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Effect of variation in physical properties of the metallic matrix on the microstructural characteristics and the ageing behaviour of Al-Cu/SiC metal matrix composites

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In this study, aluminium-based metallic matrices with varying amount of copper (1 wt % Cu and 4.5 wt % Cu) were reinforced with SiC particulates using a partial liquid phase casting technique. The results of the present investigation showed smaller sized and higher weight percent of SiC particulates being successfully incorporated with a decrease in the weight percent of copper in the matrix. Microstructural characterisation studies conducted on the composite samples revealed an increase in uniformity of distribution of SiC particulates, improved SiC/Al interfacial integrity and smaller grain size of the metallic matrices with decreasing weight percent of copper. Results of the microstructural characterisation studies also exhibited the presence of solute rich zone in the near vicinity of SiC particulates and the nucleation of secondary phases both at and in near vicinity of SiC particulates. The result of the ageing studies revealed an accelerated ageing kinetics for the Al-1%Cu/SiC composite when compared to the Al-4.5%Cu/SiC composite samples. The results of accelerated ageing kinetics were rationalised in terms of the effect of variation in the physical properties of the metallic matrix and the ensuing microstructural characteristics due to variation in the amount of copper in the matrix. © *1999 Kluwer Academic Publishers*

1. Introduction

The innate ability of metal matrix composites (MMCs) to combine the properties of ceramic phase with that of the metallic phase and its ability to serve a wide spectrum of diversified applications, has been instrumental in the insurgence of extensive research activities all over the world [1]. The suitability of these composite materials for engineering applications, however, lies in the judicious selection of synthesising/processing technique, matrix material, ceramic reinforcement and the heat treatment procedure. Among the various matrix-reinforcement combinations, silicon carbide (SiC) reinforced aluminium matrices have been widely acknowledged as the potential candidates for the weight critical automobile and aerospace applications [2]. The addition of SiC particulates has been correlated with an increase in mechanical properties such as yield strength, ultimate tensile strength and elastic modulus of the aluminium based metallic matrices [2]. This improvement can be ascribed, in part, to the particulates-assisted microstructural strengthening. In related studies, for example, investigators have reported the change in microstructural features such as dislocation density [3], grain size [4], precipitation behaviour [5] and excess solid solubility [6] as a result of the presence of ceramic particulates. The presence of ceramic reinforcement, in addition, has also been correlated with the kinetics of microstructural evolution during the ageing step of the conventional T6 heat treatment [4, 5, 7]. The change in ageing kinetics of the metallic matrix as a result of the presence of a fixed volume fraction of ceramic particulates, for example, has been reported by various investigators [4, 5, 7]. Study to correlate the effect of volume fraction of SiC particulates with the increase in heterogeneous nucleation sites in the metallic matrix and the ensuing accelerated ageing characteristic of the reinforced metallic matrix has also been conducted [8]. However, no systematic studies have been carried out to correlate the effect of variation in physical properties of the metallic matrix on the microstructural evolution and the ageing behaviour of MMCs.

Accordingly, in the present study the physical properties of the metallic matrix were varied by adding different weight percent of copper in aluminium. The synthesis of Al-Cu/SiC composites with varying amount of copper was carried out using partial liquid phase casting (rheocasting) route. Particular emphasis was placed to correlate the variation in physical properties of the metallic matrix with the microstructural characteristics and ageing behaviour of Al-Cu/SiC composites.

2. Experimental procedure

2.1. Materials

The starting nominal compositions of the aluminium-based matrix alloys used in the present study were (in wt %): 1.0Cu-Al and 4.5Cu-Al. Silicon carbide (α-SiC) particulates with an average size of 35.8 μm were selected as the reinforcement phase.

2.2. Processing

The synthesis of the metal matrix composites used in the present study was carried out using the rheocasting technique. The metal ingots, prior to melting, were properly cleaned to eliminate surface impurities. The cleaned metal ingots were melted to the desired superheating temperature in a graphite crucible. SiC particulates (equivalent to 10 wt %), preheated to 900 °C, were then added into the molten metallic melt and stirring of the composite mixture was carried out in the liquid phase regime and the two-phase regime in order to achieve the uniform distribution of SiC particulates in the metallic matrix. The composite material thus obtained was allowed to solidify in the crucible and was subsequently remelted (in the same crucible) followed by casting in the cylindrical steel moulds.

2.3. Quantitative assessment of SiC particulates

Quantitative assessment of SiC particulates in the composite samples was carried out using a chemical dissolution method. This method involved: (i) measuring the mass of composite samples; (ii) dissolving the samples in hydrochloric acid, followed by (iii) filtering to separate the ceramic particulates. The particulates were then dried and the weight fraction determined [4].

2.4. Ageing studies

Ageing studies were performed in order to obtain the peak hardness time condition for the two types of rheocast metal matrix composites. Specimens (25 mm diameter, 7 mm height) taken from as-processed Al-1%Cu/SiC and Al-4.5%Cu/SiC rods were solutionized at 392 °C and 540 °C, for one hour and isothermally aged at 160 °C for various intervals of times. The solutionizing temperatures were determined by ensuring that the Al-Cu alloy matrix is heated to the single phase α region of the Al-Cu phase diagram where all the copper will be completely dissolved in aluminium to give a supersaturated solution. Superficial Rockwell hardness measurements were made using a 1/16 in. diameter steel ball indenter with a 15 kgF major load, in accordance with ASTM E18-92 standard.

