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Evaluation of Tensile Properties of Dyneema Filament

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ABSTRACT: *The Tenacity-Elongation Curves (T-E Curves) of Dyneema Hard Ballistic-50 (DHB-50) filament under quasi-static loading have been obtained. The experimental T-E Curves response over a range of strain rates have been described with the help of the existing equation based on a three-element linear viscoelastic model. The sensitivity in reference to strain rate of DHB-50 has also been observed.*

Keywords: Dyneema hard ballistic-50; Quasi-static loading; Tenacity-elongation curves; Three-element linear viscoelastic model.

INTRODUCTION: Dyneema fibre is the brand name for a special, high- performance grade of Ultra High Molecular Weight Polyethylene (UHMW-PE). This fiber has the chemical composition $[CH_2\text{-}\ CH_2]_n$. Dyneema fibers are produced by a patented gel spinning process [1, 2]. A Dyneema sheet mainly consists of Dyneema filaments that are held together by a small amount of matrix material. The filaments are oriented in alternating orthogonal layers. These orthogonal layers are finally produced usually at 0°-90°orientations. Polyethylene fiber based armour such as dyneema offer an attractive light weight option for personal armour system. Composite and textile armour systems are increasingly being utilized as an impact protection material in weight critical environments. A distinctive application is personal protective equipment for the soldier against ballistic threat. Wang and Xia [3] had studied the effect of strain rate on the mechanical behavior of Kevlar-49 aramid fiber bundles. This study had been performed experimentally under strain rate ranges from 10^{-4} s^{-1} to 10^{3} s^{-1} and verified by existing theoretical formulation. The experimental results show that Kevlar-49 fibers have sensitivity to strain rate. Utomo and Broos [4] had determined dynamic material behavior using single fiber impact and result indicate that the failure stress and failure strain have strong dependency on the impact velocity. It's impact velocity effect is more pronounced for the aramid fiber as compared to the UHMW-PE fiber. Tan et al. [5] had studied the characterization and constitutive modeling of aramid fibers at high strain rates. The comparative study of the simulations and actual ballistic tests shows that predictions of the energy absorbed by the aramid fabric are in good agreement with each-other. Zhu et al. [6] had performed high strain testing of Kevlar-49 and concluded that the high speed testing can be performed at strain rate upto 170 s^{-1}. Further, they had also concluded that the dynamic material properties such as Young's modulus, Maximum Stress and Strain of Kevlar-49 are sensitive to strain rate. Cherif et al. [7] had performed the tensile test to the determination of the material behavior of filament yarns under high strain rates. They had concluded that the existence of suitable test machines and test methods for filament yarns are not state of the art. Hence, tensile tests with high strain rates on filament yarns are performed on standard high-speed tensile testing machines. This test concludes that there is problem in analyzing and interpreting the results and therefore it is necessary to develop special testing machines for filament yarns. Wang and Xia [8] had carried out dynamic tensile tests on Kevlar-49 fibre bundles using the Split Hopkinson Bar at the strain rates of 140 s^{-1}, 440 s^{-1} and 1350 s^{-1} imposed on specimens over a temperature range from - 60°C to 90°C. Huang et al. [9] had performed the studies on UHMWPE fibre bundles at strain rates of 300 s^{-1} and 700 s^{-1} at the temperatures of 25°C and 70°C. They have concluded that the initial modulus and failure stress decreases with increase in temperature, whereas the failure strain increases with increase in temperature. Prevorsek et al. [10] had worked on Spectra - 1000 fibres to illustrate the tension test at the strain rates up to 5×10^{2} s^{-1} using an Instron High-Rate Testing Machine. They have showed that the elastic modulus of the fibre increases with strain rate.

The aforementioned scholarly contributions indicate that there is growing concern among researchers to examine, investigate and analyze various parameters associated with tensile testing of different materials. However, on the basis of relevant and available literatures we have noted that there is still a gap in previous researches in reference to the tensile properties of Dyneema Filament (DHB-50). Seeing the present scenario we have explored the tenacity-elongation curve of Dyneema Hard Ballistic-50 (DHB-50) in addition to the strain rate.

MECHANICAL OBSERVATIONS:

FILAMENT TENSILE TESTING: Dyneema Hard Ballistic-50 (DHB-50) fabric of high- performance grade of Ultra High Molecular Weight Polyethylene (UHMW-PE) made from filament have also been used in armour application subsequently subjected to high rate of loading. Reference to the tensile testing, Quasi Static Tensile Property of DHB-50 filament has been examined. Firstly, filaments have extracted from fabric in order to get denier of the filament by using Vibroskop Machine as shown in **Fig 1**.

