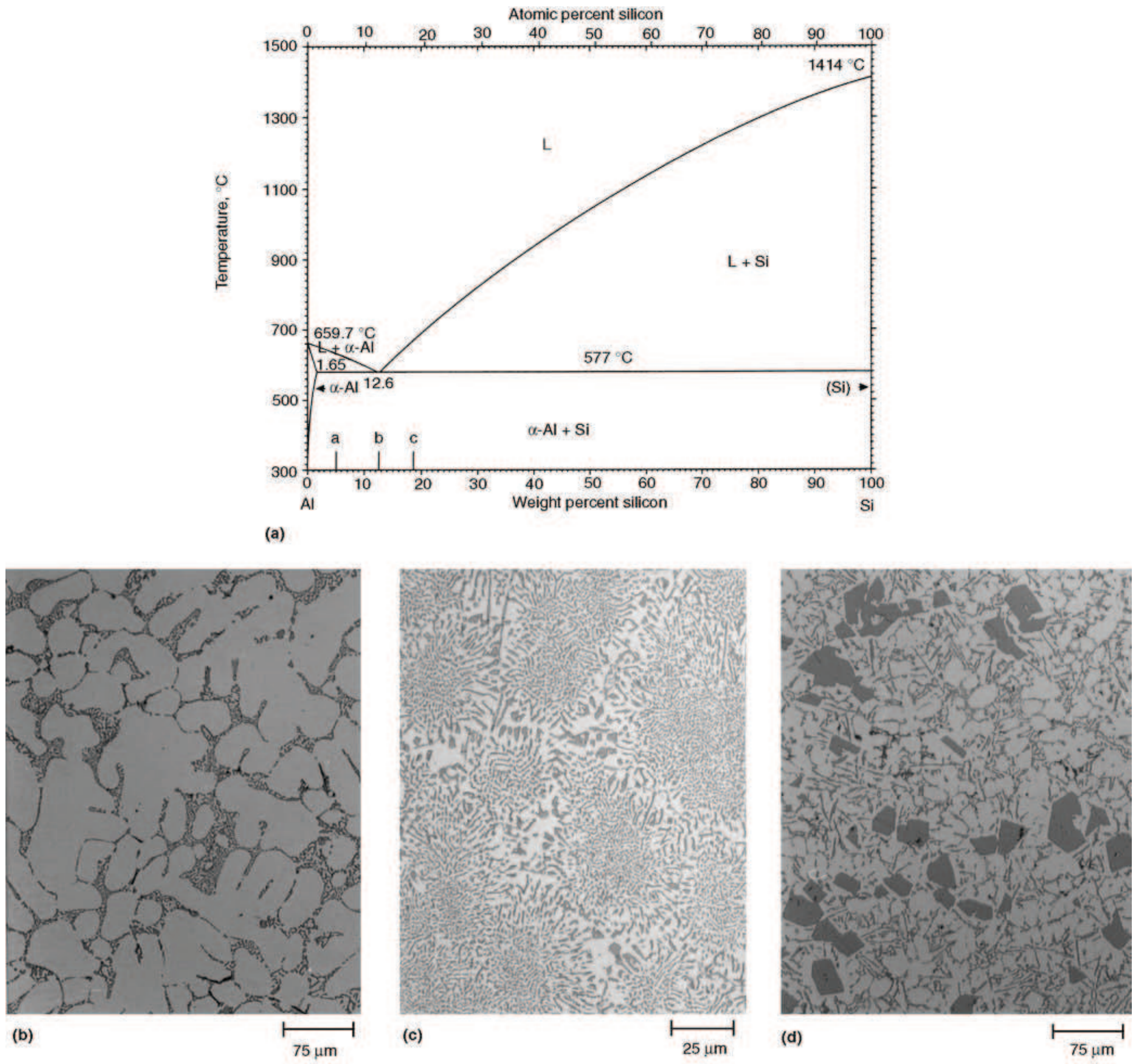

Figure 5. Commercial cast aluminum-silicon alloys. (a) Al-Si equilibrium diagram; (b) microstructure of hypoeutectic alloy (1.65–12.6 wt.% Si) 150; (c) microstructure of eutectic alloys (12.6% Si) 400; and (d) microstructure of hypereutectic alloy (>12.6% Si) 150 [16].

1.1.5. Magnesium (Mg) 5xxx

We used solid solution strengthening to improve strain hardening of metal by the alloy of magnesium with aluminum. **Figure 6** SEM micrograph of a magnesium material with porous microstructure produced using space-holding particles.

