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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF CONNECTOR WITH ELASTOMER JOINT

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Abstract

This article presents works associated with the design, numerical-analyses and experimental tests of an energy-absorbing mat designed for increasing the safety of the soldiers inside military vehicles, especially their legs. One of the most important branches of engineering interests is high technologies accompanying the safety of soldiers. Energy absorbing mats are one of an additional equipment of a military vehicle, which is directly targeted to increase leg safety during explosion of IED (Improvised Explosive Device) under vehicle. The presented invention allows protection legs of the crew's feet resting on the floor of the vehicle during explosion of a mine or IED. In most solutions, crewmembers' foot rests directly on the floor, causing serious injuries. The value of the load on the metatarsus and tibia is closely related to the overall vehicle structure, which generally has limitations in the use of available external and internal protection solutions. Energy absorbing mats are a universal solution because they are adaptable to any type of vehicle. Their role is particularly important in flat-bottomed armoured vehicles. The article will show the results of the analysis showing how the mat works. Experimental results will be compared with the results of numerical analysis. The analysis is conducted using the LS-DYNA explicit code.

Keywords: *elastomer, energy absorbing, LS-DYNA, experimental tests, FEM analysis*

1. Introduction

The problem of limiting the impact of a mine explosion is an extremely complex and difficult issue, so the scope of this article is limited to the most common injuries – the lower limbs.

The aim of the study was to perform numerical analyses of the impact of the mine explosion wave under a military vehicle on the load of the lower limbs of the crew and to investigate the possibility of reducing injuries with the use of energy-consuming materials on the mats used under the feet of vehicle occupants [4]. Mat structures must exhibit great flexibility so that they can freely deform under the force depending on the vertical acceleration and mass of the lower limbs. The material, which the mat was made, was an elastomer. Hyperelasticity of this type of materials mean the ability of a material to large elastic deformations under load of low forces without losing the initial properties.

Numerical analyses were performed using FEM (Finite Element Method) in LS-DYNA environment. Numerical models of anthropomorphic mannequins Hybrid III were used in the simulations.

2. Experimental tests

The energy-absorbing structure, made of ASMA 55°ShA elastomer, consisting of 100 tubes evenly distributed on a square pattern in rows of 10x10 pieces and coated on both sides with perforated plates, measuring 360x360 mm and 4.0 mm thick, was tested (Fig. 1) [2]. The total height of the structure is 42.3 mm.

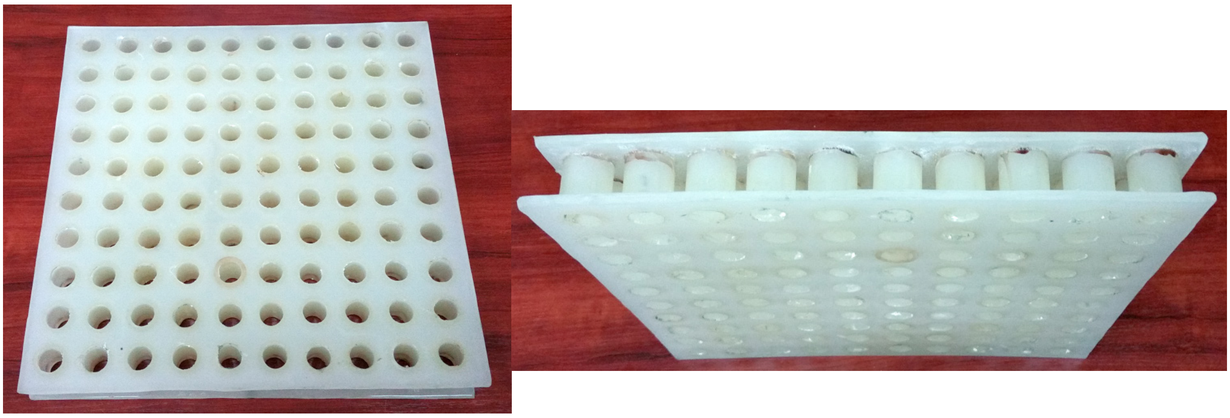

Fig. 1. Photos of the elastomeric energy absorbing mat

The dynamic tests were carried out on the basis of a gravitationally falling hammer, which is presented in Fig. 2.

