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# Ageing behavior of aluminum hybrid metal matrix composites

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## ABSTRACT

A stir casting process was used to fabricate aluminum composites reinforced with various volume fractions of 2, 4, 6, and 8 wt% rice husk ash (RHA) and silicon carbide (SiC) particulates in equal proportions. The study was undertaken to investigate the ageing response of the aluminum alloy (A356.2) when dispersed with RHA and SiC particles. A systematic study of the base alloy and composites was done using the Brinell hardness measurement and the corresponding age hardening curves were obtained. It was observed that in comparison to the base aluminum alloy, the precipitation kinetic was accelerated by adding the reinforcement. This effect reduced the time for obtaining the maximum hardness by the aging heat treatment. 

## KEYWORDS

Hybrid composites;
Ageing behavior;
RHA;
Porosity.

## INTRODUCTION

The demand for high performance materials in aerospace and automobile applications has led to the development of numerous structural composite materials[1-4]. Amongst different kinds of the recently developed composites, particle-reinforced metal matrix composites and, in particular, aluminum base materials have already emerged as candidates for industrial applications. This is due to their excellent combination of properties such as high specific strength and stiffness, improved wear resistance and the additional advantages of being machinable and workable[5, 6].

The incorporation of several different types of ceramic particulates into a single matrix has led to the development of hybrid composites. Also, using a hybrid composite that contains two or more types of particulates, the advantages of one type of particulates could complement with what is lacking in the other. Nowadays, the use of agro/industrial wastes as a secondary reinforcement in the fabrication of composites is gaining more importance. The advantages of using these wastes are, to produce low cost by-product thereby, reducing the cost of aluminum products, readily available with less cost, and often lower densities in comparison with most technical ceramics (such as boron carbide, alumina etc.). Many researches have been reported the potentials and limitations of the use of wastes as reinforcements[7,8].

Age hardening behavior of Aluminum metal matrix composite has been of great interest of present research. The nature of change in kinetics and magnitude of hardening during ageing of composites depends on matrix material[9], type of reinforcement including its size, shape and volume fraction[9], and method of synthesizing the composite, post fabrication treatment and temperature of ageing. It has been conclusively shown that the presence of ceramic reinforcement such as SiC/$Al_2O_3$ (whiskers, particle or short fibers) lead to acceleration in the ageing kinetics when compared with the unreinforced alloy. This behavior generally has been attributed to enhanced nucleation and growth due to the presence of high matrix dislocation densities, which is generated due to the coefficient of thermal expansion (CTE) mismatch between the matrix and the reinforcements. Selection of ceramic reinforcement in the current research has been constricted to few reinforcement types like $Al_2O_3$, SiC and $B_4C$. Limited work has been reported on fabrication and characterization of RHA reinforced with aluminum metal matrix composites. RHA possess high hardness, high modulus of elasticity, and excellent thermal stability.

The present study is an attempt to bring out the effect of RHA and SiC particles on the age hardening behavior of A356.2 alloy. Hence different weight fractions of RHA and SiC particles were reinforced in A356.2 alloy via stir casting technique.

## MATERIALS AND METHOD

### Matrix material

In the present study, A356.2 with the theoretic density of 2760 kg/$m^3$ was used as a matrix material. The chemical composition of the matrix material is given in TABLE 1. RHA particulates with an average size of 25 μm and SiC particulates with an average size of 35 μm are used as reinforcement materials. The chemical composition of RHA is given in TABLE 2. Magnesium was selected as a wetting agent to improve wettability between the matrix and the reinforcements during production of the hybrid composites.

### Preparation of hybrid composites

The Aluminum alloy was charged into the graphite crucible and heated to 750° C till the entire metal in the crucible was melted. The reinforcement particles (RHA) and SiC were preheated to 700° C- 800° C for 1 h before incorporation into the melt to remove moisture. After the molten metal was fully melted degassing tablet was added to reduce the porosity. Simultaneously, 1% by weight magnesium was added to the melt to enhance the wettability between the matrix and the reinforcements. The stirrer made up of stainless steel was lowered into the melt slowly to stir the molten metal at the speed of 700 rpm. The speed of the stirrer can be controlled my means of regulator provided on the furnace. The preheated SiC particles were added into the molten metal at a constant rate during the stirring time. The stirring was continued for another 5-10 minutes even after the completion of particle feeding. After this stage the Al/SiC composite slurry is allowed to maintain at 700° C for 10 minutes without stirring. The composite slurry then heated to 750° C and preheated RHA particulates were poured at a constant rate and the stirring was continued for 20 minutes. The mixture was poured into the mold (prepared for tensile test specimens) which was also preheated to 500ºC for 30 min to obtain uniform solidification. Using this double stir casting process, 2, 4, 6 and 8% by weight in equal proportions of RHA / SiC particle-reinforced hybrid composites was produced.

