RESEARCH NOTE

STUDY OF THE ENHANCED PRECIPITATION OF AN ALUMINIUM 6061 ALLOY REINFORCED BY SIC PARTICLES IN THE RANGE OF β'' PHASE TEMPERATURE

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Abstract An experimental method to follow the evolution of the precipitation phenomena in the metal-matrix composites using the thermoelectric power measurements is described. It is shown that one can follow the kinetics of the precipitation during aging. The influence of the reinforcement on the precipitation kinetics is studied in case of an aluminium 6061- SiC_p composite (where SiC_p represents SiC particles). The precipitation kinetics are accelerated in the case of the reinforced composite with respect to the unreinforced matrix. The variation of the microhardness of the specimens are also recorded during aging.

Key words Metal-Matrix Composite, Precipitation Hardening, Aging, β'' Phase, Aluminium 6061 Alloy, Age Hardening

چکیده مطالعه سرعت رسوب گذاری در کامپوزیت های زمینه فلزّی که آلیاژ زمینه قابلیت رسوب سختی دارد و مقایسه آن با زمینه تنها (بدون حضور ذرات سخت) نشان میدهد که در کامپوزیت سرعت رسوب گذاری بیشتر از زمینه تنها می باشد. یعنی تشکیل رسوب در کامپوزیت سریع تر و در نتیجه افزایش سختی شدت بیشتری دارد. در این مقاله سعی شده است که تشکیل فاز "β (در درجه حرارت C° ۱۷۵ در آلیاژ آلومینیم - سیلیسیم - منیزیم (۶۰۶۱) در دو حالت ساده و در حضور ذرات سخت SiC مطالعه شود. سرعت تشکیل رسوب با اندازه گیری تغییرات قدرت ترموالکتریک و نیز تغییرات سختی نمونه، مطالعه شده است. زمانی که بلافاصله بعد از عملیات هموژن کردن، نمونه را در درجه حرارت ۱۷۵ درجه سانتی گراد در زمانهای مختلف پیر می کنیم، مشاهده می شود که سرعت تشکیل رسوب در کامپوزیت بیش از سرعت تشکیل آن در زمینه ساده می باشد. امّا وقتیکه بعد از هموژن کردن و قبل از شروع عملیات پیر سختی، نمونه بمدت ۲۴ ساعت در درجه حرارت محیط نگهداری می شود، مشاهده می شود که سرعت تشکیل رسوب در هر دو نمونه یعنی کامپوزیت و زمینه ساده، یکسان می باشد.

INTRODUCTION

Metal-Matrix composites (MMC) having precipitation hardenable matrices are known to age conciderably faster than the associated unreinforced matrix alloy [1-8]. A mechanism commonly proposed to explain this accelerated aging in metal-matrix composites is enhanced nucleation and/or growth in the heavily dislocated matrix region adjacent to the reinforcement [4-6]. The increase of dislocation density in the MMC during thermal treatements is due to different thermal contractions of the matrix and the reinforcing phases [9-12]. The dislocation density increment in the material increases generally the precipitation kinetics of semi-coherent phases. This phenomenon has been observed for exapmle, for θ' phase in Al-Cu SiC [13], and β' phase in Al-6061-SiC [14,15] composites.

Table 1. Chemical composition of 6061 alloy

element	Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Cr	Ti
Wt. %	0.65	0.32	0.26	0.06	0.81	0.01	0.05	< 0.01	< 0.01	0.09	0.04

On the other hand, the interface of the reinforcement and the matrix, or lattice defects produced by their different thermal expansion coefficients, may influence the formation of Guinier-Preston (GP) zones at low aging temperature. This phenomenon has been reported in Al-7475-SiC composites [7].

In this paper the precipitation kinetics of β" phase were studied in an Al- 6061 alloy reinforced by SiC particles.

MATERIALS

Powder metallurgy processed 6061 MMC reinforced with 20% vol SiC particles of different aspect ratios (1.2 to 5.5) was obtained from kobe Steel Company. The SiC particle size was 4 to 8 microns. Table I gives the chemical composition of the 6061 alloy.

THERMOELECTRIC POWER MEASUREMENTS

Thermoelectric power measurements (TEP) are used extensively to study the precipitation phenomena in various metalic alloys [16]. It has been shown that this technique is utilized easily and provides accurate measurements. The principle of the method is to measure the voltage Δv between two junctions of the sample with aluminium blocks. The temperatures of these blocks are T and T + ΔT. The apparatus, which has been extensively described elsewhere [17], gives directly the TEP or (ΔS) of the alloy with respect to aluminium, $\Delta S = \Delta V/\Delta T$ (μV/K), where ΔV is the low voltage provided by Seebeck effect between the two aluminium blocks. The chosen temperatures are $T = 15 + 0.1°C$ and $\Delta T = 10 \pm 0.1°C$.

