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Heat effects measurements in process of dynamic crash of polymer composites

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Abstract. In the work, the attempt to determine the influence of loading rate on temperature of the surface of the crushed composite energy absorbing elements was undertaken. The specimens made of epoxy composites reinforced with glass fabrics and carbon fabrics of the structures $[(0/90)_T]_n$ were subjected to dynamic investigations. Thermovision investigations were conducted during energy absorbing tests. A thermovision camera enables the measurement of the temperature on the whole surface of the specimen visible in the camera lens while the measurement with the use of thermocouple is only local and has great heat inertia. During the investigations, the increase of specimen temperature related to impact velocity occurs. The temperature increase is caused by friction between the particles of the crushed specimen and by friction between the specimen and the support of the strength machine. At high loading rates, the increase of temperature on the surface of the specimens was significantly greater than the softening temperature of the epoxy resin E-53.

Key words: mechanical properties, heat effect, absorbed energy, polymer composites, experimental mechanics, dynamic investigations.

1. Introduction

The review of the modern literature concerning the investigations of the influence of the impact velocity on EA of the elements made of polymer composites shows that the investigation results do not verify the unequivocal influence of the impact velocity on EA values. Many authors report that the load velocity influences the EA value, however some of them state that EA drops along with the growth of velocity [1-3], and other works show that EA increases [4–6]. In most reviewed cases loading rate does not influence the EA at all [5, 7–11]. The relationship between load rate and EA depends on many factors such as matrix and reinforcement types, reinforcement configuration and structure or shape of the specimen. In the work [5], Fairfull and Hull presented the results of investigations concerning the influence of friction during progressive crush of composite tubes between the plates of different roughness. It was verified that the energy dissipated in the crush zone and between the specimen and strength machine plate constitutes a significant part of the total kinetic energy during crush. The work [5] suggests that the friction in the crush zone produces heat and it can contribute to the EA change along with the increase of crush velocity due to the fact that mechanical properties of polymer resins depend on temperature.The measurements of tube temperature during crush were not performed in the work. There was determined the friction coefficient, which is equal to $\mu \approx 0.35$, between a steel support of the strength machine and a composite specimen. The work [12] presents investigations for the specimens made of epoxy composites which result in obtaining the similar value of the friction coefficient – $\mu = 0.32 \pm 0.03$.

In the present work, the measurements of distribution of the temperature on the surface of the specimens during crush were taken. In order to do this, there was used the thermovision camera installed in the front of the stand for energy absorbing investigations. The measurements were taken at different load rates. The dependence of maximum temperature on load velocity was determined.

A thermovision camera enables the measurement of the temperature on the whole surface of the specimen visible in the camera lens while the measurement with the use of thermocouple is only local and has great heat inertia. No works concerned with the investigations into temperature of dynamically crushed composites have been found in literature.

2. Subject and method of investigation

The epoxy composites were subjected to dynamic investigations at the variable value of load velocity. The examined specimens were made of epoxy resin EPIDIAN E53 and reinforced with glass fabric (STR-012-350-110, produced by the Krosglass company, with a basis weight of 350 g/m^2) or carbon fibres in the form of fabric (ECC 442 from fibres TENAX HTA 5131). The specimens were prepared in the shape of tubes with the inner diameter equal to 40 mm, height 50 mm and wall thickness from 1.5 to 4.5 mm, by hand laminating method. One of the edges was cut at an angle of 45°. The shearing plays the role of the crush initiator and assures progressive crushing of the specimens. The scheme of example specimen is shown in Fig. 1.

Energy absorbing tests were conducted at the impact velocity range from 0.0007 to 7.3 m/s on two different test stands. A strength machine Instron 8802 was used in quasi-

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static and low velocity tests. On a spring stroke hammer of own production the high speed tests were performed.

