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► To cite this version:

L. Parrini, R. Schaller. AlCu-Al₂O₃ metal matrix composites studied by thermoelectric power measurements. Journal de Physique IV Proceedings, 1993, 03 (C7), pp.C7-1745-C7-1748. 10.1051/jp4:19937275 . jpa-00251916

HAL Id: jpa-00251916

<https://hal.science/jpa-00251916>

Submitted on 1 Jan 1993

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AlCu-Al₂O₃ metal matrix composites studied by thermoelectric power measurements

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Abstract

Metal matrix composite materials Al-4%Cu reinforced with different volumetric fractions of Al₂O₃ (Saffil) fibers were produced by "squeeze casting". The composites were characterized by thermoelectric power measurements, in order to identify the effect of the fibers on the precipitation of Cu and the microstructure of the alloy. The formation of Guinier-Preston zones was found to be slowed down by the presence of fibers, while the formation of θ' precipitates was favoured in the composites. A TTT diagram of Cu precipitation in the composites was drawn, which well characterized their different response to ageing compared to that of the unreinforced matrix.

Introduction

Metal matrix composites (MMC) have been developed to provide light, stiff, and strong materials, characterized by high performance mechanical properties. Fiber or particle ceramic reinforcements have allowed to maintain the lightness of some metal alloys, increasing their mechanical properties, such as the elastic modulus, the elastic limit, and the creep resistance [1]. Precipitation hardenable alloys, such as aluminium alloys, are attractive candidates for matrix materials in metal-matrix composites. However, the addition of a brittle reinforcement to these alloys can alter the nucleation and growth of the precipitates in the matrix, as compared to those in an unreinforced alloy [2-7]. Since the overall composite properties can be influenced by such a change in the precipitation characteristics of the matrix [8, 9], the study of ageing characteristics in reinforced metals is of considerable practical interest.

In this connection, the present investigation aims at studying the effect of the fibers on the precipitation of Cu in an Al-4%Cu alloy reinforced with different volumetric fractions of Al₂O₃ (Saffil) fibers. In this alloy, the precipitation chain after quenching from high temperature (535°C) is [10]:

super saturated solid solution (SSS) $\Rightarrow$ Guinier-Preston zones (GP) $\Rightarrow$ θ'' precipitates $\Rightarrow$ θ' $\Rightarrow$ θ

The measurements of thermoelectric power (TEP), which is above all sensitive to the concentration of Cu in solid solution [11, 12], allow to easily follow Cu precipitation.

Experiments

Composite samples containing 10%, 20% and 30% volumetric fraction of alumina fibers (Saffil) were produced by the method of squeeze-casting [13] at Alusuisse-Lonza Services Ltd., Neuhausen, Switzerland.

Fig. 1: Program of the thermal treatments given to the specimens during TEP measurements.

Results

TEP is above all sensitive to the concentration of Cu in solid solution, and therefore allows, by following its decrease, to follow the impoverishing of the solid solution in Cu, brought about by precipitation.

Fig. 2: TEP evolution as a function of ageing time at 50°C for the composites and the unreinforced alloy.

Unreinforced Al-4%Cu samples were produced simultaneously with the composites in the same solidification process. To make TEP measurements, plate shaped specimens 1x4x100 mm were obtained by machining. After being solution treated at 535 °C for 2 h, the specimens are quenched and subjected to isothermal cumulative annealings whose durations are shown in Fig. 1. The annealing temperatures were varied between 50 and 400 °C. TEP measurements were taken at room temperature.

The TEP values obtained were normalized to the TEP values measured after quench for all materials, in order to study just the effect of ageing at the established temperature. TEP evolution as a function of the annealing time at 50°C for the composites and the matrix is shown in Fig. 2. Since at this temperature only the transformation $SSS \Rightarrow GP$ is possible, the curves show that the precipitation of GP zones is slowed down by the presence of the fibers, in proportion to their concentration in the alloy. TEP evolution as a function of the annealing time at 230°C for the composites and the matrix is shown in Fig. 3. Contrary to the case of ageing at 50 °C, we observe that here precipitation is accelerated by the fibers.

Fig. 3: TEP evolution as a function of ageing time at 230°C for the composites and the unreinforced alloy.

Since at this temperature the precipitation reaction is $SSS \Rightarrow \theta'$, the curves show that the formation of θ' precipitates is accelerated by the presence of the fibers, in proportion to their concentration in the alloy. TEP increase during the first ageing minutes can be ascribed to the phenomenon of reversion, i. e. the resolution of clusters of Cu atoms which have been formed just after quenching. The curves show that reversion is hindered by the presence of the fibers, in proportion to their concentration in the alloy.

The obtained data for TEP evolution during ageing at different temperatures have allowed to draw the TTT diagrams of Cu precipitation in all the materials considered in this investigation. Fig. 4 shows the TTT diagrams for AlCu-20%Saffil and the unreinforced matrix. The domains of precipitation considered in the TTT diagram are taken between two arbitrary values of the normalized TEP, i.e. 0.8 for "precipitation start" and 0.6 for "precipitation end". In the figure, for each temperature domain, it is also pointed out which kind of precipitates is normally formed in an unreinforced Al-4%Cu alloy. From Fig. 4 it is evident that the introduction of the fibers in the matrix displaces the stability field of the super saturated solid solution at temperatures about 100 °C lower than those characteristic of the unreinforced matrix.

Fig. 4: TTT diagram for Cu precipitation in AlCu-20%Saffil and the unreinforced alloy.

This displacement takes into account easily of the acceleration of θ' precipitation in the composite, for temperatures around 250 °C, and of the slowing down of GP precipitation in the composite, for temperatures around 50 °C. Such TTT diagrams completely characterize the different response to ageing in the composites compared to that of the unreinforced matrix.

Discussion

In MMC which experience temperature changes, the difference between the coefficients of thermal expansion of reinforcement and matrix leads to large internal stresses and an enhanced dislocation density in the composite matrix [2]. In the case of the composites here investigated, an enhanced dislocation density can be created in the composite matrix during quenching. The generated dislocations can annihilate, in the composite matrix, the excess of vacancies created by the high temperature solution treatment. Since dislocations serve as preferential nucleation sites for θ' precipitates [2], while vacancies favour Cu diffusion at low temperature and the formation of GP zones [14], the enhanced dislocation density in the composite matrix can easily explain both the acceleration of θ' precipitation and the deceleration of GP precipitation which have been detected in the present investigation for the concerned composites.

Conclusions

Cu precipitation in Al-4%Cu based MMCs has been confirmed to be different from that in the unreinforced matrix. The formation of Guinier-Preston zones has been found to be slowed down by the presence of fibers, while the formation of θ' precipitates is accelerated in the composites. A TTT diagram of Cu precipitation in the composites was obtained, which well characterizes their different response to ageing compared to that of the unreinforced matrix.

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Acknowledgement

This work has been supported by the Swiss National Science Foundation. Alusuisse-Lonza Ltd is acknowledged for the specimen supply.