Mechanical working of 2124 Al alloy—SiC_p cast composites

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Al alloy-SiC_p metal matrix composites (MMC) fabricated by a powder metallurgy (PM) route can have fine reinforcement particle size and a spatially homogeneous distribution compared to those fabricated by the stir casting route. Despite these drawbacks, the relatively low cost makes MMC fabrication by stir casting an attractive alternative [1]. In the present paper we report the effect of hot open-die forging, on mechanical properties of stir cast MMC's with composition: 2124-Al alloy +10 vol% SiC_p. The heat treatment schedule used [2] for open-die forging was modified from that used by Jiang *et al*. [3–5]. The 2124 Al alloy was selected as the matrix alloy in these MMC's since its mechanical properties (hardness, tensile and compressive strength, etc.) are better than other Al alloys. However, the workability of 2124 alloys is comparatively poor. Further, the size of the reinforcement particles in these MMC's was relatively large ($SiC_p \sim 37\ \mu m$) and their distribution inhomogeneous. Since it is well known that particle fracture during forging leads to void nucleation and in subsequent stages crack formation [6] therefore it is necessary to evolve a heat treatment schedule through which the matrix flow is enhanced to prevent void growth.

Recent literature on secondary processing of SiC_p reinforced 2124 Al alloy composites fabricated by PM route suggests solution treatments [3–5] followed by (a) water quenching (WQ) or (b) furnace cooling (FC or over-ageing (OA)). Hot or cold working follows this with intermediate solution treatments. For age hardenable Al-alloys working after WQ treatment produces materials with higher strength in both tension and compression. Compared to this, OA treatment significantly increases ductility in compression, but decreases the tensile ductility. Hence, the workability of the matrix of 2124 Al alloy-based MMC's may be improved by OA treatment. However, such OA processing may have detrimental effects on the mechanical properties of the composite.

In the present work, the microstructural evolution with increasing deformation after OA treatment was studied. As an indicator of the mechanical properties of the MMC's we compare the hardness of the composites processed after OA with those processed after WQ. Subsequently we try to improve the properties of OA processed composites by subjecting them to another WQ treatment schedule.

The Al-2124 + 10vol% SiC_p composites (thickness 37 mm) considered in the present study were subjected to two different heat treatment schedules based on solution heat treatment followed by WQ or FC. Hot working was done using open die forging. The heat treatment and working schedule using OA treatment was in two steps.

Step 1 The composite plates were solution treated at 540 °C for 2 hr and 15 min after properly wrapping them in Al foils (for canning) followed by overnight furnace cooling. The composite plates were subjected to hot die forging at 450–470°C using MoS_2 lubricant. In the initial working, forging was normally carried out till 40% reduction from the initial thickness was obtained.

Step 2 After machining out the edge cracks, the composite plate was again subjected to solution treatment. The solution treatment time was decreased proportional to the reduced thickness of the worked composite and rest of step 1 was repeated. Thus after 40% reduction from the initial thickness the solution treatment time was also reduced by the same percentage from the initial time. However, for subsequent steps, forging was only carried out till 10% deformation. Step 1 and 2 were repeated iteratively until the required thickness of the plate was achieved.

In the heat treatment schedule based on solution heat treatment with WQ we primarily followed the procedure laid by Jiang *et al*. [4]. The composite was then subjected to hot working by open die forging. The solution treatment temperature and the hot working schedule followed are the same as in the mechanical working for the OA schedule.

For composites processed using the WQ treatment schedule, it was found that after initial 30% reduction, edge cracks developed. These cracks were machined out and the processing of plates is continued. Thereafter at each stage of reduction such cracks were found to initiate or propagate. In all cases the yield of the processed materials from the cast composite was less than 30%.

