COLD ROLLING AND ANNEALING OF PARTICLE REINFORCED ALUMINUM MATRIX COMPOSITE

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ABSTRACT Cold rolling and subsequent annealing processes are investigated to fabricate SiC particle reinforced pure aluminum composite sheets. A bar type of the composite with rectangular section is prepared by a powder extrusion. They are cold rolled in various reduction and subsequently annealed at various temperatures. The composite sheet with lower SiC volume fraction than 10% can be successfully cold rolled in higher reduction than 90 %. The proof stress and tensile strength of the composite sheets rolled in higher reduction than 60 % are independent on the rolling reduction, while those of unreinforced pure aluminum sheets are increased with the reduction. Those properties of rolled pure aluminum sheets are rapidly decreased by subsequent annealing at around 548 - 573K, but those of composite sheets are only gradually decreased with annealing temperature.

Keywords: *Metal matrix composite, Pure aluminum, Cold roll, Anneal, Mechanical property, SiC particle, Powder extrusion*

1. INTRODUCTION

Metal matrix composites (MMCs) which are reinforced with ceramic particles or short fibers are very useful to realize lightweight structural parts, because they have high specific stiffness and strength and good wear resistance. However the MMCs have not been much put to practical use in the automobile or machine industries, though many trial products have been made in various fields. Recently only a few products of MMCs can be found in those industries, for example a piston, a cylindder block and an intake valve for automobile engine. Most of them are bulk type products and they are produced directly into the final parts by liquid processing routes like a squeeze casting or a pressure infiltration. Simple shape billets of aluminum matrix composites can be now easily fabricated by either liquid phase routes like melt stirring, rheocasting, compocasting and spray deposition methods or solid phase routes like powder extrusion, hot press and HIP processes. However economical secondary processes to produce complex shape parts from those billets have not yet been established to apply them much more into the mass-products. As the MMCs can be deformed like conventional metals even at room temperature as well as elevated temperature, a deformation processing is an alternative secondary process for complex shaped components of MMCs. The authors are now focusing on the deformation processing of particle reinforced aluminum matrix composites [1 - 6].

On the other hand, sheet type products of MMCs are far behind in developing and applying in industrial fields compared with bulk type ones. It may be impossible to produce directly final parts of sheet type MMCs. They should, in the first place, be rolled from MMC billets fabricated by liquid or solid routes, then the rolled sheets should be formed into final complex shaped parts like conventional metal sheets. In general aluminum alloy sheets are hot and cold rolled and subsequently heat treated under various process conditions to arrange their optimum microstructure and mechanical properties. As the MMC consists of ductile matrix metal, hard particles and their interfaces, it will be subjected to more complicated internal stress state and microstructural behavior than conventional metals during deformation and heat treatment processing.

In the present work cold rolling and subsequent annealing processes are investigated for SiC particle reinforced pure aluminum composite sheets. At first a limit cold rolling reduction, that is the maximum rolling reduction at which the cold rolling can be successfully performed without crack initiation, is measured for the composites with various SiC volume fractions. The effects of rolling reduction and subsequent annealing temperature on mechanical properties of the composite sheets are evaluated and compared with those of unreinforced pure aluminum sheets.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

A SiC particle reinforced pure aluminum matrix composite was used in the present work. It was prepared by the powder extrusion method to perform a good dispersion of particles and to prevent some complicated chemical reactions between the matrix aluminum and particles. The matrix is an air atomized A1050 pure aluminum powder with mean diameter of around 40μm and the reinforcement is SiC particulate with mean diameter of 4.3μm.

The matrix aluminum powder and SiC particles whose volume fractions are 5, 10, 15 and 20 % were mixed using a V-type mixer for 10 hours. The mixed powder was directly consolidated by extrusion at 773K into the bar type specimen with a rectangular section to be used for subsequent rolling. The thicknesses of the bars are 3.0, 6.0 and 10.0 mm and their widths are all 10.0 mm. An A1050 pure aluminum ingot material which was also processed by extrusion and rolling in the same way was used as a reference material.

