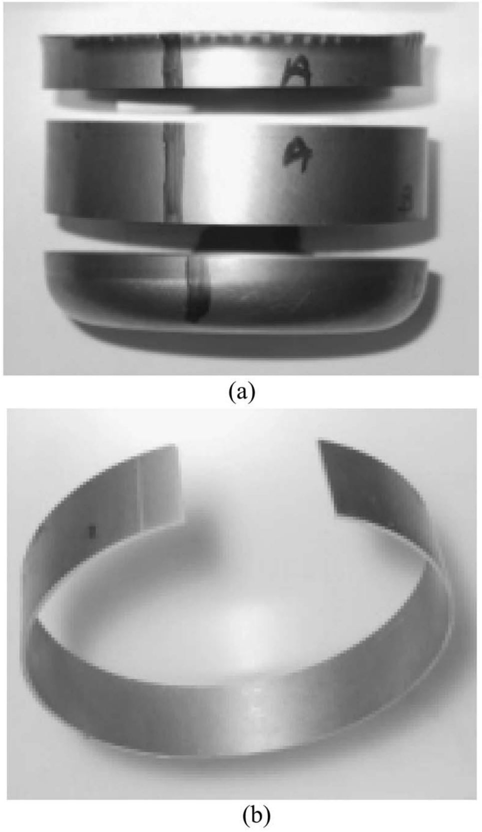
Residual Stresses in an Al6022 Deep Drawn Cup

T. Gnaeupel-Herold,[1,2] H. J. Prask,[2] U. Lienert[3]
[1]Department of Materials and Nuclear Engineering, University of Maryland, College Park, MD, U.S.A.
[2]Center for Neutron Research, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A.
[3]Advanced Photon Source, Argonne National Laboratory, Argonne, IL, U.S.A.

Introduction

The stamping of sheet metal induces complex deformations, which can have vastly different accumulated plastic strains in different regions of the sheet metal. Upon unloading by removing the die, springback occurs, which changes the dimensions of the part. Springback is caused by nonuniform residual stresses through the thickness of the sheet metal. They create a bending moment that causes a distortion of the part upon unloading. The accurate prediction of springback is of major interest with regard to small part tolerances and to avoid a costly redesign of the stamping tool. Experimental data on springback stresses are scarce in the available literature; instead, most publications deal with the modeling aspect of the problem. Thus there is a need for data that can benchmark the model predictions.


(a)

(b)

Fig. 1. Sectioned cup (a) and split ring (b).

In an attempt to simplify the problem, various studies have dealt with symmetric, generic shapes, among which circular cups have received the most attention [1-6] as a promising way to characterize a material's springback properties in a quick and consistent way. The main advantage of such a simple geometry is that the springback can be measured very easily by cutting off rings and subsequently splitting them.

For this characterization to also be useful for nongeneric parts with more complicated strain paths, the successful simulation of the springback must be based on an accurate prediction of the depth distribution of stresses. However, because of the small thicknesses involved, a pointwise stress measurement to validate the models has been very difficult. Few studies provide even approximate experimental results. To avoid the difficulties associated with destructive stress determination, there is no alternative to diffraction methods, either as neutron or as synchrotron diffraction. In practice, synchrotron diffraction is basically the only method capable both of penetrating 1 mm of aluminum and providing spatial resolutions of <0.1 mm. Here, we describe the results of such measurements on an intact and a split-ring cut from an Al6022 cup. The investigation included measurements of axial and tangential stresses on different axial locations and around the circumference.

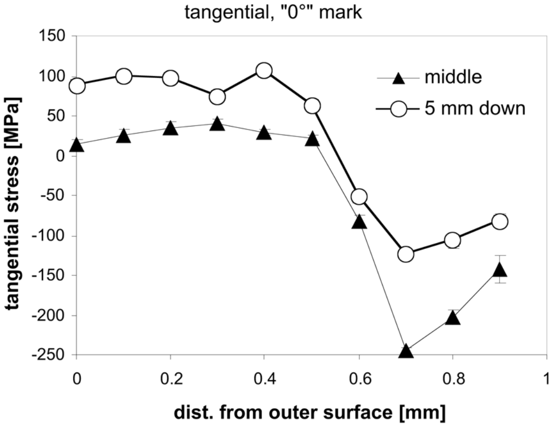
Methods and Materials

A ring that was 110 mm in diameter, 15.0 mm in height, and 0.92 mm in wall thickness was cut by electrical discharge machining (EDM) from the center section of a deep-drawn cup (Fig. 1). The procedure was then repeated on a second cup made under the same forming conditions, and the ring was split open. On the intact ring, through-thickness measurements were performed on two axial locations, one in the middle of the ring and the other 5 mm toward the cup bottom. On the split ring, measurements were performed in the middle, 4.5 mm toward the top, and 5 mm toward the bottom. The measurement locations around the circumference (intact: 0°, 180° = rolling direction [RD]; split: 90° = transverse direction, 180° = RD) were set with respect to the rolling direction of the original blank material.

