Bull. Mater. Sci., Vol. 22, No. 1, February 1999, pp. 33–35. © Indian Academy of Sciences.

Precipitation hardening in Al–Zn–Mg–$Al_2O_3(p)$ composite

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MS received 18 April 1998; revised 4 October 1998

Abstract. The precipitation hardening of a Al–Zn–Mg–$Al_2O_3(p)$ composite is explored. It is found that the peak hardness achieved is almost double that of precipitation hardening of Al–Zn–Mg alloy or dispersion strengthening of Al–Zn–Mg with 5% $Al_2O_3(p)$. Toughness is marginally improved and tensile strength is one and half times that of precipitation hardened Al–Zn–Mg alloys. The ageing time for peak hardness is reduced due to acceleration of formation of precipitate.

Keywords. Precipitation; dispersion; composite; strengthening; aluminium; alumina; hardness; toughness.

1. Introduction

Al–Zn–Mg alloys are precipitation hardenable (Martin 1961; Brooks 1982) but retention of strength is not possible at higher temperatures (Porter and Easterling 1992). Dispersion strengthening of Al–Zn–Mg with $Al_2O_3(p)$ will result in retention of strength at higher temperatures (Agarwal 1988; Minouru Taya and Arsenault 1989). By precipitation hardening a dispersion strengthened composite improvement in properties is expected as reported for Al–Cu–SiC(p) system (Rawlings and Mathews 1994).

2. Experimental

Al–7·5Zn–1·5Mg alloy was cast following standard melting practice. Al–7·5Zn–1·5Mg–$Al_2O_3(p)$ composite was also obtained by melt casting technique with different volumes of reinforcement, (1%, 3% and 5% Al_2O_3). Size of the $Al_2O_3(p)$ was 0·3 μm. Precipitation hardening was carried out on Al–7·5Zn–1·5Mg and Al–7·5Zn–1·5Mg–$Al_2O_3(p)$ systems. Solution treatment was done at 723 K. Three ageing temperatures of 348, 373 and 423 were used and ageing time was increased in steps of 30 min from 30 min to 6 h for Al–Zn–Mg alloy.

Dispersion strengthening occurred in Al–7·5Zn–1·5Mg–$Al_2O_3(p)$ and some of these composite materials were studied as such without giving precipitation hardening.

Rockwell hardness was measured on all the samples subjected to (i) precipitation hardening of Al–Zn–Mg, (ii) dispersion strengthening of Al–Zn–Mg–$Al_2O_3(p)$ and (iii) precipitation hardening of Al–Zn–Mg–$Al_2O_3(p)$.

Grain size was measured at 100x magnification on cast Al–Zn–Mg alloy and cast Al–Zn–Mg–$Al_2O_3(p)$ composite with 1, 3 and 5% $Al_2O_3(p)$ as reinforcement. Charpy impact test and tensile test were done on Al–Zn–Mg composite reinforced with 0, 1, 3 and 5% $Al_2O_3(p)$, after precipitation hardening.

3. Results

Hardness vs ageing time was plotted for all the precipitation hardened samples of Al–Zn–Mg alloy. Peak hardness values are shown in table 1. Optimum ageing temperature was 373 K and time was 150 min. Hardness values of (i) dispersion strengthened and (ii) precipitation hardened composites of Al–Zn–Mg are shown in table 2. Grain sizes of starting composite material and mechanical properties of precipitation hardened composite material are shown in table 2. Cast Al–Zn–Mg has the largest grain size and as volume fraction of $Al_2O_3(p)$ increases grain size decreases. Impact toughness and tensile strength as shown in the above table, increase with decrease in grain size. Optimum ageing temperature was found to be 373 K and time was 2 h in case of the composite with 1, 3 and 5% Al_2O_3. All the three phenomena are compared in figure 1 for 5% $Al_2O_3(p)$.

4. Discussion

In precipitation hardening of alloy, optimum ageing

Table 1. Peak hardness values of precipitation hardened Al–Zn–Mg alloy.

Ageing temperature	Ageing time	Peak hardness (RB)
348 K	3 h	56
373 K	2 1/2 h	64
423 K	2 h	55

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Table 2. Properties of Al–Zn–Mg alloy* and Al–Zn–Mg–$Al_2O_3(p)$ composites.

