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On the experimental testing procedures for ultra-high molecular weight polyethylene (UHMWPE) behaviour evaluation in static and dynamic regime

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Abstract. Over the past decade, extensive work has been carried out on the study of materials behaviour subjected to a variety type of loads, especially on new materials with improved mechanicals properties. The UHMWPE, ultra-high molecular weight polyethylene, a material with hight resistance at static, dynamic and even impulsive loads that can have a large number of practical applications is proposed to be studied in this article. The current paper aims to propose a series of experimental procedures in order to characterise the behaviour of different specimen types of ultra-high molecular weight polyethylene subjected to static and dynamic loads. Laboratory tests were performed aiming to confirm the proposed experimental approach.

Key words: mechanical testing, ultra-high molecular weight polyethylene

1. Introduction

The development of materials with high performance properties has led to the replacement of traditional materials with ceramic, plastic and composite materials.

The subject of this new materials with good properties is well represented in the scientific literature of the last decades, being intensively studied by several researchers [1, 2, 4, 5].

Moreover, a material property chart has been realized by [2] where is represented the specific strength versus specific modulus for common fibres (Figure 1).

In recent years, the aramids have been challenged by a family of polyethylene fibers, namely ultra-high-molecular-weight polyethylene (UHMWPE).

This material is known as high-modulus polyethylene and its properties depend largely on the molecular mass and the degree of polymerization. The special mechanical properties derive from the summation of weak Van der Waals bonds between molecules. The UHMWPE fibers are axially directed and have in a proportion of 95-99% a crystalline structure in a unidirectional form [1].

The disadvantage is the upper limit of the temperatures of use, inferior to the aramid fibers. Due to the fiber processing temperature limit (120° C), the range of resins with which these fibers can be combined is limited [1].

The UHMWPE fibers are mixed with a polyurethane matrix to form a 0°/90° cross-ply composite, layers bonding being obtained by hot pressing. The main types of UHMWPE fibers models are Certran fibers, Dyneema fibers, Spectra fibers and Tensylon fibers. As regards their manufacturing mode, Spectra and Dyneema are obtained by gel and fiber Tensylon, is obtained from pressed powder [2].

The polyethylene laminate proposed for the experimental study is Dyneema HB26.

Dyneema is often used by European manufacturers, is available in a wider variety of yarn sizes, and is growing in popularity in North America.

Dyneema HB26 is a lightweight polyethylene fiber composite laminate for special protection applications. A product roll consists of four unique layers of unidirectional sheets intersected at 90° from each other and reinforced with a polyurethane (PUR) matrix [3].

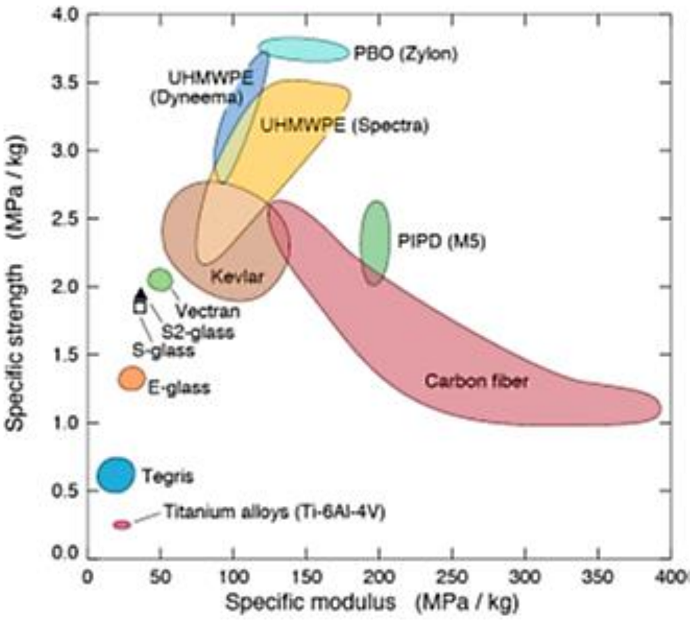


Figure 1. The specific strength versus specific modulus for common fibres organised in a material property chart [2]

The paper presents a series of experimental procedures in order to observe and analyze the behavior of different specimen types of ultra-high molecular weight polyethylene Dyneema HB26 subjected to loads in static and dynamic regime.

The laboratory tests are intended for the fundamental analysis of materials behavior with potential in mitigating the effects of mechanical stresses.

The experimental approach comprises a series of three distinct tests with three different geometry specimens: two for compression test and one for tensile test.

2. Experimental testing procedures

The experimental testing procedures have the role to see how the material behave when is subjected to different types of loads, namely compression tests and tensile tests. Also, static and dynamic regime is taking into account.

The experimental machines for static regime belong to Laboratory for testing and advanced mechanical characterization of materials from POLITEHNICA University of Bucharest.

The Split Hopkinson pressure bar belongs to the Laboratory of integrated weapons systems and CBRN defense from Military Technical Academy Ferdinand I.