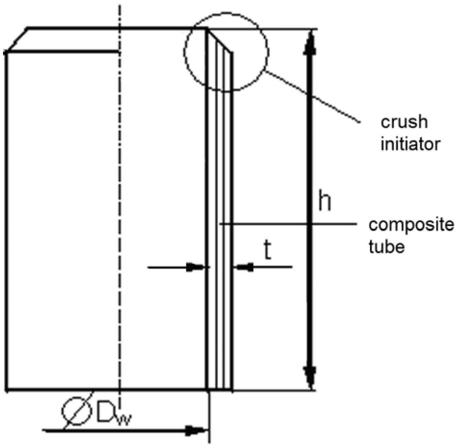

Fig. 1. Shape of the specimens used in the investigations

After determining the heat emissivity of the examined composites, the thermovision investigations were carried out. The determined emission coefficient amounts to 0.827 for carbon fabric reinforced composite (C/E) and 0.868 for glass fabric reinforced composite (G/E). During the crush process, the thermovision camera FLIR SC3600 was recording the sequence of photos with the frequency dependent on load velocity. The frequency of taking photos was equal to 900 Hz for the investigations performed on the stroke hammer. The software controlling the camera enabled the digital reading of the maximum ($T_{\max}$) temperature from the selected region of the picture. Next, the arithmetical mean was calculated from the three tests performed for a given kind and structure of the specimen. The temperature growth ΔT was determined as the temperature difference ($T_{\max} - T$).

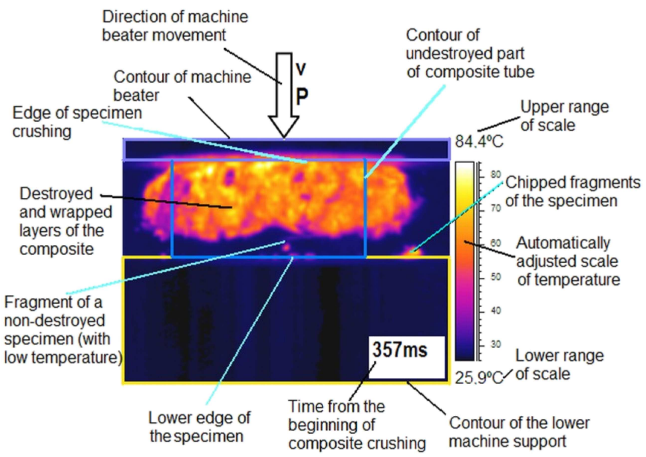

Fig. 2. The description of the crush of composite specimens obtained from the thermovision camera

Figure 2 presents an example photo recorded by the thermovision camera during the energy absorbing investigations of a composite specimen. In the picture, colour envelopes are used to mark the stand elements: a lower support, a beater and a composite specimen. The arrow and symbols mark the direction of the vector of a beater velocity (load) in respect to the specimen. The colour scale shown on the right side of the photo is selected automatically to the range of temperatures detected by the camera. At the bottom and at the top of the scale, there are boundary values of temperatures. At the left bottom corner, there is placed the time which has gone by from beginning of the specimen crush. The non-destroyed fragment of the specimen is characterised by a low temperature (close to the ambient temperature). The growth of the temperature is recorded by the camera on the surface of the crushed layers of the composite tube just below the upper edge of the crushed specimen or directly on it. In Fig. 2, there are additionally marked lower and an upper edges of the specimen.

3. Experimental results

The results of the energy absorbing and thermovision tests are compared in Table 1. There were recorded values of maximum temperature (for the whole crushing process) $T_{\max}$ for the examined composite specimens. The values constitute an algebraic average from three tests. Apart from the kind and structure description of the composites, Table 1 also shows the thickness of the tube wall – t, initial temperature value – T_0, maximum increase of temperature – ΔT as well as absorbed energy in a given crushing distance (30 mm) – EA and energy increase in relation to the static tests (0.0007 m/s) – ΔE. Along with a load ratio increase the maximum temperature increases and EA decreases. This relation is seen both in the cases of C/E and G/E composites. Thicker tubes gained a higher temperature growth. The maximum temperature for high wall thinness at load velocity 4–7 m/s is equal to 151.3°C for 2.5 mm glass composite and – 192°C for 3.0 mm carbon composite.

