NON-PROPORTIONAL DEFORMATION PATHS FOR SHEET METAL—EXPERIMENTS

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ABSTRACT- A biaxial sheet testing device was developed that prescribe arbitrary strain paths as a combination of plane strain tension and simple shear. In this way orthogonal strain paths changes with and without unloading can be obtained as well as cyclic shear loading with combined stretching. This relatively simple strain path yields interesting results in stress space when the stress crosses through the elastic domain.

INTRODUCTION: Sheet metal forming often includes biaxial in-plane deformation with non-proportional strain paths. E.g. in deep drawing of a cylindrical cup, the deformation in the flange is dominated by pure shear deformation, while it changes to plane strain when the material is drawn in into the wall area. Nontheless, only uniaxial tensile tests are commonly performed to characterize the material.
For biaxial testing of sheet material a biaxial testing device was developed at the University of Twente in the 1990's (Pijlman et al. [1999]; Pijlman [2001]), in which a specimen as depicted in Figure 1 can be loaded in plane strain tension and in simple shear. Both types of deformation be imposed independent of each other, facilitating both proportional and non-proportional loading. The lower and upper parts of the sample are clamped, leaving a deformation region of 45×3 mm. The height of the deformation area is small with respect to the thickness in order to apply simple shear without buckling. The tensile stress and shear stress are determined from force sensors on each actuator. The deformation is determined from the positions of 16 black dots that are applied to the surface of the specimen and which are tracked on-line by a digital camera (van Riel [2009]).

PROCEDURES, RESULTS AND DISCUSSION: In this section a cyclic shear experiment under increasing plane strain tensile deformation is described for a mild steel (DC06). Three tests were performed in which the amplitude of the shear strain was varied, see Figure 2. In test 1 the contribution of the shear deformation was dominant while for test 2 and test 3 the relative contribution of the tensile deformation was increased. In the first stage of the experiment, both the tensile and shear components follow an ordinary hardening curve. In stress space, Figure 2(c), the shear and tensile stresses do not increase proportionally. A

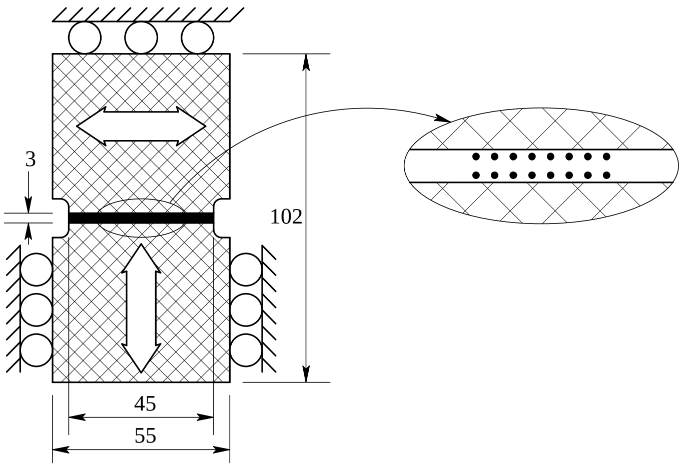
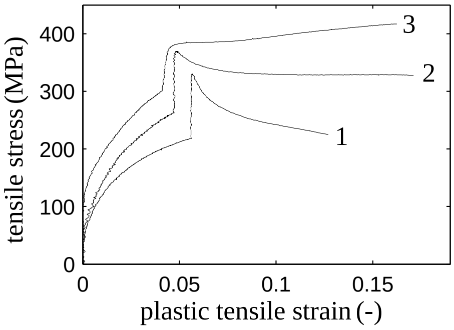


Figure 1: The shape and dimensions of the sample in mm. The black area represents the deformation area.

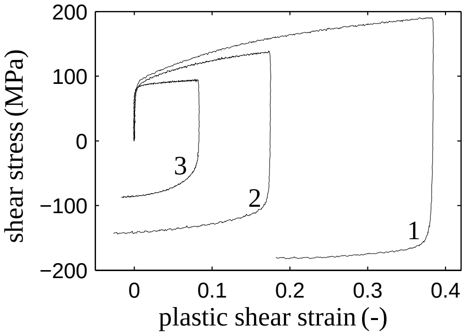
small kink is observed, which is due to the different mechanical properties of the material in the elastic and plastic regime, following Hooke's law and the normality rule respectively.

The reversal of the shear deformation results in a temporary elastic deformation. In stress space the stress cuts through the elastic domain, before it reaches the yield locus and deforms plastically again. In Figure 2(b) this shows as a drop to a negative shear stress. At the same time, the tensile stress increases with a jump of 120 MPa (Figure 2(a)). Because the stress state moves through the elastic domain, only a small increase in tensile and shear strain is observed during the strain path change. As the material becomes plastic again, the magnitude of the shear stress increases further due to work hardening (Figure 2(b)), but especially in experiment 1 the tensile stress drops further while the stress state becomes consistent with the new deformation direction, following the normality rule (Figure 2(a)). It was observed that the specimen did not show any sign of necking until this point. Experiment 3 has the largest contribution from the tensile deformation and shows a similar trend as experiment 1. However, in experiment 3 the tensile stress does not drop after the strain path change. Additionally, test 3 in Figure 2(b) shows that the elastic regime in the shear curve is relatively small. The stress path, Figure 2(c), shows that the supposedly elastic behaviour is not completely linear during the strain path change, which may be due to early re-yielding. Figure 2(a) and 2(b) show that at the end of experiment 3, the regular stress curve is resumed and again dominated by the tensile deformation. Experiment 1 fails before this trend is observed. Experiment 2 falls in-between tests 1 and 3.

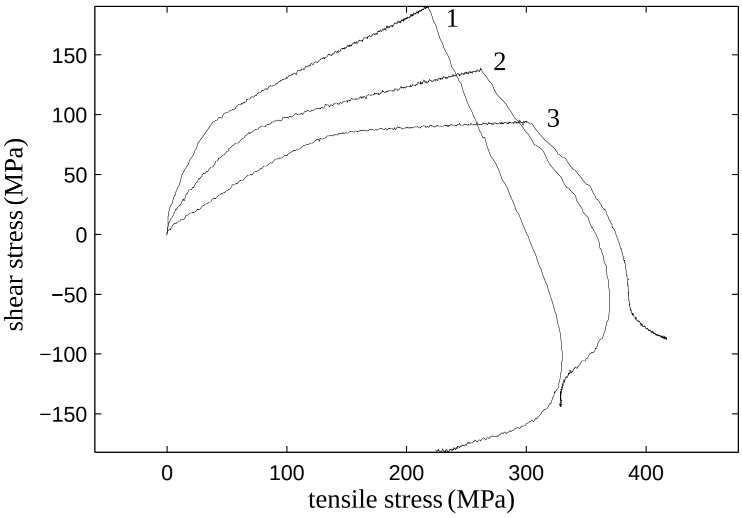
CONCLUSIONS: Experiments with combined reversed shear under tensile loading show the mechanical behaviour when a strain path is prescribed that in general is not used for the fitting procedure of material models. It can be used for an independent validation of material models. The TWENTE BIAXIAL TESTER is especially suited for this research since it allows for an independent control of plane strain and shear deformation.



(a) The tensile stress–strain component.



(b) The shear stress–strain component.



(c) The followed stress paths.

Figure 2: 3 different ratios of combined tension–simple shear experiments on DC06.

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