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Study of Mechanical and Physical Properties for SiC/Al Composites

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ABSTRACT

The micro-structural changes and mechanical properties were investigated in an Al reinforced with SiC particles which synthesized using powder technology technique. SiC/Al composites containing four different weight percentages 40%, 50%, 60% and 70% of SiC. X-ray diffraction was used to characterization and observes the phases formed in the process of sintering at different temperatures (800 ^{0}C, 1100 ^{0}C). Crystallite sizes calculated from Scherer relation, the grain size of the SiC/Al are observed to increase with the increasing in the sintering temperature of the samples. The hardness tests were conducted in the suitable Hardness Testing Apparatus by choosing appropriate scales of loading and measurement. The test revealed a marked increase in the Vickers hardness with respect to the base composites as well as silicon carbide. It was found from the experimentation that the hardness rate increases with increasing weight fraction of silicon carbide (SiC) and sintering temperature. The best results have been obtained at 70% weight fraction of SiC particles at 1100 ^{0}C. The aim of this investigation is to obtain the fundamental understanding of the micro structural changes of the Al matrix composites reinforced with SiC particles and mechanical properties.

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1. INTRODUCTION

Particulate reinforcement metal matrix composites are very attractive for extensive application in the aerospace and automotive industries because of low cost, low density (3 g/cm^3), high stiffness, low coefficient of thermal expansion (6-8*10^{-6} K^{-1}), high strength and high thermal conductivity (180-200 W/mK). The high bonding strength of the reinforced particles and matrix is the main reason for their high specific mechanical properties [1]. The main problem of Al-Si-C based ceramics is the presence of the binary aluminum carbide Al_4C_3 in the final sintering product because of its negative effects on the usability of the materials [2]. Aluminum reacts with silicon carbide to form Al_4C_3 and Si according to the heterogeneous reaction:

$$4Al + 3SiC \longrightarrow Al_4C_3 + 3Si$$

This reaction is known to degrade the mechanical properties of the composite materials due to the formation of Al_4C_3, which unstable in some environments such water, methanol, ets. [3]. In addition, Si released from SiC reinforcement with change the composition of the matrix and this affects the properties of materials after the subsequent heat treatment. As a result, much work has been done on the mechanism of the formation of Al_4C_3 and various methods have been suggested to protect the formation of Al_4C_3 [4]. Al matrix composites reinforced with SiC particles can be fabricated by several techniques, among them semi-solid forming can be easily brought to mass production and recently much attention has been given to the behavior

of material in semi solid state, although the ternary Al-Si-C system has been intensively investigated since the early 1980's. Most solid state synthesis methods were conducted in inert gas (argon) [5]-[8].

2. EXPERIMENTAL SECTION

The materials used in the present study are fine powders of aluminum metal and silicon carbide (SiC) which supplied from BDH chemicals Ltd pool England. The SiC powders were used in particle sizes (65 μm). Three batches compositions were prepared, it content Al powder with 40 wt %, 50wt%, 60 wt% and 70wt% SiC addition. The materials amounts have weighted using a sensitive four digital balance type (Precisa Instrument Ltd.). Powders were properly mixed in a porcelain mortar with 5 wt% distilled water, then, the mixture was compacted in a plate-shaped steel mold using a load of 2 Tons. Subsequently the mixture was dried in a furnace at 120 ^{0}C for two hours to eliminate the water. The weighted mass (2 gm of powder) was subject to uniaxial pressing forced through a steel die to produce a disk samples with 1.8 cm in diameter. Samples were dried for 72 hours in air and then in furnace at 120 ^{0}C for 8 hours. The prepared samples have been sintered at (800 ^{0}C and 1100 ^{0}C) for 4 hours at heating rate 15 ^{0}C /min in furnace. After furnace cooling to room temperature, the specimens were removed for characterization using X-ray diffraction (Cu-Kα radiation), the samples were also tested in Vickers micro-hardness measurements, with load of 9.8 N and loading period of 40 second was used to obtain the hardness properties for composite samples. The indentation impression was subject at four positions in addition to the center of each samples and the average has calculate. Equation (1) was used to calculate Vickers hardness [5].

$$V.H.N. = \frac{2p\sin(\alpha/2)}{2} = \frac{1854.4p}{l_{av}^2} \quad -----(1)$$

Where: 1.854 is a constant, p is the load.
$L_{av.}$ is the average of indentation diameter $(l_1+l_2)/2$.

