SPLIT FLYING BAR: Device and Method for Investigation of Mechanical Properties of Fibers Under High-Strain Rate Tensile Load.

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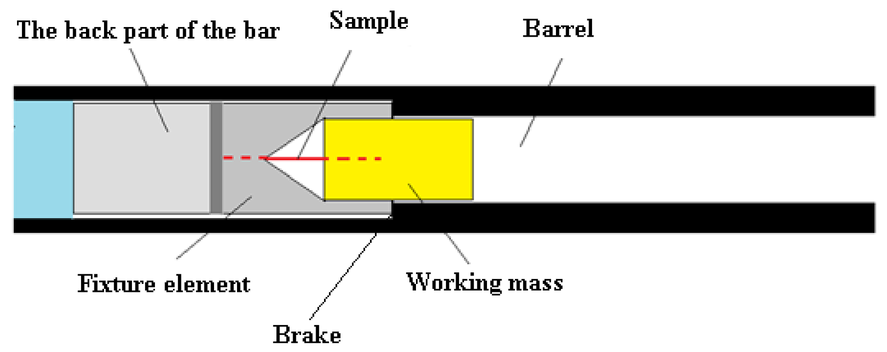
OBJECTIVES AND GOALS

- **The ability to characterize mechanical behavior of the materials under high strain rates, both under compression and tension, is crucial for the material sciences. It not only helps to predict the behavior of the materials under different loading conditions, but also it leads to the deeper understanding of physical and chemical mechanisms underlying the material performance. In turn, such understanding plays the key role in improvement of existing materials and creation of the new ones with required properties.**
- **Since the late 40's, Split Hopkinson Pressure or Tensile Bars (Davies R.M. 1948; Kolsky, 1949; Lindholm & Yekley, 1964; Gray III, 2000; Lopatnikov et al., 2004 a)) have become the most common methods of investigation of material behavior under high-strain rates. The creation of compression stress and associated data reduction are simple and has solid physical background (Gray III, 2000; Lopatnikov et al., 2004 b , Lopatnikov et al, 2011). However, tensile spit bars are significantly more complicated devices and reduction of their data causes serious questions. Moreover, using tensile Hopkinson bar it is difficult to provide enough big strains to measure properties of such important materials as polyerea. In the meantime, other mechanical tensile devices cannot provide high enough strain rate loads.**
- **A new apparatus and method is proposed for the investigation of material behavior under high-strain-rate tensile loads. We refer this apparatus as a Spilt Flying Bar. The Split Flying Bar method is based on the use of inertial forces to create the necessary stress level and strain rate. The method is highly scalable and can be used for characterization of the material properties starting from singular fibers up to specimens of macro-size.**

SPLIT FLYING BAR

The basic principal construction of the Split Flying Bar



The split bar, with the specimen fixed between working mass and back part of the bar, is accelerated by a device such as a (gas) gun, rocket, spring, gravity, etc. After reaching the necessary speed, the backing part having larger diameter is stopped by the brake. In the simplest case the brake can be the taper to the narrower part of the barrel. The working mass, continuing to move forward by inertia, leads to the tensile stress of the sample. The strain rate is dependent on the speed of the flying bar and value of working mass.

Effective strain-rate has the order:

$$\dot{\varepsilon}_{eff} \sim \frac{V}{L}$$

Here V is the speed of the working mass and L is the length of specimen

ENERGY CHOICE

One can choose the kinetic energy of the working mass in accordance with the energy required to break the sample. If the kinetic energy of the working mass is chosen so that:

$$\frac{M_w \cdot V^2}{2} >> U_{cr}$$

Here the energy of sample destruction is U_{cr}. It guaranties that the sample will be destroyed and that the effective strain rate will be practically constant during the deformation of the sample.

