

# NATURE OF REBINDER EFFECT BY NON-ORGANIC DIELECTRICS AND ROCKS FAILURE

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## ABSTRACT

This paper presents author's investigations on clearing up a mechanism of liquids influence on failure of non-organic dielectrics and rocks. Theory of Rebinder effect is suggested and the influence of electrization of fresh surfaces on failure is taken into account.

## KEYWORDS

Failure, comminution, liquid, strength, indentation hardness, aggregation, glass, rock, relaxation time, electron emission.

## INTRODUCTION

Up to now for many years the liquids capabilities to influence on the strength  $\sigma$  of both dielectrics and rocks was explained by physical adsorption of molecules in prefailure  $R_M$  zone on fresh surfaces and by reducing the specific surface energy  $\gamma_0$  up to the value  $\gamma'_0 < \gamma_0$ . Meanwhile one can demonstrate such experimental results which are not taken in relation  $\gamma_0 - \sigma$ : the nature of the cracks reversibility growth, aggregation by comminution; reason of the strength dependence on liquids dielectric constant  $\epsilon$ , on thickness of adsorptive water layer; reason of the largest strength decrease in water and its best aggregation capacity, reason of dependence of indentation hardness of dielectrics on their sensitiveness to liquid action and on aggregation capacity; reason of increase of failure rocks size ( volume of indentation ) the pressing of indenter in presence of the non-polar liquids, decrease of conventional coefficient of rocks plasticity by pressing the indenter in presence of polar liquids.

Rebinder view about the nature of liquids influence on the strength is doubtful: the Griffith model is correct for ideal elastic dielectrics without mechanical energy losses; on new surfaces the surplus charge with density  $q_0$  emerge. This is ver-

ified by both direct charge measurement and by observation of electronic emission and electromagnetic radiation.

In this paper the theory of Rebinder effect has been suggested, which considers the real fact of the prepropagating cracks sides being electrically charged by opposite electrical charges.

### MODEL CONSTRUCTION

The emergence of surplus charge results in to additional long-range force  $f_e$  between crack sides. The zone of prefailure increases up to the magnitude  $R_e > R_m$ . The forces  $f_e$  may be regarded as additional load ("electrical brake"). Effective energy of failure increases up to  $\gamma_{ef} = \gamma_0 + \gamma_e$ , where  $\gamma_e$  is energy losses of electrostatic nature. The characteristic property of electrostatic long-range forces  $f_e$  in comparison with chemical forces, which define value  $\gamma_0$ , is time dependence: the emergence of surplus charge on crack sides means the beginning of relaxation. Additional time variation of effective failure energy occurs by using the liquid.

By quasi-static growth of balancing crack with speed  $\nu$  the liquid exerts the most influence on its propagation when meeting the condition  $\nu < \nu_r$ , where  $\nu_r$  is penetrating liquid speed into space of crack. The depth of liquid penetration in crack is limited by the molecule diameter  $d$ . According to nature of forces between surfaces the crack may be separated into two parts: apex and space. Boundary is the distance equal to  $d$ . Both chemical and electrostatic forces act in the crack apex. As to the space one can observe only electrostatic forces  $f_e$ . According to (Evseyev, 1985) effective energy can be written as

$$\gamma_{ef} = \gamma_0 + ne^2(a^2 - d^2)/8\pi\epsilon_0 - A_c/2 + q_0^2 \exp(-2t/\tau)h/4\epsilon\epsilon_0 \quad (1)$$

Here  $\gamma_0$  is the invariant of chemical forces by dielectrics failure in the presence of liquids,  $a$  is interatomic distance,  $h$  is distance between crack sides,  $A_c$  is the action of wedging out forces,  $\tau = \epsilon\epsilon_0/\alpha$  is relaxation time of charges in liquid in the crack space,  $\alpha$  is liquid conductivity,  $\epsilon_0$  is vacuum permittivity. The second component in right part of the expression (1) is an invariant of electrostatic forces in the crack apex. Algebraic sum of three components in (1) defines the action of equilibrium failure  $2\gamma_0$ . It's an important characteristic of cohesion. The equilibrium failure is not realizable. The following conditions  $t \gg \tau$  will assist in approaching to such realization. This inequality defines the condition of quasi-equilibrium failure. The inequality  $\nu < \nu_r$  represents the necessary condition of quasi-equilibrium failure. Suggested model of liquids influence on the effective energy (1) change allows to qualitatively conform the theory with experimental results.

