Fabrication and Characterisation of Al-Li-SiCp Composite for Aerospace Application

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Abstract— **The desire for more fuel efficient materials in the Aerospace industry leads to the rigorous research on Aluminium-Lithium alloy since early of 19th century. Although the addition of Lithium improves additional benefits like weight reduction and improved elastic modulus of Aluminium but it also adds some of the unavoidable undesirable properties. Hence, in the search of improving the desired properties and reducing the undesirable properties due to the addition of Lithium into the Aluminium, several independent study are being undertaken by many researchers across the world through different processes. One of the methods to achieve this is addition of ceramic particulates (SiCp) with Aluminium-Lithium alloy. Hence, this paper deals with the fabrication of Al-Li-SiCp composite, which were fabricated through modified conventional stir casting machine with Argon gas environment. The present electrical aluminium stir casting machine was modified in such a way that Aluminium-Lithium alloy casting could be performed in that without losing the Lithium content in the alloy. Also the additional modification of stirrer mechanism to move UP and DOWN motion ensures thorough vortex formation in the melt thus allows proper distribution of reinforcements in the composites. The Aluminium alloy used as matrix material in the study is an 8090 Al–Li alloy which has a lithium content of about 2.14%. Two composites were fabricated with different weight fraction such as 2%, and 5% of SiCp (40µm particle size) as reinforcements. The addition of SiC particulates increases the hardness value of the composite as per their weight addition in the composite. In case of the composite reinforced with 5% SiCp, the hardness values are found to be higher than Al-Li-2% SiCp, which is higher than the past reported value from previous study. The FESEM image shows the different distribution surface morphology of reinforcements in the composites. It is evident that the difference of micro hardness value obtained between the two composites can be easily correlated with the characterisation of reinforcement distribution and its weight percentage of the addition in the composites. The study through optical microscope also shows the microstructure of Al-Li-5% SiC$_p$ composite exhibits equiaxed grain structure, but other composite exhibits dendritic nature which is the one of the reason behind the micro hardness value between the two composites**.

Keywords - Al-Li with SiCp composite, Microhardness, Modified Stir Casting, FESEM

I. Introduction

A modern technology requires materials with unusual combination of properties that cannot be achieved through available conventional metal alloys, ceramics and polymeric materials. This is truly required qualities for the materials which are used in the aerospace, under water and transportation applications. Presently, aviation engineers are continuously striving for structural materials which are possessing the qualities of low densities but higher in stiffness, abrasion, impact and corrosion resistance. This gave the way for development of composite materials. The composite material is considered to be any multi-phase material that exhibits a significant proportion of both constituent phases such that a better combination of properties achieved according to the principle of combined action. The judicious combination of two or more distinct materials will exhibit better property [1]. The composite materials have a continuous phase called the matrix and dispersed, non- continuous, phase called the reinforcement. The reinforcement material may be available in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. In the composite each materials retains its properties but when composite it yields superior properties which cannot achieved separately [2].

According to matrix constituent, composites are classified into organic-matrix composites, metal matrix composites (MMCs) and ceramic-matrix composites. Among these composites, MMCs provide significantly enhanced properties such as higher strength, specific modulus, damping capacity, stiffness, good wear resistance and weight reduction. The major disadvantage of MMC usually lies in the relatively high cost of fabrication and reinforcement materials. In terms of shape, the reinforcement material may be sub-divided into four major categories (Continuous fibers (ii) short fibers (chopped fibers which are not necessarily having same length) (iii) whiskers and (iv) particles. Among those types particles are most common and cheapest reinforcement.

Aluminum alloy is a metal alloy which could be used as matrix and it requires reinforcement materials which need to be stable over a range of temperatures and also non reactive. AMCs are emerged as a vital role of material for use in aerospace, chemical transportation and automobile industries as it offer high strength and hence require high modulus reinforcements [3]. Aluminum has high strength to weight ratio, good hardness, ductility and good tribological property, thermal and electrical conductivity; elastic modulus combined with significant weight savings over unreinforced alloys [4,5]. It is easy to recognize the same from micro structural parameters of the reinforcement such as shape, size, orientation, distribution and volume fraction are strongly influencing the elastic properties of MMCs.

Lithium is an excellent alloying element in aluminium for several reasons. First, it is the lightest metallic element [6]. With an atomic number three, only hydrogen and helium are lighter. With every 1% addition of Lithium, the elastic modulus increases about 6% [7]. This is because Lithium results in precipitation hardening in aluminium, which leads to increase in stiffness and strength. Hence, less volume of material is needed for similar structural components. Due to the reduction of alloy density, less material is needed for construction of the components; the total weight of the components can be reduced.

