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STUDIES ON SiC(p) REINFORCED Al-Al_3Ni EUTECTIC MATRIX COMPOSITES

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Abstract

An investigation on processing of Al-5.69wt% Ni eutectic reinforced with SiC particulate composites is reported. The intermetallic composites are prepared by elemental powder metallurgy route and sintered at two different temperatures, i.e., 600°C and 620°C. Results show that the metal matrix was Al-Al_3Ni eutectic. The phase analysis by XRD identified the presence of Al3Ni and Al as dominant phases together with silicon and Al_4C_3 phase as minor phases. The Al_4C_3 and Si phases are formed during sintering due to SiC-Al interface reaction. SEM micrographs also reveal the formation of microvoid surrounding the SiC particle.

Introduction

Metal matrix composites(MMC's) reinforced with particulate ceramics comprise a class of new generation of materials with significant increase in temperature capability required to meet the demands of future engineering applications such as for aerospace and automotive. These composites require a balance of properties such as high specific strength and moduli at room and elevated temperature, creep resistance and superior environmental stability, excellent wear resistance, high thermal conductivity, low coefficient of thermal expansion and good dimension stability. Materials with high specific strength and stiffness are required for aerospace applications and in rotating components. This has generated considerable interest in the development of MMC's based on light alloy matrix such as aluminium and magnesium alloy reinforced with ceramic particulates or fibers. Aluminium alloy reinforced with ceramic particulates, i.e SiC in particular, have attracted great attention and are being developed for various applications. To date, there is large research activity in developing aluminium matrix composites reinforced with SiC[1]. There are several ways of fabricating the particulate reinforced composites which include liquid metal infiltration technique and by powder metallurgy route. Powder metallurgy route has been identified as best method of processing particulate reinforced composites as it is possible to obtain a composite with large volume of reinforcement and at the same time producing homogeneous distribution of the particulate in the matrix. There is also very limited matrix-particle reaction as compared to technique involving liquid metal.

Increasing demand for better performance materials for high temperature applications has been the main driving force for development of advanced composite materials for critical components. In view of the operating temperature limitations for conventional aluminium alloy system, interest has now focused on intermetallic and structural ceramics. As compared to numerous works reported in the literature involving aluminium alloys or other metallic system as a matrix, very limited work has been reported in the literature regarding development of intermetallic matrix composites. The investigation on intermetallics reported in literature is mainly for Al-Ni and Al-Ti intermetallics.These intermetallics have excellent engineering properties and useful for high temperature service. Figure 1 shows the phase diagram for Al-Ni system that can form several intermetallics such as $AlNi_3$, Al_3Ni_5, AlNi, Al_3Ni_2 and Al_3Ni. All of these intermetallics have high melting point except Al3Ni intermetallic that has relativelylow melting temperature. Al3Ni - Al system has eutectic composition at about 6 wt% Ni and eutectic temperature for this system is 640°C. Al_3Ni is the intermetallic that has been studied to some extent while the eutectic Al_3Ni-Al got less attention. However these eutectic matrix show promising applications due to its ability to produce directional solidification in composites eutectic structure. Due to the presence of ductile Al phase and hard and brittle intermetallic phase, these materials can form a composite matrix by itself.

Materials and Experimental Procedure

The composite under investigation is an Al_3Ni eutectic reinforced with SiC particles. The intermetallic Al3Ni in eutectics is formed by the reaction of Al Powder with 5.69wt% Ni powder. In preparing the intermetallic composite, we have followed the elemental powder metallurgy route. The essential steps involved in the EPM method are shown in Figure 2. Both Al and Ni powder were obtained from Fluka . The SiC powder used for reinforcements is beta-SiC having mean size of 13micron. The mixtures of Al powder with 5.69wt% Ni were prepared and mixed with SiC and then milled in a porcelain jar using steel balls. In this work dry milling has been employed. In order to reduce excessive heating, intermittent milling has been carried out with 2 hours milling and one hour cooling time. These processes are repeated until a total of 10 hours milling time has been achieved. Milling process will produce a mechanically alloyed powder . Since Al is more ductile than Ni and SiC powder, Al grains get heavily deformed with Ni and SiC particles attached on the Al grains. After ball milling, the powder mixture is compacted uniaxially by pressing at 250MPa. The compacted powder was then sintered in a tube furnace under a flow of argon gas. The sintering is done at 600°C for 16 hours and 620°C for 4 and 10 hours.

