

Microstructure Development in a Magnesium Alloy Tube during Ring Hoop Tension Testing and Warm Gas Forming

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ABSTRACT

The evolution of microstructure in a Mg 3.4%Al-0.16%Zn-0.33%Mn alloy tube was studied during deformation by ring hoop tension testing (RHTT). When the tests were carried out at moderate temperatures and relatively high strain rates, the accompanying c-axis strains were mainly accommodated by twin formation. At temperatures above 200°C and the lowest strain rate (0.001s^{-1}), the formation of voids in the partially dynamically recrystallized regions caused premature fracture. The microstructural development in hot gas-formed samples was similar to that observed during RHTT testing. These results indicate that RHTT testing is an effective way of studying the deformation behavior of Mg alloys during tube gas forming.

INTRODUCTION

Tube hydroforming is receiving increasing attention in the automotive industry due to its capability for forming complex shapes in a single step and reducing material usage. Since magnesium is the lightest structural metal, magnesium alloy tubes have the potential for significantly reducing vehicle weight. Nevertheless, little work has been carried out to date on the hydroforming and properties of magnesium alloy tubes. Because of the similarity in strain path, ring hoop tension testing (RHTT) is of interest for studying the deformation behavior during hydroforming. For this reason, RHTT was employed to probe the circumferential mechanical material properties of the tubes [1].

In the present study, the microstructural evolution during RHTT of a Mg-Al alloy tube was examined under different conditions. The extent to which the mechanical response is influenced by the interaction between strain path and initial texture was investigated. Furthermore, as the directionality of twinning leads to strongly anisotropic mechanical behavior [2-5], the flow behaviors observed during RHTT and during tension along the longitudinal direction were also compared. In this way, the factors

influencing the ductility and anisotropy of these tubes were elucidated.

EXPERIMENTAL

The magnesium AM30 alloy tubes investigated were provided by the General Motors Research & Development Center, Warren, MI; they had nominal outer diameters of 70 mm and wall thicknesses of 4 mm. The chemical composition of this alloy is presented in Table 1.

Table 1 Chemical composition of the AM30 alloy tubes (in wt.%).

Al	Mn	Zn	Fe	Ni	Cu
3.4	0.33	0.16	0.0026	0.0006	0.0008

Uniaxial flow behaviour in the hoop direction was probed using RHTT [6]. Ring specimens were fit over a pair of appropriately sized D-blocks that are connected to a uniaxial test frame, as displayed in Fig. 1. As the D-blocks separate, the ring specimen elongates until failure occurs in the reduced section. Teflon sheet and vacuum grease were inserted between the inner surface of the ring specimen and the D-blocks to reduce friction. Ring specimens were machined out using a computer numerically controlled (CNC) machine, with the gage section positioned so as to avoid testing the extrusion seam. The four extrusion seams were identified prior to machining via a 5s etch with a solution of 12g CrO_3 , 15ml nitric acid and 85ml H_2O . The ring testing specimen geometry is also shown in Fig. 1; the gage section is 33mm long and 6.4mm wide. To check the repeatability of the results, two to five experiments were conducted under each set of conditions. The variations in flow stress were generally within $\pm 5\%$.

Two initial strain rates were used during RHTT testing: 0.001 and 0.1s^{-1} . Since twinning was of particular interest

in this study, most of the tests were conducted at ambient and moderate temperatures (at intervals of 50°C in the temperature range from 100 to 250°C) and at a strain rate of 0.1s⁻¹. The surfaces examined in the RHTT samples were perpendicular to the extrusion direction (ED). Due to the slight gradient in microstructure between the inner and outer surfaces of the tubes present from the extrusion process, all measurements were restricted to the center of the sections. The samples were prepared as described in reference [7].

