Processing Methods and Properties of Aluminium-SiC$_p$ Metal Matrix Composites Produced by Stir Casting for Marine Applications - A Review

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REVIEW ARTICLE

Abstract- Composite material is made up of at least two distinct materials functioning together to provide material properties that are different and unique to their own, with quality superior than its constituents. Generally, metal matrix composite materials consist of a matrix (bulk material) and a reinforcement of some type, which are combined primarily to enhance the strength and stiffness of the matrix. Metal matrix composites combine the metallic properties of matrix alloys with the ceramic properties of reinforcements, to develop materials with greater strength capabilities. They are materials that are attractive and suitable for a large variety of engineering applications. This work reviews the effects of silicon carbide particulate reinforcements on aluminium metal matrix composites for marine and underwater applications, with specific emphasis on improved mechanical, structural and corrosion properties. In this paper, specific reference was given to stir casting techniques as a liquid state metal manufacturing method of aluminium metal matrix composites. The work revealed that silicon carbide significantly enhances the overall mechanical and tribological strength of the composite along with corrosion resistance. It was revealed that research efforts have mostly been focused on the mechanical, physical and thermo-mechanical characteristics of the composites, more recourse to their corrosion characteristics is very significant in evaluating its application potential as marine structural materials.

Keywords- Silicon Carbide, Aluminium, Aluminium Alloy, Surface Oxidation, Stir Casting

1 INTRODUCTION

The aluminium metal matrix composites are very attractive engineering materials for numerous industrial applications. Series of efforts have been made to develop aluminium metal matrix composites (AMCs) to meet several engineering applications challenges due to their excellent physical and mechanical properties with great potential in marine, automotive, aerospace and structural applications. In order to curb the application challenges for the rising call and demand of modern technology, AMCs are among the utmost potential materials to meet the challenges. Aluminium alloys containing silicon and magnesium as major alloying elements are recently being adopted as replacement for cast iron and steel in several automobile industries (Kumar et al., 2011; Jayashree et al., 2013; Vijayaram and Baskaralal, 2016).

Stir casting method is a vastly used method in developing Al/SiC composites by virtue of its simplicity and cost-effectiveness compared to all the several techniques available such as spray deposition, powder metallurgy, infiltration technique and squeeze casting (Nagaral et al., 2016). The evolution of varied variety of aluminium alloy with varying degree of strength and ductility has wide applications in engineering structural and constructional materials.

However, the low strengths of these alloys limit their usage. Hence, the desires for strengthening these aluminium alloys for effective light weight applications where high strength to weight ratio are essential, using suitable reinforcing elements such as carbides, oxides and nitriles. Superior strength, low density, enhanced corrosion resistance, enhanced high temperature performance, better resistance to wear are the enhanced properties developed when an aluminium and its alloys are effectively reinforced with ceramic particles to fabricate suitable AMCs (Bharath et al., 2014; Moses et al., 2016; Alten et al., 2019).

In this study, the effect of magnesium (a surface-active element), the heat treatment of particles, the effect of variation of weight fraction of reinforcement on the microstructure of the composites, improvement of wettability of Al-SiC, and the effects of SiO$_2$ coating on SiC$_p$ (surface oxidation) on mechanical behaviours and corrosion resistance behaviours of the SiC$_p$ reinforced AMCs as potential structural materials for marine applications are presented.

