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► To cite this version:

Georges Challita, Ramzi Othman, Pierrick Guégan, Khalid Khalil, Arnaud Poitou. New experimental sample for shear testing of adhesively bonded structures. *International Journal of Modern Physics B*, 2008, 22 (9 11), pp.1081-1086. 10.1142/S0217979208046359 . hal-01007104

HAL Id: hal-01007104

<https://hal.science/hal-01007104>

Submitted on 9 Feb 2017

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NEW EXPERIMENTAL SAMPLE FOR SHEAR TESTING OF ADHESIVELY BONDED ASSEMBLIES

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In this paper, Split Hopkinson Bar technique was used to investigate the shear behaviour of adhesively bonded assemblies at high rates of loading. New sample geometry was adopted so that the compressive wave is transformed in a shear loading in the sample. Samples are conditioned at 20°C and 50% of hygrometry to eliminate any interference with temperature and humidity effects. The new technique is applied to an assembly built with a cyanoacrylate based adhesive and a metallic (Steel) adherent. They are found to be highly rate sensitive.

Keywords: Hopkinson bar; adhesively bonded assembly; shear; in-plane load; high strain rate.

1. Introduction

The use of adhesively bonded assemblies is widespread mainly in aeronautic, automotive and electrical engineering. This is due to many assets such as low cost and manufacturing flexibility. In these applications, the adhesive joints can subdue impact loads as well as quasi-static loadings. Therefore, it is of major concern to measure the sensitivity of the mechanical properties of these joints to the loading rate. Multiple quasi-static tests are specified in the ASTM standards.¹ Only few investigations were carried out on the impact response of these assemblies. Zachary and Burger² and Rossamanith and shukla³ investigated the stress field in single-lap joints using dynamic photo-elasticity. Kinloch et

al.⁴ investigated their fracture energy using a three-point bending specimen. Sato⁵ studied the absorbed energy in a CFRP-aluminium alloy beam. Lawrence Wu et al.⁶ used the Hopkinson bar technique to measure the absorption energy of electronic adhesive joints. Nonetheless, none of these studies did measure the strength of the joints. Harris et al.⁷ proposed an impact where the shear strength of a single-lap joint is measured. However, only low-impact velocity of 1.34 m/s is reached. Lataillade et al. proposed the use of the Hopkinson bar technique⁸⁻⁹ and a tensile technique with an inertial wheel¹⁰ to achieve much higher impact velocities. Bezemer et al.¹¹ used a rod-and-ring specimen impacted by a drop-weight system and a compressive air gun. In line with⁸, Yokoyama and Shimizu¹²⁻¹³ and Srivastava et al.¹⁴ determined the impact shear strength using a modified split Hopkinson bar. A new sample geometry was used. A pin-and-collar specimen was proposed in¹² and double-L specimen was considered in.¹⁴ The impact velocity can reach 20m/s in these techniques. Different loading configurations were also investigated. The tensile strength of adhesive joints was investigated¹⁵⁻¹⁹. Sato and Ikegami²⁰⁻²¹ used Hopkinson bar technique to apply a combined tension-torsion load. In this paper, we are interested in the measurement of the shear strength of adhesively bonded joints. We will use the Hopkinson bar technique because it takes into account the wave propagation in the experimental set-up. However, the specimen geometries, proposed in literature, yield an impedance mismatch with the bar. The incident wave, induced in the input bar by the strike of the projectile, reflects in this bar before reaching the adhesive joints. In the same way, the transmitted wave, through the adhesive joint, reflects before reaching the strain gauge cemented on the output bar. This can alter the input and output force measurements. A new M-shaped specimen is proposed. It consists of a double lap adhesive joint.

2. Experimental Set-Up

2.1. Hopkinson bar apparatus

The conventional configuration of the Hopkinson bar technique²² consists of two elastic bars (Fig. 1). One gauge station is cemented on each bar. A compressive wave is generated by the impact of striker on the input bar. This incident wave moves through the input bar till the bar-specimen interface. At this interface, a first part of the wave is reflected back into the input bar as a tensile wave and a second part is transmitted through the specimen into the output bar as a compressive wave. The input gauge station measures the incident and reflected waves and the output gauge records the transmitted wave. The input gauge is cemented in the middle of the input bar and the striker length is taken less than half the input bar length. In this case, the incident and the reflected waves are recorded separately with the input gauge. Assuming one-dimensional wave propagation, the force applied by the bars on the specimen are given by:

$$F_{in}(t) = A_{in} E_{in} (\epsilon_{inc}(t) + \epsilon_{ref}(t)) \quad (1a)$$

$$F_{out}(t) = A_{out} E_{out} \varepsilon_{tra}(t) \quad (1b)$$

where the subscripts in , out , inc , ref and tra mean input bar, output bar, incident wave, reflected wave and transmitted wave, respectively, and A is the cross-section area, E the Young's modulus, ε is the wave's strain.

