Association of Metallurgical Engineers of Serbia *Review paper*
AMES *UDC:669.715'721'3-152-174=20*

THE INFLUENCE OF THERMO MECHANICAL TREATMENT ON RECRYSTALLIZATION OF AlMg4.5Cu0.5 ALLOY

LJ. RADOVIĆ[1], M. NIKAČEVIĆ[1], M. POPOVIĆ[2], E. ROMHANJI[2]

[1]*Military Technical Institute, R.Resanovića 1, Belgrade, Serbia,*
[2]*Faculty of Technology and Metallurgy, Karnegijeva 4, Belgrade, Serbia*

ABSTRACT

Recrystallization behaviour of an Al-Mg-Cu alloy (4.5 wt. %Mg and 0.45 wt.%Cu) subjected to different thermomechanical treatments (TMTs) have been studied by means of light optical microscopy and hardness measurements. In order to provide controlled precipitation of Cu-Mg intermetallic particles two-stage annealing at 565°C/6h + 450°C/4h was applied. Then the tested alloy was cold rolled with 20, 40 and 60% reductions, and finally annealed for 3h at 250, 280 and 350°C, with slow and rapid heating rate (0.6 and 25°C/min). After annealing at 250°C/3h recovered grains were dominated in the structure. New recrystallized grains were revealed only in a few grains when r=40 and 60%. At 280°C a mixture of unrecrystallized and small new recrystallized grains (d_{av}≈20μm) was observed while after annealing at 350°C with high reductions a recrystallization process was completed. These observations were in agreement with hardness measurements. The heating rate was found also affecting the homogeneity of grain size distribution.

Key words: Aluminium alloy, AlMg4.5Cu0.5, recrystallization, microstructure

INTRODUCTION

Al-Mg based alloy sheets containing Mg from 4.5 to 5.5 wt.% are widely used for press forming, mainly due to their good combination of strength and formability. However, their use in car body constructions is followed with an undesirable softening, during the paint baking procedure. The addition of small amount of copper to Al-Mg alloys makes them precipitation hardenable and was found as a solution for undesirable softening during paint baking [1-3]. Controlling the metallurgical structure during cold rolling and subsequent annealing is of essential importance in the production of sheet products. One of the process variables, which may be used either to inhibit or to enhance recrystallization, is annealing at high temperature, because it alters the spatial distribution of dispersoids [4-7]. The high temperature annealing was suggested to accelerate microstructure development during final annealing, dissolving the fine intermetallic particles as much as possible at higher temperatures, after accelerating coarse precipitation away from the grain boundaries at lower temperatures [4]. During final annealing the material may undergo static recovery and/or recrystallization, depending on its thermomechanical history, temperature of annealing and heating rate.

The aim of this work was to study the effect of various cold rolling reductions and annealing temperatures on recrystallization behavior of an Al-Mg-Cu alloy.

EXPERIMENTAL

Chemical composition of as-received Al-Mg-Cu alloy, produced by IMPOL-SEVAL Aluminium Rolling Mill, is given in Table 1.

Table 1. Chemical composition of tested Al-Mg-Cu alloy (wt. %)

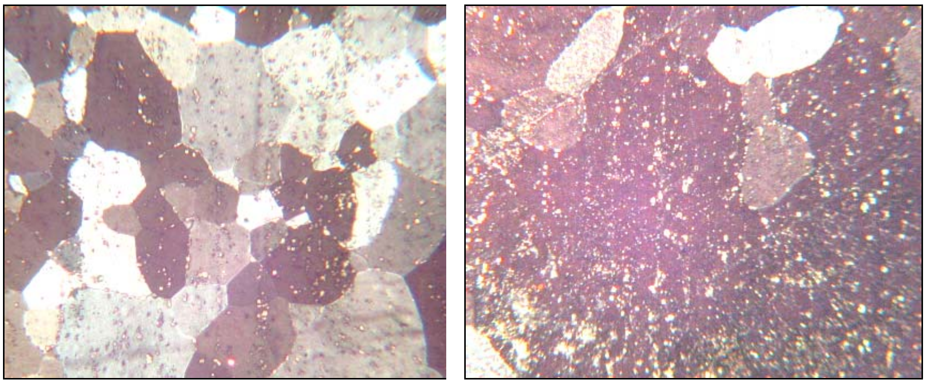
Mg	Mn	Cu	Si	Fe	Zn	Ti	Ni	*Al*
4,51	0,052	0,45	0,15	0,34	0,049	0,004	0,0008	Bal.

