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GASES AND LIQUIDS

Experimental Model of the Role of Cracks in the Mechanism of Explosive Eruption of St. Helens-80

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Abstract—A unique mini model of explosive volcano eruption through a formed system of cracks is developed. The process of crack formation and development is simulated by electric explosion of a conductor in a plate of optically transparent organic glass submerged into water. The explosion of a wire aligned with a through hole in the plate generates shock-wave loading along the plate and forms cracks. The fundamental role of high velocity flow in crack wedging by a high power hydrodynamic flow of a pulsating explosion cavity has been demonstrated.

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INTRODUCTION

Many physical, technological, and natural processes are connected with the destruction of solids by developing cracks at their dynamic loading. Explosive volcano eruptions are of great interest. It was demonstrated in [1] that some explosive-type volcanoes can be considered to be complex hydrodynamic systems that include the volcano's chamber, a vent sealed by a plug, and a system of cracks and dikes filled with high pressure magma. It is assumed that the architecture of Mount St. Helens volcano has a structure in which the chamber–vent system is similar from a physical point of view to the hydrodynamic shock tube [2, 3]. The explosive eruption of this volcano in May 1980 was initiated by a gigantic avalanche and was accompanied by a system of cyclic ejections of ash clouds from the central vent and along the landslide trajectory. In [4], the mechanism of generating the sequence of ejections of gigantic ash clouds based on the assumption that dikes open (under the action of wedging magma pressure) as a result of changing static pressure after a huge avalanche from Mount St. Helens was proposed.

Experiment formulations and laboratory modeling play an important role in investigation of these processes; they ensure detailed study of the mechanisms defining the nature of accompanying phenomena. One of the efficient methods for the laboratory study of the dynamics of crack formation and development is shock-wave loading with millisecond loading times [5] based on the generation of a short compression pulse in the studied sample. The resistance of crack growth in organic glass under dynamic loading [6], the influence of the duration of nanosecond impact [7], and the wave dynamics in solid dielectrics at electric blasting loading [8, 9] were studied from the point of view of establishing certain regularities connected with crack formation and development.

The loading pulse, which is modeled by a shock wave creating cracks, and the formed pulsating explosion cavity, which creates the wedging effect by introducing liquid into cracks at high pressure, are of interest [10]. Here, we propose a unique experimental approach implying initiation of a shock wave which acts on the inner surface of the through ring in the organic glass plate in the underwater explosion of the wire situated along the hole axis perpendicular to the plate surface.

EXPERIMENTAL MODEL OF CRACK FORMATION AND GROWTH

These studies are devoted to experimental modeling of this process based on the electric explosion of a conductor in a liquid, which allows one to control the crack formation and growth in sample plates of optically transparent organic glass (PMMA). A plate with a through hole allows one to generate shock-wave loading along the plate as a result of the explosion of the wire aligned with the hole axis. The eruption of Mount St. Helens volcano (May, 1980) is characterized by a special preexplosion state, i.e., an enormous avalanche that removed the lid from the volcano crater, which initiated its eruption from the vertical vent (conduit) (Fig. 1, left frame). The gigantic mass of soil carried to the foot of the mountain significantly reduced the pressure on the ground, which assisted in

Fig. 1. Two series of ejections of ash clouds in the eruption of Mount St. Helens in 1980: vertical ejection (main vent, left frame) and series of side ejections (right frame).

