INTRODUCTION

Most materials show a significant change in mechanical behaviour as the rate of strain (the deformation rate) is increased\(^1\) (see High Strain Rate Effects). This is particularly evident at the high strain rates (> \(10^2 \text{ s}^{-1}\)) which occur under impact or explosive loading conditions. For polymeric materials, both the elastic modulus and the flow stress can increase substantially with strain rate. The split-Hopkinson pressure bar (SHPB) technique is the best established method for determining these dynamic properties of solids at high strain rates in the range of about \(10^2\) to \(10^4 \text{ s}^{-1}\) (see refs. 2 and 3). In its various forms, the SHPB technique can produce stress/strain/strain rate data in compression, tension and torsion.

THE SPLIT-HOPKINSON PRESSURE BAR TECHNIQUE

The most frequently used version of the SHPB technique is the compression system, in which a small disc of the material being investigated is sandwiched between two long, high-strength, steel bars called the loading and transmitter pressure bars (figure 1) (see also Tensile and Compressive tests).

![Figure 1: The basic SHPB arrangement.](image)

The free end of the loading bar is subjected to axial impact by a projectile fired from a gas-gun, the projectile usually being made of a rod of the same material and diameter as the pressure bars. The impact generates an approximately flat-topped trapezoidal, elastic stress pulse which travels along the loading bar at about \(5 \text{ km s}^{-1}\) (\(5 \text{ mm } \mu\text{s}^{-1}\)) to the test specimen where it is partly reflected and partly transmitted. On each bar there are strain gauges (SG1 and SG2), usually positioned at equal distance from the
specimen, which record the loading (or incident) pulse strain $\varepsilon_I$, the reflected pulse strain $\varepsilon_R$, and the transmitted pulse strain $\varepsilon_T$. The mechanical behaviour of the specimen can be obtained by analysing these pulses, as described in the next section.

**SHPB pulse analysis**

Elementary plane-wave propagation theory shows that the engineering values of the specimen stress $\sigma_s$, strain $\varepsilon_s$, and strain rate $\dot{\varepsilon}_s$, are given by

\[
\sigma_s = \left(\frac{A_p}{A_s}\right)E_s\varepsilon_s \tag{1}
\]

\[
\varepsilon_s = -\left(\frac{2c_B}{L}\right)\int_0^t \varepsilon_R dt \tag{2}
\]

\[
\dot{\varepsilon}_s = -\left(\frac{2c_B}{L}\right)\varepsilon_R \tag{3}
\]

$L$, $A_s$ are the original length and cross-sectional area of the specimen, $A_B$, $E_B$ and $c_B$ are respectively the cross-sectional area, Young’s modulus, and axial wave speed for each pressure bar. By measuring $\varepsilon_T$ and $\varepsilon_R$ as a function of time $t$, the stress/strain/strain rate properties of the specimen can then be found.

It can be seen that the stress in the specimen is directly proportional to the transmitted strain pulse (equation 1) and the strain rate is directly proportional to the reflected strain pulse (equation 3). The strain can be obtained (from equation 2) by numerical integration of the reflected strain pulse using, for example, a simple trapezium method with a sampling interval of $1\mu$s. In practice, the strain gauge circuitry (see Transducers) is usually arranged so that the incident and transmitted pulses are recorded as positive quantities. This is done to ensure that the use of equations 1, 2 and 3 leads to the specimen stress and strain being positive in compression.

**True stress and strain**

In the above derivation of engineering stress and strain (see Stress and Strain), the increase of the area of the specimen and the decrease of its length as it deforms in compression have been ignored. Taking these factors into account gives the more realistic true stress $\sigma$ and true strain $\varepsilon$ in terms of the engineering values:

\[
\sigma = \sigma_s(1 - \varepsilon_s) \tag{4}
\]

\[
\varepsilon = -\log_e(1 - \varepsilon_s) \tag{5}
\]