As-received Al-Mg-Cu alloy sheets, 3 mm thick, were reheated at 565°C for 6h with heating rate of 35°C/h, furnace cooled to 450°C, held for 4h, and furnace cooled to room temperature. In order to examine the effect of deformation on the annealed microstructures, different cold rolling reductions were applied: 20, 40 and 60%. Further, the specimens were finally annealed at 250, 280 and 350°C for 3h with rapid heating - RH (25°C/min) and slow heating -SH (0.6°C/min). In both cases air-cooling was applied.

To reveal the grain structure, after electro-polishing, the samples were etched in Barker′s solution. The average grain size was determined by the linear intercept method. Hardness was measured by Vickers hardness test (HV5).

RESULTS AND DISCUSSION

Microstructure of the tested alloy after two-stage annealing at 565°C/6h + 450°C/4h, as an initial condition for further TMTs, is shown in Fig. 1.



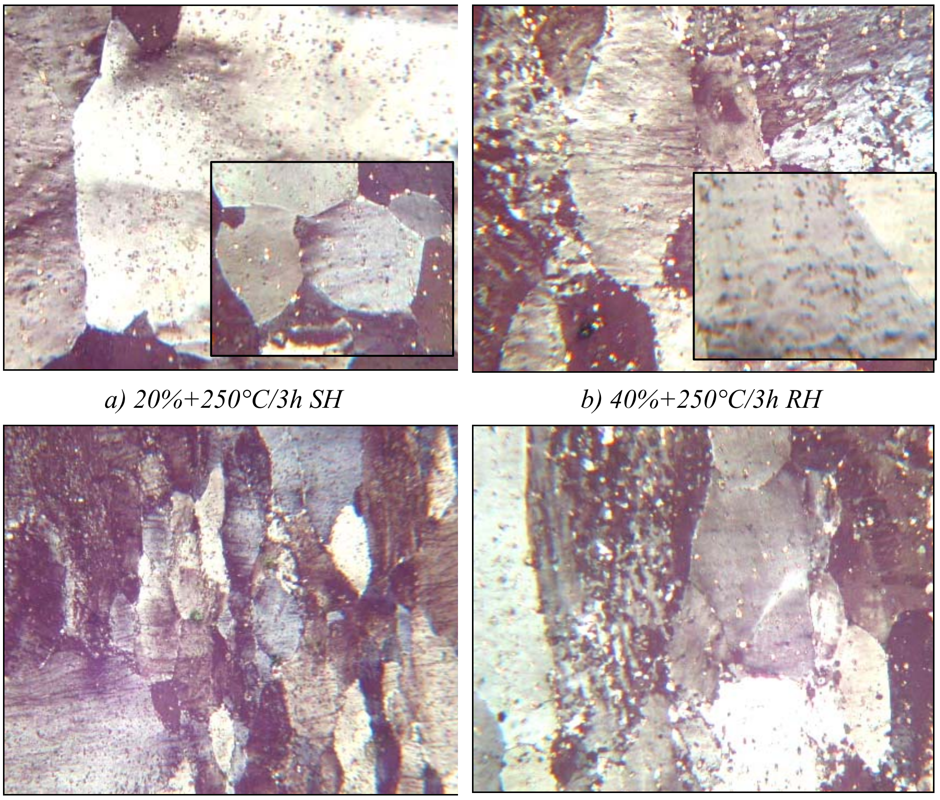
(a) *(b)* *200 μm*

Fig.1. Initial grain structure after annealing at 565°C/6h(FQ)+450°C/4h(FQ) (a) uniform grain size; (b) large grains.