The sintered specimens are subjected to XRD analysis to evaluate the success of sintering process and formation of intermetallic phase. The microstructure of the composite was characterized using optical microscopy and SEM equipped with EDX facility.

Results and Discussion

Formation of eutectic Al_3Ni-Al

Representative micrographs of the intermetallic composites with SiC particles are illustrated in Figure 3.The microstructure observation on all samples studied shows that the intermetallic phase Al_3Ni formed in all samples sintered between 600° - 800°C. Figure 3 clearly shows the presence of Al_3Ni phase in the microstructure of sintered sample. It can be seen that the intermetallic Al_3Ni phase formed during sintering is distributed within the Al matrix and there is no SiC particle in the intermetallic grains. Increasing sintering temperature or increasing sintering time will increase the amount of intermetallic phase. An attempt has been made by sintering the powder mixture at 800 °C, i.e. . involving liquid phase. The resulting microstructure is shown in Figure 4. It can be seen that Al_3Ni phase formed is coarser. Moreover, the microstructure of this sintered specimen reveals more pores than specimen sintered at lower temperature. This may be due to the migration of liquid phase from internal to the surface. This is reflected by the formation of bead at the surface of the sample. The microstructure of the bead is shown in Figure 5. The XRD analysis of the sintered sample confirm the formation of intermetallic phase.

The SiC particles appear to be distributed evenly in the matrix phase. Increasing sintering temperature seems to help in reducing porosity. It is also seen that the composites containing higher weight percentage of SiC particles exhibit a greater degree of clustering of SiC compared to the composite containing less weight percentage of SiC.

The detailed studies of the microstructure of intermetallic Al_3Ni eutectic using SEM has been carried out. The representative SEM micrograph of the composite studied is shown in Figure 6. The Al_3Ni phase formed during sintering can be seen clearly and appears as a brighter phase. The micrograph also revealed the presence of two types of pores, i.e. isolated pores in the Al matrix and pores along the SiC particles.

XRD analysis.

The XRD analysis carried out on the samples reveals not only the presence of intermetallic phase Al_3Ni, but also the presence of silicon and Al_4C_3 in the composite sintered between 600°- 660°C. The representative XRD patterns for the sintered samples are shown in Figure 7. The presence of silicon in the composite sintered at 600°C is very small as shown by a very weak peak, however the intensity of Si peak increased with increasing sintering temperature and sintering time. The same pattern is shown by the Al_4C_3 peak. The result suggests that Si and Al_4C_3 are formed from the reaction between Al-SiC. XRD analysis on samples before sintering does not show any evidence of Si and Al_4C_3. These confirm that both phases are only present in sintered sample and are due to the reaction between Al and SiC at the SiC interface. It has been suggested by earlier studies, that if the reaction between SiC and aluminium occurs, it will produce Al_4C_3 and Si with the following reaction;

$$4Al(l) + 3SiC(s) \Longrightarrow Al_4C_3(s) + 3Si(l)$$

The amount of Si and Al_4C_3 formed are dependent on sintering temperature and sintering time as revealed by these studies. Close examination on the sintered samples by SEM shows the formation of voids along the SiC particle in contact with aluminium and is another evident of this reaction.

Earlier works by Han et.al.[2] , reported the interfacial breakdown and void formation occured at SiC interfaces. They also reported that the initial interfacial decoherence was most frequently observed at sites where SiC particle clusters existed and silicon particle were often found adjacent to SiC particles. EDX analysis on the section shown in Figure 8 confirm the presence of silicon adjacent to SiC particles.

Thermodynamic phase stability calculations by Argent et. al.[3] predict the presence of Al_4C_3 only in equilbrium with liquid aluminium. However in the present investigation, Al_4C_3 is detected at sintering temperature of 600°C and 620°C much lower then the melting point of aluminium or the eutectic temperature. The result can be explained on the basis of release of heat on the exothermic reaction of formation of the intermetallic Al_3Ni. The heat produced locally by the exothermic reaction is sufficient to melt aluminium in the vicinity of the intermetallic, therby producing weak Al/SiC reaction forming very small amount of Al_4C_3. However if the temperature of sintering is raised to 800°C (liquid phase sintering), the amount of Al_4C_3 formed by the interface reaction will be more as is reflected in the present investigation.

