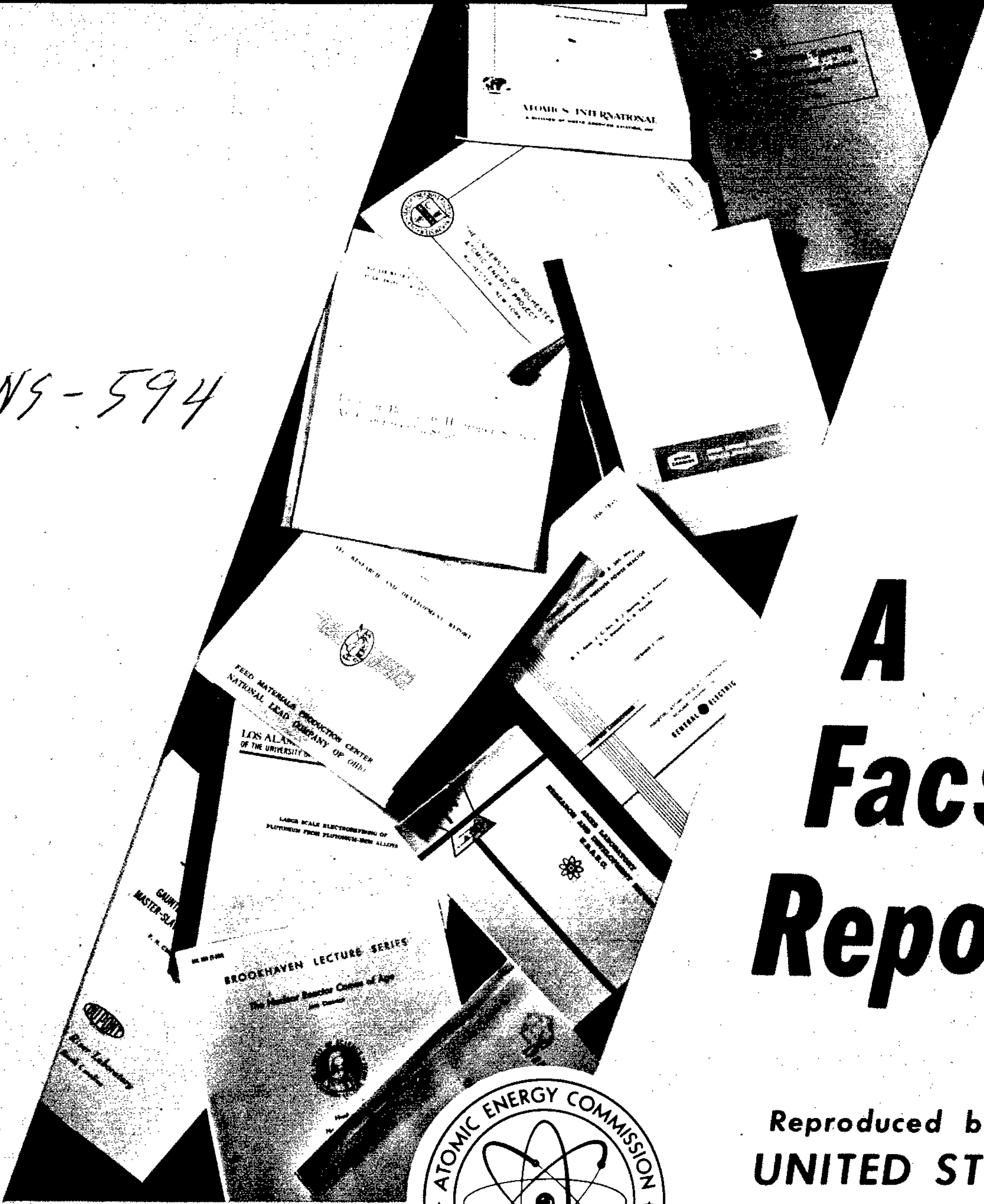

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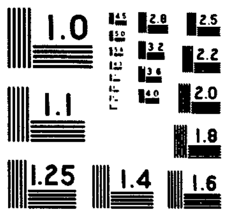

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(STRESS RUPTURE AND CREEP BEHAVIOR OF AUSTENITIC Cr-Ni STEELS IN THE PRESENCE OF Na)

(ÜBER DAS ZEITSTAND- UND KRIECHVERHALTEN VON AUSTENITISCHEN CHROM-NICKEL-STÄHLEN IN GEGENWART VON NATRIUM)

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STRESS RUPTURE AND CREEP BEHAVIOR OF AUSTENITIC Cr-Ni STEELS IN THE PRESENCE OF Na*)

By

H. Böhm and H. Schneider

Abstract (Authors)

A study was made on the influence of liquid sodium on the creep- and stress-rupture properties of two austenitic steels at 700°C. The tests were carried out on sodium filled tubes (X8CrNiMoVNb 1613 and NiCr 3020) under uniaxial stress.

