International Journal of Impact Engineering 74 (2014) 107–119

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

A critical analysis of plane shear tests under quasi-static and impact loading

F.F. Shi [a, b], R. Merle [b], B. Hou [a], J.G. Liu [b], Y.L. Li [a], H. Zhao [b, *]

[a] School of Aeronautics, Northwestern Polytechnical University, 710072 Xi'an, China
[b] Laboratoire de Mécaniqueet Technologie, ENS-Cachan/CNRS-UMR8535/Université Paris 6, 61 Avenue du Président Wilson, 94235 Cachan Cedex, France

ARTICLE INFO

Article history:
Available online 30 June 2014

Keywords:
Plane shear test
Sheet metals
Transient effect
Cumulated Eulerian strain
SHPB

ABSTRACT

This paper presents an extensive investigation of the real testing conditions of plane shear tests under quasi-static as well as impact loading. In particular, it aims at analyzing the role played by the empirical corrective coefficients commonly used in this kind of tests. For this purpose, a complete numerical model including not only specimen but also clamping device is built. Compared with usual simulations of only a shear specimen used to establish these corrective coefficients, the proposed complete numerical model permits to evaluate the influence of clamping device on the distribution of stress and strain fields. It shows that there are only limited effects under static loading, except for the early stage of loading (elastic part) where the stiffness of clamping device has to be taken into account. Under dynamic loading, a similar conclusion as the static case has been made. However, the transient effect due to the wave propagation within clamping pieces is rather important before an equilibrium state is reached. Numerical results indicate also that the shear loading on the specimen is mainly guided by the compressive wave in the massive clamping pieces, and the shear wave propagation inside the shear area is negligible. Besides, the way to calculate the equivalent strain from experimentally measured displacement is discussed. Eulerian cumulated strain, which is the default large strain definition in most commercial codes, should be used instead of the idealized small strain shear assumption. Finally, this work indicates that when the average value of equivalent stress in the whole shear area and cumulated Eulerian strain are used, commonly used corrective coefficients are no longer needed.

1. Introduction

Plane shear test is a complementary tool to the standard tensile tests for sheet metals. It can be used to verify or identify the plastic criterion of sheet metals. The shear test permits also to realize large strain loading (till 80%) while the tensile test fails to attain such a strain level because of geometric instability. The pioneer work in this domain was due to Iosipescu (1967) [1]who introduced the in-plane single shear fixture for sheet metals under quasi-static loading. Such a fixture was afterwards applied to polymer testing [2] and composites testing [3]. The well-known Arcan fixture [4] to generate in plane combined tension-shear was also quite close to this basic concept. A double plane shear test was reported in the literature in order to increase the stability of clamps [5].

Under dynamic loading, shearing tests were initially performed by Campbell and Ferguson (1970) [6]. They put a double-notched specimen directly in contact with an input Hopkinson bar and an output Hopkinson tube. However, a small double-notched specimen (gage length of 0.8 mm) was used because of the small size of Hopkinson bars. It leads to an important error due to the non-homogeneous shear strain and also to the severe plastic deformation of the specimen supports. Modifications of the specimen geometry in order to reduce testing error was also reported [7] but with a limited improvement because the gage length is fixed.

In order to overcome this difficulty and to adopt a bigger specimen as used in most quasi-static cases, an additional co–axis clamping device is designed and placed in between a large diameter Hopkinson bar system. This technique was initially reported by Klepaczko et al. [8] and Gary and Nowacki [9]with respectively 30 mm and 40 mm diameter aluminum bar. This new technique offered rather good result provided that there is no impedance jump between clamping device and the Hopkinson bars and the wave dispersion effect is well taken into account in the data

* Corresponding author.
E-mail address: zhao@lmt.ens-cachan.fr (H. Zhao).

http://dx.doi.org/10.1016/j.ijimpeng.2014.06.012
0734-743X/

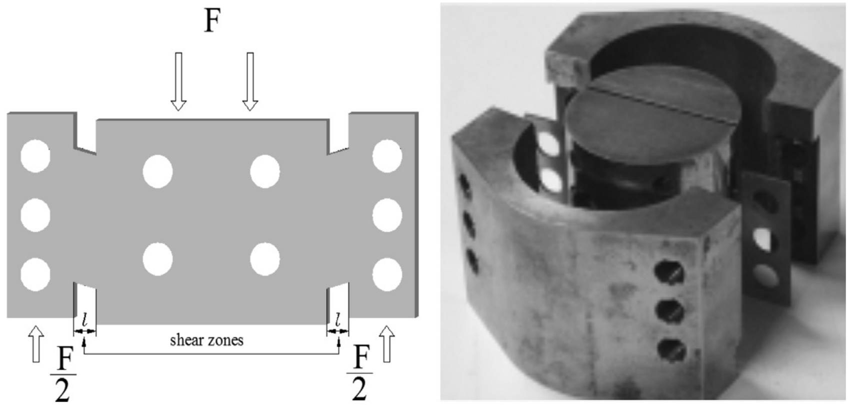

Fig. 1. Double shear specimen and clamping device.