Uses of magnesium

- They are used extensively for structural applications.
- The 5xxx series alloys are produced mainly as sheet and plate [19].
- They are also used in truck and train bodies, armored vehicles, ship and boat building, chemical tankers, pressure vessels and cryogenic tanks.

1.1.6. Magnesium and silicon (Mg_2Si) 6xxx

The alloy of magnesium and silicon to aluminum forms the compound magnesium-silicide (Mg_2Si). The 6xxx series provides heat treatability through the formation of this compound. They are easily and economically separated and often found in an extensive selection of extruded shapes. Uses of this alloy: bicycle frames, scaffolding, drive shafts, automotive frame sections,, tubular lawn furniture, stiffeners and braces used on trucks, boats and many other structural fabrication. **Figures 7–9** are SEM image of magnesium and silicon taken at different temperatures.

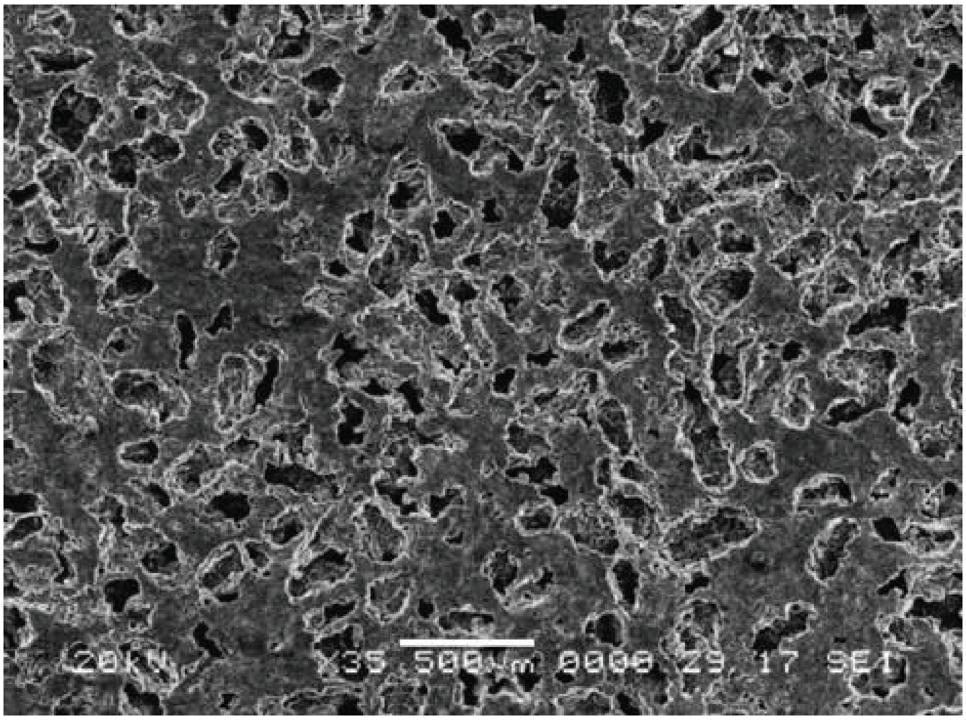

Figure 6. SEM micrograph of a magnesium material with porous microstructure produced using space-holding particles [18].

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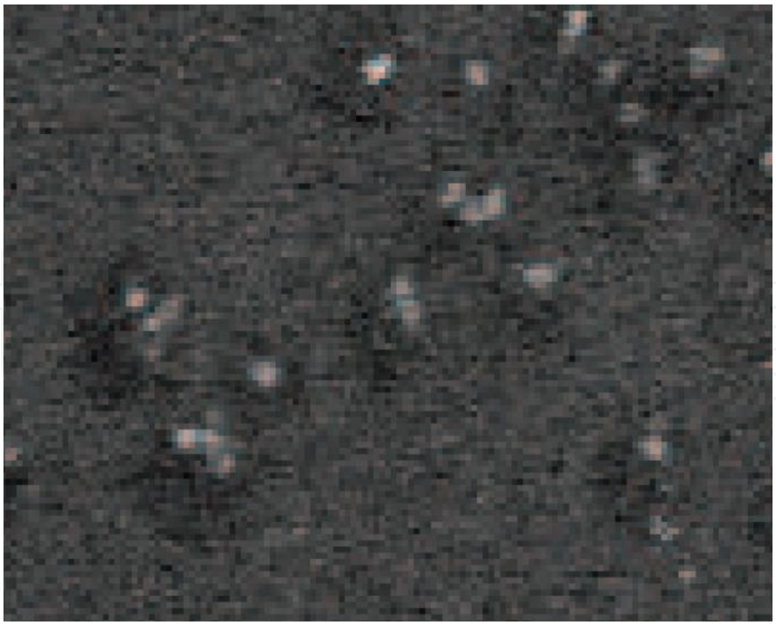

Figure 7. SEM image taken after heating to 400°C and exposure to air.