1. Introduction

The problem of the stress rupture and creep behavior of heat-resistant construction materials in the presence of Na becomes gradually more and more important in connection with the increasing application of Na as a coolant in nuclear reactors at a simultaneous increase of the temperature of the coolant. We know from experience that a knowledge of the corrosion behavior of construction materials in the corresponding metallic melt is not sufficient in order to draw conclusions concerning the influence upon the stress rupture properties. It is known e. g. that a great number of metals and alloys show a strong embrittlement in the presence of liquid metals [1].

Andrews et al [2] reported on the effect of flowing Na (flow velocity = 1.35 cm/sec) upon the stress rupture - and creep behavior of a ferritic CrMo-steel and of an austenitic steel of the type 316 (corresponds to X5CrNiMo 1810) at 600 and 650°C. The experiments which had been carried out with 1.6 mm thick plates showed a slight decrease of the time to rupture of the ferritic steel in the presence of Na without any noticeable dependence on the oxygen content (30 and 300 ppm) of Na. No change of the stress rupture strength in Na could be observed for the austenitic steel. Both alloys exhibited in Na a slight increase of the secondary creep rate as well as an increase of the fracture strain.

Start → This communication deals with the investigation of the effect of Na upon the stress rupture and creep behavior of the steel X8CrNiMoVNb 1613 (construction material no. 4988) for wall thicknesses such as are used for fuel element jackets. This steel is regarded as a promising cladding material for a Na-cooled fast breeder. The investigation on samples of Incoloy 800 (NiCr 3020) (construction material 4861) was carried out for

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*) This investigation has been carried out within the framework of the association between the Euratom and the Society for Nuclear Research Ltd (Karlsruhe) in the field of fast reactors.

the purpose of establishing the effect of a higher Ni-content, since the corrosion resistance against Na decreases with the increasing Ni-content of the alloy [3].

2. Experimental procedure

Since the creep experiments in flowing Na require an involved apparatus, it appeared to be reasonable to investigate the effect of Na in the first place in a static test. The experiments have been carried out with Na-filled tubes with the dimensions 110 x 7 x 0.4 mm under uniaxial stress at 700° (± 3°) in normal stress rupture facilities (design by Mohr and Federhaff). The composition of the investigated alloys is shown in table 1.

The cleaned tube sections were welded at first on one end with a 18/8 Cr-Ni steel screw cap by means of an electron beam welding gun. The samples were filled thereafter under argon with Na in a special apparatus whereby the Na was sucked through a frit in order to obtain an oxygen content as low as possible. The oxygen content of Na was here below 50 ppm. After the filling the tube was welded with a second screw cap. Fig. 1 shows the experimental arrangement. A protective container filled with sand, made of heat-resistant steel was placed around the sample as a protection against Na-leaks in the case of a rupture of the tube. The measurement of the strain during the experiment was carried out by means of a dial gauge at the clamping after it was established by comparative measurements with inductive strain recorders that the measuring accuracy was sufficient.

Comparative investigations on empty tube samples have been carried out in the same facility in parallel to the Na-filled samples.

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3. Experimental results.

We determined within the framework of our investigations the effect of Na upon the time to rupture, the secondary creep rate as well as the fracture strain. The experimental results are shown in the following figures. Fig. 2 and 3 show the stress rupture diagrams of the two alloys at 700° without Na and in the presence of Na. Whereas no change of the time to rupture can be observed for the 16/13-CrNi-steel, the stress rupture strength of Incoloy 800 is distinctly decreased and the effect increases with increasing time to rupture i.e. with the duration of the stress which indicates a diffusion - directed process as the cause for the decrease of the time to rupture.