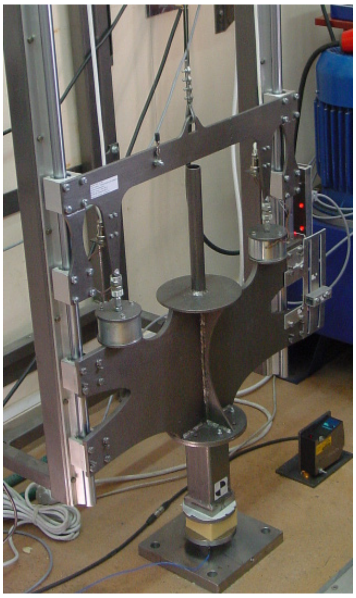

Fig. 2. View of the falling hammer

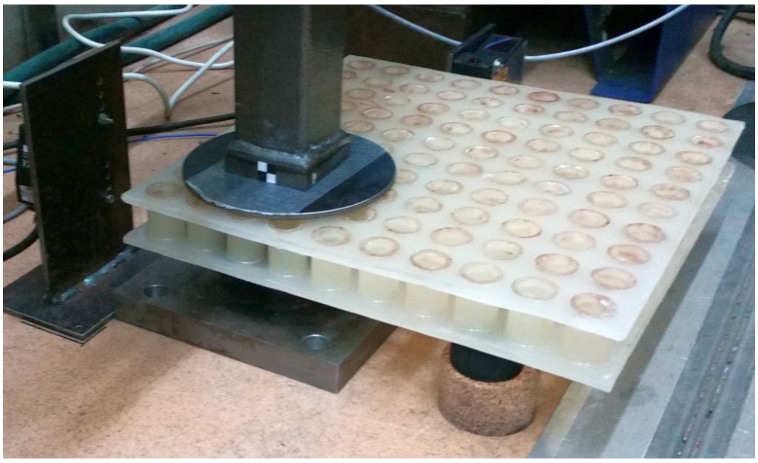

Fig. 3. Elastomer structure installed on the bench of the falling hammer

There are sensors for measuring force and displacement installed on the stand. Force measurement is done using a piezoelectric force sensor M200C50 produced by PCB Piezotronics company coupled to a signal conditioner VibAMP PA-16000D produced by EC Electronics. Displacement measurement is performed with a laser triangulation displacement sensor LKG-502 produced by Keyence.

The method of installation of the sample at the test bench is shown in the Fig. 3. The nominal dimensions of the sample far exceeded the measurement table diameters and the hammer of 160 mm, so the three corners of the plate, resting on the table, were supported by spacers made of soft material.

Based on the measured values, i.e., weight of the hammer, drop height, speed of the hammer before hitting the sample, displacement (compression of sample) and strength, there were determined energy discharge, maximum compression and maximum strength. The sample has been tested five times. On the basis of the measurements of force and time, the characteristics of force versus time were determined (Fig. 4).

The sequence of pictures in the Fig. 5 shows the process of dynamic destruction from the test_3.

