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Thermo-mechanical treatment using resistance heating for production of fine grained heat-treatable aluminum alloy sheets

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Abstract

A new thermo-mechanical treatment using resistance heating is devised to produce fine grained aluminum alloy sheets. To examine the effectiveness of the treatment, simulating experiments are conducted using a heat-treatable 6061 aluminum alloy, and the grain size, hardness property, and tensile properties are measured and compared with those of the conventionally heat-treated sheets. The results are summarized as follows: (1) resistance heating at a current density of about 100 A mm^{-2} realizes heating the aluminum alloy sheet into the solution temperature range in 2 s, (2) complete achievement of rapid solution treatment by the resistance heating requires the condition that the precipitates exist finely in the matrix, (3) the new treatment decreases the grain size by approximately one-half but the mechanical properties are not remarkably improved.

Keywords: Heat treatment; Resistance heating; Aluminum alloy sheet; Rapid solution treatment; 6061 aluminum alloy

1. Introduction

A use of high specific strength aluminum alloy sheets has increased for car weight reduction. Especially, Al–Mg–Si alloy sheets of 6000 types are targeted as materials for body panel because they are heat-treatable and have the merits of not only lowering a flow stress by solution treatment, which is advantageous to press forming, but also increasing the strength by baking in the succeeding painting operation. However, aluminum alloy sheets are apt to make a crack in press forming compared with steel sheets. Then, improvement of their press-formability is a pressing issue. The solution will be in grain refinement and various attempts using special technique, such as accumulative roll bonding [1] and differential speed rolling [2] have been made. However, to think of the current production of aluminum alloy sheets, a grain size of the produced sheets is determined by their final heat treatments because the treatments include a long-time heating process which makes the grains grow. Then, induction heating with a high heating rate has been applied to production of annealed aluminum alloy sheets with fine grains of several micrometers in size [3].

Speaking of a rapid heating method, there is a resistance heating method, which is simple and economical compared with the induction heating method. Therefore, various applications of the resistance heating technique have been proposed for material processing [4–8]. However, it has never been applied to the heat treatment of aluminum alloy sheets. One of the main reasons is there being a preconceived idea that an application of resistance heating must be unsuitable for heating of aluminum alloy sheets with high electrical conductivity. There is something in that, the authors dared to try it and devised a new thermo-mechanical treatment using resistance heating with a view of production of fine grained aluminum alloy sheets.

In this paper, the new thermo-mechanical treatment is presented together with the results of the experiments conducted to verify its effectiveness.

2. Thermo-mechanical treatment using resistance heating

Heat-treatable aluminum alloy sheets are produced by a series of operations as follows: casting, homogenizing, blooming, multistage hot rolling, multistage cold rolling, and solution and aging treatments. As seen from this, the sheets are heat-treated to recover the ductility and solution-treated for age hardening in the final stage. However, in the heat treatment, the sheets are

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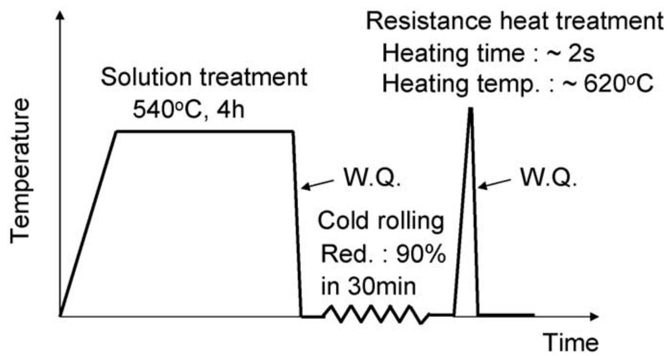

Fig. 1. Devised thermo-mechanical treatment using resistance heating.

held at high temperatures for a few minutes even the shortest in the current process and the grains grow into about 30 μm in size. This grain growth leads to degraded formability and surface roughening in press forming. Therefore, a method for rapid heat treatment is strongly desired.

Fig. 1 shows the thermo-mechanical treatment devised for suppression of the grain growth by application of rapid resistance heating. The devised process is composed of preliminary solution treatment, cold rolling, and resistance heat treatment. In this process, a cold rolled strip is rapidly resistance-heated and water-quenched so as to suppress the grain growth and produce a supersaturated solid solution for precipitation hardening. If the precipitates exist as large particles in the sheet, complete solution treatment will not be achieved by the short-time resistance heating, because the solution treatment requires diffusion of the elements composing the precipitates into the matrix. Therefore, the preliminary solution treatment in the devised process will be essential.

