Microstructural characteristics of 2124 Al – 40 vol.% SiCp metal matrix composites produced by room temperature shock consolidation and hot shock consolidation

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2124 Al – 40 vol.% SiCp metal matrix composites have been consolidated by room temperature shock consolidation using axisymmetric assembly, and by one-dimensional hot shock consolidation using underwater shock wave assembly. Trimonite powder explosive was used in room temperature consolidation and SEP explosive was used in hot shock consolidation. The thickness of the explosive layer used in room temperature consolidation was 27 mm. The thickness of the water layer employed in the hot consolidation experiments was 15 mm. The hot shock consolidation was carried out at 200°C, 300°C and 400°C. The microstructural variations across the cross section of the room temperature shock consolidated compact and, the effect of the temperature on microstructure and hardness of the hot consolidated composites have been investigated. Microstructural comparison was made between the composites produced by both room temperature consolidation and hot consolidation.

1. Introduction

Silicon carbide particulate or whisker reinforced aluminium metal matrix composites have higher stiffness, strength, fatigue properties, creep resistance and wear resistance than many wrought aluminium alloys. These materials can be fabricated by conventional metal working techniques such as extrusion, forging and rolling, which makes them attractive for many applications.

The processing of metal matrix composites by the conventional powder metallurgy is expensive due to high capital investment and long processing times. As an alternative, the shock compaction methods, which are attractive and economical, can be used for the consolidation of composites materials. The shock consolidation achieves the compaction of the powder particles in a few microseconds, thus reducing the time for fabrication of composites considerably. Although information is available on the relationship between the various process parameters and the density of the compacts of elemental powders, there is very little information available on the processing of metal-matrix composites by shock consolidation. Rabin and others attempted to produce 2124 aluminum composites reinforced with SiC particulates via dynamic compaction using explosives, and the low ductility of the composite observed in their work was attributed to the fracture occurring predominantly along prior particle boundaries [1]. The effects of process parameters like explosive thickness, impact energy and the ratio of explosive mass to powder mass on the densification of commercial pure Aluminium - 20 vol.% SiCp composites by explosive compaction were investigated by Siva Kumar and others [2]. Explosively compacted 2124 Al alloy reinforced with SiC particulate composites have been investigated, and the effect of process parameters on densification has been studied [3–5]. Microstructural variations with respect to the processing conditions have also been investigated on explosively compacted Al – SiCp composites [6, 7]. Attempts were made to produce metal matrix tubular components through explosive compaction [8]. In the present investigation an attempt has been made to produce 2124 Al – 40 vol.% SiCp composites by room temperature shock consolidation using axisymmetric assembly and also, first time by hot shock consolidation in one dimensional compaction system using under water shock wave. It is expected that the

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plastic deformation and surface melting of the powders are enhanced with the help of heating, and several positive effects have been observed using the hot shock consolidation technique [9–13]. Also, with the underwater shock wave consolidation, a relatively long-duration shock pressure is obtainable [14]. The technique was earlier used to consolidate hard ceramic powders [15, 16] and diamond powders [17]. In the present study, microstructural and hardness variations across the cross section of the room temperature shock consolidated compact have been investigated. Also, the effect of the temperature on microstructure and hardness of the composites consolidated by hot shock compaction have been investigated and microstructural comparison was made between the composites produced by both room temperature and hot shock consolidation.

2. Experimental procedure

The particle size of the 2124 Al powder and SiC particulates used in the experiments were 250 and 6 microns respectively. The 2124 Al and SiC particles were mechanically mixed in a ball mill for 20 hours. The arrangement for room temperature shock consolidation is shown elsewhere [18]. The powder mixture was packed in an aluminium tube of 11 mm internal diameter with 2.5 mm wall thickness. The metallic tube filled with composite powder, was placed in a plastic tube and the annular gap between the metallic tube and plastic tube was filled with trimonite explosive powder, which consists of ammonium nitrate, TNT and aluminium powder. The annular gap between the metallic tube and the plastic tube was 27 mm, which is called explosive pad thickness.

