Impact Force Response of Foams and Rubbers

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Abstract: Expanded polystyrene, open-closed cell foam, rubber based on synthetic isoprene and butadiene elastomers, and cork/rubber composite were tested in this work. The aim was to obtain the impact force response which can be further used either for an immediate comparison of the material energy absorbing properties or for the validation of material models. Impact tests were performed in a drop tower designed by the authors. To obtain more data for the validation, both displacement and force responses on the impact were investigated.

Keywords: drop test; open-closed cell foam; rubber; EPS; cork.

1 Introduction

Energy absorbing materials have been used in many applications: From packaging of goods to military devices, from civil to aerospace engineering [2]. Producing optimal products requires primarily the utilization of appropriate materials. Certainly, the products must also have optimal shape and dimensions. To find the optimal geometry properties, accurate material models are often necessary [3], [6].

Four materials were tested in this work:

- Expanded polystyrene (EPS), which is a crushable foam commonly used in personal protective equipment [1].
- Open-closed cell foam, which is a modern energy absorbing material having strain rate sensitivity (produced e.g. by D3O®).
- Rubber based on synthetic isoprene and butadiene elastomers (hardness 80 ShA), which is used e.g. as a damping element in rubber sprung wheels [4].
- Cork/rubber composite, which is used usually as the core material in constrained damping layer constructions (sandwich panels) [5], [8]

The aim was to obtain the impact force response which can be further used either for an immediate comparison of the material energy absorbing properties or for the validation of material models.

2 Experimental methodology

The impact tests were performed in a drop tower designed by the authors (Fig. 1). Spherical (s) and flat (f) steel impactors having weight of 2.4 kg were used. Geometry of the spherical impactor is shown in Fig. 2, the flat impactor had a square surface with side length 30 mm. The impactors reached impact velocity of 2 m/s or 3 m/s.

Rectangular samples measured 20×20 mm and had a height (thickness) of 9 mm in case of the cork/rubber composite and 10 mm in all other cases. Density and designation of the materials is listed in Tab. 1. The samples were exposed to drops repeatedly (four times in identical impact velocity). In order to distinguish test conditions in following results, a sample designation consisting of 4 symbols was used. The first symbol denotes material, the second the type of the impactor, the third the impact velocity in meters per second, and

