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Split Hopkinson bar technique in a tensile test

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1. Tensile test arrangement

1.1 Impactor device

The Hopkinson Split Bar is generally a test of the material properties of a sample tested at a fast dynamic problem. The base of the test is based on a one-dimensional theory of elastic pulse propagation. The source of the pressure pulse extending longitudinally in the measuring rods in the Hopkinson test is the impact of the small elastic bar (“impactor”) to the front of the first rod.

The value of the longitudinal strain (amplitude) on the first bar at the first passage of the pressure waveform to the strain gauge is directly proportional to the impact velocity of the impactor. The length of this first pulse depends on the length of the impactor, i.e. the time over which the kinetic energy of the pound acts on the face of the first rod. This corresponds to the length of the first input pulse of approximately 60 microseconds.

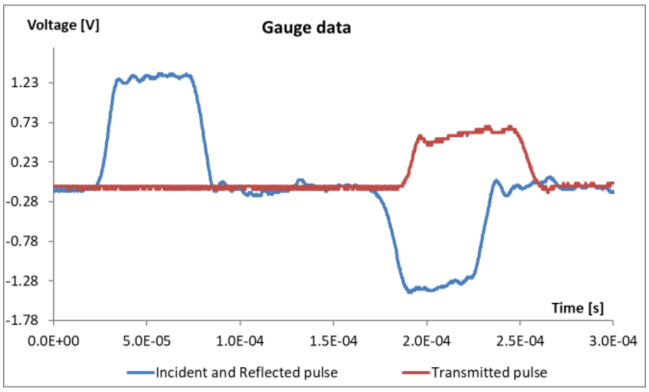

Fig. 1. Typical strain gauge recording of the Hopkinson test in pressure

The impact of the majority of similar devices is caused by the punching of the impactor from the gun with compressed air. Pulse energy is obtained by releasing compressed air from a cylinder, such as a diving or cylinder, as part of a compressor station. The device for Hopkinson's test in SVSFEM uses the energy of a small cartridge that fires a piston from the pulse generator and the end of that piston hits the rear face of the impactor. On a track of approximately 40 mm, it will give this impactor a speed of 20 to 60 m/s depending on the set size of the cartridge chamber. This speed is higher than similar equipment using compressed air. The pulse generator is based on the ANTREG pistol adapted for mounting on the proposed device. The source of the piston's energy in this pistol is a standard 9x16 mm industrial cartridge, for example from Sellier-Bellot.

1.2 Measuring rods

The new measuring device (TSHB Tri Split Hopkinson Bar) differs from conventional Hopkinson test equipment by dividing the measuring rods into three parallel bars. This solution creates a significantly larger space for the sample to be measured and at the same time it is possible to assemble the rods so that the sample is subjected to tension and pressure.

In the first variant, the numerical simulation showed that with the assumed magnitude of the input force pulse generated by an impactor hit, stress about approximately 50 MPa is generated on the specimen. This value is sufficient, for example, to measure samples of concrete and similar materials.

The disadvantage of this solution is the occurrence of bending stress on the measuring rods. More variants of the connecting part were analyzed.

In a final variant, the functional part of the measuring device has been adjusted by inserting another front and rear rod on the axis of the whole device. The force pulse in front of and behind the sample is thus always transmitted by only one rod in the axis of the device, which is not stressed by unwanted bending.

For the tensile testing variant, it is possible to replace the rear three parallel bars by simply anchoring the one rear measuring rod. This anchorage can be easily used to position a load cell that can directly verify the value of the force pulse obtained from the rear measuring rod.

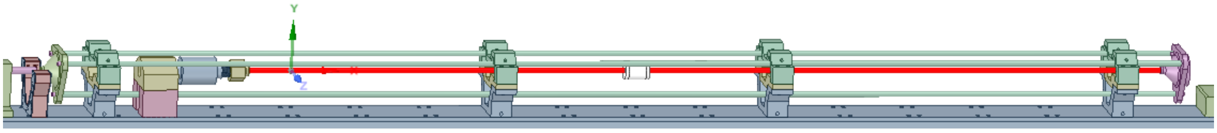

Fig. 2. Final CAD model of measurement device

2. Measurement evaluation

2.1 Capacity analysis

The exact record of deformation of the test sample in the Hopkinson test is one of the key problems of this method. The entire test time, in the order of tens of microseconds, places great demands on the write speed of the entire device while maintaining the high quality of the recorded data. The deformation of the sample is usually evaluated indirectly from the deformation of measuring rods. Assuming elastic deformation of the measuring rod and the constant cross-section, it is possible to quantify the time course of forces acting on the measured sample and thus also the deformation of the sample. The deformation of the measuring rods is usually evaluated by means of strain gauges located at half length. In some cases, the deformation is evaluated by means of capacitive sensors, which evaluate their longitudinal deformation on the basis of a change in the cross-section of the rod. Capacitive sensors record the change in electromagnetic field between two surface electrodes. The distortion of the sample in the Hopkinson test is basically also a change in the position of the two surface electrodes (sample-to-probe interface). If a voltage difference is applied to these surfaces, it would be possible to evaluate the deformation of the sample directly from the position change of the two surfaces. Most measurements are made with steel measuring rods. An electromagnetic field analysis was performed between two measuring rods.

We start from the capacitance of a plate capacitor consisting of two electrodes and a dielectric between them. The capacitance of capacitor can be calculated from geometric properties and material properties - permittivity. The relationship between these properties is apparent from the following equation

$$C = \frac{\varepsilon \cdot S}{d},$$

where C is the capacitance of the plate capacitor, ε is the dielectric permittivity, S is the electrode area above the dielectric, d is the dielectric thickness between the electrodes.

