ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1166033

EXPERIMENTAL EVALUATION OF ENERGY ABSORBING PROPERTIES OF SELECTED ELASTOMER MATERIALS

Michał Stankiewicz, Arkadiusz Popławski, Paweł Bogusz, Roman Gieleta, Grzegorz Sławiński

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 261 839654, fax: +48 261 839355
e-mail: arkadiusz.poplawski@wat.edu.pl

Abstract

The paper presents identifying studies of mechanical properties of the selected materials from the group of elastomers including Asmathane (65 ShA), Easyprene FPS (30 ShA), Biresin (U1305). The tests were carried out at the Laboratory of Strength of Materials, the Department of Mechanics and Applied Computer Science, with the use of an especially designed stand for testing the energy absorption of materials.

The research aims were to determine the basic properties and characteristics of the selected materials as well as to compare them and identify the material with the best energy-absorbing characteristics. For a single load-unload cycle, applied dynamically, the hysteresis loops were recorded. Energy-absorption of individual materials and maximum strength were determined. During the experimental test, a fast speed camera was used for accurately register the progress performance of the test. The pictures of the dynamic tests of materials behaviour are shown. The curves of the tested materials are compared in the graphs. The resulting data will help to create constitutive models of the tested materials, which in the next stages of the project will be used in numerical studies on the impact of detonation on the designed protective panel.

Keywords: *material research, experiment, elastomers, polyurethanes, energy absorption properties*

1. Introduction

The main threat in the ongoing armed conflicts are improvised explosive devices (Improvised Explosive Devices), what results from easy availability of explosives, their simple structure and simple ignition devices [1, 2]. Ensuring the safety of the crew members of military vehicles lead to a necessity to increase their protection against the effects of a shock wave caused by the outbreak of mines or IEDs [3, 4]. The load generated by the shock wave creates inertia forces, which is the most common cause of injury to the crew inside the vehicle (Fig. 1) [2].

To increase the safety of drivers and passengers of military vehicles, it is appropriate to apply additional protective structures. Traditional methods consisting in utilizing high-density materials resulting in a significant increase in weight of the vehicle, which is associated with a reduction in the mobility of the vehicle and efficiency in the battlefield. For these reasons, it is appropriate to search for new materials and energy absorbing structures for the passive protection, which will increase safety of the crew while not significantly increasing vehicle weight.

These limitations impose a necessity of using protective panels, for example, with a Sandwich structure. Energy absorbing materials used in their construction are made of different materials, including fabrics, polymers and foamed materials (metallic and polyurethane) with different degrees of porosity. The scope of this paper covers elastomers, which can withstand high deformations and can transform a part of compression energy into heat.

The results of the energy absorbing tests of selected elastomers will be used to determine their energy dissipation performance and to select the best material for multilayer structure absorbing the energy of the explosion. Obtained results will be used as a base for development of structures resistant to IED impact within a research project.

The paper presents the identifying studies of energy absorbing properties of the selected materials from the group of elastomers including Asmathane (65 ShA), Easyprene FPS (30 ShA), Biresin (U1305). The tests were carried out with the use of an especially designed stand for testing the energy absorption of materials. For a single load-unload cycle, applied dynamically, the hysteresis loops were recorded. Energy-absorption of individual materials and maximum strength were determined. During the experimental test, a fast speed camera was used for accurately register the progress performance of the test. The pictures of the dynamic tests of materials behaviour are shown. The curves of the tested materials are compared in the diagrams.

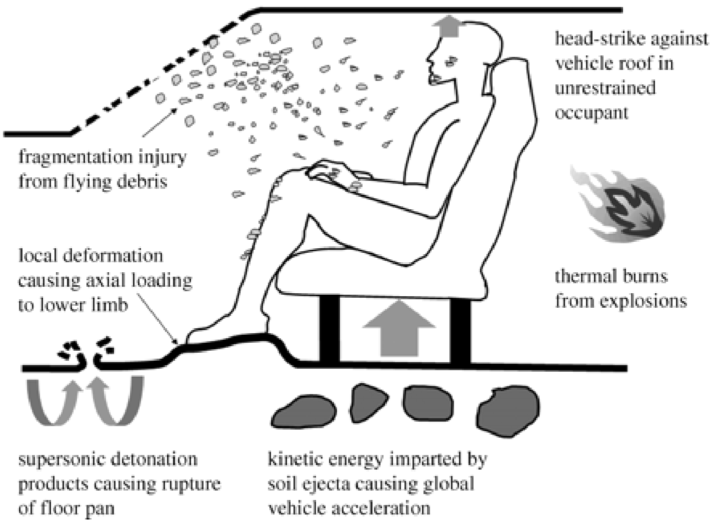

Fig. 1. Description of risks caused by mines or IED charges, which the crew of an armoured vehicle is exposed to [2]

