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Experimental study of the viscosity of polymerized epoxy resin under shock compression

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The VISAR laser interferometry method was used to study the viscous properties of polymerized epoxy resin under shock compression in the pressure range 0.8—2.7 GPa (fig. 1). The Hugoniot is obtained in the coordinates mass velocity–the velocity of the shock wave, which is consistent with the data available in the literature (fig. 2). The dependence of the maximum longitudinal strain rate on the pressure behind the shock wave front in the form of a power relationship is obtained. The value of the exponent 5.5 was significantly higher than the exponent 4, which is typical for various materials [1]. The question of achieving a stationary propagation mode by shock waves in the performed experiments is considered. The viscosity coefficient of the polymerized epoxy resin is calculated, the values of which are in the range from 0.1 to 7.3 Pa·s for the obtained shock compression pressures.

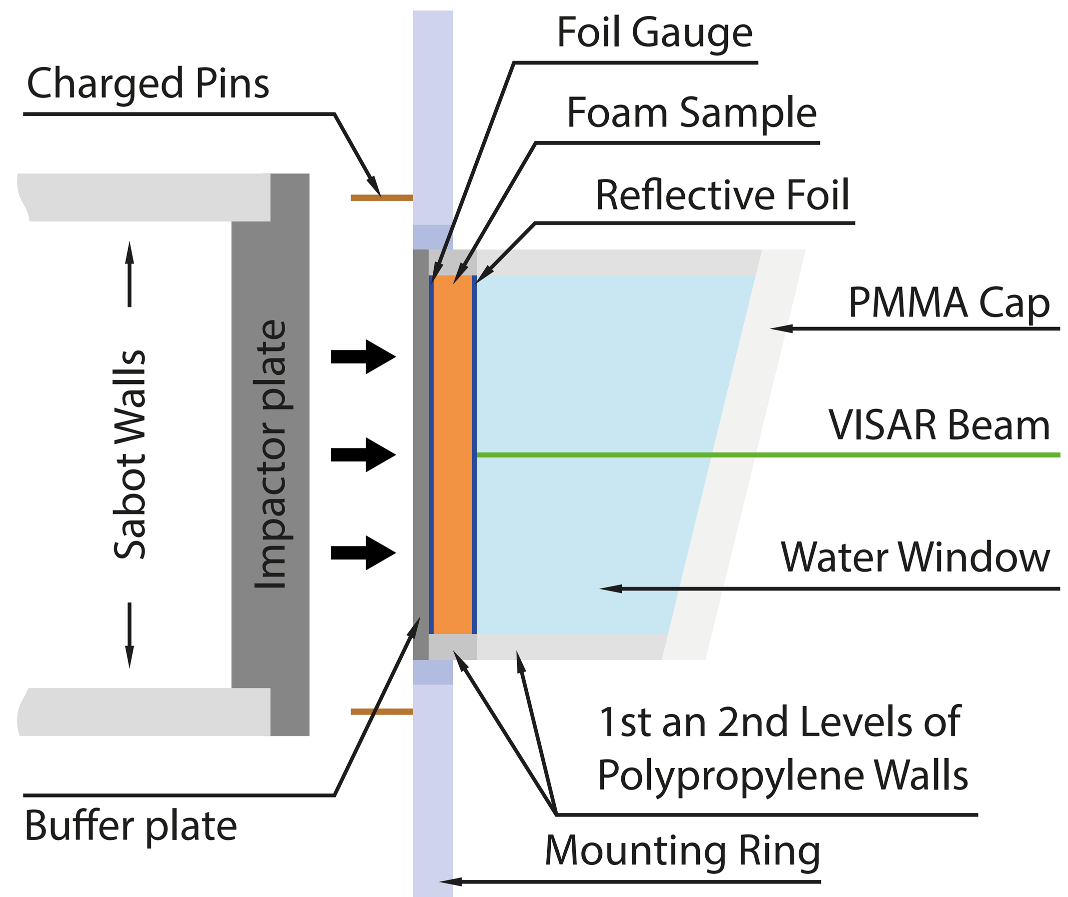

Fig. 1. The experimental configuration.
Cables and the second pair of pin gauges are not shown.

