

# From Quasi-Static to High Strain Rate In-Plane Torsion Experiments of Sheet Metal

V. Grolleau<sup>1,2,a</sup>, X. Colon<sup>1,2</sup>, B. Galpin<sup>1</sup>, C.C. Roth<sup>1</sup> and D. Mohr<sup>1</sup>

<sup>1</sup>Department of Mechanical and Process Engineering, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland

<sup>2</sup>Univ. Bretagne Sud, UMR CNRS 6027, IRDL, F-56100 Lorient, France

<sup>a</sup>vgrolleau@ethz.ch

## Introduction

During forming operations, large strains make the numerical simulation challenging. In recent years, new devices have been developed to characterize material response at large strains, while some more established tests have been enhanced. Amongst those are the sequential simple shear test [1], the in-plane torsion test [2, 3], and the bulge test.

Simple shear tests are usually carried out with devices using rectangular specimens [4]. This type of device has limitations due to the slipping of the specimen in the jaws and the effects of free edges limiting the engineering shear strain values to about 0.5 and hindering simple shear failure studies. Even if the strains are limited, it is possible to perform cyclic tests and characterize the Bauschinger effect. To achieve failure under a shear stress state, optimized specimen geometries are necessary, e.g. [5].

The problem of pre-mature fracture from the edges can be avoided when using an in-plane torsion experiment of a disc shape specimen. The in-plane torsion specimens have evolved since their first introduction by Marciniak [6]. Initially, the specimen was flat, leading to strain localization at the inner clamping. A circular groove was introduced by Yin et al. [7], with the purpose of locating the shear strains away from the inner part and reducing the required torque.

## Experimental set-up

The device used in the present study was presented by Grolleau et al. [3]. The torque is transmitted by a central shaft and a series of radial teeth connected to corresponding grooves machined on the specimen's inner clamping surface, see Fig. 1. A single nut is used to apply the clamping load to the specimen. Thanks to this system, Digital Image Correlation (DIC) can be performed using a single camera all along the circumference of the specimen (25Mpx size, 1 Hz, pixel size about 10 $\mu$ m/px).

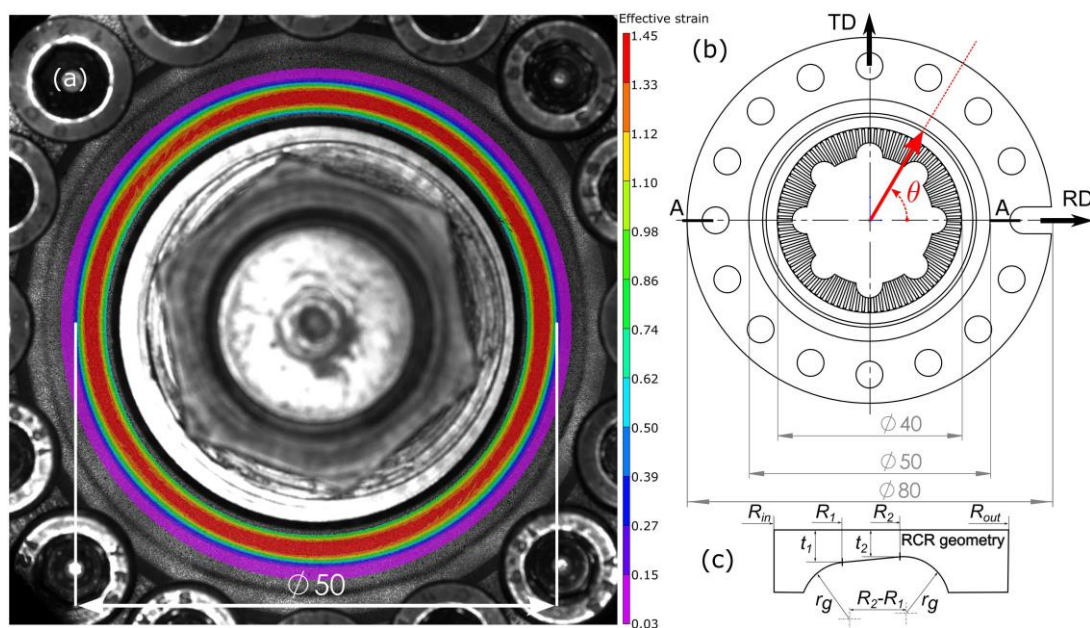


Figure 1. (a) Effective strain field extracted from DIC analysis of the torsion test performed on DC01 steel. (b) design of the in-plane torsion specimen, (c) partial cross-section cut along A-A line focusing on the groove.

A hydraulic motor is used to apply a rotation speed of about 0.025°/s to the driving shaft for quasi-static tests, leading to a strain rate of about 0.001/s.

A 5 meters long Hopkinson torsion bar is used to perform high strain rate experiments. The bar is 40mm in diameter, and made of high-strength steel. A schematic of the high-strain rate device is presented in Fig. 2.

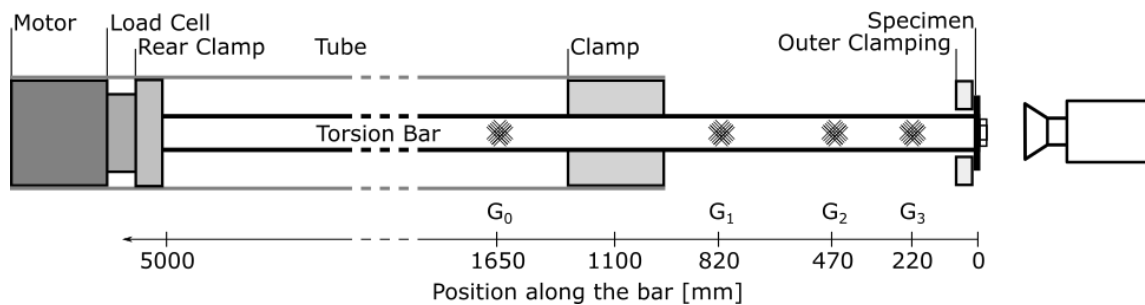


Figure 2. Schematic view of the high strain rate in-plane torsion device

A preloading-hydraulic motor is positioned at one end of the bar, while the specimen is clamped at the other end. At about 1 meter from the specimen, a clamp enables the preloading of the bar as well as the fast release of the preloaded section of the bar, leading to the propagation of the incident wave toward both ends of the bar. When the incident wave reaches the specimen, the high strain rate in-plane torsion starts, and ends with the fracture of the specimen or the arrival of the reflected wave from the other end of the bar after about 4ms, the maximum duration of the test. The bar is equipped with 4 torsion strain gauge full bridges, enabling the calculation of the loading torque of the specimen using a deconvolution algorithm. A high-speed camera is used to record the images of the specimen surface for DIC purposes, at a frequency of 80kHz and a size of 256x688 pixels focusing on one-quarter of the circumference, leading to a pixel size of about 100µm/px.

## Results

Quasi-static and high strain rate experiments are conducted on a 1.5 mm thick deep drawing DC01 steel at four different strain rates from 0.001 to 1000/s. Quasi-static tests are characterized by a nonhomogeneous strain field along the circumference of the specimen, which is a direct consequence of the anisotropy of the sheet metal. The calculated fracture strains from DIC analysis of in-plane torsion tests agree with fracture strains obtained from simple shear experiments of the same material using an optimized ASTM-B831 type of specimen at different orientations from the rolling direction. The strain rate sensitivity calculated from the in-plane torsion experiments agrees with already published results.

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