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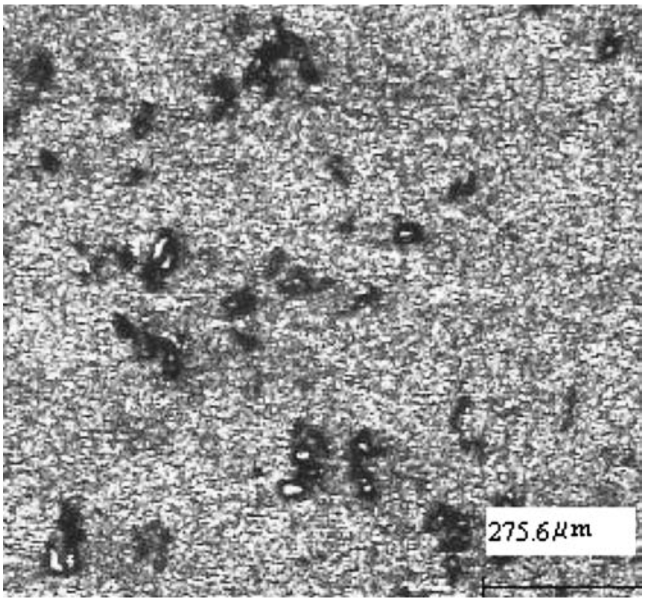
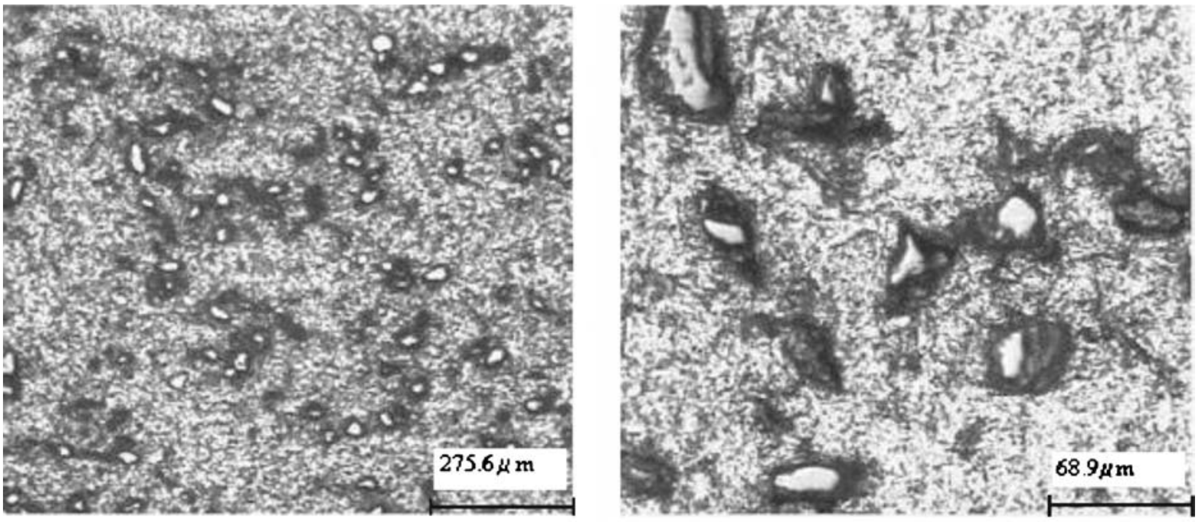
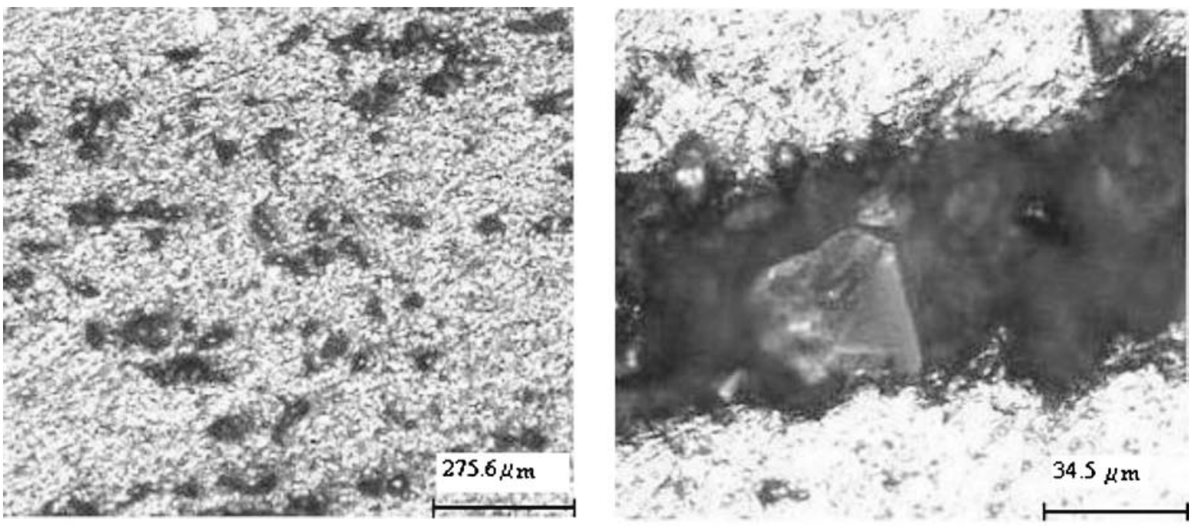


Figure 1 Typical microstructure of the as-cast composite showing inhomogeneous SiC_p distribution.