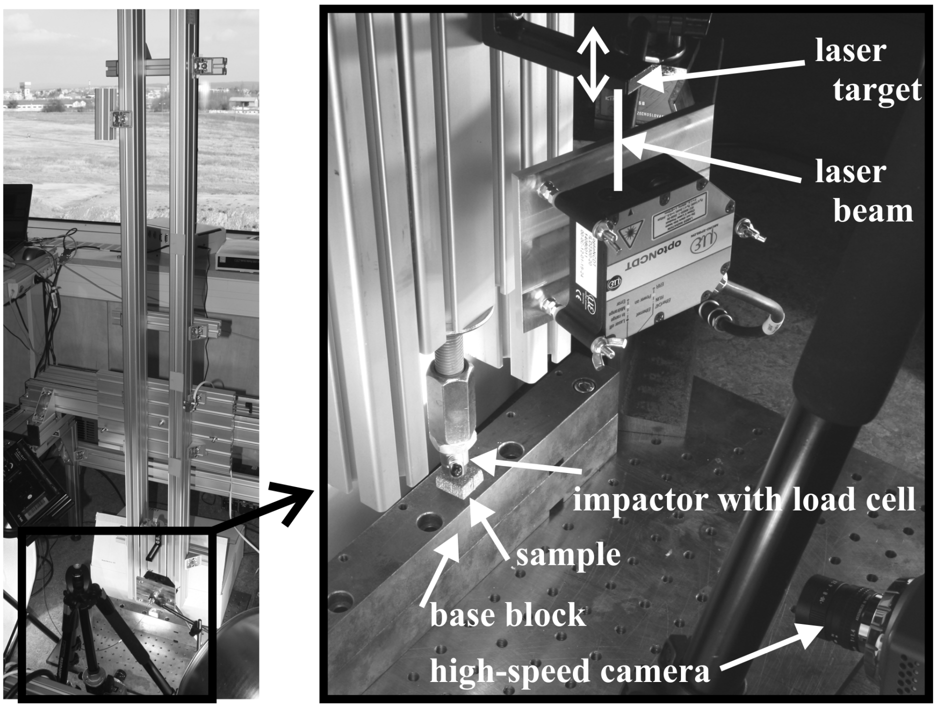


Fig. 1: Drop test.

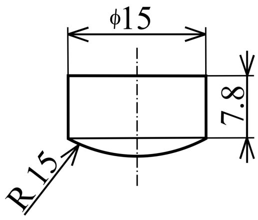


Fig. 2: Geometry of spherical impactor [mm].

the fourth the ordinal number of impact for given impact velocity (e.g. R-s-2-1 is a rubber sample that was tested using the spherical impactor and this sample was exposed to the first impact having velocity of 2 m/s).

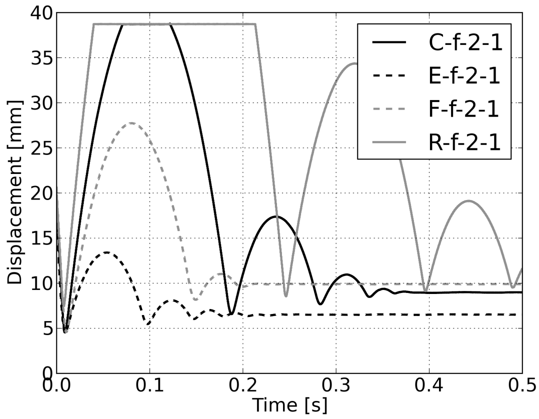
To obtain more data for the validation, both displacement and force responses on the impact were investigated. Micro-Epsilon optoNCDT 2300-50 laser and KISTLER 9712B load cell were used. Data from these devices were supplemented with images from high-speed camera OLYMPUS i-SPEED 2.

Tab. 1: Designation and density of tested materials.

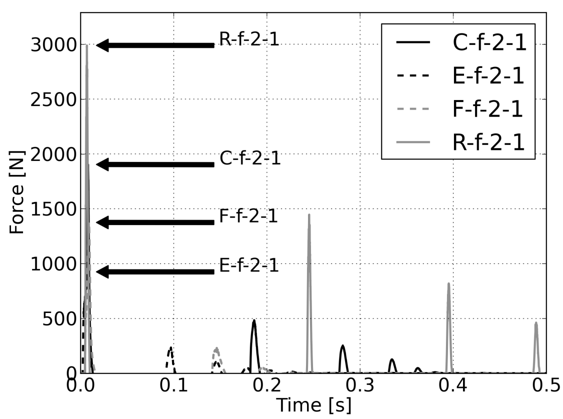
material	expanded polystyrene	open-closed cell foam	rubber	cork/rubber composite
designation	E	F	R	C
density [kg/m^3]	100	500	1200	800

3 Experimental results

Fig. 3–5 show displacement and force responses on first impacts. When an impactor touched the steel base block (sample height was zero), the displacement indicated using the laser was zero. Maximum sample compression (Fig. 6–11) and the sample height after the impact can be read from the displacement responses. Moreover, the displacement responses detected rebounds of an impactor within the analyzed time period (0.5 s). When the rebound height (RH) was higher than 38 and 46 mm in case of flat and spherical impactors, respectively, the displacements exceeding those values were not registered due to the laser measuring range. The most important information in the force responses are the peak values. Fig. 12 demonstrates these maximum forces