2.5. Microstructural characterisation

Microstructural characterisation studies were conducted on the peak aged composite samples in order to investigate: (i) distribution of SiC particulates, (ii) size of SiC particulates retained in the MMC, (iii) interfacial bonding, (iv) grain size of the matrix, (v) precipitation behaviour and (vi) segregation of alloying elements in the interfacial region between the Al alloy matrix and SiC particulate.

Microstructural characterisation studies were primarily accomplished using an optical microscope and a JEOL scanning electron microscope (SEM) equipped with energy dispersive spectroscopy (EDS). The composite samples were metallographically polished prior to examination. Microstructural characterisation of the samples was carried out in both etched and unetched conditions. Etching was accomplished using Keller's reagent ($0.5HF$-$1.5HCl$-$2.5HNO_3$-$95.5H_2O$). Grain size measurement of the alloy matrices was conducted using the linear intercept method.

3. Results

3.1. Macrostructure

Macrostructural characterisation conducted on the as-processed, machined and polished rheocast composite samples did not reveal the presence of either macropores or the macrosegregation of SiC particulates.

3.2. Quantitative assessment of SiC particulates

The results of acid dissolution experiments are summarised in Table I. The weight percentage of SiC particulates was estimated to be approximately 9.3% and 8.1% for Al-1%Cu/SiC and Al-4.5%Cu/SiC samples, respectively. The results of the experiments revealed that the amount of SiC successfully incorporated into the Al-Cu alloy matrix decreased with increasing amount of copper.

3.3. Ageing studies

The results of ageing studies conducted on the Al-1%Cu/SiC and Al-4.5%Cu/SiC composite samples are shown in Fig. 1. The results revealed that ageing time for peak hardness for the Al-1%Cu/SiC composite was 9 h as compared to 12 h for the Al-4.5%Cu/SiC composites samples.

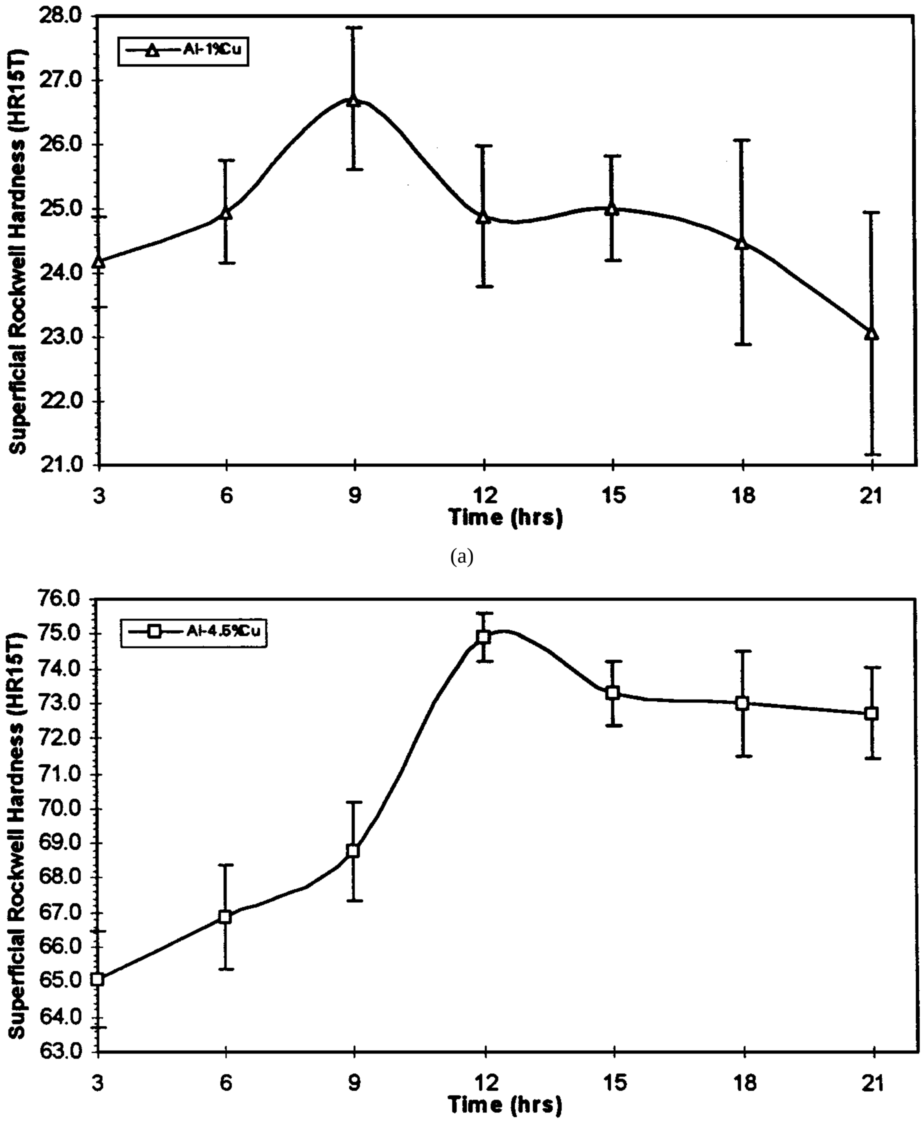
3.4. Microstructural characterisation

Microstructural characterisation was conducted on both the as-polished and etched Al-Cu/SiC composite samples using the scanning electron microscopy, optical