The experimental set-up for the hot shock consolidation using underwater shock wave assembly is shown in Fig. 1. Though in earlier experiments of hot shock consolidation, convergent shock was used to compact high hardness powders [15, 16], in the present investigation parallel shock wave was used because of soft matrix material (2124 Al). The powders were heated in Ar atmosphere. After heating the powders, the explosion part was automatically lowered and placed on the heated powder part. The detonator was ignited, after a position sensor confirmed the setting. A thin stainless steel plate was placed above the powders to avoid a rough top surface of the consolidated sample. The thickness of the water layer was 15 mm. The experiments were carried out at 200°C, 300°C and 400°C to study the effect of temperature on consolidation of the composites. The explosive used in hot shock experiments was SEP, provided by Asahi Chemical Industry, whose detonation velocity was about 7000 m/sec and the density was 1.3 g/cc, which is relatively stronger than trimonite explosive used in room temperature shock consolidation.

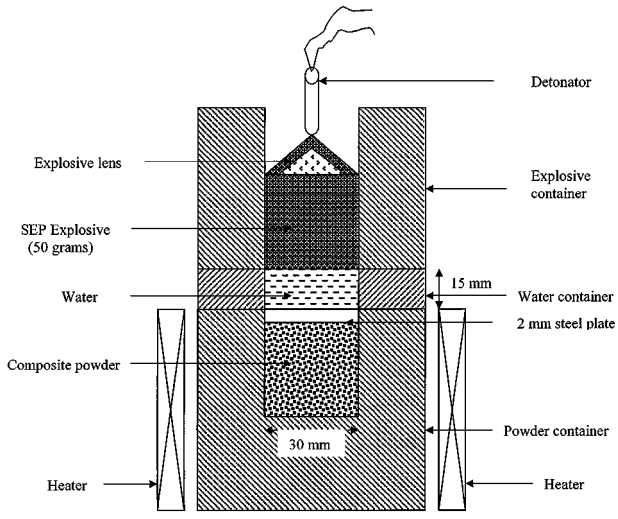

Figure 1 Schematic illustration of one-dimensional hot shock consolidation assembly.

After compaction, the compacts obtained from both the techniques were cut for microstructural and hardness studies. Optical metallography specimens were prepared by standard polishing techniques and etched with Kellar's reagent.

3. Results and discussion

The microstructure of the composite compact produced by room temperature consolidation is shown in Fig. 2. A significant variation in the microstructure was observed across the cross section of the compact. Three different microstructures were observed across the cross section of the compact as shown in the figure. Loosely bonded SiCp structure was observed at the periphery (Fig. 2a), which was followed by closely compacted SiC particulates surrounding 2124 Al particles at the intermediate region of the compact (Fig. 2b) and, uniformly distributed SiC particles in the matrix was observed at the central region of the compact (Fig. 2c). In the case of hot shock consolidation, the samples recovered were porous. The microstructures of the composite compacts consolidated at 200°C, 300°C and 400°C temperature are shown in Fig. 3. There is no variation in microstructure across the cross section of the compact. Also, there is no significant variation in microstructure of the compacts consolidated at different temperatures.

The hardness of the 2124 Al particles of the room temperature shock consolidated sample was found decreasing from periphery (122VPN, under 0.49 N load) to the center of the compact (87 VPN, under 0.49 N load). The hardness on the well-bonded SiCp around the 2124 matrix particles at the intermediate region of the compact was measured as 1615 VPN (under 1.96 N load). The over all hardness on finely dispersed composite region at the center of the composite was measured as 170 VPN (under 1.96 N load).

The hardness of the compacts produced by hot shock consolidation was found decreasing marginally with increasing temperature. The hardness of the 2124 Al particles measured on the compacts consolidated at 200°C, 300°C and 400°C were measured as 92, 87 and 80 VPN (under 0.49 N load) respectively. The hardness of the composite region in all the three samples was found to be in the range of 160–180 VPN (under 0.49 N load).