Fig 1: Vibroskop Machine: Determination of Denier of the Filament.

For taking average of filament denier, 30 tests were examined. After determining a denier of filament, tensile strength of filament has been acquired by using Vibrodying Machine as shown in **Fig 2**. In Vibrodying Machine, Upper end of filament was fixed in top chops while lower end of filament has been loaded with 150 mg weight. The test speed was 5 mm/ minute and the filament gauge length was 20 mm. The denier, modulus, elongation etc. of the DHB-50 filament has been tabulated in **Table 1**.

Fig 2. Vibrodying Machine: Determination of the Tensile Strength of the Filament.

Table 1. Physical Parameters with their values of DHB- 50 Filament.

Physical Parameters	Value
Density (g/ cm^3)	0.97
Denier (den)	1.7
Staple Length (mm)	20.0
Gauge Length (mm)	20.0
Test Speed (mm / min)	5.0
Tension Weight (mg)	150.0

The experimental mean tenacity – elongation curve of the DHB-50 filaments are shown in **Fig 3**. Microscopic optical examinations of post-test filament specimens have been done by using a Zeiss Optical Microscope (**see Fig 4**) at a magnification of 20× as shown in **Fig 5**. **Fig 5 (a)** indicates before failure and **Fig 5 (b-e)** shows after failure of the filament.

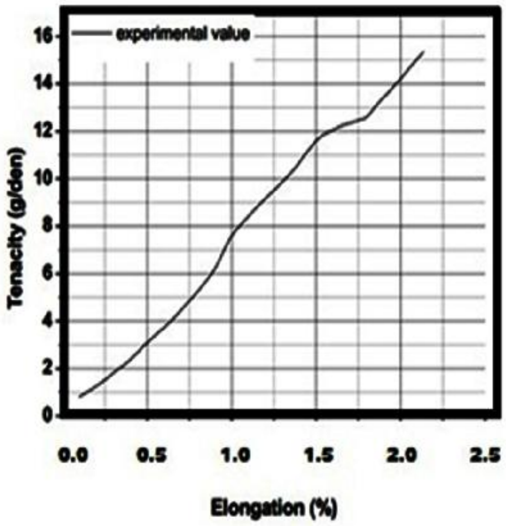
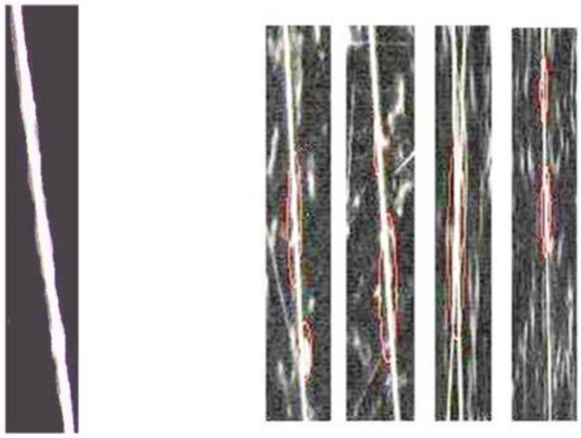


Fig 3. Tenacity-Elongation of the DHB Filament: A Mean Curve.

Fig 4. Zeiss Optical Microscope: Microscopic Optical Examinations of Post-Test Filament Specimens.



5 (b-e)

5 (a)

Fig 5. Microscopic optical examinations of post-test filament specimens at 20 × magnification. The **fig 5 (a)** indicates before failure **fig 5 (b-e)** shows after failure of the filament.

FITTING OF THREE-ELEMENT VISCOELASTIC MODEL: The experiential formulations have been fitted with existing analytical equations for linear viscoelastic constitutive relation of the filament [5]. The viscoelastic behavior of DHB-50 filaments containing system of springs and dashpots which represents the elastic-solid and fluid- like nature. The Tenacity–elongation response of a three-element viscoelastic model (see **Fig 6**) is written as [5]:

$$\sigma = \frac{k_1 k_2}{k_1 + k_2}\,\varepsilon + \frac{k_1^2 \mu}{(k_1 + k_2)^2}\,\dot{\varepsilon}\left\{1 - exp\left[-\frac{(k_1 + k_2)\varepsilon}{\mu\dot{\varepsilon}}\right]\right\} \quad \textbf{(1)}$$