2. Specimen description

The following elastomer materials were tested: Asmathane (65 ShA), Asmaprene BE (55 ShA), Asmaprene Q (55 ShA), Easyprene FPS (30 ShA), Biresin U1303 (hardener Biresin U1402), Biresin U1305 (hardener Biresin U1305), Biresin U1419 (hardener Biresin U1419). The materials have different stiffness and density. The elastomer samples made by casting the liquid elastomer in the form. The samples in the cylindrical form with a diameter of Ø66 mm and 40 mm height were prepared. Three specimens of each material were made. The geometry and dimensions of the samples are presented in Fig. 2. The illustrative samples used for the impact tests are shown in Fig. 3. The material properties based on the producer's data are presented in Tab. 1.

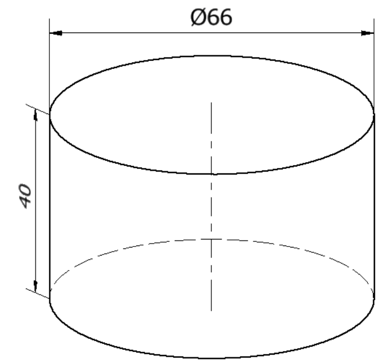

Fig. 2. The geometry and dimensions of the samples for compression for elastomer materials

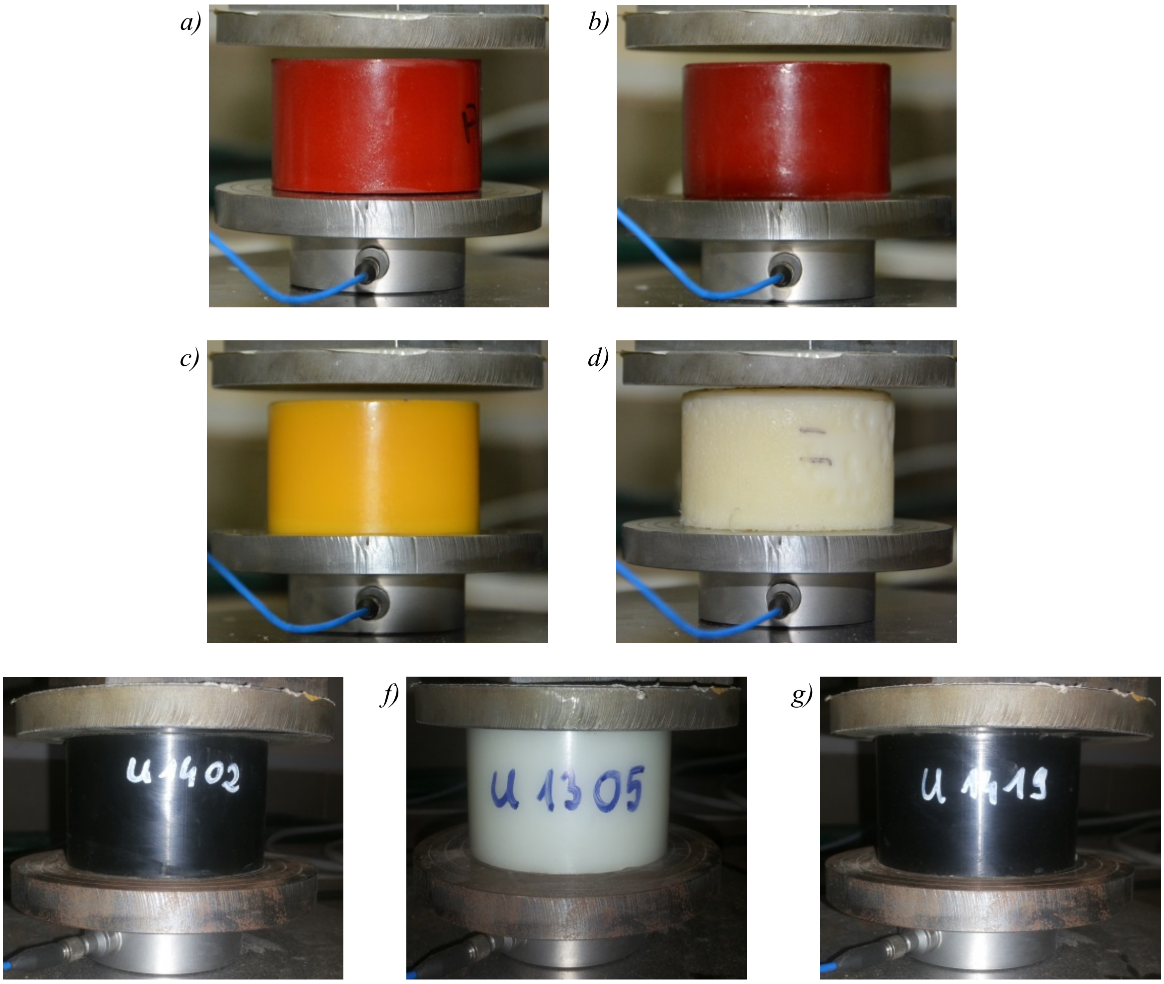

Fig. 3. View of the illustrative cylindrical samples used in the impact tests: Asmathane (a), Asmaprene BE (b), Asmaprene Q (c), Easyprene FPS (d), Biresin U1303 (e), Biresin U1305 (f), Biresin U1419 (g)

Tab. 1. The material properties based on the producers data [5-10]

Material name	Density [g/cm^3]	Hardness [ShA]	Strenght [MPa]	Elongation at break [%]	Linear shrinkage [%]
Asmathane*	1.18	65	21	930	b.d.
Asmaprene BE*	1.19	55	19	1105	b.d.
Asmaprene Q	1.25	55	20	700	b.d.
Easyprene FPS	b.d.	30	b.d.	b.d.	b.d.
Biresin U1303	1.05	81	10	400	0.1
Biresin U1305	1.20	89	25	300	0.1
Biresin U1419	1.10	98	25	375	0.05

* – approximated values for particular hardness

3. Description of the test stand

The study of energy absorption on the test stand of own design, which is presented in Fig. 4, was carried out. The research was performed on a hammer fall machine, on which the sensors to measure the force and displacement were installed. A gravity driven beam moving on rails falls on the sample placed on the measuring table. Measurement of force is carried out with the use of a piezoelectric force sensor PCB M200C50 produced by Piezotronics Company. The measurement of the specimen compression is performed with a laser triangulation displacement sensor LKG-502 a)