2 REINFORCEMENT MATERIALS

2.1 SILICON CARBIDE PARTICLES

Generally, reinforcements are stronger materials dispersed in a matrix. They are generally nonreactive and are made to enhance composites properties like strength, stiffness, creep, conductivity, fatigue, etc, of the matrix, and are stable in a given working temperature (Son Trinh 2016; Xie et al., 2019; Bakshi et al., 2010; Vijaya et al., 2014). Silicon carbide possesses a density of 3.21 g/cm$^3$, melting point of 2730°C, thermal conductivity of 41 w/mK, thermal coefficient of expansion of 5.1 – 5.8 x 10$^{-6}$/K, Vickers Hardness of 2800 HV and Young’s modulus of 476 GPa.
Silicon carbide particle is a semiconductor encompassing silicon and carbon, which occurred in nature as a very rare mineral moissanite. The characteristics of distinctive silicon carbide are relatively low density, enhanced temperature strength, oxidation resistance, enhanced strength, excellent thermal shock resistance, enhanced hardness and wear resistance, excellent chemical resistance, low thermal expansion, and excellent thermal conductivity (Hariharan et al., 2014; Adebisi et al., 2016).

The selection of silicon carbide (SiC) as the reinforcement in aluminum composite is mostly adopted for an improved and enhanced structural performance, ease of fabrication, design flexibility, enhanced wettability and robust bonding at the interface (Nwabufoh, 2015). Silicon carbide is among the most widely used reinforcement materials in metal matrix composites owing to its compatibility with aluminum alloys. Aluminium reinforced with SiC particles have up to 20% enhancement in yield strength, less coefficient of thermal expansion, better modulus of elasticity and additional wear resistance better than an equivalent un-reinforced aluminium matrix alloy system (Rino et al., 2012; Jayashree et al., 2013).

2.2 Treatment and Surface Oxidation of Silicon Carbide Particle (SiCp)

Basically, oxidation is a reaction of metal and oxygen. Generally, all metals apart from the precious metals will oxidize when exposed to oxygen and an electrolyte, such as atmospheric moisture. A measured SiCp was heated in an Electrical Resistance Heating Furnace already set to a temperature of 1300°C required for surface oxidation process to take place, where a thin layer of SiO2 was formed on its surface. The SiCp samples were held in the furnace at that temperature for 2hrs and then removed and cooled down in the air at room temperature. The SiO2 layer acts as a barrier preventing the direct contact between SiCp and aluminium alloy during the fabrication of the composites of the coated samples (Odiwo et al., 2021; Onyenanu and Nwigbo, 2021).

The oxidation of SiCp begins at temperatures above 600°C in air where a silica-rich surface layer is formed. The weight gain of SiCp powder increases with temperature until oxidized SiCp is formed at around 1200 – 1300°C when it is fully oxidized. Roy et al. (2014) reported that based on the concentration of oxygen, high temperature oxidation of silicon carbide might be either active or passive. Active oxidation decreases the strength of the samples whereas passive oxidation results in the development of coherent silica layer over silicon carbide surface, thereby enhancing its performances in several applications.

i. Active oxidation takes place at oxygen pressures below one bar, where the SiO2 produced gets vaporized after its formation thereby leading to loss or reduction of mass, where the strength of the samples reduces linearly with respect to the measured weight loss, as shown in equation (1):

\[
\text{SiC(s)} + \text{O}_2(g) \rightarrow \text{SiO}_2(g) + \text{CO}(g)
\]

ii. Passive oxidation proceeds at oxygen pressures nearly one bar, where the SiO2 forms gets deposited over the surface of SiC, leading to net increase in the mass, as shown in equation (2): (Roy et al., 2014)

\[
2\text{SiC(s)} + 3\text{O}_2(g) \rightarrow 2\text{SiO}_3(g) + 2\text{CO}(g)
\]

It was observed that SiO2 layer formed makes a coating over SiC substrates which protect it from further oxidation. The SiO2 formed at lower temperature develops layer over the surface of SiC and protects it from further catastrophic oxidation to SiO3 occurring at higher temperatures. Passive oxidation makes the SiC surface stronger and makes it applicable in most of the fields. Such protective action continues up to the melting point of SiO2 (1700°C). After formation of SiO2 layer during passive oxidation, further oxidation proceeds by the following steps:

(a) Gaseous oxygen molecules are transported to the surface of oxide and come in contact with SiC through the oxide film by diffusion.

(b) Reaction of diffused oxygen with SiC at the oxide/SiC interface.