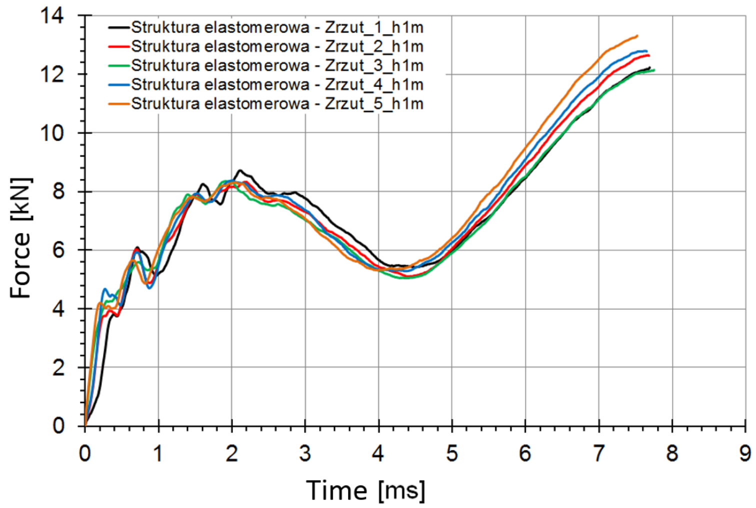

Fig. 4. Characteristic of force versus time for experimental tests

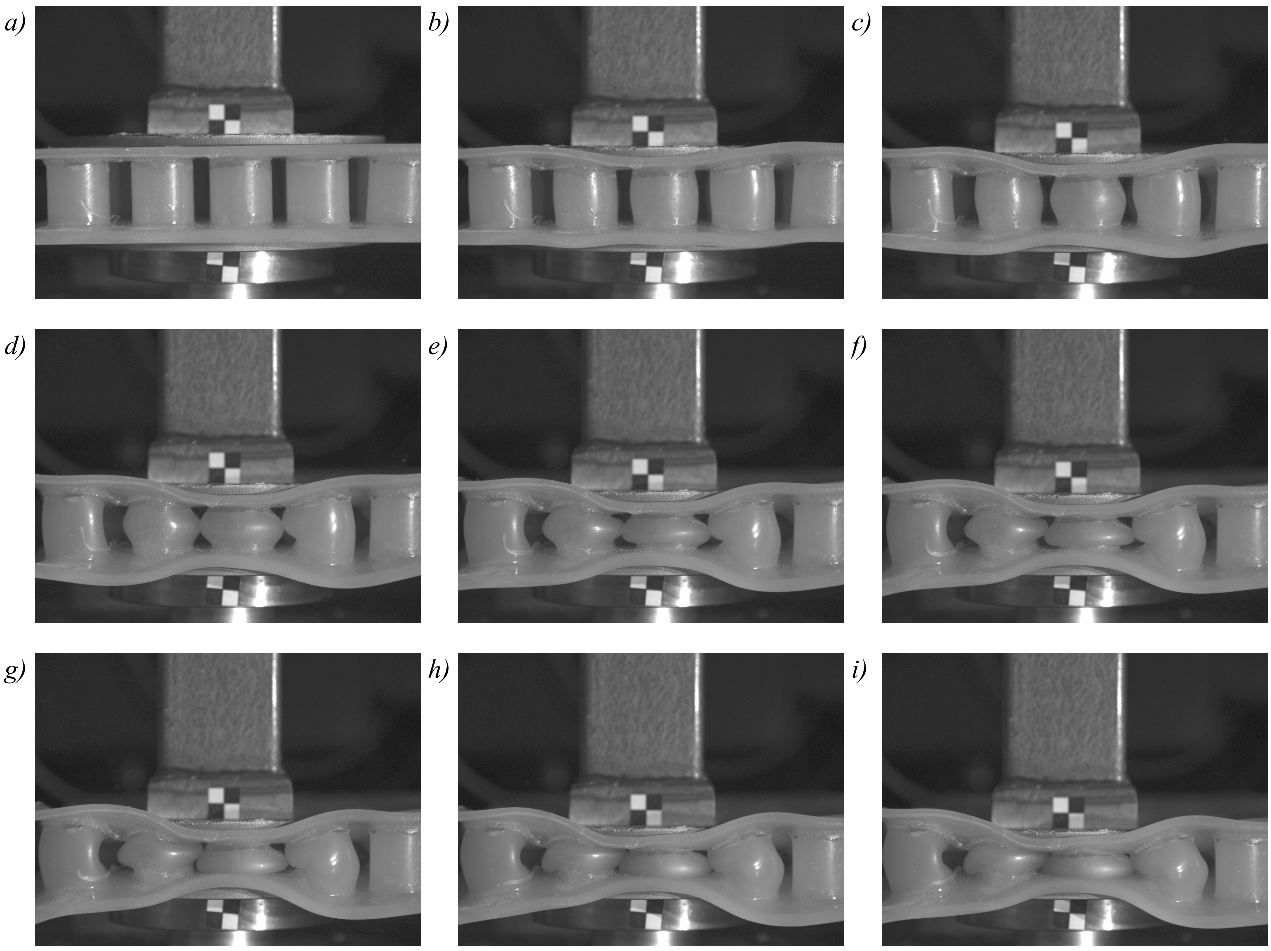

Fig. 5. Compression of the elastomeric structure during dynamic tests (test 3) over time: a) 0 ms, b) 1.3 ms, c) 2.1 ms, d) 3.5 ms, e) 4 ms, f) 4.5 ms, g) 5 ms, h) 6.5 ms, i) 7.6 ms (maximum compression)

3. Numerical analysis

Numerical model of the investigated energy-absorbing mat was developed using modern CAE tools. Geometric of a model was developed in Catia V5, a discretization process was carried out using HyperMesh software and all numerical simulations were calculated using the computational code LS-DYNA [5]. LS-PrePost was adopted for pre- and postprocessing.