### EMPIRICAL LAW ESSENCE

Liquids Influence on Strength. The dielectrics strength by constant length  $L$  of the primary defect (crack) and by realizing

the necessary condition of quasi-equilibrium failure  $\nu_r > \nu$  is directly related to non-equilibrium component of energy failure that is, by the values  $q_0$ ,  $t$  and  $\tau$  in the crack space. The electrical charges relaxation is carried out through liquid in space of crack (discharge current  $j_1$ ) and through a dielectric (current  $j_2$ ). The larger the value  $q_0$  is on the dielectric surface and the less the charges relaxation time is created by penetrating the liquid into the space (liquid as earthing connection) the more the liquid influences on the strength. With  $q_0$  being decreased, the fluid action on failure lessening drops.

From the point of view of acting on the bond split in apex of crack all the liquids should be divided into two classes: conductors and dielectrics, that is, polar and non-polar. Relaxation times of electrical charges of these liquids differ considerably. The liquid electrical conductivity is changed step by step by convergence of crack surfaces: from the primary value of initial liquid to the value corresponding to  $\epsilon$ ,  $\alpha$  of solution subjected to the crack surfaces action (thin layer of polar liquids in space acquires dielectrical properties). Because of this exact determination of time relaxation in space is made difficult. The estimation of value in space on the basis of measurement  $\epsilon$ ,  $\alpha$  of initial liquid is the approach to the value time relaxation actually determining the dielectric resistance to the failure. The less time relaxation of electrical charge in space, the less strength of dielectric. If liquid penetration of liquid into the crack space is defined by capillary flow then the different dielectric have "their own" liquid reducing the strength up to the maximum value.

Conductivity increase of the liquid in the crack space may be the result of dissolution of dielectric. The less relaxation time in space by dissolving, the more Rebinder effect. Chemical composition of dielectric will not define the relaxation time in space after preliminary injection of ionic substance in initial liquid, for example, cationic and anionic surfactant. Conductance change of distilled water (initial electrical resistance -  $65 \cdot 10^3$  Ohm, the constant of vessel -  $76 \text{ m}^4$ ) after adding cationic surfactants (sodium sulphonate (S) and sodium dodecylsulphonate (DS), non-ionic surfactant OP-10) is given in Fig.1. Trace amount of ionic surfactant induces considerable decrease of solutions electrical resistance. Exactly, the same change of initial resistance of water induces sodium oleate. Influence

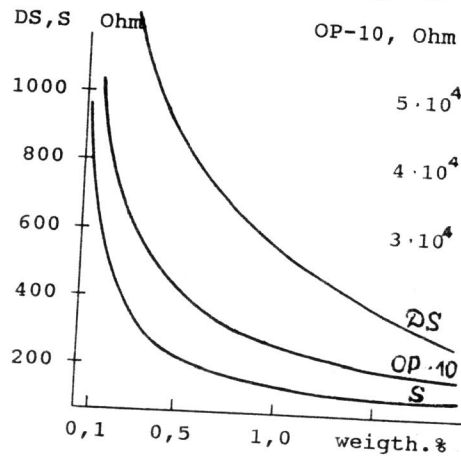


Fig.1. Electric resistance change of aqueous solutions by 22°C.

of OP - 10 on change of electrical resistance is considerably weaker.

Due to diminishing the liquid electrical conduction in space the current  $j_2$  action on the strength increases. The value current  $j_2$  is not constant: it's changed by the water absorption from the environment (air, for example). Because of this the effective energy of dielectrics failure becomes maximal and possesses the invariable value  $j_{ef}^0$  which corresponds to value  $Q_0$  on surface only after removing water from dielectrics and by failure in vacuum, of single non-polar liquids (relaxation time is  $10^6 - 10^7$  s). Under these conditions of failure reversibility of crack propagation after stress lessening is observed. Linking of sides crack is accompanied by expelling the dielectrical liquids from the crack space. At dielectrics failure in vacuum and dielectrical liquids the propagation velocity of crack decreases: the bigger  $Q_0$  on fresh surface of dielectric the bigger deceleration. Disbalance of crack propagation in single dielectrical fluid will result in the equation (Evseyev, 1985)

$$K_I^0 \sqrt{\pi L} = \int_0^L \rho(x) \sqrt{(L-x)/(L+x)} dx$$

This equation will not be fair for defining the unknown coordinates of the increasing crack ends. These  $\rho(x)$  is distribution of normal stresses in crackless dielectric,  $K_I^0$  - Irvin's notch-sensitivity index under given conditions.

Dielectrical action of single non-polar fluid will be disturbed by penetrating insignificant electrolyte impurity into it. In the state of technical purity the saturated hydrocarbons have the relaxation time only  $10^3 - 10^4$  s. This will result in time dependence of dielectrics' strength. By failure in mixtures consisting of polar and non-polar liquids the strength will change in accordance with the relaxation time changing in mixture: from maximum in single non-polar liquid to minimum in polar one. Ratio  $j_{ef}^0 / j_0$  characterises the safety margin of dielectric strength by the given value of primary defect.

