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Microstructures and Mechanical Properties of Al-Si-Mg-Ti/Egg Shell Particulate Composites

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Abstract

Al-Si-Mg-Ti alloys reinforced with egg shell particles were synthesized by stir casting process. Microstructures of the fabricated composites were examined using colour metallographic technique and the mechanical properties of the composites: elastic behaviour, ultimate tensile strength and fracture toughness were investigated using tensile studies. The dispersion of egg shell particles found easier as their specific gravity matches with aluminium alloys. The microstructure of the Al/Egg shell composites revealed aluminium matrix, hard intermetallic phase consisting of Al2Si, Mg2Si, Al3Ti and dispersed particles of CaO. The intermetallic phases found segregated along interdendritic arms. The addition of egg shell also resulted in grain refinement of Al alloys. The yield strength and UTS showed both increasing and decreasing trends. At lower wt.% of egg shell the tensile strength decreased due to formation of rosette grouping. However higher additions (>1.5 wt.%) had increased yield strength and UTS. The yield point of Al alloys became obvious by the addition of egg shell particles.

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Keywords: Al-Si-Mg-Ti/Egg shell Composite; Stir Casting Method; Egg shell particles; Metal Matrix Composite; Tensile Test.

1. Introduction

Aluminium and its alloys have attracted most attention as base metal in metal matrix composites. Reinforcement of submicron or nano-sized particles with aluminium matrix yields superior mechanical and physical properties and alters morphology and interfacial characteristics of nano-composites [1]. PMMCs contain different types of the particles either hard or soft or their mixtures in a metallic matrix. Therefore, PMMCs combine metallic properties (ductility and toughness) with the characteristics of reinforcement particles, often leading to greater strength, higher wear resistance and better properties at elevated temperature depending on the morphology and strength of particles [2].

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The particle distribution plays a very vital role in the properties of the Al-MMCs and is improved by intensive shearing. They are synthesized by dispersing the reinforcements in the Aluminium metal matrix. The advantages of adding the reinforcements are to obtain tailored mechanical, physical and thermal properties [3]. Low cost reinforcement motivated the researchers towards synthesis and utilization of using by-products from industry or naturally available as reinforcement since they are readily available at low cost. David Raja et al. [4] have reported that among various reinforcement used, fly ash is one of the cheapest available reinforcement due to its low density which opens the door for the development of cost effective Al MMCs. Naresh P. [5] reported the development and characterization of metal matrix composite using red mud an industrial waste as a reinforcement for wear resistant applications. Among the production route of metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially due to its many advantages such as its simplicity, flexibility and applicability to large quantity production [6].

Many researchers have reported that Egg Shell contains about 95% calcium carbonate in the form of calcite and 5% organic materials such as type X collagen, sulphated polysaccharides, and other proteins [7-8]. V.S. Aigbodion et al. [9] studied the effects of eggshell on the microstructures and properties of Al–Cu–Mg/eggshell particulate composites. They reported that Egg Shell particles were successfully incorporated in Al–Cu–Mg alloy by using the stir casting technique. The addition of ES particles reinforcement to Al–Cu–Mg alloy increased the tensile strength and the hardness of the Al–Cu–Mg/ES particulate composites but the impact energy is slightly reduced which is mainly attributed to the amount of hard Egg Shell phase in the ductile metal phase.

2. Experimental

2.1. Materials

White Eggshells are used which are obtained from local store in Bhopal-City, India. Al-Si-Mg-Ti alloy is used for this investigation. The aluminium alloy used in the present investigation showed a chemical composition of 5.11 % Si, 2.86% Mg, 0.5% Ti, 1.5% others and 90.03% Al.