processing. Even larger system (60 mm diameter Hopkinson bar + clamping device) was also reported and it is proven that the plane wave assumption is still valid in this case [10].However, with this new possibility of shear specimen geometry, it is still necessary to respect the limitation of the thickness/width ratio as well as width/length ratio of the shear area to prevent the buckling and instabilities [11]. Finally, the specimen geometry with 3 mm shear area was chosen in all aforementioned studies but a quasi-homogeneous state is not achieved yet.

Rusinek and klepaczko [12]performed a numerical analysis of the shear area to evaluate the homogeneous state level of the strain and stress fields in the shear area and found that they were not as homogeneous as expected. The non-homogeneous strain field was also experimentally proven by the successive digital image correlation measurement [13]. Besides, this simulation showed a significant gap between the prescribed constitutive law and the stress–strain relation obtained from simulated forces and displacements. Thus, coefficients (which is a function of the shear strain level) based on numerical simulations were proposed to fill in the gaps in stress as well as the strain. Such a concept of corrective coefficients is still used nowadays [14].

Nevertheless, such a ‘state-of-art’ is not satisfactory for many reasons. Actually, the numerical reference is a model with only a shear specimen. The stiffness of the clamping device is not taken into account, especially for the impact loading where the transient effect in the clamping device is not clear at all. Another possible discussion lies in the usual formulas relating forces and displacement to the shear stress and strain, especially under large strain. The present paper aims at a more complete analysis of the experimental conditions of this plane shear test. After a brief description of the plane shear testing arrangement as well as the commonly used formulas for stress/strain calculations, a complete numerical model (clamps + specimen) is proposed to evaluate the influence of the stiffness of the clamps in quasi-static and impact loading cases. An analysis of large strain deformation is also developed and it leads to the natural cancellation of corrective coefficients of strain.

2. In-plane double shear tests

2.1. Basic testing arrangement

The double plane shear device is composed of two coaxial pieces made of high strength steel with a double-notched specimen. The inner rectangular part of the specimen is clamped by the inner coaxial part with griping teeth aligned on the border of the shear area. The two external rectangular parts of the specimen are clamped by the external coaxial pieces with griping teeth as well. When the two coaxial pieces move relatively, the two rectangular zones (width *l*) between inner and external coaxial pieces are sheared (Fig. 1).

Quasi-static tests can be simply performed by putting the clamped specimen into a classical hydraulic testing machine. Dynamic tests can be realized by placing the clamped specimen in between the two Hopkinson pressure bars. It is of course necessary to ensure that the inner and external clamping pieces have the same acoustical impedance that equals to the pressure bar's impedance to avoid spurious oscillations. In particular, the studied device is designed for aluminum bars with a diameter of 60 mm. Thus, the overall specimen size (Fig. 1, left) is of 60 mm long and 30 mm high. The clamping pieces have a length of40 mm. Technical details can be found in (Merle, 2006) [15].The schematic drawing of the whole system of impact testing is shown in Fig. 2.

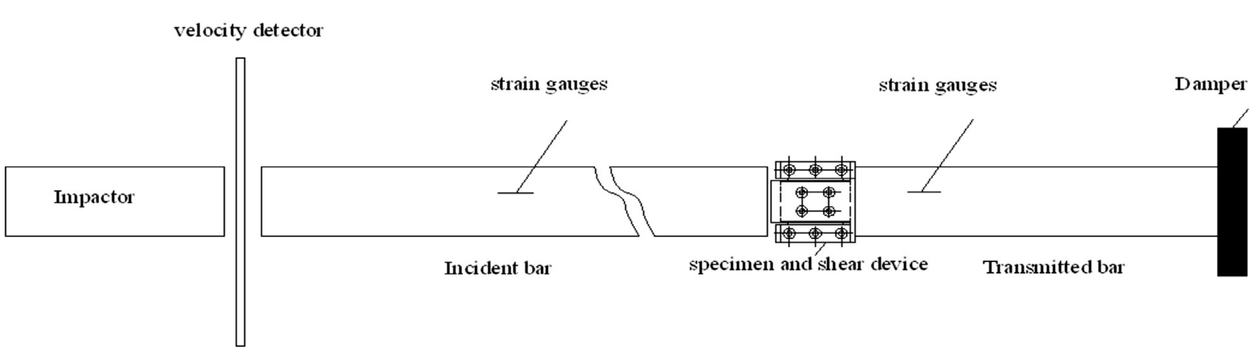

Fig. 2. Schematic drawing of Hopkinson bar and clamping device.