The variation in the microstructure found in room temperature consolidation can be explained considering the change in pressure across the cross-section of the compact. The pressure generated on the powder

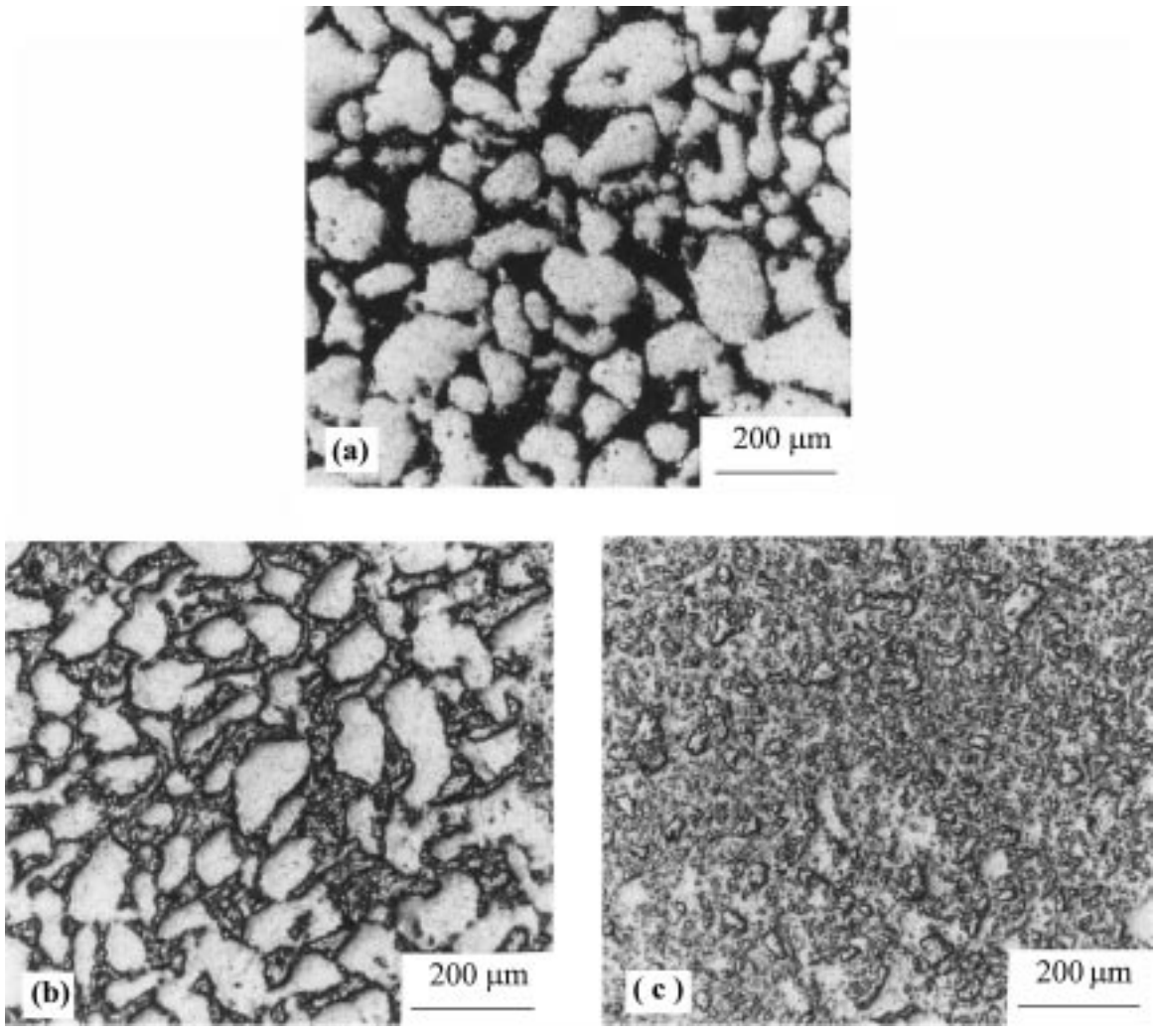

Figure 2 Microstructure of the 2124 Al – 40 vol.% SiCp composite compact produced by room temperature consolidation showing (a) porous structure at periphery, (b) closely bonded SiCp around 2124 Al particles at intermediate region, and (c) finely distributed SiCp in 2124 Al matrix at center region, across the cross section of the compact.