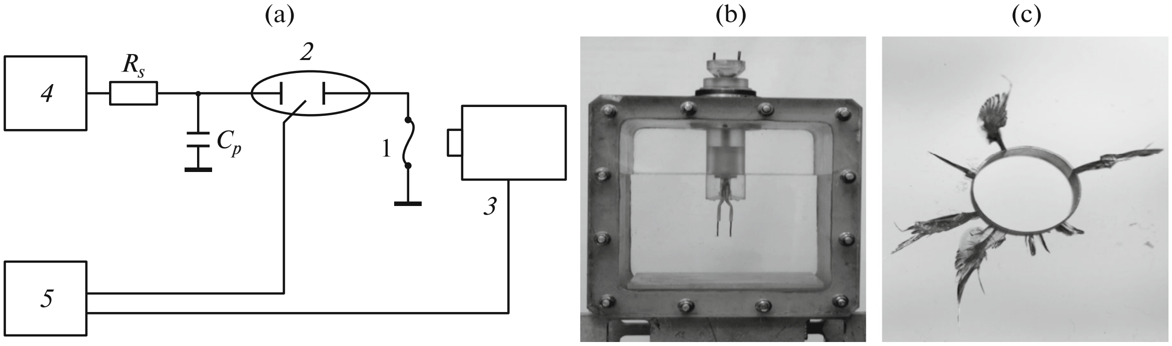


Fig. 2. Schematic diagram of the installation: (a) electric circuit, (b) explosion unit filled with water, (c) typical system of cracks in the plate during explosive loading.

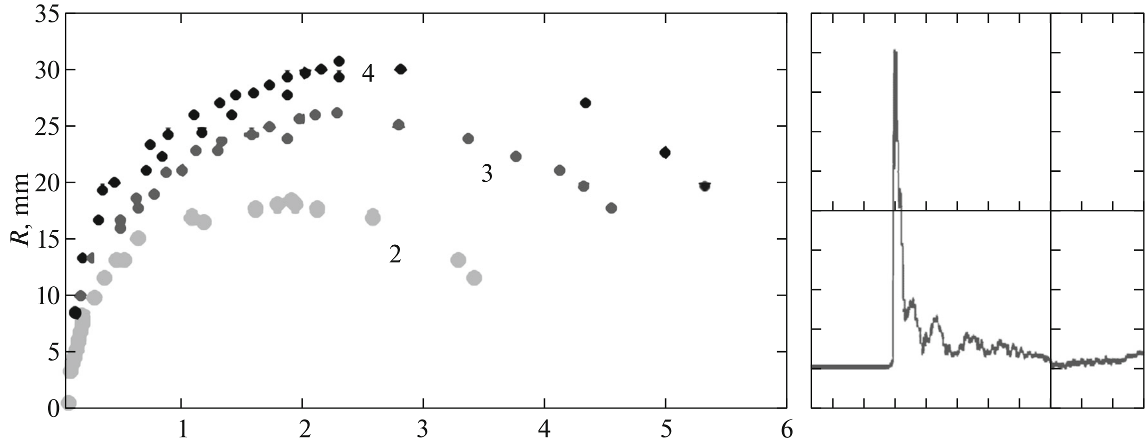


Fig. 3. Explosion cavity dynamics for 2, 3, and 4 kV loading. Typical pressure oscillogram: 10 μs/point, amplitude 9 MPa.

opening the system of dikes connected with the volcano's chamber. Their opening in the neighborhood of the bottom of the dome, the random character of successive ejections of several gigantic ash clouds along the avalanche trajectory (Fig. 1, right frame) and, as a consequence, the subsequent closure of cracks, becomes quite realistic if the absence of traces in the form of a chain of restoring plugs is taken into account [3].

The experimental simulation of the cyclic mechanism of the eruption of Mount St. Helens is based on shock-wave loading in the liquid of an organic glass plate with a hole. The laboratory modeling of the

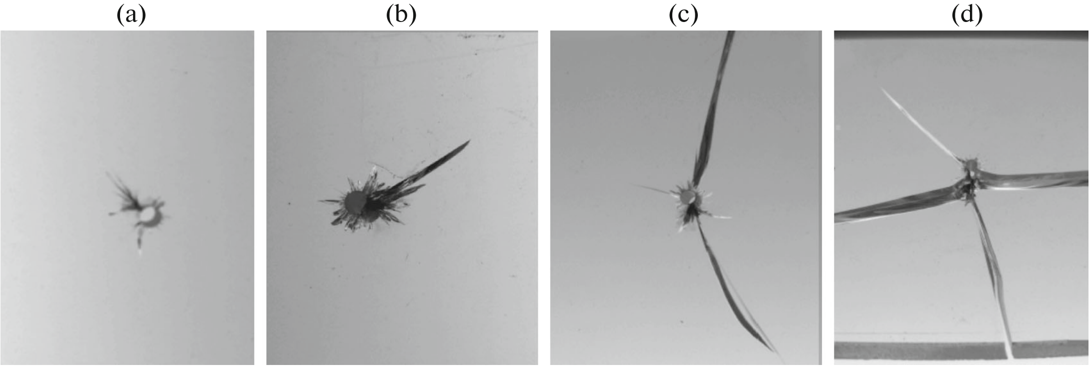


Fig. 4. Influence of loading intensity on the structure of the system of cracks.