(c) Product gases formed come out through the oxide film again by diffusion.

2.3 Magnesium

Magnesium is very light, about 75% lighter than the steel, 50% lighter than titanium, and 33% lighter than aluminium (Ojo et al., 2017). It possesses the highest known damping capacity of any structural material, which is capable of withstanding stress ten times higher than aluminium, titanium, or steel. It is one of the two most soluble elements in aluminium (the other being zinc) in the solid state, 14.9 wt.% at 451°C and 1.7 wt.% at room temperature. The addition of magnesium in aluminium enhances the wettability. However, increase the contents above 1 wt.% rises viscosity of the slurry and hence uniform particle distributions becomes difficult. It also increases strength through solid solution strengthening and improves their strain hardening ability (Ojo et al., 2017).

3 Aluminium and Aluminium Alloys

3.1 Aluminium Alloys

Aluminium is the predominant metal in aluminium alloys. The usual alloying elements are copper, magnesium, manganese, silicon, tin and zinc. The common additives that are in use to enhance mechanical features of aluminium include ceramic reinforcements like SiC, Al2O3, BN, and B-C (Nwabufoh, 2015). The cast alloys and the wrought alloys are the two main classifications of the alloys, and both are further subdivided into the heat-treatable and non-heat-treatable categories.

The groups of aluminium alloys are described by 1xxx, 2xxx, 3xxx up to 8xxx. The 1xxx series description is the unalloyed aluminium materials which are famous in accordance to their degree of purity. The 8xxx series description is the assorted forms of alloys that cannot be...
combined together in the other families. The 2xxx, 6xxx and 7xxx series of aluminium alloy are heat-treatable alloys, which gain their strength by alloying but make use of precipitation hardening as the main mechanism. The 1xxx, 3xxx and 5xxx series are the non-heat-treatable alloys; they gain their strength by alloying (e.g., increasing the content of Mg) and work hardening (Rino et al., 2012; Jayashree et al., 2013). Table 1 shows the groups of aluminium alloys and their alloying elements.

Table 1. The groups of aluminium alloys and their alloying elements (Source: Jayashree et al., 2013)

<table>
<thead>
<tr>
<th>Series</th>
<th>Primary Alloying Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>Pure Aluminium - 99.00% or Greater</td>
</tr>
<tr>
<td>2xxx</td>
<td>Copper containing alloy</td>
</tr>
<tr>
<td>3xxx</td>
<td>Manganese containing alloy</td>
</tr>
<tr>
<td>4xxx</td>
<td>Silicon containing alloy</td>
</tr>
<tr>
<td>5xxx</td>
<td>Magnesium containing alloy</td>
</tr>
<tr>
<td>6xxx</td>
<td>Magnesium and Silicon containing alloy</td>
</tr>
<tr>
<td>7xxx</td>
<td>Zinc containing alloy</td>
</tr>
<tr>
<td>8xxx</td>
<td>Other alloys</td>
</tr>
</tbody>
</table>

It is very unusual to find pure aluminium (1xxx series of alloys) selected for structural fabrication due to their strength characteristics. Although the 1xxx series is considered almost pure aluminium which responds to strain hardening and contains significant amounts of impurities like iron and silicon. However, even in the strain-hardened state, the 1xxx series alloys displays very low strength compared to the other series of aluminium alloys. When the 1xxx series alloys are selected for a structural application, they are most often selected due to their superior corrosion resistance and/or their high electrical conductivity. The addition of alloying elements to aluminium is the main method adopted to fabricate variety of different materials that can be used in a wide variety of structural applications (Jayashree et al., 2013).

The 6xxx wrought alloy series has magnesium and silicon as the major alloying elements. This class of aluminium alloys are the heat-treatable alloy which can be significantly strengthened and adopted for several applications where improved strength, ductility, toughness, corrosion resistance is vital. It has Rockwell hardness of 30 HRB, tensile strength of 115 MPa and elastic modulus of 70-80 MPa. These alloys are principally used for engineering light weight structural parts in automotive, marine and aviation industries (Kareem et al., 2021).

