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Biaxial deformation on AA5182-O aluminium alloy sheet at warm temperature

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Abstract. Warm temperature biaxial tension test apparatus was developed in this study. This device can achieve stress ratio and strain rate controls simultaneously because it is necessary to keep those parameters for an accurate measurement of equi-plastic work locus. The warm temperature biaxial tension tests were conducted on AA5182-O aluminium alloy sheet with the thickness of 1mm. The obtained results showed that the shapes of equi-plastic work loci did not have strong temperature dependency.

1. Introduction

Aluminum alloy sheets are increasing its attention in automotive industry to reduce the weight of car structure. The aluminum alloy sheet is mainly used for outer panels such as door, roof, trunk lid etc. Such outer panels are usually produced with press forming so that large springback due to the small Young’s modulus and stretcher strain mark often become problems at cold forming. Warm temperature press forming, therefore, is known as an efficient technique to overcome such drawbacks of aluminum alloy sheet. However, warm press forming simulation is not regularly incorporated in die design process compare to that for cold forming because accuracy of simulation is simply not good enough. The use of the accurate constitutive equation that can describe temperature and strain rate dependency and anisotropy is of vital importance.

In the present study, we focus on the observation of shape of equi-plastic work locus at the elevated temperature. Naka et al. \cite{1} and Naka et al. \cite{2} conducted biaxial tension tests for aluminum alloy and magnesium alloy sheets at warm temperature and showed that temperature and strain rate influenced greatly on the shape of equi-plastic work loci. Xiao et al \cite{3} also conducted warm temperature biaxial tension tests on nickel-based superalloy. However, reports of such warm temperature deformation for sheet metal under biaxial loading is very limited. Additionally, precise temperature and strain rate controls and strain measurement method must be necessary for an accurate equi-plastic work locus measurement. Hence, we developed a warm temperature biaxial tension test equipment with the aid of digital image processing. Then biaxial tension tests for AA5182-O aluminum sheet were conducted and obtained results are reported.
2. Warm temperature biaxial tension test

2.1. Experimental apparatus

Figure 1 shows the warm temperature biaxial tension test apparatus. The thermostatic bath equipped with the temperature controlling system was attached to the conventional biaxial testing machine [1]. Figure 2 (a) and (b) show the schematics of specimens used for uniaxial and biaxial tension tests, respectively. The central part of specimen was heated by heat gun from the bottom and by electric furnaces placed upper and lower sides of the specimen. Before the experiment (during heating process), specimen temperature was measured by thermocouples welded on 4 points of the specimen. Once the temperature reached the target one, it was held for 5 minutes then air temperature was kept constant during tension test. As a results, the temperature could be controlled within ±2°C error. The specimen was recorded by digital camera from upper side through heat resistant glass and strain was calculated by DIC (digital image correlation) technique using Vic-2d (Correlated Solutions, Inc.). It should be noted that that velocity in X axis and load in Y axis can be controlled simultaneously to keep the constant nominal strain rate and stress ratio in this device.

Figure 1. Warm temperature biaxial tension test apparatus.

Figure 2. (a) uniaxial tension and (b) biaxial tension specimens used for warm temperature experiments.

2.2. Material and experimental conditions

Material used for the warm temperature experiments was AA5182-O aluminum sheet with the thickness of 1mm. Electrical discharge machining was used to cut into the specimen’s shapes shown in Figure 2. The test temperature were 20, 200 and 300°C with the equivalent plastic strain rate is about
0.001/s. The test was terminated at the onset of necking at the arm of the cruciform specimen. The experiments were conducted for stress ratios \( \sigma_x:\sigma_y = 1:0, 2:1, 1:1, 1:2, 0:1 \), where \( x \) and \( y \) denote rolling direction (RD) and its transverse direction (TD), respectively.

3. Results and discussions

Figure 3 is the stress-strain curves obtained from uniaxial tension tests at 20, 200 and 300°C. Large workhardening was found at 20°C, then it became moderate at 200°C, the worksoftening almost flat or even softening occurred at 300°C. It should be noted that the Portevin-Le Chatelier (PLC) effect appeared at 20°C, with which PLC bands was formed on specimen surface and serrated flow curves was observed. Such PLC effect disappeared above 200°C. Figure 4 (a), (b) and (c) are the obtained equi-plastic work loci at 20, 200 and 300°C in which flow stresses \( \sigma_x \) and \( \sigma_y \) were normalized by the flow stress of uniaxial tension. The obtained shape of equi-plastic work locus at 20°C is almost placed on von Mises yield surface but only equi-biaxial stress is slightly higher. On the other hand, stresses for \( \sigma_x:\sigma_y = 2:1, 1:1, 1:2 \) at 200 and 300°C are rather located inside of von Mises yield surface. Because the crystal structure of AA5182 aluminum alloy sheet has the face centered cubic (FCC) so that plastic deformation takes place only on \{111\}<110> slip system. The equi-plastic work loci, therefore, had almost no temperature dependency. At the same time, one may say that dynamic recovery that should appear at 300°C does not influenced on anisotropic response of the material.

Finally, finite element calculation for the warm temperature biaxial tension test was conducted in order to validate our experimental results. The simulation was carried out using MSC simufact.forming 14.0 with 6000 hexahedral elements. The experimentally obtained equivalent stress vs. equivalent plastic strain curves at 200 and 300°C for the strain rates of 0.001, 0.01 and 0.1/s were used as the input data. In addition, temperature distribution on the specimen surface measured in the experiments were directly given on nodes. The calculated equi-plastic work locus points for the stress ratios \( \sigma_x:\sigma_y = 2:1, 1:1 \) were shown in Figure 5. The obtained points are located on the von Mises yield surface which was used for FE simulation. Therefore, it can be said that the specimen shape and inhomogeneities of temperature and strain rate do not influence the observation of equi-plastic work locus with our experiments.

Figure 3. Stress-strain curves obtained from uniaxial tension tests in RD at 20, 200 and 300°C.
Figure 4. Normalized equi-plastic work loci obtained from biaxial tension tests at (a) 20, (b) 200 and (c) 300°C.

Figure 5. Normalized equi-plastic work locus calculated by FE simulation at 300°C for 0.001/s plastic strain rate.
4. Conclusions
Warm temperature biaxial tension test apparatus was developed and it was applied for AA5182-O aluminium sheet. The obtained results were summarized below.
1) Precise temperature control (±2°C error) can be achieved.
2) Stress ratio and strain rate can be controlled simultaneously.
3) FE simulation results of biaxial tension test showed that the developed system can ignore the inhomogeneity of temperature and strain rate.
4) Although stress-strain curves showed significantly large temperature dependences, the shape of the equi-plastic work loci were almost the same for every temperature.

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