SOUND VELOCITY DETERMINATION BEHIND SHOCK FRONT IN FLUOROPLASTIC MATERIAL (PTFE) AND EPOXY RESIN

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Application of polymeric materials as structural materials in some branches of industry requires direct knowledge of material properties. The area of dynamic properties is of special interest.

Particularly, sound velocity determination gives us information on elastic-plastic properties of the materials at shock compression. Data on sound velocity are used to build-up equations of material state. In addition, knowledge of sound velocity is important for correct set up of the explosive experiments and processing of gained results.

The analysis of polymeric material shock compressibility shows that at shock-wave loading they undergo transformations of various character therefore their properties can differ from the initial ones.

For this work, we have chosen fluoroplastic and epoxy resin as test materials. These materials have features in the pressure range from 20 to 35 GPa, which can be related to phase transformations [1-8]. For clarification of phase transformation boundaries we performed explosive experiments on determination of sound velocity in shock-compressed materials using photoelectric and manganin methods. Earlier photoelectric method was not applied for determination of sound velocity in shock-compressed fluoroplastic and epoxy resin.

Figure 1 illustrates experimental set up with Photoelectric method node and x, t - diagram of wave processes.

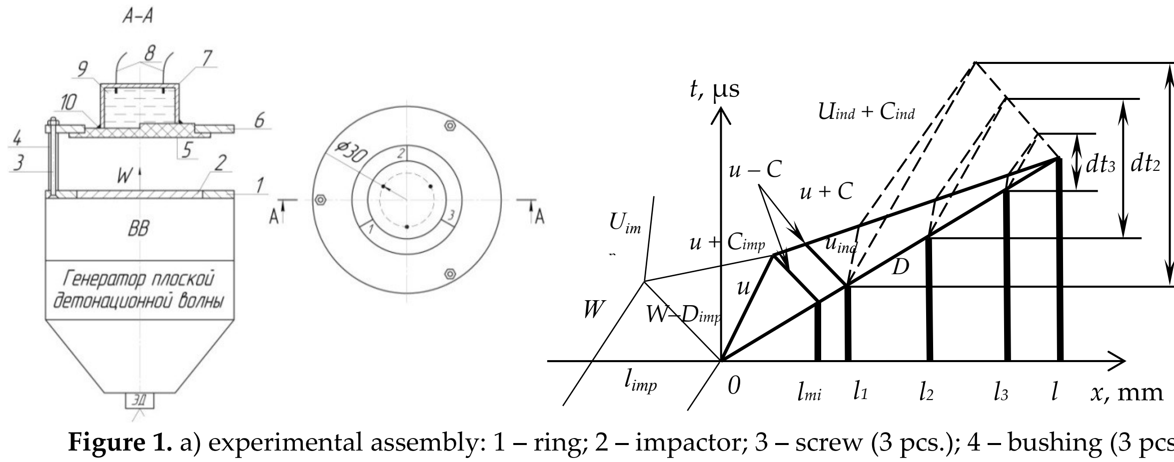


Figure 1. a) experimental assembly: 1 – ring; 2 – impactor; 3 – screw (3 pcs.); 4 – bushing (3 pcs.); 5 – the stepped sample of polymeric material, ø 90 mm, steps ø 70 mm; 6 – ring; 7 – casing; 8 – fiber optic sensors (3 pcs.); 9 – indicator; 10 – glue; b) x,t - diagram of wave processes

Loading devices of throwing type based on powerful condensed explosives were applied in the samples to create the SW. Such devices consist of the plane detonation wave generator, an explosive charge and the plate-impactor. Impactors of stainless steel 12X18H10T or steel 10 were used in the experiments. The range of the impactors flying velocities was from 2.7 to 4.8 km/s.

Taking into account an optical transparency of the investigated materials in IR-spectrum, 0.01 mm aluminum foil was sticked on each step of the sample for shielding the sensors against radiation exposure caused by shock wave compression of the sample.

The thicknesses of steps were determined from x, t-diagram so that rarefaction waves overtake the shock wave front in the indicator. Chloroform was used as the indicator. The indicator was poured in the casing (pos. 7 in Fig. 1) just before explosive experiment.

Signals from fiber optics sensors (pos. 8 in Fig. 3) were fed through electron-optical converters to oscilloscopes. Spectral sensitivity of the converters was from 480 to 960 nm and from 900 to 1700 nm.