2.2 Rolling and tensile test

When the composite was rolled in higher reduction than its rolling limit, a large crack in the center of width at the top or many small cracks at the sides were observed in the rolled sheet. The limit rolling reduction (reduction in height) of the composite, that is the maximum rolling reduction at which no cracks are initiated in the rolled sheet, was investigated using the specimen with thickness of 3.0mm. The specimen was rolled at room temperature by a method of multi pass rolling as shown in Fig. 1. Initially it was rolled in reduction of 10, 20 or 30 % per pass (this stage is called a rough rolling), and the limit reduction in the rough rolling (R_h) was decided as the maximum total reduction at which no cracks are observed in the rolled sheet. The specimen rolled until R_h was subsequently rolled in around 3 % per pass (it is called a fine rolling), and the limit reduction in fine

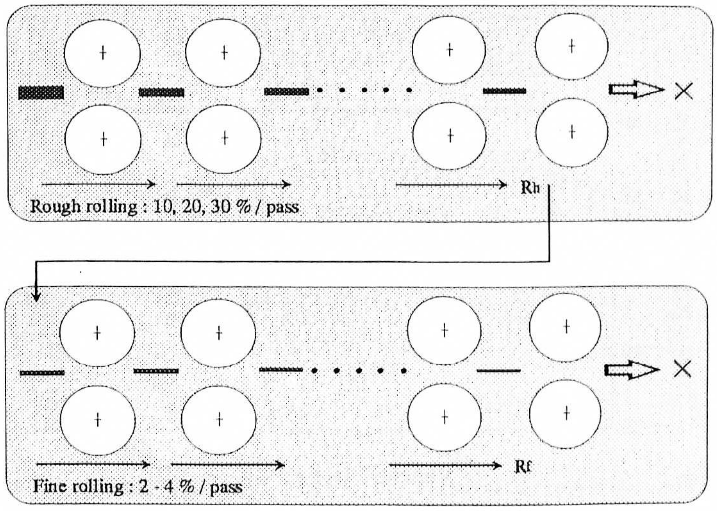


Fig. 1: Rolling process to estimate limit rolling reduction (R_h, R_f) in rough and fine rolling.

rolling (R_f) was also decided in the same manner. The effect of rolling reduction per pass in the rough rolling on the limit rolling reductions R_h and R_f was investigated for the composites with various SiC volume fractions.

Mechanical properties of the rolled composites were measured by a tensile test. In order to make uniform in 0.5 mm final thicknesses of sheets which were rolled in various reductions, extruded composite bars were pre-rolled in respective fitting reductions and subsequently annealed at 623K for 1 hour. So processed initial specimens were further rolled in reductions of 60, 70 (75 for the pure aluminum), 90 and 95 % at room temperature. The cold rolled specimens were subsequently annealed at various temperatures for 1 hour. The tensile tests were performed for not only as-rolled specimens but also annealed ones to investigate the effects of rolling reduction and annealing temperature on the mechanical properties of composite sheets.

3. RESULTS AND DISCUSSION

3.1 Limit rolling reduction

The limit rolling reductions (R_h, R_f) of the composites which depend on the SiC volume fractions can be seen in Fig. 2. A broken line and a solid line show the limit reduction in the rough (R_f) and fine (R_h) rolling respectively. Arrows mean that the final limit reduction (R_f) is much higher, but the further rolling is impossible to perform because of a mechanical limit of the used rolling mill. The limit reduction in the rough rolling (R_h) depends on the pass reduction and it increases with decreasing pass reduction. But the final limit reduction (R_f) after the fine rolling is independent on the pass reduction in the rough rolling. Therefore it can be found that the rolling limit of the SiC particle reinforced pure aluminum composite does not depend on the reduction per pass but only the total reduction. The composites with SiC volume fractions below 10 % can be cold rolled in higher reduction than 90 % without initiation of any cracks. Even the composite with 20 % volume fraction can be successfully cold rolled in around 70 % rolling reduction.