### Microstructural characterization

The microstructure of the hybrid composites was examined using an Optical microscope (OM), and scanning electron microscope (SEM). JSM-6610LV scanning electron microscope equipped with energy dispersive X-ray analyzer (EDX) was used to study microstructure of the hybrid composites. The samples of unreinforced and hybrid composites for SEM was cut from tensile specimens and were ground by means of abrasive papers followed by rotating disc cloth polishing. Keller's reagent (95 ml water, 2·5 ml HNO3, 1·5 ml HCl, 1·0 ml HF), very popular general purpose reagent for Al and Al alloys, was used as an etching agent.

### Density and porosity measurements

Density measurements were carried out on the base metal and reinforced samples using the Archimedes's principle. This method of density measurement simply involves weighing the sample in air and in another fluid of known density. Application of Archimedes' principle leads to the following expression for the density ($\rho_{mmc}$) of the composites:

$$\rho_{mmc} = \frac{m}{m - m_1}\rho_w \quad (1)$$

where m is the mass of the composite sample in air, $m_1$ is the mass of the same composite sample in distilled water and $\rho_w$ is the density of the distilled water. The density of distilled water at 20°C is 998 kg/m$^3$. Using this method, the densities of the base metal and hybrid composites was measured.

During the process of fabrication of MMCs, some porosity level is normal, because of the long particle feeding and the increase in surface area in contact with air. The volume fraction of porosity, its size and distribution in a cast MMCs play an important role in controlling the mechanical properties. Porosity levels must, therefore, be kept to a minimum. Porosity cannot be fully avoided during the casting process, but it can, however, be controlled. Porosity of the composites was estimated by the equation given hereunder

$$\text{Porosity} = \frac{\rho_{th} - \rho_m}{\rho_{th}} \quad (2)$$

Where $\rho_{th}$ and $\rho_m$ are the theoretical and measured densities respectively. $\rho_{th}$ for a single constituent can be found from the rule of mixtures.

$$\rho_{th} = \rho_m V_m + \rho_r V_r \quad (3)$$

Where $\rho_m$ is the density of the matrix, $V_m$ is the volume fraction of the matrix, $\rho_r$ is the density of reinforcement and $V_m$ is the volume fraction of reinforcement.

The empirical relation for density can be modified for hybrid composites, by including the volume fractions for both the reinforcements (RHA and SiC) as follows:

$$\rho_{th} = \rho_{Al} V_{Al} + \rho_{RHA} V_{RHA} + \rho_{SiC} V_{SiC} \quad (4)$$

Where $\rho_{Al}$, $\rho_{RHA}$, $\rho_{SiC}$, are the densities of aluminum alloy, rice husk ash and SiC respectively, $V_{Al}$, $V_{RHA,}$ $V_{SiC}$ are the volume fractions of aluminum alloy, rice husk ash and SiC respectively. Also

$$V_{Al} = 1 - (V_{RHA} + V_{SiC}) \quad (5)$$

The volume fraction of the reinforcement was calculated from equation 6

$$V_r = \frac{\rho_m - \rho_{mmc}}{\rho_m - \rho_r} \quad (6)$$

## Age hardening studies of hybrid composites

Brinell hardness measurements were used to ascertain the age hardening behavior of the composites in the present study. Prior to the ageing studies, the alloy and composites were solutionised at 540 °C for 8 h followed by quenching in cold water. This is referred to as solutionised condition. The ageing temperature was maintained at 155°C for different time intervals. The above heat treatment sequence is termed as T6 treatment. The composites subjected to ageing were tested for their hardness using a Brinell hardness tester. A test load of 500Kg is applied to the specimens for 30sec. The diameter of the steel ball indenter is 10 mm. The size of the indent (d) is determined optically by measuring two diagonals of the round indent. The Brinell hardness number (BHN) is calculated for the unreinforced and hybrid composites using the equation 7. An average of five readings was taken for each sample for hardness measurement.

$$\text{BHN} = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \quad (7)$$

Where F is the applied load in Kg, D is the diameter of the steel ball in mm and d is the size of the indent in mm. Each hardness value presented is an average of at least five symmetrical indentations.

