On a mechanism of target disintegration at shock wave focusing in ESWL

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Abstract: Experimental simulation and two-phase mathematical model are used to estimate the role of a two-phase state of real liquid containing the microinhomogeneities in the mechanisms of disintegration in ESWL systems.

INTRODUCTION

The statement of the problem is connected with the well known facts, that the real liquids contain the microinhomogeneities as microbubbles of free gas (Fig.1, 1), solid microparticles and their combinations (Fig.1, 2). Such media can be considered as inhomogeneous ones, where a rarefaction wave causes the nuclei to grow and to change essentially the state of medium as well as a mechanics of the happened processes. For example, for a distilled water the concentration of the free gas microbubbles has the order $k_0 \approx 10^3 - 10^4 \text{ cm}^{-3}$ and the microbubble radii are close to $R_0 \approx 1.5 \text{ \mu m}$ (Fig.1).

As a rule, the mechanisms of fracture are connected with the action of cumulative microjets or/and shear stresses arising inside the target under the effect of ultrashort strong shock waves and resulting in the formation of microcracks (Delius, 1990, Philipp et al, 1993, Stertevant, 1989, Tomita, Takayama, Obara, Kuwahara, 1994, Kitayama et al.,1987, Kuwahara, 1989). In the experimental simulation carried out by M.Delius, A.Philipp, a gall stone was positioned onto foil in the geometrical focus of ESWL. A stone turned out to be completely surrounded by a dense bubble layer (1). It gives the base to consider that the cavitation cloud dynamics needs the special attention to be paid as a possible source of pulse load.

CAVITATION MECHANISM OF TARGET DISINTEGRATION

According to the principles of ESWL work, a target (stone) located in the corresponding focus of ellipsoid is loaded by an incident short shock wave with a tensile phase behind the front. A series of such shock waves destroys a target after several cycles of loading. The mentioned observation shows, that a bubbly cavitation develops in the vicinity of target and its role in the mechanism of stone disintegration can be important.

Figure 1: Structure and spectrum of microinhomogeneities (marks are the experimental data). Oscillogram of acceleration ($\alpha(t)$): impact (0.09 ms) and 1st collapse of bubble layer on the bottom (7.73 ms). Pressure oscillogram ($P(t)$): main and intermediate weak hydraulic impacts, $p_{\text{max}} \approx 1.5 \text{ MPa}$
Experimental simulation. The dynamics of loading was simulated by the cavitation effects arising in liquid in the vicinity of bottom of a tube accelerated vertically downward by a single impact. An acceleration $a(t)$ and pressure $p(t)$ were measured by corresponding gauges settled on the tube bottom (Fig.1). The parameters of acceleration pulse are as the next: amplitude $-2 \times 10^4 \text{ms}^{-2}$, its maximum width $300 \mu s$. The sequence of the observed events has shown, that to the instant $t \approx 4 \text{ms}$ a bubbly layer arised on the tube bottom is transformed to a gas-vapor one which practically separates the liquid column from the bottom. To $t \approx 7 - 8 \text{ms}$ the layer collapses and creates the power pressure pulse (Fig.1, $P(t)$), as well as initiates new acceleration (Fig.1, $a(t)$) and as a result a new cavitation cluster comes to develop near the bottom. Then the process repeats several times and gauges record the repeated intense hydraulic impacts which, thus, can be considered as one of principal mechanisms of fracture.

Shock wave focusing in two-phase liquid. The problem were numerically solved within the framework of two-phase system, which includes the full one-dimensional system of equations for continuity and momentum (in Lagrange variables, cylindrical symmetry), as well as the kinetic equation for description of the two-phase state dynamics (2):

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho_0} \left( \frac{x(r,t)}{r} \right)^2 \frac{\partial p}{\partial r}, \quad \frac{\partial x}{\partial t} = u, \quad \frac{1}{\rho} = \frac{1}{\rho_0} \left( \frac{x(r,t)}{r} \right)^2 \frac{\partial x}{\partial r}, \quad p = 1 + \frac{\rho_0 c_0^2}{n p_0} \left[ \left( \frac{\rho}{1-k} \right)^n - 1 \right], \quad k = \frac{k_0}{1-k_0} \rho^3,$$

K.Eq.: $\frac{\partial S}{\partial t} + \frac{3}{2} \rho S^2 = C_1 \frac{T}{\beta^2} - C_2 \frac{\beta}{\beta} - C_3 \frac{p}{\beta} - \frac{\partial \beta}{\partial t} - S, \quad C_1 = \frac{\rho g a T_0 B}{p_0 M}, \quad C_2 = \frac{2 \sigma}{R \rho_0}, \quad C_3 = \frac{4 \mu}{R \sqrt{p_0 p_0}}.$

Here $T$ is the gas temperature in bubble, $\beta = R/R_o$, $k$ is the volumetric gas concentration ($k_0 = 10^{-4}$, $R_o = 1 \text{mm}$). Fig.2 shows that to the instant $60 \mu s$ the shock wave reaches the target wall (dotted line) and has the parameters close to ones mentioned in (3). As a result of its reflection from an axis the dense bubbly cluster (about 1-2 cm thickness) is formed to the instant $170 \mu s$: the value of $k$ on a wall increases in about 300 times. One can expect that as well as in experiments, the difference of pressure causes results in a cluster collapse and an hydraulic impact effect.

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The above simulation has shown, that the mechanism of stone destruction with high probability can be also determined by the repeated hydraulic impacts of the liquid under collapse of dense cavitation clusters on its surface. The work was supported by RFFR, grant 96-02-19369.

REFERENCES