TABLE I Results of acid dissolution test and computation for heterogeneous nucleation volume

Material	Weight percent[a] of SiC (wt %)	R	V_f	$V_{f,hv}$	$V_{f,rv}$	Peak ageing time (h)
Al-1%Cu/SiC	9.3 ± 0.5	1.96	0.081	0.525	0.394	9
Al-4.5%Cu/SiC	8.1 ± 0.3	1.62	0.071	0.230	0.699	12

[a] Values were obtained experimentally by chemical dissolution. Three samples, each taken from different section of the cast rod were used to compute the average value.



(a)

(b)

Figure 1 Graphical representations of ageing studies conducted on: (a) Al-1%Cu/SiC and (b) Al-4.5%Cu/SiC composite samples. Both composites were artificially aged at 160 °C for various time.

microscopy, energy dispersive spectroscopy and image analysis techniques. Scanning electron microscopy conducted on the etched Al-1%Cu/SiC sample revealed a relatively uniform distribution of SiC when compared to etched Al-4.5%Cu/SiC sample (see Figs 2a and b). Distribution of SiC particulates was observed to be relatively less uniform with increasing copper content in the Al-Cu/SiC composite samples.

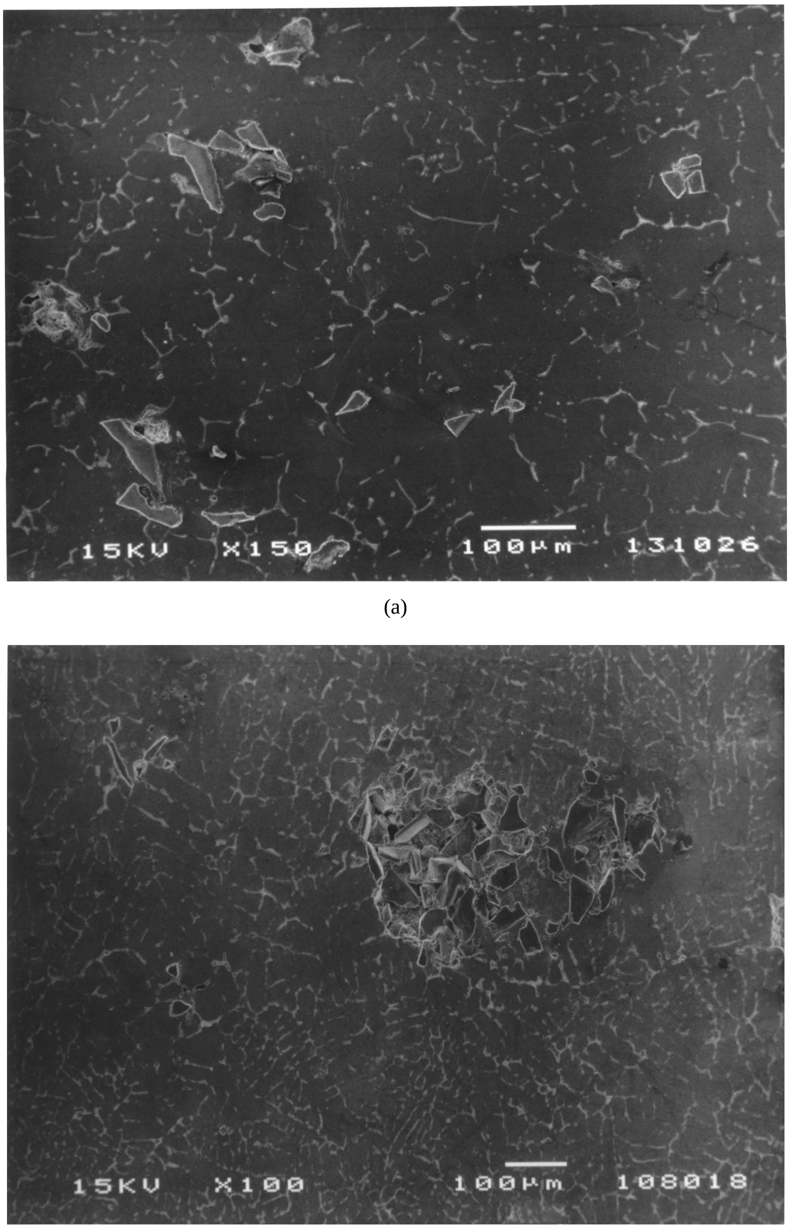
Varying degrees of SiC particulate clustering were noticed in the Al-Cu/SiC composite samples. In Al-1%Cu/SiC sample, occasional small clusters of SiC ($<50\,\mu$m) were noted while larger SiC clusters were observed in the Al-4.5%Cu/SiC samples (see Table II). In both Al-1%Cu/SiC and Al-4.5%Cu/SiC samples, SiC clusters were found to be located preferentially at grain boundaries or in interdendritic region. Microstructural study also revealed the prevalence of SiC located at grain boundary with some of the SiC particulates occasionally found in intragranular region (see Figs 3a and b).