3.2 Advantages and Properties of Aluminium

Aluminium is a very light metal having a specific weight of 2.7 gm/cm³. It is having a high deal of attention owing to its physical and mechanical properties like low density, high corrosion resistance, specific strength, excellent heat and electricity conductor and totally recyclable. Aluminium is a ductile material with low melting point and low density, which are processed in varieties of forms in a molten state. The ductility of aluminium permits products of aluminium being mostly moulded near to the required shapes and specifications (Rino et al., 2012). The usage of aluminium in automotive industries increases load capacity but decreases dead-weights and energy consumptions requirements.

3.3 Application of Aluminium Alloys

Aluminium alloys are extensively adopted in engineering components and structures where light weights or corrosion resistances are essentially required. The main limitations in the application of aluminium alloy and composite are their corrosion behaviour. The heterogeneities in the metal matrix composite tend to have an effect on its corrosion characteristics, resulting in various corrosion-related problems like galvanic coupling, voids, micro crevices, porosity and high reactivity interfacial phases (Ashok et al., 2020). Aluminium engine block, suspension component, body panel, and frame member are progressively common, coupled with the usage of magnesium in component such as instrument panels, valve covers, transmission housings, and steering column components. Replacing or combining these efforts with the usage of advanced metal matrix (micro and nano) composites (MMCs) improves reliability and efficiency (Rohagi, 2004; Hunt and Miracle, 2001). The utilizations of MMCs offer some significant benefits which including performance benefit (such as component lifetime, enhanced productivity), economic benefit (such as lower maintenance cost and energy savings), environmental benefit (such as lesser noise level and less air-borne emissions) and engineering benefit/viability in several applications like aerospace, defence, automotive, sports goods, and marine among others. Fig. 1 is an application of Aluminium Alloys and Composites.
3.4 Aluminium MMC Processing Techniques/Methods

The method of manufacturing is among the vital factors in producing AMCs as it determines the final products behaviours of the composites. Manufacturing processes of AMC is largely grouped as liquid state production, solid state production (powder metallurgy) and gaseous state production. The most common liquid state processes used are stir casting, squeeze casting and compo-casting method. The powder metallurgy method is frequently used due to possibility of incorporating very high reinforcement contents of up to 90 vol.%. Nevertheless, this method is still least used than liquid state process as it offered higher production cost than liquid state method. From the several aluminium composites manufacture techniques examined, stir casting method is the best suitable process, as the process blends matrix and reinforcement in right proportion and in so doing enhances the mechanical features of the Al-SiCₚ composites.

3.5 Stir Casting

Stir-casting process is the simplest and commercial technique of development of Al-MMCs, which involves mechanical mixing of the reinforcement particulate into a molten metal bath and transferring the mixture directly to a prepared mould. The liquid composite material is cast by conventional casting procedures and processed by conventional metal forming technologies. The fundamental thing in the process is to create good wetting between the particulate reinforcements and the molten metal. The process has main advantage of low production costs (Naresh, 2006; Rajan et al., 2007; Rino et al., 2012; Nwabufoh, 2015; Saravanan et al., 2015). Figure 2 is a Stir Casting Process.

3.6 Stir Casting Process Parameters and Effects

The parameters for consideration in fabrication of Al-MMC by stir casting are:

- **Speeds:** The cast structure is influenced by the rotational speed where increase of speed improves refinement while low speed creates instability of the liquid mass. The adequate stirring speed promotes the flow patterns of the molten metal and the wettability between matrix and reinforcements, resulting in uniform distributions of particles in the liquid and excellence interface bond. Excessively low stirring speed/rate would lead to surface lap due to the associated low temperature while high stirring can lead to turbulence and rejection (Rino et al., 2012; Rammath et al., 2014; Nagaral et al., 2016; Sharma et al., 2020). The casting is expected to be completed before the liquid metal gets sluggish.