To develop discrete models, four-node shell (for mat) and eight-node brick (for hammer plate) elements were used. In all simulated variants, the interaction between parts was taken using a contact procedure based on a penalty function method.

To describe the considered model of rubber, SIMPLIFIED_RUBBER/FOAM_WITH_FAILURE model was used, which is based on the Ogden law [3]:

$$W = \sum_{i=1}^{3} \sum_{j=1}^{n} \frac{\mu_j}{\alpha_j}\left(\lambda_i^{*\alpha_j} - 1\right) + K(J - 1 - \ln J), \tag{1}$$

$$\rightarrow \sigma_i = \sum_{p=1}^{n} \frac{\mu_p}{J}\left[\lambda_i^{*\alpha_p} \sum_{k=1}^{3} \frac{\lambda_k^{*\alpha_p}}{3}\right] + K\frac{J-1}{J}, \tag{2}$$

where: αj are non-integers, $J = \lambda 1 \lambda 2 \lambda 3$ and λ_i^* i = $\lambda i J$ −1/3, K is a material parameter that controls the size enclosed by the failure surface.

In this material, Ogden functional is internally determined from a uniaxial engineering stress-strain curve by defining a tabulated function of the principal stretch ratio as follows [2]:

$$f(\lambda) = \sum_{p=1}^{n} \mu_p \lambda^{*\alpha_p} \rightarrow \sigma_i = \frac{1}{J}\left[f(\lambda_i) - \frac{1}{3}\sum_{j=1}^{3} f(\lambda_j)\right] + K\frac{J-1}{J}, \tag{3}$$

In the analysed issue, an energy-absorbing mat was made of elastomer Asmaprene Q 55. The strength parameters, which were necessary to describe the numerical model, were tested during an experimental test and then assigned to the constitutive model [1, 6].

Tab. 1. Material properties of elastomer Asmaprene Q 55 (MAT_SIMPLIFIED_RUBBER_FOAM_WITH_FAILURE)

Parameter	Unit	Value
Density	kg/mm^3	1.25e–6
Linear bulk modulus	GPa	0.2333
PR/BETA	–	0.45
Material failure parameter K	–	100
Material failure parameter GAMA1	–	0
Material failure parameter GAMA2	–	0.02
Damage parameter EH	–	0.001
Specimen gauge length	–	1
Specimen width	–	1
Specimen thickness	–	1

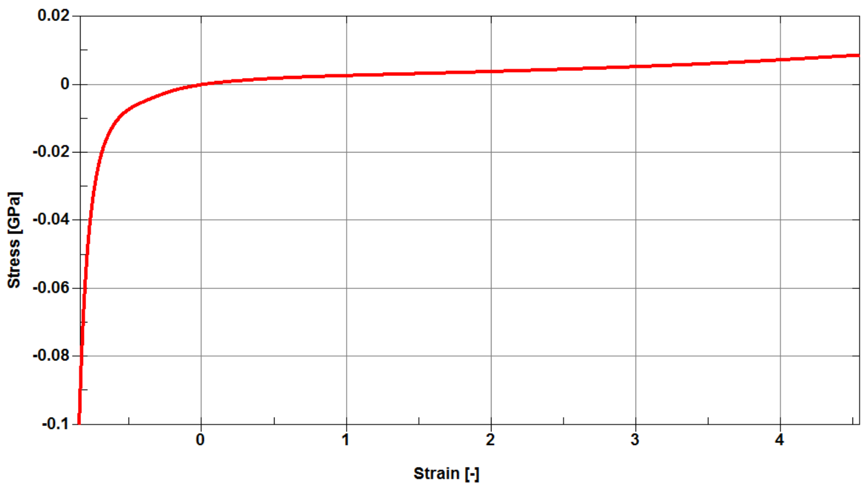

Fig. 6. Characteristic of stress versus strain used for constitutive model

To describe the material of the hammer and the test stand, MAT_PLASTIC_KINEMATIC material model was used.

Tab. 2. Material properties of steel (MAT_PLASTIC_KINEMATIC)

Parameter	Unit	Value
Density	kg/mm^3	7.85e–6
Young's modulus	GPa	207
Poisson's ratio	–	0.3
Yield stress	–	0.35

The examined mat was dynamically loaded by hitting it by a hammer weighting 15.5 kg. The average impact speed was 4.3 m/s, which translated into kinetic energy upon impact with a value of about 143.5 J. A numerical model of the measuring sample is shown in Fig. 7.

