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# Time dependent springback of a magnesium alloy

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ABSTRACT

A time dependent springback was observed in a Mg–Al–Zn (AZ31) rolled sheet after three-point bending at room temperature (RT). Two types of test were performed: (1) baseline springback – specimens were bent and immediately released and the springback was measured every month; (2) springback after holding – after bending, specimens were held in the bent state for up to five months, and the springback was measured after release. It was found that the springback increased nonlinearly with time in all the specimens. The springback dramatically decreased after being held for one month compared with specimens that were not held. The decline in springback increased as the holding time increased. These results indicate that creep and creep recovery occurred. Microstructure examinations revealed high density $\{10\bar{1}2\}\langle 10\bar{1}\bar{1}\rangle$ twins in the compression zone of the bent specimens in the form of localized twin bands. After the specimens were unloaded, detwinning occurred and continued spontaneously over the five month time period, contributing to the observed time dependent springback.



## 1. Introduction

Magnesium (Mg) alloys have drawn significant attention because their low densities are attractive for structural applications where energy efficiency is a priority. However, engineering applications of Mg alloys are limited because of their poor formability at room temperature (RT). The relatively low ductility is attributed to the limited number of easy slip systems. Thus deformation twinning serves as an important mechanism for strain accommodation in the direction where the plastic strain is difficult to be compensated by dislocation slip alone [1,2]. After thermomechanical processing of Mg alloys at elevated temperatures, e.g. rolling or extrusion, the materials are highly textured as a result of plastic deformation and recrystallization [3–5]. The basal planes of the grains tend to be aligned with the rolling or extrusion direction during deformation. The texture gives rise to anisotropic mechanical properties of wrought Mg alloys [6], which strongly affect the formability of Mg alloys. Sheet forming of Mg alloys is an important manufacturing process in which bending is significantly involved [7]. During bending of the highly textured sheets of Mg alloys, a strain gradient is generated through the thickness of the material. The activation of deformation modes, in terms of dislocation slip and twinning, varies across the strain gradient. For example, $\{10\bar{1}2\}\langle 10\bar{1}\bar{1}\rangle$ twinning is activated in grains in which the stress favors twinning [8], whereas dislocation slip is activated and dominant in grains in which the stress disfavors twinning. The combination of anisotropy, twinning and dislocation slip makes the springback behavior of Mg alloys sharply different from metals where slip dominates plastic deformation [9]. Springback has been considered the immediate recovery of elastic strain after unloading. However, the author recently observed a significant decrease in springback in a Mg alloy after the specimen was held in the bent state for an extended amount of time at RT, indicating that time dependent inelasticity plays a role. This observation motivates the current work, in which experiments were designed and conducted to investigate such time dependent springback behavior at RT by examining the microstructural evolution.

## 2. Experimental method

A twin-roll cast AZ31 magnesium sheet with a 1.0 mm thickness was used in our experiments [10]. Strong basal texture was developed during rolling. More details of microstructure and texture of the experimental material can be found in [8]. Strips with dimensions of 76 ($l$) × 9 ($w$) × 1 ($t$) $mm^3$ were sheared for three-point bending tests. Fig. 1 shows the experimental setup in this work. Three-point bending was performed on an Instron 5882 at a displacement rate 10.0 mm/min. Fig. 1a shows the geometry of the bottom half of the in-house bending fixture. The span distance is 28.8 mm. A sheet specimen (indicated by the block arrow) was bent and entirely slid into the opening of the fixture. A steel block with a trough (Fig. 1b) was machined to hold the bent specimens for different lengths of time. The trough has a width of 28.8 mm

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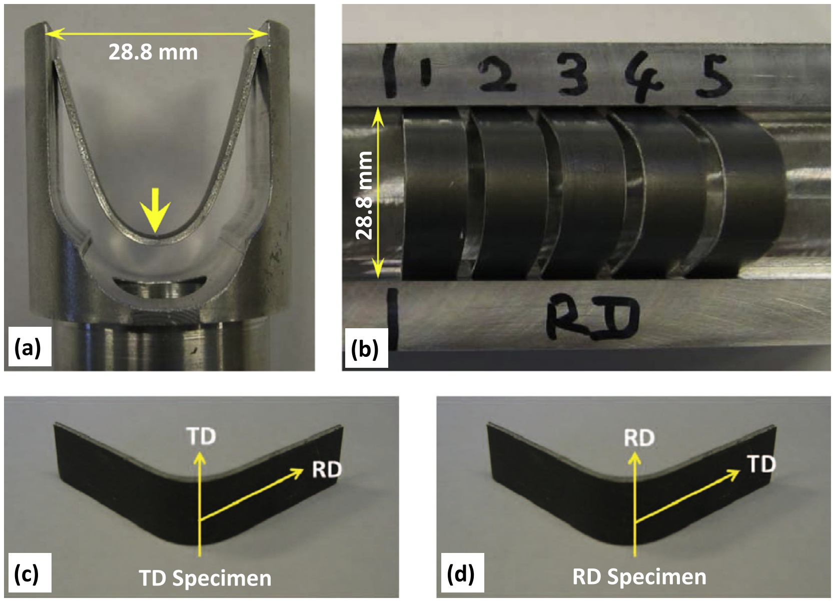