3. Experimental

The devised treatment will be conducted continuously in the practical operation as a substitute for the down-stream part after the multistage hot rolling in the current process, but the simulating experiments were conducted with the operation of each individual process one after another.

A commercial 6061 aluminum alloy sheet with a thickness of 5 mm, whose composition is given in Table 1, was used and rectangular test pieces with a length of 50 mm and a width of 50 mm were prepared and they were solution-treated by heating at 540 °C for 4 h and then water-quenched. After that, the test pieces were cold rolled into the thickness of 0.5 mm by 17 passes using a two-high mill and cut into 470 mm in length. The strip thus prepared was connected to the electrodes and it was resistance-heated at the heating rate of about 300 °C s^{-1} with the electric current density of 100 A· mm^{-2} and water-quenched just after the completion of electrification so as to suppress the grain growth and the precipitation. The heating rate is twice as large as the greatest one of the induction heating reported so far [3] and 10-times as large as that in the continuous annealing process. A maximum heating temperature of the strip in each heating was measured with an infrared thermometer, and it will be indicated by the symbol T in this paper. In the experiment, the temperature was varied in a range up to 620 °C to make clear the influence of the rapid solution treatment using the resistance heating on the mechanical properties. Conventionally O-, T4-, and T6-treated sheets were also prepared for comparison.

For the sheets thus prepared, metallographic structures were observed with an optical microscope, and then mechanical properties were evaluated from hardness and tensile tests.

Table 1
Chemical composition of 6061 aluminum alloy sheet used for experiment

Element	Si	Mg	Fe	Cu	Mn	Cr	Zn	Ti	Al
Content (mass%)	0.60	0.74	0.37	–	0.03	–	0.03	0.04	Bal.

4. Results and discussion

4.1. Effect on grain refinement

Fig. 2 shows the metallographic structures of the resistance heat-treated and conventionally heat-treated sheets. An average grain size for the sheet resistance heat-treated at T = 470 °C in Fig. 2(a) is about 9 μm, while that for the conventionally heat-treated sheet in Fig. 2(b) is about 19 μm. It is found that the resistance heat treatment is effective in suppressing the grain growth.

4.2. Effect on hardness property

Fig. 3 shows the variation of Vickers hardness with the time elapsed after the resistance solution treatment. The sheet solution-treated at T = 435 °C shows little increase in hardness as the time proceeds, but both the sheets treated at T = 487 and 540 °C show an increase. The increase for the sheet treated at

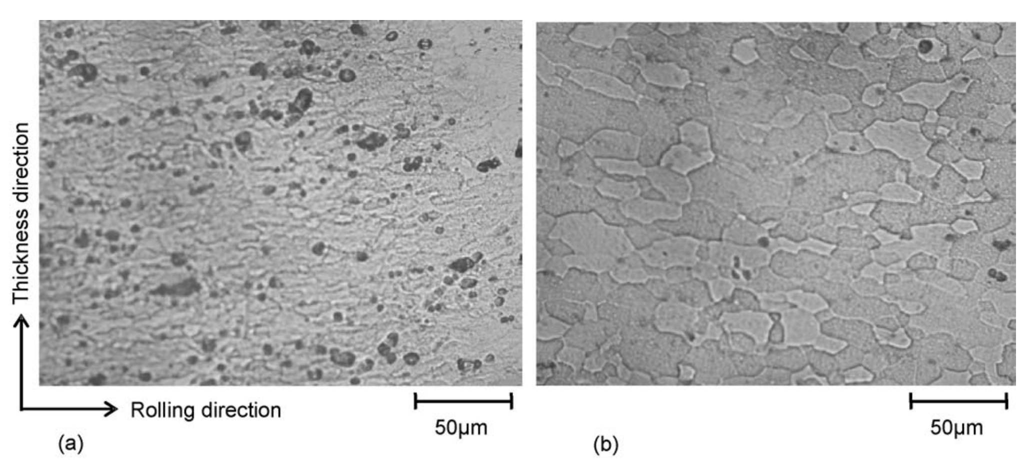

Fig. 2. Microphotographs of (a) resistance heat-treated sheet and (b) conventionally heat-treated sheet.