The average sizes of SiC particulates incorporated successfully into the two type of composite samples were determined using image analysis technique. The size of SiC particulates was found out to be 29.3 μm in case of Al-1%Cu/SiC composite samples and 45.3 μm for Al-4.5%Cu/SiC composite samples (see Table II). It may be noted that the mean size of as-received SiC particulates was 35.8 μm. The interfacial integrity between SiC and the Al-Cu matrix was found to be superior in the case of Al-1%Cu/SiC composite samples

TABLE II Distribution and size of SiC particulates in Al-Cu/SiC composites

Material	Distribution of SiC	Size of SiC cluster[a] (μm)	Average size of SiC[a,b] incorporated (μm)
Al-1%Cu/SiC	Uniform	<50	29.3 ± 12.7
Al-4.5%Cu/SiC	Less uniform	100–200	45.3 ± 20.6 [35.8 ± 16.7][c]

[a] Values obtained were determined using image analysis technique.
[b] Values shown represent the equivalent diameter of the SiC.
[c] Value represents the size of as-received SiC.



(a)

(b)

Figure 2 Representative SEM micrographs showing the distribution of SiC particulates in: (a) Al-1%Cu/SiC and (b) Al-4.5%Cu/SiC composite samples.

(see Fig. 4a) when compared to the Al-4.5%Cu/SiC composite samples (see Fig. 4b).

The grain morphology in the two types of Al-Cu/SiC composite samples investigated in this study was found to be columnar-equiaxed in nature. The result of grain size measurement conducted on etched Al-1%Cu/SiC and Al-4.5%Cu/SiC samples revealed a mean grain size of 85.8 μm and 113.5 μm, respectively (see Table III). EDS point analyses conducted at various interdendritic regions and grain boundaries revealed the presence of Cu-rich secondary phases. Volume fraction and average sizes of Cu-rich secondary phases determined using image analysis are summarised in Table III. The results show an increase in both the volume fraction and average sizes of Cu-rich secondary phases with an increase in copper amount in Al-Cu/SiC composites.

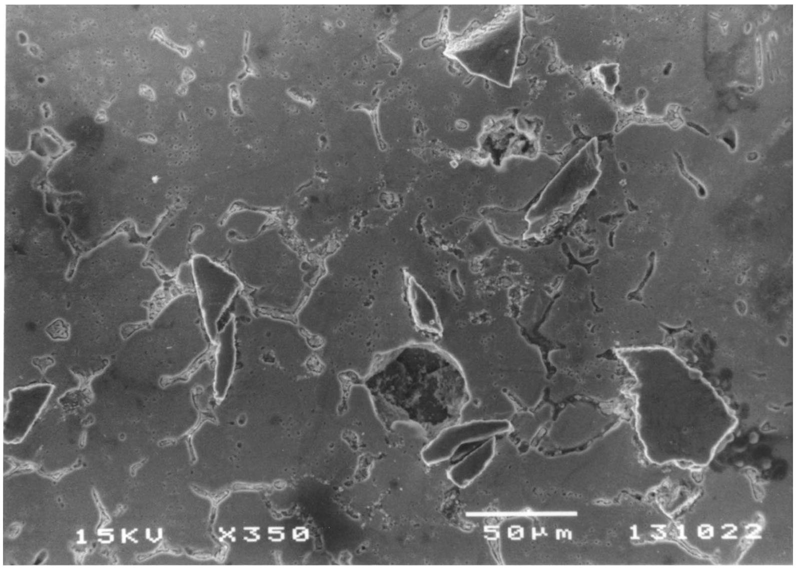
Scanning electron microscopy carried out on the composite samples also revealed the preferential presence of Cu-rich secondary phases at and in the near vicinity of the SiC/matrix interface (see Fig. 4). The identity of the Cu-rich phases was confirmed using EDS point analyses. The results of EDS analyses also revealed the enrichment of copper in the near vicinity of SiC particulates. The amount of copper content was found to decrease with increasing distance from the interface (see Fig. 5).