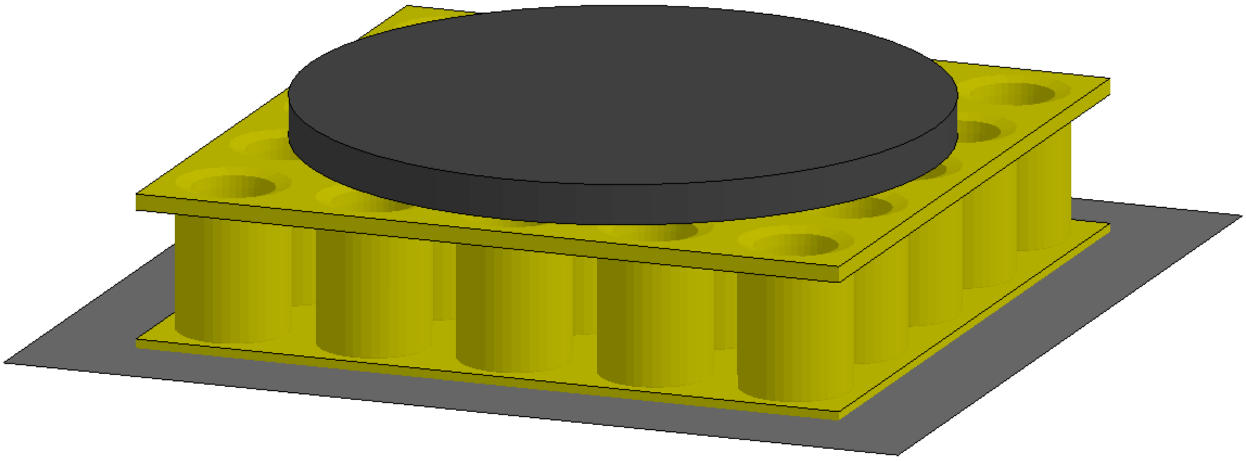

Fig. 7. Numerical model of measuring sample

The process of deformation of the mat structure filmed during experimental research and numerical analysis was presented as a sequence of images in Fig. 8.

A comparison characteristic for selected experimental and numerical analyses is presented in Fig. 9.

4. Conclusions

Based on the results, some conclusions can be formulated:

- as a result of the impact of the mass of 15.5 kg with energy 143.5 J (average – 4.3 m/s) the samples were squeezed by an average value of 20.7 mm,
- the maximum compressive strength during the test was (average) 12.6 kN,
- the maximum bending force before the bending phase of the tubes is approximately 8.4 kN for experimental tests and 8 kN for numerical analysis,
- with high compression of the tubes, at the end of the trials, the force began to grow,
- there were no signs of destruction and permanent deformation. The structure worked in the elastic range.

The numerical analyses presented in this article are an introduction to more complex numerical and experimental analyses.

The results obtained by numerical analysis are very consistent with the results of experimental research, which confirms the essence of applying the Finite Element Method to dynamic modelling and demonstrates that the analysis was carried out correctly.

a)
b)
c)
d)
e)