The typical signals gained in the experiments are given in Figure 2.

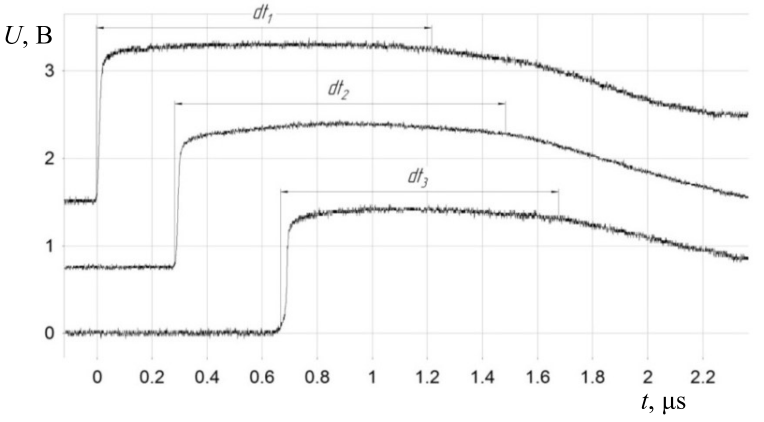


Figure 2. Typical signals of the sensors

For determining the sound velocity, we used the following expression:

$$C = \frac{C_{imp} \cdot D_{imp} \cdot R - u \cdot \left(C_{imp} + u + D_{imp} - W\right)}{C_{imp} \cdot \frac{D_{imp}}{D} \cdot R - \left(C_{imp} + u + D_{imp} - W\right)} - u \qquad (1)$$

where W_{imp} –impactor approaching velocity to the sample, [km/s]; D_{imp} – shock wave velocity in the impactor, [km/s]; C_{imp} – sound velocity in the impactor, [km/s]; u – sample substance mass velocity behind the shock wave front, [km/s]; D_{smp} – shock wave velocity in the sample, [km/s]; R – ratio of the sample thickness l, at which the first characteristics of the rarefaction wave overtakes the shockwave front, to the impactor thickness l_{imp}.

From the obtained profiles $U\ (t)$, we determined time intervals dt_i from the moment of the shock wave arrival to the boundary the sample-indicator till the moment of the rarefaction wave overtakes the shock wave front in the indicator. Then, we determined the sample thickness l, where RW overtakes SWF on the sample surface by extrapolation of dependency $dt_i = f\ (l_i)$ to $dt = 0$. The kinematic parameters were determined by $P,\ u$-diagram method according to the prior known approach velocity of the impactor. We used the following D,u-ratios while performing preliminary estimates of the shock compression parameters:

For stainless steel 12X18H10T [9]:
$D = 4.56 + 1.501 \cdot u$, (2)

For steel 10 at $1.40 \le u \le 8.00$ km/s [10]:
$D = 3.664 + 1.790 \cdot u - 0.0342 \cdot u^2$, (3)

For fluoroplastic at $0.75 < u < 4.4$ km/s [11]:
$D = 1.95 + 1.67 \cdot u$, (4)

For epoxy resin:
$D = 2.65 + 1.562 \cdot u$, at $0 < u < 2.49$ km/s,
$D = 3.84 + 1.086 \cdot u$, at $2.49 < u < 3.61$ km/s, (5)
$D = 2.86 + 1.355 \cdot u$, at $3.61 < u < 5.18$ km/s,

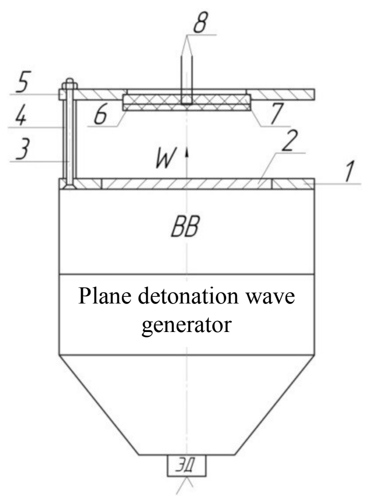
For chloroform [12]:
$D = 1.317 + 1.572 \cdot u$, for $0.8 \le u \le 2.9$ km/s,
$D = 3.456 + 0.833 \cdot u$, for $2.9 \le u \le 3.3$ km/s. (6)
$D = 1.031 + 1.539 \cdot u$, for $3.3 \le u \le 4.8$ km/s.

