RECRYSTALLIZATION IN *Al-Mn-Cr* ALLOYS

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The recrystallization behaviour of pure aluminium and three *Al*—1wt per cent *Mn* alloys containing 0.0, 0.1 and 0.5 per cent *Cr* as ternary additions has been studied at 90 per cent deformation and at 300°C and 400°C temperatures. It has been observed that *Mn* and *Cr* retard the softening process. The presence of 0.1 per cent *Cr* is useful in lowering the softening rates, whereas 0.5 per cent *Cr* enhances the softening of the alloy. The results are discussed on the basis of the role of precipitate particles and dissolved solute atoms on recrystallization behaviour.

Among elements which affect the deformation and recrystallization behaviour of aluminium, *Mn* has been recognised as one of the most efficient, its influence mostly depending upon the supersaturation of the alloy and on size and distribution of the precipitate Al_6Mn eventually present in the matrix. Manganese and chromium are the most common alloying additions used to improve the mechanical properties of aluminium. Considerable work has already been done in the past on the recrystallization behaviour of aluminium-manganese alloys[1—5]. The purpose of this work is to carry out investigations on the combined effect of manganese and chromium on the recrystallization characteristics of aluminium.

The constitution of aluminium-rich aluminium-chromium-manganese alloys has been examined by Raynor & Little[6]. The micrographic constituents observed are the primary solid solution (∝), $MnAl_6$ and a ternary compound G, and the θ phase, which is based upon the primary aluminium-chromium intermediate phase $CrAl_7$. The compound G, which appears in the form of metastable precipitates G_1 and G_2 in the aluminium-manganese system, is stabilized by the addition of chromium[7].

The diffusion in aluminium-manganese-chromium system is very sluggish both in liquid and solid states. Because of very sluggish diffusion, chromium would be expected to decrease the recrystallization rate of aluminium-manganese solid solutions.

EXPERIMENTAL MATERIALS AND PROCEDURE

Investigations were carried out on aluminium (99.99%) and aluminium-manganese-chromium alloys of the following compositions :

(i) *Al*—1 wt % *Mn*

(ii) *Al*—1 wt % *Mn*—0.1 wt % *Cr*

(iii) *Al*—1 wt % *Mn*—0.5 wt % *Cr*

The alloys were prepared from 99.99% pure aluminium and 99.99 per cent pure manganese and chromium. The base metal had following chemical composition (by wt) :

Al	99.99 %	*Si*	0.002 % max
Cu	0.0005 % max	*Fe*	0.0015 % max
Mn	0.002 % max	*Ti*	0.0005 % max
As	0.00002 % max	*N*	0.0005 % max

Thus in the present study, the effect of iron and silicon, which drastically enhance the diffusion rate in aluminium-manganese alloys cannot be completely neglected.

All the alloys were melted in a graphite crucible and stirred with graphite rods to avoid contamination. The melts were heated upto 720-750°C, stirred, fluxed and then cast in graphite moulds.

Because of their sluggish diffusion rates the cast alloys were homogenised at 600°C for 16 hours to ensure removal of microheterogeneity. They were then cold rolled to required thickness in the form of thick strip. To remove the effect of cold working, these thick strips were then annealed at 600°C for 20 hours and quenched into water. This treatment resulted in homogenised specimens of 0.25 mm grain size. The strips so obtained were given 90 per cent deformation by cold rolling.

Annealing of cold deformed specimens was carried out at 300 and 400°C in salt bath furnaces, the temperature of which could be controlled to ± 2°C. The salt mixture used was 50% $NaNO_2$ and 50% KNO_3.

After annealing treatment, all the samples were quenched in order to retain the high temperature microstructure at room temperature.

The process of recrystallization was followed by Vicker's hardness measurements using 5 g load. Twenty hardness indentations were made on all specimens (size: $15 \times 15 \times 5$ mm) after successive stages of annealing. Statistical average of the hardness values corresponding to these indentations were plotted in the form of hardness (VHN) versus annealing time curves at 300 and 400°C. The range of scatter in the hardness values is also shown in these plots.

RESULTS

The change in hardness as a function of annealing time at 300 and 400°C is shown in Fig. 1 and 2 respectively. It is clearly seen that manganese greatly influences the high temperature hardness of

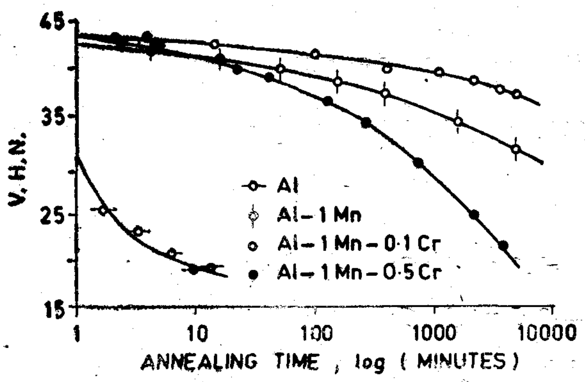

Fig. 1—Variation of hardness with annealing time of *Al* & *Al-Mn-Cr* alloys at 300°C.