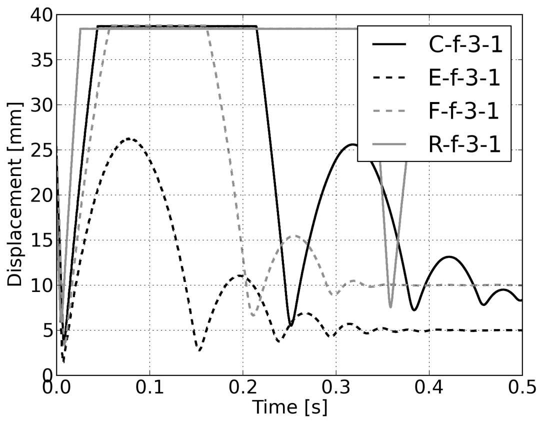


(a) Displacement response

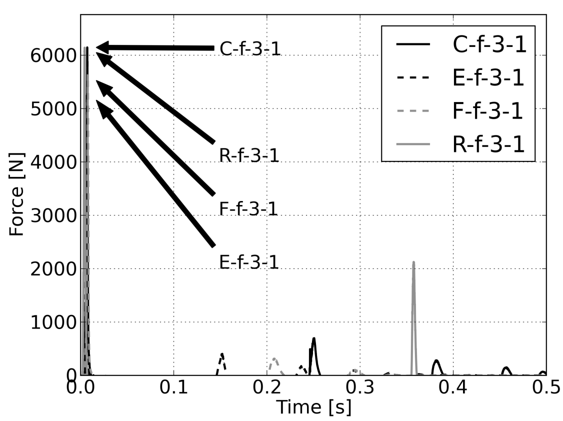


(b) Force response

Fig. 3: Responses on impacts of flat impactor for velocity of 2 m/s.

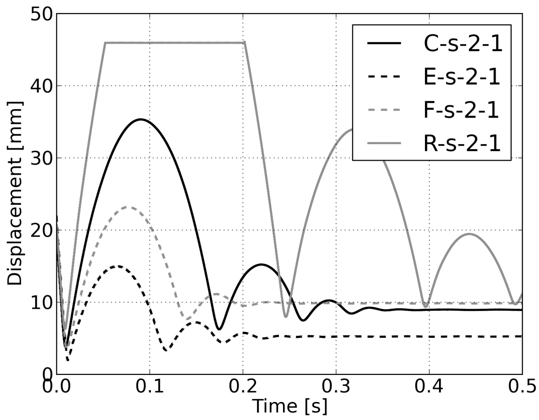


(a) Displacement response

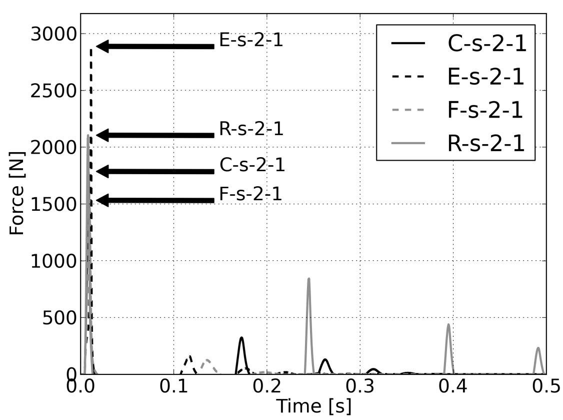


(b) Force response

Fig. 4: Responses on impacts of flat impactor for velocity of 3 m/s.