b)

Fig. 4. Test stand for testing the energy absorption (a) with computer recording the results of (b)

produced by Keyence Company. The drop energy is regulated by changing the drop height and the weight of the whole beam. The tests were recorded with a high-speed camera Phantom V12 produced by Vision Research company.

The total mass of the beam including the ram was 15.5 kg. The drop tests were carried out from the height of 1 m, which gave drop energy equal to 152.1 J. In the case of elastomer materials with significantly higher hardness (> 70 ShA) increased the ram mass was increased to 40.5 kg and the drop height to 2 metres, which resulted in drop energy equal to 794.6 J.

4. Test results

Based on the following measured quantities: ram weight, drop height, ram impact speed, graphs of force-deflection of the specimen, there were determined: drop energy, impact energy, the maximum compression of the elastomer and the maximum force. The energy absorbed and the energy dissipated as heat was defined. Three specimens were tested for each of elastomer type. The averaged test results for materials of Asmathane and Easyprene type are shown in Tab. 2, and for materials of Biresin type in Tab. 3.

Energy absorbed is considered to be the area under the force-displacement graph up to the moment of the maximum compression of the sample. The area inside the hysteresis loop shows the dissipated energy. A measure of energy absorption capability is the relative energy absorbed, i.e. energy related to the mass of the destroyed part of the sample. In this case, no destruction of the

Tab. 2. Research results comparison for materials of Asmathane and Easyprene materials type

Material name	Asmathane	Asmaprene BE	Asmaprene Q	Easyprene FPS
Impact velocity [m/s]	4.4	4.4	4.4	4.4
Impact energy [J]	149.2	148.9	149.2	149.4
Maximum displacement [mm]	16.8	18.8	18.9	27.2
Maximum force [kN]	18.1	16.2	16.8	13.4
Energy absorbed [J]	148.9	148.5	148.5	149.1
Energy dissipated [J]	129.8	131.6	124.0	143.5
Relative absorbed energy [J/mm]	8.9	7.9	7.9	5.5
Relative dissipated energy [J/mm]	7.7	7.0	6.6	5.3
Absorbed to dissipated energy ratio [%]	87.2	88.6	83.5	96.2

