Experiment on wave propagation in soft resins

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The wave propagation in a group of soft resin based (3d printed) materials is investigated by using a Split Hopkinson Bar test. The principal assumptions and the role of pulse shaping, as an approach to achieve constant strain rates and dispersion reduction, is discussed. The experimental stress-strain curves, gained by aluminium Split Hopkinson bars, are presented and indicates that tough and white standard resins have a dynamic elastic modulus of almost 3 GPa.

1 Introduction

The investigation of wave propagation is fundamentally helpful to study the dynamic behavior of materials and play an important role to improve the design in mechanical and structural components. In this study, a Split Hopkinson Bar (SHB) setup is used in order to induce a wave by applying dynamic impact.

Four types of resin based materials, mainly used as 3D printer materials, are selected to investigate the wave propagation. Tough, white standard, durable and flexible resins are considered. The mentioned resins are elastomers and thermoplastic materials, all representing a soft material behavior. The specimens were manufactured by 3D printing a cylindrical shape with a diameter of 18 mm and a length of 9 mm.

2 Working principle and assumptions

The SHB test was designed to perform dynamic tests and to characterize the material properties of various specimens at medium and high strain rates [1, 2]. The SHB consists of a gas gun, which initiates the process by launching the striker, an incident and a transmission bar and also a data acquisition system to collect and transfer the measured data. The specimen is placed between the bars. When the striker hits the incident bar, a compressive pulse is generated and transferred through the specimen and the transmission bar. In this study, aluminum incident and transmission bars of 20 mm diameter and 1800 mm length each are used [3]. It should be noticed that the materials of the sample and bars should have similar susceptibility to wave propagation, which is known as acoustic impedance. In the interface of the bar and specimen the wave splits, a part is reflected and a part propagates to the transmission bar [1, 2]. By considering one-dimensional wave theory, we can deduce stress \( \sigma \) and strain \( \epsilon \) in the specimen.

\[
\epsilon_s = \frac{c_b}{L_s} \int_0^t \left( \epsilon_I - \epsilon_R - \epsilon_T \right) dt
\]

\[
\sigma_s = \frac{E_b A_b}{2A_s} \left( \epsilon_I + \epsilon_R + \epsilon_T \right) = E_b \frac{A_b}{A_s} \epsilon_T
\]

Indices I, R and T indicate incident, reflected and transmitted wave pulses as a function of time, \( E_b \) is the bar’s Young modulus and \( c_b \) is the wave speed in the bars \( c_b = \sqrt{E_b/\rho_b} \), in which \( \rho_b \) represents the bar density; \( L_s \) is the length of the specimen and \( A_s \) and \( A_b \) are cross sectional areas of the specimen and the bars, respectively. Furthermore, by considering local stress equilibrium as one of the fundamental assumptions in SHB tests, the strain can be specified to

\[
\epsilon_s = -2 \frac{c_b}{L_s} \int_0^t \epsilon_R dt
\]

and the dynamic Young’s modulus of the specimen is then derived by considering stress and strain in the sample.

\[
E_s = \frac{\sigma_s}{\epsilon_s}
\]

The SHB experiments are based on some fundamental assumptions; the first assumption is related to the alignment of the bars (one dimensional wave propagation theory), otherwise the results would be gained within massive dispersion. Stress equilibrium is another assumption, which simply stands for a uniform deformation in the specimen [4]. It is also essentially important to gain a constant strain rate during the SHB test and in order to do so, a pulse shaping technique is required. In addition, there often exist inertia effects in the SHB test which need to be minimized during the experiment [2, 5].

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3 Pulse shaping

In order to achieve the previously mentioned assumptions and also to design the experimental condition in a reproducible way, thin pulse shapers were used. The pulse shapers are placed between the incident bar and the striker. It is essential that the pulse shaper must be plastically deformable. Therefore, in this study, cylindrically shaped lead and aluminum foil papers with the thickness of 0.5-2 mm were chosen to shape the wave pulse.

![Incident and transmission wave propagation of a tough resin sample with the striker velocity of 10.51 m/s and strain rate of 260/s](image)

**Fig. 1:** Incident and transmission wave propagation of a tough resin sample with the striker velocity of 10.51 m/s and strain rate of 260/s

The introduction of the pulse shapers effectively diminished the dispersion and improved the constant strain rates, which is shown in Fig. 2a. It should be noticed that the different resins have different elastic moduli and slightly different mechanical properties and the transmitted and reflected wave pulses differ.

4 Experimental results

The stress-strain behavior of the tested resins is indicated in Fig. 2b. Each group of resins includes ten samples and each curve represents the mean. As it can be observed from the graph, the tough and white standard resins have almost the same compressive strength, while the flexible resins show the lowest elastic resistance. The dynamic elastic modulus of the different tested resins are derived from relation (4) and show that, among the tested resins, tough resins have the highest dynamic elastic modulus of 3.3 GPa and flexible resins have the lowest of 565 MPa. Moreover, in parallel to the experiment the finite element simulation of SHB test is performed in Abaqus to validate the experimental results. Fig. 2c indicates the displacement contour of a tough resin sample. In addition, PMMA bars were employed in the SHB setup and the results from these bars indicated nearly similar values of the elastic modulus.

![Stress-Strain curves of tested resins](image)

**Fig. 2:** a) Shaping of the incident wave, the marked area indicates an almost constant strain rate of about 500/s, b) Stress-Strain curves of tested resins, c) Finite element simulation; displacement contour of a tough resin sample

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