2.2. Method

The egg shells were washed, dried in sun light and subjected to ball milling at 300 rpm for 4 hours. Subsequently the particles were sieved and collected from 200 Mesh. The Al alloy used in the present investigation was remelted in graphite crucible. The powdered egg shell was weighed, added into liquid metal, stirred with stainless steel stirrer and casted in cast iron moulds. The procedure was repeated with various weight percent of egg shell particles: 0, 0.5, 1.5 and 3.0 wt%. After casting, the samples were machined to prepare standard specimen for tensile testing [10] and metallographic analysis. A 400 kN UTM (Model: Mechatronic) is used to study the tensile properties of the composites. All the tests were carried out at 27^0C and the strain rate was maintained at $2x10^{-3}$ S^{-1}. The microstructures of the samples were investigated using the techniques of colour metallography. A Weck's reagents (4 gm. $KMnO_4$, 1 gm. NaOH and 100 ml Water) were used to differentiate the phases in the microstructure.

3. Results & Discussion

The similar studies on addition of egg shell on microstructure and mechanical properties were reported elsewhere [9]. The authors had investigated in detail about the chemical composition of egg shells. As reported elsewhere the egg shell primarily consists of CaCO3. The elemental composition of egg shell particles includes Ca, Si, O, C, Mg and P [9]. At high temperatures CaCO3 decomposes and forms CaO, thus addition of egg shell results in dispersion of CaO in the metallic matrix.

The microstructures of Al-Si-Mg-Ti alloy dispersed with different fractions (0, 0.5, 1.5 and 3%) of egg shell are delineated in fig. 1-4. A colour metallographic technique is used to differentiate the aluminium and other intermetallic phases. The Weck's reagent used in the analysis colours the second phase particles while metallic phase is unaffected. The microstructure (fig.1) before addition of egg shell particles reveals Al matrix (light) and intermetallic phase (dark) consisting of Al_2Si, Mg_2Si and Al_3Ti particles [11]. The Ti additions had resulted in grain refinement of these alloys.

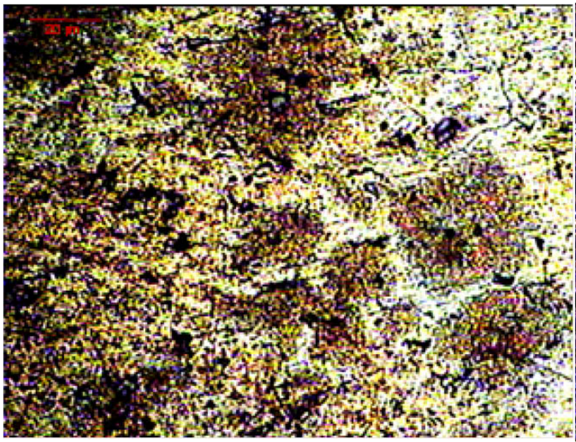

Fig. 1: Microstructure of Al-Si-Mg-Ti alloy before addition of egg shell particles