Tab. 3. Research results comparison for materials of Biresin type

Material name	Biresin U1303	Biresin U1305	Biresin U1419
Impact velocity [m/s]	6.3	6.3	6.3
Impact energy [J]	794.6	794.6	794.6
Maximum displacement [mm]	25.6	14.5	14.3
Maximum force [kN]	89.8	76.2	77.0
Energy absorbed [J]	790.9	724.9	763.3
Energy dissipated [J]	692.2	715.0	755.0
Relative absorbed energy [J/mm]	30.9	50.0	53.4
Relative dissipated energy [J/mm]	27.0	49.3	52.8
Absorbed to dissipated energy ratio [%]	87.5	98.6	98.9

samples took place, but only the elastic deflection. Therefore, the absorbed energy was related to a maximum deflection. The samples had the same diameter and height of the initial parameters. The density was also at a similar level for all the examined materials.

In the next step, the relative energy absorbed and the relative energy dissipated were calculated. Percentage of the energy dissipated to the energy absorbed at maximum deflection of the sample was also determined.

Figure 5 presents the collective graph of compression curves for the example tested elastomer samples (one of three tested) of Asmathane and Easyprene type. Asmathane elastomers curves are very similar. The maximum force exceeds the value of 15 kN. For the Easyprene material, the maximum compression force is smaller and the deflection greater. It is the least stiff material. The use of this type of material allows achievement of a smooth progress of the force increase. Easyprene is characterized by a high-energy dissipation coefficient; however, it absorbs the least amount of energy relative to the deflection.

Figure 6 presents the collective graphs of compression curves for the example elastomer samples (one of three tested) of the Biresin type. Materials U1305 and U1419 are characterized by similar properties. The course of compression graphs is similar. The initial increase of load is steep; however the force is approximately constant at further flexing deflection. In the case of U1303 material, the force increases gradually, and the maximum force is much greater. It absorbs less energy compared to other Biresin elastomers.

Figure 7 shows photos of energy-intensive absorbing dynamic tests for Asmathane and Easyprene elastomer samples, and Fig. 8 – analogous photos for Biresin type elastomers. The presented photographs show the maximum deformations of particular materials recorded with a high-speed camera.

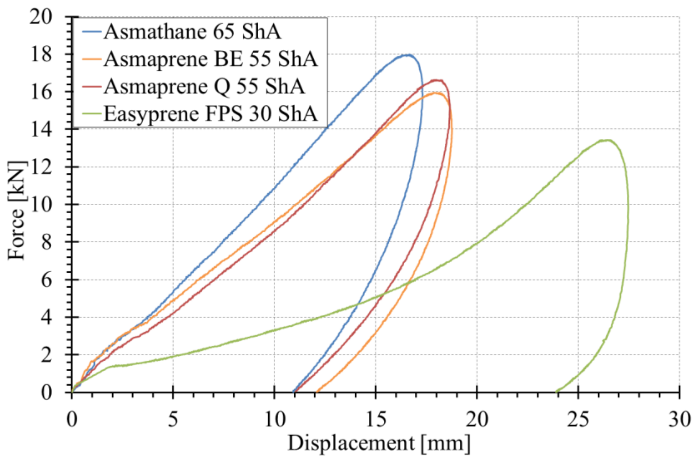

Fig. 5. Research results comparison for elastomer materials of Asmathane and Easyprene type