3. RESULTS AND DISCUSSION

X-ray diffraction analysis

X - ray diffraction methods were used to characterization and observe the phases formed in the process of sintering at high temperatures. Results show that the reaction between Al and SiC is known to be deleterious to the properties of the composites since it leads to the degradation of the SiC reinforcement and produces a brittle intermetallic compound ($Al_4C_{3)}$.
Results from X-ray diffractions were given in Figures 1 and 2 and Table 1.

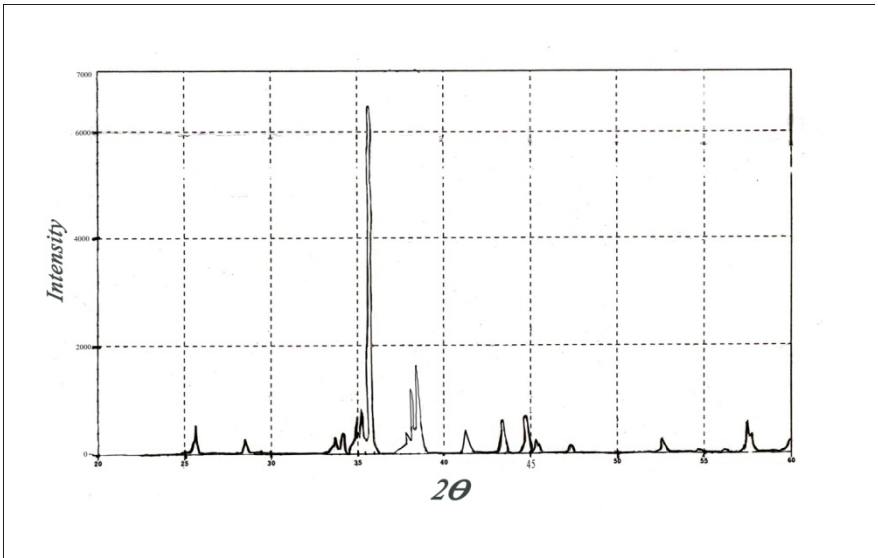

Figure 1. X-ray diffraction patterns of SiC/Al sintering at 800 ^{0}C with SiC wt 70%

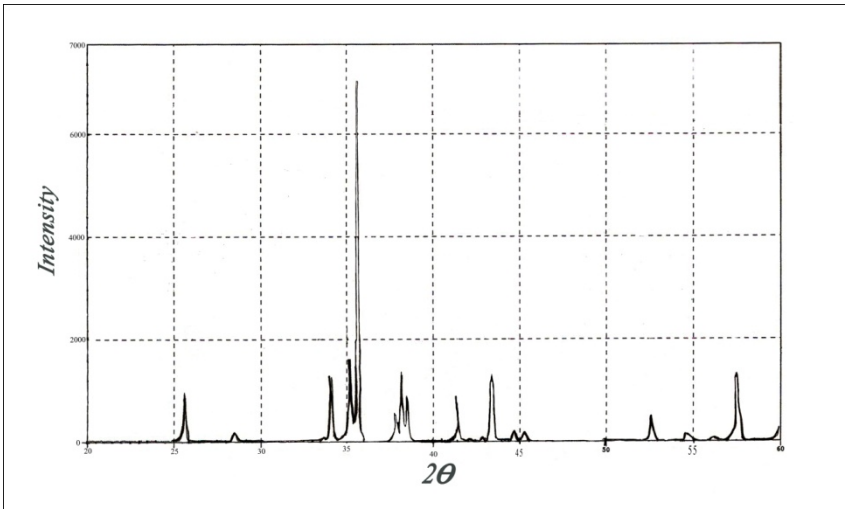

Figure 2. X-ray diffraction patterns of SiC/Al sintering at 1100 0C with SiC wt 70%

Table 1. Phases detected with X-ray diffraction

Condition	Observed Phases
Sintering at 800 ^{0}C with SiC 70%	$Al_4Si_2C_5$,SiC, Al, $Al_4Si_3C_6$, Al_4C_3
Sintering at 1100 ^{0}C with SiC 70%	Al_4SiC_7, $Al_4Si_2C_5$

Figure (1) shows strong peaks with 2θ values about (35.6921^0, 38.5240^0 and 38.2079^0), weak peaks with 2θ value about (28.5377^0, 33.7649^0). Figure (2) shows strong peaks with 2θ values about (35.6462^0, 35.2043^0 and 57.5395^0), weak peaks with 2θ values about (37.8251^0, 52.5975^0).