TABLE III Results of grain size measurement and amount of Cu-rich phases

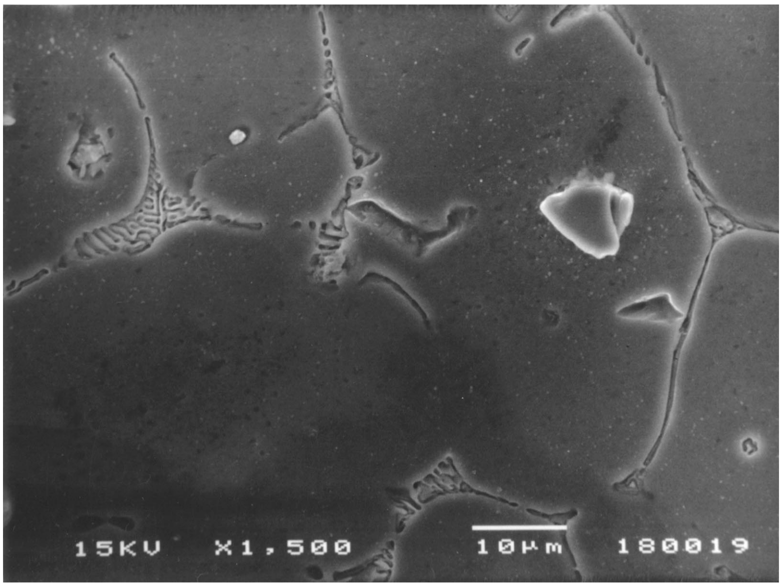
Material	Grain size[a] (μm)	Volume fraction of Cu-rich phases[b]	Average size of Cu-rich phases[c] (μm)
Al-1%Cu/SiC	85.8 ± 5.5	0.03	1.5 ± 0.9
Al-4.5%Cu/SiC	113.5 ± 6.9	0.11	4.7 ± 2.6

[b] Grain size was determined using the linear intercept method.

[b,c] Values were obtained using image analysis technique.



(a)



(b)

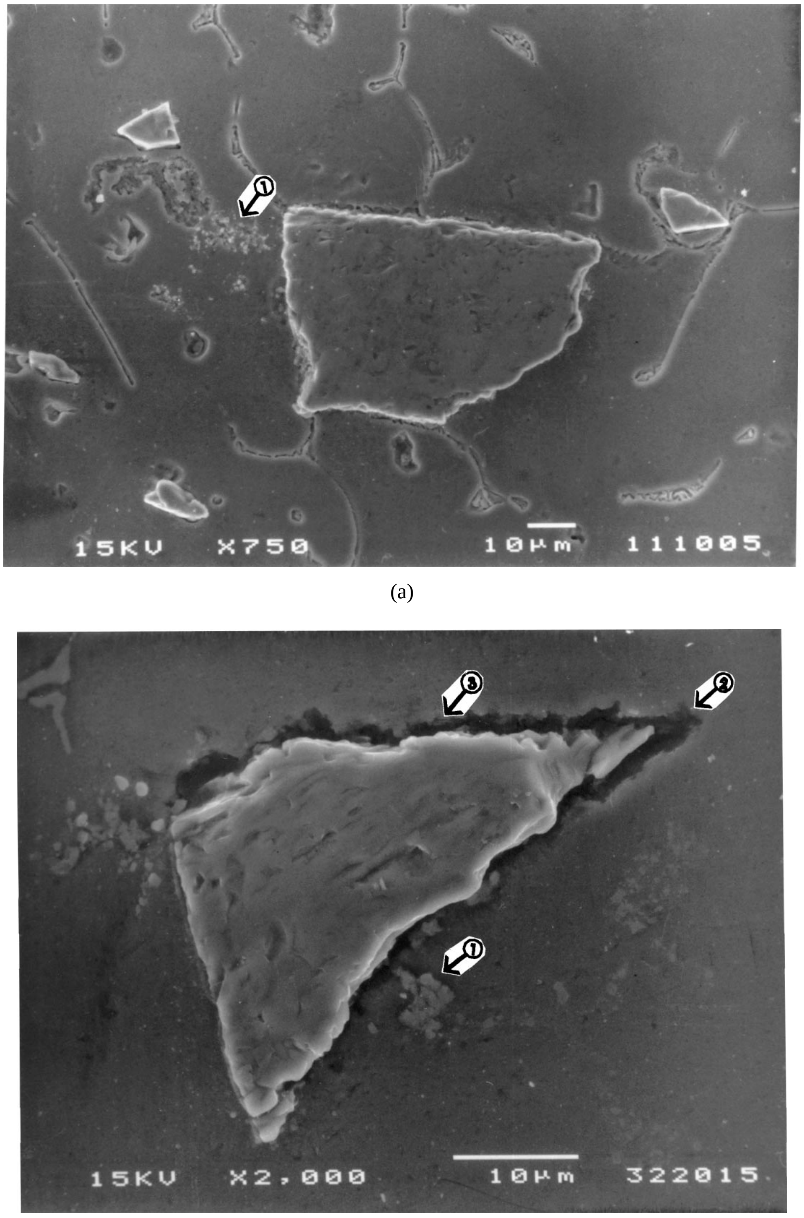
Figure 3 Representative SEM micrographs showing the presence of SiC particulate(s): (a) at grain boundaries and (b) in the intragranular region.