Table 1
The results of thermovision and energy absorbing tests of composite specimens

composite kind and structure	$V_{\text{initial.}}$ [m/s]	t [mm]	T_0 [°C]	$T_{\max}$ [°C]	ΔT [°C]	EA [kJ]	ΔEA %
G/E $[0/90]_T$	0.0007	1.5	27.1	34.3	7.2	0.37	–
G/E $[0/90]_T$	0.06	1.5	27.1	79.1	52.0	0.33	−10.8
G/E $[0/90]_T$	4.4	1.5	25	114.0	89.0	0.31	−16.2
G/E $[0/90]_T$	0.0007	2.5	26.8	38.4	11.6	0.74	–
G/E $[0/90]_T$	0.06	2.5	26.9	90.1	63.2	0.70	−0.54
G/E $[0/90]_T$	6.0	2.5	25	151.3	126.3	0.66	−10.8
C/E $[0/90]_T$	0.0007	1.5	26.9	42.5	15.6	0.40	–
C/E $[0/90]_T$	0.06	1.5	27.1	96.0	68.9	0.39	−2.5
C/E $[0/90]_T$	4.4	1.5	26.2	146.7	120.5	0.35	−12.5
C/E $[0/90]_T$	0.0007	2.0	27.1	40.7	13.6	0.55	–
C/E $[0/90]_T$	0.06	2.0	26.9	93.9	67.0	0.52	−5.4
C/E $[0/90]_T$	6.3	2.0	25	152.0	127.0	0.43	−21.8
C/E $[0/90]_T$	0.0007	3.0	26.9	45.4	18.5	0.98	–
C/E $[0/90]_T$	0.06	3.0	26.9	101.6	74.7	0.90	−8.1
C/E $[0/90]_T$	7.3	3.0	25.7	192.0	166.3	0.74	−24.4

The exemplary photos from FLIR camera showing the progress of the temperature distribution on the surface of the specimen made of G/E composite at load velocity 0.06 m/s are presented in Fig. 3. However, Fig. 4 presents the photos from the crushing process at the load velocity 7.5 m/s for C/E composite. It is important to underline that the photos shown in Fig. 3 were taken with the camera rotated by 90° due to the conditions of the camera installation. The higher crush speed and more composite strength, the higher temperature growth. The temperature increases in the area near crushing zone, while below – the temperature stays relatively low.