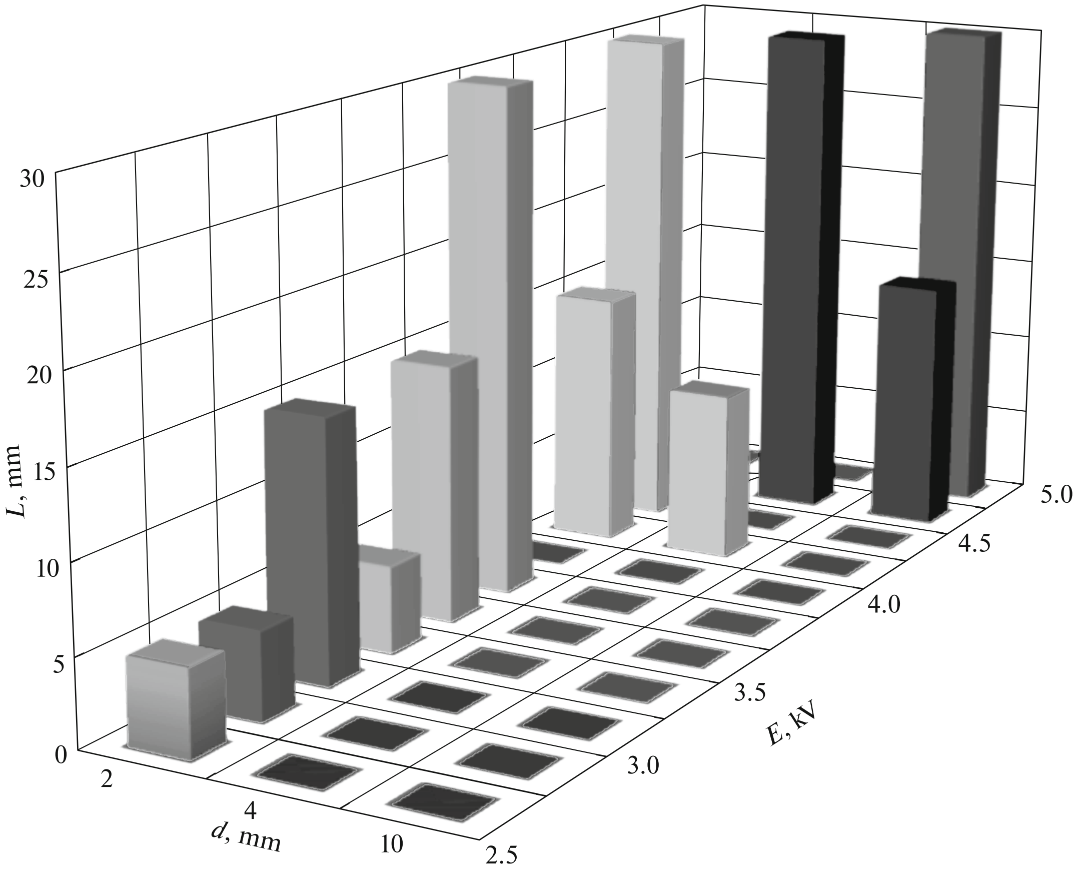
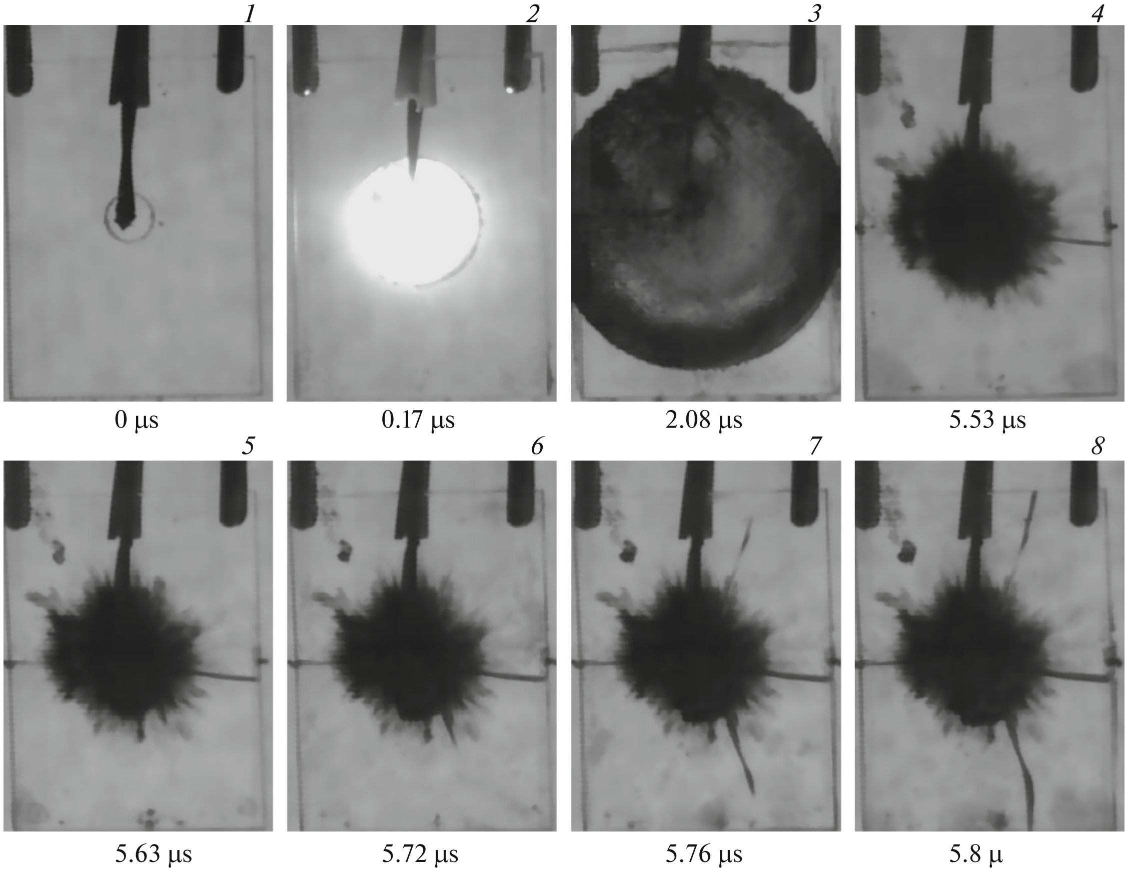


