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Effect of Processing Temperature and Holding Time on Al/Sic Composites: An Experimental Study

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Abstract

The bonding at the interface between metal-ceramic is very important phenomena in the metal matrix composites. The properties of composite are mainly depends on the behavior of interface. Therefore, it is essential to understand the nature of interface bonding between metal and ceramic. The bonded samples of aluminium and silicon carbide were prepared at different processing temperatures with different holding time. The formation of intermetallic compounds at the interface was evaluated by energy dispersive spectroscopy and scanning electron microscopy. The interface strength was evaluated by tensile and microhardness test.

Keywords: Metal – Ceramic bonding, SEM, EDS.

1. Introduction

The metal matrix composites (MMCs) have been continued existence since last few decades, their commercial applications have been used widely due to their low cost, improved in the mechanical properties such as specific strength and stiffness even at the elevated temperatures[1,2]. Aluminium based MMCs have the potential of being cost effective, low density, which makes them to fit for automotive components, machine parts and related industries. These mechanical properties are depending upon the load transfer across the interface and ductility is influenced by relaxation of higher stresses near the interface [3]. The interface is a key region to determining the set of properties of composites materials. The formation of strong interface mainly depends on the processing method, composition of matrix material, processing temperature and holding time. The chemical reaction which intern to produce intermetallic product when liquid matrix material contacts with solid reinforcement at higher temperature for prolonged contact time. This interfacial reaction product becomes high stress concentration area that makes the interface lose its stability and the ability of transferring the applied load. Thus, it is not surprising to more that much of the research in mechanism of composites materials has focused on the interface, but due to the complexity of this subject many issues still remain unclear and unsolved. Therefore, it becomes extremely important to understand the nature of interface in composite materials. The bonding strength of metal-ceramic bonding is an important property which should be known if needs optimize the process-structure-property for functional usage them. There are several methods [4, 5] are used by researchers earlier to measure the bonding strength of the composites.

The focus of present work is to evaluate the interface composition of Al/SiC system at various temperatures with different holding time. The aim is to understand how the composition of matrix materials modifies the interface bonding between matrix and reinforcement and also the influence of processing temperature on the effective bonding between them. This interface compounds were evaluated by energy dispersive spectroscopy and scanning electron microscope.

2. Experimental Procedure

The SiC plates of 75x100x6mm were prepared by sintering process with 1900^0 C at 3000 psi for 2 hrs. These samples were fully densed SiC particles with density of 3.2 g/cm^3 and elastic modulus of 410 GPa. The aluminium alloy (Al -11.12 Si- 0.92 Mg) was used. The SiC plate was kept in a special steel mold and a clay graphite crucible was kept over the mold which contains Al alloy. The whole setup was kept inside the furnace. The heating rate in the furnace varies between 8^0C to 15^0C. The experiments were conducted at different temperatures such as 700^0C, 750^0C, 800^0C, 850^0C and 900^0C, with different time of 10, 20, 30 mins. During the holding time, liquid aluminium contacts with SiC plate without any force (natural contact), after which the furnace was shut off. The mould was taken out and cooled at room temperature. The casting specimen is shown in Fig.1. The bonded Al/SiC samples were cut from the casting specimen. Both interface reaction and wetting behavior in the molten Al/SiC bonded were evaluated by SEM and the elements at SiC/Al interfaces were determined by EDS microanalysis. The specimens were prepared using conventional metallographic techniques for aluminium matrix composites: grinding with SiC paper up to 600 grades and polishing with diamond paste of decreasing particle size (3, 1 and 0.1 µm). The tensile strength of the bonded samples were evaluated by FIE tensile machine. The microhardness was measured from the interface by using Wilson Wolpert hardness tester with 500g load at different location across the interface region.

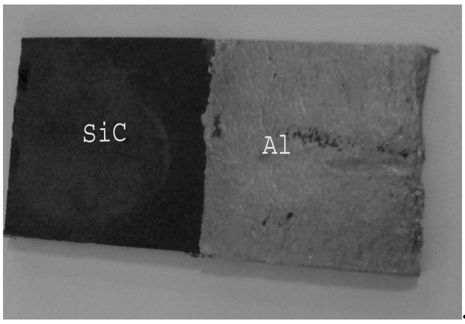
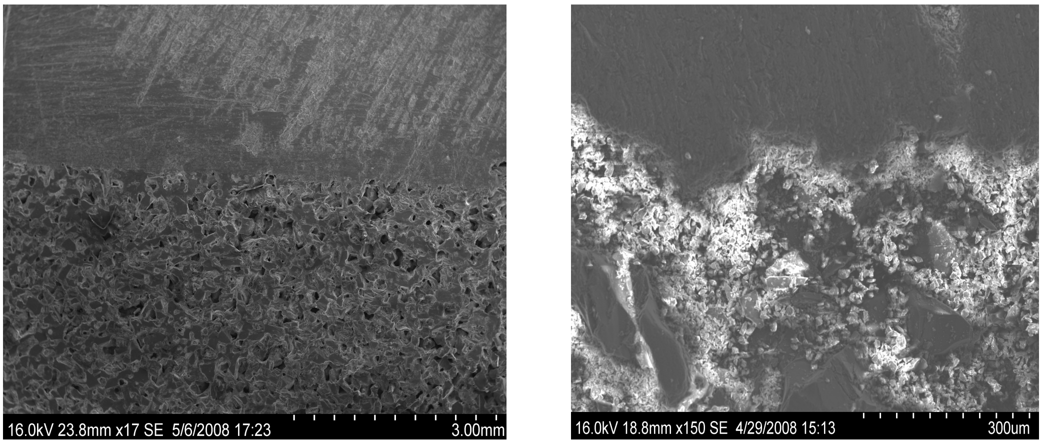