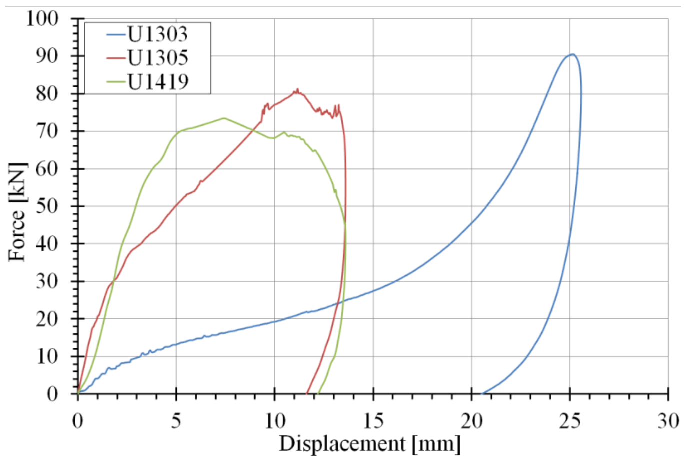

Fig. 6. Research results comparison for elastomer materials of Biresin type

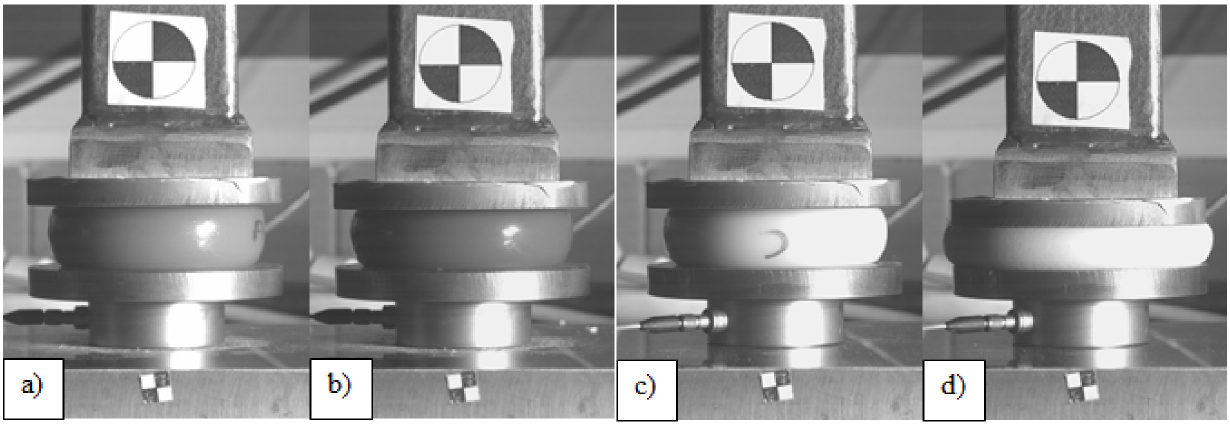

Fig. 7. The maximum deformation of the elastomer samples during impact load: Asmathane 65 ShA (a), Asmaprene BE 55 ShA (b), Asmaprene Q 55 ShA (c), Easyprene FPS 30 ShA (d)

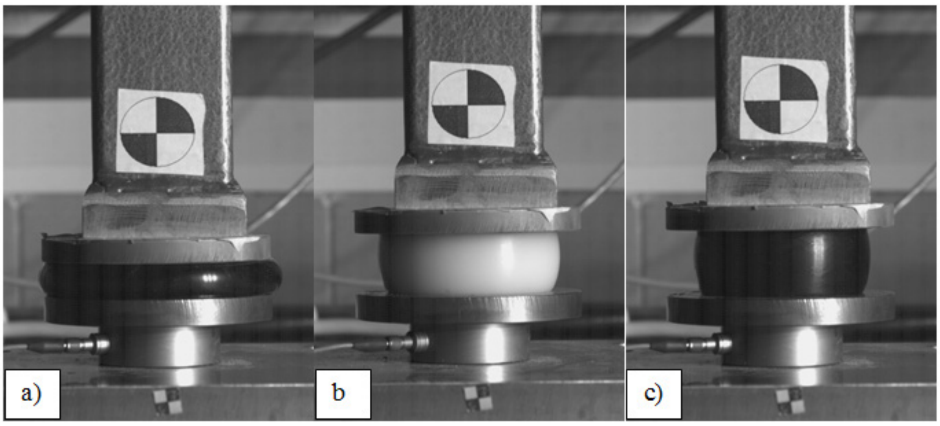

Fig. 8. The maximum deformation of the elastomer samples during impact load: Biresin U1303, (a), Biresin U1305 (b), Biresin U1419 (c)

It was found that all elastomers have been compressed, and after the test, they reverted to their original dimensions. They have not been permanently damaged (deformed) and did not break. The impact energy was has been converted into work of elastic deformation. Part of this energy has been transformed into heat and has been dissipated into the surrounding area. Shortly after the test had been completed, all the samples reverted to their initial height.

