EAN 2018
56th conference on experimental stress analysis

Mechanical Behaviour of Foam Used in Joint Protectors

KOTTNER Radek[1, a], KAŇÁKOVÁ Sandra[2,b] , ŠOLTÉS Lukáš[1,c], BOŃKOWSKI Tomasz[1,d] and KRYSTEK Jan[1,e]

[1]NTIS - New Technologies for the Information Society, Faculty of Applied Sciences, University of West Bohemia, Technická 8, 301 00 Pilsen, Czech Republic

[2] Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia, Technická 8, 301 00 Pilsen, Czech Republic

[a]kottner@kme.zcu.cz, [b]kanaksan@students.zcu.cz, [c]soltesl@ntis.zcu.cz, [d]tomasz@ntis.zcu.cz, [e]krystek@ntis.zcu.cz

Keywords: Compression test, foam, impact test, joint protector, tensile test.

Abstract. This work demonstrates experiments carried out on a foam, which is used in joint protectors. Three types of experiments were carried out: a compression test, a tensile test and an impact test. The compression and the tensile tests were each realized for two different strain rates. The impact test was carried out for three impact velocities, for which ten repetitions were realized. Tested samples were cut from the shoulder protector by CNC milling machine. Obtained data were evaluated and subsequently can be used as a target for material model optimization.

Introduction

The best possible means of protection are not only matter of professional sportsmen and military services, but also motorcyclists. Motorcyclists are frequently exposed to dangerous high-speed situations, so it is natural that they demand effective protective equipment. However, creating a reliable protective equipment can be time consuming and expensive concern. Therefore, it is convenient to be able to simulate a mechanical response of the used material [1]. This ability subsequently allows easier improvement of the protector design.

This work pursue the previous research [2] and demonstrate the behaviour of an energy absorbing foam in the course of different loading and validate different types of means used for the force determination. Tested foam is widely used in motorcyclist protective equipment, e.g. shoulder and spine protectors. Used samples were cut from the central part of the shoulder protectors.

The aim was to obtain the force response during the different type of the foam loading, namely for compression, tension, and impact tests. Emphasis was put on the impact test, because this type of test matches presumed loading of the protector. Even though, the tension, especially for higher value deformation, is not usual type of loading of this material. Unfortunately, the tension stress/deformation curves are required for some material models. Therefore, it was necessary to realize this test. An example of the material model created from a series of stress/strain curves is shown in [3].

Obtained material data can be used either for the comparison with another type of material or its material model identification. Using the model of the foam together with the model of the leather [4] will allow the creation and evaluation of different designs of motorcyclist garments including the protectors. Furthermore, these models will be coupled with the model of a motorcyclist body and together will be used for simulations of motorcycle accidents [5].

Experiments

Three types of experiments were carried out: a compression test, a tensile test and an impact test. The samples used for each experiment were cut from the shoulder protector by a CNC milling machine. All the experiments were realized in the temperature equal to 23 ± 1 °C and the humidity equal to 5 ±6 %.

Compression test. The experiment was carried out in the ZWICK/ROELL Z050 universal testing machine. Two different deformation velocities were selected to demonstrate the strain rate dependency, which is typical for energy absorbing materials. It was 0.00909 s^{-1} for the slow test and 0.90909 s^{-1} for the fast test. Measured samples were in a truncated cone shape. The geometry of the samples is specified in Table 1. Samples were compressed until their deformation reached the value equal to 0.8, then they were left 60 s to relax, and subsequently they were relieved. Force response was detected during the process.

Tab.1 Compression test samples parameters
($\dot{\varepsilon}$ is the strain rate, r_1 the upper base radius, r_2 the lower base radius, l_0 is the sample height)

$\dot{\varepsilon}$ [s^{-1}]	0.00909	0.90909
r_1 [mm]	14.0	14.5
r_2 [mm]	15.5	15.0
l_0 [mm]	11	11

The results of the compression test are displayed in Fig. 1. It is necessary to convert the force response to the nominal stress in order to compare detected values for each velocity. The strain rate dependency is evident from Fig. 1. The maximal nominal stress reaches the value equal to 2.422 MPa for the slow test and the value equal to 8.170 MPa for the fast test. Ability of the foam to relax is also apparent from Fig. 1, where is a considerable decrease of the nominal stress value in the case of the maximal deformation.

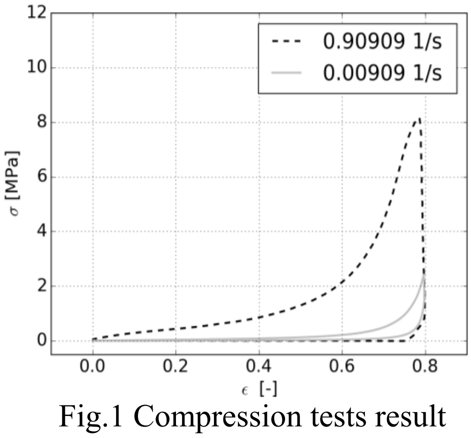

Fig.1 Compression tests result

Tensile test. This experiment was designed to correspond with the compression test, therefore, it was carried out for the same strain rates, 0.00909 s^{-1} for the slow test and 0.90909 s^{-1} for the fast test. The slow test was performed in the ZWICK/ROELL Z050 universal testing machine and the fast test in the INSTRON 8850 testing machine. The sample had the rectangular base of 11 x 20 mm and its length was 180 mm. The length measured by an extensometer was 80 mm for the fast test and 40 mm for the slow test.

