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CONDITIONS FOR S'-FORMATION IN AN Al-Cu-Mg ALLOY

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DSC-measurements show in a simple and convincing manner that the precipitation of the metastable S'-phase in an Al-2.1% Cu-1.3% Mg alloy is enhanced in the presence of lattice defects (dislocation loops, helices, dislocations), but is little influenced by pre-existing GPB-zones.

Literature on aluminium alloys with small additions of copper and magnesium is not very abundant. Figure 1 shows the equilibrium phases which appear in the Al-rich corner: $\Theta(Al_2Cu)$ at high Cu/Mg ratios, $S(Al_2CuMg)$ and $T(Al_6CuMg_4)$ at increasingly lower ratios. In the $(\alpha+S)$ range, several metastable phases have been identified [2]: GPB-zones, S', perhaps also a second type of zones and an S''-phase.

The present work intends to clarify the conditions for S'-formation at temperatures above 200°, with the help of DSC-measurements. This metastable phase has an orthorhombic structure and grows as rods parallel to the $<100>$ cubic matrix (M) direction [3]. When formed initially, it is almost coherent with the matrix, but as the precipitate grows, it breaks the coherency and approaches the cell dimensions of the stable S-phase. At higher (Cu + Mg) concentrations, laths form instead of rods and grow on (210) planes along $<100>_M$ directions [3, 4]. The most recent investigation of the crystallography and morphology of the S' precipitates is given by [5].

Experimental

Investigations were carried out on an alloy prepared in form of rolled sheets having the composition (in mass %) Al - 2.1.%, Cu - 1.3%, Mg -

0.09%, Zr - 0.02%, Ti - 0.04%, Si - 0.03% Fe - 0.0002% Na. Zirconium has been added for grain refining.

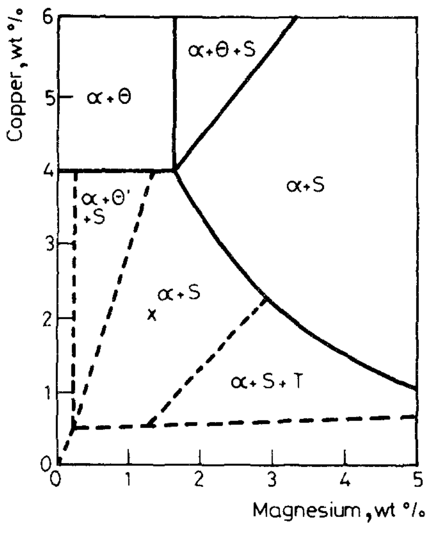

Fig. 1 Isothermal sections of the Al-Cu-Mg system (taken from [1]). The composition of the present alloy is indicated by a cross x. Phase boundaries at 500°C — — ; at 190°C - - -

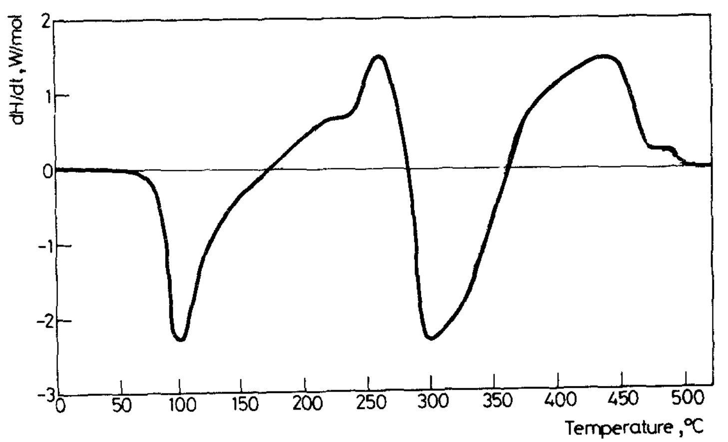

Fig. 2 DSC scan, at 20 deg/min, of an Al-Cu-Mg alloy in the quenched state

Solution treatment was performed for at least 20 min at 500° and followed by quenching into water at 20°. The supersaturated solid solution was either scanned immediately or aged for different periods at room temperature (RT), 100, 135 or 150°. In a second series, the quenched sheets were elongated by 2% before RT aging followed or not by a second aging at 100, 135 or 150°.

