Microstructure and Mechanical Properties of Al-Mg-Si Hybrid Composites Reinforced with SiC/TiO₂

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Abstract:

The current work aims to investigate the influence of adding different weight percents of TiO2 and SiC 1.5:0,3:0, 4.5:0, 0:1.5, 0:3, 0:4.5, 1.5:1.5, 3:3, 4.5:4.5 particulate reinforcement on mechanical and microstructure characters of base alloy Al-Mg-Si. The base alloy and composites as hybrid were set via method of stir casting. The mechanical characters of base alloy and composites as hybrid were detected by using hardness and tensile tests. The electron microscope as scanning (SEM) and spectroscopy of dispersive energy (EDS) were utilized for inspection of the topography of fracture surfaces. The results were showing that the strength of tensile as ultimate, strength of yield, and hardness, elevated with elevating the weight reinforcement percentage to 4.5% of TiO2/ SiC. In contrast, the rate of elongation is decreased. The optical microscope inspection represents that the particles distribution in the matrix is uniform without any voids. The X-Ray diffraction manifested the presence of different phases and inter metallic compounds Mg5Si6, Mg2Si, Al2O3, Mg6Si3.3., Al3Mg2 and Al3Ti.

Keywords: Vortex method, single composite, hybrid composite, mechanical properties

1. INTRODUCTION

The matrix composites of Al- metal were utilized widely in different industrial uses i.e., electronic packaging, sporting goods, and automotive industries. The Al-alloys are more active because of their best properties for corrosion resistance, low density, the best thermal and electrical conductivity, and improving the strength by precipitation hardening [1]. Al-metal matrix composites contain reinforcement materials carbides, or oxides (SiC, AlN, B4C, TiC, Si3N4, TiB2, TiO2) integrated into the matrix of Al that offers unique more characters compared to matrix Al-alloys . Such including resistance enhancement of creep ,resistance of abrasion , remarkably well strength / weight , and ratios stiffness / weight, stability of dimensional, and best performance of elevated -temperature [2].Matrix composites of Al-possess excellent mechanical properties and wear resistance in comparision to Alalloys irrespective of load being applied and speed of sliding. Such is chiefly due to particles being hard i.e., Al2O3,WC and SiC,etc. When dispersed in the matrix, make it restricted plastically and enhance base alloy temperature elevation[3]. Most of the composite materails reinforced with particles by liqued metallurgy method(or so- called vortex method) have the advantage over the traditional techniquesas simple, inexpensive, good binding to the matrix, more comfortable to control the composition of the mixture, flexibility, and application for larger production quantities. Numerous studies and reserchers have been published in this field.

Ashok et al.[4] investigated the best wear parameters of Al /6061-T6 reinforced by adding 15wt%Al2O3 and 15 wt% SiC particulates having a particle size of 37 μ m. The results represent that

the incorporation of Al₂O₃ and SiC prefers to anelevating the wear hybrid composites resistance. Kenneth et al. [5] investigated the Al-Mg-Si matrix wear behaviour and corrosion reinforcing by the ash of silicon carbide(SiC) and rice husk ash (RHA). SiC and RHA mixed in proportions of weight as 0:1, 1:0 1:3, 1:1, and 3:1 were utilized. Results obtained showed that resistance of wear for composites as hybrid was better comparing to the matrix alloy of Al-Mg-Si reinforcing by only SiC. Also, the alloy reinforced with SiC and RHA enhancing the resistance of corrosion resistance in a 3.5% NaCl solution. Kataiah et al. [6] investigated the influence of TiO₂ with particles size 30-50 µm additions by different weight percentage 0% to 20% on mechanical Al-Mg-Si base alloy features. The production of composites via vortex method. The results showed that hardness and the ultimate strength of tensile increased, but the flexibility decreased with increasing the weight reinforcement percentage. Alaneme et al.[7] investigated alloy of Al-Mgbehaviours and corrosion reinforcing via bamboo leaf ash (BLA) and Si wear alumina .Thereinforcement powder consists of 0:10, 2:8,3:7, and 4:6 theleaf ash of the bamboo and alumina weight percentage respectively. The corrosion and wear test performed to assess the resistance of the composites in 3.5 NaCl solution. The wear behavior of the single and hybrid composite studied by using a load of 25 N was utilized for 1000 seconds at 5 Hz speed. The results represent that the composites corrosion resistance decreased with additons of BLA in 3.5 % NaCl, but therate of wearof the a hybrid composite containing 4wt% BLA was noticedasmore than composites.

2.Experimental work

In this research, we used two types of particles (SiC and TiO₂) with particle size ($<75\mu$ m) as a reinforcement phase embedded in Al-Mg-Si as a matrix phase, the table (1) show the alloy chemical composition.

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Elements	Si	Fe	Cu	Mn	Mg	Cr	Ti	Zn	Al
Casting alloy	0.53	0.27	0.181	0.041	0.954	0.067	0.014	0.004	Bal.
Standered alloy	0.4-0.8	Max.0.7	0.15-0.4	Max.0.15	0.8-1.2	0.04-0.35	Max.0.15	Max.0.25	95.8- 98.6

 Table 2: Alloy of Al-Mg-Si chemical composition (wt%)

Figure (1) and (2) represent the SEM and EDS examination of powders.