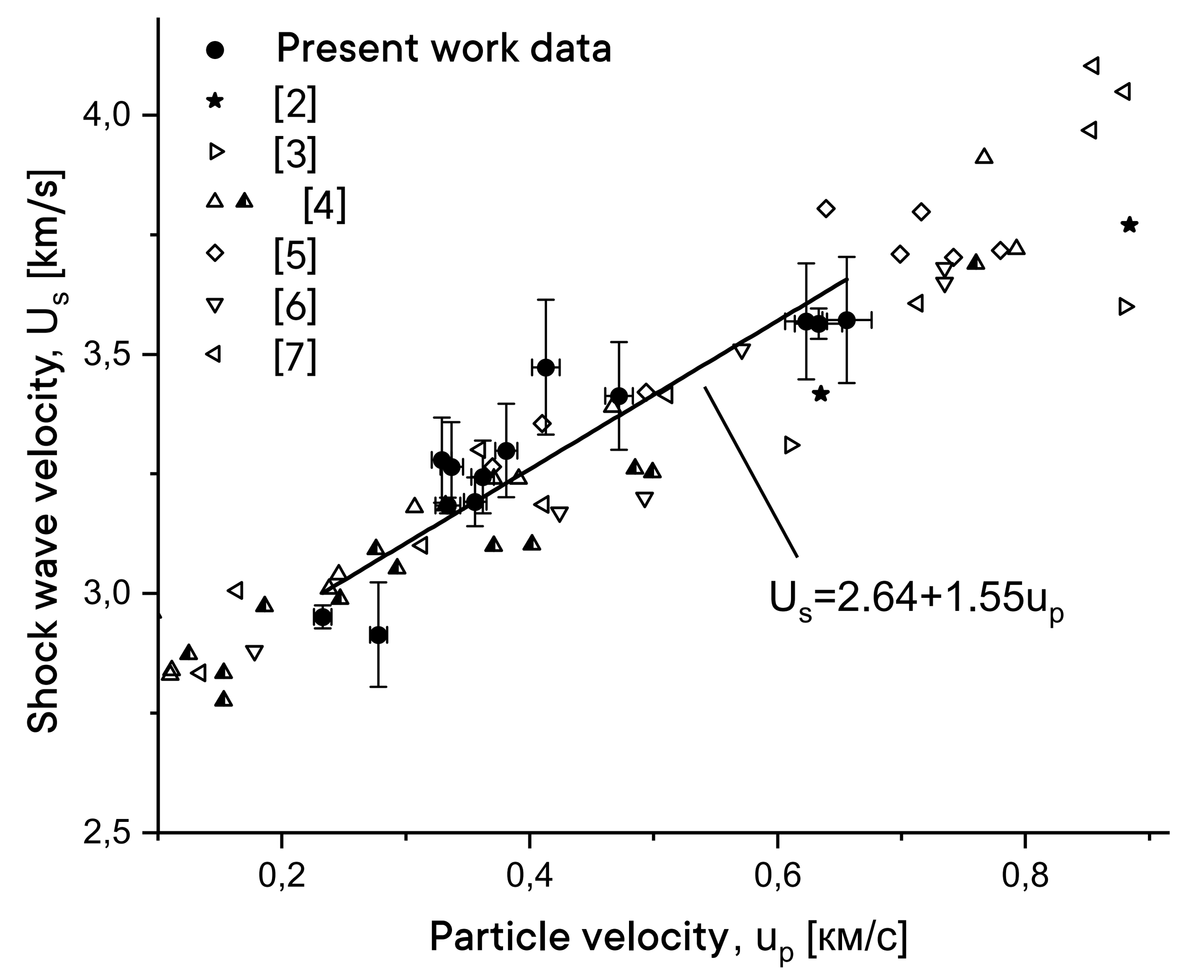

Fig. 2. The measured Hugoniot data on the wave velocity - particle velocity plane compared with previous results.

