REVERSIBLE CREEP OF BUILDING MATERIALS UNDER CONSTANT AND REPEATED LOADING

M.LORDKIPANIDZE, L.MINKIN, N.CHAKHVASHVILI, N.BOCHORISHVILI

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Abstract

The results obtained for various materials in liquid surface-active media (SAM) showed that the limit deformation of reversible creep is achieved under cyclic loading many times faster than under constant loading. The only exception is steel in the gaseous hydrogen medium. This suggests an idea that the phase state of a SAM plays the decisive role. The kinetics of the growth of pre-critical Griffiths micro cracks is provided by the joint action of mechanical stress and a surface active medium and is determined by the velocity with which a surface-active medium moves to the crack vertex via fine channels.

An important feature of the phenomenon of reversible creep of solid bodies in SAM is the complete reversibility of creep independently of the number of cycles of placing the specimen in the SAM which is subsequently removed. The specimen's properties remain constant: in the absence of the SAM, the elastic deformation value does not change and in the presence of the SAM the reversible creep parameters also remain constant.

The phenomenon of reversible creep of solid bodies under the SAM action is a unique tool of investigation of the formation and growth of pre-critical cracks in stressed materials. Further investigation of this phenomenon can facilitate the understanding of the nature and mechanism of catastrophic failures of stressed structures.

Keywords: ***bond rupture, creep, dislocation model, loading, micro-crack, Rebinder's effect.***

INTRODUCTION

The results obtained for various materials (concrete, tufa, gypsum, silicate glass, acrylic plastic glass, rubber, naphthalene monocrystal) in liquid surface-active media (SAM) showed that the limit deformation of reversible creep is achieved under cyclic loading many times faster than under constant loading. The only exception is steel in the gaseous hydrogen medium. This suggests an idea that the phase state of a surface-active medium plays the decisive role. The kinetics of the growth of pre-critical Griffiths micro-cracks is provided by the joint action of mechanical stress and a surface active medium and is determined by the velocity with which the medium moves to the crack vertex via fine channels.

An important feature of the phenomenon of reversible creep of solid bodies in SAM is the complete reversibility of creep independently of the number of cycles of placing the specimen in the SAM which is subsequently removed. The specimen's properties remain constant: in the absence of the SAM, the elastic deformation magnitude does not change and in the presence of the SAM the reversible creep parameters also remain constant.

The phenomenon of reversible creep of solid bodies under the SAM action serves as a unique tool of the investigation of formation and growth of pre-critical cracks in materials under the action of external stresses.

EXPERIMENTAL AND ANALYTICAL INVESTIGATION

The study of the reversible damped creep of concrete and other materials in surface-active media revealed that under cyclic loading-unloading a highly accelerated creep occurs in most materials placed in SAM [1,2]. This phenomenon was observed in two kinds of tests: a) a weight is attached to the tested specimen under constant loading until maximal deformation caused by reversible creep is achieved; b) the tested specimen is brought to a given stressed state at a low loading velocity using the rupture machine (for tension) and the mechanical press (for compression) and after that the specimen is slowly unloaded. Such cycles are repeated several times until the loading-unloading process gives an increase of deformation.

Both kinds of tests are graphically presented in Fig. 1: (a) the thin line is deformation under the action of constant load; the dotted thick line is deformation observed in the tests carried out in loading-unloading conditions; $t_{макс}$ is the time during which maximal deformation due to reversible creep is achieved under the action of constant load; $t^*_{макс}$ is the time during which maximal deformation due to reversible creep is achieved under the action of cyclic load; (b) the graph of deformation development in solid materials in surface-active media in repeated cyclic tests with a constant loading velocity; ε_{max} is maximal residual deformation under cyclic loading at a constant velocity.

When no load is applied to the specimen during a long time, the accumulated creep deformation disappears (shown by the arrow in the figure) as a result of the emergence of elastic after-action [3].