- **Temperatures:** The processing temperature influences aluminium matrix viscosity. The matrix particles distributions are subjected to change of viscosity. With an optimal temperature of about 630°C, there is better interaction between matrix and reinforcements as aluminium is kept in semisolid state. Low temperature castings are connected with supreme grain refinements and equiaxed structures while high temperatures produce columnar development in the alloys. Excessive low pouring temperature would lead to surface lap (Rajan et al., 2007; Rino et al., 2012; Nagaral et al., 2016). The pouring temperature must be adequately high to guarantee reasonable metal flow and freedom from collapse while avoiding coarse structures. An adequate mould temperature is very essential for effective casting as the risk of tearing in casting is moderated by expansion of the die with preheating. Reinforcement is preheated at a specified temperature to increase its wettability with matrix. It also helps in removing the moisture and gases present within the reinforcements and results in quality casting (Rino et al., 2012; Nagaral et al., 2016; Adebisi et al., 2016; Soltani et al., 2017; Sharma et al., 2020).

- **Mould Coatings:** Countless forms of coating materials are available for use in mould coating. The inner parts of metal mould are being sprayed to control the heat transfer to the mould, to eradicate the shrinkage and cracking defects that are likely to occur in metal moulds, consequently increasing the die life. By careful choice of the coating layer thickness, the effects of coating and solidification can be varied to the optimal value for a specific alloy. For aluminium alloys under consideration, the coating material is a combination of silicate and graphite in water. (Rajan et al., 2007; Rino et al., 2012; Ramanathan and Rajaraman 2019; Odwo et al., 2021).

3.7 Wettability and Interfacial Bonding Between Matrix Alloy and Reinforcement

Wettability is tendency of a liquid to spread on and maintain contact with solid surfaces. When the interfacial bonding strength between matrix and reinforcement exceeded the liquid’s surface tension, the wetting takes place. The interfacial bond strength between matrix and reinforcements can be improved by stimulating wetting and by reducing the formation of oxides. Nevertheless, in
the molten metal-ceramic reinforcement metal matrix composites, it is hard to achieve wetting, because of the higher surface tension of molten MMCs. Thus, wetting can be enhanced by any of these processes: increasing the surface energies of the solid, decreasing surface tensions of liquid matrix alloy, or decreasing the solid-liquid interfacial energy at the particles-matrix (Habibur, 2013).

Rino et al. (2012) revealed that some used methods of enhancing the wetting of reinforcement particles with molten matrix alloy includes:

i. the coating of reinforcements particles,

ii. the addition of alloying element to molten matrix alloy,

iii. the treatment of particles, and

iv. ultrasonic irradiation of the melt.

It was reported that metal coating on ceramic particles boosts the general surface energy of the solid, and improves wetting by increasing the contacting metal-metal interface instead of metal-ceramic interface (Odiwo et al., 2021). In general, coatings are adopted to protect reinforcements from damage during handling, to enhance wetting and to enhance dispensability prior to its addition to the matrix. Heat treatment of the reinforcement particles prior to dispersion into the melt assists their transfers by creating desorption of the gases adsorbed from particles surface. According to Odiwo et al. (2021), heat treatment of silicon carbide particles at temperature of 900°C in Heat Resistance Furnace led to formation of an oxide layer on the surface which helps in:

i. removing the surface impurities,

ii. the desorption of gases,

iii. alters the surface compositions.

Thus, a clean surface offers an improved opportunity for melt-particles interaction, and thus, enhances wetting which results in very strong interfacial bonding (Rino et al., 2012). The role and effect of the reaction at interface is highly substantial, as a new and innovative system is generated from it. The chemical reactions in addition to the interactions between matrix and reinforcements component institute the interface adhesion, alter the characters of composites components and affect mechanical properties accordingly. The interfacial phenomenon influences the ultimate properties of composites.