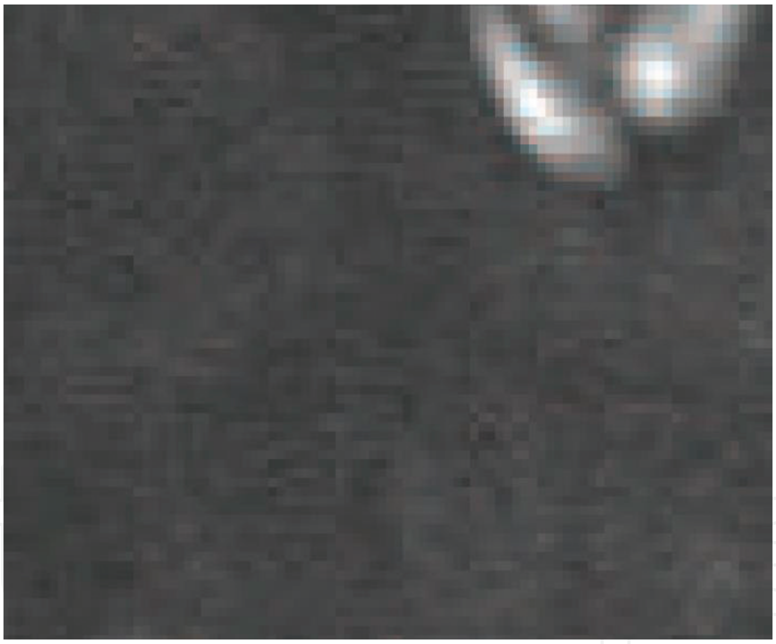

Figure 8. SEM image after heating to 490°C.

1.1.7. Zinc (Zn) 7xxx

The mixture of zinc and aluminum with other trace element such as magnesium and copper produces heat-treatable strong aluminum alloys. The zinc add to the strength and allow precipitation hardening. Some of these alloys are subject to stress corrosion cracking and for this reason are not usually fusion welded. There is a decrease in the 7xxx series Al alloys with these over-aging treatments. The 7xxx series Al alloys and re-aging (RRA) treatment possess

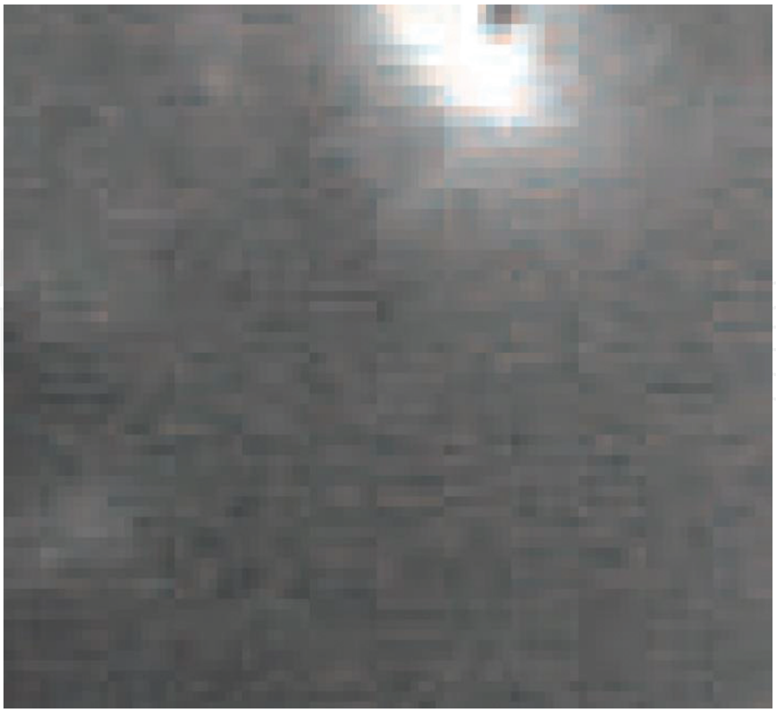

Figure 9. SEM after heating to 500°C [15].