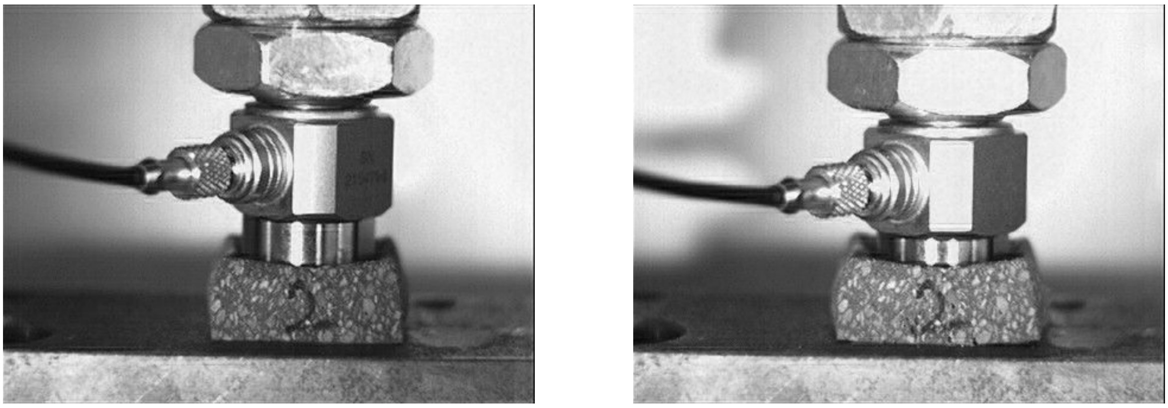


(a) Displacement response



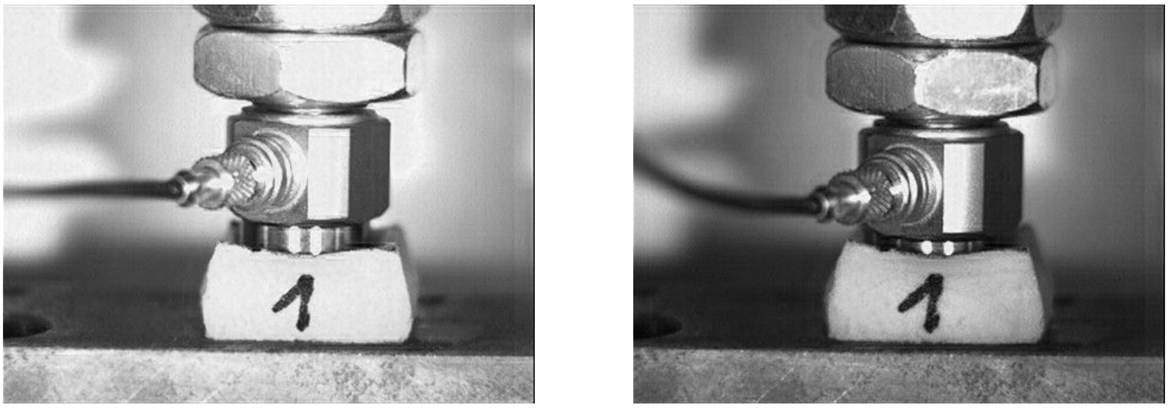
(b) Force response

Fig. 5: Responses on impacts of spherical impactor for velocity of 2 m/s.



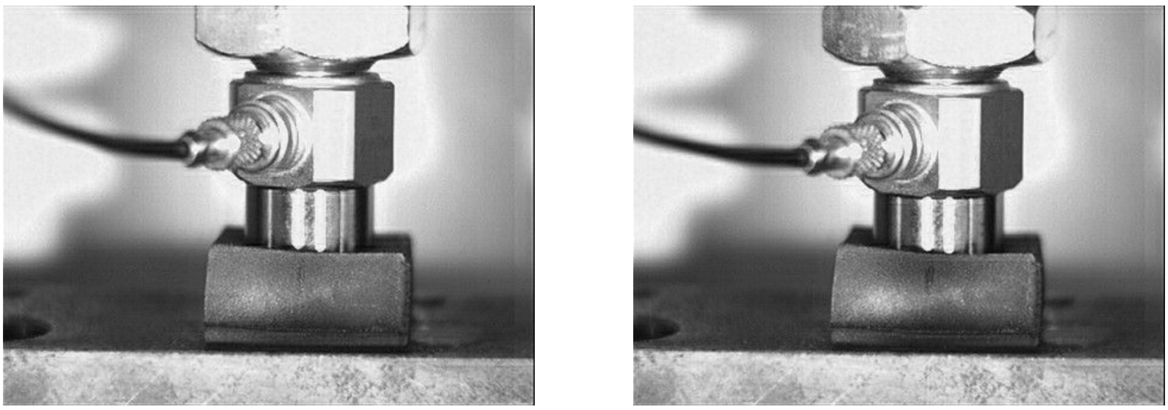
(a) Velocity of 2 m/s (C-s-2-1) (b) Velocity of 3 m/s (C-s-3-1)