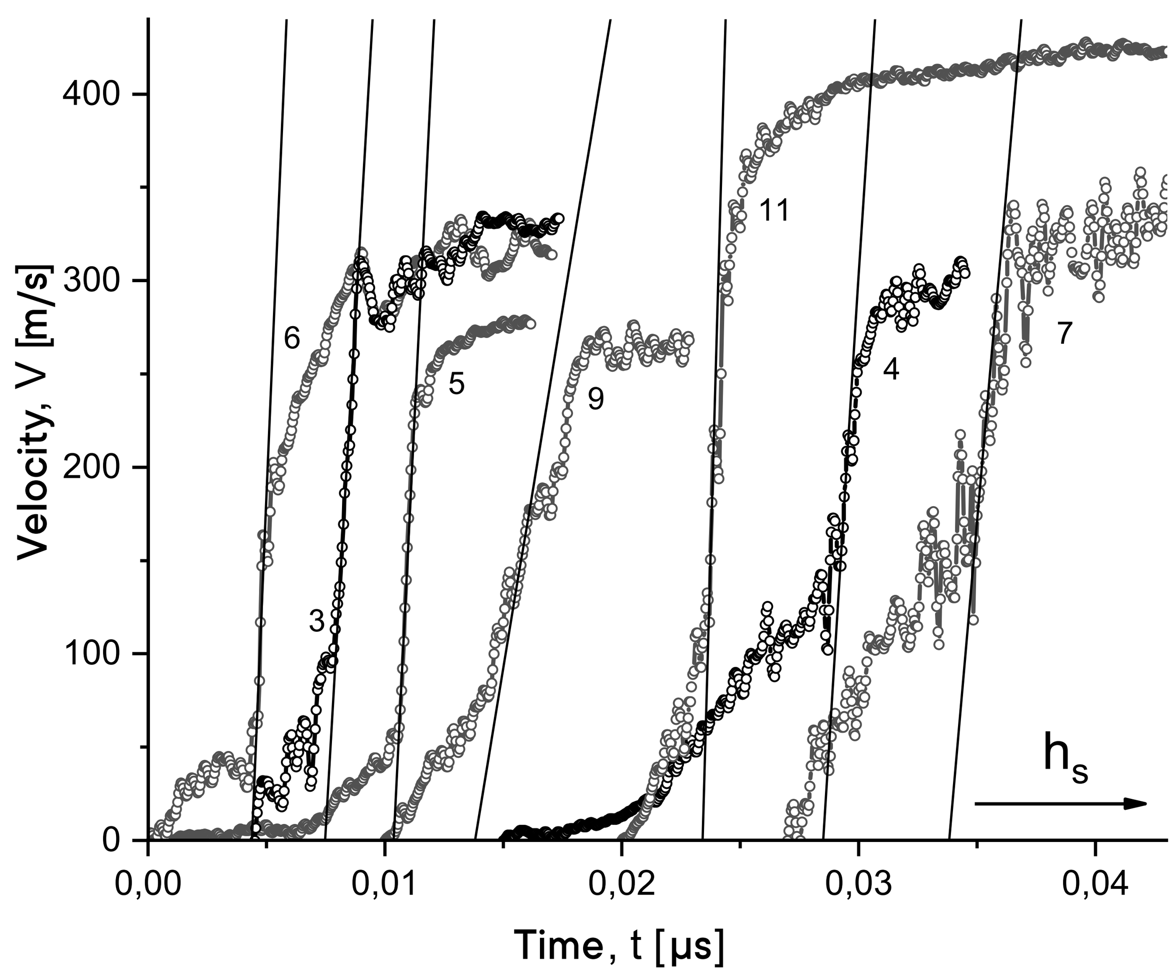

Fig. 3. Evolution of shock wave front in polymerized epoxy resin with increasing propagation distance (4.62 - 14.57 mm) at P~1.3 GPa. The dashed lines correspond to the measured maximum velocity gradients in wave fronts

The scaling law relationship between pressure and maximum longitudinal strain rate for polymerized epoxy resin (fig. 4):

$$\dot{\varepsilon}_x = 11.76P^{5.5}\ [\mu s^{-1}]$$

The viscosity coefficient (fig. 5) was calculated using the formula [8]:

$$\eta = \frac{\tau}{\dot{\varepsilon}_x},\ [\mathrm{Pa{\cdot}s}]$$

where τ is the maximum shear stress.