Fig. 1: Bonded aluminum–silicon carbide specimen.

3. Results and Discussion

3.1 Interface structure of Al/SiC

The SEM image of Al /SiC was shown in Fig 2. This image was taken from the processed Al /SiC sample at 850^0C, 20 mines holding time and it shows clearly the interface region. The compositions of matrix at the interface were evaluated by using EDS analysis was shown in Fig.3. When the processing temperature is increased to certain level the chemical reaction has been taken place between liquid Al with solid SiC. At high temperature it was found that the solid SiC was segregated into Si and C. The reaction takes place as follows: $SiC \rightarrow Si + C$[6]. When the temperature increases, the segregation level of the elements increased. The Si concentration level increased at the interface and it dissolves faster in the liquid aluminium compared to carbon. Further, the presence of carbon near the interface reacts with Al to form the Al_4C_3[7], according to the following reaction: $4Al + 3C \rightarrow Al_4C_3$.The higher concentration of Si may reduce the reaction kinetics at the interface [8].



(a) (b)

Fig. 2: Scanning electron microscope image of interface of Al / SiC at 850^0C (a) low magnification, (b) Higher magnification

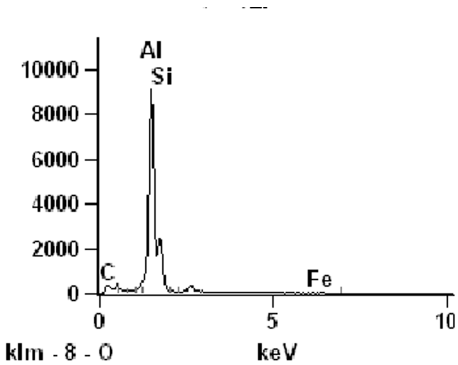
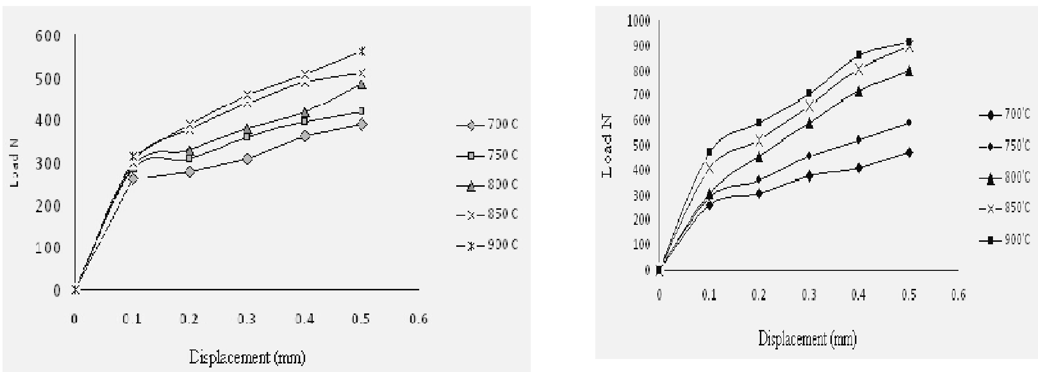


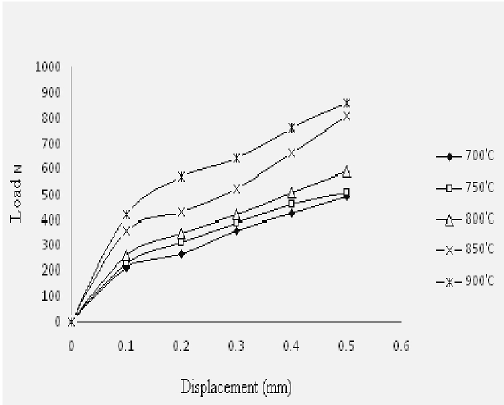
Fig. 3: EDS analysis of interfacial compounds at the interface of Al / SiC.