Properties	Volume of fraction of $Al_2O_3(p)$ nil*	1%	3%	5%
Grain size of as cast and homogenized composite material (μm)	150	130	100	60
Tensile strength after precipitation hardening (MPa)	181	208	220	291
Toughness after precipitation hardening (J)	1·20	1·30	1·4	1·6
Hardness after precipitation hardening (RB)	59	68	76	104
Hardness after dispersion strengthening (RB)	31	38	44	52

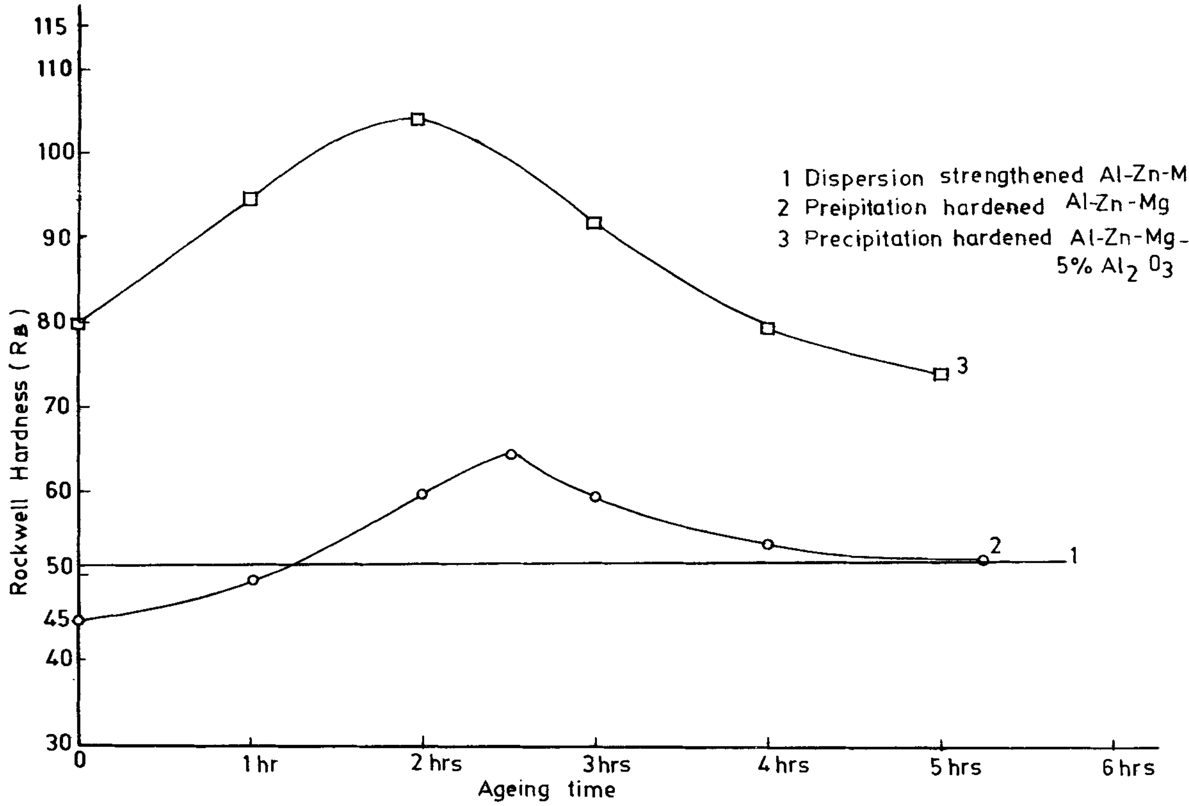

Figure 1. Comparison of precipitation hardening of Al–Zn–Mg–5%Al_2O_3 with precipitation hardening of Al–Zn–Mg and dispersion strengthening of Al–Zn–Mg–5%Al_2O_3.

temperature is 373 K, ageing time, 150 min and peak hardness value, 64 RB. In dispersion strengthening of composite, at a volume fraction of 5%, maximum hardness obtained is 52 RB. Peak hardness of precipitation hardened 5% $Al_2O_3(p)$ composite is 104 RB and is obtained in 2 h. This acceleration is due to promotion of precipitation by Al_2O_3 particles which act as additional nucleation centres for precipitation. Thus precipitation hardening of a dispersion strengthened composite shows improved properties over individual precipitation hardening or dispersion strengthening. This is due to three aspects of hardening in the precipitation hardened composite, viz. the stoppage of dislocation movement by (i) precipitates such as $MgZn_2$ (precipitation hardening) (Rajan *et al* 1992), (ii) particles of alumina (dispersion strengthening) (Broutman and Krock 1967) and (iii) by grain boundaries (fine grain size means more grain boundary area) (Reed Hill and Reza Abbaschian 1994).

As all the three mechanisms operate together, precipitation hardening of a dispersion strengthened composite is preferable to individual precipitation hardening or dispersion strengthening. Not only strength is improved but also toughness which is due to fine grain size. But it is countered by precipitates and particles which act as crack initiation sites. Therefore toughness is only marginally increased.

5. Conclusions

Precipitation hardening of a dispersion strengthened composite gives double the strength of precipitation hardening or dispersion strengthening considered alone due to the combined action of grain size, precipitates ($MgZn_2$) and particles (Al_2O_3) on the free movement of dislocations. Maximum hardness obtained was 104 RB with an ageing temperature of 373 K and ageing time of 2 h. Corresponding UTS was 291 MPa and toughness 1·6 J.

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