ON RATE-INDEPENDENT CONTINUUM THEORIES OF GRAPHITE AND THEIR EXPERIMENTAL VERIFICATION

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Uniaxial tension-compression tests with artificial graphites, see, for example those of Arragon and Berthier [1] , have shown that in the temperature range from 78° to 700°F these materials exhibit essentially rate-independent elastoplastic behavior. Consequently, a rate-independent continuum theory of graphite is appropriate for representation of the behavior of these materials within the temperature range indicated above. These experiments have also shown that the stress-strain curves are nonlinear even at low stress levels both for loading and unloading. It follows that a region of purely linear response is either very small or nonexistent. The classical theory of plasticity must therefore be modified to become applicable to the mechanical behavior of artificial graphites.

This paper discusses two methods of developing the theory. The first method consists of applying the ideas of Koiter [2] and Mroz [3] to the description of the behavior of graphite. The second method consists of a generalization of concepts introduced by Phillips and Sierakowski [4] and in their application to the description of graphite behavior. The paper develops both theories and critically compares them, pointing out their limitations.

The last part of the paper proposes proper experiments to verify the theories. In particular, it is shown that tests with proportional loading are not sufficiently general to verify the theories.

REFERENCES

1 Arragon, P.P. and Berthier, R.M., "Characterisation Mecanique du Graphite Artificiel", Industrial Carbon and Graphite, Society of Chemical Industry, London, 565-578 (1958)

2 Koiter, W.T., "Stress-Strain Relations, Uniqueness and Variational Theorems for Elastic-plastic Materials with a Singular Yield Surface", Quart. Appl. Math., 11, 350-353 (1953)

3 Mroz, Z., "On the Description of Anisotropic Workhardening", J. Mech. Phys. Solids, 15, 163-175 (1967)

4 Phillips, A. and Sierakowski, R.L., "On the Concept of the Yield Surface", Acta Mechanica, 1, 29-35 (1965)

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DISCUSSION

Q N. CRISTESCU, Roumania

1. Is the "coming back" of the yield surface in a reloading test not a "rate effect" or "time effect" ?

2. Since the graphite is porous one has not to consider the hydrostatic pressure as a dominant parameter in the description of plasticity of this material ?

A A. PHILLIPS, U. S. A.

1. It does not seem to be primarily a time effect although some amount of time effect is there.

2. As mentioned in the paper the general theories take into account the effect of hydrostatic pressure on the behaviour of graphite.

Q - A. N. KINKEAD, U. K.

These most interesting and significant theories of Professor Phillips were referred to aluminium as well as to graphite and would no doubt be applicable to many other materials.

I should like to enquire whether these theories have been actually applied to check engineering designs involved in space travel applications (or even in civil aviation development) or are men being sent to the moon on the basis of a calculated risk in the design safety of their capsules and rockets, without proper knowledge of the structural material behaviour.

A A. PHILLIPS, U. S. A.

These theories have not been used for the purposes mentioned by Mr. Kinkead since they are much too recent.

Q B. A. BOLEY, U. S. A.

You have outlined three different possibilities for constructing non-linear theories valid for materials such as graphite. Have you done any work in which the predictions of the three theories are compared for some typical example ? Such a comparison would tell us whether any significant difference is to be expected from the several theories, and then whether it is reasonable to expect to be able to distinguish between their validity by means of an experimental study as proposed.

A A. PHILLIPS, U. S. A.

Some significant difference is to be expected since the non-linearities are significant. I cannot, however, quote actual values at this time since I believe more experimentation is necessary before theoretical work can be done.

Q

F. C. WEILER, U. S. A.

Comment amplifying question asked by Prof. N. Cristescu, Roumania. I do personally think that since graphite is a porous material, that its strength is affected by a hydrostatic component of stress, i. e., a hydrostatic pressure. There will be some experiments performed in the near future to check the validity of this hypothesis. I cannot help but think that since hydrostatic pressures affect other materials that are porous, such as Brea Sandstone, that it will also be significant in a theory describing graphite.

A

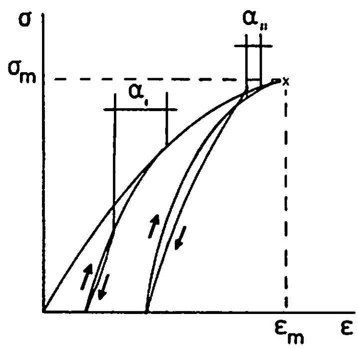
A. PHILLIPS, U. S. A.

I am glad to hear that experiments will be performed to answer questions on the influence of hydrostatic pressure on graphite. This is a most important problem.

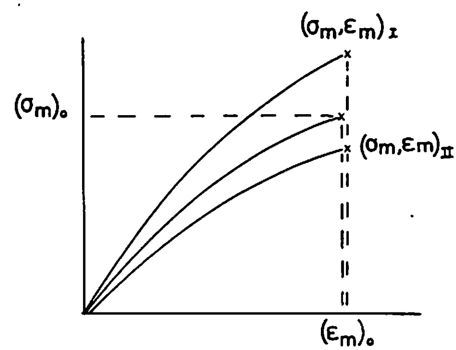
Q

V. LUNGAGNANI, JRC Petten, The Netherlands

For graphite (at least the Gilso-graphite we have tested) the "strain dispacement" α is strong by a function of the strain level when deloading $(\alpha_{II} < \alpha_{I})$.



Experiments done by successively breaking graphite cylinders (second, third, etc. fractures being equivalent to test with "deloaded specimens") are producing couples of values $(\sigma_m, \varepsilon_m)_0$, $(\sigma_m, \varepsilon_m)_I$, $(\varepsilon_m, \varepsilon_m)_{II}$ where $(\sigma_m)_n$ is sometimes higher, sometimes lower as $(\sigma m)_0$, whereas ε_m remains unchanged.



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A. PHILLIPS, U. S. A.

More experimentation is also needed with artificial graphites. Experimental results, of course, depend on the equipment used and the material preparation.