3.2 Effect of processing temperature

There are number of factors which are influencing the properties of composite materials. These factors are complex and interrelated. The processing temperature, one of the most important factors influencing the properties of MMCs. whereas; the increase in processing temperature results in altering the matrix composition there by modifies the reaction kinetics between matrix and reinforcement. The general perception of interface bond strength has been confirmed in Al/SiC systems which were processed at various processing temperatures with various holding time. Fig.4 shows the variation of maximum tensile strength of the samples. When processing temperature increases, the fracture strength increasing gradually, despite the fact that concentrations of silicon at the interfaces were increased. At low processing temperatures an adequate segregation of Si not formed and bond strength is very low. Thus, higher concentration of silicon at the interface to increased wettability around the surface of reinforcement and improved the strong interface bond between aluminium and silicon carbide. The hardness values were measured at the interface. The hardness values were increased toward to interface is shown in Fig.5.



(a) **(b)**



(c)

Fig. 4: Load Vs displacement of Al/SiC system (a)10 mines holding time, (b) 20 mines holding time,(c)30 mines holding time.

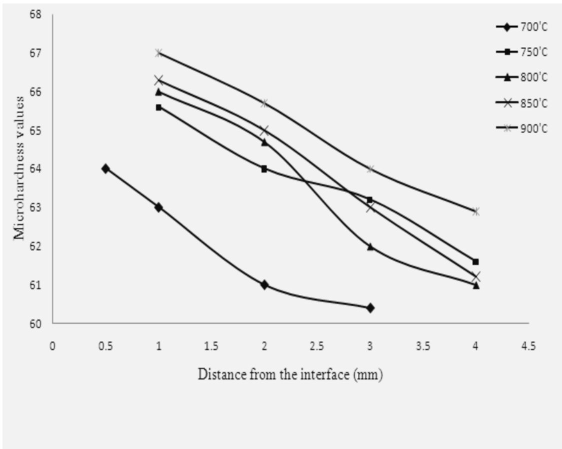


Fig. 5: Microhardness values taken near the Interface in Al/SiC

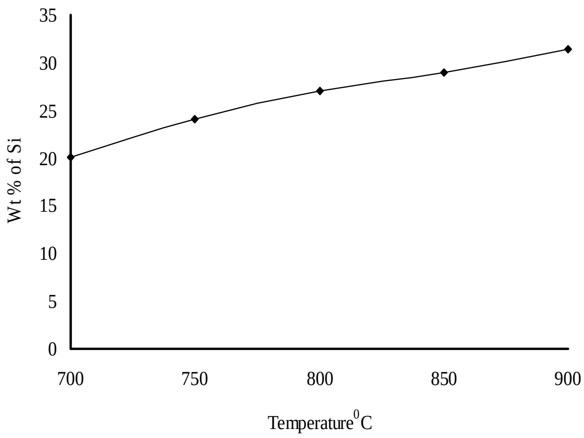


Fig. 6: Weight percentage of silicon concentration at the interface.

The hardness values increased with increasing processing temperature, which related to better wettability and presence of more silicon at the interface at higher temperatures. When increase the processing temperature, the silicon concentration level increased at the interfaces are shown Fig.6. This wettability causes a better incorporation of SiC in the matrix, more dislocation and prevents of their mobility, hence the hardness values were increased towards the interface [9].

3.3 Effect of holding time

The interface bonding strength of the Al-SiC system was increased with increasing holding time. The silicon elements were segregated from the SiC and diffused into the liquid Al alloy more efficiently as the holding time was prolonged which enhances the contact between solid SiC and liquid Al alloy. Therefore, concentration of the silicon increases gradually at the interface with increasing holding time, which decreased the formation of alumina carbide at the interface of Al/SiC [10]. The diffusion rate of Si is often satisfactorily expressed by Arrhenius equation [11]. $D = D_0 \exp(-E_a/RT)$, $E_a = (E_{al},_{int} - E_{al})$,Where E_a- activation energy of Si at the interface,D -diffusion co-efficient or diffusivity,D_0 -pre exponential co-efficient ,$E_{al, int}$ -activation energy for Si in Al, E_{al}-activation energy of vacancy formation in Al ,R- universal gas constant .Arehenious equation is used to determine length of diffusion of Si elements in the Al alloy matrix. The length of diffusion [12]: $L = \sqrt{4Dt}$,Where, L- Diffusion length of Si,t - Time of diffusion between matrix and reinforcement It has been found that the rate of diffusivity of Si increases with increase in temperature and time. Hence, the diffusion rate of Si in the matrix region depends on the holding temperature and time.

4. Conclusions

The characteristics of interface compounds of Al/SiC system has been studied by using bonding process. The following observation can be drawn from this investigation

- The segregation of elements of Silicon and carbon were increased with increases in processing temperature and holding time
- The concentration of Silicon at the interface increases with increase in holding time at higher temperature
- The fracture strength of interface increases with increase in processing temperature and increasing holding time
- The diffusion length of silicon increased with increasing holding time.

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