The results are displayed in Fig. 2. The negative stress values are notable for the slow test, which was caused by the inability of the foam to relax fast enough. The maximal nominal stress is 0.312 MPa and the minimal nominal stress is -0.022 MPa. The peak at the beginning of the fast stress/deformation curve was caused by the INSTRON jaw inertia. Unfortunately, a sample failure occurred at the end of the sample loading, therefore there are no relaxation and unloading data. There is a marginal decrease of nominal stress, apparent in Fig. 2. Due to the character of the stress/strain curve, the maximal nominal stress was reached before achieving the deformation of 0.8. Its value is 0.812 MPa.

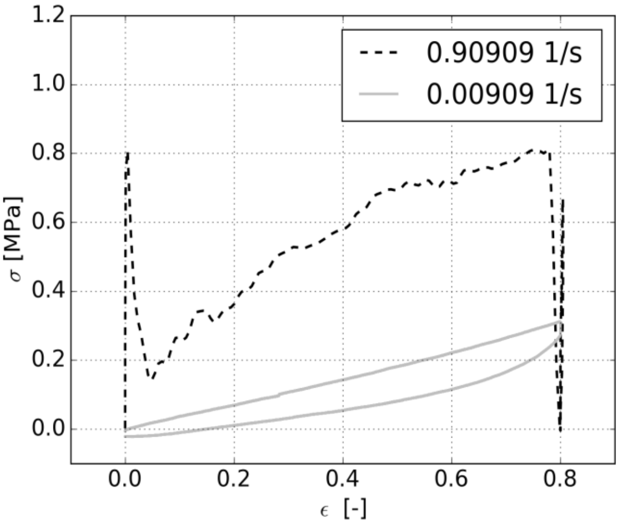

Fig.2 Tension test results

Impact test. This experiment was performed in a drop tower designed by the authors. The impact test was carried out for three impact velocities, namely 1 m·s^{-1}, 2 m·s^{-1}, and 3 m·s^{-1}, for which 10 repetitions were realized. The impactor with a flat steel head weighted 2.454 kg. The impactor displacement, the force response and the impactor acceleration were measured during the experiments. The reaction force was determined in three ways, directly by the force cell KISTLER 9712B5000 and indirectly as the multiple weight of the impactor and its acceleration. The acceleration was measured by the accelerometer KISTLER 8702B500M1T in one case and it was calculated as the second derivative of the impactor displacement in the another one. The displacements were measured using the Micro-Epsilon optoNCDT 2300-50 laser. Sampling frequency was 26 kHz.

The impactor releasing height was determined as:

$$h = \frac{v^2}{2g} + l_0, \tag{1}$$

where v is the impact velocity, g is the gravitational acceleration equal to 9. 81 m·s^{-2} and l_0 is the sample height. Its values are stated in Table 2.

Tab.2 Impact test parameters
(v is the impact velocity, b_1 and b_2 are the rectangular base length, l_0 is the sample height, h is the impactor releasing height, m is the sample mass)

v [m·s^{-1}]	1	2	3
b_1 [mm]	21	20	21
b_2 [mm]	20	19	20
l_0 [mm]	11	11	11
h [mm]	62	218	470
m [g]	1.30	1.18	1.27

Fig. 3 shows the maximum deformation for 10 repetitions of each impact velocity. In the legend, the index symbol denotes the impact velocity value in m·s^{-1}. It is obvious that the maximal deformation values increase with the increasing velocity.