compact in room temperature axisymmetric assembly is calculated by the equation given by Pruemmer and Ziegler [19]. The detonation pressure P acting on the container wall is proportional to the square of the detonation velocity V_d and the density of the explosive:

$$P = 2.5\rho V_d^2 \quad (1)$$

Where ρ is the density of the explosive and V_d is the detonation velocity of the explosive. As the detonation velocity of the explosive varies with the explosive pad thickness used [20, 21], the pressure generated on the powder is thus dependent on the explosive pad thickness. With 27 mm thick explosive pad, the corresponding pressure generated was calculated to be 3.9 GPa. It is known that the pressure generated in axisymmetric explosive compaction will increase in order from periphery to the center of the compact [22]. The loosely bonded SiCp around the matrix particles at the periphery can be attributed to the insufficient pressures to compact the powders (Fig. 2a). As one moves radially inwards the pressure increases due to convergent shock waves. This increase in pressure could have resulted in well-bonded SiCp around the 2124 matrix particles at the intermediate region of the compact as shown in Fig. 2b. The high hardness, 1615 VPN, of SiCp around 2124 Al particles at this region confirms that the bonding between the silicon carbide particles is good, as a result of local sintering due to high temperatures generated. The high pressure due to convergent shock waves at the center of the compact resulted in temperature raise, which caused softening of the 2124 Al particles. The softening of the matrix is supported by decrease in hardness on 2124 Al matrix particles from periphery (122VPN, under 0.49 N load) to the center of the compact (87 VPN, under 0.49 N load). The aluminium evidently melted at the center of the room temperature consolidated sample. The structure present at the center of the compacts (Fig. 2c) could be due to melting of aluminium matrix and also simultaneous dispersion of fragmented SiC particles in the molten matrix as a result of high pressures generated. The increased over all hardness (170 VPN, under 1.96 N load) on finely dispersed composite region at the center of the composite is a good indication for improved properties.

In our earlier work, using one dimensional compaction system at room temperature, the consolidation of 2124Al–40 vol % SiCp composites powders was not successful. The bonding between the matrix particles was not good. The prior particle boundaries were seen