Quasi-equilibrium of dielectric failure in conducting liquids will be disturbed by increasing the crack propagation up to value  $\nu > \nu_r$ . This time, splitting zone of bonds presents itself capacitor, full of liquid, its vapour and vacuum. In a part of crack space not filled with liquid, high energy electrons emission occurs. Emission intensity drop obeys the law of charges relaxation  $J = J_0 \exp(-t/\tau)$ , where  $J_0$  is initial emission intensity, defined by the charges  $Q_0$  density.

Effective relaxation time

$$\tau_{ef} = \epsilon_0 [z(\epsilon - 1) - 1] / [(1 - z)\alpha' + z\alpha]$$

where  $z$  is a part of space full of liquid,  $\alpha'$  is "conductivity" of vacuum interval in space, defines the resistance to dielectric failure. Violation of quasi-equilibrium failure necessary condition results in increasing the solid strength. Strength growth  $\Delta\sigma$  by given value  $Q_0$  is the more considerable, the nearer dielectric failure to equilibrium one under the condition  $\nu < \nu_r$ . Strength growth is equal to zero both in vacuum, and in

pure dielectrical liquids:  $\Delta\sigma = 0$ . Stress relief from dielectric results in reversibility of crack propagation and by failure of dielectrics in single dielectric fluid: fluid will be expelled from crack by reversibility of crack propagation in the part of space free of fluid.

Violation of quasi-equilibrium failure necessary condition creates a condition for relaxation third current of electrical charges in space - discharge current of high frequency  $j_3$ . The current emergence in the part of space free of the phase liquid layer will result under satisfying the condition

$$q_0 \lambda \epsilon_0 \gg U,$$

where  $\lambda$  is free path of high-speed electron,  $U$  is ionization potential of molecule vapour phase.

Dependence of emission intensity of electrons, electromagnetic emission (pulse counting rate of electromagnetic waves  $N$ ), disbalance of a component of fracture surface energy on charges  $Q$  density defines the same mandatory requirements to samples by preparing them to experiments: it's necessary to diminish the current  $j_2$ ; at failure of dielectrics in liquids this operation must be supplemented by careful cleaning of liquids from electrolytical contaminants. The value  $J, N, \sigma$  change as a function of  $Q$ . This enables to judge about comparative values of others according to changing of one of these values by dielectric failure.

#### MANIFESTATION OF REBINDER EFFECT

Comminution of Dielectrics in Liquids. By comminution of dielectrics the predominance of adhesion interaction electrical component over intermolecular one will result in specific manifestation of Rebinder's effect: aggregating of powders both in pure dielectric liquids and in vacuum. Aggregates stability and particles density in them will increase with the growth of  $Q_0$  on dielectric's surface. For better aggregating it's necessary to decrease the influence of current  $j_2$  on charges relaxation. By producing the finely dispersed powders aggregation is a negative phenomenon. Possibility of aggregates' destruction - disaggregation - is connected with increasing of currents  $j_1$  and  $j_2$ . Disaggregation can be caused by several mechanisms. Artificial disaggregation can be accomplished by additional comminution of aggregates' powder not only in conducting liquids but also in ionized gases. And natural aggregation (at prescribed value  $Q_0$ ) can be accomplished by changing the value  $\tau$  as a result of diffusional penetrating of conducting liquids molecules to aggregates. The increment of surface powder as a result of its disaggregation is the more considerable, the more  $Q_0$  is on surface and the less the relaxation time in coagulation structure. When  $Q_0$  decreases choice of liquids for spontaneous disaggregation is wider.

Electron Emission off Glass Surface and Glass Strength. Since both the glass strength and mica fracture surface energy possess

identical change under similar conditions, and value of dynamic coefficient (3,6 for mica, 3,3 - 4,5 for glass) suggest the electrization of fresh glass surfaces (electrization of mica crystal is evident). This assumption contradicts to conclusion of experimental research ( Deriagin et al., 1973 ), where absence of high-speed electrons from fresh surfaces of glass is connected with its amorphous structure. Judging from changing strength of glass in vacuum (Zhurkov, 1931) and the dependence  $Q = Q(f_1, f_2)$  available we may suppose that absence of high-speed electrons is connected with insufficient moisture removal from the glass samples in vacuum  $10^{-4} - 10^{-6}$  torr. For moisture removal from glass samples it's necessary to combine the vacuum treatment of samples with prolonged warming up. Our research (Evseyev and Kuznetsov, 1979) has shown that failure of preliminary treated glass samples in vacuum  $10^{-6}$  torr by 120, 220 and 450°C is accompanied by high energy electron emission. Being in vacuum at 20°C no emission occurs. Availability of electron emission from fresh glass surface is a sound argument in favour of electrization of glass surfaces by failure. This allows to suppose that charging the surfaces of crack either is not connected with degree of ordering the dielectrics structure, or takes place in those places of glass structure, which are similar to crystalline structure in close atom surroundings, but differ in absence of distant order and symmetry.