Oppositely, if kinetic energy of the working mass is chosen so that:

$$\frac{M_w \cdot V^2}{2} < U_{cr}$$

One will observe both loading and unloading behavior of the specimen. Under this condition the sample will not be destroyed. Changing the working mass simultaneously with the speed of the Flying Bar so that kinetic energy remains the same, one can obtain the set of equai-energy stress-strain diagrams completely representing the rheology of the sample material. It is important in these experiments that the strain rates can vary under the same energy of impact in the wide range. For example, if the length of specimen is equal to 1 cm and velocity of the bar is equal to only 10 m/s, the strain rate will be equal to $10^3 s^{-1}$

In the meantime the Flying Bar can easily reach speeds of 20, 50, 100 m/s or even higher, which would result in strain-rates in the range of $10^4 s^{-1}$

DATA REDUCTION BASICS

Considering established equilibrium, if one can neglect the mass of sample in comparison with the working mass, then the suggested experimental scheme can be described by the simple "pendulum" model: in general one can consider a specimen as a non-linear spring:

$$M_w \frac{d^2 X_W(t)}{dt^2} = F\left(X_w(t)\right) \equiv -S\sigma\left(X_w\right)$$

to get the loading curve of the specimen, it is enough to measure only one value: the speed of the working mass as a function of time. In this case, one obtains the strain of the sample as:

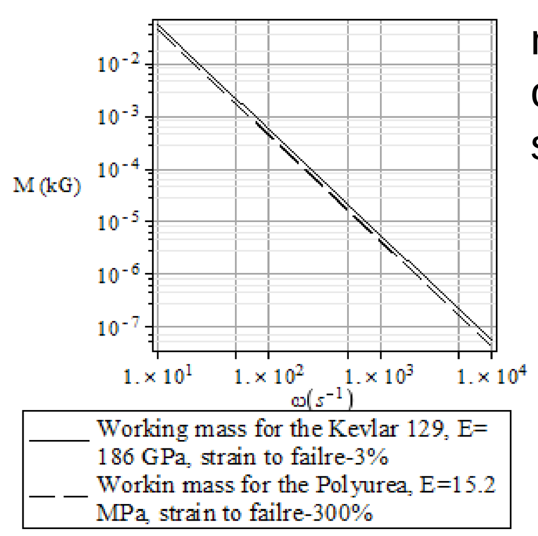
$$\varepsilon(t) = \frac{X_w(t)}{L} = \frac{1}{L}\int_0^t V(t)\,dt$$

stretching stress simply by one-time differentiation of speed:

$$\sigma(t) = -\frac{M}{S}\frac{dV(t)}{dt}$$

CHOICE OF WORKING MASS - I

Here we present a model calculation of the working mass needed to break the sample as a function of the strain rate $10^3 s^{-1}$ The plots are for a 20 micron diameter fiber, having 1 cm-length, strength equal to 186 GPa (which is typical for Kevlar129) and 3% strain to failure, and for polyuria with strength 15.2 MPa and strain to failure 300%, suggesting linear behavior of the sample up to the failure.



One can see that both masses are close to each other. Thus, to reach a strain-rate of $10^3 s^{-1}$ and break the 20 micron diameter 1 cm long fiber one needs a mass approximately equal to 0.05 g

CHOICE OF WORKING MASS - II

If one chooses the working mass significantly bigger, the speed of working mass, and thus the strain-rate will be practically constant up to the destruction of specimen. If one chooses this mass smaller than the mass defined by (9), the specimen will not be destroyed and oscillations of working mass will be observed. One will be able to measure up-load-down-load characteristics of the material, physical energy absorption, progressive failure, etc.

It is clear that proposed method of SLFB can not only be used for obtaining the stress-strain-strain-rate diagrams of the materials, but for many other experiments. For example, to prove high-strain-rate pull-out experiments, investigate high-strain-rate behavior of adhesion layers, connecting fibers and matrix and effect of nano-inclusions.

Method can also be used for macro-specimens and under ballistic speeds.

CONCLUSION

We propose a method for investigation of material behavior under high strain-rate tension. The method is highly scalable and can be applied to a wide range of problems.

It does non have disadvantages of tensile Split Hopkinson Bar, permits wide variety for measuring parameters of interest (stress, strain, strain-rate), and can be used in simple modifications up to ballistic velocities.

Acknowledgments

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