Only eight components exceed a solid solubility of 1% in Aluminium. Lithium is one of these, and only 3 elements exceed its solubility. Though Lithium does have a tendency to burn if exposed to excessive heat or time when being alloyed, it is relatively easy to alloy with aluminum [6].

Because of these benefits offered by lithium, much research has been directed toward aluminium-lithium alloys. Research of Al-Li alloys began in the U.S and Germany in the early 1920s [8]. Several patents were given during this time, with most of the patented alloys having high Lithium contents. However; due to their poor performance in the properties, they never used in commercial applications.

Interest in Al-Li alloys diminished for several decades until exponential oil crisis occurred during 1973.when high fuel prices forced the airline industries to purchase fuel -efficient aircraft. Again the possibilities of aluminum-lithium alloys were researched. Between 1980 and 1987, four international conferences regarding Al-Li alloys were held [6]. This research led to the second generation of alloys, including 2090, 2091 and 8090 among others. The second generation alloys certainly had improved mechanical properties when compared to the first generation alloys. The 8090 alloy, the most successful of the second generation, was used in EH101 helicopters in Europe. The main reason for usage of Al-Li (8090) is its low density property. If the alloys could be used in the commercial aircrafts, saving from the fuel cost will be beneficial for both the industry and passengers. Also, endurance will be increased if it is used in fighter jets.

A numerous methods have been developed/ adapted for fabrication of particle/ whisker/ short fiber-reinforced composites. All these methods are capable of producing material with high micro structural quality; however their usage is limited due to its manufacturing cost. Presently, Stir casting technique is one of the cheapest and simplest ways of generating particle -reinforced composites. In this study, a simple and cost effective set up has been used by modifying the conventional stir casting technique for the fabrication of Al-Li-SiC_p composites. Further FESEM micro graphs and micro hardness measurements of the composites containing 2% and 5% of SiC_p as a reinforcement are discussed. The aluminum alloy 8090 (Al-Li) used as matrix material in the present study, its elemental composition is given in the table1. SiC_p particles used as reinforcement had an average size of 40 μm.

II. Experimental Procedure

A modified stir casting equipment was developed to fabricate Al-Li alloy matrix composites containing 2 wt. % and 5 wt. % of SiC_p. A design and configuration of modified stir casting setup is demonstrated in Figure 1. When compared to the conventional melt stirring technique, which involves the transfer of molten metal to permanent mould after stirring, but in the modified stir casting equipment which incorporates automatic bottom pouring arrangement, which is operated by using OPEN/CLOSE switch provided in the control panel. Bottom pouring arrangement drastically reduce the difficulties associated with melt pouring and avoid the oxide inclusions in the final casting which form at the melt surface, thereby reducing the percentage of porosity in the cast sample.

A two-bladed stainless steel stirrer with reciprocating and rotational movement along with UP and DOWN movement is provided to stir the melt at variable speed (100–1500 rpm) in order to achieve a homogeneous distribution of particles in a molten alloy and to enhance the wettability of the particles. A lifting mechanism is used for stirrer assembly to facilitate the stirrer positioning and to withdraw the stirrer from the melt. The available aluminium stir casting machine was modified in such a way that the aluminium Lithium alloy can be casting in this machine without loss of lithium by providing steel hood to maintain inert condition in the crucible. Also, argon gas supplied to the melt during the melting and casting process provide extra cover to the melt for preventing interaction of Lithium in the alloy with the environment during the entire process.

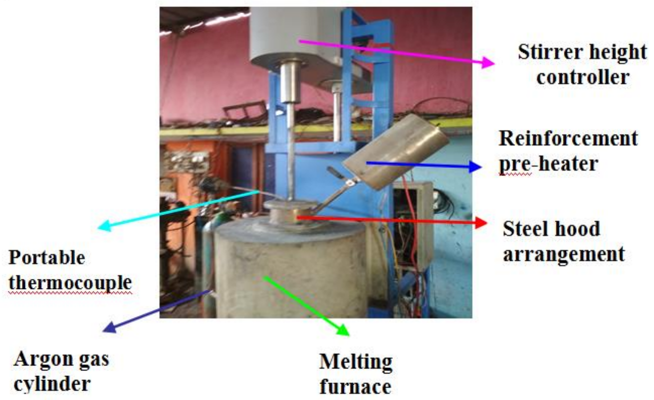

Figure 1 Modified stir casting machine

The aluminium Lithium alloy was melted in the crucible upto 1033 K with steel hood in its closed position condition and also argon gas supplied at the rate of 2 Lpm. The actual temperature of the melt also measured by dipping portable thermocouple in the crucible through the opening provided in the steel hood for the thermocouple without lifting the steel hood to ascertain the actual temperature of the melt. The argon gas was supplied in the melt during the entire process to prevent loss of lithium into the atmosphere and also ruling out of any fire incident. Then the stirring (380-390 rpm) is carried out for the duration of 10 minutes for allowing thorough formation of vortex in the melt, which allows homogeneous distribution of the reinforcement when it is introduced. After the stirring action completed the preheated SiC_p particulates by percentage of weight proportion was introduced into the melt. Once the reinforcement added into the melt, the entire melt was allowed to pour into the preheated cylindrical cast iron metallic mold. Thus the composites containing 2 and 5 % of SiC_p particles were successful fabricated. The composites fabricated and used in this study are designated as MMC 2 and MMC 5 respectively. The specimen for Microstructural characterisation and microhardness measurements were made from the castings by using wire cut EDM. Figure 2 shows the composites fabricated by modified stir casting equipment.