Fig. 6: Maximum compression of C samples using spherical impactor.



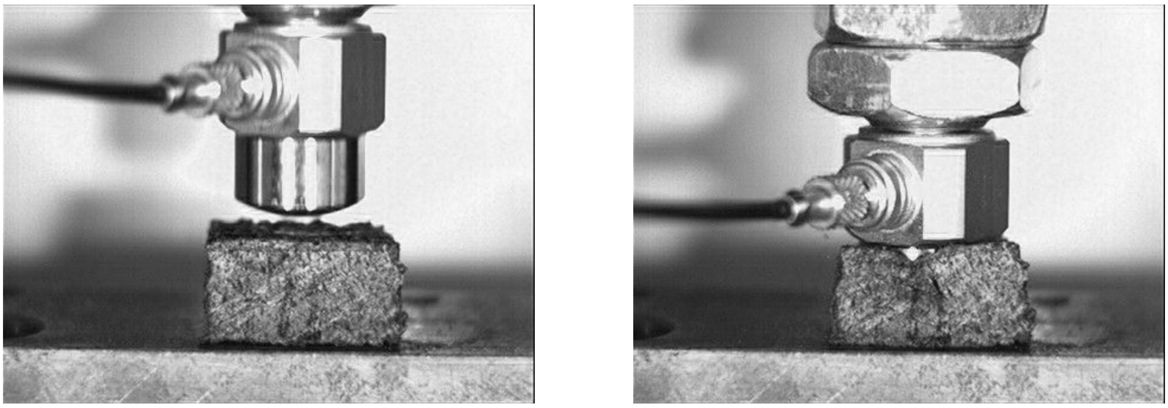
(a) Velocity of 2 m/s (F-s-2-1) (b) Velocity of 3 m/s (F-s-3-1)

Fig. 7: Maximum compression of F samples using spherical impactor.



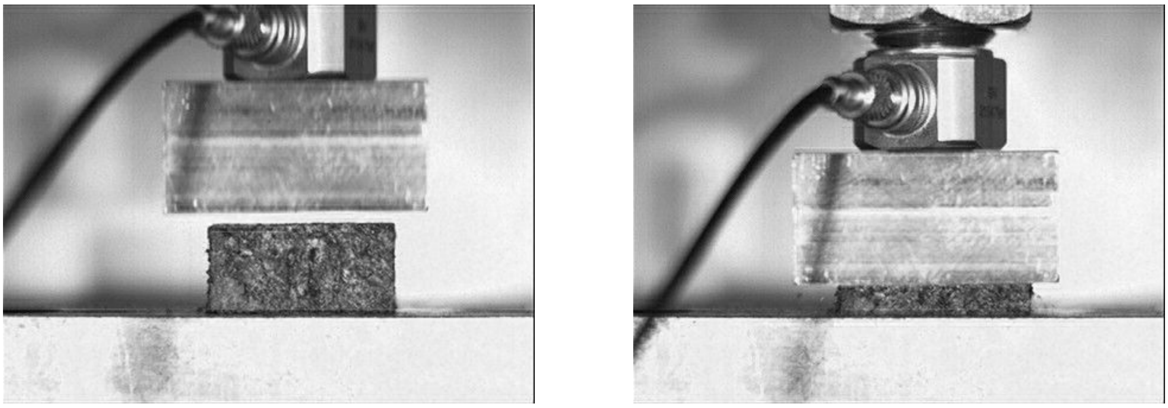
(a) Velocity of 2 m/s (R-s-2-1) (b) Velocity of 3 m/s (R-s-3-1)

Fig. 8: Maximum compression of R samples using spherical impactor.