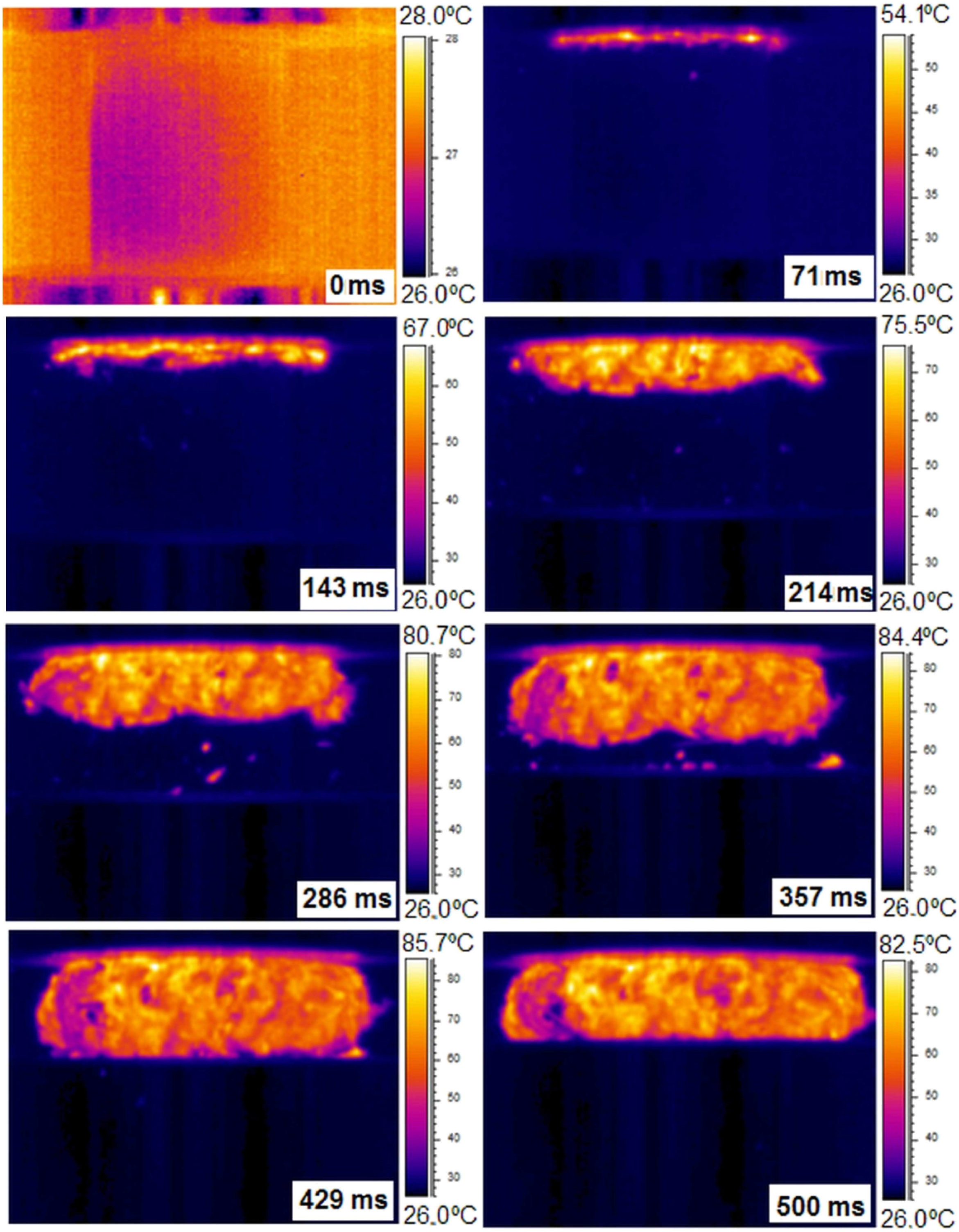

Fig. 3. Exemplary set of photos of G/E composite at velocity 0.06 m/s recorded by the camera

