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An experimental and numerical investigation of different shear test configurations for sheet metal characterization

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ABSTRACT

Simple shear tests are widely used for material characterization especially for sheet metals to achieve large deformations without plastic instability. This work describes three different shear tests for sheet metals in order to enhance the knowledge of the material behavior under shear conditions. The test setups are different in terms of the specimen geometry and the fixtures. A shear test setup as proposed by Miyauchi, according to the ASTM standard sample, as well as an in-plane torsion test are compared in this study. A detailed analysis of the experimental strain distribution measured by digital image correlation is discussed for each test. Finite element simulations are carried out to evaluate the effect of specimen geometries on the stress distributions in the shear zones. The experimental macroscopic flow stress vs. strain behavior shows no significant influence of the specimen geometry when similar strain measurements and evaluation schemes are used. Minor differences in terms of the stress distribution in the shear zone can be detected in the numerical results. This work attempts to give a unique overview and a detailed study of the most commonly used shear tests for sheet metal characterization. It also provides information on the applicability of each test for the observation of the material behavior under shear stress with a view to material modeling for finite element simulations.

1. Introduction

During sheet metal forming operations, materials are subjected to high shear stresses (Bae and Ghosh, 2003). Sheet metal characterization under shear loading is therefore an important method to obtain reliable material data for a numerical process design of sheet metal forming operations. Nowadays, the parameters of the needed constitutive laws are determined by standard material characterization methods, such as the standardized uniaxial tensile test. With a view to modern and complex constitutive laws, as for example presented by Barlat et al. (2003) or Banabic (2010), the parameter identification using uniaxial tensile tests is insufficient for their description; further experimental setups generating different load cases need to be considered. In order to identify additional material parameters, many studies of the constitutive behavior during shear deformation, especially for the examination at large strains, were made by Rauch (1992). Bouvier et al. (2006) analyzed the homogeneity of the shear zones depending on the geometric ratio of the shear gauge. They recommended a ratio of 10:1 for the shear bridge length to height in order to maximize the homogeneous part. Kang et al. (2008) compared the results of shear tests to uniaxial tensile results, demonstrating good agreement. The isotropic and kinematic hardening behavior can be observed in cyclic shear tests without changing the testing device or the sample geometry. Various experimental approaches and specimen geometries are suggested in literature. This work presents a comparison of three representative shear test setups: the shear test originally proposed by Miyauchi (1984), the standardized test according to ASTM B831 (ASTM, 2005), and the twin bridge shear test as described in Brosius et al. (2011). We present the experimental analysis of strain distributions and the resulting

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flow curves for an interstitial free steel. Furthermore, we discuss a numerical study of the stress state.

2. State of the art

2.1. Sheet metal characterization

Various testing methods for the characterization of the plastic behavior of sheet materials are established today. Fig. 1 schematically shows some well-known tests and the corresponding stress states in the $\sigma_1 - \sigma_2$ plane. The yield locus can be divided into four quadrants. The first quadrant represents the biaxial tensile stress states, while the third quadrant corresponds to biaxial compression. Shear deformation with one tensile and one compression stress component is located in the second and forth quadrants. The simple tension test can be found on the positive half of the axes. Due to its simplicity and the homogeneous stress and strain distribution, this test is considered as a standard test for many applications. The maximum achievable strain is limited by necking, which occurs for normal sheet metals at an equivalent strain of 0.2–0.3 or even below. On the compression side, the uniaxial compression test bears many difficulties for sheet materials due to their tendency to buckle. This issue is particularly important for applications of cyclic loadings as shown by Cao et al. (2009). Different testing methods are applied to study biaxial tensile stress states: the hydraulic bulge test (Panknin, 1959), the biaxial tensile test (Hannon and Tiernan, 2008) and the stack compression test (Merklein and Kuppert, 2009). Biaxial compression represents the highest difficulty for sheet metal testing. Zillmann et al. (2011) have recently proposed a new test setup using very small quadratic specimens and an optical strain measurement to further analyze this load case.