The set up data and the results of experiments on the sound velocity determination with photoelectric method are given in Table 1.

Table 1. Set up data and experimental results (photoelectric method)

Sample material	**EK-34** by OST B95 2372-83						**F-4** by TS 6-05-810-88			
# experiment	1	2	3	4	5	6	1	2	3	4
Impactor material	12X18H10T					Steel 10	12X18H10T			
P_{imp}, g/cm^3	7.89	7.91	7.87	7.93	7.92	7.84	7.88	7.92	7.86	7.90
H_{imp}, mm	4.00	4.00	3.98	4.02	4.02	3.03	3.99	3.97	3.98	3.98
W_{imp}, km/s	2.65	3.64	3.84	4.01	4.01	4.80	2.65	3.64	3.84	2.65
ρ_{0smp}, g/cm^3	1.18						2.16			
h_1, mm	8.84	7.87	7.90	8.90	8.84	5.89	8.18	8.02	7.94	8.02
h_2, mm	11.86	9.89	9.90	11.94	11.88	7.87	10.15	9.99	9.92	9.98
h_3, mm	14.86	11.86	11.85	14.94	14.81	9.94	12.16	11.86	11.99	11.91
u, km/s	2.248	3.045	3.203	3.342	3.341	3.893	2.079	2.783	3.203	2.08
D, km/s	6.161	7.143	7.314	7.466	7.465	8.140	5.422	6.598	7.314	5.424
ρ, g/cm^3	1.86	2.06	2.10	2.13	2.13	2.26	3.50	3.73	3.77	3.50
P, GPa	**16.35**	**25.66**	**27.65**	**29.44**	**29.43**	**37.40**	**24.35**	**39.66**	**43.44**	**24.35**
dt_1, μs	1.600	1.590	1.419	1.022	0.993	-	1.343	1.269	1.477	1.321
dt_2, μs	0.893	1.255	1.073	0.818	0.742	0.626	0.870	0.935	1.094	0.897
dt_3, μs	0.582	1.014	0.794	0.435	0.464	0.392	0.583	0.590	0.698	0.460
C, km/s	**7.28**	**7.85**	**8.90**	**7.72**	**7.59**	**9.48**	**6.15**	**7.58**	**7.72**	**6.54**

Besides, we performed the explosive experiments on determination of sound velocity in shock-compressed materials using manganin sensor method. Sound velocity was determined by the rarefaction overtaking technique and by the rarefaction oncoming technique. Devices with the impactors of steel 12X18H10T, similar to the first series of experiments, were used for the shock wave loading. Figure 3 illustrates experimental set up scheme.



1 – ring;
2 – impactor;
3 – screw (3 pcs.);
4 – bushing (3 pcs.);
5 – ring;
6 – screen ø 60 mm;
7 – sample ø 60 mm;
8 – manganin sensor

Figure 3. Experimental assembly scheme

Manganin sensor (pos. 8 in Fig. 3) was placed between the screen and the sample (pos. 6 and 7 in Fig. 3, accordingly), thus the sensing device was positioned in the centre of the sample. Gap between the shield, the sample, and the holes in the sample with sensor leads were filled with the composition based on the epoxy adhesive. Widths of the shield and the sample were determined from x, t-diagram (were not shown here) so that to eliminate interaction of overtaking and oncoming rarefactions.
The set up data and the results of experiments are given in Table 2.

Table 2. Set up data and experimental results (MS)

Sample material	EK-34								F-4	
# experiment	1	2	3	4	5	6	7	8	1	2
W_{imp}, km/s	2.35	2.91	2.90	3.58	3.60	3.62	3.85	3.87	4.03	4.05
ρ_{0smp}, g/cm³	1.19	1.19	1.19	1.19	1.18	1.19	1.19	1.18	2.15	2.20
u, km/s	2.003	2.457	2.448	2.995	3.01	3.028	3.21	3.228	3.055	3.056
D, km/s	5.779	6.488	6.474	7.089	7.105	7.125	7.326	7.341	7.052	7.054
ρ, g/cm³	1.81	1.91	1.90	2.05	2.05	2.06	2.11	2.12	3.79	3.88
***P*, GPa**	**13.66**	**18.81**	**18.70**	**25.07**	**25.32**	**25.55**	**27.74**	**28.13**	**46.77**	**47.14**
***C*, km/s**	**6.50***	**7.89***	**7.13****	**7.06***	**7.62***	**8.26****	**7.27***	**8.48****	**7.89***	**7.35****

* – Sound velocity was determined by the rarefaction overtaking technique;

** – Sound velocity was determined by the rarefaction oncoming technique.

Figures 4 and 5 present the results of this work in graphic form. The error of the sound velocity determination by photoelectric method is 6 %, by manganin technique is 8 %. For comparison Figures 4 and 5 demonstrate data of the authors [1-5, 8] obtained earlier using other methods of dynamic parameters recording. Besides, sound velocities under normal conditions obtained by ultrasonic method are also marked in the Figures [13].