## RESULTS AND DISCUSSION

### Microstructural characterization

Figure 1a and Figure1b shows the scanning electron micrographs of RHA and SiC samples respectively. It could be observed that the rice husk ash consists of particulates with different sizes and different shapes. The average size of the RHA and SiC samples are found to be 25μm and 35μm respectively. The optical micrographs of aluminum composites reinforced with RHA and SiC are shown in Figure 2a and 2b. Optical micrographs of hybrid composites shows clearly the uniform distribution of RHA and SiC in the matrix and no void and discontinuities are observed. There was a good interfacial bonding between the particles and matrix material (Figure 2b). Figure 3 shows the Scanning electron micrograph of the hybrid composite. It could be observed that fairly uniform distribution of the RHA and SiC particulates in the aluminum alloy and good interfacial bonding has also been observed.

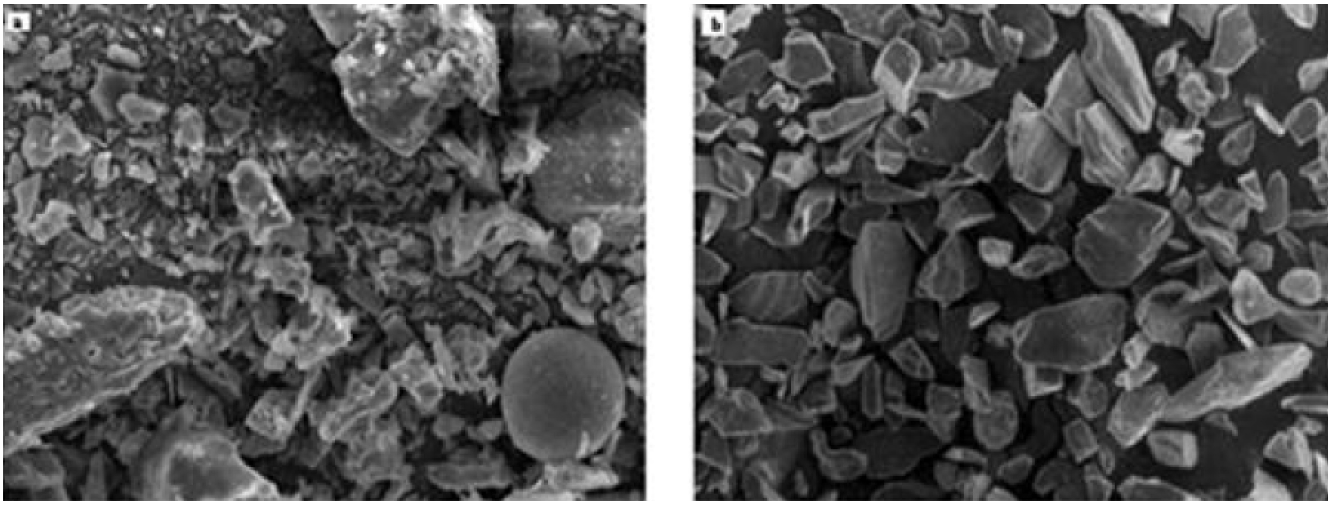

Figure 1 : Scanning electron micrographs of a) rice husk ash sample b) SiC particulates

