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An improved thermo-mechanical treatment of high-strength Al–Zn–Mg–Cu alloy for effective grain refinement and ductility modification

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ABSTRACT

A simple thermo-mechanical treatment (W-TMT) based on the idea of deformation-enhanced precipitation (DEP) and particle-stimulated nucleation (PSN) of recrystallization was proposed for Al–Zn–Mg–Cu alloy. The AA 7075 alloys were subjected to the proposed W-TMT, conventional hot rolling or a traditional thermo-mechanical treatment (RI-ITMT). During W-TMT, the coarse $MgZn_2$ particles induced by DEP create preferential nucleation sites for recrystallization, and tailoring the sizes of these particles can effectively regulate or control the final grain sizes. Under the same total reduction of 85%, the grain size of W-TMT processed sheet can be decreased to $\leq 10\,\mu m$, similar to that of RI-ITMT processed sheet while relatively coarse grains (grain size > 25 μm) were obtained by hot rolling. After peak-aging (T6) treatment, the strength of all processed sheets were identical to each other, yet the fracture elongation of W-TMT processed fine-grained sheet was notably increased to 18.5%, compared to 13.1% for hot rolled sheet with coarse grains. Resultantly, this proposed short-cycled W-TMT processing possesses the synergetic capacity of grain refinement, ductility modification, as well as strength retention for Al–Zn–Mg–Cu alloy.

1. Introduction

The precipitation-strengthened 7000 series (Al–Zn–Mg–Cu) alloys have been widely used for aerospace and transportation applications because of their high strength and heat treatability (Williams and Starke, 2003). The mechanical property as well as other properties of 7000 alloys can be further reinforced by grain refinement. To be specific, El-Baradie and El-Sayed (1996) revealed that ductility/strength of solutionized 7075 alloy was enhanced by decreasing grain size from 45 to 16 μm; Paton et al. (1982) showed that the exfoliation corrosion resistance of fine-grained (~10 μm) 7075 was markedly superior to the conventional coarse-grained one; Smolej et al. (2001) found that the super-plasticity of 7075 alloy also benefitted from grain refinement. It is well-documented that grain refinement of 7000 alloys can be achieved through various processings such as severe plastic deformation (SPD) (Sitdikov et al., 2009), cryo-rolling (Gopala Krishna et al., 2012), or other controlled thermo-mechanical treatment (TMT) (Niinomi et al., 1987). However, neither SPD nor cryo-rolling method is a practical way for manufacturing large-sized Al alloy profiles. The TMTs that combine deformation with heat treatment together such as so called ITMT (intermediate thermo-mechanical treatment) technique are widely applied for high-strength aluminum alloys.

Di Russo et al. (1974) designed the first ISML-ITMT (Fig. 1a) to fabricate fine-grained 7075 sheets, which consists of the following steps: initial cast plate → low-temperature homogenization (aimed at gaining coarse $MgZn_2$ precipitates to act as preferential nucleation sites for recrystallization) → warm deformation → solutionizing/static recrystallization. According to Di Russo et al. (1974), the success of the ISML-ITMT process is based on making the Cr elements supersaturated in the aluminum matrix during both the partial homogenization and warm deformation stages, and Cr-dispersoids will precipitate during subsequent recrystallization treatment thus to retard grain growth. However, it is rather difficult to obtain initial cast plates with Cr in solution and successful deformation of these plates is hard to realize. Soon after, Waldman et al. (1974) developed a relatively simple FA-ITMT (Fig. 1b) to overcome above problem, who adopted step-

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Nomenclature

TMT	Thermo-mechanical treatment
ITMT	Intermediate TMT
ISML-ITMT	ITMT designed by Istituto Sperimentale dei Metalli Leggeri of Italy (Fig. 1a)
FA-ITMT	ITMT designed by Frankford Arsenal (Fig. 1b)
RI-ITMT	ITMT designed by Rockwell International Science Center (Fig. 1c)
W-TMT	Simplified TMT based on warm rolling and continuous rolling (Fig. 1d)
DEP	Deformation-enhanced precipitation
PSN	Particle-stimulated nucleation
LAGB	Low angle (misorientation < 15°) grain boundary
RD, TD, ND	Rolling, transverse and normal directions
UTS, YS	Ultimate tensile strength and yield strength
Rx	Recrystallization
T6	Peak-aging
ASTM	American society for testing and materials
SADP	Selected area diffraction pattern

homogenization instead of low-temperature homogenization to obtain large-sized particles without considering whether the Cr-dispersoids are in solution or not. But the necessary long-period step-homogenization treatment (several days) makes FA-ITMT hard to commercially-viable. Subsequently, Wert et al. (1981) proposed a simpler RI-ITMT (including four steps: solutionizing, 400 °C/8 h overaging, warm rolling and solutionizing, as shown in Fig. 1c), which can impart considerably fine grains of ≤ 10 μm to 7075 alloy. And from then on RI-ITMT is extensively used for grain refinement applications in Al–Zn–Mg–Cu alloys (*e.g.*, Malek and Cieslar (2002) got fine-grained (~13 μm) Al–6.6Zn–2.3Mg–1.7Cu alloy sheet by adopting RI-ITMT; 400 °C/8 h overageing treatment was still applied by Kumar et al. (2009) to obtain coarse $MgZn_2$ particles in AA 7449 alloy).

