HIGH STRAIN RATE TESTING OF MATERIALS

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Polymers, composites and some metallic materials are viscoelastic and strain-rate sensitive. Under high strain rates the micro mechanisms by which these materials deform is different than that experienced at low strain rates. Consequently, use of quasi-static stress-strain data may not produce accurate and reliable predictions of material and product performance at high strain rates. The use of such data in simulation and FEA leads of improper design of engineering components. An understanding of the mechanical properties of polymers over a range of strain rates, temperatures, and frequencies is thus an imperative requirement. As well as being governed by the composition and microstructure of the materials, these properties are highly dependent on a number of external factors. Common applications where the high strain rate properties are critical are composite and steel material properties in high speed crash analysis of automotive and aerospace structures, high speed ballistic impacts and drop impacts of consumer durables and electronic items.

Most polymers and composite materials exhibit time and temperature dependent mechanical behaviour. This can be inferred by their rate dependent Young’s modulus, yield strength, and post yielding behaviour. Over a range of strain rates from low to high the mechanical properties of these materials may change from gel-like to rubbery to ductile plastic to brittle like ceramics. Along with these strain rate effects, polymers also exhibit large reversible deformations in addition to incompressibility.

Viscoelastic properties of materials play a very critical part in defining the short and long-term behaviour of metals, polymers and composites. To fully characterize this time, frequency and temperature dependent properties of the materials it is important to characterize them in the defamation modes and the rates at which this materials and their products will perform under field service conditions.

Quasi static characterization test methods assess the properties of the material under static conditions. This serves as a good starting point in product design but when the goal is of full field 360 degree characterization of properties to serve the full range from implicit to explicit FEA simulations for drops impacts, to high speed deformation cases then the use of such data will lead to wrong simulation and interpretation of results.

Different types of testing techniques are used to generate data under high speed and dynamic conditions. Each test method satisfies a specific range of strain rates and deformation characteristics. Electro-mechanical test systems, Servo-hydraulic test systems and Split Hopkinson bar testing apparatus are typically used to characterize the properties of these materials at progressively high strain rates. Complexities in applying this testing techniques come from multiple factors such as sample gripping, calculation of strain and strain rates, test data acquisition and analysis of the test data to generate the right response curve.

Figure 1: Electromechanical and Servo-hydraulic Test Setup at AdvanSES

At AdvanSES, we have capabilities to test these materials characteristics using all the three testing apparatus mentioned above.

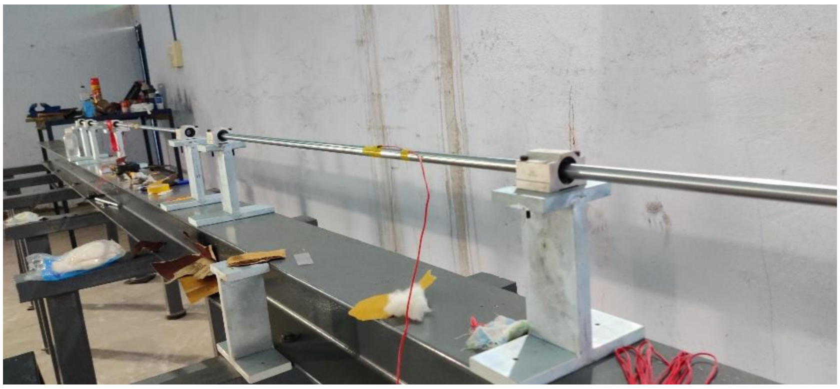

Figure 2: Split Hopkinson Pressure Test SHPB Test Setup at AdvanSES

Strain rate is the change in strain of a material with respect to time. Longer testing time is related to low strain rate, and shorter testing time is correlated to higher strain rates.

When a sample in a tensile test is gradually stretched by pulling the ends apart, the strain can be defined as the ratio ε between the amount of stretch on the specimen and the original length of the band:

$\varepsilon(t) = L(t) - L0/L0$

Where, L_0 is the original length of the specimen and $L(t)$ is the length at time *t*. Then the strain rate is defined by,

$$\acute{\varepsilon}(t) = \frac{\mathrm{d}\varepsilon}{\mathrm{dt}} = \frac{\mathrm{d}(\mathrm{L}(\mathrm{t})-\mathrm{L0})}{\mathrm{L0}} = \frac{1}{\mathrm{L0}}\left(\frac{(L(t)-L0)}{L0}\right) = \frac{1}{\mathrm{L0}}\frac{\mathrm{dL}}{\mathrm{dt}}(\mathrm{t}) = \frac{\mathrm{v}(\mathrm{t})}{\mathrm{dt}}$$

where, $\boldsymbol{v}(\boldsymbol{t})$ is the speed at which the ends are moving away from each other. The unit is expressed as time^{-1}.