The crystallites size of the grains in the composite is estimated using the Sherer formula [9]:

$$D = \frac{K\lambda}{\beta_{2\vartheta}\cos\theta}$$

Where
K: is a constant taken to be 0.94,

λ : the wavelength of X-ray used (λ =1.54060 $\overset{0}{A}$),

$\beta_{2\theta}$: is the full width at half maximum of (002) peak of X-ray pattern,

2θ: is the Bragg angle.

The value of crystallite size is found to be (51.63 nm, 58.11nm).

The strain (ε) of the sample is determined with the use of the following formula:

$$\varepsilon = \frac{\beta\cos\theta}{4}$$

The values of 2θ, $\beta_{2\theta}$ the full width at half maximum, grain size, strain and intensity of the X-RD peak in the SiC/Al composite of different sintering temperature with SiC amount (70%) are given in table 2.

Table 2. Comparison of structural parameters, FWHM, Grain size, Strain and Peak Intensity of the SiC/ Al at different sintering temperature.

Sintering temperature ^{0}C	Angle 2θ	$\beta_{2\theta}$ radian	Grain size Nm	Strain ε *10^{-4}	Peak Intensity a.u
800	35.6921	0.0028	51.63	6.99	3237
1100	35.6462	0.0024	58.11	5.99	3248

Iseki et al. [10] have reported that the extent of the reaction between SiC and Al can be monitored by measuring the intensities of Al, SiC and Al_4C_3 peaks. The reaction between SiC and Al is:

1. Chemical reaction (dissolution) of Sic with Al
2. Diffusion of Si and C atoms away from SiC surface into Al.
3. Formation of compounds until the concentration of Al and C reaches the equilibrium concentration of Al_4C_3

   It is believed that increasing the amount of Si in the matrix can reduce the dissolution of SiC and prevent the formation of Al_4C_3 [11].

Vickers Hardness Measurement

The effect of reinforcement amount on the density of the composite material, was shown in figure (3), from the figure it was clear that with increasing SiC amount density of the composite increases this is due to the presents of high SiC content (from 40% to 70% by volume), that is void fraction of the material decreases with increasing reinforcement content.

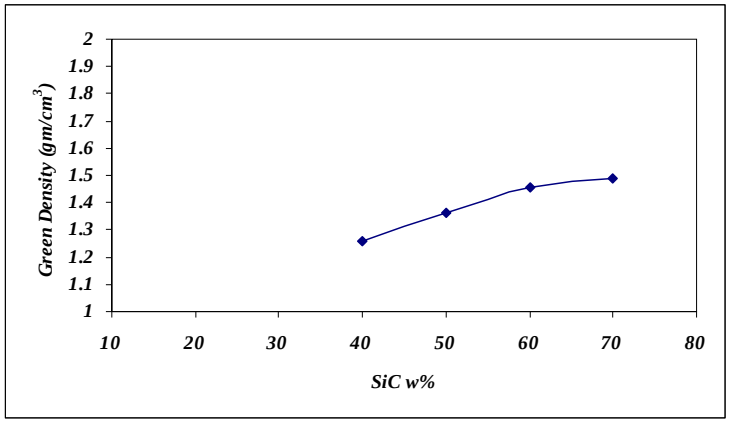

Figure 3. Variation of the green density as a function of SiC wt %

The influences of sintering temperature on the samples components were shown in figure (4). It was clear that bulk density of the composite increases with increasing SiC amount and sintered temperature.

