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Dynamic Fracture of Ductile Materials

An Experimental Technique For The Characterization Of Adhesive Joints Under Dynamic Multiaxial Loadings

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Abstract

This paper deals with experimental testing of adhesive joints, whose characterization under static loadings drove a large number of studies and techniques. However, few studies deal with dynamic loadings and most of them are limited to the characterization of the shear strength of the bonded assembly. Indeed, dynamic tests often rely on single or double-lap joint specimens that do not enable to investigate multiaxial loadings. This paper is dedicated to the development of an innovative experimental technique for the characterization of adhesive joints under dynamic multiaxial loadings. The experimental apparatus consists in a conventional Split Hopkinson Pressure Bar (SHPB), a newly designed specimen named DODECA and local measurements performed by Digital Image Correlation (DIC). The specimen conception and sizing are detailed with numerical computations as well as preparation procedures. One of the advantages of the proposed specimen is the possibility of testing three distinct multiaxial loadings with the same methodology. This new technique enables to measure strains in adhesive joints accurately with a dynamic loading.

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Keywords: Adhesive joints ; Hopkinson bar ; Dynamic loading ; Digital image correlation

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1. Introduction

Adhesive joints cover an increasing share of the bonding techniques applied in industrial structures. They have different advantages when compared to classical methods like riveting or welding, which stem from the possibility to combine a large range of materials, their intrinsic properties or the ease of deployment in manufacturing. Thus, systematic characterization methods should be established so that adhesive joints can be certified for critical structures. For many applications such as aircraft industry, a wide range of multiaxial loadings should be considered, from quasi-static to dynamic regimes. Numerous studies deal with quasi-static loadings [1, 2]. In dynamics, most studies use Hopkinson bar systems with the single-lap joint specimen [3] or the double-lap joint specimen [4] and measure only the shear strength of the bonded assembly. Although this type of specimen remains a good choice for studying dynamic shear in bonded assemblies, even if stress gradients can be high, these studies do not explore the multiaxial loading space and do not provide any local measurements.

To achieve multiaxiality in Hopkinson bar systems, there are two solutions: design new specimen shapes [5, 6] or use tensile/torsional Hopkinson bar systems [7]. It is much easier to explore the multiaxial loading space with the first solution. That is why the latter will not be developed. As already mentioned, dynamic testing of adhesive joints has been done only with lap-joint specimens. However, if the constraint of testing bonded assemblies is relaxed, the literature is much richer and a large number of specimen shapes have been invented in order to reach a well-defined stress state in a homogeneous material. CCS (Compact Compression Specimen) [5] makes it possible to obtain a multiaxial state with a large traction component and a low shear component at the crack tip. The advantage of this specimen is to create traction with a conventional compression Hopkinson bar system. Another example is the SCS (Shear Compression Specimen) [6] which enables the user to characterize 2 mm-thick polymer films under a biaxial stress state of compression and shear. Finally, the BD (Brazilian Disk) specimen is very well-known and allows us to test infinite number of stress states. It has been widely used with Hopkinson bar system to determine material toughness. Moreover, in quasi-static regime, some studies on bonded assemblies have been done with sandwich Brazilian disk specimen [8]. By varying the angle between the loading direction and the adhesive direction, the multiaxiality is changed and one has access to an infinite number of stress states.

Local measurements coupled with a Hopkinson bar system have been developed for several years and the most promising works relate on high speed imaging system and Digital Image Correlation (DIC) [9]. Local displacements and strains have been measured with a millimetric resolution. The main limitation is the low spatial resolution due to the high acquisition speed.

This paper presents an innovative experimental procedure that overcomes both difficulties, i.e. the characterization of the local behaviour of adhesive joints on the one hand and multiaxial loadings on the other hand. A conventional SHPB setup is used to apply a dynamic compressive loading and the multiaxial stress state is obtained through novel particular specimen geometries. Design computations and preparation procedures are presented, and then the entire experimental set-up and main experimental results are detailed in order to validate this innovative high strain rate testing technique for adhesive joints.

2. Specimen DODECA

2.1. DODECA design

The sandwich Brazilian disk specimen [8] has been the main inspiration for the proposed work because an infinite number of stress states are available with a unique geometry. This point is crucial as specimen preparation requires a specific device to produce a high quality bonded assembly. Thus, with a unique geometry specimen and a unique bonding device, several stress states are reached.

The innovative specimen named DODECA is shown in Fig. 1. This is a 10 mm-thick dodecagon inscribed in a 40 mm-diameter circle. The two aluminium half-dodecagons are bonded with an epoxy-based adhesive joint. Typical adhesive joint thickness is around 300 µm. One drawback of the Brazilian disk specimen is the bad contact between the Hopkinson bar and the specimen. The actual contact zone is therefore poorly defined which leads to experimental and numerical modelling issues. In order to get a plane-to-plane contact between the bars and the specimen, flat spots have been added on the side to transform the disk in a dodecagon. As a consequence, this