2.1 On the material and material specimens

The Dyneema HB26 is a fiber reinforced composite with reinforcing yarns of grade SK76 made of ultra-high molecular weight polyethylene. The yarns have 780 filaments which are embedded in a matrix of polyurethane. The strength value for this material is 3,6 GPa [3].

Three types of specimens are proposed to be tested for material evaluation from a panel with a thickness of 15 mm and density of 980 kg/m^3. The specimen types are presented in Figure 2: dog-bone specimen, cylindrical specimen and cubic specimen.

Figure 2. The Dyneema HB26 material sample and the three types of specimens proposed for experimental testing

2.2 On the tensile laboratory tests

For tensile test the INSTRON 8872 system for static and dynamic axial tests was used. The system has two-column that ensures increased rigidity, an actuator cylinder and force cell positioned at the top on the movable cross member. The Bluehill® Universal software combined with the system allows extract data about the test performed with accuracy and integrity.

The Dynacell dynamic load cell incorporates dynamic compensation, which minimizes the effects of inertia on the force measurement. This is particularly important in tests where the load cell is subjected to rapid or prolonged acceleration.

In Figure 3 the experimental set-up for tensile test is presented.

Figure 3. Experimental tensile testing of specimens in static mode (2 mm/min)

2.3 On the compression laboratory tests

For compression test the INSTRON 8800 system was used.

The testing system has a digital 8800 controller that provides full system control with features such as, specimen protect, automatic loop tuning, amplitude control, 19-bit resolution across the full range of transducers, and adaptive control technology. It also allows access to Bluehill® Universal software for static tests for data recording. In Figure 4 the experimental set-up for compression test is presented.

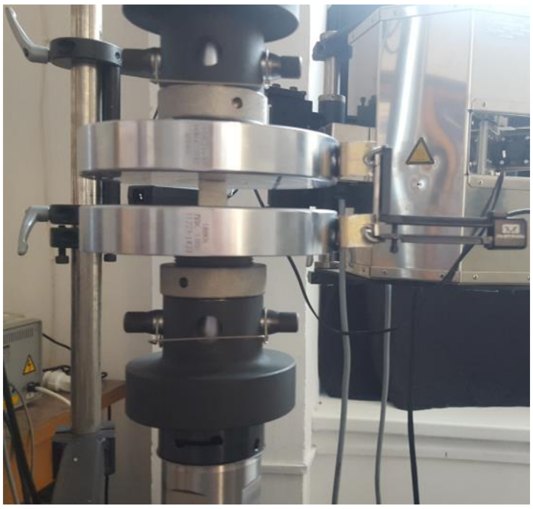


Figure 4. Experimental set-up for compression testing of specimens in static mode (1 mm/min)

2.4 On the Split Hopkinson pressure bar dynamic tests

For experimental tests with Split Hopkinson pressure Bar an experimental set-up was realized. Besides the experimental device, the following equipment were used: Picoscope 6 Data Acquisition and Measurement System and the ultrafast film shooting system PHOTRON FASTCAM SA3 model 120K-C2. In Figure 5 is presented a schematic view of Split Hopkinson Pressure Bar with an illustration of the general configuration of transducer location [4]. The sample behavior will be characterized using the elastic strains of installation bars recorded in time.

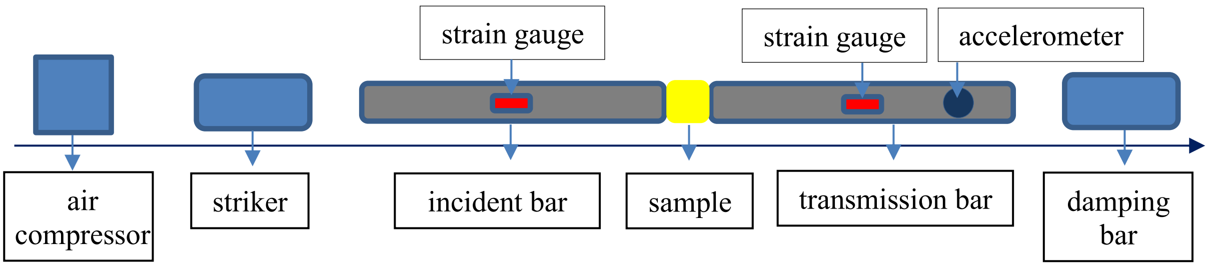


Figure 5. Experimental set-up of Split Hopkinson pressure bar experimental device

The Picoscope 6 Data Acquisition and Measurement System is composed of: an analog-digital multi-channel acquisition system of functional parameters, two strain gauges and an accelerometer. It will measure at the same time on the 3 channels from 8 available. The multichannel analog-digital acquisition system of the operational parameters consists of: signal conditioner, PICOSCOPE 3424 oscilloscope and notebook (Figure 6). The PICOSCOPE 3424 oscilloscope is a four-channel digital oscilloscope designed to measure multiple signals simultaneously, very useful for field trials for is small size.