high strength and good SCC resistance [12]. However, the RRA treatment shows short retrogression time and cannot be used for large-section Al alloys. Novel heat treatment have been developed to keep the high strength of the 7xxx series Al alloys and improve their corrosion resistance simultaneously [15, 20] advanced a novel aging treatment, called high temperature pre-precipitation(HTPP) aging treatment. In the present work, the comparative study of the effects of the various heat treatments, especially the secondary aging and HTPP aging omits tensile properties, corrosion behaviors and microstructures was carried out on different alloy group. Other alloys within this series are often fusion welded with excellent results. Some of the common applications of the 7xxx series alloys are aerospace, armored vehicles, baseball bats and bicycle frame [16]. **Figure 10** is the SEM micrograph for an aluminum alloy that is (a) cast-solutionized, (b) cast-solutionized-aged at 20°C—60 min, (c) hot-rolled and (d) hot-rolled-aged at 200°C—60 min.

1.1.8. Iron (Fe)

Iron is added to some pure alloys to provide the increase in strength which is the most common impurity found in aluminum.

1.1.9. Chromium (Cr)

The essence of chromium to aluminum is to control grain structure, to protect grain growth in aluminum-magnesium alloys, and to prevent recrystallization in aluminum-magnesium-silicon or aluminum-magnesium-zinc alloys during heat treatment. Chromium will also reduce stress corrosion y and improves toughness.

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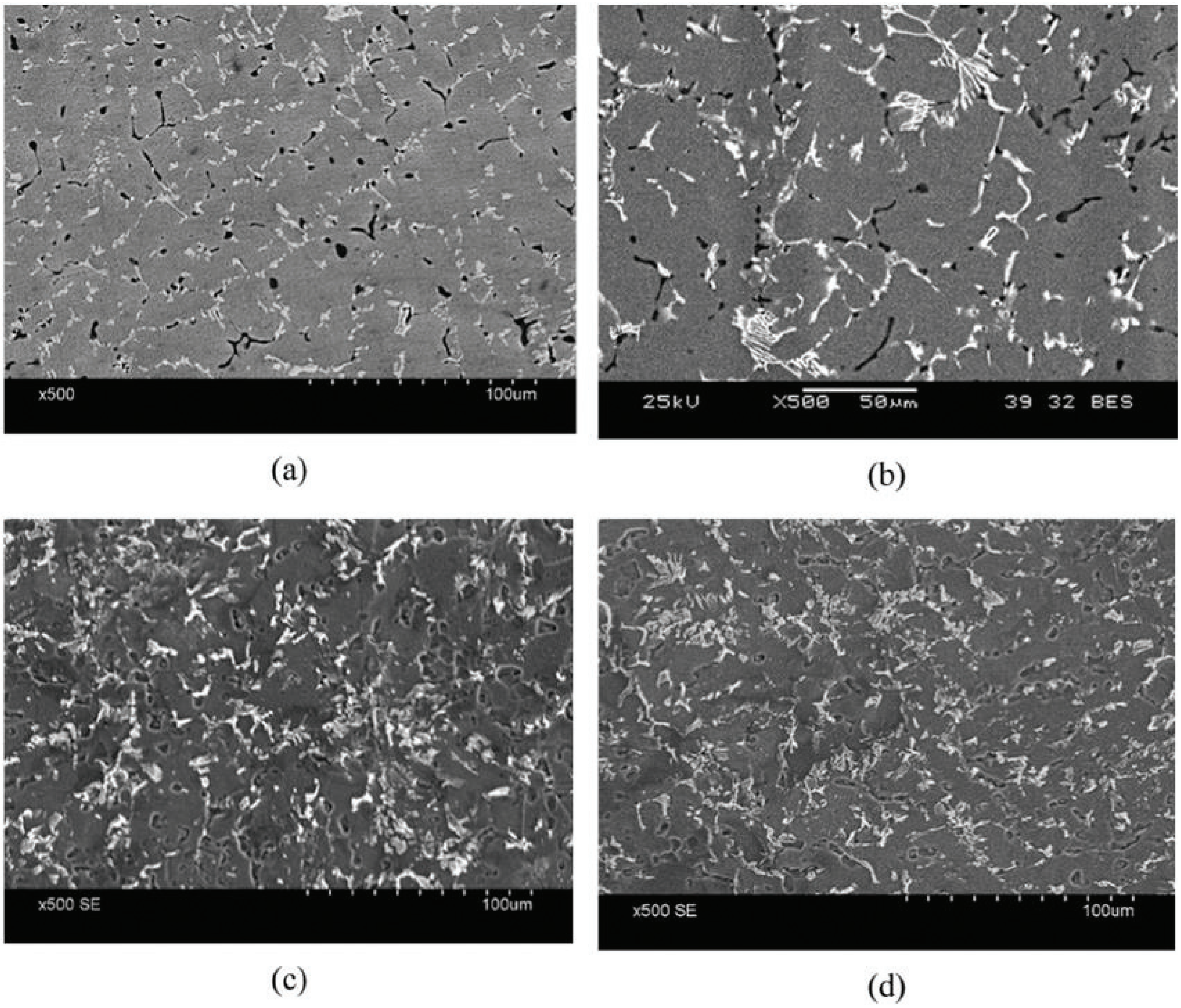