It is clear that a long over-aging or pre-precipitation interval is indispensable to acquire certain numbers of large particles during all aforementioned ITMT techniques, even the simplified 400 °C/8 h overaging treatment in frequently-used RI-ITMT is still energy- and time-consuming. At present, a short-cycled thermo-mechanical treatment (W-TMT, Fig. 1d) based on DEP and PSN was proposed to produce fine-grained Al–Zn–Mg–Cu alloys, the effects of processing parameters on microstructural characteristics of 7075 and corresponding PSN mechanism during W-TMT were examined in details. The microstructures as well as mechanical properties of 7075 samples with different grain sizes were studied as well.

2. Experimental procedure

The starting material was a 15 mm-thick commercial AA 7075 plate (Al-5.4Zn-2.3Mg-1.5Cu-0.18Cr-0.28Fe-0.11Si [wt%]) in the T6 (peak-aging) temper. To obtain supersaturated solid solution the alloy was solutionized for 475 °C/1.5 h with subsequent rapid water quenching (WQ-7075). Fig. 2 shows that WQ-7075 owns quite coarse grains (grain sizes are hundreds of micrometers in RD direction) with 74% low angle grain boundaries (LAGBs). Then, the coarse-grained WQ-7075 were subjected to RI-ITMT, W-TMT and hot rolling (conventional hot rolling at 420 °C with 85% thickness reduction) processings.

For RI-ITMT (Fig. 1c), 400 °C/8 h over-aging and 85% warm rolling at 250 °C were applied to WQ-7075. During W-TMT (Fig. 1d), WQ-7075 were firstly warm rolled to a thickness reduction of 50–80% at 350–450 °C with re-heating for 5–10 min after every two passes (first-step warm rolling); then warm rolled plate was further continuously rolled to a constant thickness reduction of 70% without any re-heating during the 2nd-step rolling. Please note that the continuous rolling step applied in W-TMT and the warm rolling step used in RI-ITMT are both aimed at introducing deformation zones around large $MgZn_2$ particles. Yang et al. (1992) found that the capacity of coarse $MgZn_2$ to refine grains was hardly altered by the temperature of the warm rolling step during RI-ITMT (*e.g.*, when warm rolling reduction kept constant, increasing the rolling

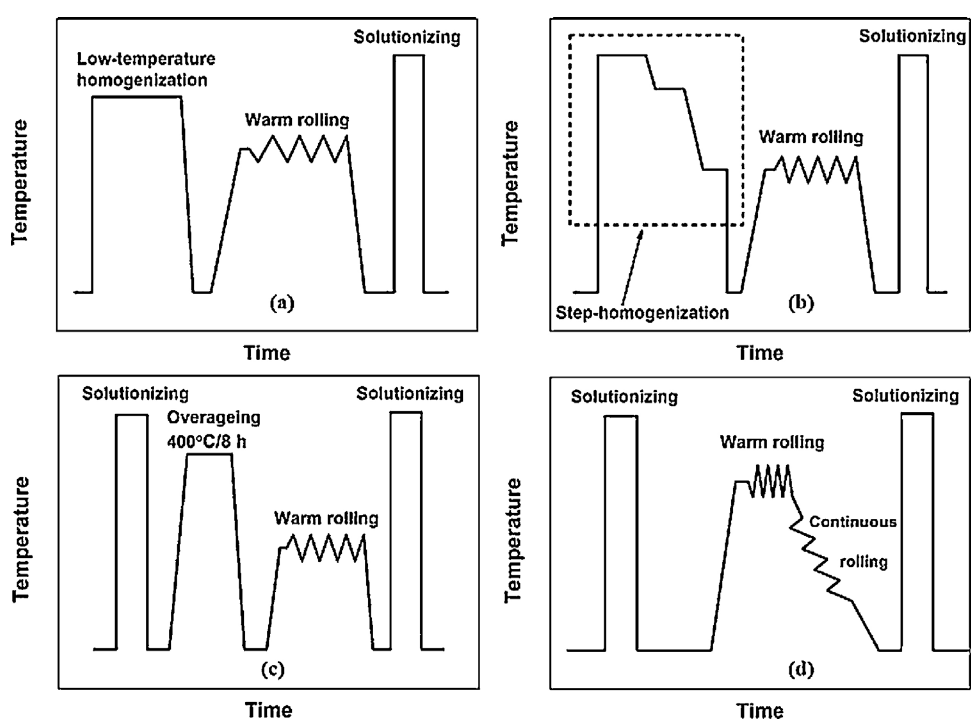

Fig. 1. Schematic presentation of ITMTs: (a) ISML-ITMT; (b) FA-ITMT; (c) RI-ITMT; (d) W-TMT.