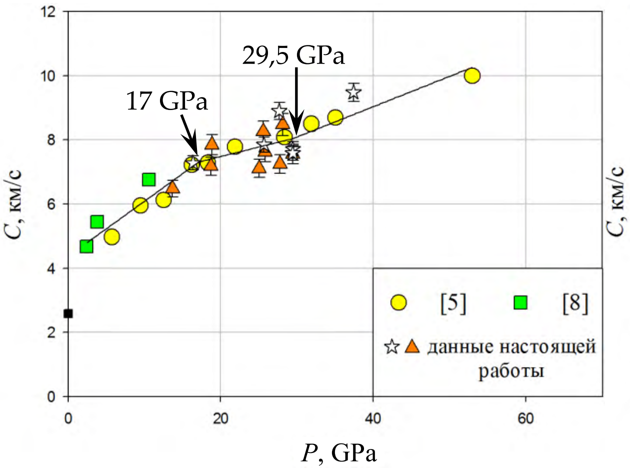


Figure 4. Sound velocity in shock compressed F-4

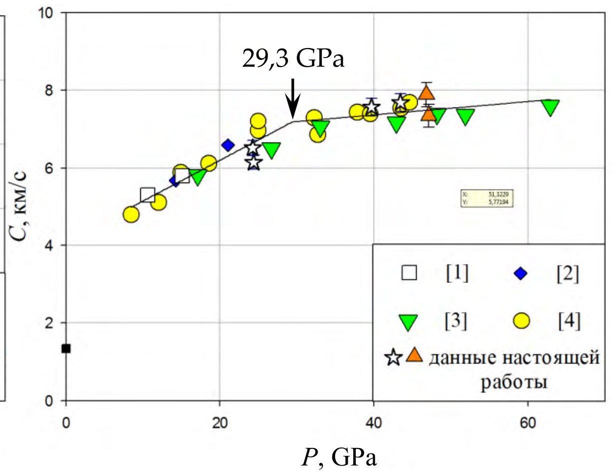


Figure 5. Sound velocity in shock compressed EK-34

Results of the present work correlate with the findings [1-4] in determination of sound velocity in the shock compressed fluoroplastic material. The total data set has been approximated by the linear function. As can be seen from Figure 4, the approximation line undergoes a kink at pressure of 29.3 GPa that can be caused by phase transition in substance at shock compression. In paper [3] *C*, *P*-characteristics kink is determined at pressure of 34 GPa, which the authors explain by fluoroplastic dissociation into pure carbon and gaseous fluorocarbons.

From Figure 5 we can see that the line of approximation of epoxy resin dependence *C* (*P*) changes an inclination at pressures of 17 and 29.5 GPa that can testify phase transformation of epoxy resin at the specified pressures. The upper boundary of the supposed phase transformation is determined rather conditionally. For its clarification, we need data on the sound velocity at pressure > 30 GPa.

The considerable data scattering on the sound velocity is observed in a range of pressures 25 ÷ 30 GPa. Such substance behaviour is typical in the presence of phase transition and can be stipulated by bond openings and chemical bondings formation what was discussed in [5]. However, one must not eliminate such factors, as: various initial components and sample fabrication technique, methods of shock-wave loading and dynamic parameters recording.

This paper presents the results of the sound velocity determination in fluoroplastic and epoxy resin in the pressure ranges from 24 to 44 GPa and from 14 to 38 GPa, correspondingly. The sound velocity in shock compressed materials was determined by photoelectrical and manganin methods. The results of the present work agree satisfactorily with the results of [1-8].

By the results of the total data set approximation boundaries of the supposed phase transitions were established for each material: in fluoroplastic - at pressure of 29.3 GPa, in epoxy resin - at pressures of 17 and 29.5 GPa.

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