Fig. 5. Crack length L, mm, as a function of loading intensity, for holes of three sizes: 2, 4, and 10 mm.

effect was performed at the test facility (Fig. 2a), which including a high voltage capacitor C_p bank with an accumulated energy of up to 200 J, a charging system *4* and a synchronization system *5*, a fast digital video camera *3* (up to 700 000 frames per second), and a working chamber (Fig. 2a (*2*), Fig. 2b). The organic glass plate (60 × 50 × 4.5 mm) with the through cylindrical hole was fixed between the chamber electrodes (Fig. 2c). The studies of crack formation in the plate submerged into water were performed based on the original method proposed to generate the shock-wave loading of the hole boundary (ring with a width of 4.5 mm and different radius) along the organic glass plate via the electric explosion of the wire aligned with the hole axis.

Table

L, m	U, kV	$R_{\max}$, m	$T_{\max}$, s	$P_0V_{\max}$, J	E, J	Efficiency, %
0.005	2	0.018	0.0018	2.95	20	14.75
0.005	3	0.025	0.0026	7.524	45	16.72
0.005	4	0.03	0.0029	12.72	80	15.9



0 μs 0.17 μs 2.08 μs 5.53 μs

5.63 μs 5.72 μs 5.76 μs 5.8 μ

Fig. 6. Hole diameter of 10 mm, loading intensity of 125 J.