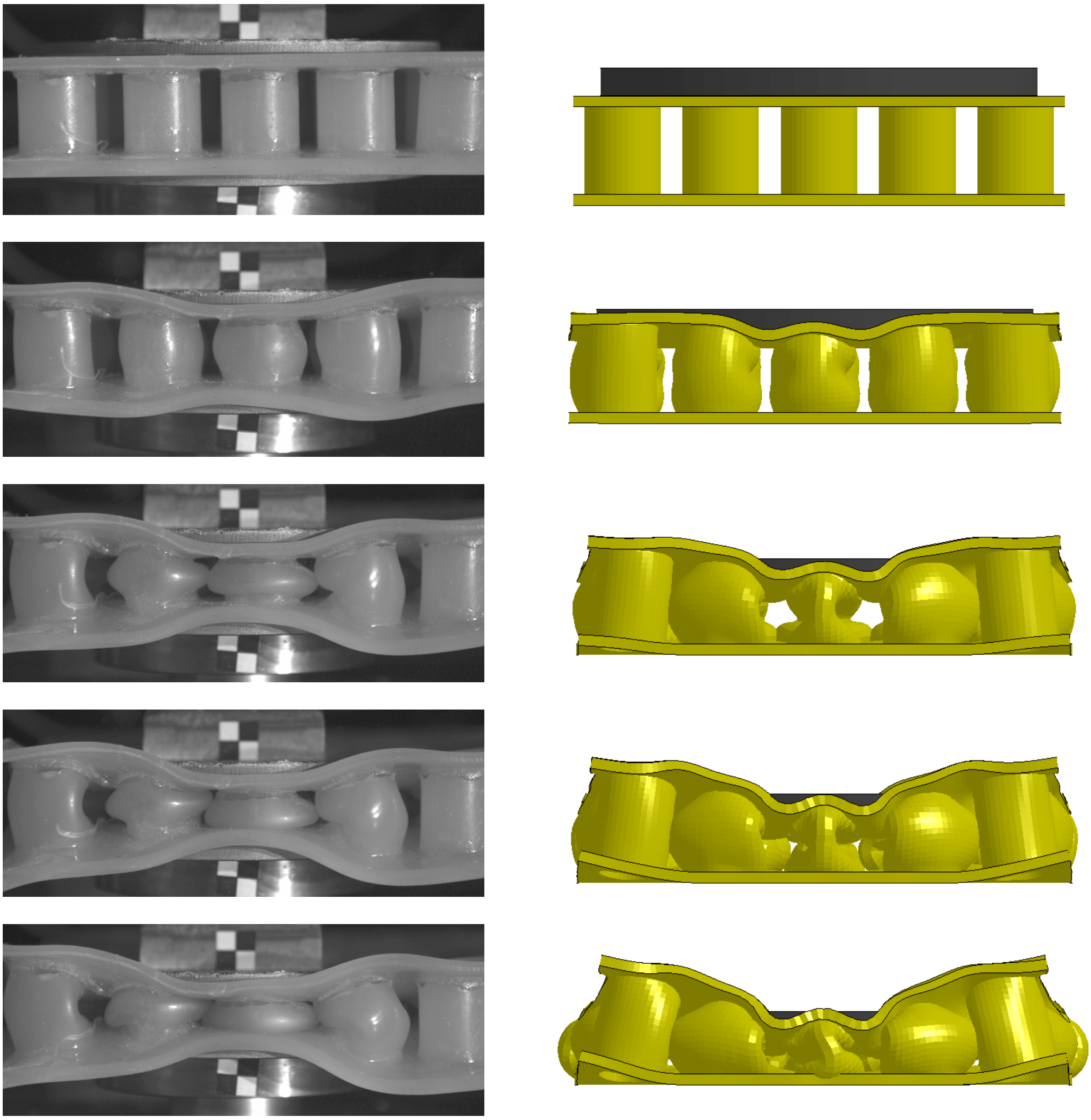

Fig. 8. Comparison of compression of the elastomeric structure during experimental and numerical tests over time: a) 0 ms, b) 2.1 ms, c) 4 ms, d) 5 ms, e) 7.6 ms (maximum compression)

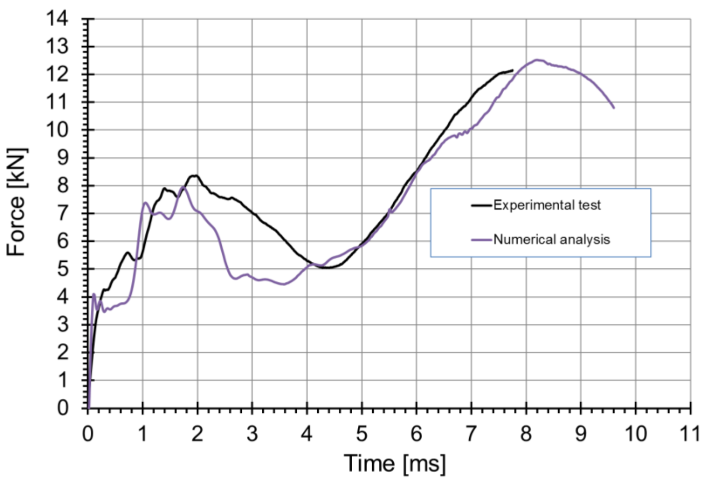

Fig. 9. Characteristic of force versus time for experimental and numerical tests

Acknowledgment

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