Disks having a diameter of 5.9 mm and a thickness of 1 mm were carefully cut from the sheets before the heat treatments, these dimensions being appropriate for thermal analysis with a DuPont apparatus, model 990. The specimens were examined at two different heating rates, 5 and 20 deg/min, between -20 and 520°.

Results

Figure 2 shows the precipitation sequence upon heating a supersaturated solid solution at 20 deg/min. Exothermal effects due to formation of GPB-zones set in above 50°, followed by their dissolution. The hump in the corresponding endothermal curve indicates the existence of the S''- phase, which is confirmed by electron microscopic studies [6]. Above about 275°, S'-formation starts at this particular heating rate and overlaps initially with the end of GPB-zone reversion. The S'-precipitation is closely followed but still distinguishable from that of S. Likewise, the S' - and S-dissolution peaks overlap. The sum of both is of the order of 350 J/mol. The very last, small effect is due to the dissolution of some Θ nucleated on β'-(Al_3Zr) particles present in the industrial alloy [7].

If the solid solution is aged for 77 days at RT before being heated in the thermal analyser (continuous curve of Fig. 3), the S'-precipitation sets in at approximately the same temperature as in the quenched sample, but reaches a higher extent, whereas the S-peak becomes smaller.

Cold deformation before aging enhances considerably the S'-precipitation: the exothermal part of the discontinuous curve in Fig. 3 is shifted to lower temperatures which respect to the continuous curve and goes to higher values.

The influence of aging at temperatures above RT on the S'-formation is illustrated in Fig. 4 (100°) and 5 (150°); the curves obtained on samples aged at 135° fit in perfectly. According to the continuous curves, S' starts to precipitate at about the same temperature, quite independently from the aging temperature including RT. The discontinuous curves confirm the enhancement of S'-precipitation after cold deformation; important heat evolution set in about 10^0 earlier than in the non-deformed samples and attain much higher peak values.

The same pattern of the DSC-curves, but shifted to lower temperatures, is observed when reducing the heating rate to 5 deg/min.

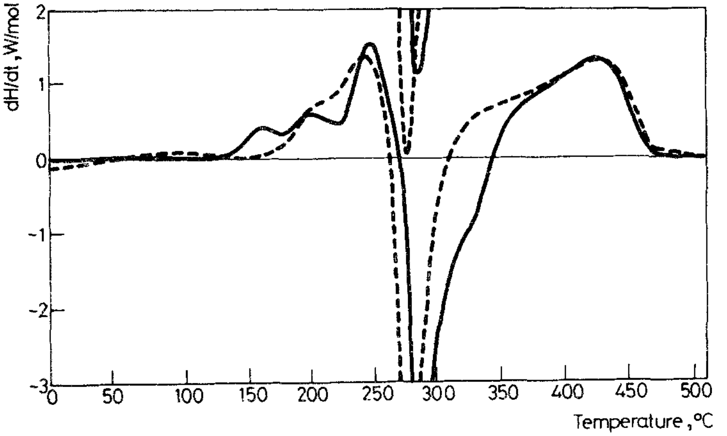

Fig. 3 DSC-scans, at 20 deg/min, of non deformed and 2 % stretched Al-Cu-Mg samples aged at RT —— 500 →20 →77 days/RT; – – 500 →20→2 % →77 days/RT