Figure 10. SEM micrograph for an aluminum alloy that is (a) cast-solutionized, (b) cast-solutionized-aged at 20°C—60 min, (c) hot-rolled and (d) hot-rolled-aged at 200°C—60 min [20].

1.1.10. Nickel (Ni)

Alloy of Nickel and aluminum-copper improve hardness and strength at elevated temperatures and reduce the coefficient of expansion.

1.1.11. Titanium (Ti)

Titanium is added to aluminum to serves as a grain refiner. The grain refining effect of titanium is enhanced if boron is present in the melt or if it is added as a master alloy containing boron largely combined as TiB_2. Titanium is a common addition to aluminum weld filler wire as it refines the weld structure and helps to prevent weld cracking.

1.1.12. Zirconium (Zr)

The fine precipitate of intermetallic particles that inhibit recrystallization is produced when Zirconium is added to aluminum.

1.1.13. Lithium (Li)

The addition of lithium to aluminum increases strength and Young's modulus, It also provide precipitation hardening and decreases density.

1.1.14. Lead (Pb) and Bismuth (Bi)

These are added to aluminum to assist in chip formation and improve machinability. These free machining alloys are not weld able because the lead and bismuth produce low melting constituents and can produce poor mechanical properties and high crack sensitivity on solidification [6]. **Figure 11** is the microstructure of alloy Al-6.16Zn-3.02 Mg-1.98Cu, aged at 172°C for 4 h: (a) SEM micrograph, showing S phase and Al_7Cu_2Fe particle; (b) TEM micrograph, showing η phase and Al_7Cu_2Fe particles [21].

