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Shock characterization of a fused silica glass direct bonding with a new experimental bench

M. VOISIN^a, A. MAUREL-PANTEL^a, F. LEBON^a, F. MAZEROLLE^a, S. BEGOC^b, N. COCHETEAU^c

a. Aix Marseille Univ, CNRS, Centrale Marseille, LMA, Marseille, France, voisin@lma.cnrs-mrs.fr

b. Centre National d'Etudes Spatiales, 18 Avenue Edouard Belin 31400 Toulouse, France

c. Thales SESO SAS, Aix en Provence, France

Abstract:

Fused silica direct bonding is of particular interest for optical systems manufacturing for spatial applications. However, these systems need to respect the European Space Agency requirements to be used in space. A new experimental test is developed to characterize interface shock resistance of direct bonding. In this work a preliminary step is performed, it consists to perform an experimental shock campaign with an aluminium assembly bonded with a Cyanoacrylate Permabond 910.

Keywords: direct bonding, shock, Arcan device

1 Introduction

The fused silica glass direct bonding consists in joining two surfaces without using any adhesive. This technology is used in particular to manufacture optical systems as optical slicers or interferometers used in terrestrial optic systems. The final aim of this investigation consists to validate the spatialization of this technology. It is obvious that the spatial environment is totally different from the terrestrial one. Indeed satellite may undergo shocks, vibrations or thermal fatigue. It is necessary to characterize with accuracy the direct bonded interface to respect the European Space Agency requirements. In these investigations, the shock strength is characterized from the experimental point of view.

In the literature, shock strength has been investigated on bonded assemblies with an adhesive. Several shock test devices have been designed:

- The pendulum test bench [1, 2] is interesting, in case considered low impact speeds are needed, so this solution is not chosen;
- Another classic experimental shock bench is the drop towers [3, 4] but proposed system own two impact points, much accuracy is needed to synchronize these impacts;
- Then, there are systems more simples like the weight falling device [5] with only one impact point.

In these devices generally a single lap joint assembly is characterized, so the adhesive properties are investigated only in shear mode.

The modified Arcan device allows to solicit an adhesively-bonded assembly with different loading modes: tensile mode, shear mode, or mixed mode [6]. This device is classically used for static solicitation. In this paper, we have decided to couple the Arcan device with an experimental weigh falling bench.

2 Development of shock experimental fixture

A new experimental device is designed to characterize mechanical interface strength solicited by shocks. The aim of this device is to be able to generate a shock for different solicitation modes (mode I, mode II and mixed-mode). In order to do that, the new experimental test is based on two principles:

- The modified Arcan fixture developed by Cognard [6]. It is composed by two half disks with several attachment points on their periphery. These attachment points allow installing the mount on a standard tensile testing machine.
- And the Beevers and Ellis testing machine [5], imposes a tension load on a specimen by the falling weight along a tube connected to the specimen. In the concept developed in this paper, the specimen in the Beevers and Ellis machine is replaced by the Arcan fixture as related in Figure 1.

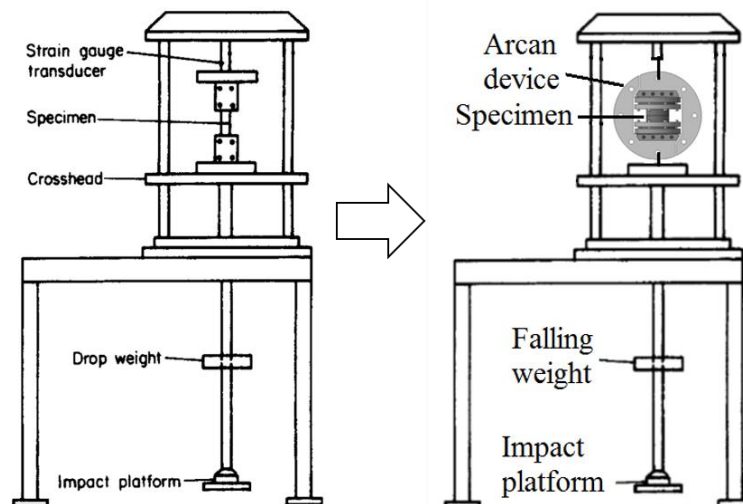


Figure 1 Adaptation of the Beevers and Ellis testing machine

Unlike the specimen proposed by Cognard et al. [6], the specimen used exhibit a circular bonded surface in order to simplify the fabrication of direct bonding glass samples. The specimen is placed in a clamping system as related in Figure 2. These clamps fix the specimen using uniformly distributed screws avoiding preload of the adhesive. Two different diameters of specimen can be considered in order to choose the dimension of the bonded area that is most adapted: the large area is for the fused silica direct bonding samples and the small area is for the bonded aluminium samples.

