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Study on the dynamic and static softening phenomena in Al–6Mg alloy during two-stage deformation through interrupted hot compression test

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ABSTRACT

The dynamic and static softening phenomena in Al–6Mg alloy were studied through interrupted two-stage hot compression test performed isothermally at 480 °C and strain rate range of 0.001–0.1 s^{-1}. The interruptions of 29 and 90 s were considered when the true strain reached 0.5. It was concluded that the effect of static softening on the flow stress was not highlighted by extending the interruption at a constant strain rate. Also, it was exhibited that softening rate highly enhanced with the strain rate decrement at a constant time. Moreover, the static and dynamic recrystallization was revealed as the dominant softening mechanisms at low and high strain rates, respectively.

1. Introduction

Highly formable alloys, such as Al–Mg alloys, have been used widely in automotive and aerospace industries [1–3]. It is reported that the complex changes in metallurgical structures that occur during the multi-pass thermo-mechanical processes such as hot rolling and hot forging are resulted from the balance between work hardening and softening phenomena in these alloys [4].

So far, many researchers have assessed the fraction of recrystallization by using semi-empirical equations, finite element analyses, Monte Carlo method and neural networks to quantify the extension of softening. Also, it has been demonstrated that the static recrystallization occurs generally due to high strain content and short time in hot rolling [5]. Lin et al. [6] indicated the severity of static softening with increment of deformation temperature, temperature between deforming stages and delay time in aluminum alloy 2519. Also, Raok et al. [7] studied the fractional softening during multi-pass deformation processes.

Dynamic recovery and recrystallization happen during metalworking operations such as hot rolling, extrusion and forging. They are important because they reduce the flow stress of testing material; thus, enable it to be deformed more easily and also, they might have influence on the grain size of final product. Poschmann and McQueen [8] concluded that the flow softening of Al–5Mg coincided with transformation of dislocation structures into the subgrains and it was not related to the dynamic recrystalliza-

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tion. Sakai and Takahashi [9] founded that grain boundary sliding took place frequently while deforming and the flow softening in some regions resulted from the apparent grain refinement based on the folding of pancake-shaped grain structures, as well as, grain boundary sliding.

In order to obtain an acceptable restoration mechanism during and after deformation and to gain suitable ductility and flow stress, the combined effect of different parameters such as deformation temperature, strain rate and content along with temperature and delay time must be studied. In the present work, different softening phenomena in Al–6Mg alloy were studied during two-stage hot compressive deformation at various strain rates and interruption times. Besides, the effect of strain rate on the microstructural evolutions was discussed. To the knowledge of the authors, such similar investigation on Al–6Mg alloy has not been carried out before.

2. Material and methods

As-received Al–6Mg slab with composition of Al–5.96Mg–0.71Mn–0.63Cu–0.42Fe–0.12Sc (weight pct.) was utilized as the starting material. Cylindrical specimens (h = 13.5 and φ = 9 mm) were machined in order that the compressions were aligned with the rolling direction. Then, prepared specimens were got deformed at a constant crosshead velocity using an Instron universal testing machine. Isothermal and interrupted compressions were carried out at 480 °C with the strain rate range of 0.001–0.1 s^{-1}. The interrupted deformations were performed with delay times of 29 and 90 s after achieving the true strain of 0.5. Throughout the examinations, boron-nitride and mica utilized as lubricants to reduce friction. Meanwhile, the study of microstructural evolutions was conducted utilizing optical microscopy in such a way that samples were sectioned along the compressive axis. Prevalent metallographic stages were accomplished and finally specimens were etched using JE-WorldTech® patented etchant [10].