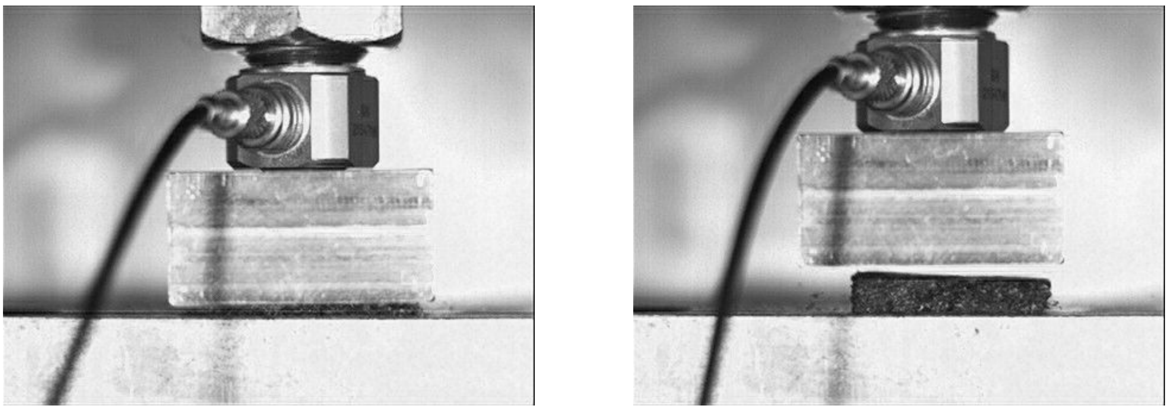
(a) Before impact (b) Maximum compression

Fig. 9: Test of E sample using spherical impactor for velocity of 2 m/s (E-s-2-1).



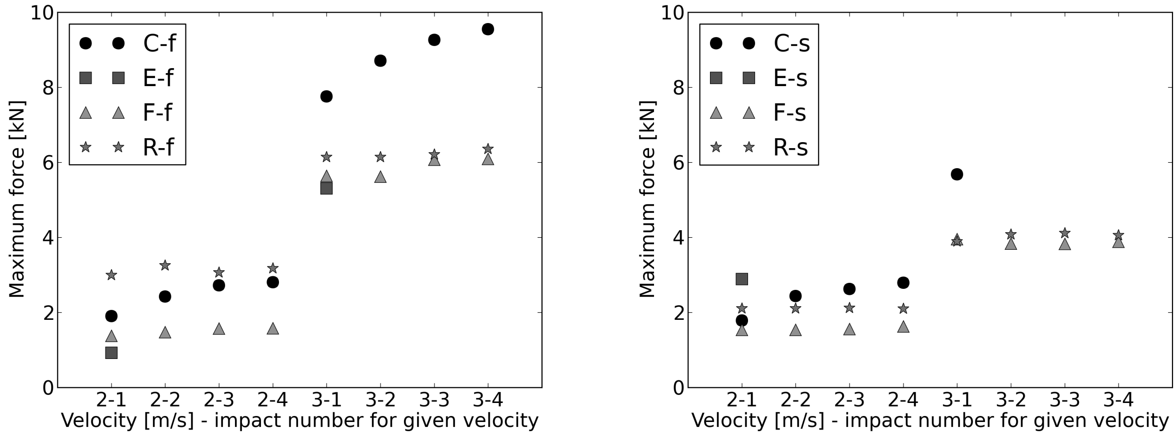
(a) Before impact (b) Maximum compression

Fig. 10: Test of E sample using flat impactor for velocity of 2 m/s (E-s-2-1).