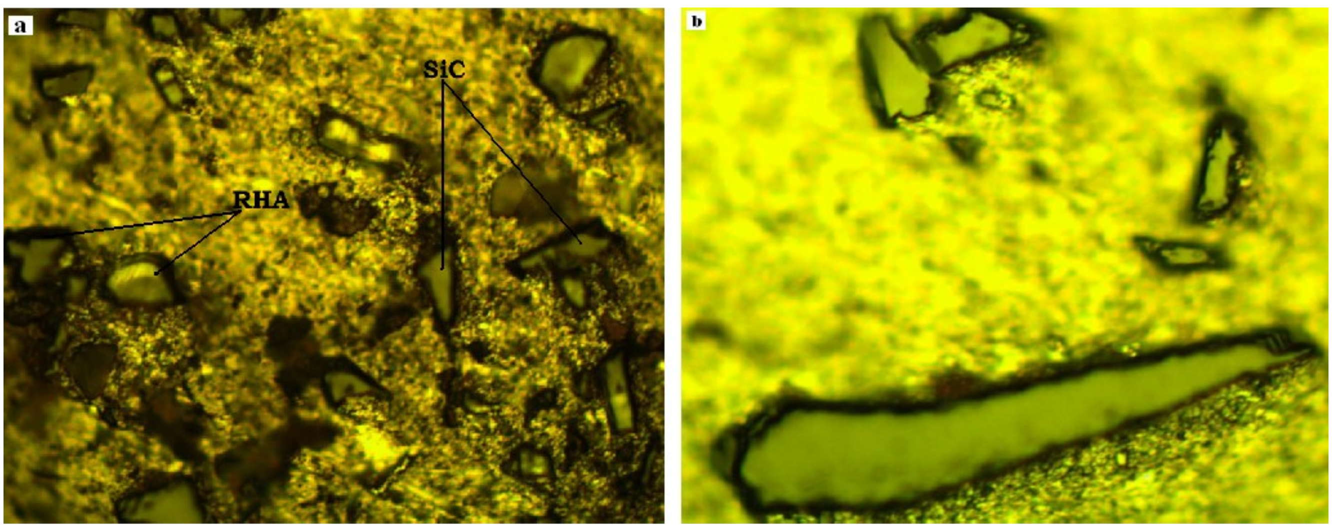


Figure 2 : Optical micrograph a) hybrid composite b) at the interface, 100X

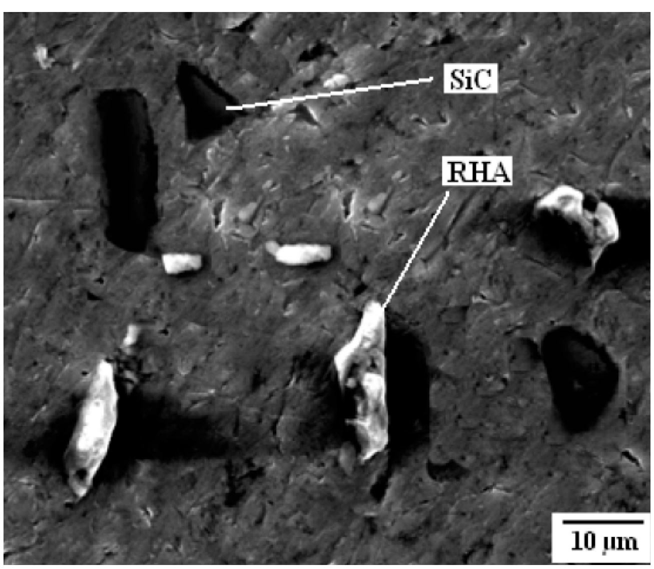


Figure 3 : Scanning electron micrograph of the hybrid composite

## Density and porosity measurements

Figure 4 shows the variation of measured density and the porosity on the base metal and the hybrid composites. It could be observed that the density decreases with the increase in the reinforcement. The decrease in densities of the hybrid composites was due to the presence of low density RHA particulates. The theoretical densities are obtained from the rule of mixtures using equations from 1-7. Based on the measured and theoretical densities the porosity of aluminium alloy and the hybrid composites has been measured and found to increase with the increase in reinforcement as shown in Figure 4. The increase in porosity can be attributed to gas entrapment during mixing, hydrogen evolution, and shrinkage during solidification and air bubbles entering the slurry either independently or as an air envelope to

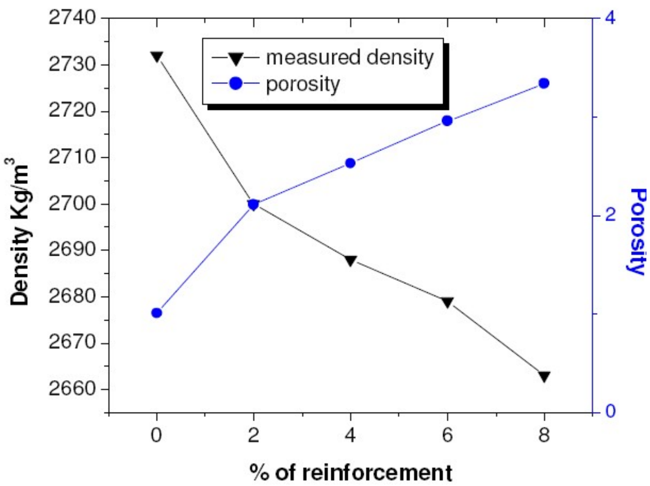


**Figure 4 : Variation of density and porosity with % reinforcement**

the reinforcement particles.

## Ageing studies of A356.2/RHA/SiC hybrid composites

The ageing response of the A356.2/RHA/SiC hybrid composites at a temperature of 155°C was studied. The preliminary observations from the assessment of the hardness results indicated that the hardness of the composites increased with increase in volume percent of the reinforcement particulates. In the as cast condition, there is an overall increase of hardness by about 36 BHN in A356/8%RHA/8%SiC hybrid composite as compared to the base alloy as shown in Figure 6. In absence of the reinforcement particles, i.e., A356.2 alloy, the age hardening curve is very sharp and a peak hardness value of 111 BHN is attained after