4 CORROSION IN MMCS

4.1 CORROSION IN SEAWATER

The seawater as a corrosive media has chloride content that gives maximum corrosion rate. A survey revealed that aluminium alloys are more susceptible to localized pitting corrosion in chloride environment (Kumar et al., 2019). The effect and nature of material-environment interactions are very significant in the optimal design and performance of the engineering material, as the effectiveness and retention of those properties cannot be dissociated from the prevailing environmental conditions. Any important approach to the corrosion occurrence was the structural characteristics of the engineering materials considered, in addition to the nature of the environment and the reactions of the material to the environment. Corrosion environments are broadly classified into two: the aqueous environment and the atmospheric environment. The factors common to both classifications are fluids (water, acid, alkalis, salt, steam and gases) flow velocity, temperature, pressure, air, humidity and concentration of the reactive species. They are the main influences that stimulate corrosion (Herting et al., 2008; Fayomi et al., 2019). The monthly corrosion rate of Aluminium was 2 to 21.8 mg/sq.dm while the yearly corrosion rate was 15.9 to 47.8 mg/sq.dm (Vashi and Kadiya, 2009).

4.2 FORMS OF CORROSION

The principal sources of MMCs corrosion consist of the galvanic corrosion between MMC constituents, chemical degradation of the interphases and reinforcements used, the microstructure influenced corrosion and the processing stimulated corrosion (Hihara, 2005; Bobic et al., 2009). Corrosion exists in countless methods and can be activated by several mechanisms. Accelerated corrosion may be initiated from the chemical and the electrochemical contact between MMC constituents, the micro structural effects and from problems related to its production. Corrosion can influence the metal matrix composite in different ways depending on its nature and the prevailing environmental circumstances (Bobic et al., 2009). Various researchers (Shreir et al., 2020; Roberge 2000; Landolt 2006; Bobic et al., 2009) gave broad classification of corrosion as uniform (or general) corrosion, pitting corrosion, galvanic (or bimetallic) corrosion, crevice corrosion, stress corrosion cracking, corrosion fatigue, microbial corrosion, and tribo corrosion.

4.3 CORROSION EVALUATION (TEST AND EVALUATION)

The major limitations in the applications of MMC are their corrosion behaviour. The heterogeneities in MMC tends to affect its corrosion characteristics. Galvanic coupling, micro crevices, porosity, voids, and high reactivity interfacial phases are some of the corrosion-related problems in MMCs (Bakkar and Neubert, 2007). Various corrosion tests available to study the corrosion behaviour of MMCs are linear polarization resistance (LPR), weight loss analysis, immersion test and potentiodynamic test. These tests are used to examine the composites vulnerability to corrosion in 3.5% NaCl (simulated seawater) at ambient temperature (Bobic et al., 2009).

5 REVIEW OF PREVIOUS WORKS

Lee et al. (2020) studied the outcome of interface variation on the wear properties of high-volume fraction Al/SiCp composites reinforced with thermally oxidized SiCp particle through liquid pressing method. AA7075 alloy with 10 μm and 30 μm SiCp particles were used to produce the composites. Using a box furnace at 1400°C with a heating rate of 10 °C/min for 2 hours, 55% SiCp particulates silicon carbide was oxidized thermally to developed the SiO2 layer of 200-μm thick on the SiC particles. The SiO2 layer was transformed into MgAl2O4 layer which eliminated the formation of Al2O3 thereby increased the hardness and interface bonding of the
composites developed. The various wear characteristics of high-volume fraction Al/SiCp composites were compared to low-volume fraction composites where larger reinforcement exhibited enhanced wear resistance as it supports the composites to sustain rigidity under intense shear distortion process.