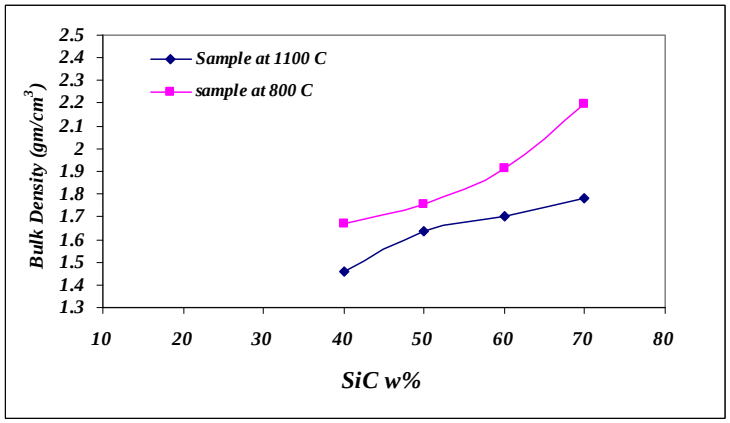

Figure 4. Variation of the bulk density as a function of SiC wt %

The variation of the Vickers hardness of the composite as a function of SiC amount was shown in figure (5), from the figure it is clear that with increasing SiC amount hardness of the composite was increases. The highest value of V.H. was obtained for samples sintering at 1100 ^{0}C with SiC wt 70% due to the stiffness of the matrix material. The incorporation of particles in the matrix results in an increase in work hardening because of the lower matrix volume [12].

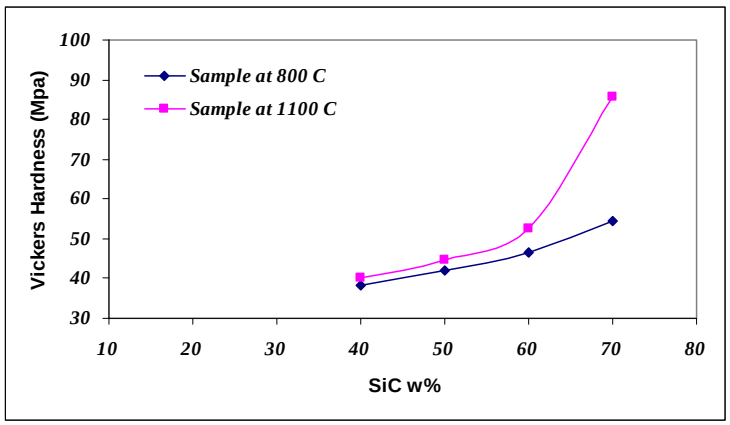

Figure 5. Variation of the Vickers hardness of the composite as a function SiC wt%

The variation of V.H. as a function of Temperature was shown in figure (6), from the figure it is clear that with increasing sintering temperature V.H. of the composite was increases. The highest value of V.H. was obtained for samples with SiC amount 70% sintering at 1100 ^{0}C. The mechanical behavior of the composite is also very much dependent on the relationship between particle/ matrix interface strength and particle strength [13]. It is desirable to have a very high-strength particle/ matrix interface to maximize the load transfer to the particle up to the point of fracture.

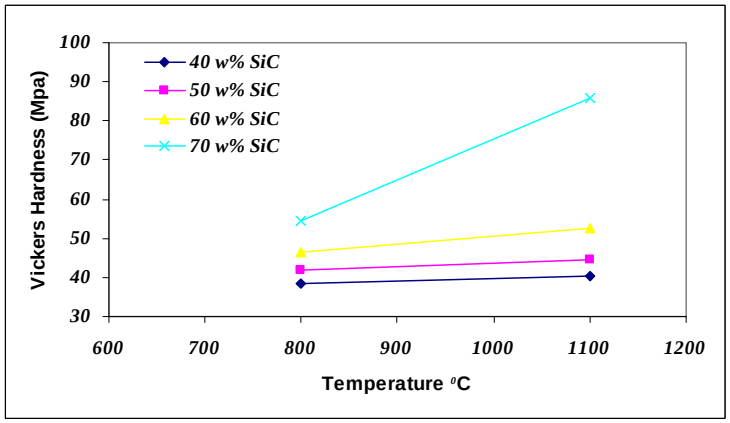

Figure 6. Variation of V.H. as a function of sintering temperature

The hardness behavior observed is ascribed essentially to the perform characteristics. And as it may be recalled, the preforms may differ either in percent porosity or in SiC particle size [14].

4. CONCLUSION

The experimental study reveals following conclusions:

1. Sic/ Al composites have been characterized using X-RD. The formation of aluminum carbide Al_4C_3, which commonly has negative effects to Al-Si-C based ceramics, could be successfully prevented by controlling the reaction conditions.
2. Increasing SiC amount and sintered temperature density of the composite increases.
3. Increasing sintering temperature V.H. of the composite was increases.

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