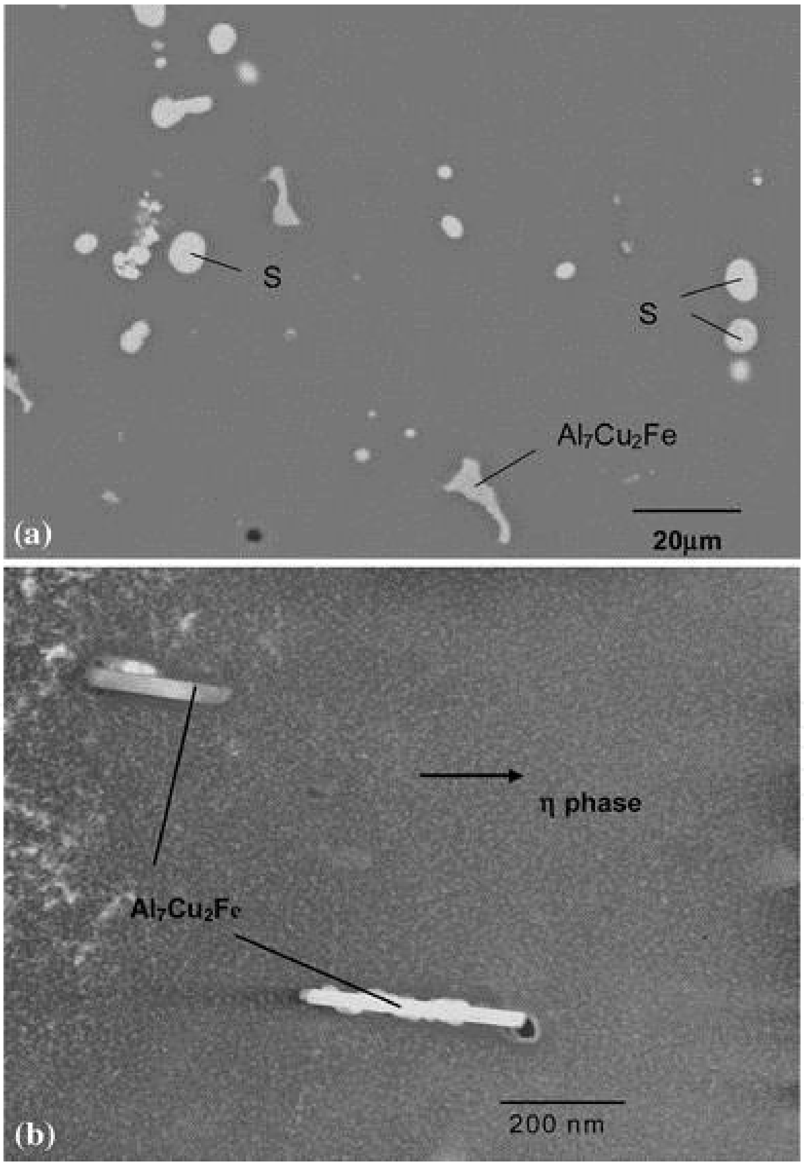

Figure 11. Microstructures of alloy Al-6.16Zn-3.02 Mg-1.98Cu, aged at 172°C for 4 h: (a) SEM micrograph, showing S phase and Al_7Cu_2Fe particle; (b) TEM micrograph, showing η phase and Al_7Cu_2Fe particles [21].

1.2. Other applications of aluminum alloy

- In the chemistry

The properties of aluminum such as strength, density, workability, electrical conductivity and corrosion resistance are affected by adding other elements such as magnesium, silicon or zinc.

- Bradley fighting vehicle

7xxx series and 5xxx series aluminum alloys is used to produce the military Bradley Fighting Vehicle.. It is trusted to keep soldiers safe and mobile, aluminum is also used in many other military vehicles.

- Our favorite beverage container

Aluminum alloys is used to produce America's favorite beverage container, the aluminum can, is made from multiple. The shell of the can is composed of 3004 and the lid is made from 5182. Sometimes it takes more than one alloy to make one, everyday item [7].

- Hot and cold

Application involving the use of aluminum alloys is made stronger through heat-treatment or cold working. The attributes of a particular alloy are different because of their additives and treatment. **Table 2** is the percentage composition of aluminum alloys of different metal.

1.3. Aluminum alloy designation

Aluminum alloys for sheet products are identified by a four-digit numerical system which is administered by the Aluminum Association. The alloys are conveniently divided into eight groups based on their principal alloying element [9]. **Table 3** shows the different alloy group and alloying element.

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn
wt.%	0.4	0–5	0.1	0.2	3.5	0.05	0.25

Table 2. Composition of aluminum alloys.

Alloy group	Principal alloying element	% Aluminum
1xxx	Unalloyed aluminum	Purity of 99.0%
2xxx	Copper	Heat treatable alloys
3xxx	Manganese	Non heat treatable alloys
4xxx	Silicon	Low melting point alloys
5xxx	Magnesium	Non heat treatable alloys
6xxx	Magnesium and silicon	Heat treatable alloys
7xxx	Zinc	Heat treatable alloys
8xxx	Other elements	None

Table 3. Different alloy group and alloying element.

2. Methodology

2.1. Stir casting

Stir casting is generally accepted as a particularly promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimize the final cost of the product. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies [9]. Factors considered in preparing metal matrix composites by stir casting method are [10],

- To ensure uniform distribution of the reinforcement material
- It is to achieve wettability between the two main substances
- To control porosity in the cast metal matrix composite

The material properties and process parameters are used to determine the final distribution of the particles in the solid such as the wetting condition of the particles with the, melt, relative density strength of mixing,, and rate of solidification. The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added [5].

2.2. Process parameters

2.2.1. Stirrer design

Stirrer design is used in stir casting process to form vortex. The blade angle and number of blades give the flow pattern of the liquid metal. The stirrer is immersed to two third the depth in molten metal. The essence is for uniform distribution of reinforcement in liquid metal and perfect interface bonding.