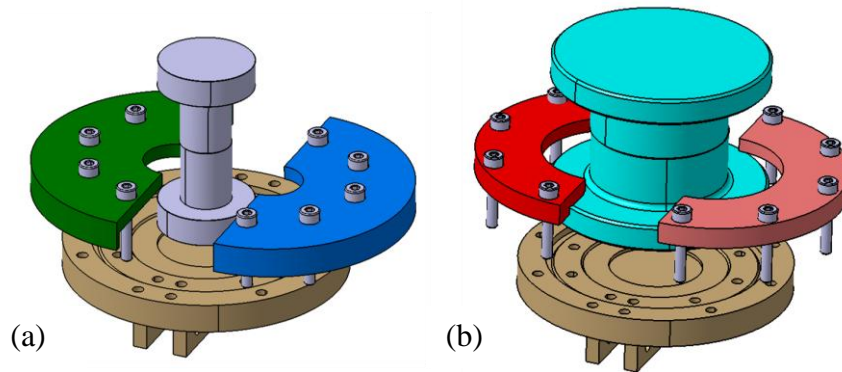


Figure 2 Clamping systems for specimen in aluminium (a) and in glass (b)

Then sample support is fixed on both Arcan half discs. These discs are connected respectively on the frame and the tube by a pivot link. This assembly is linked to a guide system using bars and ball sleeves in order to avoid any rotation of the system during the shock due to the falling weight as described in Figure 3.

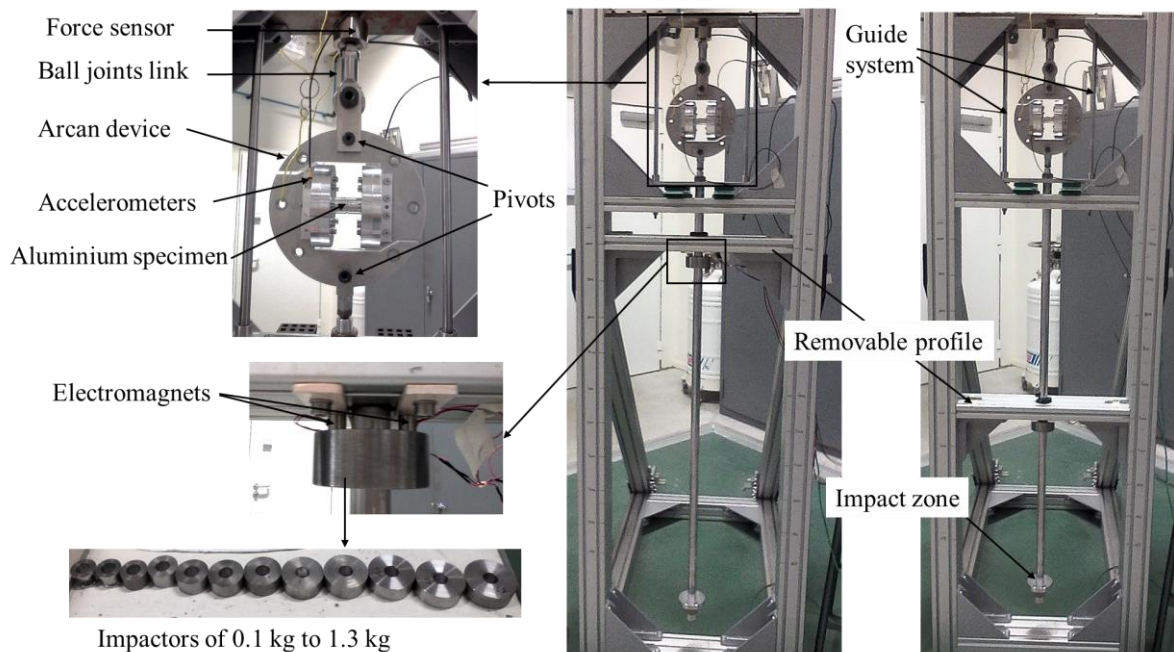


Figure 3 Details of the test bench

In order to generate shocks, an impactor is positioned on the tube. This impactor is maintained with two electromagnets. When the start button is pushed the impactor slides along the tube to finish on the impact area. The specimen is solicited in tension through the tube and the Arcan device. The removable profile allows adjusting the height of fall of the impactor up to 1 metre in order to modify impact energy value. The mass of the impactor is also a parameter to modify the impact energy value; steel impactors from 100 grams to 1,300 grams are used. The system is equipped with a load sensor U9C/50kN from HBM, who has a maximum capacity of 50kN and two accelerometers of type 8339 of Brüel Kjaer with a capacity of 20 000g. A PCI Express card with a sampling at 1 MHz is used for high frequency data acquisition.

