FRACTURE OF CREEP-RUPTURE SPECIMENS IN LIQUID SODIUM AT 550 °C

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INTRODUCTION

The structural materials of the primary cooling circuits of fast breeder reactors are in contact with flowing liquid sodium at temperatures around 550 °C. At this level there is only limited corrosion due to the reactions of stainless steels with the liquid metal. The exchange of carbon and nitrogen may however cause losses of high-temperature strength or ductility of the materials. A programme to test the mechanical properties of stainless steels which are chosen for the application as structural materials of the SNR 300 was initiated at the Kernforschungszentrum Karlsruhe. The experimental sodium loop CREVONA was constructed to perform such tests in sodium of well defined parameters.

FORMATION AND GROWTH OF CRACKS

The creep-rupture behaviour of the austenitic stainless steel type AISI 304 was influenced by the pres--ence of very pure liquid sodium at 550 °C (Huthmann et al. (1)). The fast flowing sodium caused the decarburization of this steel (Borgstedt et al. (2)) due to its very low carbon potential a = 0.002. The effect of this environment was a slight reduction of the time-to-rupture and a minor enhancement of the creep rate. Examinations of the specimens indicated that the observed effects on creep life and creep rate were related to the formation of intergranular micro cracks.

The nucleation and the growth of the surface micro cracks was studied by means of interruptions of creep-rupture tests. The specimens were unloaded and taken out of the sodium test sections after one quarter, a half, and three wuarters of the time-to-rupture. Metallographic and scanning microscopic techniques were applied to detect intergranular effects.

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After one quarter of the life time of the creep-rupture specimens the formation of chains of microscopic holes in grain boundaries could be detected. Grain boundary cracks were developed in these corroded sites of the specimens during the continuation of the creep-rupture tests. They were clearly visible after a half of the life time. After three quarters of the time-to--rupture their number was increased, while their depth did not exceed a layer of 0.2 mm thickness.

The tertiary creep regime was reduced in all the tests, the failure of the specimens was, however, ductile in the uneffected center of the specimens. The different behaviour of the steel AISI 304 in flowing sodium compared to the air environment was obvious from the shape of the creep curves as well as from the results of examinations. The statistics of the surface cracks of specimens tested in both environments, sodium and air, clearly indicated that the liquid metal had some influence on the number of surface cracks. The maximum and the average values of the crack depth in the specimens were considerably larger after the in-sodium tests, indicating a sodium-assisted growing of the micro cracks. While the crack density decreased with increasing stress in the reference tests in air, an opposite tendency occured in the in-sodium tests. The development of cracks in the surfacenear zone influenced the material behaviour in the bulk material, where wedge cracks seemed to be present in smaller numbers and dimensions than in the reference tests.

DISCUSSION

The results gained in a large number of creep-rupture tests in liquid sodium indicated that the decarburizing liquid metal caused local corrosion of surface grain boundaries. These grain boundaries were depleted in chromium and carbon, thus becoming more sensitive to crack formation under stress. The crack-growth rates were related to the proceeding of the grain boundary corrosion in the liquid sodium environment. The early formation of cracks in the creep-rupture tests in this steel reduced the cross section of uneffected material. This was the reason for the build-up of a concentration of stresses in the remaining cross sections. The reduction of diameters was in the order of 5 % of the initial cross sections. The increase of the creep rates corresponded to this loss of thickness. The results gained in the creep-rupture tests in flowing liquid sodium indicated that the corrosion induced crack formation did not cause a fast failure of the specimens, since the growth of micro cracks did not proceed into the uneffected zones of the material. The growth of cracks might be related to the low effective diffusion rate of carbon in the steel, in which a large part of it was precipitated in form of carbides at grain boundaries. The first step of the crack formation seemed to be the dissolution of grain boundary carbide particles situated near the surfaces due to the decarburization. The effect of sodium was nearly suppressed in tests in which the decarburization was reduced by raising the carbon potential of the sodium (Borgstedt and Huthmann (3)) or by decreasing the carbon content of the steels. The grain boundary decarburization reaches into much deeper zones of the steel than any other effect of the liquid metal.

REFERENCES

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