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EFFECT OF PLASTIC STRAIN ON MODULUS AND SPRINGBACK PREDICTIONS OF AN ALUMINUM ALLOY

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ABSTRACT: This paper examines the hypothesis that the under-prediction errors of current finite element analysis (FEA) springback models would be eliminated by the inclusion of changes that occur in the elastic modulus with the large plastic strains of forming. This hypothesis was evaluated by comparing the results of an FEA model that used either a constant elastic modulus or a modulus with plastic strain dependence determined from experiments, to laboratory springback measurements. This comparison found that the measured decrease in the elastic modulus with plastic strain was insufficient to fully explain the springback prediction errors.

INTRODUCTION: One of the most vexing problems facing the automotive industry in their move toward increased utilization of lower density and higher strength materials is springback. This industry is using finite element analysis (FEA) models to address this problem, but the current models consistently under-predict the observed springback. The alloy and strain dependent nature of these errors indicates that a property of the formed material is responsible. Recently, several investigators have reported observing a decrease in the elastic modulus of different alloys with plastic strain and some have concluded that inclusion of this plastic strain-dependence of the elastic modulus into FEA models would eliminate these errors in springback predictions (Morestin and Boivin [1996], Cleveland and Ghosh [2003] and Luo and Ghosh [2003]). The fact that the elastic modulus of metals and alloys decreases slightly with plastic strain has been known and studied for decades (Smith, [1953], Nowick, [1957]). However, this effect is usually neglected in elastic models because it is small compared to other sources of uncertainties (e.g. geometry, composition, texture). Of course, these errors can be eliminated by using either an elastic modulus back-calculated from trials or adjustable parameters determined from trials; but, these approaches do not identify the physical origins of the errors or a property measurement that would enable accurate predictions in the future. Therefore, the objective of the present study was to evaluate this hypothesis for the origin of these errors.

PROCEDURES, RESULTS AND DISCUSSION: This hypothesis was evaluated by comparing the results of an FEA model that can make springback predictions with either the traditional assumption of a constant elastic modulus or with a plastic strain dependent elastic modulus, to springback measurements. The springback measurement method selected for this model was that of a 3-point bend test (ASTM E 855-90) modified for springback measurement as shown in Fig. 1(a). This figure includes the three sample sizes and loading geometry. The modifications to this experiment that enabled measurement of springback consisted of: (i) rapid loading and unloading of the sample with closed-loop control of loading grip position, (ii) plastic deformation of the sample (≈ 20 degree total bend angle), and (iii) measurement of sample position independent of the loading grips. Since the objective was to evaluate the physical origin of the under-prediction errors, Al alloy 5052 was selected for this investigation because Dayan et al. [2003] had recently determined the variation of the elastic modulus of this alloy with plastic strain. A commercial FEA code and 3-D solid element were used for this simulation. The plastic deformation was modeled by the J_2 flow plasticity theory with isotropic hardening. The same stress-total strain curve was input for both the constant modulus and the plastic strain-dependent modulus cases. A user-defined subroutine (USDFLD) was used to extract the plastic strain dependent elastic modulus.

Fig. 1(b) shows the force and displacement measurements for unloading in a typical experiment. This figure also includes a line for the linear elastic prediction calculated from the analytical relationship for bending and a handbook value for the modulus. This prediction underestimated springback by ≈ 22 % which is in the range of FEA under-prediction errors for Al alloys. The FEA predictions for an assumed constant modulus come very close to the elastic prediction of the equation in Fig 1. The equivalent plastic strain distributions determined by the FEA model for the two different types of modulus behavior are shown in Fig. 2. Because the plastic strain in these 3-point bend experiments is limited, the calculated differences between strain-independent and plastic strain-dependent cases are not immediately obvious. However, close examination of this figure will show that the equivalent plastic strain determined using a constant elastic modulus is slightly larger than that determined for the plastic strain-dependent modulus. The corresponding elastic strain distribution was smaller for the assumption of a constant modulus than that determined including the plastic strain dependence. Since springback is determined by the elastic strain distribution and the modulus, this distribution will influence springback. Fig. 3 shows the difference between the displacements calculated for the two types of modulus behavior for the three sample sizes used during force controlled experiments and Fig. 4 shows the force difference for displacement controlled experiments. By examining these figures, it can be seen that while plastic strains are small, there is no difference for the two types of modulus behavior. However, once plastic strains become significant, deviations are observed. For force-controlled experiments, the displacements are larger for the constant modulus case while for displacement control the constant modulus case yields smaller forces. However, in all cases the differences are too small to explain the observed under-prediction errors.

CONCLUSION: Since an FEA model using the best available data on the plastic strain dependence of the elastic modulus was unable to fully describe springback measured in a laboratory experiment, it is concluded that while this effect will contribute to springback prediction errors, that some other phenomena are also making significant contributions.

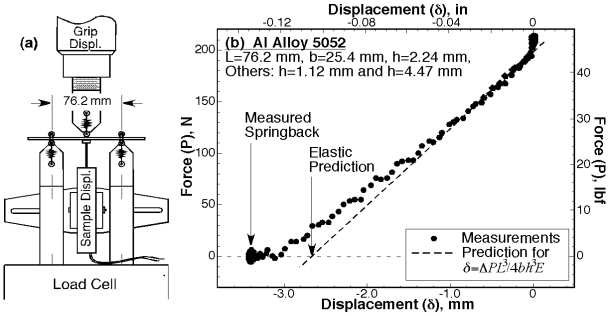

Fig.1 Three-point bent experiment and measurements.

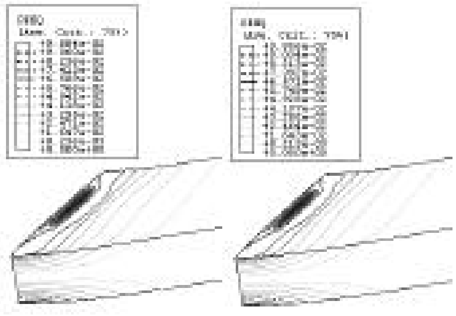

Fig. 2 Plastic strain distribution for constant and strain-dependent modulus.

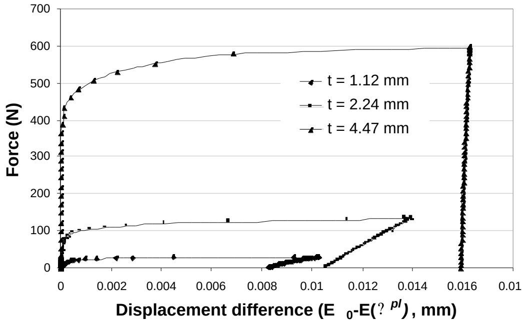

Fig.3 Difference in the displacement for constant and strain-dependent modulus for three sample thicknesses. (force control).

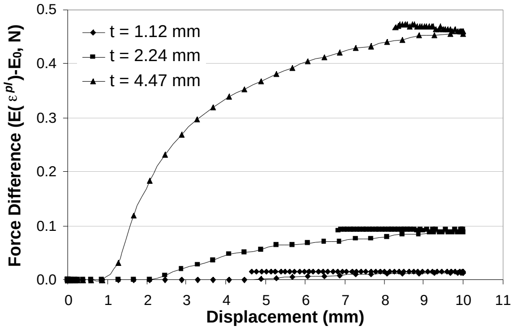

Fig.4 Difference in the force for strain-dependent and constant modulus for three sample thicknesses (displ. control).

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