Electrization availability of fresh glass surfaces brings about the peculiarities of changing its strength under different loading conditions. In accordance with (1) dielectrics strength can be presented in the terms of  $\sigma = (\sigma_p + \sigma_n)^{1/2}$ , where  $\sigma_p$  is the endurance limit,  $\sigma_n$  is the disbalance strength component. Time effects will be observed when fracturing the dielectrics under constant rate of loading in different liquids and with different rate of loading in the same liquid.

Two phase system "glass-water" at insignificant loading time is not a stable one. Decreasing the glass strength in water occurs with "acceleration" in accordance with the continuous change of aqueous solution conductivity in space. The better the glass gives the ions off the surface moisture increasing its conductivity, the more visible will be the glass strength decreasing.

Minimum value of the dielectrics strength in water and its best disaggregational ability mean that the aqueous solutions resulting from fracturing and crashing induce less electric conductivity in the crack space and coagulation structure than the solutions resulting from another liquids. In this connection we note that it is water which possesses the unique solubility distinguishing it from another liquids. The water is distinguished by its small size of molecules and great ratio  $\sigma_e / \eta$ , where  $\sigma_e$ ,  $\eta$  are coefficient of surface tension and dynamic viscosity. These values result in decreasing the invariants failure and more prolonged meeting the conditions of quasi-equilibrium failure.

The appreciation of liquids "earthing action" by the value of their relaxation time of charges in space allows to understand

the nature of exceptional action of nitrobenzene on failure surface energy of glass (Berdennikov, 1934): nitrobenzene is considered to be one of the best dielectrics among polar liquids (Evseyev, 1979).

Rocks Failure Due to Indentation. This type of failure is largely realized by drilling the boreholes where compressive strain prevail and occurs in presence of liquid. Rocks failure under indenter by its forcing into the specimen is determined by efficiency of axial force transmission through prefailure core to enclosing rock. Because of uncountable set of stress concentrators available in rock forming of prefailure core will take place as a result of crack propagation both of adhesion and cohesion types and will result in breaking the rock under indenter. Experimental check of powder dispersivity under indenter by its forcing into average granular marble showed that process rock failure may be classified as comminution: particles of even microscopic size are present in powder. For determining the power-intensity of the indenter forcing process into rock we use modified Rebinder law:

$$A = \kappa V + \gamma_{ef} \Delta S = A_d + A_z$$

where  $\kappa$  is the proportionality coefficient,  $V$  is the compressed rock volume,  $\Delta S$  is the fresh surface growth,  $A_d$  is the cubic strain work,  $A_z$  is the failure rock work. The conventional coefficient of rocks plasticity  $K$  should be determined by the formula  $K = 1 + A_z / A_d$ . Rocks indentation hardness and size of its failure (volume  $V$  of indentation) are defined by comminution quality of rocks under indenter in the presence of liquid: the bigger powder dispersivity under indenter, the more effective transmission of axial load on the enclosing rock and the less is the depth of indentation. Indentation volume will reach the maximum value by forcing an indenter into the specimen of rock in the presence of pure dielectric liquid after preliminary removal of moisture from specimen. By increasing the conductivity of solution core localization of prefailure under indenter, i.e. reducing the volume indentation will occur. Simultaneous reduction of conventional yield point of rock will occur owing easier slip grains of minerals along the grain boundaries and reduction of conventional coefficient of rocks plasticity owing to decreasing the power intensity of rock's failure under indenter. Change of relaxation time in solution will not result in regular variation of specific crushing energy  $A_v = A / V$  because of indential change of  $A$  and  $V$ .

For increasing rock failure efficiency on the hole bottom the drilling should be carried out with such values of rotation rate and axial load of the drill bit which ensure the relaxation of non-equilibrium component of strength: the reduction of the rotation rate must predominate as compared with increasing of axial load. It accounts for such paradoxical fact (Kolesnikov, 1984) of the rotation rate decrease of better rock failure effectiveness on hole bottom and gives a chance of optimizing the drilling conditions.

## CONCLUSION

The advance of Rebinder effect reseach is not due to studying the of physical properties of liquids thin layers on the dielectric surface and in space of crack, but also to electrization nature origin by failure, and to physical action on dielectric resulting in necessary change of value  $\varphi$  on dielectric surface. If the density of charge  $Q_0$  is defined by presence of dielectric defects, such action may be preliminary annealing of dielectric at different temperature: change of  $Q_0$  on surface will cause the change of dielectric sensitivity to action of liquid on it.

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