

## New Al-Mg-Si(-Cu) Alloys Used for Automotive Body Panels

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### 1 Instruction

In the continuing drive for automobile weight reduction, Al-Mg-Si(-Cu) alloys are considered to be the most promising candidates for heat-treatable body sheet materials. However, this type alloys are not thermodynamically stable at room temperature after solutionising and quenching, and this natural ageing phenomenon will suppress the paint-bake response. Furthermore, the holding time during the paint-bake process is usually not long enough to lead to the peak aged condition for Al-Mg-Si(-Cu) alloys, so that the potential strength of Al-Mg-Si(-Cu) alloys cannot be fully exerted. Hence, composition optimisation and processing control should be employed to increase the strength of Al-Mg-Si(-Cu) alloys in the paint-bake condition.

Based on AA6022 alloy, in this work, some new Al-Mg-Si(-Cu) alloys were developed, the influence of the chemical composition, natural ageing and pre-ageing on the paint bake response was investigated, and a appropriate process was put forward to put these alloys into practice.

### 2 Processing and Testing

The studied alloys require processing typical for heat treatable aluminium alloys, i.e. homogenisation, fabrication, solution treatment, quenching and artificial aging. The alloys were cast and fabricated on an industrial scale, and optic microscopy, SEM, TEM and mechanical property tests were used to investigate the microstructure evaluation and mechanical properties.

Table 1 Composition of the studied alloys (in wt%)

Alloy	Mg	Si	Fe	Cu	Mn	Zn	Ti
6022 based alloys	0.52	1.33	0.12	0-0.19%	0.06	0.19	0.01

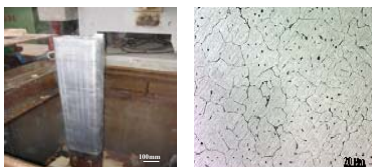


Fig. 1 DC cast ingot and as-cast microstructure (Cu-free alloy)

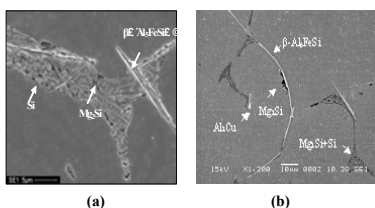


Fig. 2 SEM analysis of the primary precipitates of as-cast alloys. (a) Cu-free alloy, (b) 0.19% Cu alloy



Fig. 3 Hot rolling and hot rolled coils



Fig. 4 Cold rolling and cold rolled coils

### 3 Results and Discussion

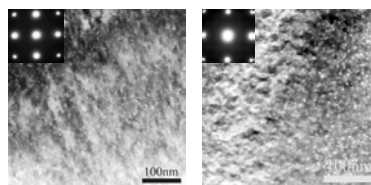


Fig. 5(a) Fig. 5(b)

Fig. 5 Transmission electron micrographs taken with  $B = [001]_{Al}$  showing the precipitates of the alloys after solutionised and immediately artificially aged at  $180^{\circ}C$  for 30 minutes. (a) Cu-free alloy; (b) with 0.19%Cu.

In Fig. 5, since the contrast due to the particles is still spherical rather than needle-shaped, and the SAED patterns show neither extra reflections nor diffuse scattering. This suggests that the precipitates are fully coherent with the matrix and do not have any distinct structure. The precipitates are considered as the spherical GP zones. The density of the GP zones in the alloy containing 0.19%Cu is higher than that in the Cu-free alloy, suggesting that the addition of Cu increases the density of the precipitates.

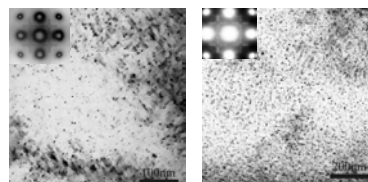


Fig. 6(a) Fig. 6(b)

Fig. 6 Transmission electron micrographs taken with  $B = [001]_{Al}$  showing the precipitates of the alloys after solutionised and immediately artificially aged at  $180^{\circ}C$  for 4 hours. (a) Cu-free alloy; (b) with 0.19%Cu.