The measured sample, together with the bars, forms a plate capacitor which changes its capacity during deformation depending on the change in the dielectric thickness. By measuring the change in capacity over time during the deformation phenomenon, it is possible to determine the strain over time. The hypothesis applies only to dielectric (non-conductive) samples of course.

The deformation of the measured specimen is approximately 10-20%. Typical specimens are made of materials, wood, plastics or fabrics. Their relative permittivity is very low in the range of 1 - 10. This makes the ambient air permittivity negligible for the electric field. The thickness of the wood specimen is usually approximately 8 mm.

The relative permittivity of the specimen is selected with a value of 2. The analysis is calculated as electrostatic with a potential of 12 V between the electrodes. By analytical calculation we can determine the approximate capacity.

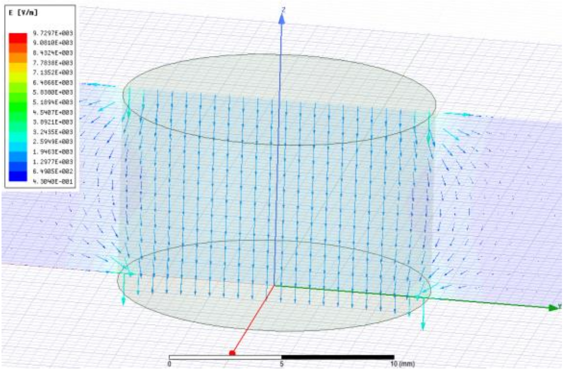

Fig. 3. Electric intensity field

$$C = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot S}{d} = \frac{8.854 \cdot 10^{-12} \cdot 2 \cdot 1.54 \cdot 10^{-4}}{8 \cdot 10^{-3}} = 340.74\,fF$$

The capacity of a capacitor with a specimen thickness of 8 mm is determined from the finite element model through the electrostatic field energy. Due to the environmental impact, the capacity value has changed by more than 30%.

$$C = \frac{2W}{U^2} = \frac{2 \cdot 3.2239737 \cdot 10^{-11}}{12^2} = 447.7\,fF$$

Next figure shows a very small change in capacity at 15% strain of the capacitor. For mm units, the capacity changes only in tens of fF. The evaluation of the deformation of the sample by means of the electromagnetic field between the measuring rods is therefore theoretically possible, but it is practicaly difficult to implement due to the very small measured values. This method was not used in final device assembly.

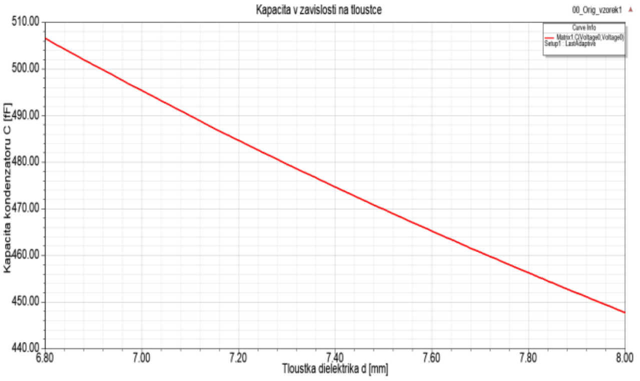

Fig. 4. Capacity versus specimen thickness

2.2 Stress-strain analysis

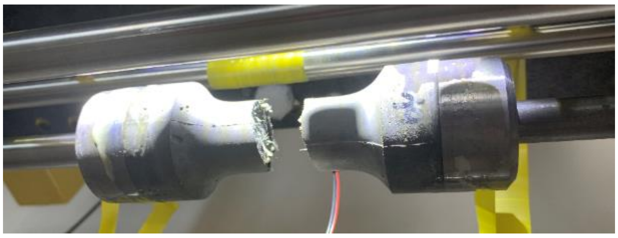

Fig. 5. Concrete specimen after test

The new measuring device (TSHB Tri Split Hopkinson Bar) was tested by the first set of measurements. The specimen was made from UHPC concrete including 6 mm length Aramid fibers.

Gauge sensors were placed on the front and back measurement rods. There was found a good agreement with the previous numerical simulations. The strain history of the specimen was measured directly by the videoextensometr Model 200XR from H.-D. Rudolph GmbH company. The stress-strain curve of the specimen evaluated from combination of the gauges and the videoextensometr is presented in next picture.

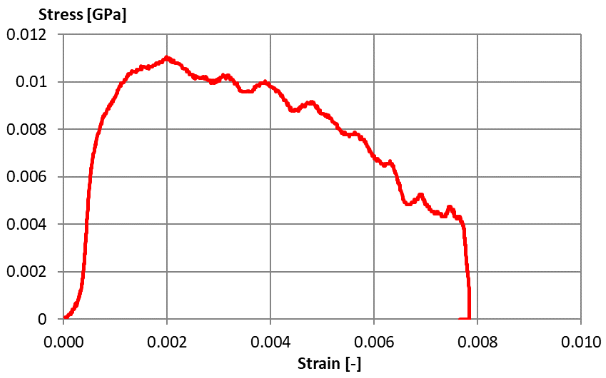

Fig. 6. Stress-Strain curve of the UHPC specimen

3. Conclusion

The tensile test of the UHPC specimen was performed on the new measurement device Tri-Split Hopkinson Bar (TSHB). The specimen deformation was caused by a hit of the impactor to pair of measurements rods. The impact velocity was about 50 m/s. Stress-Strain history of the specimen was evaluated by a combination of gauge measurement and optical measurement.

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