Loto and Babalola (2019) examined the effects of variation of SiCp particle sizes on the corrosion resistance and metastable pitting properties of AA1060/7.5 wt% SiCp composites in 0.05 M H2SO4 0.3 M NaCl and 0.5 M H2SO4/0.3 M NaCl solutions were examined with potentiodynamic polarization, open circuit potential measurement and optical microscopy. The 3, 9, 29 and 45 µm particle size SiCp powder were preheated at a temperature of 1100 °C and used to fabricate the composites by stir casting process. The results obtained showed the least corrosion rate values at Lotto 3 µm and 45 µm SiCp particle sizes. The corrosion rate value of AA1060/SiCp (0-3 µm) diminished from 0.875 mm/y to 0.438 mm/y in H2SO4/NaCl solution, 0.112 mm/y to 0.080 mm/y in H2SO4 solution, and 0.21 mm/y to 0.014 mm/y in NaCl solution respectively. In the mixture of sulphate/chloride solution, the corrosion rate observed is higher. Morphological damage of AA1060/SiCp at 0 µm was significantly higher than the deterioration at 3 µm and 45 µm.

Fenghong et al. (2019) synthesized Al6061/WC/SiC hybrid composites using the stir casting process under the various weight percentages of reinforcement. The different properties like wear resistance, tensile strength, hardness, and compressive strength were characterized and investigated. The microstructural analysis results obtained showed that the reinforcement particles were uniformly distributed with no visible clustering in the matrix. The precipitates of Mg/Si including undissolved Al−(Fe and Mn) are noticed due to interfacial reactions. The study resolved that hardness of composite was enhanced due to the incorporation of stronger and stiffer reinforcement in the matrix.

Mohammed and Anwar-Khan (2019) revealed that addition of Al2O3, SiC, B4C and Fly Ash reinforcements in the aluminium base alloys could affect the protective oxide layers of the metal surface which displays less corrosion resistance, due to the discontinuity in the layer initiation of corroded surfaces of the aluminium matrix composite material. They stated that the factors that affect the corrosion resistance of the AlMMCs are base material composition, the reinforcement used, the porosity, the micro-cracks, the residual stresses, and development of inter metallic brittle phases. The corrosion tests were performed by using the electrochemical analyser and the Tafel Polarization Technique (TPT). The work observed that corrosion increased with increase in wt% of reinforcement compared to the base alloy.

Abdulkader et al. (2016) examined the static electrochemical corrosion behaviour of nano SiCp based aluminium alloy in 3.5% NaCl and discovered that Al/SiCp composites possessed higher corrosion resistance than aluminium matrix. The corrosion resistance exhibited was very high by the increases in the weight percentage of the nano SiCp. The corrosion rate was discovered to be increased by increasing the weight of the percentage of the nano SiCp particles up to 12%.

Loto and Adeleke (2016) fabricated Al/SiCp composites by stir casting process and examined the effects of SiCp particles and microstructure in localized corrosion process. The electrochemical conduct of UNS A0332.005, A0332.205, UNS A0539.005 and A0539.205 alloys were exposed to 3.5% NaCl media and examined for corrosion susceptibility by weight-loss method, potentiodynamic method and cyclic polarization process respectively. A0332.205 and A0539.205 were both reinforced with SiCp particles of 20% by volume but the remaining two samples were used reinforced. SEM and EDS were employed to analyse the effect of intermetallic phases of the individual corroded and non-corroded aluminium alloys samples. It was discovered that unreinforced alloys exhibited lesser corrosion rates in comparison with the SiCp particles reinforced alloys. Reinforced alloys displayed more pits effects (numerous, shallower and widespread) than the monolithic alloys. Al/SiCp interface particles and intermetallic phases were formed at the mouth of the pits particularly for the alloys reinforced with SiCp particles. This contributed significantly to the weakening of the phase which showed the localized corrosion being developed on the region. Of all the alloys compared, UNS A0359.005 aluminium alloy earlier developed a protective layer of oxide than the reinforced samples, and had the least corrosion rate of 1.4639 mpy compared to the other samples. The result revealed that intermetallic phases may affect the corrosion performance of the aluminium alloy.

