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# Fabrication, Surface Morphology and Corrosion Investigation of Al 7075-$Al_2O_3$ Matrix Composite in Sea Water and Industrial Environment.

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**Abstract**

Al 7075 matrix composites are widely used in structural and aerospace industry because of its higher hardness, wear resistance and strength to weight ratio. But properties such as low formability and poor corrosion resistance restrict its wider usage. Therefore this experiment is performed to investigate distribution of higher percentage of reinforcement in matrix and to study the corrosion behaviour of base Al 7075 alloy and Al 7075 reinforced with 10% wt and 15% wt of $Al_2O_3$ fabricated by stir casting method. Metallographic study of composite was carried out using optical microscope, XRD, SEM with EDX. Density of prepared composite was determined by Archimedes principle. Corrosion study was performed in Sea water and industrial environment for three different samples, Al 7075 monolithic alloy, Al 7075 reinforced with 10% and 15% wt of $Al_2O_3$ particles. Experiments were conducted using electrochemical analyzer using Tafel Polarization Technique (TPT). From the analysis of SEM images it reveals that pitting corrosion was observed in sea water environment and inter granular corrosion was observed in industrial environment. It was observed that corrosion rate of Al 7075 increases with increase in reinforcement volume and Al 7075 undergoes severe corrosion in sea water environment than Industrial environment. Tafel polarization measurement of corroded Al 7075-$Al_2O_3$ (15%wt) in seawater environment and industrial environment is shown below


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## 1. Introduction and literature review

Composite consist of two phases a matrix phase and reinforcement phase. Main challenge for researcher today in field of aerospace, automobile and structural is to select a material which is light weight and has higher strength. Aluminium is widely preferred as metal in these areas because of its light weight. But aluminium alone cannot provide the required strength. Therefore reinforcements are added to it to enhance its strength to weight ratio. Aluminium Metal Matrix composite refer to composites that have Aluminium has base matrix and ceramic particles as reinforcements. Compared to pure alloys and metals (i.e unreinforced materials) Aluminium MMC's exhibit high strength, temperature resistance, hardness, abrasion and wear resistance, lower co-efficient of thermal expansion, damping capabilities etc [1]. Because of their improved properties, in recent decades Al MMC's have been used to produce high performance products in aerospace, architectural, marine and mineral processing industries. Ceramic reinforcements are available in form of whiskers, continuous fibres, particulates [1] .$Al_2O_3$, SiC, $B_4C$ are some of the commonly used reinforcement in Al MMC's. Stronger the matrix produced stronger will be the composites [2, 3]. Aluminium 7075 alloy is widely used in aerospace and structural applications because of its improved properties such as higher toughness, high strength to weight ratio, high hardness etc [2, 3]. Among the commercially available aluminium alloys, Al 7075 is strongest available aluminium alloy [3, 4]. According to literature survey we can observe that very few experiments has been done using Al 7075 with Alumina as reinforcement, therefore in our experimental study we have preferred Al 7075 with Alumina as reinforcement. For better observations in experimental study it is necessary to produce Al MMC's with an efficient fabrication technique. Improper distribution of reinforcement material in matrix, porosity formation, decrease in wettability between matrix and reinforcement are some of the common problems faced during fabrication of Al MMC's. Therefore it is necessary to choose an efficient fabricating technique. Stir casting, powder metallurgy, squeeze casting, spray casting etc are some of the common fabricating techniques that are used in manufacturing of Al MMC's. Among the available fabricating techniques, Stir casting is widely preferred in manufacturing of Al MMC's because of its simplicity, can be used for large production, economical [5]. Microstructure of a composite depends on composition of alloy, pouring temperature, viscosity of melt and cooling rate etc [2]. Therefore in order to obtain uniform distribution of reinforcement particles in matrix, stir casting method is preferred in our experimental study.

Aluminium is highly resistant to most chemical agents and atmosphere because of the it's oxide film which provides higher inert and protective characteristics to the metal surface. Though Al MMC's have enhanced mechanical properties, the effect of reinforcement on corrosion resistance acts as an obstacle for wider usage. Protective oxide film which imparts corrosion resistance to metal surface may be affected when reinforcements are added which may lead to discontinuity in the film. At the site of discontinuity in the film corrosion is initiated leading to severe corrosion of the composite material [6, 7]. Corrosion resistance of the Al MMC's is mainly affected by the composition of the base material, reinforcement, residual stresses, porosity, micro cracks, formation of inter-metallic brittle phases etc [7]. Corrosion resistance of the Al MMC's also depends upon type of processing technique used, reinforcement type, reinforcement size and amount of reinforcement added. Since corrosion resistance of Al MMC's is very important in ensuring material reliability when it comes in contact with various environments therefore it has become necessary to study the behavior of Al MMC's in sea water and industrial environment.

