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Investigation of the Dynamic Behavior of a PU Based Adhesive using Split-Hopkinson Tensile and Compression Bars

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Abstract

The applicability of the Split Hopkinson Bar method to test PU based adhesive with thick bondlines is investigated. An adhesive is tested in tension, compression and shear with a Split Hopkinson Tension Bar (SHTB) and a Direct Impact Split Hopkinson Pressure Bar (Direct SHPB). Specifically developed sample geometries and corresponding experimental setups are briefly presented. Results for tension specimen obtained with SHTB are compared to results gained from tests using hydraulic machines (standard and VHS). The comparison shows that with the current setup, the SHTB is very well suitable to characterize the dynamic stiffness of the adhesive bond. Compression and shear tests have also been successfully performed using Direct SHPB and SHTB, however, due to limited space in this extended abstract, the compression and shear results will be given in the oral presentation.

Keywords: Adhesives, Split Hopkinson Bar, Experimental Methods

1. Introduction

Adhesive joints have a broad range of application. In cars, two different types of adhesive joints are common. On the one hand, there are structural bonds with thin film adhesives. These adhesives are mainly based on epoxies, they have high strength, but relatively small strain to failure. On the other hand, there are thick layer adhesive joints based on polyurethane (PU), such as the Sikaflex® adhesive investigated here, which are used for mounting, sealing and damping, e.g., to bond the windscreen of a car to the metal car body. The strength of these joints is usually lower than that of joints with epoxy-based adhesives, while larger displacements can be achieved between the adherents due the thick bondline and the material properties of the adhesive. This is mandatory for the bonding of windshields, one reason is that glass and metal have different coefficients of thermal expansion: without a flexible bond line, the glass would break due to its brittle behavior if the car is subjected to a substantial temperature change.

Nowadays, there is a continuing trend toward more and better virtual design within product development. The goals are further product improvements, lower manufacturing and material costs, but also the reduction of the number of expensive prototype tests in the development phase. In the automotive industry, this is amongst others done by reducing the number of crash tests. In order to achieve this goal, predictive simulations are required. The work presented here is part of a project with the goal to develop improved simulation models for laminated glass and its bond to the car structure. In this context, a simulation model for the strain rate dependent material behaviour of the thick layer adhesive joints shall be developed. Therefore, methods to experimentally characterize the adhesive at various strain rates are required. This is traditionally done using dogbone, single or double lap shear and T-Peel tests in hydraulic testing machines, drop towers or similar devices, see [1] [2].These methods, however, become more and more difficult for increasing testing velocities due to oscillatory stress waves overriding the measured force-displacement signals.

Therefore, Split Hopkinson Bars (SHB) are often used to test at the high strain rates seen in automobile crash applications. Due to the long bars and free surfaces being far away from the sample, stress wave transmission and reflection at the bar/sample interfaces can be precisely observed and used to calculate stresses and strains in the sample. In typical SHB set ups, velocities up to 20 m/s and, depending on the specimen geometry, strain rates up to 10000 s^{-1} can be reached. For PU materials, Fan et. al. [3] showed that SHB tensile testing can successfully be applied. Compressive testing of PU films has been presented by Zhang et. al. [4]. Here, we investigate the applicability of the SHB technique for tensile, compressive and shear testing of a PU based adhesive (Sikaflex®).

2. Experimental Method

2.1 Specimen Geometry

Adequate specimens had to be designed and manufactured to account for the specific properties of thick layer adhesives. One of the requirements was that the thickness and width of the bond line and thus the lateral strain distribution and stiffness of the bond were similar to the actual dimensions in the components. Therefore, a width of 9 mm and a thickness of 7 mm was used in all specimen presented here. Tests with alternative adhesive cross sections have also been performed and will be presented elsewhere. The design of the specimens is shown in Figure 1. The tension and compression specimens are hollow aluminium cylinders, where the adhesive was applied with a Teflon insert to insure the internal diameter of the specimen. For tension tests, the specimens have to be firmly fixed to the end of the bars, this is achieved with the M24x3 threads at each end. The Compression specimen was shortened to decrease the mass of the specimen and the side with the hole for the Teflon insert was fitted with a threaded aluminium insert to allow the load to be transferred through the entire end of the specimen. For the shear testing, two different concepts are compared, one with tension shear loading and one with compression shear. The long free path for the compression shear specimen is to allow a complete failure of the adhesive during the test.