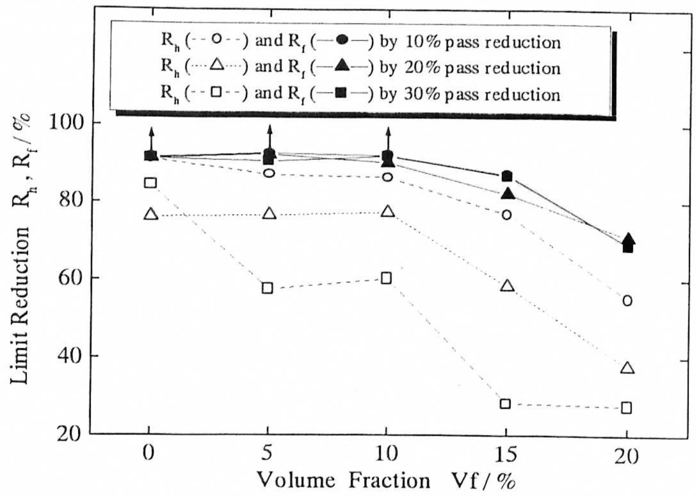
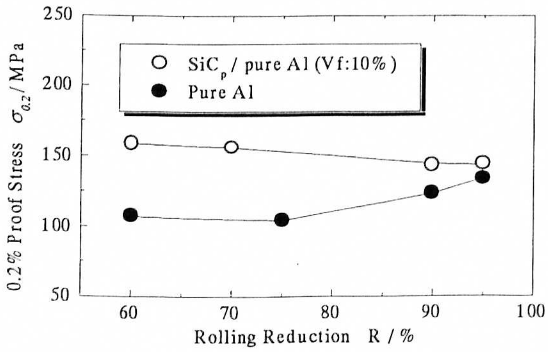
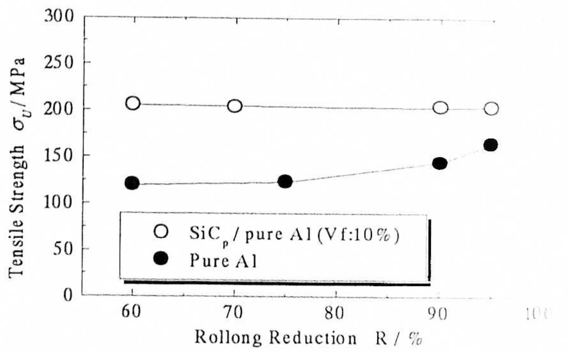


Fig. 2: Effect of pass reduction in rough rolling on limit total reduction.

3.2 Mechanical properties

Proof stress, tensile strength and uniform elongation of the composites with the 10% SiC volume fraction which were rolled in various reductions are shown in Fig. 3 in comparison with those of pure aluminum specimens. The proof stress and tensile strength of the pure aluminum are increased with the rolling reduction, while those of the composite are hardly varied or slightly





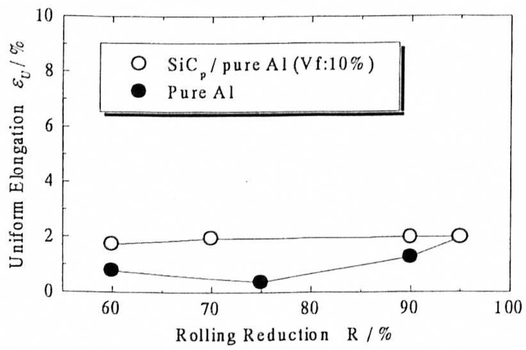


Fig. 3: Effect of cold rolling reduction on proof stress, tensile strength and uniform elongation.

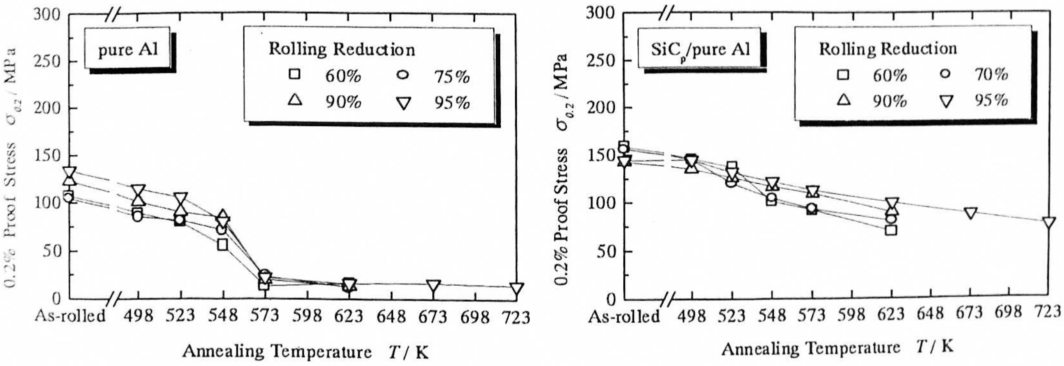


Fig. 4: Effect of annealing temperature on proof stress of cold rolled sheets.

