# Effect of The Reinforcing by WC on Microhardness, Roughness and Corrosion Behavior of Al-12Si Alloy

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## ABSTRACT

This work investigated the effect of Tungsten Carbide as reinforcement with 1, 2 and 3 wt.% on some properties of matrix Al-12Si alloy. Al-12Si/WC composites were fabricated by stir casting method. Micro hardness and roughness have been tested to investigate the role of WC reinforcing. Corrosion behavior of these composites also investigated in 0.2M HCl solution using the potentiostat instrument.

The results show a good incorporation between the matrix and WC particles with probability to form $Al_{12}W$ and $Al_4C_3$ phase in addition to eutectic structure of Al-12Si alloy. The micro hardness was increased with increasing the weight percent of WC, while the roughness was decreased due to the better interfacial bonding. Corrosion protection properties of composites were better than that of base alloy due to the behavior of WC as a cathodic site which reduces the dissolution of metals from the metallic surface.

**Keywords:** Al-Si composites, WC, Stir casting.

## INTRODUCTION

The application of composite materials governed by selection of a suitable matrix. The light metal composite materials are mostly used as matrix materials which have stiffness, strength and lightness [1]. To produce properties that are fit to given propose must choosing a proper combination of matrix and reinforcement of material civil, modern aviation and both military is a prime example.

In aeronautic, astronautic, and automobile industries Al–Si alloy is mostly used because it has a microstructure consists of a coarse silicon phase in eutectic matrix (fibrous). But the poor properties of Al–Si alloys, due to the brittleness coarse silicon crystals which lead to initiation of crack and fracture in tension [2-5].

Tungsten carbide is a gray powder uses in cutting tools, industrial machinery, abrasives, armor-piercing rounds, instruments, other tools and jewelry. WC oxidizes at 500–600 °C and resist to acids except mixtures of hydrofluoric acid/nitric acid ($HF/HNO_3$) above room temperature [1].

Many authors highlighted to study properties of of Al-Si alloy and its composites, Suresh et al. fabricated Al–Si–Mg composites by adding Beryl/ containing (2–10 %) by squeeze casting [5]. Alo et al. studied the effects of silicon and silicon carbide particles contents on the hardness, microstructural and thermal behavior of Al-Si-$SiC_p$ composites by using stir casting method [6]. While Rana studied the effect of yttria with three wt. % (1, 2 and 3 %) on the corrosion measurement of Al-Si-Cu alloy in alkaline solution [7]. Other researchers studied the effect of



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carbide on properties of aluminum matrix composites especially silicon carbide and boron carbide [8-16].

This work aims to study the effect of WC as reinforcement for Al-12Si alloy through testing micro hardness, roughness and corrosion behavior in 0.2M HCl at room temperature.

**Experimental Procedure**

**Synthesis of Al-12Si/WC**

To produce Al-12Si/WC composites used stir casting method. Al put in a crucible and melted it at 700 °C with 5 °C/min. Si powder (with purity 97.4%, China) was added to melted aluminum with 12wt.% to obtain Al-12Si matrix. Electrical Stirrer (Arrow, Model 850, 1000 rpm max, 120V and 60Hz) used to stirring and immersed in a liquid metal during preparation. The appropriate amount of WC with (purity 99.7%, China) was added in the liquid metal (with 1, 2 and 3 wt.%) by a funnel during the mixing process. After the addition of reinforcements to liquid matrix and stirred for about 3 min at 300 rpm to allow for WC particles in homogeneous in the mixture. When stirring was completed, the liquid melt was poured in to steel mold with dimension 20 mm diameter and 170 mm height and cooled to room temperature.

The base alloy was examined by Spectro MAX to get chemical composition as shown in Table (1).

**Sample Preparation**

Fabricated specimens were cut to a cylindrical shape (20 mm diameter and 4 mm height), grinded and polished with emery papers with 500, 800, 1000 and 1200 grid mesh and then rinsed with acetone.

**Optical Microscopy**

The microstructure evolution was investigated by means of optical microscope using (POLARIZING MICROSCOPE model MT9430 MEIJI TECHNO CO. LTD., Japan) microscope which connected to a computer at a magnification of 20X. The specimens were etched by Killers solution (2 ml HF +3 ml HCl + 5 ml $HNO_3$ + 190 ml $H_2O$) as etchant for 10-30 sec for optical examination.

**Microhardness**

HVS-1000 micro hardness tester from (LARYEE, China) has been used for measuring of micro hardness of specimen according to ASTM E384 and ISO 6507. The used indenter was made of Diamond Head and gave similar indentations at all testing forces, with a load of 9.8N for 15 seconds in the micro hardness tester. Averages then obtained from these measurements.

**Roughness**

The roughness was tested by TA 620 measuring platform with TR200 hand-holding roughness gauge and TR240 portable roughness gauge.

**Corrosion**

M Lab 200 potentiostat/Galvanostat with SCI software was used for electrochemical measurements at a scan rate 5 $mV.sec^{-1}$, to obtain corrosion data by changing the potential, ($E_{oc}$) ±200mV. Tafel extrapolation method used to measurement the corrosion current density ($i_{corr}$) and corrosion potentials ($E_{corr}$).