4. Discussion

The results of ageing studies conducted on the composite samples revealed an increase in ageing kinetics with a decrease in weight percent of copper in the Al-based matrix. The difference in ageing kinetics between Al-1%Cu/SiC and Al-4.5%Cu/SiC may primarily be attributed to the change in physical properties (such as density, thermal conductivity and coefficient of thermal expansion) of the metallic matrix as a result of different amount of copper and its influence on the microstructural evolution during processing. The results of the present study indicated that presence of lower amount of copper in the metallic matrix results in an increase in heterogeneous nucleation sites leading to an accelerated ageing kinetics. The increase in heterogeneous nucleation sites in Al-1%Cu/SiC when compared to Al-4.5%Cu/SiC, can be attributed to the coupled influence of:

(i) incorporation of finer size of SiC particulates,
(ii) incorporation of higher weight percent of SiC particulates,
(iii) more uniform distribution of SiC particulates,
(iv) smaller grain size of the metallic matrix, and
(v) larger variation in coefficient of thermal expansion (CTE) between metallic matrix and SiC particulates.

The increase in heterogeneous nucleation sites in Al-1%Cu/SiC samples when compared to Al-4.5%Cu/ SiC samples can be attributed to the smaller size of incorporated SiC particulates (see Table II). The smaller size of SiC particulates indicates larger surface area for nucleation of strengthening precipitates in the metallic matrix even for the similar weight percent of SiC particulates. The smaller size of incorporated SiC particulates in the case of Al-1%Cu/SiC composite may be attributed to the settling of larger SiC particulates during the remelting step as a result of lower viscosity and density of the Al-1%Cu melt. Studies [9] on the effect of alloying



(a)

(b)

Figure 4 Representative SEM micrographs showing the SiC/matrix interfacial characteristics in case of: (a) etched Al-1%Cu/SiC composite sample and (b) polished Al-4.5%Cu/SiC composite sample. (1) Presence of Cu-rich phase at and in the vicinity of SiC interface. (2) Partial interfacial debonding at sharp corner of SiC. (3) Partial interfacial debonding at irregular jagged edges of SiC particulate.

additions on the fluidity of aluminium revealed that elements such as titanium, iron and copper increase the viscosity of aluminium while silicon and magnesium decrease it. The results in the present study are consistent with the findings of Samuel *et al.* [10] who reported an increase in sedimentation with increasing fluidity of the molten material.

Another factor that may be attributed to the increase in heterogeneous nucleation sites in the case of Al-1%Cu/SiC composites is the higher weight percent of incorporated SiC particulates (see Table I). The reduced incorporation of SiC particulates in the Al-4.5%Cu metallic matrix under similar processing condition can be attributed to the lower affinity of copper towards oxygen, leading to reduced tendency of the metallic melt to wet SiC particulates [11]. The results are also consistent with the work of other investigators showing constitution-dependent ability of metallic matrices to wet ceramic particulates [11–13]. The presence of higher weight (or volume) percent of particulates in the metallic matrix can lead to an increase in heterogeneous nucleation sites in two ways:

(a) increased number of SiC particulates and
(b) higher volume fraction of the defect-rich interfacial region in the near vicinity of SiC particulates.

The ability of SiC particulates to act as heterogeneous nucleation site has been convincingly established for Al-Mg-Si and Al-Zn-Mg systems [8, 14, 15]. This is also consistent with the microstructural characterisation studies carried out in the present work revealing the presence of Cu-rich phases located at the Al-Cu/SiC interface. The results thus indicate that an increase in number of SiC particulates as a result of increase in weight percent will increase the number of

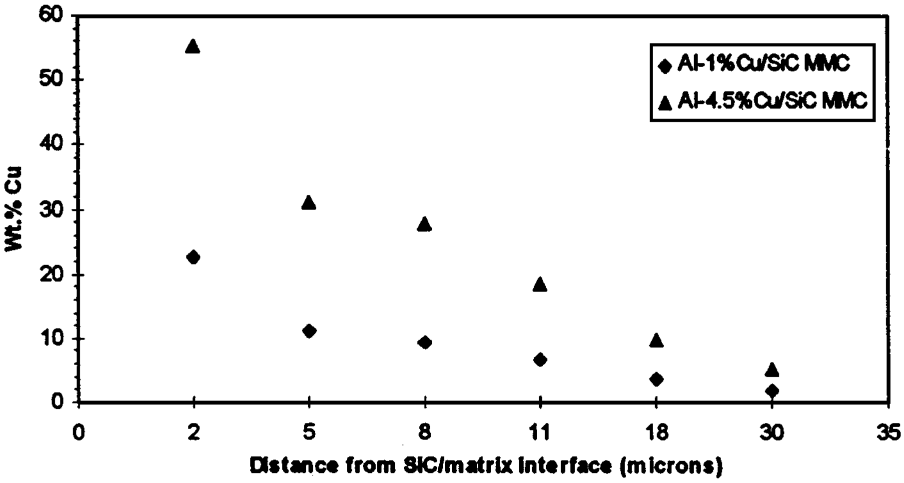


Figure 5 Graphical representation of the segregation pattern of Cu observed at varying distance from the Al-Cu/SiC interfacial region.

heterogeneous nucleation sites for the precipitation of strengthening phases.

