The use of hat-shaped specimens for dynamic shear tests

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Abstract

Adiabatic Shear Bands (ASBs) are a thermodynamic characteristic phenomenon associated with deformations at high strain-rates and for large values of strain. The main mechanism is the competition between strain hardening and thermal softening. The formation of ASBs causes the material to lose its load carrying and energy absorption capacity [1]. Adiabatic shear bands are observed in many applications such as machine chips, forging, ballistic impact loading and fracture. In most cases the occurrence of adiabatic shearing is undesirable. On the other hand, recently developed adiabatic cutting and blanking techniques make explicitly use of the ASB phenomenon.

In the past, a dozen of experimental techniques have been developed to characterize the process of ASB formation. This contribution focuses on one technique which is based on the dynamic deformation of hat-shaped specimens in a split Hopkinson pressure bar (SHPB) setup. In the last two decades, hat-shaped specimens have been used to investigate the shearing behaviour and the formation of adiabatic shear bands [2-6]**.** Due to the specific geometry of the hat-shaped specimen, shear strains are concentrated in a narrow region where adiabatic shearing is likely to occur.

This technique is especially interesting for metallurgists because even materials that do not localize spontaneously in shear can be forced up to shearing failure. On the other hand, determining material properties from these experiments is not straightforward because of the complex stress state in the shearing region. Furthermore, the initiation and propagation of adiabatic shear bands is affected by this stress distribution.

More insight in the stress distribution in the specimen is needed for a more comprehensive use of this technique. Furthermore, as the nucleation and propagation of ASBs depends on the stress condition [7], knowledge of the stress distribution is crucial. Moreover, several researchers used different specimen dimensions in their experiments. The outcome of these experiments is affected not only by the tested material but also by the specimen geometry.

The goal of this contribution is to relate the specimen dimensions with the stress distribution in the specimen. In addition, the existence of an optimal specimen geometry to achieve an as pure as possible shearing stress state, is studied. Both experiments and simulations are carried out.

In this work, the stress distribution and stress evolution in the specimen is examined by means of numerical simulations with ABAQUS/Explicit for TA6V and Ti-6Al-4V. A 2D axis-symmetric model has been defined, using ABAQUS/Explicit. The load is applied by a uniform velocity of the top-face of the specimen while the bottom-face is fixed. Strain-rate and temperature dependency of the material behaviour is modelled by

the Johnson-Cook phenomenological model. Heat, generated due to the plastic work is included. To overcome difficulties from extensive element distortion, ALE adaptive meshing is used. In some of the simulations, a shear damage criterion is used. Although the model is rate-dependent, mesh sensitivity of the simulations cannot be prevented by the current model. Moreover, since a phenomenological material model is used, the FE model is not capable of studying the shear band formation and propagation itself. Nevertheless, the predicted global specimen response can provide good agreement with experimental data.

Several slightly different geometries are simulated. The relation between geometry and global behavior of the specimen is studied. Attention is paid on the stress tri-axiality as well as on the ratio of the pressure to the shear stress in the shear region. The stress and strain homogeneity is also examined. It can be concluded that the specimen geometry and small imperfections have a major influence on the experimental results. Therefore, despite its simplicity, the technique with hat-shaped specimens is of rather limited use. A second purpose of these simulations is to find out whether it is possible or not to retrieve information about the shearing process from the signals in the Hopkinson bars. The shear stress can be estimated quite easily but on the other hand the shear strain is impossible to determine.

Hopkinson experiments and static experiments on a series of slightly different hat-shaped specimens of a Ti-6Al-4V alloy are carried out. The experimental results are compared with the simulations. In addition, Light Optical Microscopy (LOM) and microhardness measurements are used to investigate the shear region of the specimen after the experiment.

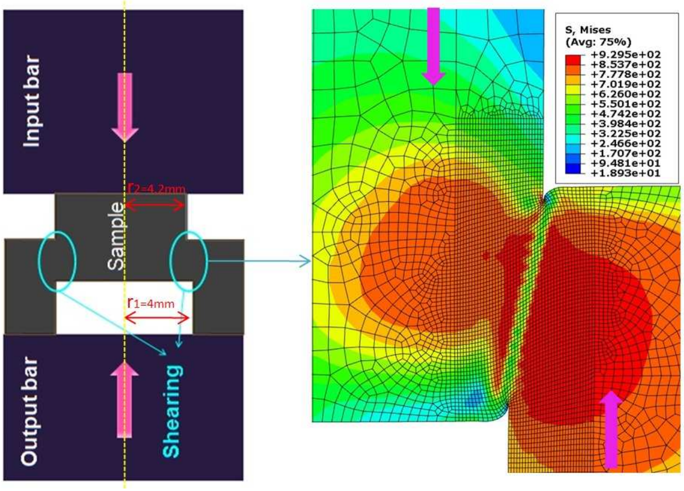

Figure 1: Principle of hat-shaped specimen testing and simulation

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