(a) Maximum compression (b) Sample after first impactor rebound

Fig. 11: Test of E sample using flat impactor for velocity of 3 m/s (E-f-3-1).



(a) Flat impactor

(b) Spherical impactor

Fig. 12: Maximum force (MF) dependence on impact repetition.

(a) E sample for velocity of 2 m/s (E-s-2-1)

(b) C sample for velocity of 3 m/s (C-s-3-1)

Fig. 13: Samples after test using spherical impactor.

(MF) in case of repeated impacts (excepting EPS; unimpacted E samples were used for each test of EPS).

Lowest RH and MF values were determined in the E-f-2-1 test (see Fig. 3 and 12). EPS exhibited lowest RH and MF values also in the E-f-3-1 test in comparison to other tested materials impacted using the flat impactor and having velocity of 3 m/s. However, when the spherical impactor was used, the MF value of the E-s-2-1 test was the highest (Fig. 5 and 12). The reason for that is that the impact loading was concentrated (diameter of the impactor was too small). The sample thickness between the spherical impactor and the base block in time of the maximum compression (see Fig. 9) was only 1 mm (see Fig. 5(a)). Therefore, E samples were not tested using the spherical impactor for velocity of 3 m/s (danger of the load cell damage). The E sample thickness between the impactor and the base block in time of the maximum compression was also very small when the flat impactor was used (see Fig. 4(a)) and 11(a)), however, the distribution of the loading in the sample was significantly more uniform. Significant plastic deformations of E samples after the tests are obvious from Fig. 11(b) and 13(a). Since majority of the shock-absorbing capacity was exhausted [7], E samples were not exposed to drops repeatedly (danger of the load cell damage).

In case of the spherical impactor (Fig. 5), the lowest MF value was determined in the test of open-closed cell foam. RH and MF values were the second lowest in F-f-2-1 and F-f-3-1 tests (Fig. 3 and Fig. 4). Considering repeated impacts (Fig. 12), F samples responses in all four drops for a given velocity were nearly identical.

The highest values of RH and MF were determined in case of rubber except tests where the impact loading was concentrated or where samples were exposed to drops repeatedly. When R samples were exposed to the impacts repeatedly in tests having velocity of 3 m/s (Fig. 12), the MF had nearly identical values as those of the F samples.

In case of first impacts of the cork/rubber composite, RH and MF values were lower than in case of rubber (Fig. 12). Shock-absorbing properties of C samples in repeated impacts were reduced by damage which occurred in the material (see Fig. 13(b)). When an unimpacted C sample was impacted in the C-f-3-1 test (without any previous test having velocity of 2 m/s), the MF value was 6146 N, which is nearly identical MF value as in the case of other tested materials. Similarly, when an unimpacted C sample was impacted in the C-s-3-1 test, the MF value was 4552 N. In contrast to it, when C samples had been already exposed to four drops having velocity of 2 m/s, the MF values in C-f-3-1 and C-s-3-1 tests were 7758 N and 5683 N, respectively (Fig. 12).

4 Conclusions

Displacement and force responses on the impact of two types of impactors were investigated. Results of the four tested materials (considering used samples thickness) showed that the maximum reduction of impact forces can be achieved using expanded polystyrene despite having the lowest density. However, the impact loading of the EPS sample must be sufficiently distributed into sample volume. Moreover, EPS is not suitable for repeated impacts. In contrast to that, open-closed cell foam and rubber based on synthetic isoprene and butadiene elastomers are suitable for repeated impacts. Significantly lower values of impact forces were determined in tests of open-closed cell foam in comparison to rubber testes when the flat impactor were used and impact velocity was 2 m/s. Cork/rubber composite can be exposed to impacts repeatedly, however, its shock-absorbing properties worsen with each impact. When responses on only first impact were compared, cork/rubber composite samples had better or similar shock-absorbing properties as rubber samples despite having smaller thickness.

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