## Results and Discussion

### Structure Examination

Optical examination of Al-12Si alloy and its composites is shown in figure (1) with three weight percent of WC include (1, 2 and 3), 12% Si in Al alloy has eutectic composition which may be acicular or lamellar and then produce large plate with sharp sides and edges. The microstructure consists of well-developed equiaxed grains (α-Al), spherical Si particles (Eutectic Si) and fine intermetallic phases. Micrographs of composites reveal that there is fairly uniform distribution of WC in Al-Si base alloy as observed by Swamy et al. [17] who fabricated Al 6061/WC MMCs.

Figure (1) also indicates that the porosity is low in composites which suggest the higher hardness may be getting in MMCs. The main suggested intermetallic in fabricated composites is $Al_{12}W$ in addition to form $Al_4C_3$. This phase also observed by Ehsanto identify the structure of WC-Co particles reinforced aluminum matrix [18]. The $Al_{12}W$ phase is revealed at interface between matrix and reinforcement and close to the WC particles. Increasing the weight percent of WC led to increasing the participation of the phases at interfaces between Al and WC.

### Microhardness and Roughness

The matrix-reinforcement interface can be characterized by micro hardness measurement. Since the movement of the ceramic particles can be hindered by strong adherent between matrix and reinforcement and vice versa. Consequently, micro hardness test identified the goodness interface bonding. The data of micro hardness of Al-12Si alloy and its composites with WC are listed in Table (2). These data show the increasing in micro hardness after adding WC as reinforcement from 75.02 to 125.015 MPa. This result confirms the strong boding between Al-alloy and WC as illustrated in optical examination. Simon et al. also obtained the improvement in hardness and wear rate of Al/WC composites [19]. The current result also indicates that WC successfully incorporated into the matrix.

The data of roughness in Table (2) indicate the decreasing in roughness for composites compared with base Al-12Si alloy. The lowest roughness was equal to 0.058 µm after adding 2%WC as reinforcement. The optical examination showed the uniformly distribution of WC at matrix/reinforcement interface with low porosity and high hardness, these observations lead to decreasing in the roughness of composites and get good surface finish.

### Corrosion Behavior

Tafel plots of Al-12Si alloy and its composites are shown in Figure (2). This figure indicates the cathodic and anodic regions as a behavior of base alloy and its composites in acidic medium (0.2M HCl solution). Since at cathodic sites, the reduction of hydrogen ions takes place as follow:

$2H^{+} + 2e \rightarrow H_2\uparrow$ …………(1)

While at anodic sites, the aluminum undergoes the dissolution to ionic form according to the following reaction:

$Al \rightarrow Al^{3+} + 3e$ …………(2)

Chloride ions increased the dissolution of metals due to chemically bonded of $Cl^-$ to formation of different mixed oxohydroxo – and chloro complexes according to the following formula [20]:

$Al[O_x(OH)_y(H_2O)_z] + Cl^- \rightarrow Al[O_x(OH)_{y-1}Cl(H_2O)_z] + OH^-$ ………….(3)

$(AlOOH)_4.H_2O + Cl^- \rightarrow (AlOOH)_3.AlOCl.H_2O + OH^-$ …………(4)

$AlOOH + Cl^- \rightarrow AlOCl + OH^-$ ………….(5)

$Al(OH)_3 + Cl^- \rightarrow Al(OH)_2Cl + OH^-$ ………….(6)

Finally the $[AlCl_6]^{3-}$ complex is produced.

The presence of WC as reinforcement in composition of Al-12Si alloy led to shifting corrosion potential to noble direction in addition to get smaller corrosion current density especially with 2 and 3%WC. This behavior suggests that WC particles behave as cathodic sites where reduction reactions can occur and reducing the dissolution of metals in corrosive medium for Al-Si alloy [21].

The Tafel slopes were very much influenced in the presence of WC particles in composition of composites. Generally, the cathodic and anodic Tafel slopes ($b_c$&$b_a$) were decreased for composites compared with base alloy and anodic Tafel slopes have values higher than those of cathodic Tafel slopes. It is inferred that the rate of change of current with change of potential was smaller during anodic polarization than that during cathodic polarization due to the behavior of $Al_{12}W$ phase.

The film formed on material surface leads to get small slope. This means that the metal dissolution reaction is obstructed. In spite of these obstructions, the electrochemical reaction may be occurring because of permeability of ions and electrons across oxide layer [22].

The data of corrosion rate shows decreasing of dissolution of Al in composites compared with Al-12Si alloy as shown in Table (3).

## CONCLUSION

Aluminum matrix composites (AMCs) take a wide range to use in many applications. This is needs to investigate the properties of any fabricated AMC. Optical microscopy was characterized interaction between the matrix and reinforcement. Micro hardness and roughness were tested and the results showed the increasing of micro hardness due to strong bonding between Al matrix and WC particles and this also led to decreasing the roughness to get good surface finishing. Corrosion behavior of base alloy and its composites with WC was examined in 0.2M HCl and the results indicated the decreasing in corrosion rate for composites compared with base alloy due to good interaction between matrix and WC which successfully incorporated in Al solid solution with higher hardness and low roughness which reduces the formation of galvanic cells on the metallic surface.