The secondary creep rate of both alloys is shown in fig. 4 as a function of the stress. We can see that all values lie within the normal range of scattering so that no explicit effect of Na upon the secondary creep rate can be observed.

The linear correlation between the creep rate and the time to rupture in a double logarithmic presentation shows that the strain dependence of the creep rate can be described satisfactorily in both cases by the equation

$$\dot{\epsilon} = K\sigma^m .$$

The stress exponent m is obtained from fig. 4 as equal to 4.5 for X8CrNiMoVNb1613 and 5.0 for Incoloy 800 which agrees well with the theoretical value [4].

Whereas the stress rupture strength and creep rate are affected only slightly by Na or not at all the fracture strain of both alloys shows a distinct reduction in the presence of Na as can be seen in fig. 5 and 6. The course of the fracture strain over the time to rupture is similar for Na-free and Na-filled samples. We deal in the 16/13-CrNi-steel evidently with an effect upon the tertiary creep stage and namely in such a manner that the fracture starts very soon after the attainment of the tertiary creep stage whereas the samples without Na show a considerable strain in the tertiary region. Fig. 7 shows this behavior on the basis of creep curves at 18 kp/mm² where the secondary creep rates are equal with and without Na.

The short duration of the tertiary stage as compared with the time to rupture, which is usually smaller than the relatively high scattering of the values of the time to rupture explains why at the shortening of the tertiary stage a strong decrease of the fracture strain is observed but no effect upon the time to rupture.

Incoloy 800 shows on the basis of the measured values that we deal like in X8CrNiMoVNb1613 with a distinct shortening of the tertiary stage by Na and that there occurs in addition an early start of the tertiary stage produced by Na which leads to a distinct decrease of the time to rupture.

In order to obtain data concerning the fracture behavior, we investigated the stress rupture samples metallographically in the fracture zone. Fig. 8a-h shows the structures of the samples of Incoloy 800 within the fracture zone for samples tested at different stresses in air and in the presence of Na. Whereas the "normal" samples show a great number of intercrystalline fissures which occur uniformly over the cross-section and whose number and size decreases as expected with increasing stress i.e. with the increasing rate of strain, the samples treated in the presence of Na do not exhibit any intercrystalline fissures in the interior and there emerge only a few intercrystalline fissures from the surface which stands in contact with Na. A similar behavior is observed also in samples of X8CrNiMoVNb-1613.

4. Discussion of the experimental results.

The results obtained show clearly that Na affects the processes of fissure-and fracture formation which occur in the tertiary creep stage, whereas the secondary creep rate is not changed to an extent which exceeds the normal scatterings. Since in the austenitic steel X8CrNiMoVNb1613 essentially only the tertiary region is shortened, and the moment of its start remains unchanged, we can assume that Na favors rather the propagation of fissures than their formation. The early start of the tertiary stage by Na in Incoloy 800 indicates that we deal here also with an effect upon the fissure formation which is produced probably by the increased corrosive attack which can occur possibly also in the interior of the crystal.

The change of the fissure propagation which occurs in the two alloys becomes particularly distinct on the basis of the structural patterns of the samples within the fracture zone. The absence of larger intercrystalline fissures in the interior of the "Na-samples" shows in the first place that the fissures which occur in the structure of "normal" samples grow only very late in the tertiary region to the size visible in normal samples. Of a particular importance, however, is the fact which follows from the absence of the fissures, that small fissures which emerge from the surface lead in the presence of Na to a rapid fracture, before the fissures in the interior attain a visible size. The causes of the accelerated fissure propagation in the presence of certain metal melts are not quite clear yet. In contrast to the frequent statement [1] that the embrittlement is caused over a decrease of the surface energy by the absorption of atoms from the melt (this would decrease the stress required for the growth of a fissure), Stoloff and Johnston [5] explain the decrease of the fracture stress and ductility by a decrease of the binding forces at the tip of the fissure caused by chemically absorbed atoms.

If we compare our results with the data obtained by Andrews et al [2] then we observe considerable differences in some points. Here the increase of the secondary creep rate by Na (as compared with that in air) which was not observed in our experiments is definitely less pronounced than the very diversified effect upon the fracture strain. In contrast to the strong decrease of the fracture strain observed in our experiments, Andrews et al found even an increase of the fracture strain in the presence of Na.

