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Al-Cu-Si - $(Al_2O_3)_p$ composites using A 384.1 Al Alloys.

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Al-Cu-Si $(Al_2O_3)_p$ composite containing 5% Al_2O_3 with particle size 0.220 µm were fabricated by modified stir casting technique. The addition of Al_2O_3 in A.384.1, Al Alloy was found to increase hardness, proof stress and ultimate tensile strength. The fabricated composites showed higher peak hardness and lower peak ageing time as compared to the unreinforced Al alloy. In addition, ageing is found to increase the strength, micro and macro-hardness of the fabricated composites. The reinforced composite samples with different particle sizes of Al_2O_3 i.e. 0.220, 0.106 and 0.053 µm were also fabricated to further investigate the interfacial characteristics. It is observed that the samples with small particle size exhibited clustering, whereas, the larger particles were found to mix up homogeneously in Al alloy matrix.

Key Words: Al Alloys, composites, ageing, X-ray diffraction.

INTRODUCTION

Composite materials are designed and manufactured to have physical and mechanical properties suitable for the engineering applications. As compared to un-reinforced alloys, the reinforced materials are generally brittle and have a small elongation to tensile failure and low fracture toughness[1-2]. However, Al/Al alloy based ceramic particulate composites exhibit relatively promising characteristics as compared to others. Although there are a few reports on Al/Al alloys based MgO, SiC and Al_2O_3 composites in recent years[3], but as a whole these composites have been rarely investigated and thus received relatively limited attention. A number of methods have been reported in literature for fabricating these alloy composites[3] but due to high cost of manufacturing many of them have limited use[4]. Melt stir casting technique is the simplest and most economical fabrication method for these materials. In earlier studies, stirring of the melt has been done in open air[4]or using a furnace having provision to create an inert environment[3-4]. A simple modification of the conventional technique as proposed by Surappa & Rohatgi [3] leads to remarkable improvement in this method. Besides the other components required in the technique, we have an additional steel cover fitted with glass wool lining to make an inert atmosphere in order to prevent reaction of aluminum with environmental gases.

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EXPERIMENTAL

A simple and cost effective experimental set up for melt stir casting as described above has been used in this study. The base A384.1 Al alloy was melted in an alumina crucible in furnace up to 810°C. The steel cover was then removed to add the preheated (810°C) Al_2O_3 particles in the melt. A protective atmosphere was maintained during stirring by holding a pipe carrying inert gas over the melt. After the addition and through mixing, the melt was poured into tool steel moulds. Samples, with particle sizes of 0.220, 0.106 and 0.053 µm containing 5% (wt) of Al_2O_3 particles were fabricated successfully. The structural and micro-structural characterization of these composites was done using X-Ray Diffraction (BRUKER-D-8-ADVANCE) and SEM/EDAX (FE-I-200F-QUANTA). The sample preparation for these studies was done first by polishing the sliced samples with emery paper up to 1200 grit size, followed by polishing with Al_2O_3 suspension on a grinding machine using velvet cloth. Finally, the samples were polished with 0.5 µm diamond paste. Vickers Microhardness of the un-reinforced alloy and composites has been measured using a Dynamic Ultra Micro Hardness Tester ™ (DUMHT) at a load of 75gm. Brinell Macrohardness (BH) was also measured using Indentec Hardness Tester™ (IHT) in the cast and peak aged conditions at a load of 62.5 Kg. The tensile properties were measured at room temperature using standard ASTM method at a strain rate of 10^{-3} s^{-1}. Compressive tests were carried out at room temperature on cylindrical specimen with a diameter of 8mm and a height of 8 mm using a Dartec Machine™ with a constant strain rate of 10^{-3} s^{-1}. Some concentric grooves were made at both the faces of the specimen to retain the lubricant.Both the tensile and compressive tests were also done at peak aged conditions to assess the effect of the heat treatment on mechanical properties. Samples were heated to 530^{0}C for 2 hours, and then quenched in the water kept at room temperature. The quenched samples were transferred to an oil tank and heated to a temperature of 165^{0}C for aging. Again micro-hardness measurements were carried out using DUMHT at an interval of 30 minutes to determine the peak hardness and time of peak ageing.