**Table (1) Chemical composition of experimental alloy**

| Element | Si | Cu | Fe | Zn | Mg | Mn | Ti | Al |
|---|---|---|---|---|---|---|---|---|
| Wt% | 12.2 | 1.0 | 0.8 | 0.6 | 0.4 | 0.3 | 0.5 | Rem. |

**Table (2)Micro hardness and roughness of Al-12Si alloy and its composites.**

| Specimen | MicrohardnessMPa | Roughnessμm |
|---|---|---|
| Al-12 Si alloy | 75.02 | 0.182 |
| Al-12/1%WC | 78.21 | 0.152 |
| Al-12/2%WC | 86.15 | 0.058 |
| Al-12/3%WC | 125.015 | 0.062 |

**Table (3) Corrosion parameters of Al-12Sialloy and its composites in 0.2M HCl solution**

| Specimen | $E_{corr}$ mV | $i_{corr}$ μA/cm$^2$ | $-b_c$ mV/dec$^{-1}$ | $+b_a$ mV/dec$^{-1}$ | $C_R$ mpy |
|---|---|---|---|---|---|
| Al-12 Si alloy | -901.6 | 61.98 | 123.3 | 121.9 | 26.5322 |
| Al-12/1%WC | -665.9 | 60.56 | 99.9 | 116.4 | 25.9243 |

| | | | | | |
|---|---|---|---|---|---|
| Al-12/2%WC | -697.9 | 10.92 | 97.3 | 100.5 | 4.6746 |
| Al-12/3%WC | -663.0 | 9.230 | 39.9 | 57.4 | 3.9511 |

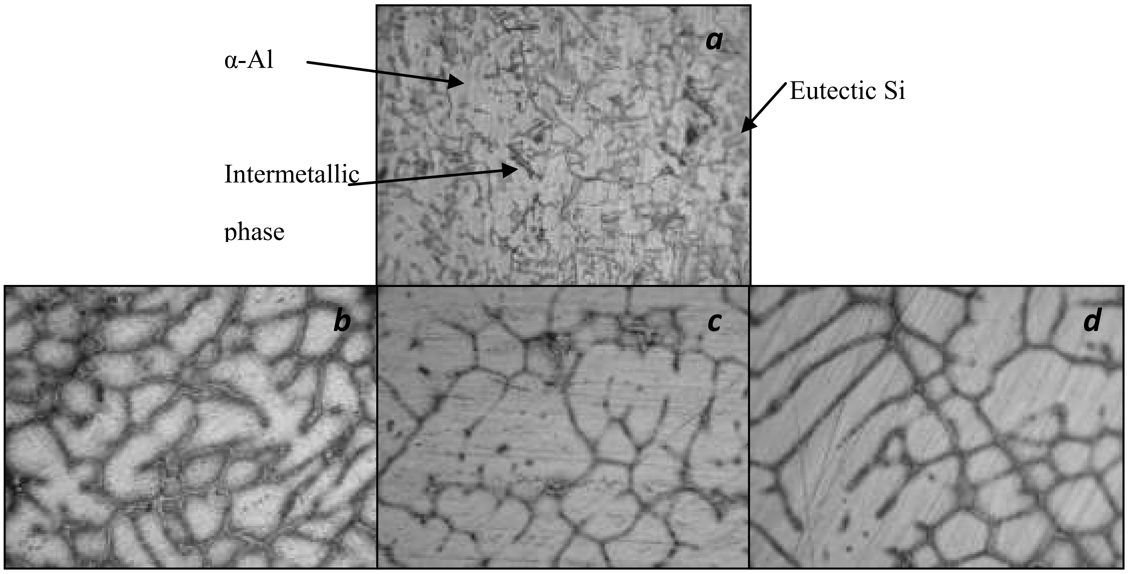


**Figure (1) Optical microscopy images of Al-12Si alloy (a) and its composites with 1%WC (b), 2%WC (c) and 3% WC (d)**

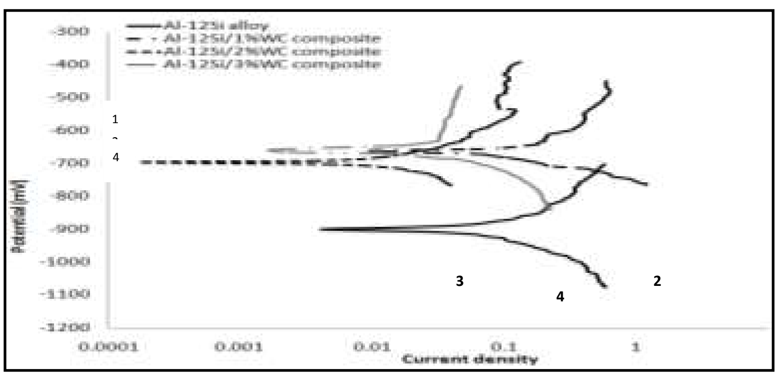


**Figure (2) Tafel plots of Al-12Si alloy and its composites With three percents of WC in 0.2M HCl solution.**

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