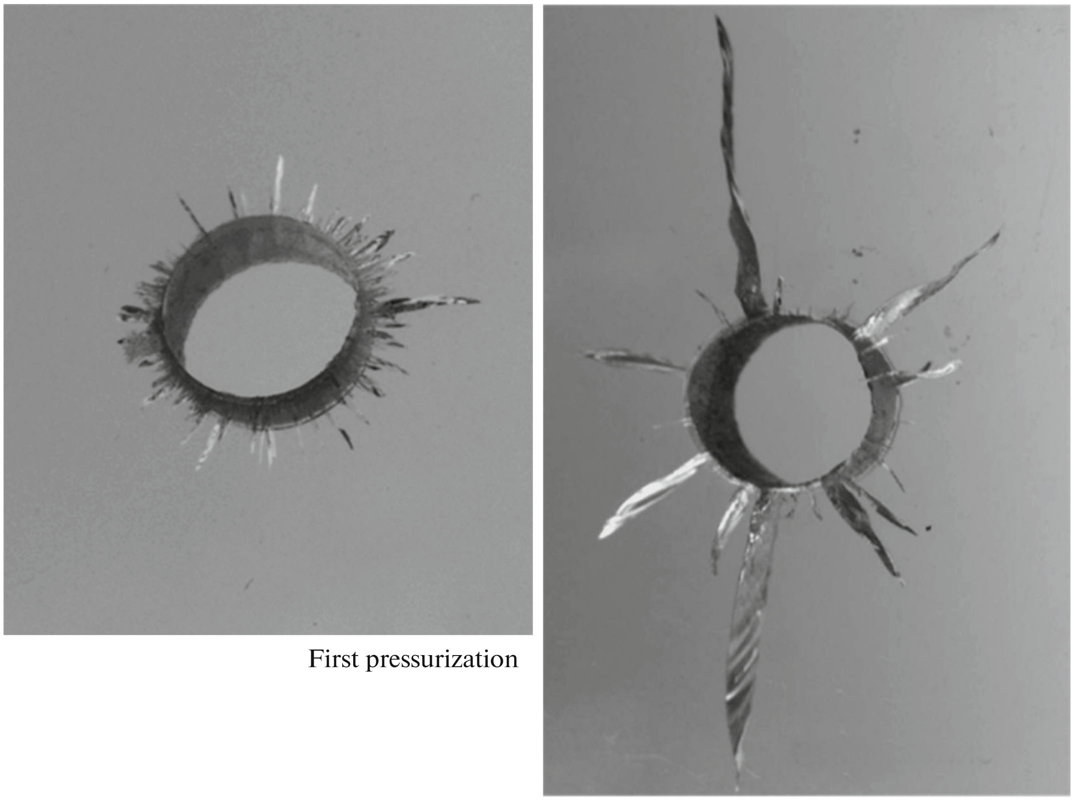
The parameters of the gas cavity upon the explosion of a nichrome wire with a length of 5 mm in a water-filled tank and a voltage drop at the capacitor bank plates with the capacity $C_p = 10$ μF in an interval of 2–4 kV were experimentally registered. The bubble dynamics was registered by a fast camera with a rate of 6×10^4 frames per second. The cavity dynamics for three energies in the accumulator (Fig. 3) was constructed, and the fraction of energy released in the explosion products (conditional efficiency) was determined. The obtained data are given in the table.

The studies of the explosion cavity dynamics showed that the explosion products energy makes 14.7–16.7% of the accumulator energy. The shock wave forms the system of cracks and the high velocity flow of the expanding or collapsing cavity with the explosion products provide the dynamic load on the cracks and their wedging. The dynamics of the explosion cavity pulsations at a loading of 2.3 and 4 kV is shown in Fig. 3 for a typical pressure oscillogram $P_{\max} = 9$ MPa and 10 μs/point at a distance of about 5 cm from the exploding wire (a loading of 3 kV, 45 J) in an open space without a plate.