In two-stage annealed samples a wide range of grain sizes revealed, in the range from 50-100μm to 2000 μm. Some abnormal grain growth occurred during reheating of as-received material was assumed to be due to the low Mn content, enabling high mobility of grain boundaries and abnormal grain growth.

Annealing at 250°C. Microstructures of the specimens processed by cold rolling and annealing at 250°C/3h, developed by recovery and/or recrystallization processes, are shown in Fig. 2. After 20% reduction and annealing at 250°C, with both heating rates, the structure consists of recovered grains with non-homogenous grain sizes (Fig. 2a).

After 40% reduction and annealing at the same temperature recrystallization started in some grains, but only in rapidly heated specimens. Fig. 2b shows the nucleation of new grains. The recrystallization nuclei are observed both in the region of grain boundaries and within the grains, probably in the area of highly localized deformation [8]. After 60% reduction and annealing at 250°C the structure consists of elongated grains (Figs.2c-d). Recrystallization started only in rapidly heated specimens, too (Fig. 2d). The fraction of recrystallized structure was increased in comparison with 40% deformed specimens.



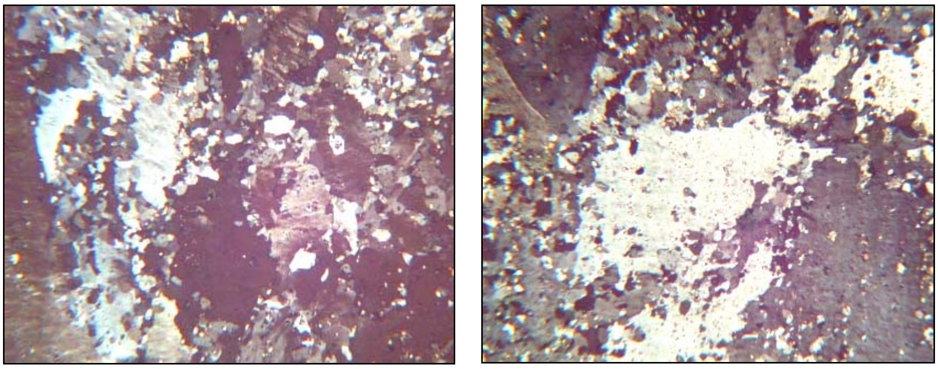
a) 20%+250°C/3h SH *b) 40%+250°C/3h RH*

c) 60%+250°C/3h SH *d) 60%+250°C/3h RH* *200 μm*

Fig. 2. Microstructures after cold rolling followed by annealing at 250°C/3h (SH-slow heating, RH-rapid heating)

Annealing at 280°C. New recrystallized grains weren't observed in specimens with 20% reduction. The recrystallization has started in specimens deformed 40% (Fig. 3a) and annealed at 280°C using both heating rates. After 60% reduction, the volume fraction of recrystallized structure increased, but the recrystallization process was not completed (Fig. 3b).

Annealing at 350°C. New recrystallized grains were observed after 20% cold rolling reduction and annealing at 350°C/3h, but the recrystallization wasn't completed (Fig. 4a). The recrystallization was completed after 40 and 60% deformation (Figs. 4b-d). The non- homogeneity of initial and deformed structure imposed that recrystallization didn't start in all grains at the same time. This behaviour leads to non-homogeneity of the final structure as Fig. 4c has shown. Similar structure with non-homogenous grain size was obtained after 60% reduction (Fig. 4d).



a) 40%+280°C/3h SH *b) 60%+280°C/3h SH* *200 μm*

Fig.3. Microstructures after cold rolling followed by annealing at 280°C/3h.

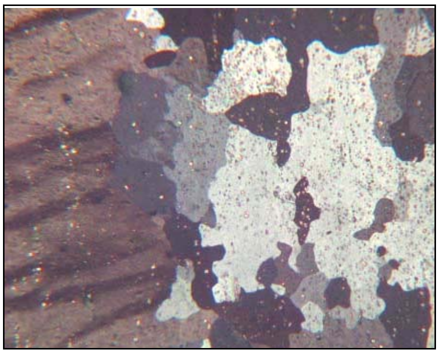
Besides the temperature and deformation, the given results indicate that heating rate has an important influence on the recrystallization process, i.e. grain size and their homogeneity of distribution. It is assumed that rapid heating suppresses recovery, resulting in both preservation of complete driving force for recrystallization and very high concentration of vacancies, what in turn lead to high rate of nucleation [9, 10]. It is assumed that during the slow heating grain growth rate is lower, leading to more uniform grain size in comparison to microstructure obtained after rapid heating.