There has been significant amount of study been conducted by researchers in determining mechanical properties of Al MMC's [2]. Studies have also been conducted in determining parameters affecting surface finish during machining of Al MMC's [9]. F. Toptan et. al has studied the effect of $B_4C$ on corrosion behavior of Al MMC's in 0.05 NaCl Solution [7]. In study conducted by A.Pardo et.al, author concluded that corrosion of MMC's increases as reinforcement percentage increases in 3.5% wt NaCl Solution [6]. Geetha Mable Pinto et. al has studied corrosion behavior of Al-6061 with 15% wt SiC in a mixture of 1:1 Hydrochloric and Sulphuric acid medium [8]. P. Muhamed Ashraf et. al has studied the effect of Cerium oxide on corrosion behavior of Al MMC's in marine environment [10]. In study done by S.B. Jamaludin et. al, author concluded that Al reinforced with $Al_2O_3$ has higher corrosion rate compared to Al reinforced with SiC in 3.5% wt NaCl solution [11].MMC prepared with Cerium Oxide has higher corrosion protection [ 10]. Author Sinnur Candan concluded that as percentage of Mg increases corrosion of pressure infiltrated Al-Mg alloy with SiC as reinforcement decreases in 3.5 % wt NaCl [12]. S.L.Winkler et. al has studied pitting corrosion behavior of Al 7XXX alloys and fibre reinforced MMC's and author concluded that addition of 1% wt of Ag reduces corrosion rate [13]. From the work done by Kenneth Kanayo Alanemea et. al, author concluded that corrosion resistance of single reinforced Al–Mg–Si/10 wt.% $Al_2O_3$

composite is better than Hybrid composite in 3.5% NaCl solution [14]. J.Datta et. al concluded that addition of Sc reduces corrosion rate of Al MMC [15].

It is clear from the literature survey that no experimental work has been reportedly carried out to study Micro-structure, XRD, SEM and EDAX analysis of Al-7075 alloy with 10%, 15% wt $Al_2O_3$ reinforcement. In addition no experimental work has been reported to investigate the corrosion behavior of Al-7075 alloy and Al 7075 reinforced with 10%, 15% wt $Al_2O_3$ in sea water and industrial environment.

## 2. Problem definition

The main objective of this experimental study is to investigate distribution of reinforcements ($Al_2O_3$) in matrix of Al-7075 alloy reinforcement and to investigate the corrosion behavior of Al 7075 alloy and Al 7075 reinforced with $Al_2O_3$.

Al-7075 with 10% and 15% wt $Al_2O_3$ was characterized by using metallographic techniques (XRD, SEM). Microstructure of the cast specimen was studied using optical microscope connected to computer imaging system. Corrosion behavior of Al 7075 alloy and Al 7075 reinforced with 10% and 15% wt of $Al_2O_3$ is studied in sea water and industrial environment. The experimental details are listed as follows:

- Matrix – Al7075
- Reinforcement – $Al_2O_3$ (20 µm - 15% wt)
- Fabricating technique – Stir Casting.
- X-ray Diffractometer- D8 Advanced, Bruker
- Solutions
  - Sea water environment (3.5 wt% NaCl)
  - Industrial environment (NaCl + $(NH_4)_2 SO_4$)
- Corrosion testing machine – CH instruments electrochemical analysis machine.
- Polarization Technique to determine corrosion rate: Tafel extrapolation method.
- Chemical Composition of Base material and reinforcement used in study is shown in Table 1 and Table 2.

Table 1 Chemical composition of Al 7075 alloy

| Chemical Composition | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| Al 7075 | 0.4 | 0.5 | 1.2-2.0 | 0.3 | 2.1-2.9 | 0.18-0.28 | 5.1-6.1 | 0.2 | Rem |

Table 2 Chemical composition of Aluminium oxide powder

| Chemical Composition | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | $Na_2O$ | $Al_2O_3$ |
|---|---|---|---|---|---|
| Wt % | 0.15 | 0.05 | 0.15 | 0.45 | Rem |