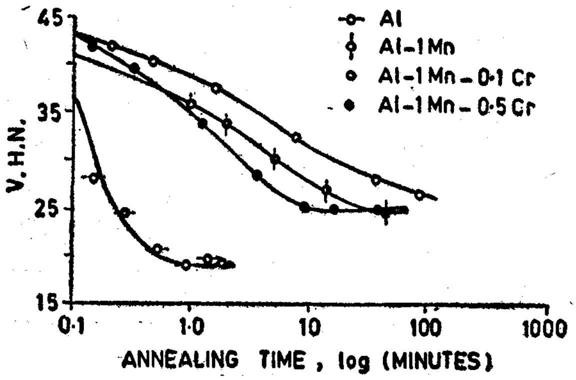

Fig. 2—Variation of hardness with annealing time of *Al* & *Al-Mn-Cr* alloys at 400°C.

aluminium. Whereas pure aluminium takes nearly 10 minutes to soften completely at 300° C, the *Al*—1 *Mn* alloy is not completely softened even after annealing for 100 hours. It is also seen that very small concentration of ternary chromium (*Al*—1 *Mn*—0.1 *Cr* alloy) further raises the high temperature properties of the *Al-Mn* alloy. The fall in hardness with annealing time in the *Al*—1 *Mn*—0.1 *Cr* alloy is much slower than that in the case of *Al*—1 *Mn* alloy. Large additions of ternary chromium (*Al*—1 *Mn*—0.5 *Cr* alloy) accelerates the softening of the *Al*—1 *Mn* alloy. As is seen in Fig. 1 and 2 the fall in hardness of *Al*—1 *Mn*—0.5 *Cr* alloy is faster than that of *Al*—1 *Mn*—0.1 *Cr* alloy.

It is also clearly seen that the recrystallization characteristics are very much temperature dependent. The softening rate of cold worked alloys at 400°C is much faster as compared to that at 300°C.

DISCUSSION

Since the recrystallization process involves formation and migration of high angle boundaries, both the solute atoms as well as the precipitate particles must play important role in the recrystallization characteristics of an alloy[8]. The interaction between the moving high angle boundary and solute atoms largely depends on the difference between the radii of solvent and solute atoms. In the *Al*—*Mn* alloys this difference is very large (~12%) and the recrystallization process is, in general, greatly hindered by the manganese atoms. It has been well established that precipitation of the solute atoms in the form of Al_6Mn particles greatly enhances recrystallization in these alloys. The high interfacial energy associated with these precipitates further promotes recrystallization and the hardness falls at faster rate with annealing time. The activation energy for ternary *Al-Mn-Cr* alloys has not been measured as yet. The results of Raynor & Little[6], however, indicate that diffusion in ternary *Al-Mn-Cr* alloys is much more sluggish than in binary *Al-Mn* alloys. This would suggest that small additions of chromium to *Al-Mn* alloys should result in a slower rate of softening, as seen in *Al*—1 *Mn*—0.1 *Cr* alloy.

The faster rate of hardness fall in the case of *Al*—1 *Mn*—0.5 *Cr* alloy as compared to that of *Al*—1 *Mn*—0.1 *Cr* alloy is probably due to the fact that because of high supersaturation in *Al*—1 *Mn*—0.5 *Cr* alloy the rate of precipitation is much faster as compared to that in *Al*—1 *Mn*—0.1 *Cr* alloy. The interfaces of the precipitating particles with the matrix usually have high interfacial energies and help in the nucleation of low and high angle boundaries, which give rise to a fast rate of recrystallization process and thus a faster rate of softening. As is seen in Fig. 1 and 2, the fall of hardness in the case of *Al*—1 *Mn*—0.5 *Cr* alloy is even faster than in *Al*—1 *Mn* alloy.

CONCLUSION

Manganese and chromium both retard the softening process of work-hardened aluminium. Chromium as ternary addition in aluminium-manganese alloys is useful only if it is added in very small amounts. Excessive amount of chromium causes supersaturation and enhances the rate of precipitation and accelerates the softening rate of *Al*—*Mn* alloys.

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