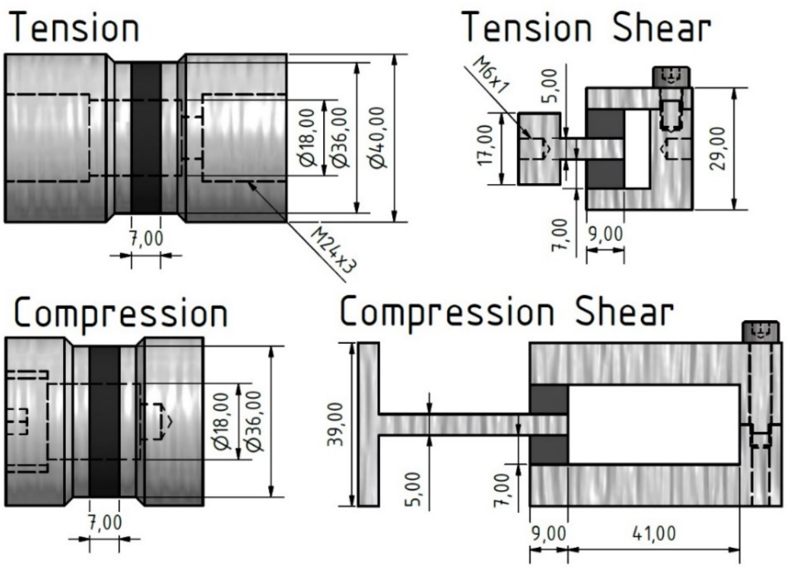

Figure 1: Specimen Geometry

2.2 Testing methods

Four different testing machines were used in this program: two hydraulic testing machines, one for low speed, one for high speed testing, and two Split Hopkinson Bars, one in tension and one in compression. Figure 2 shows test setups for all of the four testing machines.

A hydraulic testing machine (H) was used for the quasi-static tests and the tests at a nominal strain rate of 1 s^{-1}. It was used for both compression and tension and for both butt-joint and shear geometries. Depending on specimen geometry, either a mechanical extensometer or DIC was used to determine strain. The force was measured using the machine’s built-in load cell. Tests at higher velocities were performed with a Very High Speed (VHS) hydraulic machine. With this setup, the butt-joint specimen could be tested in tension, but not in compression. The machine pulled on a metal rod that was threaded into the specimen allowing the system to get up to the desired speed before applying load on the specimen.

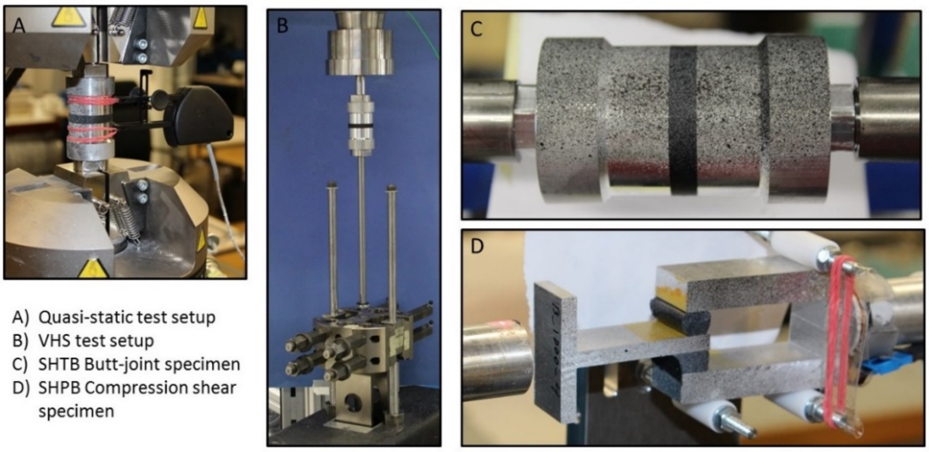

Figure 2: Test setups.