Figure 2:Particles of TiO₂,(A) SEM,(B)EDS.

Alloy of Al-Mg-Si was melted in crucible of alumina at 700 $^{\circ}$ C in furnace being electric and then pouring in steel mold at 250 $^{\circ}$ C preheated to the prepared base alloy. The composites have been prepared by stir casting method where it was melting the alloy of base in a furnace being electric at 750 $^{\circ}$ C, that is over temperature of liquidus .Melt was held at such temperature for approximately fifteen minutes for compostion homogenization , then added flux(1%wt.). Materials of reinforcing (titanium oxide and SiC) added gradually to the alloy molten along with stirrerbeing mechanical , addition of particulates with 1.5:0,3:0, 4.5:0, 0:1.5, 0:3, 0:4.5, 1.5:1.5, 3:3, 4.5:4.5wt % was used, that they were wrapped by Al- foil and to 550 $^{\circ}$ C preheated for one hr.for moisture removing and to assist improving wettability with alloy melt of Al-Mg-Si following vortex production within melting via stirrer being electric of rotational speed (800 r.p.m) for obtaining a good reinforcing dispersion within the melt. Addition of Mg (1wt%) to improve the wettability between the base metal and reinforcement. Then, melting pouring mold preheated to obtain material as composite for reinforcing through particles of TiO₂andSiC, where process for all additions is replicated .After preparation of all samples

of the base alloy and composites, it has been done a machining process(turning) for castings according to the standard dimensions required for each test.

3.Examinations and Test

3-1 Microstructure Examination

The Al-Mg-Si alloy cast and composites hybrid samples in dimensions of (15x10) were cut. Samples were arranged by grinding and polishing, then etching by 1%Hf. Specimens prepared were tested using microscope as metallurigical aided with digital camera of an optical microscope to study the microstructure. "SEM" and (EDS) detector have been utilized type of ((VEGA 3 LM)) to invetigate the reinforcements topographic and specimens after tensile test and to obtain the micro-chemical composition. Diffraction inspection as X-ray were advanced to detect the resulting composites and base alloy phases.

3-2 Test of Tensile

Test of tensile was continued for samples following (ASTM E8) prepared as standard as illustrated atFigure (3), test of tensile was done via utilizing machine of Instron (DWD-200E).



Figure (3) Standard specimen of tensile test [8].

3-3 Hardness Test

Tester of Vickers was utilized to hardness measurment for the base alloy and composites after prepared. The applied load was (200 g) for dwell time (15 sec). And five readings of hardness value were taken in each sample to more accuracy.

4.Results and Discussion

4.1 SiC and TiO₂ additives effect on Al-Mg-Si alloy microstructurer

The most crucial element in obtaining a homogeneous discontinuously property of composites reinforced material is the best uniform ceramic reinforcement particles dispersion. Figures (4 -

7)observation that the micro-structure almost nodular in a shape, and the distribution is uniform partialyall through the matrix in association with the particles coalescence at the grain boundaries and inside the grain. It is anticipated that the contact between the ceramic particles of renforcing and Almelt resulting in layer of iteraction that enhances the wetability between the base alloy and ceramic particles.



Figure (4) Base alloy microstructure



Figure (5) Micro-structure of (a) 1.5% TiO₂ composite, (b) 1.5% SiC composite, (c) Hybrid1.5%



a

b

с

Figure (6) Micro-structure of (a) 3%TiO2 composite, (b) 3%SiC composite, (c)Hybrid 3%



Figure (7) Micro-structure of (a)4.5% TiO₂ composite, (b)4.5% SiC composite, (c)composite4.5% hybrid

The reaction at the interfacial between reinforcement and metal matrix in the base alloy is so significant due to upper bonding as interfacial allows load transfering and distribution from matrix to support.Figures (8-17) highlighted diffraction of X-ray results which illustrated the precipitates Al-phase and different compounds being intermetallic i.e., Mg₅Si₆, Mg₂Si, Al₃Mg₂, Mg₆Si_{3·3}, Al₃Ti and Al₂O₃.



Figure (8) Al-Mg-Si alloy analysis of diffraction X-Ray



Figure (9) 1.5% TiO₂ analysis of diffraction X-Ray







Figure (11) 1.5 hybrid composite analysis of diffraction of X-Ray.



Figure (12) 3%TiO₂ analysis of diffraction of X-Ray



Figure (13) 3% SiC analysis of diffraction of X-Ray



Figure (14) 3% hybrid composite analysis of diffraction of X-Ray



Figure (15)4.5%TiO₂ analysis of diffraction of X-Ray



.Figure (16) 4.5%SiC analysis of diffraction of X-Ray



Figure(17)4.5 % hybrid composite analysis of diffraction of X-Ray.

