EFFECTS OF STRESS CONCENTRATION AND DEFECTS ON MATERIALS CONSTITUTIVE EQUATIONS UNDER DYNAMIC LOADING

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SUMMARY

Calculation methods in the elasto-plastic field applied to fast breeder reactor structures subjected to impulsive loading in case of an accident, require material constitutive equations for dynamic conditions.

In order to determine such an equation which relates the flow stress to the current strain and strain rate, it is necessary to carry out tests either at constant strain rate, or at constant stress, where strain rate is rapidly changing. If the material conforms to a mechanical equation of state, the stress-strain diagrams for a given strain rate which were determined by the two methods, coincide.

In collaboration with national projects we have performed dynamic tensile tests on short (~ 1 cm) specimens of various austenitic stainless steels (AISI 304, AISI 316, AISI 321) at strain rates ranging between 10^{-2} and 10^{3} sec^{-1}, test temperature up to 950 °C, using some devices based on the principle of the split Hopkinson bar, which permits performances of constant strain rate. Another device permits the determination of the mechanical characteristics of metals under dynamic conditions by measuring the elasto-plastic wave front as it travels along a long (> 100 cm) specimen. The velocity of propagation of plastic waves calculated from the stress-strain diagram obtained on short specimens must coincide with that measured during plastic waves propagation experiments in long specimens.

From the results obtained in the strain-rate range mentioned before, which have noted that with increasing strain rate the flow stress at a given strain normally increases (which is favourable to safety); however, elongation to rupture is reduced (this parameter reduces safety). This strain-rate dependence of flow-stress at a given strain and of elongation to rupture is strongly influenced by temperature and by manufacturing processes such as cold working or heat treatments to which the material was subjected. The effects of temperature are complex:

— for temperatures up to about 550 °C one notes a dependence on strain-rate of small importance;
— for temperatures between 550 °C and 950 °C the dependence on strain-rate becomes very important.

The effects of manufacturing processes are important:

— cold worked materials showed higher strain-rate sensitivity than materials subjected to annealing processes.

Furthermore we have noted that austenitic stainless steels show instabilities in the stress-strain diagram at high strain rates.

Since brittleness can be increased by: notches, irradiation, increase of grain size due to welding, high strain rates (up to 10^{4} sec^{-1}), — we are now performing tests on materials, related to construction and operation of reactor structures, affected by all these parameters.

Results obtained on weld material or from the heat-affected zone showed a decrease of the fracture strain up to 50% at 10 sec^{-1} strain rate as compared with the fracture strain produced on virgin material. First results on irradiated materials will be available at the time of the conference.

We are also performing tests at constant stress in order to verify if the materials obey an equation of state. The strain-rate history effects will be studied also with experiments of propagation of waves on long specimens utilizing the superposition of reflected waves in the specimen itself.