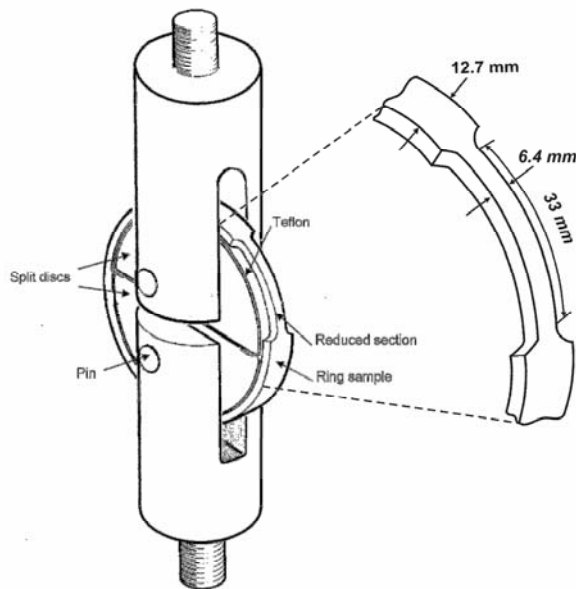


Figure 1 Schematic of the RHTT test fixture [6] and dimensions of the RHTT samples.

Automated electron backscattered diffraction (EBSD) was performed using a LEO 1455 VP SEM equipped with TSL data acquisition software at the GM R&D Center in Warren, Michigan. An acceleration voltage of 20 keV, together with a working distance of 18 mm and a sample tilt angle of 70° were selected to maximize the intensity of the EBSD patterns.

RESULTS AND DISCUSSION

INITIAL TEXTURE

The textures of the as-received AM30 tubes were determined by EBSD and are presented in Fig. 2. The initial grain orientations can be divided into two groups: one with their c-axes approximately parallel to the tube radial direction (called the RD or $\{10\bar{1}0\} <0001>$ component) and the other with their c-axes approximately parallel to the tube tangential direction (called the TD or $\{11\bar{2}0\} <10\bar{1}0>$ component). The two components had similar volume fractions: 48% (on average) for the TD component and 39% (on average)

for the RD component [8]. When a specimen of the present type is subjected to circumferential tension, there is contraction along the thickness and extension along the circumferential directions. These are parallel to the c-axes of the RD and TD texture components, respectively. Thus the RD component grains in the RHTT samples are ideally oriented for contraction and double twinning, while the TD component grains are orientated for extension twinning. This was confirmed with the aid of EBSD maps, as displayed in ref. [8].

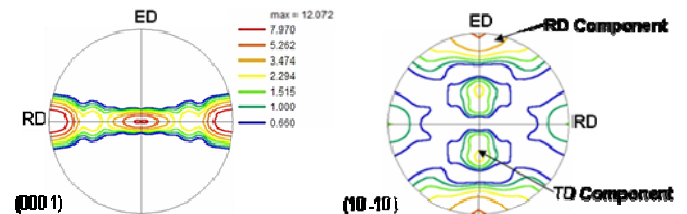


Figure 2 Textures of the as-extruded AM30 tubes; ED=extrusion direction, RD=radial direction.

RING HOOP TENSION TESTING

Microstructures

The microstructures developed during RHTT at 200°C/0.1s⁻¹ and various strain levels are shown in Fig. 3. The presence of twins can clearly be seen, but the distribution is not even. At a strain of 0.04, some grains are almost fully twinned while others remain unchanged. In addition, within particular grains, many parallel twins have already coalesced. On further straining to 0.08, significant twin coalescence has taken place. On the other hand, some of the previously untwinned grains are now observed to contain thin straight twins (identified by the black arrows). At a strain of 0.15, the number of grains containing thin straight twins has increased. However, except for the thin straight twins, essentially all the other twins have now impinged on each other and coalesced. In addition, some thin straight twins (identified by the dotted black arrows) are observed in some of the fully twinned grains, where twin boundary remains can still be seen. These thin straight twins are $\{10\bar{1}1\}$ contraction and $\{10\bar{1}1\} - \{10\bar{1}2\}$ double twins,

Since the critical shear stress necessary for activating $\{10\bar{1}2\}$ extension twinning is much lower than that for $\{10\bar{1}1\}$ contraction twinning (2-4 MPa vs. 76-153 MPa) [4], when both types of twins can form, $\{10\bar{1}2\}$ extension twinning will take place first in the TD component grains. The RD component grains will not experience contraction and double twinning until the local stress reaches a value necessary for contraction twinning. Therefore, during the early stages of straining, most of the RD component grains remain unchanged.