4.2 Tensile Test

Figure 18 represents the relationship between the weight reinforcement percentage and strength of yield, strength of ultimate, and elongation. The ultimate and strength of yield elevated with increasing the weight support percentage, whereas the rate of elongation decreased. The reason is that hardened particles being ceramic nature that composite added has bonding being strong between matrix and particles [9].





Figure (18) Correlation between, (a)Ultimate strength and weight percentage of reinforcement, (b) Yield strength and weight percentage of reinforcement, (c) Elongation and weight percentage of reinforcement

The X-ray showed the presence of different intermetallic compounds, such as $(Mg_5Si_6, Mg_2Si_{3.3}, Al_3Mg_2, Mg_2Si_., Al_3Ti, and Al_2O_3)$. Such precipitates scattered in alloy base and also, the variance in thermal cofficient expansion between particles of ceramic and matrix led to the results in amassed dislocations density in matrix [10]. For passing dislocations via the scattered particles in a matrix , such particles operate as a barrier to alter the alloy base because of coherence being active between particles of reinforcement and alloy base led to high interfacial bond resistance permitting transfer of load between particles of reinforcement (particles of SiC and TiO₂) and matrix . Also , it can be noticed that elongation declines due to particles of ceramic elevate brittleness . Figure (19) denotes the fracture shape following the tensile test .



Figure (19) Samples after tensile test

Figures (20-29) display the fracture surface examined by elemental mapping using a scanning electron microscope. The fracture composites surface reinforced with particulates of SiC and TiO₂ primarily contains a bimodal dimples distribution .Dimples of large size are connected with the ductile matrix fracture , nevertheless the specimen of tensile composite fractured in fashion as brittile with no whichever obvious necke formation and few numbers of dimples. Such might because gtowth of void nucleation , and coalescence rapidly occurred ,and all this added to fracture being final. Also localized

crack proning inititation and elevated embittlement influence is because of local concentration sites stress at matrix interface and reinforcement .









m 50µm 50µm

.Figure (21) Elemental composite 1.5% TiO2 mapping via SEM utilizing



.Figure (22) Elemental composite 1.5%SiC mapping via SEM utilizing



Figure (23) Elemental 1.5% hybrid composite mapping via SEM utilizing.



Figure (24) Elemental composite 3%TiO₂ mapping via SEM utilizing





Figure (25) Elemental composite 3%SiC via SEM utilizing.



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Figure (26) Elemental 3% hybrid composite mapping of via SEM utilizing'





Figure (27) Elemental composite 4.5% TiO₂ mapping via SEM utilizing.





Figure (28) Elemental composite 4.5%SiC mapping via SEM utilizing



Figure (29) Elemental 4.5% hybrid composite mapping via SEM utilizing

4.3 Testof hardness

Figure 30 manifests the link between the base alloy hardness values composites, being hybrid and single. It was noticed the composites hardness elevated by increasing the weight reinforcement particles % because of such particles turn as refining composite materail grains. The composite hardness increase because of hardness being high and thus increases strength based on equation of Hall Petch ,which represents the link between size of grain and hardness. this obstructs the dislocations movement , also shows that the composite as hybriddisplayes greater hardness compared to composite as single. The resistance deformation to plastic being localized is elevate because of particles are an impediment dislocatios to movement and because of $Mg_6Si_{3.3}$ that is often considered the most effective , also , the

an intermetallic compound prescipitate such as Mg₂Si, Al₃Mg₂, Al₃Ti and Al₂O₃. Alsothe more added ceramic particles to composite declines distance of inter-particulate between particles of hard SiC and TiO₂ resulting in elevation in dislocations pile- up. One excessive benefit of such strength of dispersion influence is that it is reserved eventhough for lengthy times and times and at increased temperatures . Also figure displayes that the composite hardness increase in the resistance of the dislocations movement [11]. The composite hardnesse increase because of the high reinforcement particles hardness, to resistance increase of localized deformation plastic because of needle-shaped β " phase Mg₂Si that is frequently regarded as mostly operational precipitate of hardening the intermetallic Mg₂Si_{3.3}, Al₃Mg₂, Mg₂Si, Al₃Ti and Al₂O₃ [12, 13]. As more addition of compound precipitate ceramic particles to composite, the decline in distance of inter-particulate between the hard particles SiC and TiO₂ leads to elevation in pile-up dislocation. One pronounced benefit of such strength of dispersion influence is that it is reserved eventhought at high temperaturse and for lengthy times .Figure 28 also demonstrates that the composite reinforcement hardness with SiC is greater compared to reinforced composite with oxide of titanium since SiC has a greater hardness in compairson to base alloy and $TiO_2[13,14]$.



Figure (30) The relationship between hardness and reinforcements

5. Conclusions

1- Improve the base alloy microstructure after particles addition of SiC and titanium oxide where the change from dendrites structure to parallel axes structure roughly.

2- The hardness elevated with elevating the weight percent of SiC and TiO₂ additions.

3- Strength of yield and tensile increased by increasing the wt% additions of TiO_2 and SiC.

4- The elongation decreases for single and hybrid composites with increasing the TiO_2 and SiC weight percentage.

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