Figure 3below shows the stress-strain results from a typical tensile test on a polymer material, as can be seen the test plot is made up of four different regimes. The macro-mechanical response of the material comprises of 4 distinct deformation characteristics.

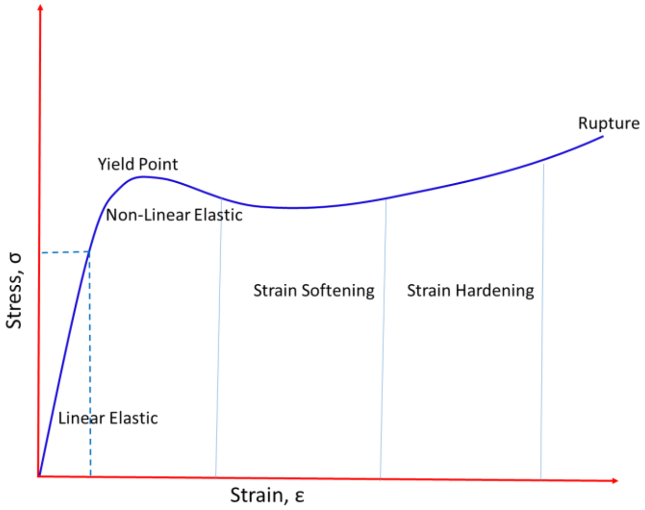

Figure 3: Uniaxial Tension Test Results for a Viscoelastic Rate Dependent Material

The test results show that the slope of the line is not constant throughout the 4 regimes and the material is thus said to exhibit non-linear elasticity. The elastic region is defined in the small initial portion of the results where the slope is constant. On the molecular level the linear elastic phase is caused by the Van der Waal forces acting between the polymer chains. These forces resist the deformation, however once the strain in the material reaches a critical level, the polymer chains begin to slide with respect to one another. The response is non-linear deformation once the Van der Waal forces are overcome.

The yield point shows the local maximum stress value of the material after which the polymer chains show large scale sliding. Subsequently, the response shows a relative softening and later hardening of the material. The strain hardening phase is a result of the randomly oriented polymer chains re-aligning themselves in such a way that requires a higher force application for continued deformation.

Figure 4 shows the test results from testing Polyethylene material as per ASTM D638 at three different speeds under isothermal conditions. At the slowest crosshead speed of 5 mm/minute, the yield strength and the modulus of the material are at their lowest value. As the test speed increases, the yield strength and modulus also increase. The material stiffness increases with the increase in strain rate. The material appears to be getting stronger and tougher under high strain rate conditions. The same effect can also be carried out by keeping the strain rate constant but by decreasing the temperature progressively.