A type of elastomers should be adapted to the specific application. While choosing the material, the following factors should be taken into consideration: density, the expected energy of the load and possible compression of the (allowable thickness) energy absorbing structure material. In general, the higher the relative value of the energy absorbed and the greater share of the energy dissipated to energy absorbed, the material indicates better energy absorbing properties.

Small share of energy dissipation means that after some time the elastic energy will be released back to the protected system. Another important element is the material stiffness. Too stiff material cause large force during compression work. Material with insufficient stiffness does not absorb enough energy during its deflection. Using elastomers in the panels protecting against the effects of loading by a blast wave may result in very large energies.

The tested materials have similar density, slightly exceeding 1 g/cm^3. Biresin type materials are elastomers with the highest stiffness among the examined types, and, in their case, the energy absorbed is the highest. For Biresin U1419 it amounts to 53.4 J/mm. Hardness is also the highest. Biresin U1305 has very similar properties.

Asmathane and Easyprene materials are characterized by the lowest stiffness and hardness. Easyprene has a coefficient of relative energy absorbed equal to 5.5 J/mm, approximately 10-times less than for Biresin materials.

All the materials showed a high proportion (over 80%) of the dissipated energy to the absorbed energy during the compression. The best materials, in this respect, proved to be Easyprene FPS, U1305 and U1419 Biresin.

5. Conclusions

The conclusions drawn from the studies on Asmathane, Easyprene and Biresin type elastomers are as follows:

1. For all the examined materials, an energy dissipation coefficient is very high and amount to over 80%. The best materials, in this regard, proved to be Easyprene FPS, U1305 and U1419 Biresin.
2. Biresin type elastomers have a nearly ten times higher energy absorption relative coefficient than the Asmathane and Easyprene type elastomers.
3. The Biresin U1419 is the best material considering the applied criteria of maximum relative energy absorbed and the greatest share of energy dissipated to the energy absorbed. On the other hand, Biresin U1305 material is also adequate, as it has similar properties to the U1419. The course of the compression curves in the graphs is steep; however, at the further compression, the value of the force is constant.
4. For Easyprene material, the maximum compression force is the smallest and the deflection is greater, which means a low rate of energy absorption. It is the least stiff material. This condition allows for the smooth progress of the force increase. Easyprene material is also characterized by a high-energy dissipation coefficient.

The obtained data will help to create constitutive models of the tested materials, which in the next stages of the project will be used in numerical studies on the impact of detonation on the designed protective panel.

References

[1] Ramasamy, A., Hill, A. M., Clasper, J. C., *Improvised explosive devices: pathophysiology, injury profiles and current medical management*, Journal of the Royal Army Medical Coprs, 155 (4), pp. 265-272, 2009.

[2] Ramasamy, A., Masouros, S. D., Newell, N., Hill, A. M., Proud, W. G., Brown, K. A., Bull A., Clasper, J. C., *In-vehicle extremity injuries from improvised explosive devices: current and future foci Phil*, Trans. R. Soc., B 366, pp. 160-170, 2011.

[3] Saska, P., *Improwizowane urządzenia wybuchowe stosowane w konflikcie Irackim*, Szybkobieżne Pojazdy Gąsienicowe, Nr 1 (24), 2009.

[4] Saska, P., Klimentowski, F., Kowalczyk, P., *Charakterystyka improwizowanych urządzeń wybuchowych stosowanych w konflikcie Irackim*, Zeszyty Naukowe WSOWL, Nr 1 (147), p. 41-57, 2008.
[5] Asmaprene_BE_Englisch.pdf, http://www.pur-elastomere.at/pages/home.php.
[6] Asmaprene_Q_englisch.pdf, http://www.pur-elastomere.at/pages/home.php.
[7] Asmathane_Englisch.pdf, http://www.pur-elastomere.at/pages/home.php.
[8] Biresin_U1303_eng.pdf, http://deu.sika.com/en/tooling-and-composites-redirect/tooling_composites/Dokumentendownload_Tooling/Produktdatenblaetter_Tooling.html, 2015.
[9] Biresin_U1305_eng.pdf, http://deu.sika.com/en/tooling-and-composites-redirect/tooling_composites/Dokumentendownload_Tooling/Produktdatenblaetter_Tooling.html, 2015.
[10] Biresin_U1419_eng.pdf, http://deu.sika.com/en/tooling-and-composites-redirect/tooling_composites/Dokumentendownload_Tooling/Produktdatenblaetter_Tooling.html, 2015.