2.2.2. Stirring speed

Stirring speed is an important parameter to promote binding between matrix and reinforcement i.e. wettability. Stirring speed decides formation of vortex which is responsible for dispersion of particulates in liquid metal. In our project stirring speed is 300 rpm.

2.2.3. Stirring temperature

Aluminum melts around 650°C, at this temperature semisolid stage of melt is present. Particle distribution depends on change in viscosity. The viscosity of matrix is mainly influenced by the processing temperature. The viscosity of liquid is decreased by increasing processing temperature with increasing holding time for stirring which also promote binding between matrix and reinforcement. Good wettability is obtained beekeeping temperature at 800°C.

2.2.4. Stirring time

As stirring promote uniform distribution of reinforcement partials and interface bond between matrix and reinforcement, stirring time plays a vital role in stir casting method. Less stirring leads to non-uniform distribution of particles and excess stirring forms clustering of particles at some places. Stirring time is 5 minutes in our case.

2.2.5. Preheat temperature of reinforcement

Casting process of AMC's is difficult due to very low wettability of alumina particles and agglomeration phenomenon which results in non-uniform distribution and poor mechanical properties [1]. Reinforcement is heated to 500°C for 40 minutes. It removes moisture as well as gases present in reinforcement.

2.2.6. Preheat temperature of mold

This is used to remove the entrapped gases from the slurry to go into the mold. It also improves the mechanical properties of the cast AMC. The mold is heated to500°C for 1 h.

2.2.7. Magnesium

Addition of magnesium enhances the wettability. However increase the content above 1 wt.% increases viscosity of slurry and hence uniform particle distribution becomes difficult [7].

2.2.8. Reinforcement feed rate

Non-uniform feed rate promotes clustering of particles at some places which causes the porosity defect and inclusion defect, so to have a good quality of casting the feed rate of powder particles must be uniform. The flow rate of reinforcements measured is 0.5 gram per second [5].

2.2.9. Pouring of melt

Pouring rate and pouring temperature plays significant role in quality of casting. Pouring rate of slurry must be uniform to avoid entrapping of gases. At this stage the temperature of melt is 800°C. The distance between mold and crucible also plays vital role in quality of casting. Apart from this size of reinforcement plays significant role in quality of casting.

2.2.10. Speed of rotation

Speed of rotation issued to influence the structure; increase of speed promotes refinement and very low speed results in instability of the liquid mass. It is logical to use the highest speed to avoid tearing.

2.3. Experimental setup and procedure

The process of stir casting starts with placing empty crucible in the furnace. The heated temperature is then gradually increased up to 800°C. Aluminum alloy is cleaned to remove dust particles, weighed and charged in the crucible for melting. Required quantities of reinforcement powder and magnesium powder are weighed on the weighing machine.

Reinforcements are heated for 45 minutes at a temperature of 500°C. When matrix was in the semisolid stage condition at 650°C, 1% by weight of pure magnesium powder is used as wetting agent. After 5 min the scum powder is added which forms a scum layer of impurity on liquid surface which to be removed. We increase the heater temperature to 800°C. Stirring is started at this heater temperature and continued for 5 min. Speed controller help Stirring rpm to increase from 0 to 300 RPM. We add preheated reinforcement during 5 min of stirring. Conical hopper is used to pour reinforcements manually with the help of. The flow rates measured in 0.5 g/s. It is then gradually lowered to the zero. The molten composite slurry is poured in the metallic mold without giving time for reinforcement to settle down at crucible bottom. Before pouring the molten slurry in the mold, it is preheated at 500°C temperature for 1 h. The flow of the slurry is kept uniform to avoid trapping of gas. This is necessary to maintain slurry in molten condition throughout the pouring. While pouring the slurry in the mold, also distance between crucible and the mold plays a vital role in quality of casting. **Figure 12** is the Schematic view of stir casting setup.