Conclusion.

The investigation has established that there is an interface SiC/Al reaction resulting in the formation of Si and Al_4C_3 even at sintering temperatures lower than the melting point of aluminium or the eutectic temperature. The observation has been explained on the basis of exothermic reaction during formation of Al_3Ni intermetallic.

References.

1. Andreas Mortensen and Michael J. Koczak, Journal of Materials, 1993, No.3, p10-17.
2. N. Han, G. Pollard and R. Stevens, Materials Science and Technology, 1992, Vol 8, p184-186.
3. B.B. Argent, Private Communication.

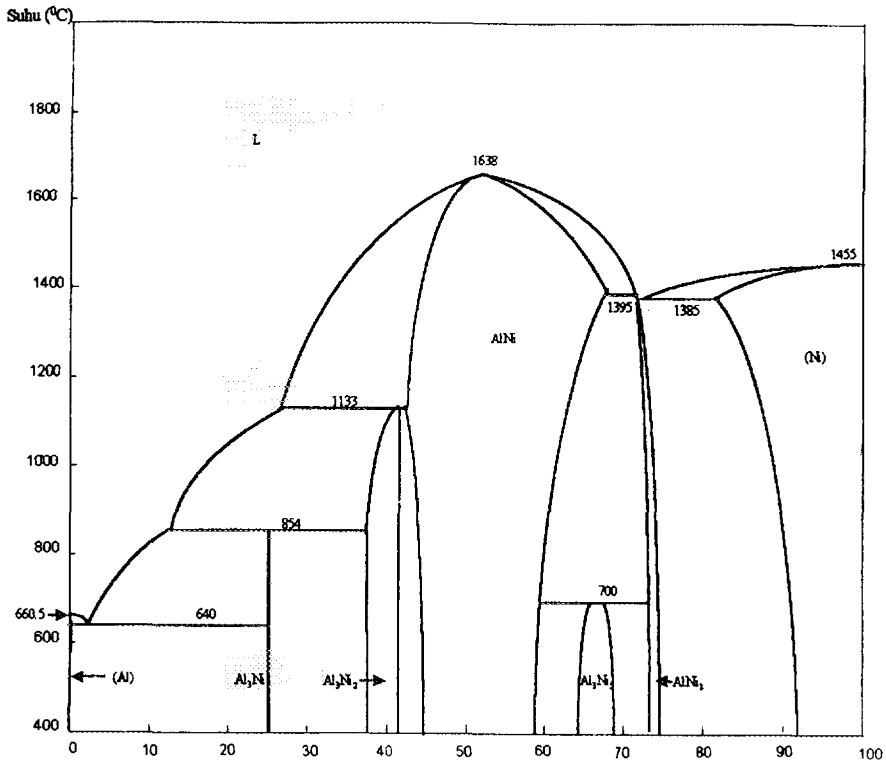

Figure 1. Binary phase diagram for Al-Ni syatem.

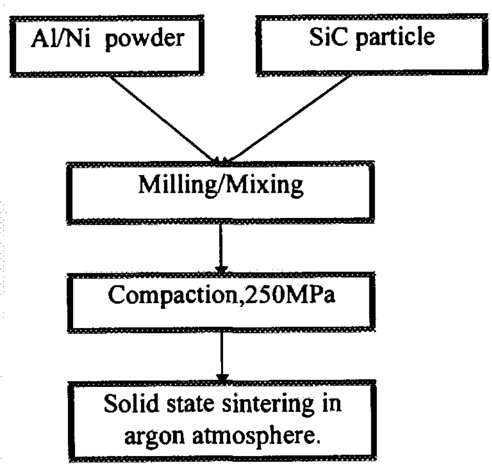

Figure 2. Schematic flow diagram for EPM processing of Al-Al_3Ni eutectic composite reinforced SiC.