Compared with Fig. 5, in Fig. 6, in addition to the contrast due to the spherical GP zones, fine needle-shaped contrast is observed in the bright-field images of the directly aged alloy for 4 hours. In the SAED patterns, streaks along the  $\langle 001 \rangle$  directions corresponding to the reciprocal space of the  $\langle 001 \rangle$  needle-shaped precipitates are observed, these precipitates are designated as  $\beta''$ . The density of the  $\beta''$  is much higher in the alloy with 0.19% Cu than that in the Cu-free alloy, also suggesting that, at the same ageing condition, Cu addition facilitates the precipitation of GP zones and  $\beta''$  phase. This trend shows good agreement with the results of the hardness measurement. The hardness values of the 0.19%Cu alloy are always larger than those of the Cu-free alloy, as shown in Fig. 8 and Fig. 9.

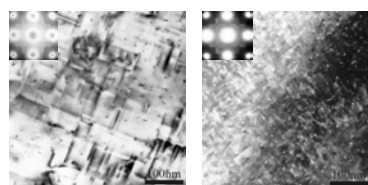


Fig. 7(a) Fig. 7(b)

Fig. 7 Precipitation morphologies of both alloys aged at  $180^{\circ}C$  for 16 hours immediately after solutionising and quenching. At this stage, for both alloys, rod-like precipitates predominate. The dominant precipitates are the  $\beta'$  and  $\beta''$  rather than the  $Q$  or  $Q'$  phase. The precipitates in the alloy with 0.19% Cu are much finer when compared with its counterpart.

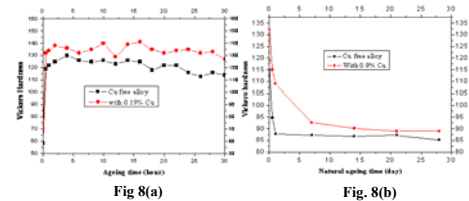


Fig. 8(a)

Fig. 8(b)

Fig. 8(a) shows the hardness variation as a function of artificial aging time for the alloys after solutionising and immediately aging at  $180^{\circ}C$ . For the Cu-free alloy, the hardness increases with the aging time up to about 4 hours. After that, the hardness decreased slightly. For the alloy with 0.19%Cu addition, the hardness values are always larger than those of its counterpart, and the peak value is at about 16 hours.

Fig. 8(b) presents the hardness variation as a function of natural aging time when naturally aged for different periods after solid solution and then aged at  $180^{\circ}C$  for 30 min. With the increase of the delay time between solid solution and artificial aging, the hardness after artificial aging decreases until a certain value for both alloys.

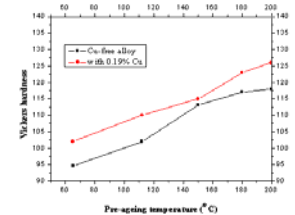


Fig. 9

Fig. 9 shows the influence of pre-ageing on the paint-bake response. The process is: alloys are immediately pre-aged after solid solution and then naturally aged for a certain period, then artificially aged at  $180^{\circ}C$  for 30 minutes. The hardness of both alloys are obviously influenced by the pre-aging conditions. With the increase of the pre-aging temperature, the hardness increases substantially for both alloys. When pre-aged at more than  $150^{\circ}C$  for 5-10 min, the hardness only has slight decrease compared with those aged immediately after solid solution treatment.

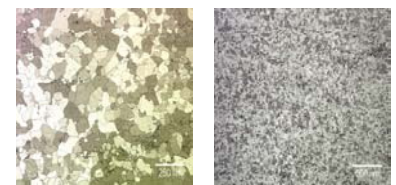


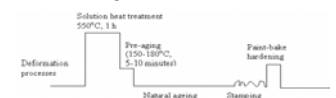
Fig. 10(a)

Fig. 10(b)

Fig. 10 shows the optic microstructure of the alloys after paint baking. The alloy with 0.19%Cu presents a microstructure more homogeneous (Fig. 10(b)) than that without Cu addition. This is in good agreement with the results of the  $r$  value evaluation.

### 4 Conclusion

1) The appropriate processes for two studied Al-Mg-Si(-Cu) alloy sheets is the following:



2) The main mechanical properties for these two alloys are:

For the Cu-free alloy: For the 0.19%Cu alloy:

In T4p state:	In T4p state:
Rm = 221MPa	Rm = 259 MPa
Rp0.2 = 135MPa	Rp0.2 = 145MPa
A = 35.9 %	A = 29.6 %
r = 0.79	r = 0.81
After paint bake:	After paint bake:
Rm = 313MPa	Rm = 341MPa
Rp0.2 = 214MPa	Rp0.2 = 238MPa
A = 22%	A = 20%