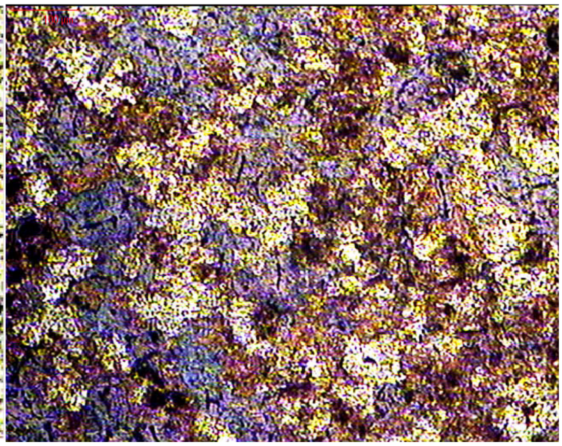

Fig. 2: Microstructure of Al-Si-Mg-Ti alloy with addition of 0.5 wt% egg shell

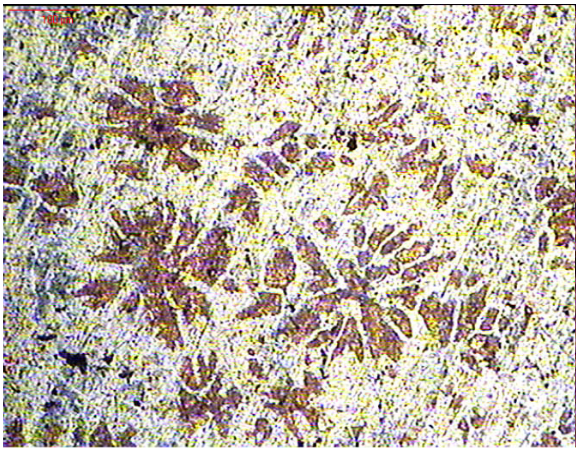

Fig.3: Addition of 1.5 wt% egg shell shows dendrites in the microstructure

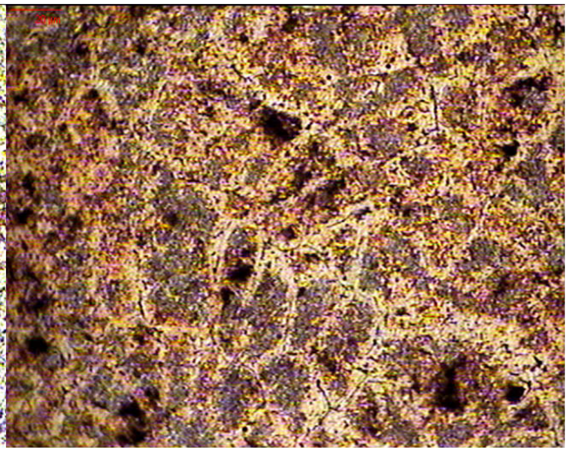

Fig. 4: Microstructure with addition of 3 weight percent of egg shell

Fig. 2-4 shows the microstructure of these alloys after addition of egg shell particles. The addition of egg shell particles had resulted in dispersion of CaO apart from α-Al and intermetallic phases. The light phase in the microstructure is aluminium metallic phase while the dark phase is intermetallic phases. A close observation of the dark phases showed different intermetallic particles. The microstructure also revealed that aluminium solidifies as dendrites and the intermetallic particles found segregated at dendritic arms. Fig. 3 shows the microstructure of Al-Si-Mg-Ti/Egg shell composite with 1.5 wt.% egg shell particles. It clearly reveals that the intermetallic particles and CaO clustered as rosette groups. The formation of rosette groups reduced the strength significantly. On the other hand, Al alloy reinforced with 3 wt.% egg shell particles shows a different morphology. Networks of Al matrix and intermetallic/dispersed phases inside the grains are observed. The addition of egg shell has reduced grain size significantly. Before addition of egg shell the grain size is found to be 257 μm while the grain sizes of 0.5 wt.% , 1.5 wt.% and 3 wt.% ES-Al alloy composites are 207 μm, 134 μm and 103μm respectively.

There are contradictory reports especially on tensile strength of composites reinforced with egg shell. Few studies reported increased tensile strength while others report decreased UTS [11-13]. The tensile properties of Al-Si-Mg-Ti alloy/egg shell composites are illustrated in the stress-strain curve shown in Fig. 5.