2.4. Hardness

The Brinell hardness tests were carried out on Brinell hardness tester. Six samples of Al/Sic-MMC's for different sizes and weight fraction of SiC particles were prepared. After test and hardness value on dial, the Brinell hardness values with reference to scale HRB were taken for all samples and shown by graphs. Impact Strength and Impact Test were carried out over Charpy

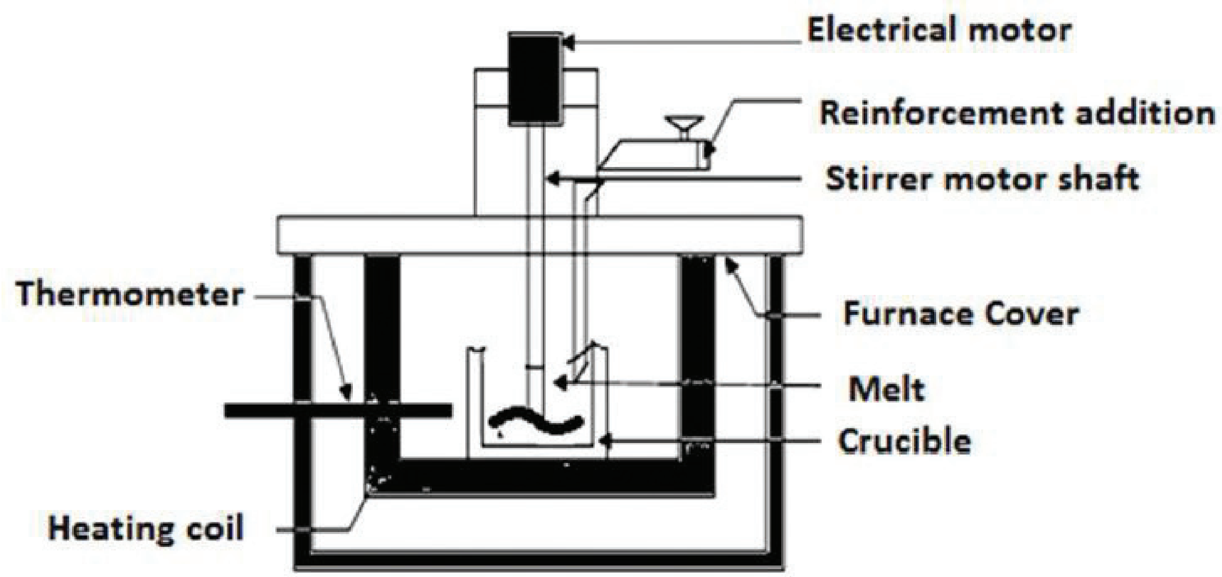

Figure 12. Schematic view of stir casting setup [7].

Impact Testing Machine and results were recorded. According to size and weight fraction of SiC particles, 12 specimens Al/Sic-MMC's of Square cross-section of size (10 × 10 × 55) with single V-notches are planned. The size of V-notches is 45° and 2 mm depth.

3. Results and discussions

Following conclusions are given from present work,

- Stir casing process can successfully be used for manufacturing of AMC's having low density and enhanced mechanical properties.
- Stir casting process is cost effective and conventional route for manufacturing of composite material.
- Material having isotropic nature can be manufactured successfully.
- Preheating of mold reduces porosity and enhances mechanical properties.
- Addition of magnesium is important to increase wettability.
- Design of stirrer decides the flow pattern of melt.
- Stirrer speed, stirring time decides quality of casting.
- Preheat temperature of mold, preheat temperature of reinforcement, reinforcement size, reinforcement feed rate and melt pouring rate are also the important parameters in stir casting method.

4. Conclusion

To conclude majority of authors fabricated the composite by stir casting process with different reinforcements like SiC, Al_2O_3, fly ash, ground nut and rice husk ash. In this study stir casting process is the simplest and cheapest route to fabricate the particulate type metal matrix composites. However, agglomeration of particles added in molten matrix is the difficulty faced by most of the authors during fabrication process. The mechanism to avoid agglomeration of particles is through coating of the reinforcement and inert gas environment during fabrication process. We use two step and electromagnetic stir casting process to improve the homogeneity of particles during fabrication. This method gives high specific strength, greater strength to weight ratio at elevated temperature, greater wear resistance as compare to matrix phase. If you increase the Zn content, modeling results will also show that the Zn contents has been increased, but the electrical conductivity and thermal conductivity reduce slightly with the Zn addition. For Mg variation, the strength property of the alloy improves in the range of 2.7–2.9 wt.% Mg, Increase of Mg contents will reduce the electrical conductivity and thermal conductivity. In general, the experimental evidence for microstructures is in accordance with the predictions in the modeling processes [21].

Author details

Ojo Sunday Isaac Fayomi[1,2]*, Abimbola Patricia Idowu Popoola[2] and Nduka Ekene Udoye[1]

*Address all correspondence to: ojo.fayomi@covenantuniversity.edu.ng

1 Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria

2 Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa

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