3 Shock experimental tests

The shock experimental test campaign is performed on an adhesively-bonded assembly for the preliminary tests. The specimen used is in aluminium 2017 and it is bonded with the Cyanoacrylate Permabond 910. This glue has a very small thickness (0.01mm) and a brittle mechanical behaviour, it is the adhesive closest to the direct bonding interface. A bonding experimental protocol is set up to minimize bonding defects and to ensure reproducible test conditions.

In first time, the substrates are cleaned with acetone [7]. After, a device is used to join the substrates. It allows respecting the concentricity between the two bonded substrates and the five samples are joined at one time as described in Figure . Once the assembly is done, we have to wait for the adhesive polymerization during 24 hours.

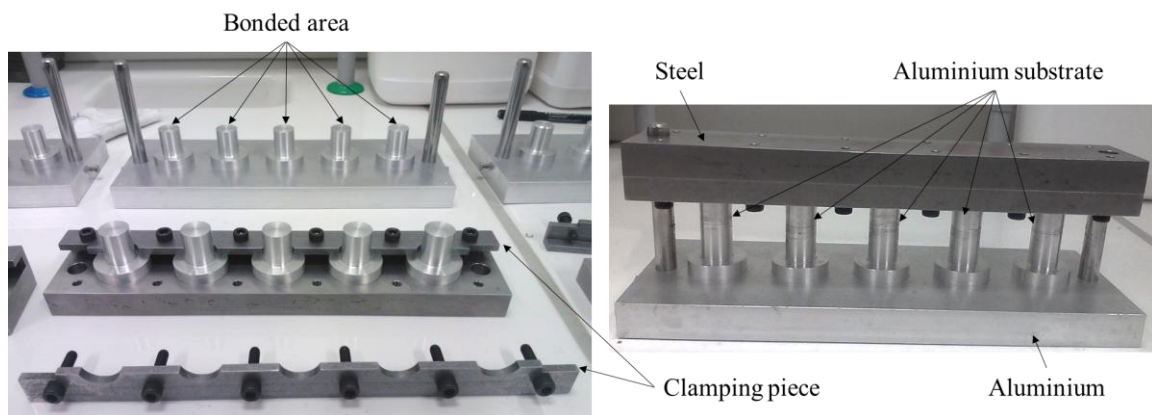


Figure 4 Device for bonding the samples

The experimental test consists in measuring the specimen behaviour in function of the imposed impact energy. This impact energy (E) depends of the drop height of the impactor (h) and the mass of the impactor (m).

$$v = \sqrt{2gh} \text{ with } g = 9,81 \text{ m.s}^{-2} \quad (1)$$

$$E = mgh \quad (2)$$

We want to measure the impact energy necessary to lead on to fracture the bonded samples. For each impact energy, a minimum of five specimens is tested to have a good statistic. With these tested specimens, the fracture rate is calculated, it depends on the number of broken specimens as a function of the number of specimens tested for a given energy as explained in equation (3).

$$\text{Rupture rate} = \frac{\text{Broken specimen number}}{\text{Specimen total nombre tested}} * 100 \quad (3)$$

This first test campaign is performed in tensile and shear modes as related in Figure 4. The substrate in aluminium of the specimen has a chamfer of 45° (Figure 5). This configuration, with a stress concentration at the interface bonded joint, is chosen to be the same used for direct bonding assemblies.

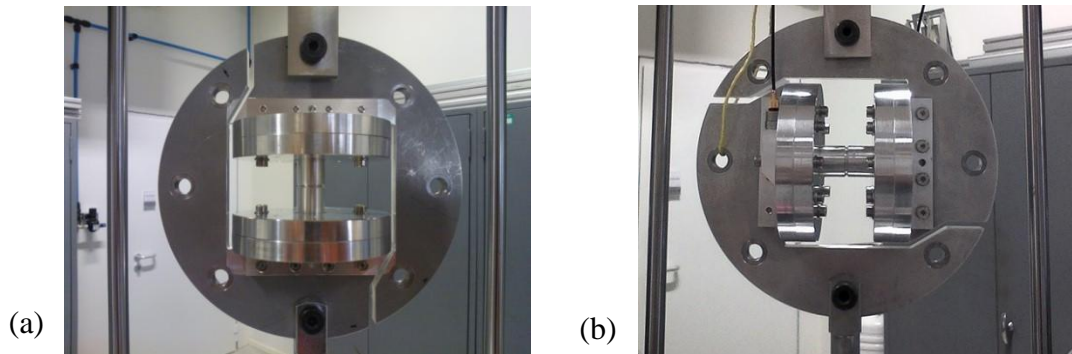


Figure 4 Two modes of solicitation of the bonded assembly (mode I in tensile (a) and mode II in shear (b))