Fig. 1. Simplified Scheme of the Hopkinson bar apparatus.

2.2. Specimen geometry

The specimen consists of three adherent plates bonded by two adhesive layers (Fig. 2). The middle adherent plate is shifted from the two others. It is aligned with the output bar end. Whereas, the lower and the upper plates must be aligned with the input bar end. The specimen can be easily sandwiched between the two bars without any modification on the conventional configuration. The mechanical impedance of each adherent plate is constant to not induce any undesired reflexion of the waves. The in-plane movement of the bars is transformed by the geometry of the specimen to a shear loading on the adhesive layers. Assuming dynamic equilibrium in the specimen, the shear stress is deduced from the input and output forces as follows:

$$\tau(t) = \frac{F_{in}(t) + F_{out}(t)}{4A_{adh}} \quad (2)$$

where A_{adh} is area of a single-lap joint.

2.3. Specimen preparation

To ensure the good alignment of the specimen a special mounting device is developed (Figs. 3). To prepare the specimen, the following steps are followed:

- (1) The three adherent plates are deburred with an abrasive paper P220.
- (2) The faces of the adherent plates are polished with paper P220.
- (3) The adherent plates are wiped with dry paper.
- (4) The thickness of each plate is measured using a micrometer.

Fig. 2. Specimen Geometry: (a) side sight (b) rear sight.

Fig. 3. Specimen preparation, bonding steps.

- (5) The adherent plates and the mounting device are cleaned with acetone.
- (6) The adhesive is spread on the upper face of the lower plate, this plate is then fixed by a screw in the mounting device as shown in Fig.3a.
- (7) The adhesive is spread on both faces of the middle plate, this plate is then fixed by a screw in the mounting device in the opposite side of the first screw to create the gap between the two plates, as shown in Fig.3b.
- (8) The adhesive is spread on the lower face of the upper plate, this plate is fixed by a screw in the mounting device in the same side of the first screw, as shown in Fig.3c.
- (9) The whole specimen is then fixed in the mounting device by a vertical pressure screw to keep a constant pressure and ensure a convenient adhesion between the three plates, as shown in Fig.3d.

- (10) The specimen is cured at room temperature for 24 hours.
- (11) The specimen is kept in a conditioned room (local temperature 20°C, relative hygrometry 50%) for at least one week.
- (12) The specimen is tested at room temperature after no more than two hours from getting it out from the conditioned room.

3. Experimental Results

For high rate of loading, a steel Hopkinson bar is used (Fig. 1). The bars are 16mm in diameter. The Young's modulus is 190GPa. The elastic limit is 1400MPa. The specimen is made of three steel (35NCD16) plates bonded by a cyanoacrylate based adhesive (2610). The adhesive layer is $20\mu\text{m} \pm 8\mu\text{m}$. The strain measurements are recorded at a frequency rate of 10MHz. The force at the two specimen-bar interfaces are computed using the software DAVID²³ developed at the Ecole Polytechnique (France). Then, the shear strength is deduced using Eq. (2). The same geometry is tested with a conventional quasi-static machine to compare the impact shear strength with the quasi-static values. Fig. 4 shows the variation of the shear strength with the mean value of the shear rate. The shear strength is found highly rate-sensitive. A bilinear behavior is observed. In fact the gradient increases considerably at high rates (greater than $5 \cdot 10^5 \text{ MPa s}^{-1}$). Two joint overlap lengths (l_j : see Fig. 2) are tested (9 and 14 mm). The results obtained with the short specimens confirm the bilinear behavior.

Fig. 4. Variation of the shear strength with the loading rate.

4. Conclusion

In this paper, new sample geometry was tested by the Hopkinson bar technique. The influence of the loading rate on the shear strength of double-lap adhesive joints was investigated. The advantage of the new geometry is that it minimizes the impedance

mismatch with the bar. Moreover, a mounting device is developed to ensure the good alignment of the specimen with the two bars.

Acknowledgments

The authors want to Franc Pasco, Luc de Pin, Alexandre Duchêne, Jose Maria Bian for their help in the experimental work.

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