Zakaria (2014) examined the effects of the sizes (11, 6 and 3 µm) and volume fraction of up to 15% SiCp particulates on the microstructural and corrosion behaviour of Al/SiC metal matrix composites and reported that the Al/SiCp displayed higher density than the pure aluminium matrix. The static immersion corrosion tests conducted on Al/SiCpMMC in 3.5% NaCl aqueous solution at varied temperatures revealed that at ambient temperature, the Al/SiCpMMC possessed better corrosion resistance than the pure aluminium matrix. Also, decreasing the SiCp particles size and/or increasing the volume fraction of the SiCp particulates reduce the corrosion rates at 50°C and 75°C than the pure aluminium matrix.

Rajesh et al. (2012) examined the mechanical behaviours of particulate reinforced aluminium and silicon carbide MMCs by stir casting method and stirred the MMC slurry in partial molten state to disperse ceramic particles into matrix material properly. The holding temperature, the stirring speed and the size and the positions of impeller are the vital factors considered during the composite casting. The obtained results stated that mechanical properties and the wear rate of the composite decreased with an increase in weight percentage of the SiC. It was reported that for better corrosion and wear resistance, the
composite materials can be used at elevated temperatures.

Sanjay et al. (2012) investigated the influences of seawater on mechanical properties of SiCp particle reinforced aluminium alloy using 5, 10, 15% reinforcement through tensile tests. It was discovered that samples were degraded in the seawater for 90 days of intervals of 10 days. The surfaces observation revealed the corrosively degraded samples were as a result of pitting around the intermetallic compound and SiCp particles while the corrosive degradation of composite samples was as a result of the synergy effects of pitting and intergranular corrosion. The mechanical strength of aluminium alloy was discovered to be lower compared to that of the composites tested. The reduction of the ultimate tensile strengths was better in the Al/SiCp compared to the aluminium under the same test condition. The investigational results analysis regressively revealed that reduction of tensile strengths is proportional to the sea water exposure rates.

6 Conclusion

The work reveals that aluminium matrix composites (AMCs) are an attractive material for advanced applications in structural, marine, aerospace and automotive applications because their properties that can be tailored to a specific requirement through the addition of carefully selected reinforcements. Silicon carbide is widely used reinforcement materials in metal matrix composite owing to its compatibility with aluminium alloys. The work further reveals that stir casting method is one of simplest and cost-effective methods of fabrication of Al-SiCp MMCs. Stir casting process parameters such as the speeds (stirring speed, rotation speed and pouring speed) determine the flow pattern of melt and the quality of the casting. The temperatures (preheat temperature, mould temperature, pouring temperature), as well reinforcement size among others are also essential process parameters. The study shows that addition of magnesium alloy increases the wettability, preheating of mould reduces porosity and enhances mechanical properties of the composite.

The work shows that matrix metal and reinforcing phase need to be properly selected and controlled to achieve the desired composite properties. The sizes of the reinforcement, the pouring rate, the pouring temperature, the distance in between the crucible and the mould are significant factors for quality casting, and to evade entrapping of gases (Sharma et al., 2020). The reinforcement of aluminium alloys with SiCp particles enhances the composites properties such as tensile strength, hardness, wear and corrosion resistance of the composites developed. SiCp particles as reinforcement material in aluminium alloy has a good match of chemical, mechanical and thermal properties for application in marine environment.

The review further shows that Al-SiCp MMCs are susceptible to localized corrosion (pitting and crevice corrosion) in marine environments. This corrosion behaviour is sensitive to the processing condition due to the composite microstructure. Hence processing condition is a significant factor in the production of Al-SiCp MMCs. Heat treatments of SiCp prior to casting improved corrosion resistance significantly. The work reveals that less literature is available on marine application of Al-SiCp MMCs compared to other areas of applications such as automobile materials (wear resistance), aerospace, transportation, electronics, etc. Further works is recommended to critically exploit this important marine application area.

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