3. Results and discussion

Fig. 1 exemplifies compressive stress-strain curves of Al–6Mg examined in different conditions. Fig. 1(a) shows the variation of flow stress in single-stage isothermal compression at 480 °C by strain rate of 0.1 s^{-1}. From figure, the curve exhibits a peak due to beginning of dynamic softening. Also, Fig. 1(b) and (c) represents the effect of delay

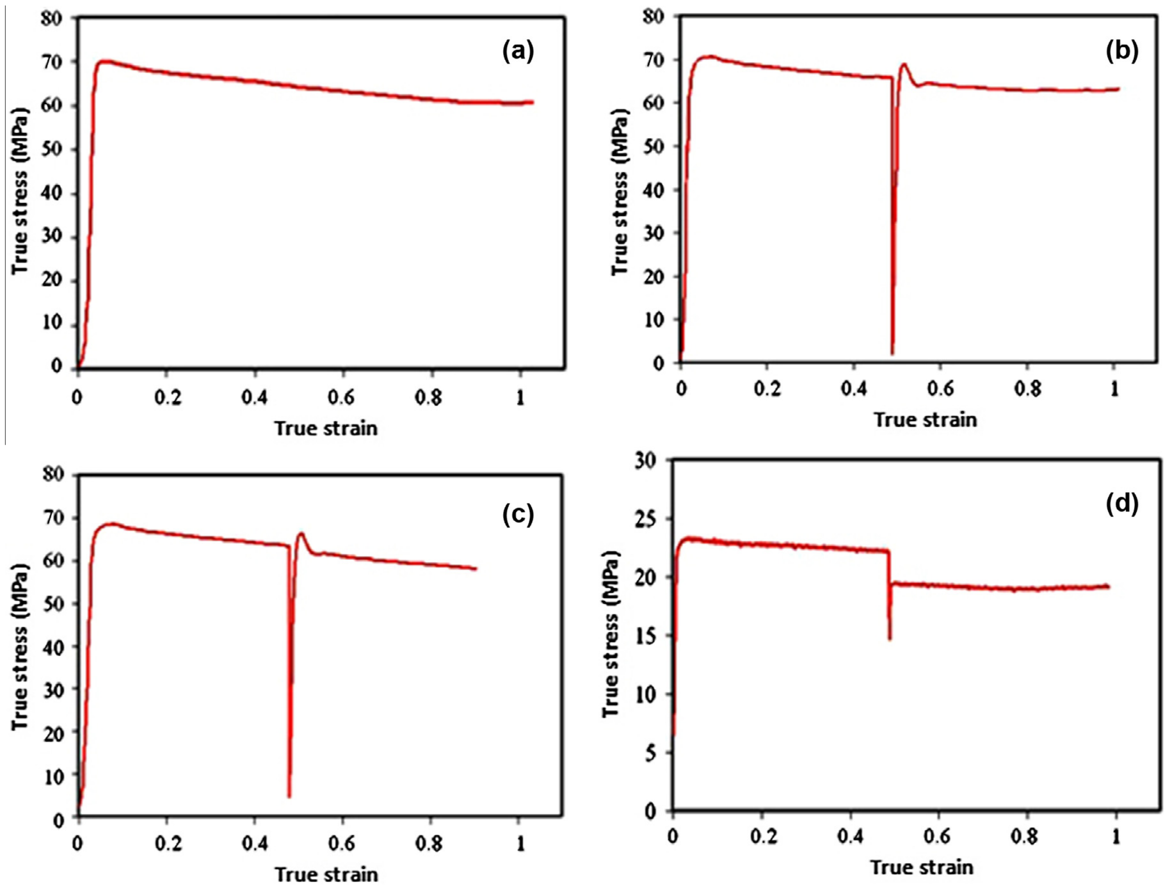

Fig. 1. True stress–strain curves obtained from the isothermal compression of Al–6Mg at 480 °C and different deformation conditions of (a) single-stage, 0.1 s^{-1}, (b) two-stage, 0.1 s^{-1}, 29 s, (c) two-stage, 0.1 s^{-1}, 90 s, and (d) two-stage, 0.001 s^{-1}, 29 s.