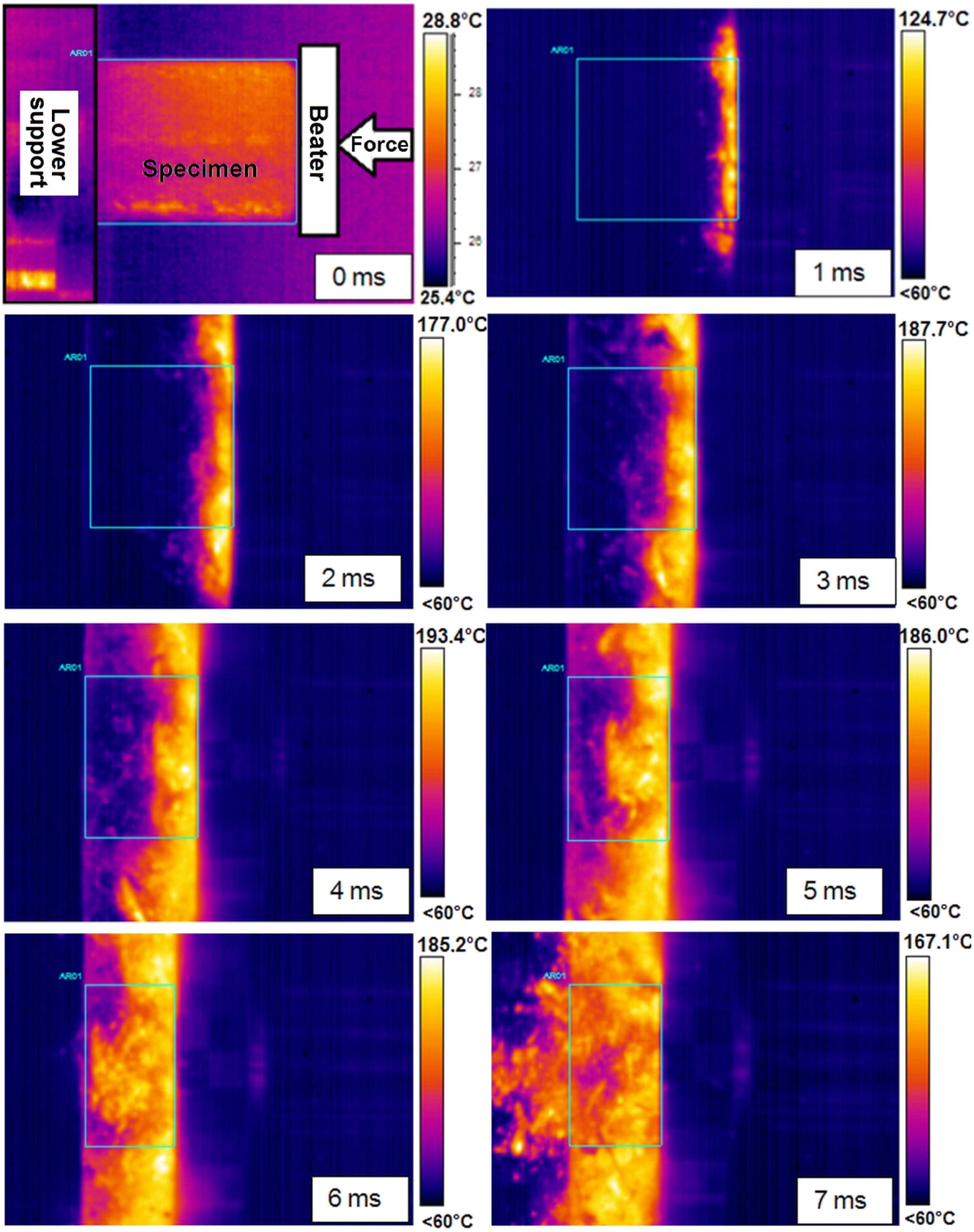

Fig. 4. Exemplary set of photos recorded by the camera with frequency approximately every 1 m/s for the C/E composite at velocity 7.5 m/s

Figure 5 presents the dependence of maximum temperature $T_{\max}$ in the function of time for the specimen which results are shown in Fig. 4. The graph was executed at the range of time from the beginning of the specimen crushing to the time of 20 ms. At this time the specimen maximum temperature increased locally from ambient to nearly 200°C in about 5 ms and then dropped to 130°C. As the result of friction between the specimen and the machine support and friction of particles of the crushed specimen there is emitted heat which leads to the significant temperature growth. Temperature of the epoxy resin E 53 softening, determined with the use of the Martens method, amounts to 55°C and is significantly lower than $T_{\max}$, that can result in premature specimen crushing. The EA drop at the velocity range 0.0007÷7.0 shown in Table 1 and clearly seen in example of composites reinforced with carbon fabric $[(0/90)_n]_T$ is explained by the influence of high temperature on the crushing process. It is concluded that at high load velocities the temperature growth on the specimen surface (even locally) influences the drop of a force crushing the specimen, which results in a drop of absorbed energy.

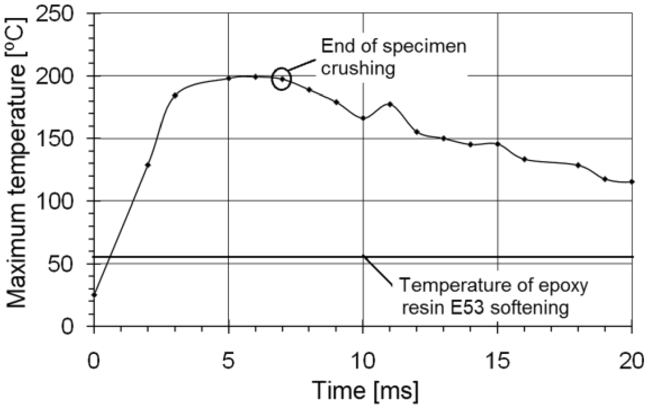

Fig. 5. The temperature progress in the function of time for the C/E specimen presented in the photos in Fig. 4

On the basis of the results of the measurements of temperature during the impact research (Table 1), the graphs of the maximum temperature growth (above ambient temperature) were executed for C/E (Fig. 6) and G/E (Fig. 7) with different wall thicknesses. The velocity growth of composite specimen load causes an approximately linear increase of a maximum temperature on the surface of the tubes. The wall thickness impact is less significant.

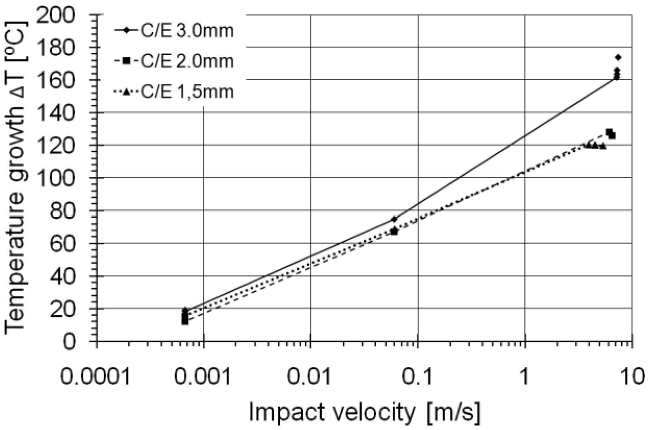

Fig. 6. The influence of load velocity on the temperature growth of the specimens made of C/E composites with different tube wall thickness