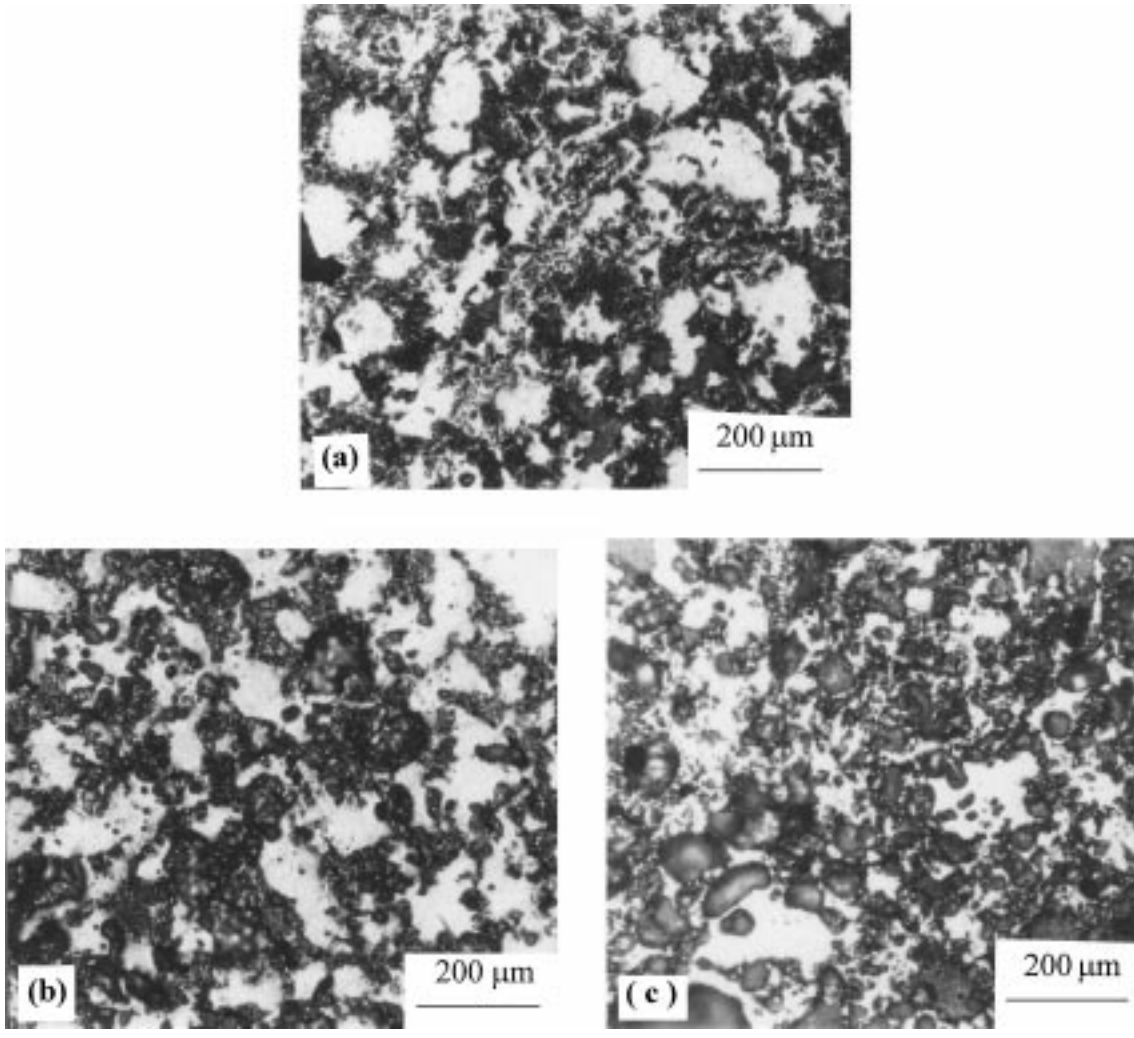

Figure 3 Microstructure of the 2124 Al – 40 vol.% SiCp composites compacts produced by hot shock consolidation at (a) 200°C, (b) 300°C, and (c) 400°C.

even after consolidation. Most of the reinforced silicon particles were removed during cutting and polishing, indicating poor bonding conditions. This could be due to insufficient pressure to consolidate the composite powders at room temperature. To improve the bonding between the particles, in the present experiments, the consolidation temperature was increased keeping the compacting pressure constant.

The maximum shock pressure applied to the composite powder in one-dimensional hot shock consolidation was estimated to be 5 GPa based on the impedance matching method [23]. The decrease in the hardness