Figure 2 composite MMC 2 and MMC 5 as cast condition

A *Microstructural characterisation*

The morphology of the SiC_p particles was examined by a Field emission scanning electron microscope (FESEM) [Model name- Carl Zeiss]. The sliced samples of composites were polished with emery paper from 400 to 2000 grit sizes followed by polished with 0.5 µm diamond pastes. Micro structural characterisation of the polished samples was done by FESEM and optical microscope.

B. Mechanical properties

Vickers micro indentation hardness measurement of both the composites were conducted using Tukon 1102 & 1202 Vickers Series Hardness Testing machine in the micro hardness range of (0.24 N - 4.9 N). All the micro indentation hardness measurements were conducted in the matrix away from the SiC_p. The micro indentation hardness measurement were conducted for the loads from 0.24 N to 4.9 N force for each composites and five indentation values were measured for each load and the final optimal value calculated from the chart.

III. Results And Discussion

A. *Microstructure*

The FESEM micrograph in Figure 3 shows that the morphology SiC_p particles were irregular in shape and the average particle size measured to be 40 µm. The particle size distribution was in the range of 20 to 50 µm. Figure 4 shows uniform distribution of SiC_p particulates in the MMC 5 composite. It is also found out that the increase of weight fraction of reinforcement in the composite will result in finer the grain size of the composite.

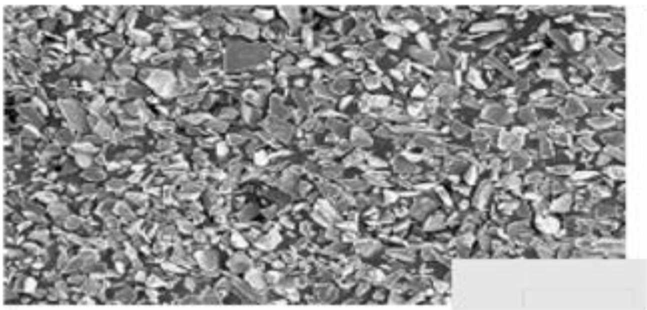

Figure 3 FESEM image of SiC_p

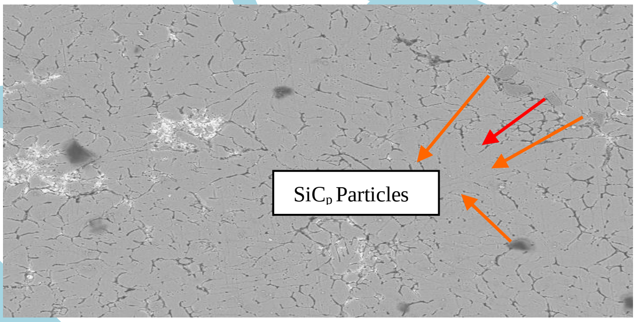

Figure 4 FESEM image of MMC 5

B. Microhardness

Figure 5 shows the micro indentation hardness values of MMC 2 and MMC 5 composites as cast condition. The MMC 5 exhibits higher micro indentation hardness value than the MMC 2 composites at all the load variance from 0.24 N to 4.9 N. The hardness of the composites is the function of different weight fraction percentage of SiC in the matrix at various loads is shown in the graph. It is due to the matrix of composites experiences high dislocation density due to dissimilarity in thermal expansion coefficient between the matrix and the reinforcements. The figure 6 shows the optical microscope image of MMC 5 and Figure 7 shows the optical microscope image of MMC 2. From the microstructure images it can be seen that the MMC 5 grain found to be equiaxed and finer and MMC 2 grain structure found to be dentritic in nature. The one of the reason behind this variation of microstructure is due the higher weight content of SiC particulates in the MMC 5 composite than the MMC 2 composite. Thus the presence of SiC particulates refines the grain size, the finer the grain size also increases the hardness value of the composites.