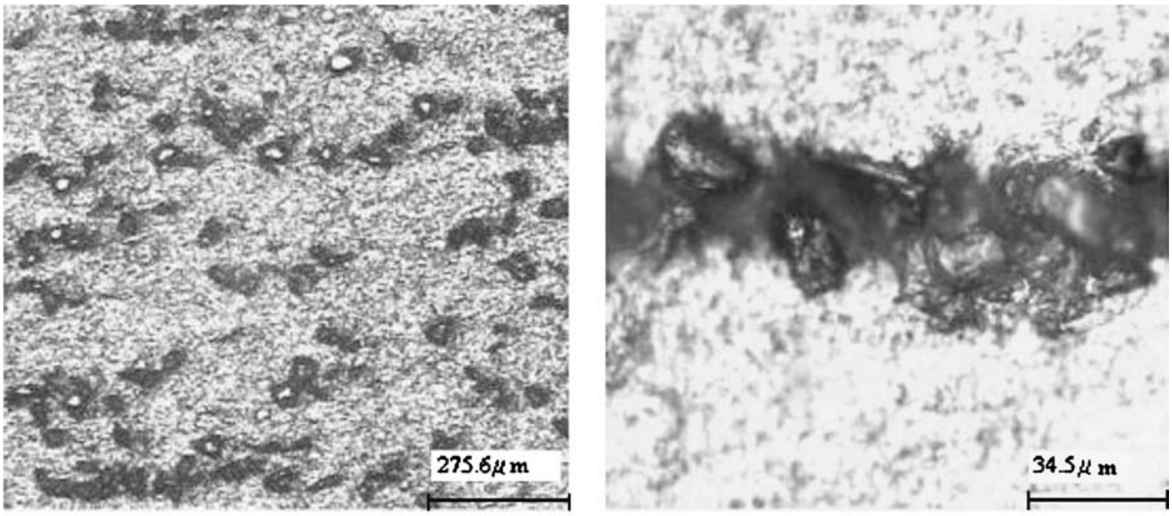
(a) (b)

Figure 2 Microstructures at different magnifications of the same region of the composite, processed under FC treatment, after 65% reduction in thickness. In comparison to Fig. 1, note the more homogenous distribution of SiC_p in Al alloy matrix in (a) and in (b) at higher magnification.



(a) (b)

Figure 3 Microstructures of the composite, processed under FC treatment, after 75% reduction in thickness. In (a) the SiC particles have become smaller through fragmentation but are agglomerated. Figure (b) shows a microcrack with an SiC particle in it.



(a) (b)

Figure 4 Microstructures of the composite, processed under FC treatment, after 85% reduction from the initial thickness. The distribution in (a) of SiC particles is similar to that after 75% reduction. Particle agglomeration and formation of cracks is shown in (b).

In composites subjected to OA treatment, no or negligible edge crack formation was observed up to 55% reduction from the initial thickness. After the machining out of these cracks, further crack generation occurred at a much slower rate than in the WQ composites. The yield of the processed composites from the cast material was always above 60%.

We now present the microstructural evolution during deformation of composites subjected to OA treatment schedule. The average SiC_p size is large (∼37 μm) and also the distribution is highly inhomogeneous in the as-cast MMC's (Fig. 1). Under FC treatment processing, after 65% reduction, there was decrease in particle size owing to their fragmentation (Fig. 2a and b). The particle distribution in the matrix became more homogeneous and there was very little void formation owing to particle fracture (Fig. 2b).

This indicates that fragmentation of particles is followed by the flow of matrix into the resulting void regions [7], leading to effective redistribution of the smaller particle fragments when further forging occurs.

In Figs 3 and 4, after approximately 75% reduction, clusters of SiC_p are formed by their further fragmentation. The smaller interparticle distance in these clusters hinders matrix infiltration among particles; leading to formation of voids (Figs. 3a and 4a). Further, the lack of flow of the matrix into the voids hinders the redistribution of the fragmented SiC particles in these MMC's [8, 9]. Hence, microcrack formation and growth keep increasing for further reductions (Figs 3b and 4b). This is due to decrease in matrix recovery with increased deformation.

TABLE I Vicker's hardness values of 2124 Al alloy −10%SiCp MMC's (Hv)

Processing conditions	As-cast	75% deformation	85% deformation
Processing under WQ treatment	110 (After WQ and 72 hr natural ageing)	126	137
Processing under FC treatment	79 (After FC)	89	100
Processing under FC conditions then WQ treatment and natural ageing for 72 hr	121 (FC then WQ and natural ageing for 72 hr)	–	145

The consequences of the above microstructural changes on hardness, as a useful indicator of the trend that may be followed by various mechanical properties of the composite, are now discussed. Hardness was measured at three different stages for processing using FC and WQ treatments: (a) as-cast, (b) 75% reduction and (c) 85% reduction (Table I).

The softness of the matrix under compression after OA treatment allows effective mechanical working of the composites leading to finer SiC_p sizes and their more homogeneous distribution (Table I). Another WQ treatment of these processed MMC's led to dissolution of all precipitated phases present. Further, natural ageing of these MMC's (with better microstructural homogeneity) led to precipitation hardening of the matrix [10]. Consequently, better hardness is achieved than by processing using WQ treatment only.

In summary, the mechanical working of the 2124 Al alloy-10vol%SiC_p cast MMC has been carried out by enhancing the ductility of the matrix by OA treatment. The particulate size of SiC was observed to be finer and its spatial distribution more homogeneous in the matrix by the above mentioned working schedule using OA treatment. The hardness of this processed composite has been enhanced by precipitation hardening of the matrix by natural ageing, after another solution treatment.

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