**Fig. 1.** Experimental setup: (a) The bottom half of the three-point bending fixture in which an AZ31 sheet specimen (indicated by the block arrow) was bent into the opening. (b) The bent specimens were carefully transferred and remained in the bent state in the trough in a steel block. Every month, a specimen was taken out and the springback was measured. (c) The bend parallel to the transverse direction (TD) is designated as TD specimen. (d) The bend parallel to the rolling direction (RD) is designated as RD specimen.

which is the same as the span distance of the bending fixture. Two groups of specimens were prepared with the length either parallel to the rolling direction (RD) or the transverse direction (TD). Fig. 1c and d shows the designation of the specimens: the bend parallel to the RD was designated as the "RD specimen" and the bend parallel to the TD was designated as the "TD specimen". Two types of springback tests were performed:

(1) Baseline springback: a RD and a TD specimen were bent and immediately taken out of the bending fixture, and the springback was immediately measured as the baseline springback values. These specimens were left in the free state in the laboratory, and the distance between the two legs (the maximum opening) was measured every month for a total of five months. The time interval (one month) and the total amount of experimental time (five months) were selected solely based on our experience.
(2) Springback after holding: after a specimen was bent and entirely slid into the opening of the bending fixture, the fixture along with the bent specimen was removed from the machine, and the specimen was carefully slid out of the fixture and transferred to the trough such that the specimen remained bent by the trough. This was achieved by aligning the fixture with the trough, and then gradually and slowly sliding the bent specimen from the bending fixture into the trough. During the transfer, the distance between the two legs of the bent specimen was maintained at 28.8 mm such that no relaxation occurred to the specimen. Five RD specimens and five TD specimens were prepared, bent and transferred to the trough. Every month, a RD and a TD specimen were taken out of the trough and the springback was measured. After the specimens were retrieved from the trough, the distance was measured every month while the specimens remained in the free state. All the tests and measurements were performed at RT.

In order to examine the microstructural evolution while the specimens remained unloaded, another RD specimen was sheared, bent, immediately released and mounted for metallography examinations. The microstructure of the freshly bent RD specimen was compared to that of the baseline RD specimen which was bent five months earlier. The mounted specimens were mechanically polished with a series of sand papers down to 2400 grit number. The final polish was performed with a suspension composed of alumina powder (50 nm in particle size) and ethylene glycol. An etchant comprising picric acid, deionized water, acetic acid and ethanol was used to reveal the microstructure.

## 3. Results

Fig. 2 shows the evolution of the springback of the baseline RD and TD specimens. In general, the springback distance increases as time increases. The rate of increase in the first month is most

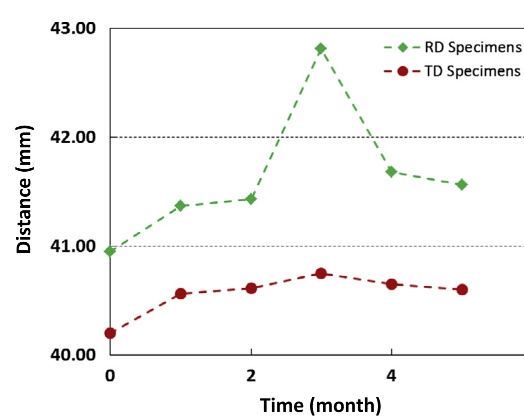


**Fig. 2.** Time dependent springback of the baseline specimens which were retrieved immediately after bending. The distance between the two legs of the bent specimens (RD and TD) was measured in a time interval of one month. It can be seen that the springback increases with time. For the RD specimen, a conspicuous increase in springback can be observed at the third month. For both the RD and the TD specimens, the springback reaches a maximum at the third month, and then decreases.