In addition to the composition of the studied construction materials and the experimental procedure also other important parameters such as the wall thickness and the deformation state of the samples as well is the Na-temperature are very different, so that a comparison of the results of the two investigations is not easy and further studies will be required in order to explain the different behavior.

5. Summary.

A study was made on the effect of liquid Na upon the stress rupture and creep behavior of two austenitic steels at 700°C. The tests were carried out on Na-filled tubes (X8CrNiMoVNb1613 and NiCr3020) under uniaxial stress.

It was found that the secondary creep rate is not affected by Na. The stress rupture strength of NiCr3020 is decreased by Na. The tertiary creep stage is shortened by Na and results in a reduction of the fracture strain.

Literature cited.

1. W. Rostoker, J. M. McCaughey and H. Markus, Embrittlement by Liquid Metals (Reinhold, New York, 1960)
2. R. C. Andrews, R. H. Hiltz, L. H. Kirschler, S. J. Rodgers and F. Tepper, Effect of high temperature sodium on austenitic and ferritic steels; MSAR-61-18, MSAR 64-81, MSAR 65-194, MSAR 66-149.
3. B. A. Nevsorov et al., 3. U.N. Intern. Conf. peaceful uses of Atomic Energy (1964). Paper 28/P/343.
4. J. Weertman, J. Appl. Phys. 28 (1957) 1185.
5. N. S. Stoloff and T. L. Johnston, Acta Met. 11 (1963) 251.

Table 1
Composition of the investigated samples (wt.%)

Element	X8CrNiMoVNb1613	Incoloy 800 (NiCr 3020)
C	0.07	0.016
Si	0.40	0.60
Mn	1.22	1.35
P	0.018	0.01
S	0.007	0.006
Cr	17.10	20.6
Ni	13.61	31.9
Mo	1.30	-
V	0.70	-
Nb/Ta	0.85	-

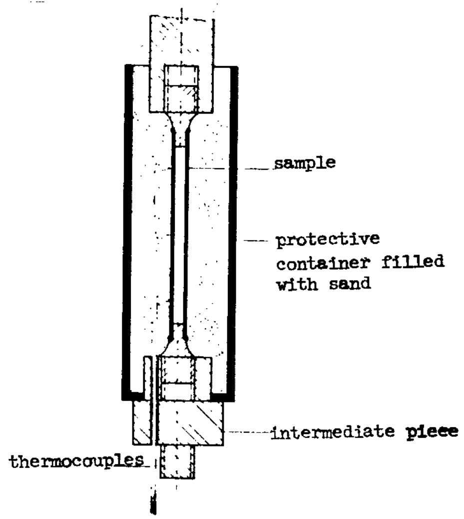


Fig. 1. Facility for stress rupture tests with tubes (filled with Na)

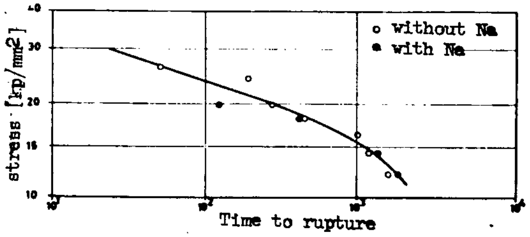


Fig. 2. Stress rupture diagram of the steel X8CrNiMoUNb1613 at 700°C.

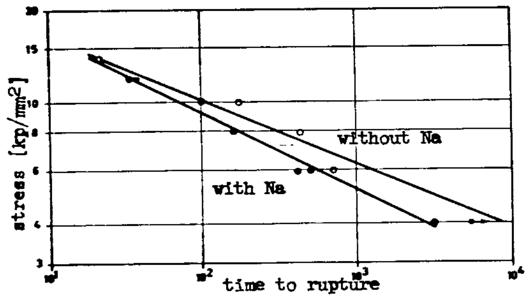


Fig. 3. Stress rupture of Incoloy 800 at 700°C without Na and in the presence of Na.

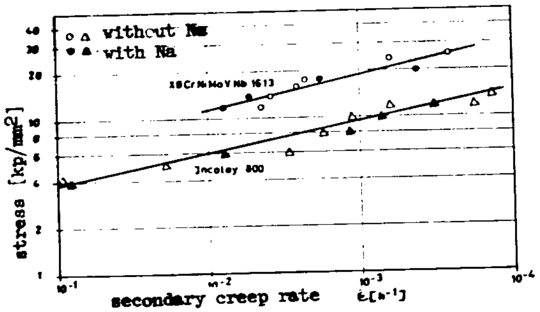


Fig. 4. Secondary creep rate of Incoloy 800 and X8CrNiMoVNb-1613 in dependence on the strain at 700°C.