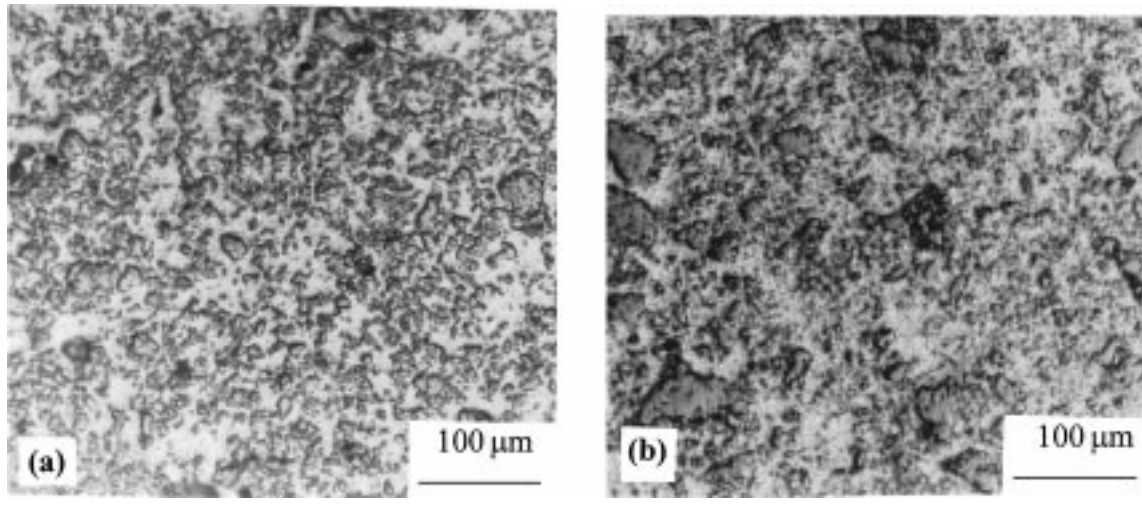

Figure 4 Microstructure showing finely dispersed silicon carbide particulate in 2124 Al matrix in the compacts produced by (a) hot shock consolidation and (b) room temperature shock consolidation (central region).

of the 2124 matrix particles on increasing the consolidation temperature can be attributed to the increased porosity. Whereas, the increased overall hardness in the composite region could be due to the finely dispersed silicon carbide particulates in 2124 Al matrix, which is shown in Fig. 4. The aluminium evidently melted through out the hot consolidated sample. Interestingly, the microstructure of the compact produced by one-dimensional hot shock consolidation (Fig. 4a) shows almost the same microstructure obtained at the center of the compact consolidated by room temperature shock consolidation using axisymmetric assembly (Fig. 4b). This observation supports the argument that there is an increase in temperature at the center of the compact produced by room temperature consolidation due to convergent shock waves. In high temperature one-dimensional compaction system, the porosity observed in the compact probably came from adsorbed gas on the powder particles. The high hardness (160–180 VPN) on the composite structure of hot shock consolidated samples, shows that improved properties can be obtained by the hot shock consolidation also. The experimental results indicate that hot shock consolidation using one-dimensional compacting system can be used for consolidation of composites with uniform structure, which is at present a serious problem in the composites produced by room temperature consolidation using axisymmetric assembly. But, the hot shock consolidation process is to be further optimized to reduce or completely eliminate the porosity.

4. Conclusions

A significant variation in the microstructure was observed across the cross section of the room temperature consolidated composite compact. Loosely bonded silicon carbide around the 2124 matrix particles, closely compacted silicon carbide particulates surrounding 2124 Al particles and uniformly distributed silicon particulates in the matrix were observed at the periphery, intermediate and central regions respectively in the compact produced by room temperature shock consolidation using axisymmetric geometry. The variation in the microstructure was attributed to the difference in the pressure across the cross section. The hardness of the matrix was found to decrease from periphery to the center due to softening of the matrix as a result of temperature increase due to convergent shock waves. Uniformly distributed silicon carbide particles in 2124 Al matrix at the center of the compact showed increased hardness.

There is no variation in the microstructure of the compacts obtained by the one-dimensional hot shock consolidation. The microstructure is almost the same in all the compacts consolidated at 200, 300 and 400°C temperature. The hardness of the compacts slightly decreased with increasing consolidation temperature. The finely distributed silicon carbide in the matrix in hot shock consolidated samples, which is similar to the structure obtained at the center of the compact produced by room temperature consolidation, has shown high hardness indicating that improved properties can be obtained by the hot shock consolidation.

The aluminium evidently melted at the center of the room temperature consolidated sample and throughout the hot consolidated sample.

Thus, the hot shock consolidation using one-dimensional compacting system can be tried as an alternative method to produce composites with uniform structure, which is at present a serious problem in the composites produced by room temperature consolidation using axisymmetric assembly. The hot shock consolidation process is to be further optimized to reduce or completely eliminate the porosity.

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