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Impact rupture of structural adhesive joints under different stress combinations

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Abstract

The paper reports the results of an experimental study on bonded joints, carried out by means of an instrumented impact pendulum, equipped to load overlap specimens in shear. Such testing configuration is the most adequate and natural to study the possible modifications of the behavior of the joint, changing from static to dynamic loading condition, keeping the same specimen type. The specimens were steel strips bonded by an epoxy adhesive (Hysol 3425). Several values of lap length, adhesive and adherends thickness were adopted, to achieve rupture under different peel and shear stress combinations. The stress state at rupture has been calculated by means of a structural solution. The results show that the failure points, in a chart having as axes the maximum values of peel and shear structural stress, lie outside the rectangular limit zone previously obtained under static conditions. Therefore, in spite of the concerns associated with the impact condition, the strength of the tested adhesive does not decrease with respect to the case of static loading. In alternative, also the evaluation of the stress intensity factor proves to be effective to predict failure in the considered cases.

Keywords: Impact; Epoxy adhesive; Stresses; Failure

1. Introduction

In many real life cases, for instance in applications related to transportation systems, bonded joints may undergo impact loads that, conceptually, can be of two different types. To the first type belong the occasional heavy impacts that cause irreversible damage (i.e. automotive crash), the main issue in this case is the absorption of the kinetic energy obtained through plastic deformation. Of the second type are the frequent low-energy impacts, that the structural members and joints must withstand without damage; in this case the issue is high elastic strength. The present paper deals with this latter aspect.

The basic test to obtain experimental information on this topic is based on the impact of a pendulum onto a block bonded on a base (ASTM D950) [1]. Another popular test, especially in the automotive applications, is the ISO wedge impact test [2], which—more realistically—considers a joint of sheet metals to evaluate the adhesive fracture energy, but can be affected by the friction and the plastic deformation of the adherends [3].

The main limitation of the tests of this type is that they only give comparative results of different adhesives, and are not useful to obtain data—for example in terms of stress—suitable for design. With this aim, some studies presented in recent years propose some improvements and/or modifications of the standards, or make use of different impact conditions based on impact testing facilities adapted to test adhesives in bulk or joints.

A new testing method is proposed in [4], in which the block impact test is replaced by a pin-collar scheme to avoid the peel stress. Also the study in [5] shows the use of a system, formed by a prism bonded on two plates and hit by a falling weight, to measure the strength of the adhesive to impact shear. A discussion of the impact wedge-peel test is presented in [6], which, also by means of FEM modelling, shows the correlation between cleavage force and adhesive fracture energy G_c.

Many proposals concern realistic joints tested under different loading conditions. In simple cases, even the

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simple dropping of the bonded assembly is adopted [7] to assess the strength of an electronic package.

Moving to applications of higher structural interest, some studies considered the case of a lap joint subjected to impact bending caused by a weight falling transversally onto the overlap. The work [8] is focused on the dynamic behavior, whilst in [9] the stress field is evaluated by FEM. However, in both studies the elastic behavior is considered.

Another case that has received attention is the joint between two tubular elements, subjected to axial and/or torsional loading [10,11]. In addition to the possible practical application of such a geometry, the interest for this case stays in the fact that two different stress components are simultaneously applied, and this is helpful in establishing a failure criterion, as done in [11].

In our opinion, a very interesting approach is to test under impact the standard geometries which are usually tested in static conditions. This allows for appreciating the effect induced by the loading rate, since the two types of results (static/dynamic) are comparable. This is done in [11], where single lap joints are axially loaded by means of a drop weight facility, and in [12], where the joints are loaded by an impact bar and also the effect of tapering the ends is considered.

Our work proceeded in similar way, the attitude was to attain failure under different blends of stress components. This was accomplished by preparing non-standard specimens differing in lap length, thickness of the adhesive, thickness of the adherends. The paper is structured as follows. First, the features of the equipment used for testing are reported. Secondly, the tests are described and the obtained results are shown in synthesis. Finally, on the basis of the structural stress state, the failure condition is assessed both in terms of the failure locus in the stress space and of the stress intensity factor.

Fig. 1. Instrumented pendulum carrying a specimen.

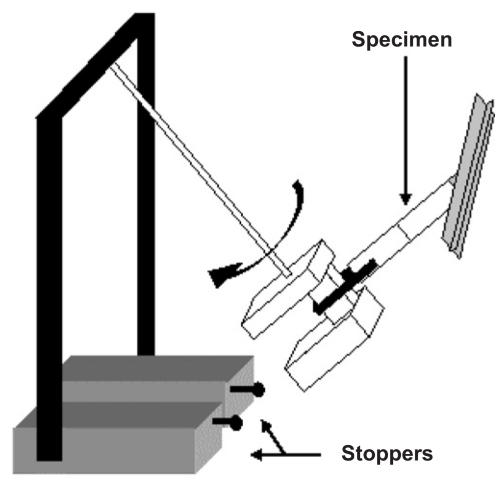

Fig. 2. Specimen loading.

2. Test rig

The testing machine used in the work is an instrumented Charpy pendulum for polymers, shown in Fig. 1. The energy of the hammer is 7.5 J, the linear speed at impact is 3.8 m/s. The impact force is measured by means of a piezoelectric load cell (PCB 201 A04) situated behind the impacting knife, the load signal is recorded by a National Instruments acquisition board operating at 250 kSamples/s.

A special fixture has been designed to apply the tensile load to the specimens by means of the available pendulum. The specimens are of single lap type and have the classical "dog bone" shape to allow for clamping. In the commonest case the specimen rests in the pendulum base, clamped at the back end, the hammer hooks the other end and exerts the traction. In this work the opposite scheme [13] has been used: the specimen is fixed to the hammer at the front end, the rear end is connected to a transverse tail which hits two stoppers fixed on the pendulum base, as sketched in Fig. 2.

The fixture, shown in Fig. 3, holds the specimen during the fall of the hammer and transmits the load to the cell by means of the U shaped bar (No. 1 in Fig. 3). The main problem regarding the fixture is that two opposite requirements should be fulfilled. From one viewpoint, the part must ensure the maximum possible stiffness to minimize the effect on the load transmission, on the other side it must have a negligible effect on the features related to the inertia properties of the pendulum (energy, impact speed). Similarly, the tail connected to the back end of the specimen must be stiff and resistant enough to stop the half-specimen without adding significant inertia to the system. With this aim, it has been manufactured as a beam in aluminum alloy with T cross section.

The concerns related to the inertial modification induced by the fixture and the specimen have been verified by comparing the oscillation period of the hammer alone with that of the hammer carrying the assembly fixture +