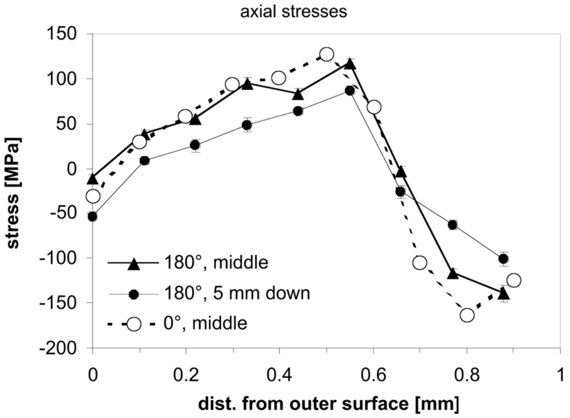
In sheet metal forming, one has to deal with plane stress states for which the normal stress can be safely set to zero everywhere. This allows the use of a scheme in which an estimate for the unstressed d-spacing is sufficient.

Despite the relatively low photon energy of 20 keV, the high intensity of the primary beam allowed the use of the Al(422) sample reflection, thus increasing the Bragg angle 2θ to approximately 44°. This choice decreases the notorious “diamond” distortion of the sampling volume and maintains the nominal spatial resolution. In order to minimize the intrinsic blurring of the shape of the sampling volume due to cold-work-induced peak broadening, a Si(111) analyzer crystal was used to restrict the acceptance angle of the detector. The typical uncertainty of the peak position was $\leq 5 \times 10^{-5}$.

Despite the small sampling volume (≈ 0.003 mm^3) and the fact that aluminum alloys virtually always contain large grains, the intensity fluctuations of the reflected peak were within 62% of the average for the same orientation but different locations.



(a) tangential



(b) axial

Fig. 2. Comparison of stresses in the intact ring.

Results and Discussion

We have investigated the depth distribution of axial and tangential stresses in both the intact and the split ring. The change of the tangential stresses with the axial position has been pointed out in the literature [1-3]. In this case, we found a difference of appoximately 50 MPa over an axial distance of 5 mm, increasing from the mid-line toward the cup bottom. The intact ring is not in the tangentially unloaded state, and the stress distribution is analogous to that of a plastically bent beam in a loaded configuration. The through-thickness axial stresses, on the other hand, show little change in the axial direction (Fig.2).

The comparison of the axial stresses in the ring middle and 5 mm down shows a gradient of about 5 MPa per millimeter of decrease toward the bottom. Otherwise, the stresses in the ring middle, at both the 0° and the 180° mark, are almost identical. This was the case for the tangential stresses, thus confirming the accuracy of the data. The axial stresses show a behavior similar to that of the tangential stresses, but they are well balanced, with the resulting axial bending moment being ≈ 0. This is a consequence of cutting the ring from the cup bottom, thus setting the axial bending moment to zero everywhere in the ring.

Splitting the ring partially releases the tangential stresses. It also resets the total tangential bending moment to zero, which is analogous to an unloading in the example of a plastically bent beam. By averaging the measured tangential stresses from all locations, we can estimate the total tangential stress change from the intact ring to the split ring, which is shown in Fig. 3.

This stress change can be used to calculate the radius of the split ring. It was found to be within 3% of the measured radius. When we keep in mind that diffraction

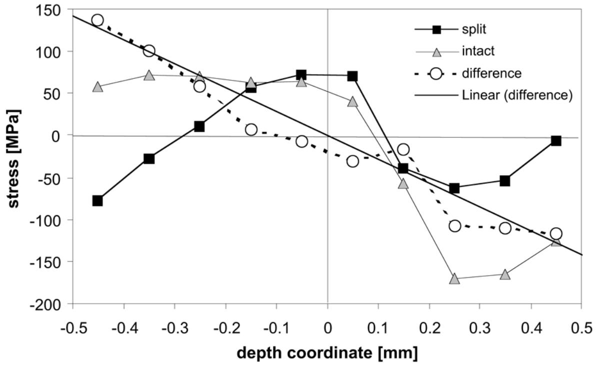


Fig. 3. Average tangential stresses in the intact and split ring as well as the difference between them plotted. The linear regression line is the average stress change from the loaded configuration to the unloaded configuration.

can inherently measure only elastic strains, we find that within the accuracy of the measurement (the standard error of the intercept is 8%), there is no indication of plastic recovery that would appear as a difference between the calculated radius (purely elastic, calculated from through-thickness stress) and the measured radius of the split ring. The latter contains both the elastic effect and the plastic recovery.

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