The presence of SiC particulates in the metallic matrix also lead to the formation of defect-rich interfacial region. The formation of defect-rich interfacial region can be attributed to difference in coefficient of thermal expansion between metallic matrix and the SiC particulates [13, 16, 17]. The heterogeneous nucleation capability of the defect-rich region can primarily be attributed to the presence of high dislocation density [1–4, 6, 14, 16, 17]. The increase in dislocation density promotes the dislocation-assisted diffusion of the alloying element from the adjacent dislocation lean areas of the matrix resulting into the solute enrichment in the interfacial region, thus making the compositional requirement for the precipitation more favourable [8]. This is consistent with the microstructural characterisation results revealing the presence of solute-rich region (see Fig. 5) and the presence of Cu-rich phases (see Fig. 4) in the near vicinity of SiC particulates. The microstructural characterisation results of the Al-Cu/SiC interfacial region are also consistent with the transmission electron microscopy results of other investigators conducted on the spray deposited Al-Cu/SiC metal matrix composites [4].

Furthermore, the accelerated ageing kinetics observed in the present study can also be attributed to an increase in the heterogeneous nucleation volume formed around SiC particulates (see Fig. 6) with an increase in the volume fraction of SiC particulates. The volume fraction of heterogeneous nucleation volume around SiC particulates ($V_{\mathrm{f,hv}}$) and the remaining matrix volume ($V_{\mathrm{f,rv}}$) can be computed from the volume fraction of SiC particulates (V_{f}) using the following expressions suggested by Wu and Lavernia [18]

$$V_{\mathrm{f,hv}} = (R^3 - 1)V_{\mathrm{f}} \tag{1}$$

$$V_{\mathrm{f,rv}} = 1 - R^3 V_{\mathrm{f}} \tag{2}$$

where R is the ratio of the size of the heterogeneous nucleation zone to that of the reinforcement particulate. The results of the segregation studies (see Fig. 5) revealed the value of R to be 1.96 and 1.62 for Al-1%Cu/SiC and Al-4.5%Cu/SiC composite samples, respectively. The value of R obtained in the present study are in close proximation with the theoretically predicted value of R (equal to 1.5) by other investigators [19]. The results of heterogeneous nucleation volume calculations, summarised in Table I, show a higher value of $V_{\mathrm{f,hv}}$ in case of Al-1%Cu/SiC samples. The heterogeneous nucleation capability of heterogeneous nucleation zone or plastic zone [18] formed around SiC particulates as a result of the variation in coefficient of thermal expansion between the SiC particulates and the metallic matrix can primarily be attributed to the presence of high dislocation density and relatively finer subgrain size [3, 20]. The heterogeneous nucleation of matrix precipitates on the dislocations is favoured since it lowers the elastic strain energy associated with the dislocations [21]. Moreover, in related studies, Song and Baker [5] attributed the accelerated ageing observed in powder metallurgy processed AA 6061/15 vol % SiC composite to the lower activation energy required for the ageing process arising as a result of the dislocation-assisted nucleation process in the composites. The results thus obtained in the present study clearly indicate the increasing ability of SiC particulates, with an increase in volume fraction, to inflict the constitutional

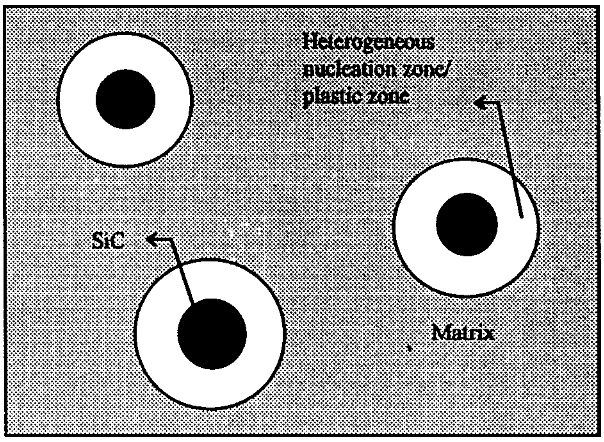


Figure 6 Schematic illustration showing the presence of heterogeneous nucleation zone around SiC particulates in the metallic matrix.

and microstructural changes in the interfacial region leading to an increase in heterogeneous nucleation sites thus enhancing the ease of precipitation.

Another important microstructural feature that can be attributed for the accelerated ageing kinetics exhibited by Al-1%Cu/SiC composites is the more uniform distribution of SiC particulates (see Fig. 2a). The final distribution pattern of the ceramic particulates in the metallic matrix can be attributed to a number of factors such as:

(i) distribution in the molten melt as a result of stirring.
(ii) distribution in the melt after stirring but before solidification [22], and
(iii) redistribution as a result of solidification.

Since the stirring conditions and time lapses between end of mixing and onset of solidification were maintained identical during processing, the influence of the first two factors on the final distribution of SiC particulates can be considered minimal.