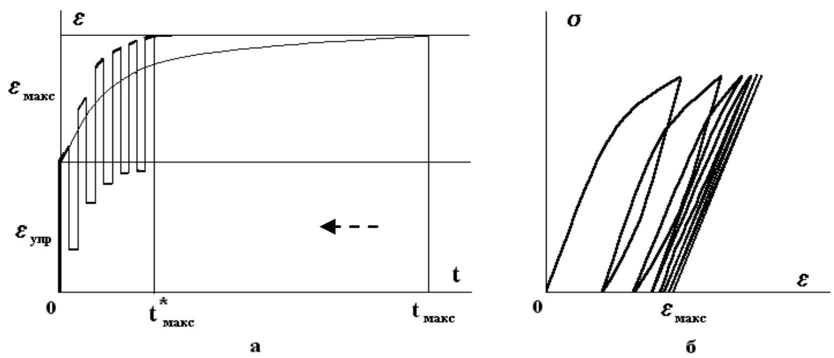

Fig. 1. Graph of the reversible creep of solid materials in surface-active media under the action of load

The results of the tests of different materials placed in liquid surface-active media were analogous and showed that limit deformation due to reversible creep occurs under cyclic loading much faster than in the case of constant loading. The only exception is steel in the gaseous hydrogen medium. This suggests that the phase state of a SAM plays a major role. The nature of such an accelerated growth of pre-critical cracks under the action of a liquid SAM can be described as follows. When the specimen experiences tension in a medium under constant tensile stress, we observe pre-critical (according to Griffiths) cracks (micro crevices), the emergence of which is caused by the combined action of mechanical stress and a surface-active medium, which, on the one hand, promotes the rupture of bonds in a solid body, and, on the other hand, provides the stabilization of embryo cracks, which, according to thermodynamics, should merge. The kinetics of growth of such micro-cracks is determined by the velocity with which the surface-active medium penetrates into the crack vertex through fine channels.

As a concrete model we propose a very simple dislocation scheme shown in Fig. 2. Under the action of stress the Frank-Read dislocation source generates dislocations in the sliding plane which on their way meet with a barrier in the form of boundary of the grain G and get accumulated in front of this barrier. Frontal dislocations merge forming the combined kernel D which is a dislocation tube that comes out onto the surface and serves as a transport path for motions of the surface-active substance. Under the action of stress, when dislocations cannot get over the barrier formed by the grain boundary, in the neighboring grain, according to Mott, there emerges a micro-crack C [4, 5].

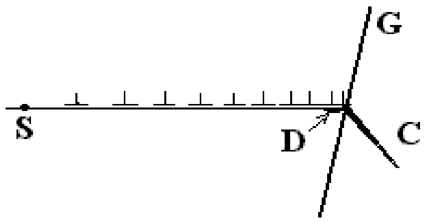

Fig. 2. Dislocation model scheme

At some moment of time the external stress is relieved. Dislocations return to the source, the dislocation multi-kernel at least partly closes and the surface-active medium gets locked in the crack. The external stress which has one stress tensor component transforms to the hydrostatic pressure of the liquid of the same value. But this pressure is the spherical tensor having three stress components. Thus shearing stresses are added to tension stresses, which, by the hydraulic rupture mechanism, bring about an accelerated growth of the crack. Therefore the removal of load not only suspends the propagation of the crack, but, to the contrary, leads to its more accelerated growth. Naturally, when the surface-active medium is gas, such an accelerated growth of cracks under cyclic loading-unloading does not take place, which we observe e.g. in the experiments with steel in the gaseous hydrogen medium, and also with rubber in benzene, where reversible creep is related to the swelling of rubber in benzene which is activated by the applied tension stress [6].

We should emphasize one more important peculiarity of the reversible creep phenomenon of solid bodies in surface-active media – this is the complete reversibility of creep. Independently of the number of cycles of placing the specimen in an active medium and its subsequent absence, the specimen's properties remain constant: in the absence of the medium, the elastic deformation value does not change and in the presence of the medium the reversible creep parameters also remain constant. This shows that the processes of formation of pre-critical cracks are reversible in both thermodynamic and dynamic senses. Analogously to I.V. Obreimov's classical experiments with the splitting of mica in the vacuum [7], by which it was established that the crack reversibly closes and the same force is required for its recurrent formation, the reversible creep experiments showed that embryo cracks also completely close after the surface-active medium is removed.

The phenomenon of reversible creep of solid bodies under the SAM action serves as a unique tool of the investigation of formation and growth of pre-critical cracks in stressed materials.

Nevertheless, there arises a question – why does the premature failure of mechanically stressed structures (autoclaves, gas pipes and others) occur all the same when the acting stress is a priori smaller than the critical stress which brings to the irreversible growth of cracks? After all we know that according to the law of thermodynamics the number of formed cracks must nor

exceed their number corresponding to the elastic stress density. It is obvious that this law does not take into account the factor of cracks coalescence. By using the proposed simple dislocation scheme we may suppose that dislocation that moves in the sliding plane, where the crack lies, runs into the crack and then comes out on the opposite side. In certain conditions this is equivalent to the movementt of the crack by one inter-atomic distance. We may also suppose that such embryo cracks move in a non-homogeneous field of stress. Anyhow, coalescing cracks may form the only critical crack which will be the embryo of brittle failure of the material in the SAM in which the investigated structure operates.

