Magnesium Technology 2011
Edited by: Wim H. Sillekens, Sean R. Agnew, Neale R. Neelameggham, and Suveen N. Mathaudhu
TMS (The Minerals, Metals & Materials Society), 2011

THE EFFECT OF PRECIPITATE STATE ON THE CREEP PERFORMANCE OF Mg-Sn ALLOYS

Mark Gibson[1], Xi-Ya Fang[2], Colleen Bettles[3], Christopher Hutchinson[3]

[1]CAST CRC and CSIRO Manufacturing and Infrastructure Technology; Private Bag 33, Clayton, Vic, 3169, Australia
[2]Monash Centre for Electron Microscopy; Monash University, Clayton, Vic 3800, Australia
[3]ARC Centre of Excellence for design in Light Metals; Department of Materials Engineering, Monash University, Clayton, Australia

Keywords: creep, precipitation, micro-alloying

Extended Abstract

The Mg-Sn system has recently received attention as a potential basis for the development of creep resistant alloys. This is an age hardenable system with the potential to form ~10 vol. % of Mg_2Sn. The Mg_2Sn precipitate has a high melting temperature (~770 °C) and alloys based on this system might be thought to show some promise for use in applications requiring elevated temperature creep resistance [1]. The age hardening response of the binary alloy is only modest, despite the large volume fraction of precipitates that may be formed [2]. The reason is that the precipitates form with a relatively coarse distribution, in laths parallel to the basal planes of the magnesium matrix. This configuration is relatively inefficient at impeding dislocation motion [3].

Mendis *et al.* [3,4] have recently shown two methods for improving the room temperature precipitation hardening response of Mg-Sn based alloys. The first approach involved using micro-alloying additions to catalyze a greatly refined distribution of precipitates. The basic idea is to create heterogeneities in the matrix at which Mg_2Sn may precipitate. A qualitative thermo-kinetic criterion for choosing micro-alloying additions was proposed and, using additions of Na, a two orders of magnitude increase in the number density of precipitates and an augmentation of the hardening increment of 270% were achieved [3]. In a second, more ambitious approach, Mendis *et al.* used Zn additions to attempt to manipulate the shape of the Mg_2Sn precipitates [4]. The premise was to manipulate the lattice misfit normal to the basal plane of the magnesium matrix in an effort to change the shape of the Mg_2Sn precipitates. This was also shown to be successful and a substantial increase in age hardening was realized. As a final step, the two approaches were used simultaneously (Na+Zn additions) realizing a further increase in the precipitation hardening response. In all cases the precipitate remained almost exclusively Mg_2Sn. The age hardening responses of the binary alloy, the alloy containing Zn, and the alloy containing Zn+Na have been reported by Mendis *et al.* [4].

However, designing microstructures for high strength is not the same as designing materials for creep resistance. Creep resistance also requires stability of microstructure. Under conditions where the creep strain is accommodated mainly by dislocation motion, stability in the precipitate state is crucial for creep resistance. Approaches to strengthening that involve an increase in precipitate number density suffer from a potential disadvantage for applications requiring creep resistance because for a given volume fraction of precipitates, increases in the number density necessarily correspond to a decrease in the mean particle size. The driving force for coarsening is the excess energy stored in the particle/matrix interfaces and the coarsening rate of a particle distribution scales as R^{-2}. Thus, the increase in strength of precipitate strengthened alloys achieved through refinements in scale may come at the cost of a decrease in the thermal stability of the precipitate distribution.

The Mg-Sn-Zn-Na alloy examined by Mendis *et al.* exhibited a two orders of magnitude increase in the precipitate number density. A surprising result was that the long-term aging behavior of the alloy did not result in significant softening of the alloy, even for times approaching 1000 h at 200 °C. Such stability in properties indicates stability in microstructure and suggests that this alloy may have very interesting creep properties.

In this work, the tensile creep properties of a binary Mg-Sn alloy, a ternary Mg-Sn-Zn alloy and an alloy containing both Zn and Na additions were examined. Sample preparation is outlined in [1]. Each of the three alloys was aged to peak strength at 200 °C. Peak strength for the binary, ternary and quaternary alloys corresponded to ~1000 h, ~200 h and ~7 h, respectively. The average grain size of the alloys was ~150-200 µm. Tensile creep tests were performed in oil at 177 °C with a load of 60 MPa. Selected tests at 150 °C or with loads of 35 MPa were also performed.