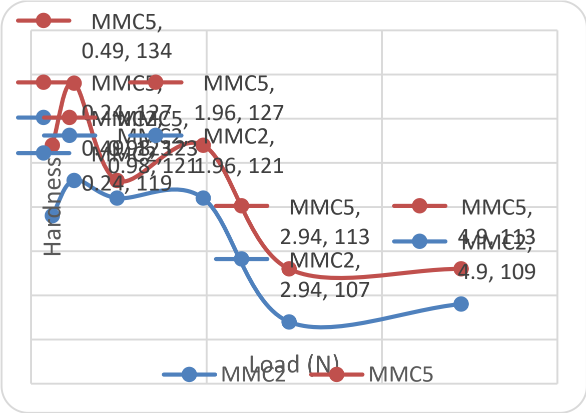

Figure 5 HV with indentation load for MMC 2 and MMC 5

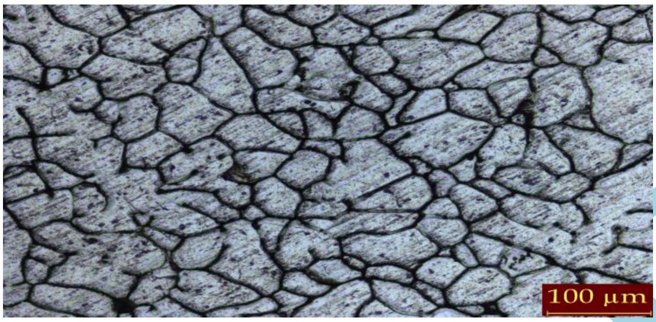

Figure 6 Microstructure image of MMC 5

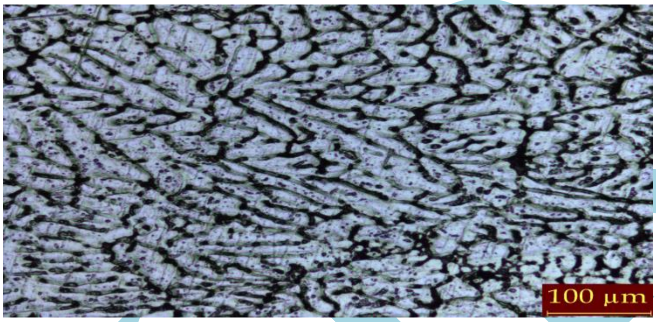

Figure 7 Microstructure image of MMC 2

IV. CONCLUSIONS

Al-Li-SiC_p composites were fabricated by modified stir casting technique. The micro indentation hardness value of the MMC 2 and MMC 5 shows that the micro indentation hardness value of the composites are increases correspondingly with the increase in weight addition of reinforcement in the composites. It is due to the addition of SiC particulates refines the grain size of the matrix. Finer the grain size of the composite will increase the hardness. Al-Li- 5% SiC_p (MMC 5) composite exhibits higher micro hardness value than the Al-Li 2% SiC_p (MMC 2) due to the higher weight percentage of SiC_p added in the MMC 5 and good inter-facial bonding occurred in Al-Li-5% SiC_p composite. It is evident that the difference of micro indentation hardness value obtained between the two composite are due to the characterisation of reinforcement distribution in the matrix and its weight percentage of addition in the composite.

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REFERENCES

[1] William D. Callister, “Materials science and Engineering,” department of Metallurgical Engineering the University of Utah (16.1)

[2] M.K Surappa, “Aluminium matrix composites challanges and oppurtunities” Sadhana Vol.28 parts 1&2, pp 313-334, February / April 2003.

[3] S.Suresh, N. Shenbaga Vinayaga Moorthi, Aluminum-Titanium Diboride(AL-TiB2) Metal Matrix Composites: Challenges and Opportunities, Procedia Engineering 38 (2012) 89-97.

[4] Afsaneh Dorri Moghadam, Emad omrani, Pradeep L. Menezes , Pradeep K. Rohatgi , Mechanical and tribological properties of self lubricating metal matrix nano composites reinforced by carbon nanotubes (CNTs) and grapheme, 77 402-420, (2015).

[5] Ansari, M.I., and Thakur, D.G., “Tribological properties of electroless nanocomposite depsoits with influence of Aliquat 336 on 6061 aluminium alloy” Trans. Indian Inst. Met. (in press) DOI: https://doi.org/10.1007/s12666-017-1269-5

[6] Martin,J.W., “Aluminium -Lithium Alloys”, Annual Review Material Science, Vol.18,pp 101-117 (1998).

[7] Gupta, R.K, Nayan,N.,Nagasireesha, G., and sharma,S.C., “ Development and Characterisation of Al-Li alloys,” Materials Science and Engineering, Vol.A 420, pp 228-234(2006).

[8] Balmuth, E. and Schmidt, R., “ A Perspective on the Development of Al-Li Alloy,” Aluminum Lihium Alloys; Proceeding of the First Aluminum-Lithium conference, pp 69-88 (1981)