a 

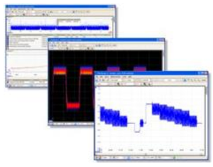
b  c

Figure 6. Picoscope 6 Data Acquisition and Measurement System:
a) 8-channel signal conditioner 498A, b) Picoscope Oscilloscope, c) Picoscope 6 Software

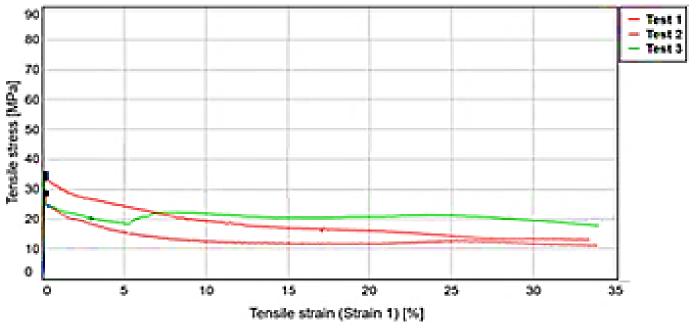
The software used, PicoScope 6, includes the following features: advanced zoom functions, mathematical functions, reference databases, resolution enhancement, spectral analysis functions, data processing capabilities. Real-time signals can be viewed on the notebook and can be easily analyzed.

Ultrafast film shooting system PHOTRON FASTCAM SA3 model 120K-C2 is a high-speed camera featuring sensor that enables double-exposure operation, making it easy to record motion at very high speeds. The sensor delivers color digital images with a resolution of 1.3 million pixels (1280Hx1024V) and the image acquisition rate can increase up to 100,000 frames/second. The camera is intended for use in industrial applications and scientific research.

3. Results and discussions

The experimental results are referring to different data that are provided by the testing systems and also to the observations regarding the post-test aspects of specimens.

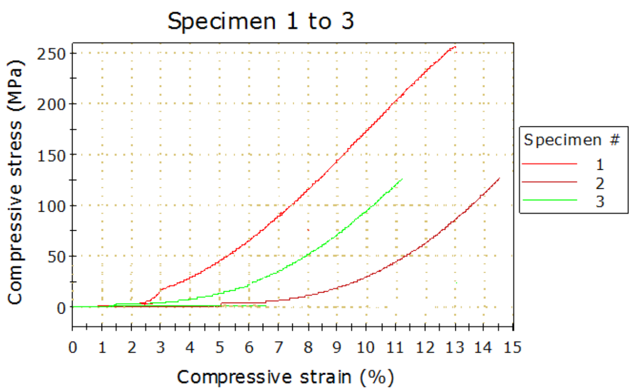
For the static tensile testing, in Figure 7a the tensile strength-tensile strain curves are presented. In terms of dog-bone specimen's aspect, the delamination process for upper layers is observed (Figure 7b).



a)  b)

Figure 7. Static tensile test results with Instron system (2mm/min)

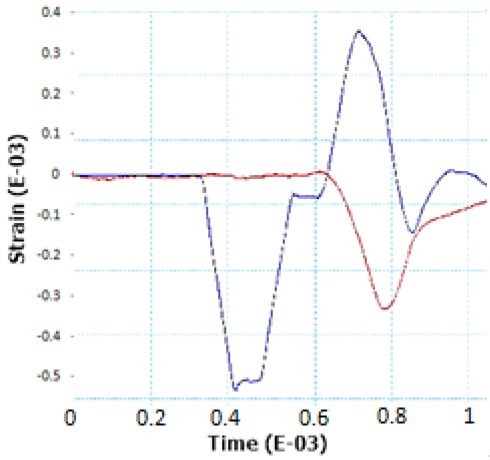
For the static compressive tests, in Figure 8a the compressive strength-compressive strain curves are presented. In terms of cubic specimen's aspect, the fiber slipping process for inner layers (Figure 8b) is observed.



a)  b)

Figure 8. Static compression test results with Instron system (1mm/min)

For the dynamic compressive testing with SHPB system, in Figure 9a the elastic strains curves are presented. In terms of cylindrical specimen's aspect, the fiber slipping process for inner layers is observed (Figure 9b).



a)


b)

Figure 9. Dynamic compression test results with the Split Hopkinson pressure bar system (5m/s)

4. Conclusion

The ultra-high molecular weight polyethylene has become intensely studied in the field of special applications because of the highest impact strength given by intermolecular interactions.

The measurement procedures and methods are based on the observation and measurement techniques in the field of UHMWPE testing standards. The mechanical behavior characterization implies the determination of constitutive models which must be in good correlation with the experimental stress/strain diagrams given by experimental equipment.

Laboratory tests were performed aiming to confirm the proposed experimental approach.

The experimental tests must be continued with experiments that induced high strain rates in tested specimens to analyze also the material dynamic/impulsive mechanical behavior.

Further a series of theoretical and numerical simulations and analysis approaches can be developed to investigate the Dyneema HB26 and must be conducted in order to validate the constitutive laws.

Acknowledgements

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