Shear tests are a convenient way to characterize materials under shear loadings. Hardening curves can be recorded without limitations inherently associated with friction, buckling or necking. Numerous different specimen geometries and testing devices have been proposed for shear testing. Iosipescu (1967) presented a *V*-notched geometry which was further developed and, for example, documented in the ASTM D5379 standard (ASTM, PA). G'Sell et al. (1983) and Rauch and G'Sell (1989) introduced a plane shear test for polymer or metallic sheet materials. This test allows the setting of the principal stress axes in rolling and transverse directions of the sheet. Due to the inhomogeneous strain distribution induced by edge effects, (Bouvier et al., 2006) suggested to increase the ratio of length to width in order to generate a larger central area. Miyauchi (1984) suggested a specimen with two shear gauges and three clamping areas. By a translational movement of the inner area parallel to the outer clamps, both shear gauges are deformed symmetrically, which reduces the rotation moment on the machine. An et al. (2009) compared two Miyauchi-type specimens with rectangular shape and slit shape of the shear zones. For rectangular geometries, the strain distribution is quite homogeneous in the majority of shear length of specimen, while for specimens with slits, the strain distribution is rather inhomogeneous across the larger part of the shear length. The ASTM standard B831–05 (ASTM, 2005) describes a shear specimen that can be directly used in uniaxial testing machines because of its simple geometry. Diagonal slits are arranged on a sheet strip so that a small zone is sheared when tensile loads are applied. Shouler and Allwood (2010) also studied the fomability of sheet materials using shear specimens. While shear tests are commonly conducted using a translational displacement, torsion also leads to simple shear deformation. Marciniak (1961) proposed the in-plane torsion test for sheet metal testing, which was further developed by Pöhlandt and Tekkaya (1985) and Bauer (1989). Recently, a shear test using the in-plane torsion kinematics was also suggested by Brosius et al. (2011): the so-called twin bridge shear test. In the remainder of this paper, we focus on three approaches for shear testing: the Miyauchi shear test, the shear test according to ASTM B831 and the twin bridge shear test using in-plane torsion.

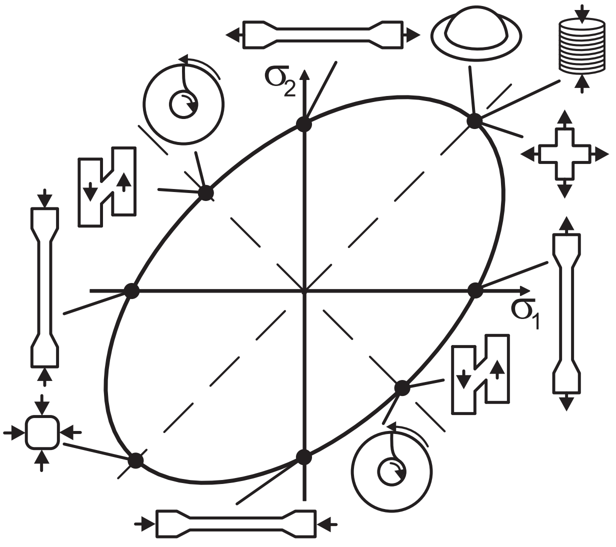

Fig. 1. Overview of testing methods for sheet metal characterization.

2.2. Miyauchi shear test

Miyauchi (1984) proposed a simple shear test with two shear zones, Fig. 2. The specimen has three bars that are all clamped, and that are connected by the regions that represent the two shear zones. When a tensile load is applied to the middle bar, the connecting regions will be deformed by shear deformation. This geometry reduces the rotation of the shear zone during loading. However, while this approach provides a work-around for the rotation of the shear direction, it creates a different rotation of the principal stress directions in the two shear zones during deformation. As a consequence, an anisotropic material response may be partially averaged out and may probably not be fully represented by the experimental data. The slits in the specimen help to reduce the premature failure due to stress concentrations on the edges. The geometry of the specimen, especially the length of the shear zone, can affect the measured work hardening, as investigated by An et al. (2009), where two different geometries were used. An et al. (2009) recommended the rectangular specimen since the strain distribution in the shear zone is quite homogeneous. The

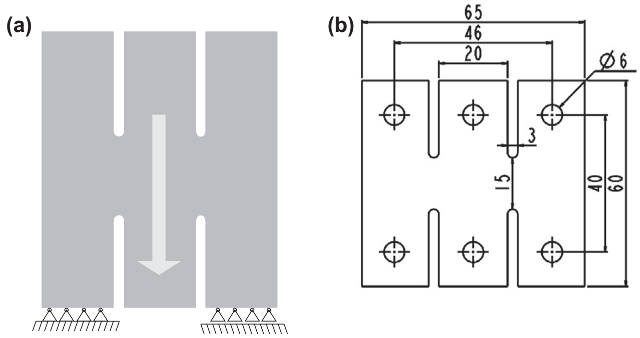

Fig. 2. Schematic representation of the (a) Miyauchi test setup and (b) specimen geometry proposed by Zillmann et al. (2012). The arrow indicates the direction of force.