The tensile creep strain as a function of loading time at 177 °C under a load of 60 MPa is shown in Fig. 1a for the three alloys. The creep performance of the binary alloy is quite poor and this is consistent with previous reports and expectations based on the low static strength of this alloy. The performance of the ternary alloy containing Zn is much improved compared with the binary alloy but the performance of the Zn+Na containing quaternary alloy is rather striking. The creep performance is orders of magnitude better than both the binary and ternary alloys. The creep performance of the Zn+Na containing quaternary alloy is plotted in Fig. 1b with an extended time axis to illustrate the creep lifetime. Lifetimes in excess of 400 h were obtained under tensile loading conditions at both 177 °C and 150 °C. The tests were stopped soon after 400 h.

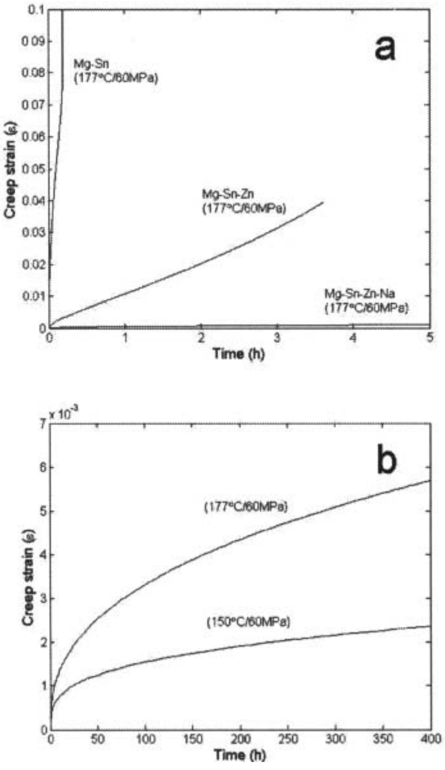

Figure 1. Tensile creep curves for a) the Mg-Sn, Mg-Sn-Zn and Mg-Sn-Zn-Na alloys at 177 °C under a load of 60 MPa and b) the Mg-Sn-Zn-Na alloys at 177 °C and 150 °C under a load of 60 MPa. These tests were stopped after ~ 400 h.

The quaternary Zn+Na containing alloy has a creep rate approximately five orders of magnitude lower than the binary alloy under loads of 60 MPa.

Transmission electron micrographs of the peak-aged microstructures and as crept microstructures of the Mg-Sn-Zn-Na alloy are reproduced in [1,3,4]. The as-crept microstructure of the Mg-Sn-Zn-Na alloy shows very little change from the peak-aged structure, confirming the thermal stability of the precipitate structure. The excellent creep resistance of the Mg-Sn-Zn-Na alloy is linked to the excellent thermal stability of this microstructure.

What is the origin of the thermal stability of the precipitates in the Mg-Sn-Zn-Na alloy?

This thermal stability is not exhibited by the alloy containing Zn additions only so it is tempting to look to the Na for an explanation. Na additions were chosen because they were expected to cluster on the magnesium lattice during aging and hence catalyze the nucleation of Mg_2Sn. Since the Na additions are expected to be intimately linked with the Mg_2Sn precipitates, it may be expected that the Na is either incorporated into the Mg_2Sn precipitate as it grows or may be located at the precipitate/matrix interface. In either case, it would not be surprising for such segregation to affect the lattice misfit between the precipitate and matrix, and therefore the interfacial energy which drives coarsening processes, or in the case of incorporation of the Na into the Mg_2Sn precipitates, the intrinsic thermodynamic stability of the Mg_2Sn precipitates. The obvious next step is to experimentally identify the exact location of the Na additions in the microstructure, and any possible association with the Zn additions. This information would aid in the optimization of the micro-alloying additions for the most beneficial impact on the mechanical properties.

This work illustrates that, through the judicious selection of alloying additions, it is possible to very substantially affect the size and shape of Mg_2Sn precipitates in Mg-Sn based alloys. These modifications are beneficial for the tensile creep performance of these alloys. In particular, The Mg-Sn-Zn-Na alloy exhibits excellent thermal stability of the precipitate structure leading to tensile creep properties that are of practical significance and have a five orders of magnitude improvement in secondary creep rate compared to the binary Mg-Sn alloy.

Acknowledgements

The CAST Co-operative Research Centre was established under, and is funded in part by, the Australian Government's Co-operative Research Centres Scheme. The Australian Research Council is gratefully acknowledged for funding the ARC Centre of Excellence for Design in Light Metals.

References

1. Gibson M., Fang X., Bettles C.J., Hutchinson C.R., *Scripta Materialia*, 63 (2010), 899-902.
2. Van der Planken J., *Journal of Materials Science Letters*, 4 (1969), 927.
3. Mendis C.L., Bettles C.J., Gibson M.A., Gorsse S., Hutchinson C.R., *Philosophical Magazine Letters*, 86 (2006), 443.
4. Mendis C.L., Bettles C.J., Gibson M.A., Hutchinson C.R., *Materials Science and Engineering A*, 435-436 (2006), 163.