REULTS AND DISCUSSION

Density and Porosity, hardness, Compressive and Tensile properties

In Table-1 the results of density and porosity measurements of un-reinforced Al alloys and composites has been shown. More density is registered in composite-I as compared to other composites and unreinforced alloys. But the composite-III has more porosity as compare to others.

Table-2 show micro-hardness and macro-hardness of the unreinforced Al alloy and the composites in the as-cast and peak aged conditions. The matrix of composites contains higher dislocation density due to mismatch in thermal expansion coefficient between the matrix and the reinforcement. This results in

Table-1 Density and Porosity of the un reinforced Al Alloy-A384.1 and its composites

Property	Al Alloy	Composite-I (Al_2O_3 0.220 µm)	Composite-II (Al_2O_3 0.106 µm)	Composite-III (Al_2O_3 0.053 µm)
Density (gm/cm^3)	2380	2521	2499	2491
Porosity	2.01	3.13	3.19	4.01

Table-2 Macro-hardness and Micro-hardness of un reinforced Al alloy-A384.1 and its Composites in the as cast and peak aged conditions (sizes of the particles vary from 0.220~0.53µm)

	Property	Al alloy	Composite-I	Composite-II	Composite-III
Micro-hardness	As cast	106	108	110	110
	Peak aged	166	182	189	193
Macro-hardness	As cast	97.3	103	103	105
	Peak aged	107	111	115	116

Table-3 Compressive and Tensile properties of un reinforced Al Alloy-A384.1 and its composites at peak aged conditions.

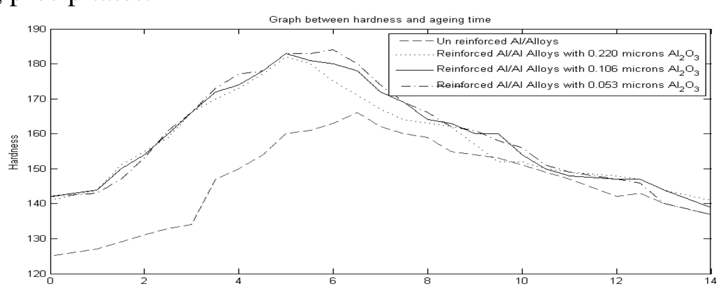
Material	Compressive properties			Tensile properties		
	0.2% Proof stress (MPa)	Compressive strength (MPa)	e_f (%)	0.2% Proof stress (MPa)	UTS (MPa)	e_f (%)
Al Alloy	271.2	521	22.3	267	333.1	7.9
Composite-I	393.1	740	24.3	389	423.69	9.7
Composite-II	394.2	759	25.2	390	424.4	9.9
Composite-III	394.6	761	25.9	392	428.1	10.3

higher hardness in the composites than the unreinforced Al alloy. The macro-hardness and micro-hardness of all the composites studied are higher than the un-reinforced Al alloy in both as-cast and peak aged conditions.

Table-3 shows the compressive and tensile properties of Al Alloy and its composites. 0.2% proof stress and compressive strength of all the composites are higher than the un-reinforced alloy. Al_2O_3 shows higher strength in the as cast and peak aged conditions. This can be explained in the light of integrity of microstructure with particle clustering and porosity. The interface between the reinforced and matrix plays a determined role on mechanical properties of composites[7]. The strength in composites comes from effective transfer of load from the matrix to the particle via the interface[5]. Therefore, in order to realize the strengthening effect of the reinforcement, the interfacial bonding between the particle and matrix must be strong. It can be seen from table-3 that the composites containing Al_2O_3, exhibit higher 0.2% proof stress and ultimate tensile strength (UTS) compared with the un-reinforced Al Alloy.

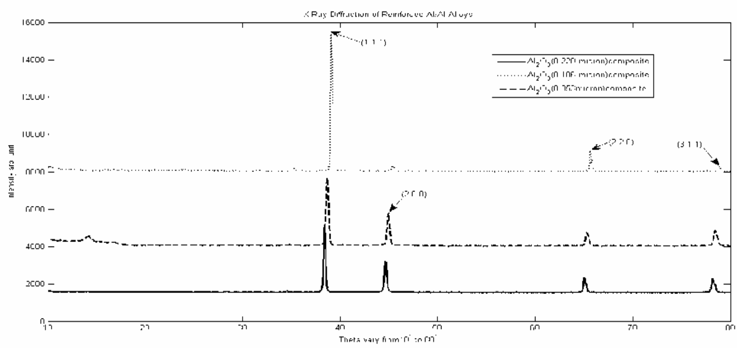
Effect of ageing on mechanical properties:

Graph shows the ageing curves (plots of hardness vs. ageing time) of A 384.1 alloy and its composites aged at165 ^{0}C. Hardness increases with ageing time, achieving peak value and there after decreases. The matrix alloy contains Cu and Mg, which form S_0 (Al_2CuMg) precipitates during ageing, causing an increase in hardness. After the peak ageing time larger precipitates grow at the expense of smaller ones, resulting in a decrease in hardness. It can be observed that peak hardness is higher and peak ageing time is lower in composites compared with the unreinforced alloy. The peak hardness in Al alloys with the reinforcement of Al_2O_3 (particle size varies from 0.220,0.106,0.053 microns) MMC is 182(0.220) at 5.0 Hours,183(0.106)at 5.0 Hours,184 (0.053) at 6.0 Hours compared with 166 at 6.5 hours in the unreinforced alloy. The main strengthening precipitate in the matrix alloy is S_0. S_0 precipitates nucleate heterogeneously on discontinuities like dislocations[6]. Composites contain higher dislocation density near the particle–matrix interface due to the large difference in thermal expansion coefficient between the matrix and reinforcement[6]. Therefore, a large number of precipitates are present in composites, giving rise to higher peak hardness and shorter peak ageing time. Both macro- and microhardness increase significantly after peak ageing (Table- 2). Table-3 also shows the tensile and compressive properties in peak-aged condition. It can be seen that there is a considerable improvement in strength of the alloy and composites after peak ageing, due to the formation of hardening precipitates.



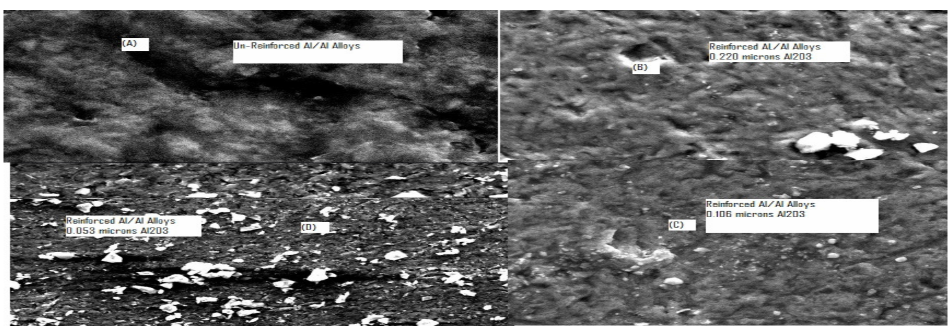
X-Ray Diffractions

The scanning electron micrographs of the samples were taken on a JEOL JSM 480A electron microscope, equipped with energy dispersive X-ray microanalyser. X-ray diffraction studies on the reinforced Al Alloys indicated that samples with 0.220,0.106 and 0.053 microns Al_2O_3 showed peaks corrosponding to orthorhombic symmetry and the metallurgical reaction takes place. With the increase in size of the reinforced particle, the homogeneous and unform distribution of metal in matrix of the composite material increases.



SEM Analysis

SEM analysis of the un-reinforced Al/Alloys and the reinforced Al/Al Alloys with Al_2O_3 have different particle size (0.220, 0.106, 0.053) are shown below from A,B,C,D figures respectively. The Figure D shows more clustering of reinforced with the matrix than the other different size reinforced particles (as in C & B). The interfacial bonding between Al_2O_3 particles and matrix was also observed under SEM. The bonding is good and there is no sign of any interfacial reaction. The higher volume fraction of particles is expected to generate greater thermal stresses. These clusters can generate high thermal stresses and lead to cracking at the interface.



Conclusions

Al–Cu–Si- Al_2O_3 composites are fabricated by a simple and cost-effective stir casting technique. Composites show higher 0.2% proof stress and higher modulus compared with the unreinforced alloy. The composites exhibit higher peak hardness and accelerated ageing compared with the unreinforced alloy. Al–Cu–Si- Al_2O_3 -5% composite shows higher ultimate tensile and compressive strength compared with unreinforced Al Alloy in peak-aged condition.

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