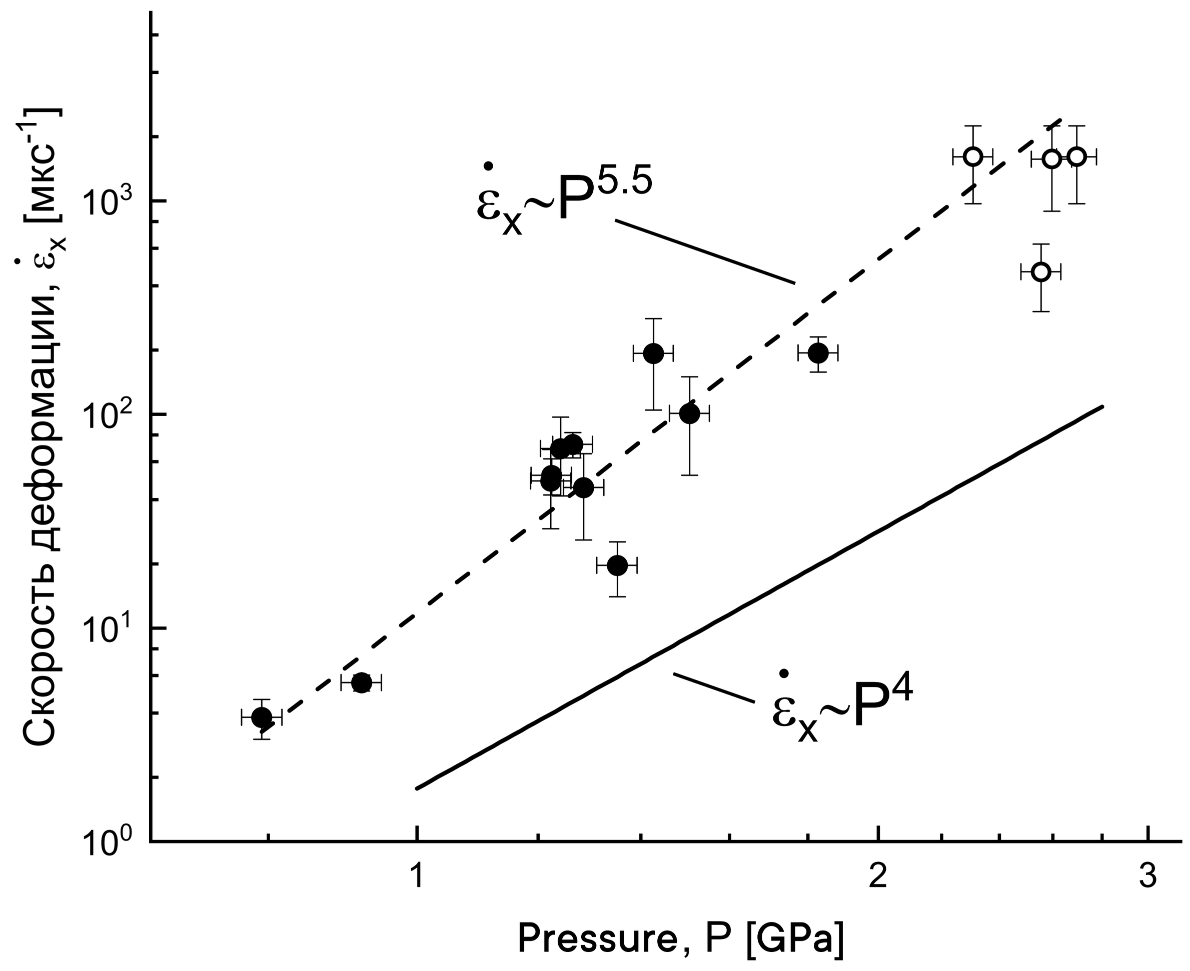

Fig. 4. Maximum longitudinal strain rate within shock wave front versus pressure behind shock wave front.