The influence of cold rolling reduction on grain size after annealing at 350°C with different heating rate is shown in Fig. 5. It is clear that both recovered and recrystallized grain size decreases with increasing cold rolling reduction prior to annealing, due the strain induced nucleation. Also, it can be noted that the range of grain size is wider in rapid heated specimen, i.e. more homogenous structures were obtained when slow heating was applied.

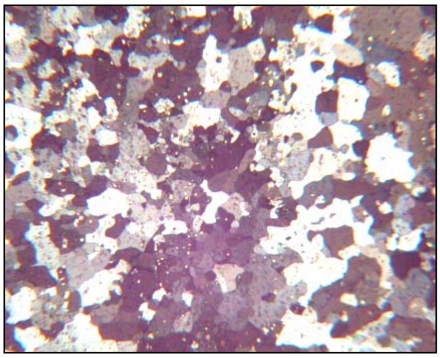
The influence of cold rolling reduction on the hardness after annealing at different temperatures is shown in Fig.6. After annealing at 250°C/3h the hardness increases with increasing prior strain, while at 350°C shows opposite behavior.

After annealing at 280°C the hardness first shows small changes up to 40% reduction and than drops. Results of hardness measurements are in a good agreement with results of metallographic examination given in Figs. 2-4. The hardness increases with increasing strain in recovered structure (Fig.2). When recrystallization starts the hardness is little increased (r = 20-40% at 280°C, open symbol). The hardness decreases when fraction of the recrystallized grains increases (r = 60%). Decrease of hardness after 40% reduction and annealing at 280°C is directly related to the start of recrystallization. The higher hardness drop is result of larger fraction of recrystallized structures during rapid heating (open symbol).

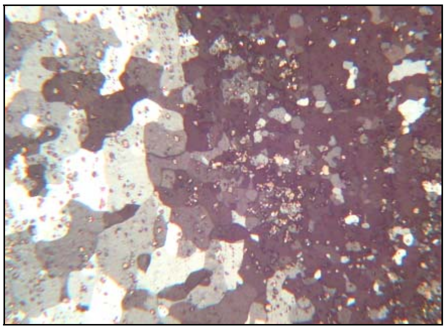
Fig. 7 shows that hardness decreases as the annealing temperatures increases as expected, and the highest hardness drop was obtained in specimens with 60% reduction in both cases with slow and rapid heating. The lower hardness after annealing at 280°C RH - curve (Fig. 7b) compared to data in Fig. 7a is related to larger fraction of recrystallized structure.



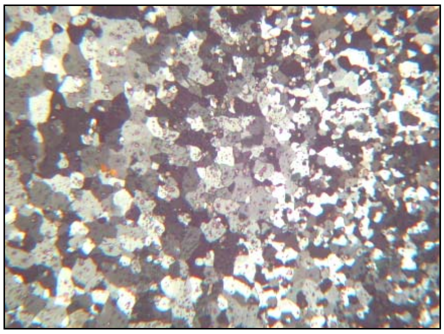
a) 20%+350°C/3h SH



b) 40%+350°C/3h SH



c) 40%+350°C/3h RH



d) 60%+350°C/3h RH *200 μm*

Fig. 4. Microstructures after cold rolling followed by annealing at 350°/3h.

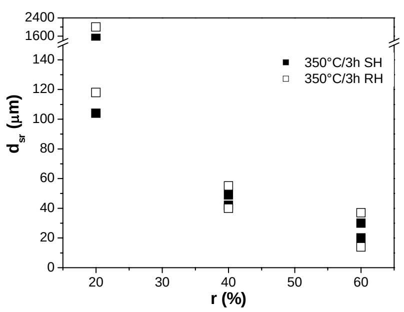


Fig. 5. The influence of cold rolling reduction on grain size.