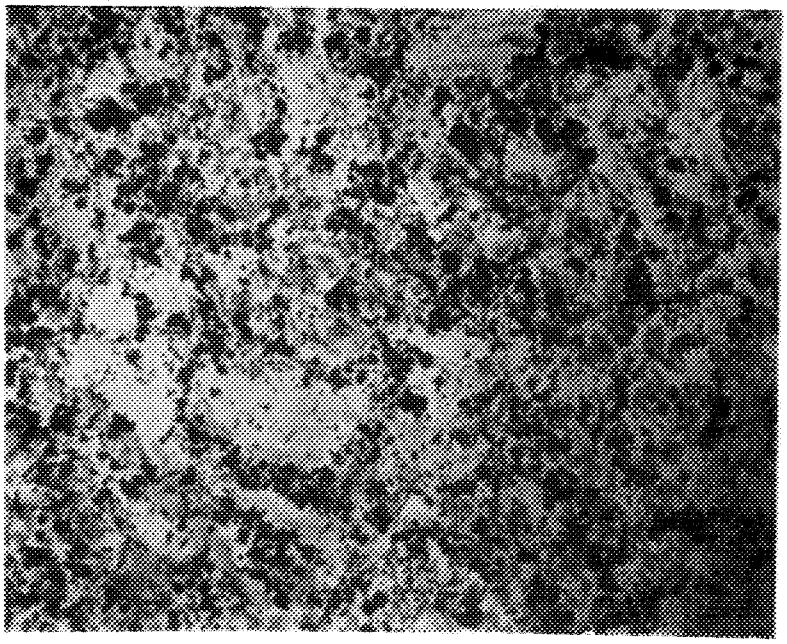

Figure 3. Representative micrographs of $Al\text{-}Al_3Ni$ eutectic composite reinforced with 15% SiC sintered at 620°C.(100x)

Figure 4. Microstructure of $Al\text{-}Al_3Ni$ eutectic composite with 15wt% SiC sintered at 800°C.(100x)

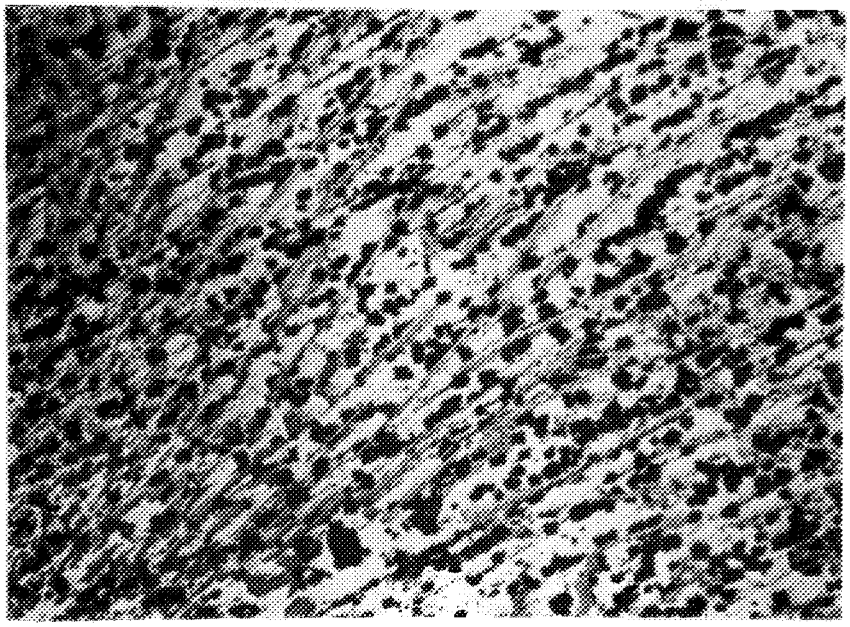

Figure 5. Microstructure of the bead formed at the surface of the composite sintered at 800°C.