The TEP is always a function of the amount of elements in solid solution. In the case of dilute alloys, the modified ΔS at a given temperature of the diffusional component of TEP is given by the Gorter-Nordheim rule [17].

$$\Delta S_d = [\sum_i \Delta\rho_i \Delta S_i]/[\rho_0 + \sum_i \Delta \rho_i]$$

where, ρ_0 is the resistivity of the matrix free of solute atoms (but including eventually the increase in resistivity due to precipitates) at the test temperature, $\Delta\rho_i$ is the increase in resistivity due to solute atoms i and ΔS_i is the specific thermoelectric power of solute atoms i in the pure solvent. It has been shown that, in the case of multicomponent alloys, the effect of impurities on TEP can be considered as additive. This effect can be positive or negative. For example, in the case of the main alloying elements in 6061 alloy, Si has a low negative effect and Mg has a positive effect on TEP [14, 17]. Table II gives the Δs_i values of the main alloying elements in 6061 alloy. From these values it may be concluded that the solid solution effect of Mg_2Si precipitation might correspond to a decrease in the TEP Δ (ΔS) of the alloys. In fact, it has been shown that intermediate metastable phases have often an intrinsic effect on TEP of the alloy, so that the TEP variation may be more complicated and exhibit a non-monotonous variation in the case of a precipitation sequence involving succesively several

Table 2. Δ S values of the main alloying elements of 6061 alloy [17].

element	Mg	Si	Cu	Fe	Mn
Δ S μV/K	+ 2.40	-0.74	+ 2.10	-8	-6.8

metastable phases. In any case, the essential facts to be considered to analyse TEP variation is that the precipitation of a given phase corresponds always to a monotonous variation in TEP and that each transition between succesive metastable phases is detected by a transition in the TEP variation.

EXPERIMENTS AND RESULTS

The generally admitted precipitation sequence in aluminium 6061 alloy are : [18-19] supersaturated solid solution ----> vacancy silicon clusters ----> GP zones---->β"coherent needle phase precipitates---->β' semicoherent rods ----> equilibrium β platelets. The classical heat treatments which are used principally are as follow: after homogenization treatment at temperature T_h, the sample is usually quenched to room temperature T_R and then aged at the desired aging temperature T_a for a given time t_a. TEP measurements are done after each aging sequence performed on the same sample and followed by a water quench [Figure1].

In order to study the influence of the reinforcement on precipitation kinetics of β" precipitates, the samples were homogenized for two hours at 535°C and then quenched to room temperature and immediatly aged at 175°C for various times. Figure 2 shows the variation of $\Delta(\Delta S) = \Delta S_t - \Delta S_0$ as a function of aging time t_a for a reinforced and unreinforced specimens. ΔS_t is the TEP of the sample after aging at time t and ΔS_0 is the initial TEP of the sample before aging. It can be seen that the precipitation rate of β" phase in the reinforced material is faster than that of unreinforced matrix. In fact the decrease of TEP values is due to the precipitation of β" phase in this temperature range (150-200°C).

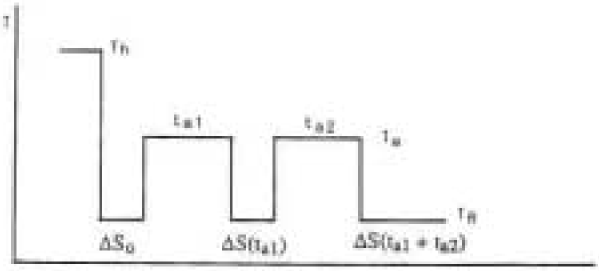

Figure 1. Schematic representation of classical aging procedure.

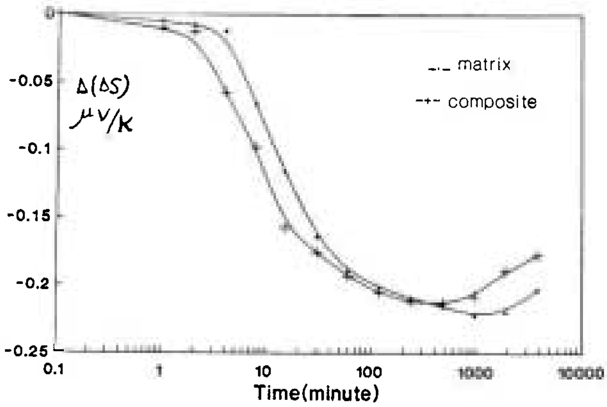

Figure 2. Variation of Δ (ΔS) as a function of t_a in the case of water quench and immediatly aging at 175°C.

The hardness was also measured after different aging times. Figure 3 presents the variation of microhardness with aging time in both reinforced composite and unreinforced matrix. This figure shows an increase in the precipitation rate in the reinforced material (the maximum hardness shifts to shorter aging time in the case of composite).