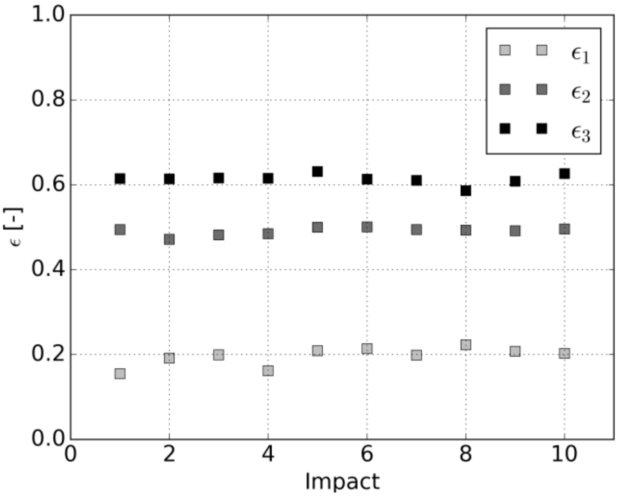

Fig.3 Maximum deformations during impact test

Fig. 4 shows maximum forces during the impact test for the three impact velocities. It also shows the comparison of the three ways of the force response determination. In the legend, the index symbol denotes the device used for the force response determination, index f belongs to the force cell, a to the accelerometer and d to the laser (the displacement second derivation). The number in the legend determines the value of the impact velocity in m·s^{-1}. It is obvious that the used accelerometer is not suitable tool for the reaction force determination. However, disunity of the measured values could be caused by the accelerometer fastening, which contained from the magnet. It is possible that there was an unpredictable movement during the impact. On the other hand, the force cell and the laser appear to be eligible for this task. The force response, determined with the second derivation of the displacement, is slightly higher than from the force cell. This phenomenon does not have to be necessarily incorrect. Thus the determined force response can be considered safer. From the increasing trend of the force response values, the most notable for impact velocity of 3 m·s^{-1}, it is apparent that 60 s relaxation period was not sufficient. Force response values for the first impacts are stated in Table 3.

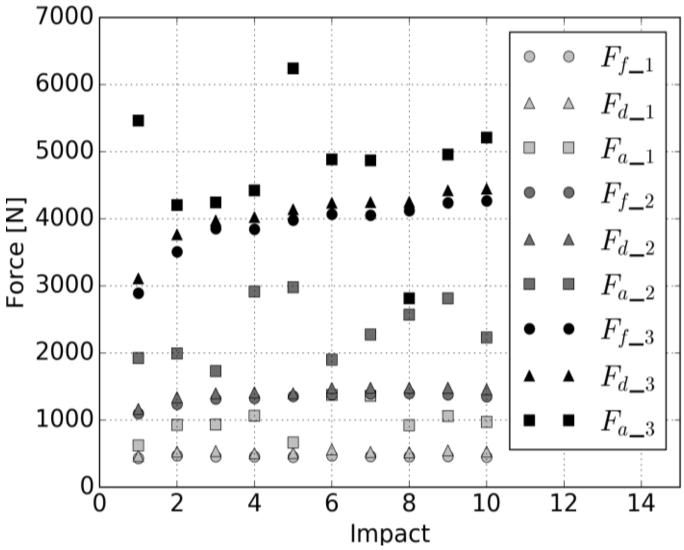

Fig.4 Maximum forces during impact test

Tab.3 First impact test results
(v is the impact velocity, F_f is the force response measured by force cell, F_d is the force response determined by second displacement derivation and F_a is the force response calculated by measured acceleration)

v [m·s^{-1}]	1	2	3
F_f [N]	430	1099	2895
F_d [N]	468	1168	3110
F_a [N]	622	1927	5464

Conclusions

The accelerometer was not proved as a suitable tool for the reaction force determination. However, the force determined as a multiple of the impactor mass and the second derivation of the displacement, appears to match directly to the measured force response.

The energy dissipation, which significantly rises with the increasing strain rate value, proves the foam suitability as a protector. Although the increasing trend of the maximal force response values was registered, the foam still protects even when the impact is repeated. This is the distinctive benefit over the plastic protector, which can get destroyed after the first impact.

The obtained data serves as the target for the identification of the material model. Since the higher temperature can negatively affect the energy dissipation ability and the higher temperature exposure is a real possibility for motorcyclists, the experiments will be also carried out under different temperature conditions in the future.

Acknowledgement

The work was supported by the research project LTC17001 “Exploitation of virtual human model for reducing injury risk of PTW riders” as the national link to the COST Action TU1407 “Scientific and technical innovations for safer Powered Two Wheelers (PTW)” and the internal grant project SGS-2016-059 “Computer modelling and monitoring of human body used for medicine”. The authors would like to thank PSí Hubík for providing foam samples.

References

[1] The P. Talaia, D. Moreno, D., M. Hajžman, L. Hynčík, A 3D model of a human for powered two-wheeler vehicles, 23rd International Conference on Noise and Vibration Engineering (2008) 2229-2238.

[2] L. Šoltés, T. Bońkowski, R. Kottner, L. Hynčík, Drop test of foams used in motorbike protectors, 55th Conference on Experimental Stress Analysis (2017).

[3] G. Milne, C. Deck, N. Bourdet, Q. Alline, A. Gallego, R.P. Carreira, R. Willinger, Assessment of bicyclist head injury risk under tangential impact conditions, IRCOBI Conference (2013).

[4] T. Bońkowski, L. Šoltés, L. Hynčík, R. Kottner, P. Kochová, Leather for motorcyclist garments: Multi-test based material model fitting in terms of Ogden parameters, Applied and Computational Mechanics 11 (2017) 129-136.

[5] L. Hynčík, T. Bońkowski, R. Kottner, Virtual assessment of motorcycle helmet contribution to decreasing injury risk in impact, 37th FISITA World Automotive Congress (2018).