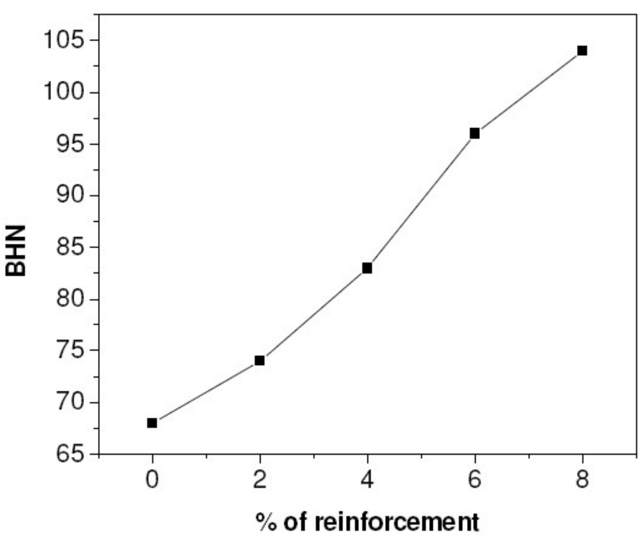


**Figure 5 : Variation of hardness with % reinforcement**

300 min (5 h) of ageing, while in case of the composites the curve is the curve is quite smooth, i.e., the drop in hardness with time is gradual.

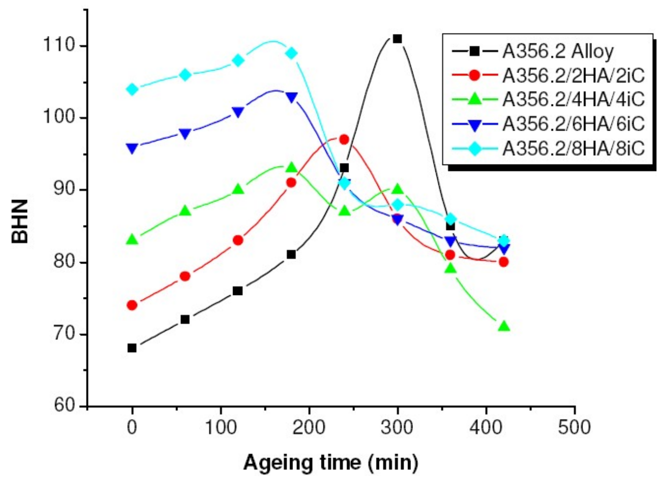


**Figure 6 : Brinell hardness versus the aging time for the alloy and hybrid composites**

Figure 6 shows the effect of aging time on the hardness of reinforced and unreinforced A356.2 alloy. One can notice that an increase in the hardness of the composite materials occurred after the aging treatment. However, it is of interest to note that peak hardness was observed at lower aging times for the hybrid composite compared to the Al base alloy (240 min for the A356.2/2%RHA/2%SiC hybrid composite, 180 min for A356.2/4%RHA/4%SiC, A356.2/6%RHA/6%SiC, A356.2/8%RHA/8%SiC hybrid composites and 300 min for the Al alloy).

These results indicate that the addition of reinforcement to the aluminum matrix accelerates the aging kinetic. This behavior can be related to the high matrix dislocation density induced by the mismatch between the matrix and the reinforcement. It is well known that high dislocation density in the metal matrix promotes dislocation-assisted diffusion of the aging elements. On the other hand, the influence of the reinforcement on the aging behavior can be attributed to the heterogeneous nucleation capability of metastable phases on the reinforcement particles. It can, therefore, be concluded that both nucleation and growth of the GP zone are influenced by the ceramic particles. GP zones are the meta-stable phases (or precipitates), which, due to their high degree of dispersion and correspondingly large contribution to strength, are of primary interest. These precipitates are crystallographically coherent with the matrix and their fine dispersion enhances the mechanical properties of the alloy. The size of these GP zones is of the order of few nanometers. Such small size is the primary reason of very high mechanical strengthening of the material.

## CONCLUSIONS

- In this investigation, the stir casting process was successfully implemented for producing aluminum hybrid composites containing 8% wt SiC/ 8% wt RHA particles.
- It was observed that the density decreases and porosity increases with the increase in percentage reinforcement.
- The hardness of the composites increases with the increase in percentage reinforcement.
- It was found that in comparison to the base aluminum alloy, the precipitation kinetic was accelerated by adding the reinforcement. This effect reduced the time for obtaining the maximum hardness by the aging heat treatment. The reason for the improvement of the kinetics of GP zone formation is related to the higher dislocation density of the metal matrix, due to the thermal mismatch. This not only enhances the nucleation rate (heterogeneous nucleation), but also affects the diffusion rate of the solute elements.

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