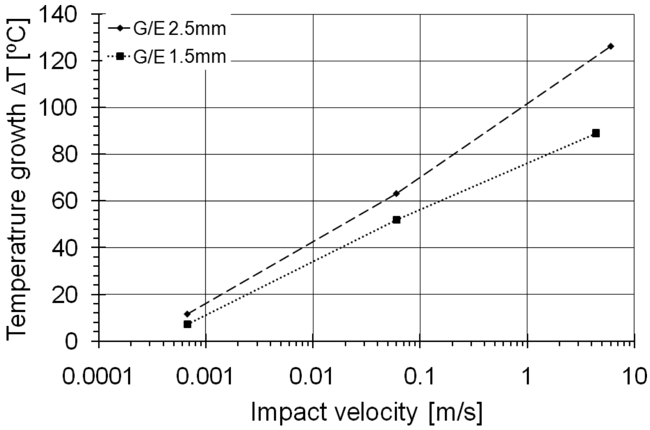

Fig. 7. The influence of load velocity on the temperature growth for the specimen made of G/E composites with different tube wall thickness

4. Conclusions

The research results unequivocally indicate that:

1. The velocity growth of composite specimens reinforced with carbon fabric and glass fabric crushing causes the increase of a maximum temperature on the surface of the tubes. The main factors influencing the high temperature growth is high load velocity and a composite structure as well as small thermal conduction of the polymer composite. Thick walls additionally influence an increase of the temperature growth.
2. The EA drop at the velocity range 0.0007÷9.0 shown in Table 1 for C/E and G/E composites is explained by the influence of high temperature on the crushing process. It is concluded that at high load velocities the temperature growth on the specimen surface influences on the drop of a force crushing the specimen, which results in a drop of absorbed energy.
3. The epoxy resin Epidian E53 is characterised by small resistance to high temperature which is indicated by its properties, such as a low softening temperature determined in Marten's method and equal to 55°C. It is appropriate to apply resins of higher heat properties in the energy absorbing constructions.

REFERENCES

[1] M.R. Schultz, "Energy absorption capacity of graphite-epoxy composites tubes", *PhD. Thesis*, Engineering Mechanics Institute, Blacksburg, 1998.

[2] A.G. Mamalis, D.E. Manolakos, M.B. Ioannidis, and D.P. Papapostolou, "On the response of thin-walled CFRP composite tubular components subjected static and dynamic axial compressive loading: experimental", *Composite Structures* 69 (4), 407–420 (2005).

[3] D.W. Schmueser and L.E. Wickliffe, "Impact energy absorption of continuous fiber tubes", *J. Eng.Materials and Technology*, *Trans. ASME* 109 (1), 72–77 (1987).

[4] G.L. Farley, "The effects of crushing speed on the energy-absorption capability of composite tubes", *J. Composite Materials* 25 (70), 1314–1329 (1991).

[5] A.H. Fairfull and D. Hull, "Energy absorption of polymer matrix composite structures: frictional effects", *Structural Failure* 1, 255–279 (1989).

[6] R. Keal, "Post failure energy absorbing mechanisms of filament wound composite tubes", *Ph.D. Thesis*, University of Liverpool, Liverpool, 1983.

[7] P.H. Thornton, "Energy absorption in composite structures", *J. Composite Materials* 13 (3), 247–262 (1979).

[8] P.H. Thornton and P.J. Edwards, "Energy absorption in composite tubes", *J. Composite Materials* 16 (6), 521–545 (1982).

[9] P.H. Thornton, J.J. Harwood, and P. Beardmore, "Fiber-reinforced plastic composites for energy absorption purposes", *Composite Science and Technology* 24 (4), 275–298 (1985).

[10] G.L. Farley, "Energy absorption of composite materials", *J. Composite Materials* 17 (3), 267–279 (1983).

[11] G.L. Farley, *Relationship Between Mechanical-Property and Energy-Absorption Trends* $0/\pm 45_2$, $0/\pm 75_2$ *for Composite Tubes*, NASA-TP-3284, 1992.

[12] P. Gotowicki, "Influence of the structures of selected composites on the energy absorption capability", *Ph.D. Thesis*, Military University of Technology, Warsaw, 2008, (in Polish).