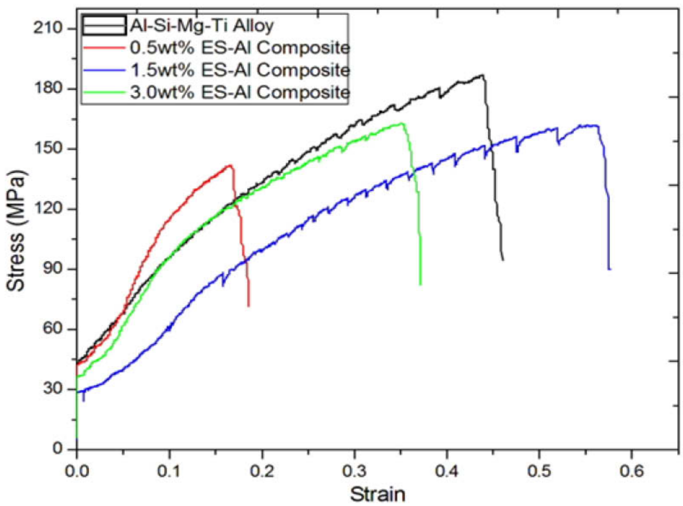

Fig. 5: Tensile behaviour of Al-Si-Mg-Ti/ Egg Shell Composites with varying composition

The tensile strength of the alloy before addition of egg shell is about 187 MPa. On contrary, addition of 0.5 wt% Egg shell particles decreased the tensile strength considerably and is equal to 141.8 MPa. The reduced strength can be attributed to the rosette grouping of intermetallic/dispersed phases. As the weight percent of egg shell particles were increased to 1.5 wt% in Al-alloy, the tensile strength is increased to 162 MPa. On increasing the composition of Egg shell particles from 1.5 wt.% to 3 wt.%, no change in tensile strength is observed and is equal to 163 MPa.

The addition of eggshell had significantly altered the elastic behaviour of Al alloy. The young's modulus, stiffness and yield strength of the alloys were increased by addition of egg shell except 0.5 wt% additions. Unlike conventional Al alloy the yield point is obvious in the alloys added with eggshell. Thus the new composites shows 7-10% reduction in weight and about 8% increase in yield strength. However the fracture toughness of the Al-Si-Mg-Ti alloys is significantly reduced by 0.5% egg shell addition whereas 1.5% addition of eggshell particles increased it by 6%. The fracture toughness of these materials was calculated by measuring the area under the stress-strain curve.The fracture toughness of the composites was reduced about 30-70 percent in comparison to the original alloys. This can be attributed to the weaker interfaces between the matrix phase and second phase dispersed particles.The strain hardening exponent is calculated by non-liner curve fitting carried out in OriginPro Analysis Software v8.0. Mathematical expression used for non-linear curve fitting is shown below (equation 1). Strain hardening exponent for 1.5 and 3 wt.% Al-Si-Mg-Ti/Eggshell composite exhibit very high values as compared to other common Aluminium alloys. The value of Strain hardening factor (n) and Strength Co-efficient (K) are shown in the Table 1 along with other mechanical properties of Al-Si-Mg-Ti/Egg shell composites. Stress-Strain curve of samples are shown in fig 6 after non-linear curve fitting.

$$\sigma = K\varepsilon^{n} \text{ - Equation 1}$$

Where σ represents applied stress on the material,
ε is the strain,
n is Strain hardening exponent,
K is the strength coefficient.

Table 1: Yield Strength of Al-TiB$_2$/Egg shell Composite

Composition	Yield Strength (MPa)	UTS (MPa)	Fracture Toughness ($J \cdot m^{-3} \cdot 10^4$)	Strain Hardening Exponent (n)	Strength Coefficient (K)
0 wt% Egg shell/ Al alloy	90.41	187.09	60.74	0.24	147.45
0.5 wt% Egg shell/ Al alloy	85.60	141.82	18.17	0.25	146.50
1.5 wt% Egg shell/ Al alloy	102.90	162.14	64.53	0.55	236.17
3.0 wt% Egg shell/ Al alloy	107.52	163.03	43.16	0.46	267.61