In the present study, the primary factor which influences SiC particulate distribution is the solidification process itself. In addition to the movement of dispersed particulates in the melt, interactions between these particulates and the growing solid phase determine the spatial distribution of particulates in cast composites. During solidification, individual particulates may be either pushed by the moving solid/liquid interface into the last freezing interdendritic regions, or they may be engulfed in situ by the growing cells and dendrites and become dispersed in the matrix [23–26]. One of the important criterion that governs the engulfment or rejection of the reinforcing particulates is their ability to nucleate the primary solidifying phase [27]. The particulates are rejected when the reinforcing particulates do not serve as the nucleation sites for the primary phase. It has been reported previously [23], that the primary α-aluminium do not nucleate on the surface of graphite, silicon carbide, alumina or silica particles. The observation thus made regarding the grain boundary-segregated distribution of SiC particulates in this study conforms well with the work of other investigators [23–27].

The relatively non-uniform distribution and presence of larger size of SiC clusters in case of Al-4.5%Cu/SiC composite samples may also be related to the solidification rate [27]. Increasing weight percent of copper results in a decrease in the thermal conductivity of aluminium [9]. The solidification rate for the Al-1%Cu/SiC and Al-4.5%Cu/SiC composites besides being processed using similar processing conditions may be different as a result of difference in the thermal conductivity of aluminium with increasing weight percent of copper. Relatively slower solidification rate is therefore expected in the Al-Cu/SiC composite with greater weight percent of copper. During slow solidification of composites, the dendrites of α-aluminium are large and the SiC particulate present in the volume is segregated in the interdendritic regions. This is consistent with the results of grain size measurements (see Table III) that revealed an increase in grain size with an increase in weight percent of copper. At higher solidification rate, finer dendrite size is achieved and the dendritic arm spacing decreases, thereby giving a more homogeneous particulate distribution and smaller SiC clusters as observed in the Al-1%Cu/SiC composite sample. This is also consistent with the work carried out by Samuel *et al.* [10] who reported a more uniform distribution of SiC particulates due to a finer microstructure brought about by a higher solidification rate.

The uniform distribution of SiC particulates (see Fig. 2a) and the reduced tendency of SiC clusters formation (see Table II) as a result of superior solidification condition accomplished in Al-1%Cu/SiC composites might have contributed, in part, to an increase in heterogeneous nucleation sites in the metallic matrix for the precipitation of the strengthening phases. It may be noted that the SiC particulates that are present in the form of clusters may not be able to bring appreciable microstructural and constitutional changes in the adjacent metallic matrix, leading to their reduced ability to serve as heterogeneous nucleation sites [28]. Moreover, the clustering of SiC particulates also reduces the Al-Cu/SiC interfacial area, thus decreasing the resultant heterogeneous nucleation volume [28].

The accelerated ageing kinetics exhibited by Al-1%Cu/SiC composite can also be attributed to its finer matrix grain size (see Table III). The decrease in grain size of the metallic matrix as a result of a lower weight percent of copper, leads to an increase in grain boundary area. The increase in grain boundary area assists in increasing the frequency of nucleation of the strengthening phases as a result of the reduced activation barrier for heterogeneous nucleation [21]. The experimental confirmation to this phenomenon has been established previously in case of Al-based matrices [4, 29]. In related studies, investigators have convincingly established the heterogeneous nucleation ability of grain boundaries [4, 21, 29] and the accelerated ageing kinetics exhibited by the materials associated with finer grain size [30].

Apart from the above mentioned factors, the accelerated ageing kinetics exhibited by Al-1%Cu/SiC samples can also be attributed to the variation in CTE of Al-Cu alloys with different weight percent of copper. Studies [9] have shown that additions of copper to aluminium reduces its expansion coefficient in approximately a linear manner. According to Arsenault *et al.* [3], a simple model based on prismatic punching suggests that dislocation density is directly proportional to the difference in coefficient of thermal expansion (ΔCTE) between the matrix and reinforcement particulate. Hence, the decreasing difference in ΔCTE between SiC and Al-Cu matrix, due to a decrease in expansion coefficient of the Al-Cu alloy matrix with higher weight percent of copper, will lead to a relatively lower dislocation density. The accelerated ageing kinetics thus exhibited by Al-1%Cu/SiC composite samples can be attributed, in part, to an increased dislocation density (as a result of increased CTE difference) and the associated heterogeneous nucleation sites for the strengthening phases in the metallic matrix.

The aforementioned discussion thus strongly indicates the interrelationship between constitution, physical properties, microstructure and ageing kinetics of the reinforced metallic matrices.

5. Conclusion

The accelerated ageing kinetics exhibited by the Al-1%Cu/SiC samples when compared to Al-4.5%Cu/SiC samples can primarily be attributed to:

(i) reduced density and viscosity of metallic matrix resulting into the entrapment of finer distribution of SiC particulates,
(ii) higher thermal conductivity of the matrix leading to more uniform distribution pattern of SiC particulates, reduction in SiC cluster formation tendency and reduction in grain size, and
(iii) higher difference in coefficient of thermal expansion between metallic matrix and the ceramic reinforcement leading to an increase in dislocation density.

The presence of finer size of SiC particulates, higher weight percent of SiC particulates, uniform distribution of SiC particulates, smaller matrix grain size and higher difference in coefficient of thermal expansion between SiC particulates and metallic matrix in the case of Al-1%Cu/SiC samples, in common, lead to an increase in number of heterogeneous nucleation sites in the metallic matrix, thus accelerating the ageing kinetics.

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