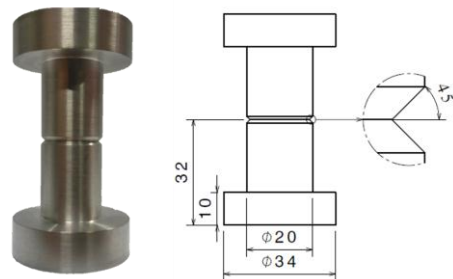


Figure 5 Bonded specimen in aluminium

4 Results

For shocks in tensile mode, the impact falls by 1 meter. Figure 6 shows the rupture rate defined in equation (3) as a function of the impact energy. At the beginning (for small energies), zero percent of specimen was broken until an impact energy of $E_0=2\text{J}$. After we observe a zone where the percent of rupture increases almost linearly. Then from a critical energy value (here $E_{100}=6.9\text{J}$), all specimens were broken.

In shear mode, the impact falls by 0.5 meter. The height has been changed because all the specimen broke with 1 meter of fall. The same evolution of curve that in tension mode is observed. The energy for total fracture is defined at $E_{100}=3.9\text{J}$ but E_0 is not determined because the impact energies are still too large.

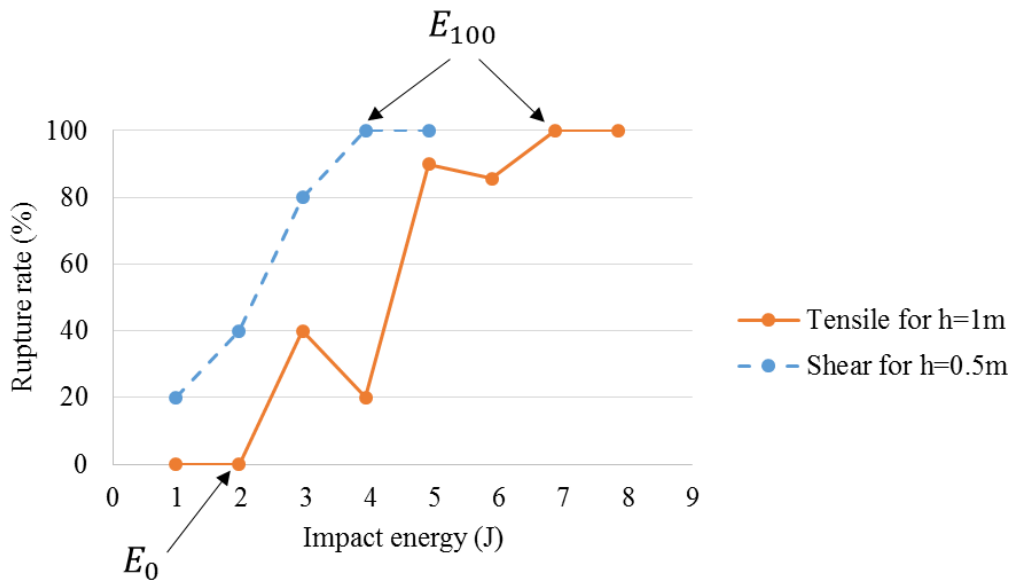


Figure 6 Shock mechanical strength results with a Cyanoacrylate adhesive in tensile and shear modes.

5 Conclusion

The first test campaign allows understanding the behaviour of the new shock test bench. The behaviour of the bonded assembly evolves in the same way in front of the different impact energies. More the energy is important more the rupture rate is important. The Cyanoacrylate bonded assembly have a better strain to shocks in tensile than in shear.

For the shear tests, we can observe that to study the behaviour of a brittle glue, low impact energies must be used. In future work, the test campaign with fused silica direct bonding will be performed with the same experimental bench. A falling weight more small than for the Cyanoacrylate will be used, indeed even if the bonded surface is larger the adhesion is lower. Some results on the direct bonding will be present during the conference.

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