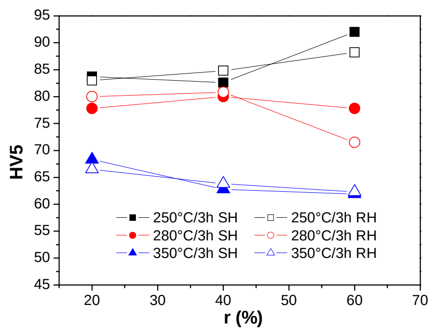
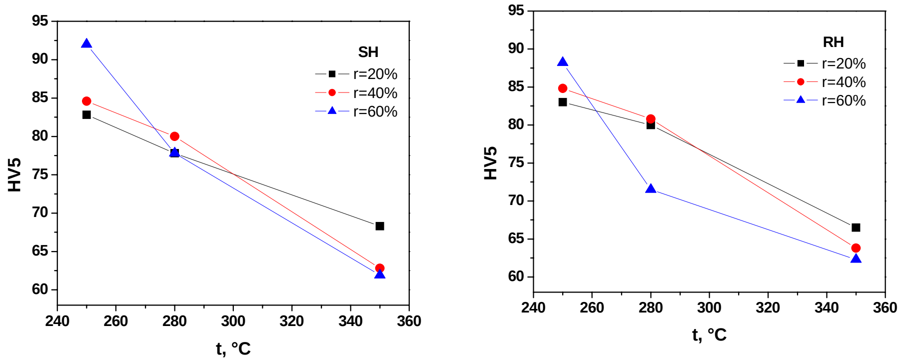


Fig. 6. The influence of cold rolling reduction on hardness.



a) *b)*

Fig. 7. The influence of annealing temperature and heating rate on hardness.

CONCLUSION

Recrystallization behaviour of an Al-Mg-Cu alloy (4.5 wt. %Mg and 0.45 wt. %Cu) has been studied after initial annealing and cold rolling (reductions 20, 40 and 60%), followed by final annealing at different temperatures (250, 280 and 350°C for 3 h).

Microstructure development after cold rolling and annealing is closely related to both deformation and annealing temperature. Increasing the rolling reduction and annealing temperature promote recrystallization resulting in either a partially or fully recrystallized structure. After annealing at 250°C and 280°C (for all reductions), recovery and partial recrystallization have occurred, while after annealing at 350°C partial recrystallization (reduction 20%) or full recrystallization (reductions 40 and 60%) has occurred.

The recrystallized grain size is strongly affected by cold rolling reduction prior to annealing and it was refined by increasing the cold rolling reduction.

The heating rate has influence on recrystallization and structure homogeneity. More homogenous structures were obtained when slow heating was applied. It is assumed that during slow heating grain growth rate is lower, leading to more uniform grain size.

REFERENCES

[1] P. Ratchev and et al., Scripta Materialia, Vol.38, No. 8, 1998, pp.1195-1201
[2] B. Verlinden, A. M. Zahra, Mat.Sci.Forum, Vols.426-432, 2003, pp.423-428
[3] M. J. Starink, A.Dion, Thermochimica Acta, 417, 2004, pp.5-11
[4] M. Osman et al., Mat. Sci. Forum, Vols. 396-402, 2002, pp.351-356
[5] T. Sheppard, N.Raghunathan, Mat.Sci.Tech., Vol.5, 1989, pp. 268-280
[6] M. A. Zaidi, T.Sheppard, Met. Tech., Vol. 11, 1984, pp. 313-319
[7] B. Verlinden et al., Recrystallization and Grain Growth, Proc. of the First Joint Int. Conf., Eds. G. Gottstein and D. A. Molodov, Springer-Verlag, Berlin, 2001, pp. 1249-1254
[8] N. Ryum and J.D.Embury, Scand.J.Metall., 11, 1982, pp.51-54
[9] R. Grimes, Grain control in aluminum, Paper No.MS 353. "Recrystallization in the Control of Microstructure", London, 1973
[10] S. S. Gorelik, Recrystallization in metals and alloys, Mir publishers, Moscow (1981) pp. 163