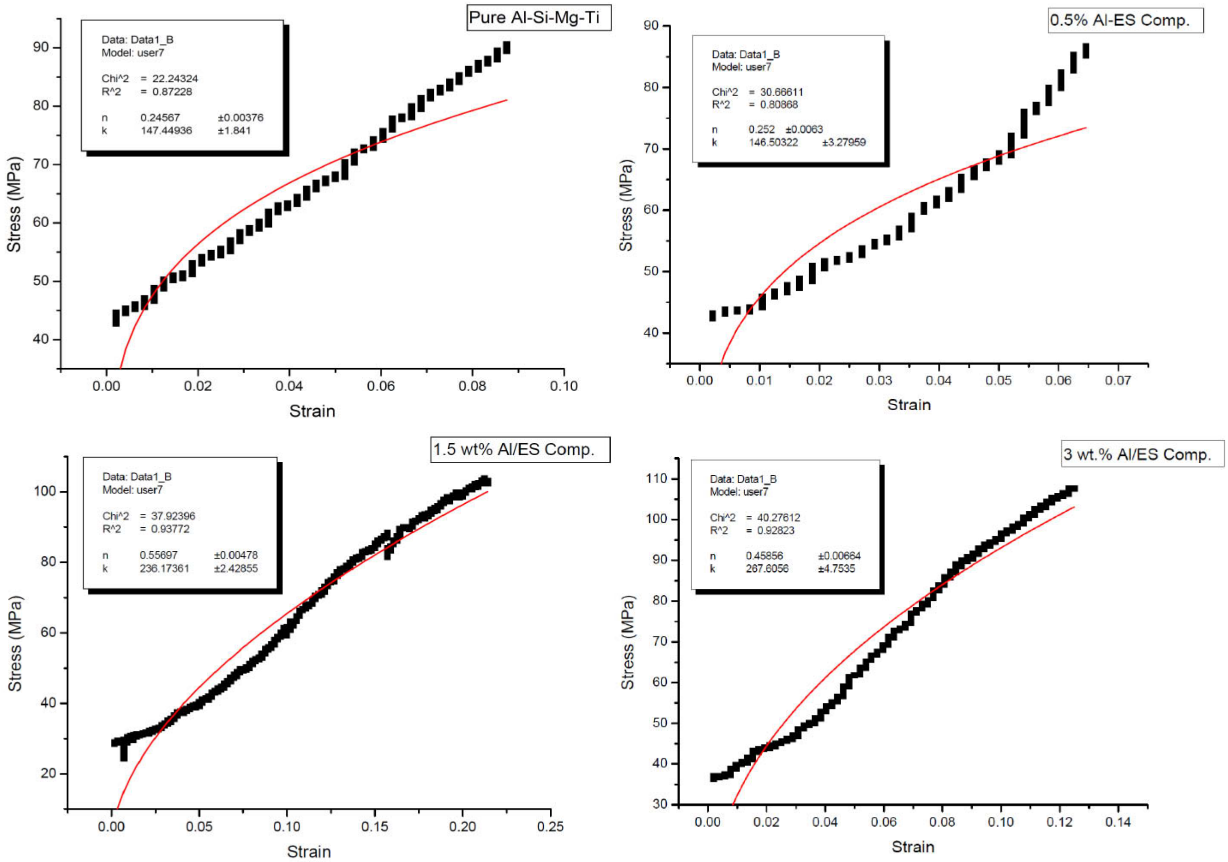

Fig. 6: Stress-strain curve of Al-Si-Mg-Ti/Eggshell Particulate Composites after non-linear curve fitting

4. Conclusions

It could be stated on the basis of the structure micrographs that Egg Shell particles were successfully incorporated in Al–Si-Mg-Ti alloys by using the stir casting technique. The microstructure analysis shows the formation of Al matrix and intermetallic phases at interdendtritic arms. The egg shell addition had formed CaO phase dispersed between intermetallic phases. At lower additions the intermetallics/dispersed phases grouped as rosette groups and reduced the tensile strength of the composites. However at higher additions the Al matrix formed a network like structure and the dispersed CaO had raised the yield strength and tensile strength of the composites. The Al-Si-Mg-Ti/Egg shell composites showed 7-10% reduction in weight and about 8% increase in yield strength. However the fracture toughness of the material is significantly reduced by egg shell addition.

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