## 3. Experimental work and procedure:

In order to obtain a composite material with enhanced properties it is necessary for a good interfacial bond condition between matrix and reinforcement phase. In experimental work conducted by J.Hashim et.al. Author concluded that wettability can be improved by reducing contaminants on adsorbed substrate. In order to eliminate contaminants, improve wettability and to obtain good interfacial bonding, it is necessary to preheat the reinforcement particles [5]. Therefore reinforcement ($Al_2O_3$) is preheated to $600^0$ C using Preheater Furnace. This Stir cast Machine consists of a two bladed stirrer which is driven by a DC motor. In our experimental study matrix phase (Al-7075) and reinforcement phase ( $Al_2O_3$) are taken in ratio of 85:15 respectively. Al-7075 was heated up to $850^0$C in electric furnace and once metal starts to melt, flux was added to remove impurities and magnesium of 2% Wt was added to improve wettability. Later $Al_2O_3$ was added to molten metal and stirring was done at 650rpm for 10min.Inert atmosphere was maintained by using Argon gas. Once the reinforcement was thoroughly stirred in matrix phase, melt was poured into a die. Fabricated Composite was skin turned on a medium duty lathe and samples were prepared in size of 1cm diameter and 3mm length for corrosion study.

## 4. Metallographic study

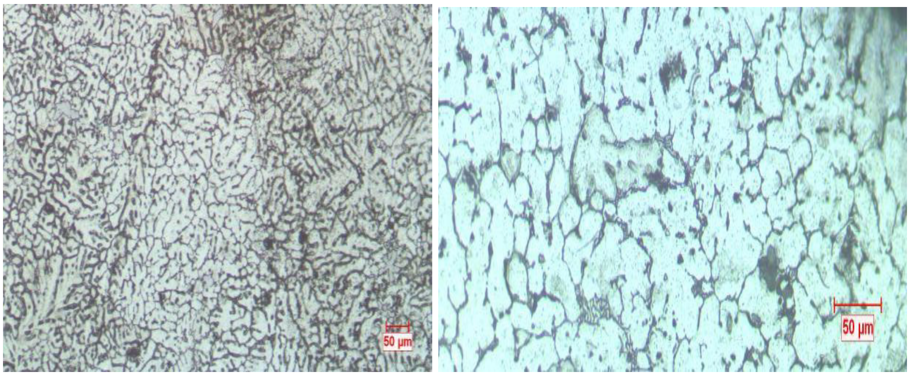


Fig 1 Microstructure of Al-7075 with 10% wt $Al_2O_3$ at (a) 100X (b) 200X

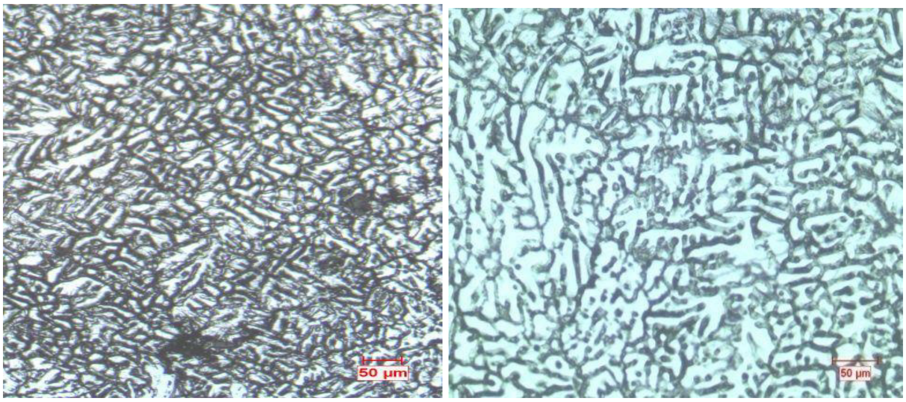


Fig 2 Microstructure of Al-7075 with 15% wt $Al_2O_3$ at (a) 100X (b) 200X

It is necessary to check quality of fabricated specimen by investigating distribution of reinforcement in matrix. Surface morphology study of specimen helps in revealing quality of fabricated specimen. Surface Morphology study of fabricated specimen was carried out by using optical microscope connected to computer imaging system, scanning electron microscope and XRD analysis. Fabricated specimen was skin turned and specimen of size of 28.8mm diameter and 5mm length was used to study microstructure. The specimen was initially polished using emery paper of grit size 200, 400, 600, 800, 1000 .In order to obtain mirror finish the specimen was later polished using disc polishing machine. Kellar reagent was applied to specimen before observing sample under optical microscope. Microstructure of prepared composite was observed at 100X and 200X.

Specimen was Polished and analyzed in scanning electron microscope. It was observed that reinforcement distribution is more uniform in 10% then in 15% wt $Al_2O_3$ sample and observed that at some places particles were agglomerated in small quantity. we can observe that cracks formed may be due brittle nature of the reaction product formed. From elemental analysis, elements likeAl, Mg, O, Fe, C were traced in composition. Presence of oxygen may be due to addition of $Al_2O_3$ and due to oxide layer formation on prepared cast composite. From elemental analysis it was observed that chemical composition of Aluminium in prepared composite in both specimen was reduced to 86.53% and 84.64% due to addition of $Al_2O_3$ reinforcement. From study done by K.M. Shorowordi et.al., presence of voids at reinforcement/matrix interface may be due to weak bonding between aluminium and alumina [16].