In addition to the hydraulic testing, two Split Hopkinson Bar test setups were used, a Split Hopkinson Tension Bar (SHTB) and a Direct Impact Split Hopkinson Pressure Bar (direct SHPB). In general, the Split Hopkinson Bar is a one dimensional wave mechanics test system. The specimen is placed between the input and the output bar and loaded with an impact-generated stress pulse. Strain measurements at the bars and wave theory are used to evaluate stresses and strains in the sample, see e.g. [5], where a more detailed description of the method is given. In the SHTB, the specimen is attached to the bars using threaded adaptors. The input bar has a flange that is impacted by the striker, thus imparting a tension wave into the specimen. Our SHTB has a design that is similar to the one presented in [6]. Compared to other designs, the pulse of length t=1 ms is relatively long. Whereas the force is measured in the traditional way using the calibrated strain gauges on the output bar, the strain is measured optically. With the direct SHPB, the specimen is directly impacted by the striker, the force is measured using a Piezo Film sensor (PVDF) at the end of the specimen; as in the SHTB, the strain is measured optically.

3. Results

Results of tension tests at four different strain rates using the hydraulic machine (strain rate 0.01 s^{-1} and 1 s^{-1}), the VHS (strain rate 100 s^{-1}) and the SHTB (strain rate 1000 s^{-1}) are compared in Figure 3. Note that all stress, strain and strain rate values given are nominal (technical) values. Due to the high failure strain of the adhesive, the pulse length of 1 ms is still too short to achieve failure in the SHTB test.

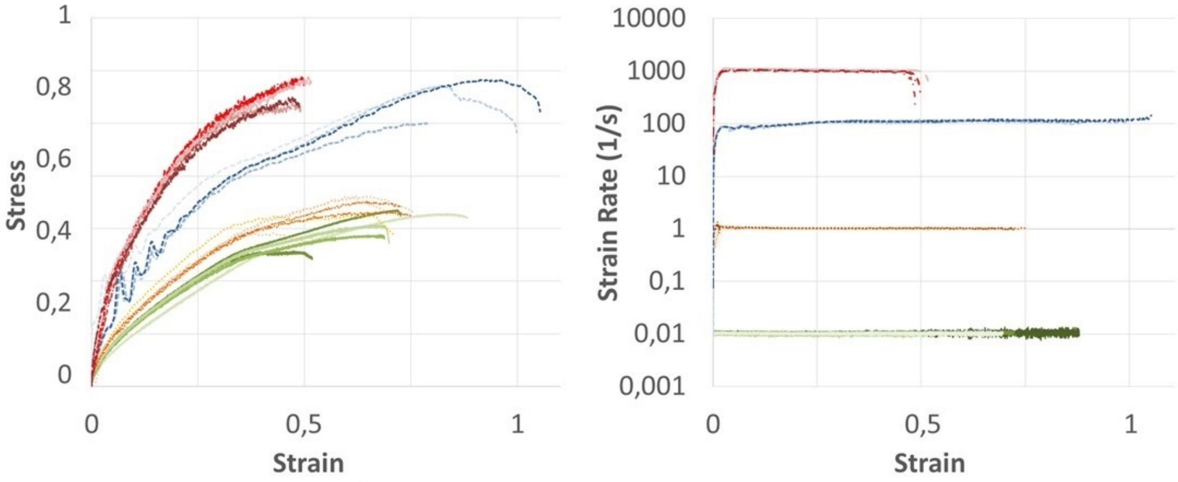

Figure 3: Results of tension tests (normalized stress/strain/strain rate). Red: SHTB tests, blue: VHS tests, orange and green: hydraulic tests. Note: the stress and strain axes have been normalized.

In summary, the results of the tension tests show that the adhesive has a clear strain rate dependence in stiffness and strength. From the hydraulic and VHS tests, some rate dependency of the strain to failure can be assumed. The VHS (blue) show oscillations at the beginning of the test. In VHS Tests with higher velocities (not shown here), the signal quality drops significantly. In contrast, the signal quality obtained in the SHTB (red) is clearly improved, while the strain rate is even higher. Besides that, the strain rate is more constant at the SHTB. This shows that the SHTB is very well suitable to test thick adhesives at high strain rates. If the strain to failure of the adhesive at the highest rate is of interest, the adhesive thickness could easily be reduced so that the duration of the pulse is sufficient.

The results from the compression and shear tests will be given and discussed in the presentation at the conference.

4. Conclusions

The applicability of the Split Hopkinson Bar method to test PU based adhesive with thick bondlines was investigated. Specimen and Setups for tensile, compression and shear loading were presented which can also be used for hydraulic loading. The results show that the SHTB is very well suitable to test the adhesive. The tested adhesive showed a clear strain rate-dependence of stiffness and strength, and some indication for a rate dependent strain to failure. The pulse length limits the maximum strain in the SHTB test, thus, the adhesive thickness needs to be reduced if failure shall be reached.

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