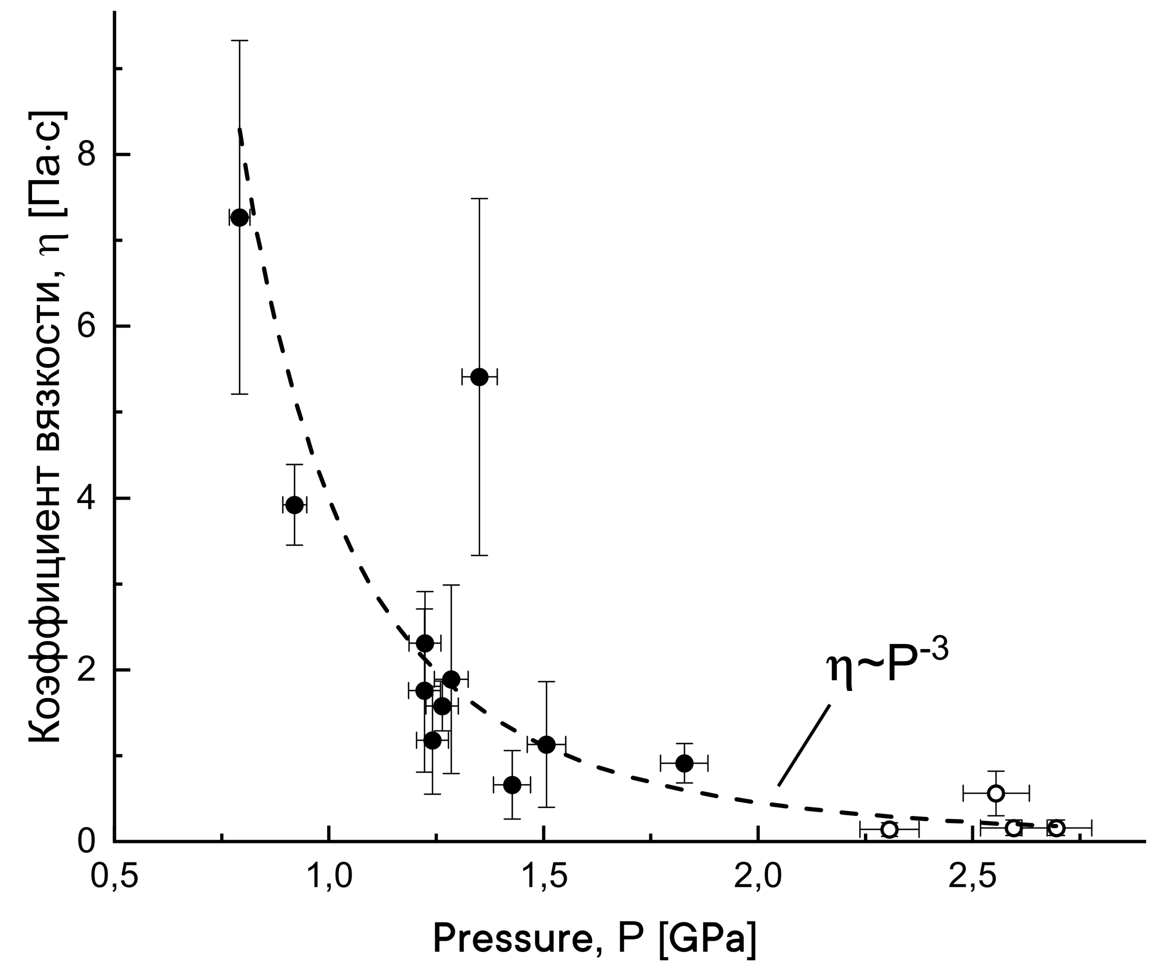

Fig. 5. Viscosity coefficient versus pressure behind shock wave front.

Conclusions:

1) The obtained exponent 5.5 is noticeably higher than the universal value 4. The explanation of the difference, apparently, must be sought in the difference between the mechanisms of plastic deformation of high-molecular substances such as epoxy resin and metals, mainly for which n≈4 is true.

2) As the stress increases, the viscosity coefficient decreases, which is probably due to the heating of the material behind the shock front.

References:

1. Grady D.E. Structured shock waves and the fourth-power law // J. Appl. Phys. 2010. V. 107. 013506.
2. Bushman A.V., Efremov V.P., Fortov V.E., Kanel' G.I., Lomonosov I.V., Ternovoi V.Ya., Utkin A.V. Equation of state of composites under high energy densities // Shock compression of condensed matter 1991 / Ed. by S. C. Schmidt, R. D. Dick, J. W. Forbes, D. G. Tasker – Elsevier Science Publishers B. V., 1992. P. 79-82.
3. Мочалова В.М., Уткин А.В., Павленко А.В., Малюгина С.Н., Мокрушин С.С. Импульсное сжатие и растяжение эпоксидной смолы при ударно-волновом воздействии // ЖТФ. 2019. Т. 89. Вып. 1. С. 126-131.
4. Munson D.E., May R.P. Dynamically determined high pressure compressibilities of three epoxy resin systems // J. Appl. Phys. 1972. V 43. P. 962-971.
5. Carter W.J., Marsh S.P. Hugoniot Equation of State of Polymers. — Los Alamos National Laboratory, New Mexico, US, Los Alamos Report LA-13006-MS. 1995. 25p.
6. Millett J.C.F., Bourne N.K., Barnes N.R. The behavior of an epoxy resin under one-dimensional shock loading // J. Appl. Phys. 2002. V. 92. N. 11. P. 6590-6594.
7. Hazell P.J., Stennett C., Cooper G. The shock and release behavior of an aerospace-grade cured aromatic amine epoxy resin // Polym. Compos. 2008. V. 29. P. 1106-1110.
8. Канель Г.И., Савиных А.С., Гаркушин Г.В., Разоренов С.В. Оценка вязкости глицерина по ширине слабой ударной волны // ТВТ. 2017. Т. 55. №2. С. 380-395.