XRD result of Al-7075 alloy reinforced with $Al_2O_3$, we can confirm the presence of Al matrix and $Al_2O_3$ reinforcement in prepared cast composite. Interfacial reaction between Al matrix and $Al_2O_3$ reinforcement is needed because this interfacial reaction permits efficient transfer of load from aluminium matrix to $Al_2O_3$ reinforcement. Presence of voids reveals that it may due to formation of strong inter-metallic brittle phases such as $CuAl_2$ and Mg $Al_2O_4$ between matrix and reinforcement. From study done by Belete Sirahbizu Yigezu et. al., author reported that formation of these brittle inter-metallic phases reduce bonding strength between aluminium and alumina which results in lower strength consequently reducing load transfer [17]. Presence of brittle inter-metallic phases will also raise local stress in microstructure and form particle cracking which results in lower mechanical properties. It was observed main peaks are of Al matrix and $Al_2O_3$ reinforcement which indicates uniform distribution of reinforcement in matrix.

## 5. Density Measurement

Density was determined using Archimedes Principle. From table 3 we can observe that density reduces as percentage of reinforcement increases. Lower density with increases in reinforcement may be due to presence of voids in matrix, fracture of reinforcements and low interface bonding between reinforcement and matrix. Presence of higher Porosity may be due to solidification nature and due to agglomeration of Alumina [18]. From SEM micrographs we can observe that presence of voids in matrix which affects densification and bonding between Al 7075 and $Al_2O_3$.

Table 3 density of composite by Archimedes principle

| Sl.No | % of reinforcement | Density |
|---|---|---|
| 1 | 0 | 2.81 |
| 2 | 10 | 2.72 |
| 3 | 15 | 2.64 |

## 6. Corrosion studies

### *6.1. Corrosion Medium:*

Standard solutions of sea water environment [NaCl] and industrial environment [NaCl+ $(NH_4)_2SO_4$] were prepared by dissolving analytical grade pellets in distilled water**.**

### *6.2. Electrochemical Measurements:*

Electrochemical analysis is carried out using an electrochemical analyzer CHI604E series with CH instrument beta software. The electrochemical cell used in the study was a normal three electrode cabin having glass cell with reference electrode as saturated calomel electrode (SCE) and counter electrode as platinum. Working electrode is made up of Al7075 alloy and Al7075 + $Al_2O_3$ composites (10%, 15%). All the experiments were carried at room temperature.

### *6.3. Tafel Polarization and SEM micrograph Studies:*

Finely polished base alloy and composites specimens were exposed to corrosion environment of [NaCl] and [NaCl+ $(NH_4)_2SO_4$] solutions at room temperature and are allowed to establish a steady state open circuit potential (OCP). Curves of Potential (E) vs Log Current (log i) were recorded at $1mVs^{-1}$. To study the type of corrosion in the sample, SEM images were obtained and analyzed.

### *6.4. SEM study of Corroded Samples:*

Surface morphology images are obtained by SEM (Scanning Electron Microscope). Surface morphology of base alloy and composites after corrosion are studied by those images**.**

## 7. Corrosion Rate

Table 4 Corrosion Rates in mpy.

| Percentage reinforcement | CR in Sea water environment (mpy) | CR in Industrial environment (mpy) |
|---|---|---|
| 0 | 33.85 | 14.03 |
| 10 | 58.48 | 28.32 |
| 15 | 151.6 | 39.54 |

## 8. Conclusion:

Tafel Polarization, Density and SEM micrograph was used to obtain corrosion rate, type of corrosion in this paper:

- Al7075 showed better corrosion resistance than the prepared composite.
- Tafel plots for corrosion behaviour of Al7075-$Al_2O_3$ in sea water environment and industrial environment are shown above. It is inferred that corrosion rate increases with increase in percentage of reinforcement.
- Al 7075 - $Al_2O_3$ corroded more in sea water environment than in industrial environment.
- In sea water environment pitting corrosion was observed and in industrial environment Intergranular corrosion was observed.
- Corrosion resistance of composite was decreased as percentage of reinforcement increases due to depletion of Cr, increase in void in matrix, low interface bonding and fracture of reinforcement particles.
- By correlating Density measurement, Tafel Plots, SEM Micrograph we can come to conclusion that as reinforcement increases, interface bond between matrix and reinforcement reduces therefore porosity increases and corrosion rate increases.

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