CRACK FORMATION

The experimental studies yielded characteristic structures of the system of cracks determined by the loading intensity and the hole size. It has been demonstrated that it is possible to analyze and control the processes of crack nucleation, formation, and wedging. As expected, the influence of the shock wave and the cavity with the explosion products on the formation of the system of cracks can be separated by limiting the hole diameter in the plate. A typical example is shown in Fig. 4 for the 2 mm hole. Figures 4a–4d correspond to variations in the source voltage from 2.5 to 4.0 kV with a step of 0.5 kV.

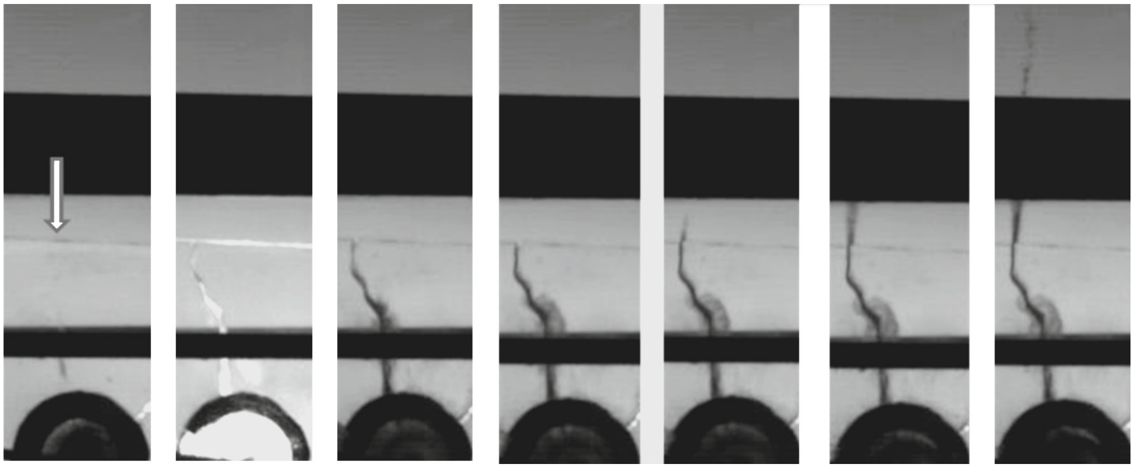
It can be easily seen that, at just 3 kV, the shock wave generates mostly main cracks in the plate submerged into water. It is interesting to note that, for large diameter of the loaded region and limiting (for the considered conditions) intensities of shock-wave loading, the size of the nucleation cracks generated in the organic glass plate is insignificant. A rather complete pattern connecting the two main parameters, the diameter d of the hole in the plate and the loading intensity (via the voltage U at the capacitor plates) are shown in Fig. 5. This figure shows the data on the crack size L dynamics depending on the input voltage



First pressurization

Second pressurization

Fig. 7. Creation of dikes by a series of repeated loadings (3 kV, 10 mm, closed cuvette).



0 μs 0.132 μs 0.264 μs 0.462 μs 0.594 μs 1.122 μs 2.376 μs

Fig. 8. Explosion at $t = 0.132$ μs (partial exposure of the cuvette and the crack), crack development, opening at the plate boundary (shown by the arrow), and liquid ejection into the atmosphere.

intensity at the capacitor bank and the hole radius in the plate. Note that the longest cracks shown in Fig. 5 are the main cracks that opened at the boundaries of the studied plates.

It follows from the experiment shown in Fig. 6 that the main role in the formation of large cracks can be played by the second phase (here, $t = 2.08$ μs is the beginning of this phase) of the underwater explosion, and the converging flow formed by the collapsing cavity. It is possible that, in this case, strong instability also has a complex effect and may result in the formation of a high density two-phase cluster-type flow (instead of a cavity) and large pressure growth. The first three frames in the figure represent the initial position of the wire before the explosion, glowing explosion products of the expanding explosion cavity, and its maximum size. It can be seen in Fig. 6 that high-intensity wedging and, correspondingly, the dynamic loading of nucleation cracks occurs when the diameter of the cluster cavity with an absolutely unstable boundary decreases by a factor of approximately two. The dynamics of crack formation and development can be represented (clockwise) as follows: 0–16 (5.53 μs), crack 0–45 is added at 5.63 μs; and, in the next three frames, the formation, development. and wedging of two more cracks can be observed, namely, 0–05 and 0–25, which go out to the plate boundary.