FURTHER RESEARCH

Further investigation of the reversible creep phenomenon is desirable as it may contribute to a better understanding of the nature and mechanism of catastrophic failures of stressed structures.

CONCLUSIONS

The investigation of the nature, laws and mechanism of the phenomenon of reversible creep of solid bodies in surface-active media allows us to make the following conclusions.

1.The phenomenon found is one of the forms of manifestation of Rebinder's effect which

occurs because of an active growth of micro cracks caused by a decrease of surface energy as a result of contact with the surface-active medium.

2. The thermodynamic description of the phenomenon is based on the Griffiths scheme of crack growth and takes into account the decrease of surface energy of a solid body as a result of contact with a surface-active medium, and also on the concepts of embryo formation in the metastable conditions.

3. The phenomenological description of reversible creep is obtained by the combination of two Kelvin elements; under great loads for which a certain fraction of irreversible deformation appears they should be complemented with a combination of Hooke and Saint-Venant elements connected in parallel.

4. The molecular mechanism of Rebinder's effect, in particular, for the occurrence of reversible creep, can be explained as follows. Previously, it was believed rightful to consider the action of a surface-active substance as a particle which either enters into interaction with stressed atoms at the vertex of the crack and weakens their attraction to one another, i.e. promotes the rupture of the bond, or as a particle which under the action of two-dimensional pressure splits like "a wedge" the crack and thus promotes its growth. In recent years, preference is given to the first mechanism since it was established that this physical model enables one to perform calculations by the method of molecular dynamics. Such calculations were carried out by E.D. Shchukin and V.S. Yushchenko for a two-dimensional model and they indeed showed the weakening and facilitation of the bond rupture in the virtual solid body in the presence of a surface-active atom [9]. For the wedge-like split of the crack the construction of such a model seems impossible because it is difficult to model the geometry of a micro crack and the distribution of forces between the atoms of a solid body and the surface-active particle. In favor of the first mechanism we also have the case of hydrolytic splitting of glass and other silicate-containing materials because it is firmly established that the facilitation of the Si-O bond rupture is conditioned by the simultaneous rupture of the H-O bond in a water molecule and the restructuring of bonds with formation of the Si-Oh group on the formed surface of the crack which causes failure [10].

5. The phenomenon of reversible creep of solid bodies under the action of surface-active media serves as a unique tool for investigating the formation and growth of pre-critical cracks in materials which are under the action of external stresses.

REFERENCES

[1] Balavadze V.K.., Lordkipanidze M.M., "Investigation of the Nature of Damping Creep of Concrete under Axial Compression", ***Soobshscheniya AN GSSR*** **(*Bull. Acad. Sci. GSSR*), Georgia, V. 103, No. 1, 1981.**

[2] Lordkipanidze M.M. "Slow Reversible Deformation of Concrete and Solid Bodies in Surface-Active Media - A new form of Rebinder's Effect", Technical University Press, Tbilisi, Georgia, 2009, 206 p.

[3] Rebinder P.A., Loginov G.I., "Change of the Elastic Properties of Mica under Penetration of Liquid into the Deformed Crystal", ***DAN SSSR*, Russia, New Series, V. 30, No. 6, 1941.**

[4] Van Buuren, "Defects in Crystals", Izd-vo Inostr. Literatiri (Foreign Literature Press), Moscow, 1962.

[5] Cotrell A..Kh., In the book: "Atomic Mechanism of Failure", Metallurgizdat, Moscow, 1962.

[6] Lordkipanidze M.M., "Reversible Creep of Organic Materials", ***Energy*, No. 4(24), 2002.**

[7] Obreimov I., "Treatment Strength of Mica", ***Proc. Roy.Soc.*, V. A127, 290, 1930.**

[8] Shchukin E.D., Yushchenko V.S., "Effect of Environment on Fracture Mechanisms, Embrittlement by Liquid Metals", New York, 1966.

MERAB LORDKIPANIDZE, Doctor of Technical Sciences, Professor
(+995 32) 2180951; Mob.: +995 558 776559
E-mail: tami@dsl.ge; lordkipanidzemerab@yahoo.com