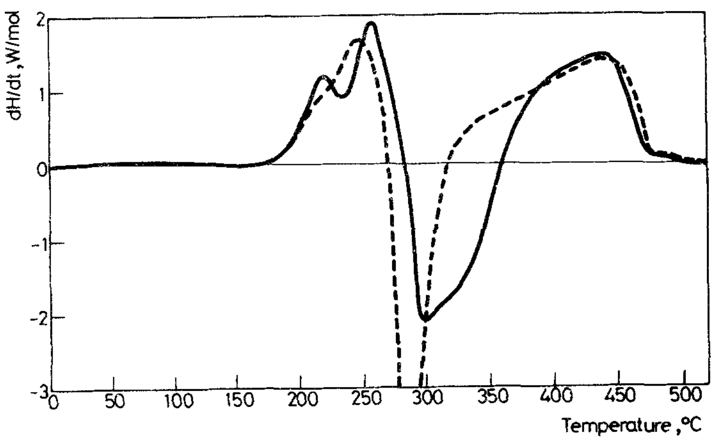

Fig. 4 DSC-scans, at 20 deg/min, of non deformed and 2 % stretched Al-Cu-Mg samples aged at 100°C —— 500 →20 →8 days/100°C; – – 500 →20→2 % →8 days/100°C

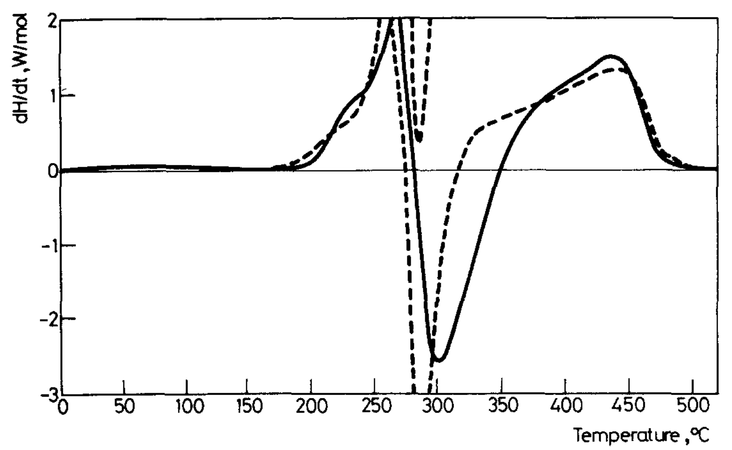

Fig. 5 DSC-scans, at 20 deg/min, of non deformed and 2 % stretched Al-Cu-Mg samples aged at 150°C —— 500 →20 →4 days/150°C; – – 500 →20→2 % →3 month/RT→4 days/150°C

Conclusions

DSC-studies performed on the Al - 2.1%, Cu - 1.3% Mg alloy indicate clearly that prolonged RT-aging enhances the rate of S'-formation, whereas higher aging temperatures leading to greater GPB-zone sizes have no major influence. Cold deformation after quenching also accelerates S'-precipitation upon heating, contrary to [2].

It may be concluded that the apparition of the metastable S'-phase is favoured mainly by lattice defects whose concentrations increase upon quenching and upon plastic deformation. It is known from electron microscopic investigations [4] that the S'-phase may nucleate heterogeneously on dislocation loops and helices produced by the condensation of vacancies during low-temperature aging after quenching. The fact that the S'-precipitation peak increases with aging time at RT is simply a consequence of the higher density of loops and helices present before the thermal analysis.

The introduction of dislocations by plastic deformation also raises the density of heterogeneous nucleation sites for S'-precipitation. The DSC-curves confirm that they facilitate the apparition of the S'- and S-phases and assure a finer and more homogeneous distribution. Hence a preaging stretch improves the mechanical properties of the alloy.

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Zusammenfassung — DSC-Untersuchungen zeigen auf einfache und überzeugende Weise, daß die Bildung der metastabilen S'-Phase in einer Al-Cu-Mg-Legierung (Al-2.1%, Cu 1.3 %Mg) in Gegenwart von Gitterdefekten (Versetzungsringe, Wendeln, Versetzungen) gesteigert, aber durch vorherige GPB-Zonen nur wenig beeinflußt wird.