The explicit expression of stress (σ) as a function of strain (ε) and strain rate ($\dot{\varepsilon}$) is apparent from **Eq (1).** For initial conditions: strain (ε) = 0, strain rate ($\dot{\varepsilon}$) = 0 and σ = 0, the explicit expression of Young's Modulus (E) as a function of strain (ε) and strain rate ($\dot{\varepsilon}$) can be written as **Eq (2)** :

$$E = \frac{k_1 k_2}{k_1 + k_2} + \frac{k_1^2}{k_1 + k_2}\,exp\left[-\frac{(k_1 + k_2)\varepsilon}{\mu\dot{\varepsilon}}\right] \quad \textbf{(2)}$$

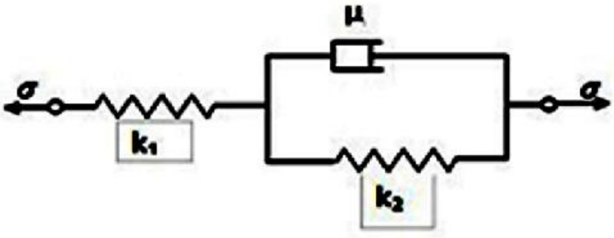


Fig 6. Three element viscoelastic model.

It shows that stiffness is a function of strain rate ($\dot{\varepsilon}$) with parameters k_1, k_2 and μ. The optimized values of these three parameters have been determined from least - square fit method with the help of **Eq (1)**.

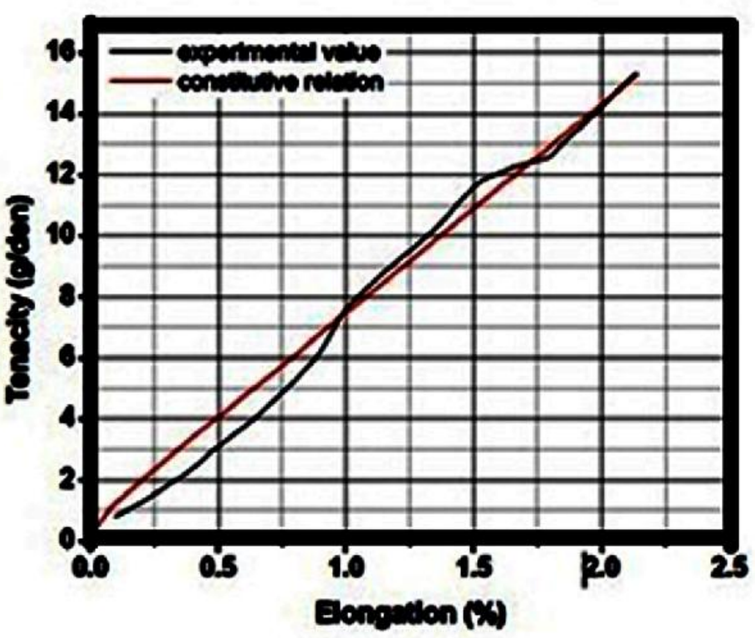


Fig 7. Comparative Tenacity-Elongation Curve of experimental vs. analytical data at Quasi-Static Strain Rates (4×10^{-3} s^{-1}).

Fig 7 shows a comparative Tenacity-Elongation Curve of experimental vs. analytical data at Quasi-Static Strain Rate (4×10^{-3} s^{-1}). It has been found that the value of the parameters k_1, k_2 and μ are 19.5 GPa, 10.6 GPa and 372.1 MPas respectively. These results are reasonably correlated with the experimental data.

RESULTS AND CONCLUSIONS:

Following lines summarize the results and conclusions of the evaluation of tensile properties of dyneema (DHB-50) filaments:

- The tensile test of DHB-50 filament shows modules 7.52 (g/den) and elongation 2.14% at strain rate of 4×10^{-3} sec^{-1}.
- A constitutive relationship based on three element linear viscoelastic model has been formulated to describe the experimental tenacity elongation curve.
- Three element model has been adopted because it embodies the essential characteristic of viscoelastic behaviors (Creep and Stress relaxation) which are significant in polymeric material.
- There is close correlation between the analytical and experimental results at the strain rate of 4×10^{-3} sec^{-1}.
- The parameters k_1, k_2 and μ are 19.5 GPa, 10.6 GPa and 372.1 MPas respectively.
- The fracture observed in DHB-50 filament is splitted axially at strain rates of 4×10^{-3} sec^{-1} with fibrils.
- The limitation of the analytical model cannot fully capture the small degree of non-linearity at quasi-static strain rates.

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