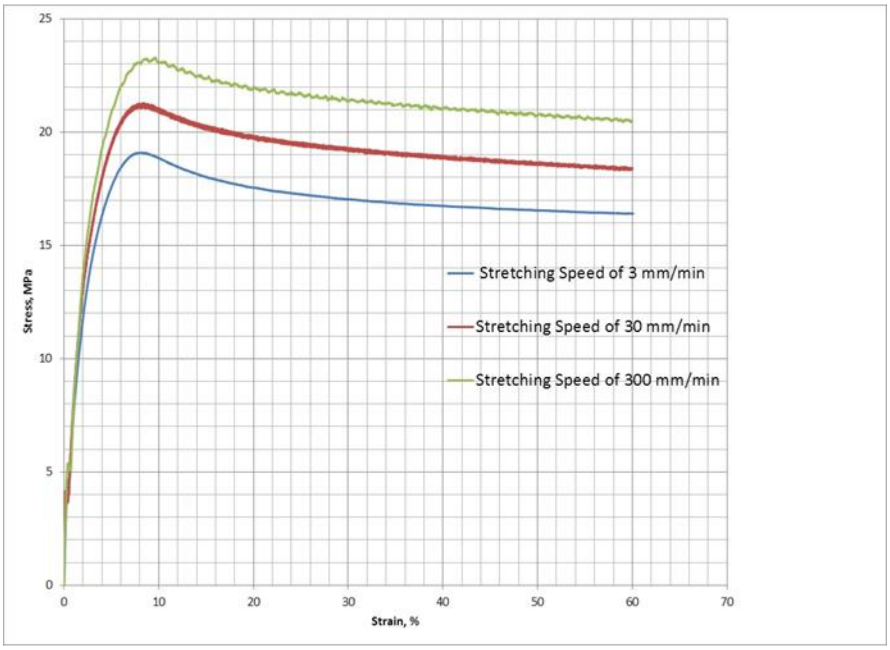

Figure 4: Test Results for PE Material under Variable Strain Rate/Speed

At our laboratory we have studied the mechanical behaviour of High Density PolyEthylene (HDPE) polymer under the effect of various temperatures and strain rates. Uniaxial tensile tests were performed to determine the dynamic response of HDPEs at strain rates varying from 0.0001 sec-1 to 10 sec-1. Dynamic tests were performed at seven different strain rates, and the results in terms of true stress-strain curves are shown in Figure5. The results show that yield stress increases with the increase in strain rate.

The experimental results reveal that the stress-strain behaviour of HDPEs is much different at lower and higher strain rates. At higher strain rate, the HDPEs yield at higher stress compared to that at low strain rate. At lower strain rate, yield stress increases with the increase in strain rate while it decreases significantly with the increase in temperature. Likewise, initial elastic modulus increases with the increase in strain rate. Yield stress increases significantly at higher strain rates in the material.

The stress-strain curves show almost similar mechanical response in which initial nonlinear elastic behaviour was observed followed by subsequent yielding, strain softening and hardening. Yield stress changes significantly with the increase in strain rate. An increase of 20.6 % in yield stress was calculated with strain rate increase from 0.0001 sec-1 to 100 sec-1 At all strain rates, ductile behaviour of HDPEs was observed. Strain-rate dependency of the stress-strain behaviour of polymer materials has now been well documented. This feature of mechanical behaviour is important in engineering applications for automotive and aerospace crashworthiness where the design of a polymer component is required to resist shock and impact loading and other strength stiffening effects.

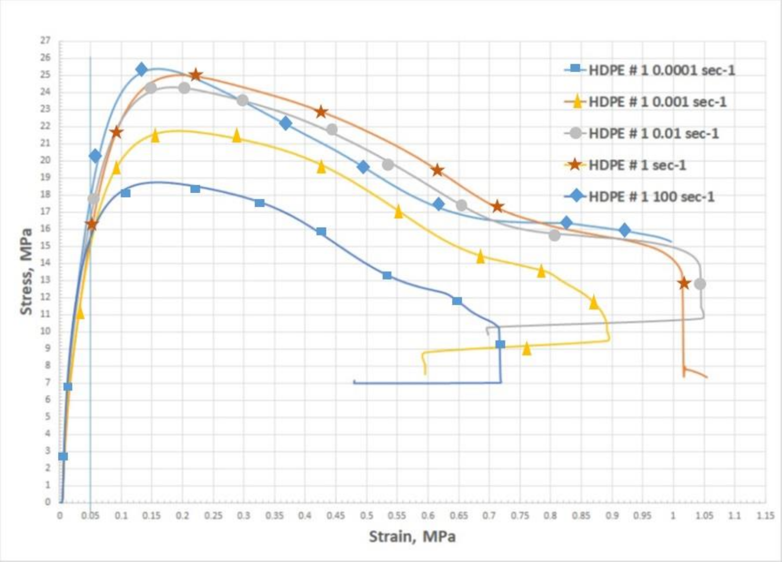

Figure 5: Test Results for HDPE Material under Variable Strain Rate/Speed

Figure 6:AdvanSES Non-contact Measurement and DIC Setup

Some materials have higher strain rate sensitivity as compared to other materials. This is more dependent on the micro structural makeup and deformation physics. It is advisable to test the materials over a range of strain rates and use the data in FEA modelling and simulation.

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