ON MATHEMATICAL MODELS FOR CALCULATING THE MECHANICAL BEHAVIOUR OF COATED FUEL PARTICLES

H. WALTHER,

SORIN, Società Ricerche Impianti Nucleari, Saluggia, Italy

Coated fuel particles, as used in high temperature gas cooled reactors, consist of a fuel kernel and a spherically symmetric multilayer coating. During their lifetime they undergo varying stress states, caused by the simultaneous occurrence of a number of basic physical effects.

These effects are discussed on the basis of the presently known data and classified in "actions" and "reactions": The actions, tending to cause deformations, are fuel swelling, fission gas development, irradiation induced dimensional changes and thermal expansion; the reactions, tending to restrain the deformations, are elastic and plastic effects, characterized by the build up of stresses.

Model calculation of the stress and deformation state in the system is complicated by delayed elastic- and plastic effects, called transient- and steady state creep, and by the anisotropy and the differential behaviour in and between the materials: UO_2 , pyrocarbon, SiC. Model development, which is reviewed here, however allowed one to describe the total "stress history": it begins with differential thermal expansion during and after fabrication and continues with fast and thermal neutron induced dimensional and density changes, fuel swelling and gas pressure development. It still proceeds when mechanical effects such as decoupling, recoupling and failure of single layers occur as a consequence of critical states of stress and deformation. It does not end before all layers are broken.

The concepts of such a highly developed mathematical model are discussed. They are based on a division of the stress history into single consecutive intervals, each one with small enough deformation- and stress variations to allow treatment by the methods of the "classical" linear theory of elasticity. The accumulative deformations and stresses might be large however and not directly treatable by any linear approximation.

Calculated examples are given, which predict the mentioned physical and mechanical effects, whilst micrographs show where they have indeed occurred.

Present practical experience and knowledge of data show, that mathematical model considerations cannot replace test experiments as much as in classical fields. They are important however in designing the experiments and necessary in interpreting them; they provide the only reasonable possibility of extrapolating the results of test irradiations to power reactor conditions.

DISCUSSION

K. DRITTLER, Germany

Q

Your formula of incremental strains has - besides others - two terms: the first is the incremental strain due to radiation induced dimensional changes, and the second term is the incremental strain referring to creep. To evaluate the whole strain of these two terms, that is the sum, you can first add the two incremental terms and then sum. Secondly, you can sum the incremental terms themselves and then add the two sums. Since the relation is linear you must get the same result. But from your argumentations it follows that you take only the first way, and, therefore, you would be within the limits of linear elasticity theory. However, the second way you would not. Can you explain this contradiction?

H. WALTHER, Italy

A

Certainly, the model works in the first way, that is to sum within a calculation step all incremental deformations, including unrestrained dimensional changes and creep, and calculate then the incremental stresses. Simple summation of the total incremental deformations is possible only when the resulting accumulative deformation is still small against unity, which is the case here.

The second way, that is to consider the accumulative sum of deformations in a calculation step, as done in other models, is equally correct, as long as this accumulative sum is again small against unity. As this is the case also here, there is no contradiction and I might be misunderstood.

I should like to point out that the fact of splitting up the radiation induced deformation in two terms, the unrestrained one and the one of creep, has experimental reasons only, but no mathematical consequences with respect to linear treatability. Their single values are not - their sum is however small against unity because they tend to compensate each other.

I should point out further that the first way probably offers a possibility to treat also with large accumulative deformations. As far as I can see, two things must be modified when this should become necessary: The summation of the incremental deformations substituted by an integration, and the geometry of the body stepwise changed according to the incremental displacements.

K. BONGARTZ, Germany

Q

You have introduced into your model something new which is transient creep. Is it necessary to introduce new material data as well, and if so, can they be measured or estimated?

H. WALTHER, Italy

A

For the general case of anisotropic transient creep one must introduce as new data a matrix of transient creep coefficients consisting of 4 independent values. Up to now,

no measurement of such data has been performed, so we must as usual simplify and treat with assumptions on one side and parametrical exploration on the other side. First is to assume isotropic transient creep behaviour, which is quite allowable for steady state creep as we know, in order to reduce the number of new data to two coefficients. Assuming a "Poisson ratio" as in steady state creep of 0.5 or 0.4 we could evaluate the remaining coefficient in the way that transient creep becomes comparable with elastic strain as it really is. Last thing is then to evaluate the right time constant. Probably data from graphite will help us to do this.

I suppose that Dr. Graham sitting here with us would be the best person to establish such approximative data, as he has done before at the very beginning of our model calculations.

Q

K. R. MERCKX, U. S. A.

What models and computer analyses have been used to obtain the material properties required for your analyses ?

Which data files have you encountered to aid in evaluating the validity of your deformational models ?

A

H. WALTHER, Italy

Data and material properties used in our stress analyses have been taken from the literature and from measurements on samples performed within the different high temperature reactor projects.

A survey on these data and properties is given in my paper. As far as I know, computer analyses were little used for establishing models for describing these data, they have been accepted as empirical or phenomenological results.