The effect of preaging at room temperature, after

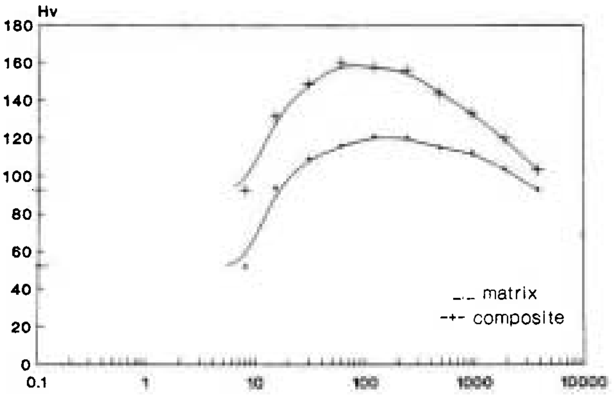

Figure 3. Variation of microhardness as a function of t_a in the case of water quench and immediatly aging at 175°C.

the first quench (the quench just after homogenization), on the kinetics of precipitation was also studied. The variation of Δ (ΔS) as a function of aging time at 175°C in samples preaged 24 hours at room temperature, are shown on Figure 4. The microhardeness changes of these samples with aging time are also shown in Figure 5. From these figures it can be deduced that after preaging at room temperature the reinforcement has no significant effect on the kinetics of precipitation. This fact could be observed either on TEP measurements or microhardness: the minimum of the Δ (ΔS) and the maximum of the hardness reach in the same time for both reinforced and non-reinforced material.

DISCUSSION

As mentioned earlier, the precipitation sequences in 6061 aluminium alloy are: supersaturated solid solution ---> vacancy silicon clusters ---> GP zones ---> β" coherent phase ---> β' semicoherent rods ---> equilibrium β. The rapid decrease in TEP values is due to the formation of β" phase which leads to an increase in the hardness of the specimen. In both cases (TEP and microhardness measurements) the formation of β" phase seems to be accelerated in the reinforced material, i.e. the minimum of the Δ (ΔS) and the maximum of the hardness reach sooner in the case of the reinfoced composite. The further increase in TEP values can be attributed to transition β" ---> β' precipitates [14].

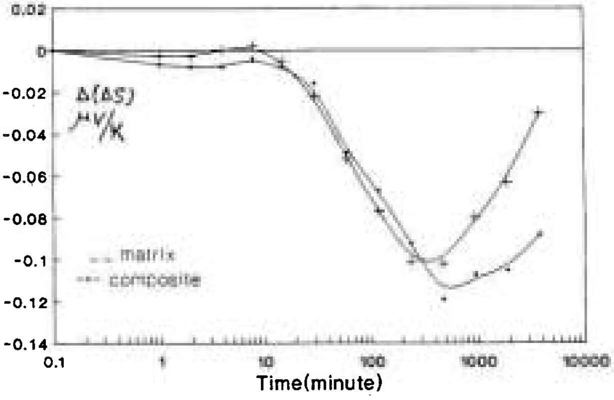

Figure 4. Variation of Δ (ΔS) as a function of t_a in the case of water quench, preaged 24 hours at room temperature and aging at 175°C.

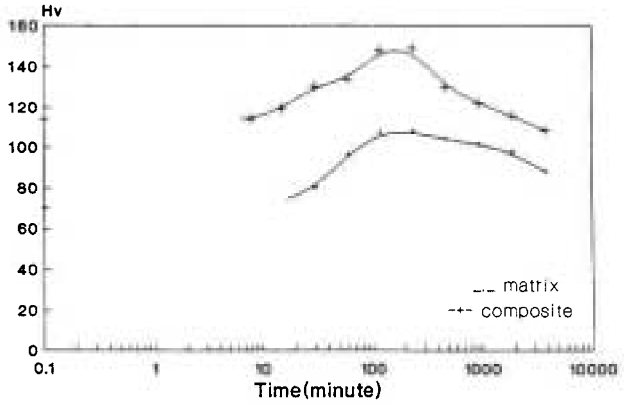

Figure 5. Variation of microhardness as a function of t_a in the same condition as Figure 4.

SiC particles introduce a mean tensile residual stress field in the matrix [20], whereas the presence of GP zones causes a compressive stress field [21]. Thus, there is a decrease in the germination energy of precipitate as a result of reinforcement. This effect can be important in short times but after 24 hours at room temperature the germination rate seems to be the same for reinforced and unreinforced materials. So there is not a significant increase in precipitation rate of composite when the specimen was preaged at room temperature for 24 hours. (Figures 4 and 5).

CONCLUSION

Precipitation kinetics studied by TEP measurements in unreinforced and SiC particles reinforced aluminium 6061 alloy show an acceleration in the precipitation of β" coherent phase in the latter. This acceleration was comfirmed by microhardness measurements.

After preaging at room temperature, the acceleration in the precipitation of β" coherent phase was not very important in reinforced material.

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