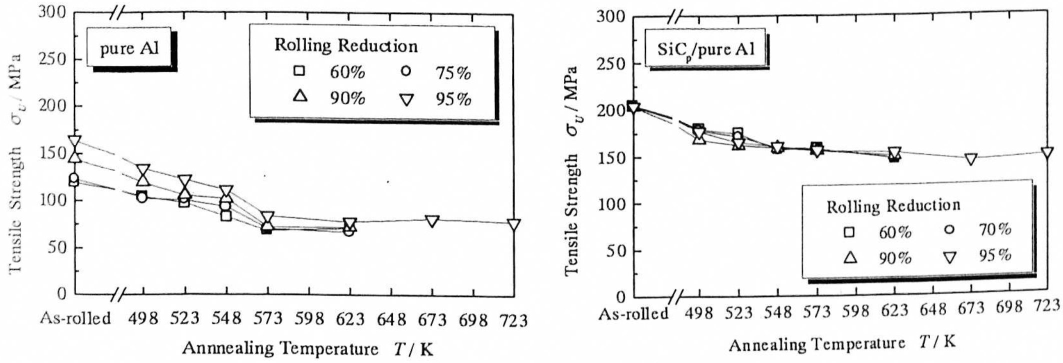


Fig. 5: Effect of annealing temperature on tensile strength of cold rolled sheets.

decreased. When hard particles are dispersed in metal matrix, strain hardening of the matrix metal is accelerated, because much dislocation can be easily generated and accumulated in the matrix due to the dispersed particles. Therefore the strain hardening of the composite is larger and saturated at smaller deformation than the unreinforced metal. As a result the reinforcement effect of the dispersed particles in the rolled composite sheet is reduced with increasing rolling reduction.

The composite with 10% SiC volume fraction and pure aluminum which were rolled in different reductions were annealed at various temperatures for 1 hour and their proof stress, tensile strength and uniform elongation were measured. Figs. 4, 5 and 6 show the effects of the annealing temperature on the mechanical properties of the sheets. Their changes by annealing are very remarkable in the pure aluminum. The proof stress and tensile strength are slowly decreased at lower temperature than 548K and rapidly decreased at 573K, then they are not changed at higher temperatures than 573K. The elongation is rapidly increased by annealing at 573K, it means that the rolled sheet is almost completely annealed at that temperature. On the other hand, the tensile properties of the rolled composite sheets are not rapidly change at any temperatures but only slowly changed from 498K to 723K. From the result it is predictable that the recrystallization of the matrix aluminum by annealing is gradually progressed with increasing temperature but not completed in the composite, while it is rapidly progressed and completed at around 548-573K in the pure alumi-

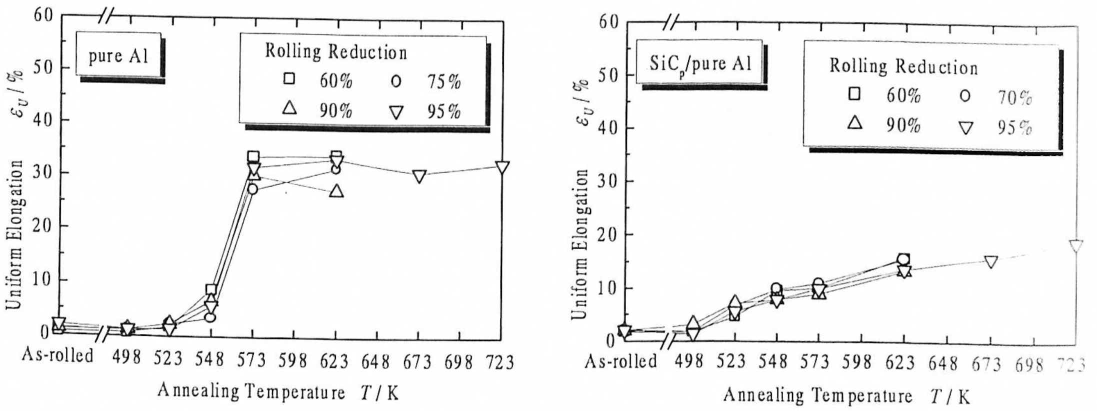


Fig. 6: Effect of annealing temperature on uniform elongation of cold rolled sheets.

num. Such tendency of change in mechanical property is independent on the rolling reduction of sheets. Therefore the reinforcement effect of SiC particles, namely the difference of the property between the composite and pure aluminum is the largest in the sheet annealed at around 573K.

4. CONCLUSION

The cold rolling limit of the SiC particle reinforced pure aluminum composite does not depend on the reduction per pass but only the total reduction. The composites with lower SiC volume fractions than 10 % can be cold rolled in higher reduction than 90 % without initiation of any cracks. Even the composite with 20 % volume fraction can be successfully cold rolled in around 70 % rolling reduction. The proof stress and tensile strength of the composite sheets rolled in higher reduction than 60 % are hardly varied or slightly decreased with the rolling reduction, while those of unreinforced pure aluminum sheets are increased. Those properties of rolled pure aluminum sheets are rapidly decreased by subsequent annealing at temperature of 548 - 573K, but those of composite sheets are only gradually decreased with annealing temperature.

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