MINI MODEL OF MOUNT ST. HELENS WITH A SYSTEM OF DIKES

The results detailed above are the basis for applying the described method of developing an experimental mini model of a volcanic chamber of Mount St. Helens volcano with a system of dikes. An original design is proposed as the model; this includes a plate from optical organic glass with a hole that is fixed via a set of seals between thick transparent side walls of organic glass with the system of electric contact leads, the wire, and the system for filling the closed cuvette with a liquid, which are aligned with the cuvette. The next task is to develop a system of several main dikes going out of the cuvette. For this purpose, we proposed a method of successive shock-wave loading of the cuvette walls by the wire explosion. As a result, we obtain a mini model of a volcanic chamber (cuvette) with a system of dikes, the basic structure of which is shown in Fig. 7. This figure shows the result of double loading the closed system. After the first loading, the system of cracks consisted of a set of small cracks in the millimeter range; then after the second loading, it was transformed into a system of main cracks with arbitrary length and orientation. This latter structure was used for the final experiment on modeling slot eruption. The experimental studies were used to choose the optimal energy stored in the accumulator and the cuvette size (3 kV for a hole of 10 mm).

It should be noted that the method of shock-wave loading is unique, since the state of the pre-explosion ejection of the liquid in the cuvette is created by the shock wave and the dynamic pressure of the expanding cavity forms the crack opening process. If the loading energy is sufficient, the system of cracks reaches the plate boundary, opens, and ejects liquid into the atmosphere (Fig. 8). The figure shows the upper part of the initial system of cracks. Arrow points to the upper boundary of the cuvette plate on which cracks open and ejection takes place; it can be seen from the last frame (t = 2.376 μs) that this boundary goes beyond the end of the assembly, the mini model of the volcanic chamber with cracks.

CONCLUSIONS

The results of the presented experimental studies have proved the efficiency of the proposed method in which the crack opening at the plate boundary takes place at different time instants and is determined by the mechanisms of independent processes of crack development, arbitrary delays in their reaching the boundary, and random time instants of their opening. Ejections of ash clouds in slot eruptions along the trajectory of the gigantic avalanche, which considerably reduced the pressure on the system of cracks, can be considered one of the possible mechanisms of the formation of random side ejections of Mount St. Helens in 1980.

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REFERENCES

1. V. K. Kedrinskii, Shock Waves **18**, 451 (2009).
2. http://www.uaf.edu/geology/PIRE.pdf.
3. H. M. Gonnermann and M. Manga, Nature **426**, 432 (2003).
4. V. Kedrinskii, in *Proc. 26th Int. Symp. on Shock Waves, Göttingen, Germany, 2007*, Ed. by K. Hannermann and F. Seiler (Springer, 2007), Vol. 1, p. 19.
5. N. A. Zlatin, G. S. Pugachev, L. D. Volovets, and S. A. Leont'ev, Zh. Tekh. Fiz. **51**, 1507 (1981).
6. V. P. Efimov and E. N. Sher, J. Appl. Mech. Tech. Phys. **42**, 918 (2001).
7. Yu. V. Petrov, I. V. Smirnov, and A. A. Utkin, Mech. Solids **45**, 476 (2010).
8. V. V. Burkin, N. S. Kuznetsova, and V. V. Lopatin, Tech. Phys. **54**, 644 (2009).
9. I. V. Smirnov and Yu. V. Sud'enkov, Tech. Phys. **56**, 1811 (2011).
10. A. A. Skulkin and V. K. Kedrinskii, in *Proc. All-Russia Conf. "New Mathematical Models in Continuum Mechanics: Development and Analysis," Novosibirsk, Russia, 2014*, p. 129.

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