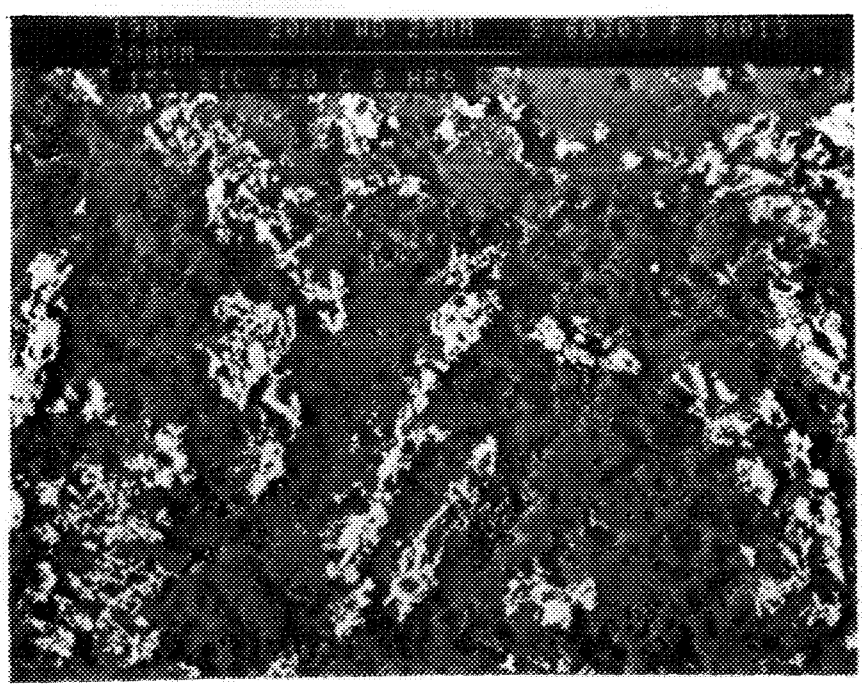

Figure 6. The representative SEM micrograph of the $Al-Al_3Ni$ eutectic composite reinforced with 15wt% SiC and sintered at 620°C.The micrograph revealed the presence of pores along the SiC particles.

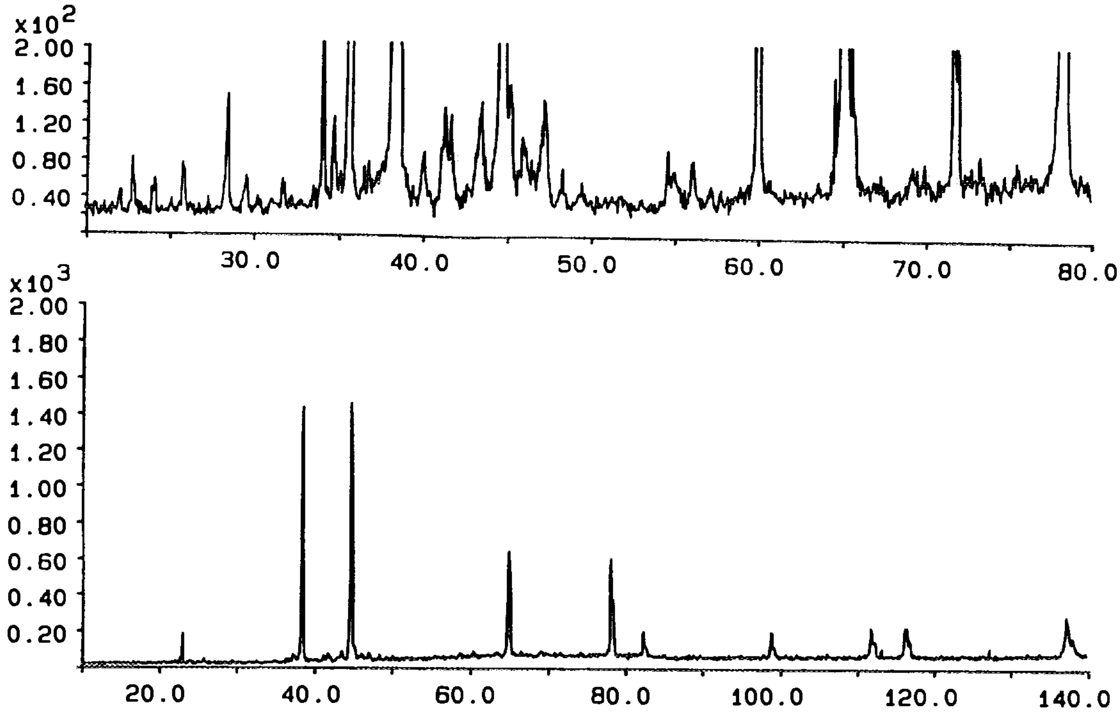

Figure 7. XRD patterns of the Al-Al_3Ni eutectic composite reinforced SiC (a) 15wr% SiC (b) the bead formed at the surface.

Figure 8. SEM micrograph of composite showing the presence of intermetallic phase and SiC particles.