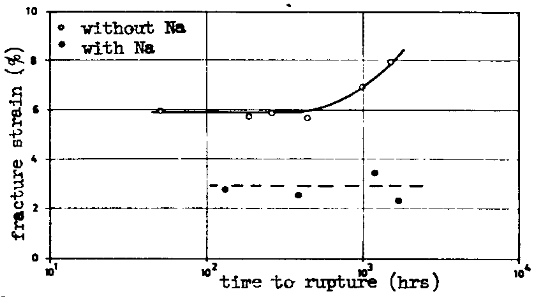


Fig. 5. Fracture strain of the steel X8CrNiMoVNb1613 in the stress rupture test at 700° without Na and in the presence of Na.

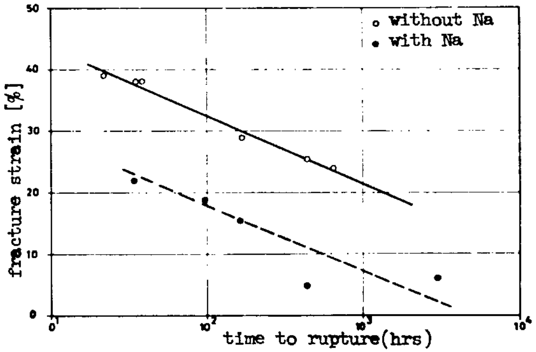


Fig. 6. Fracture strain of the Incoloy 800 alloy in the stress rupture test at 700° without Na and in the presence of Na.

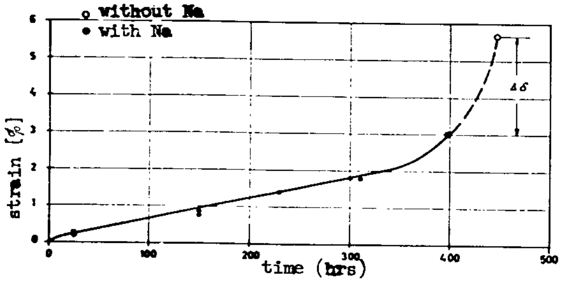
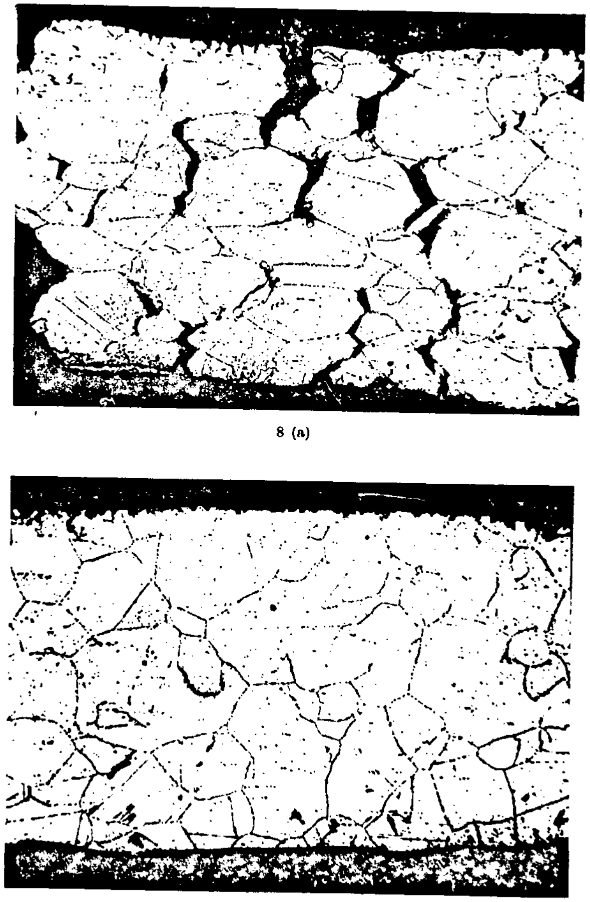


Fig. 7. Creep curves of the steel X8CrNiMoVNb1613 at 18 kp/mm² and 700°C.



8 (a)

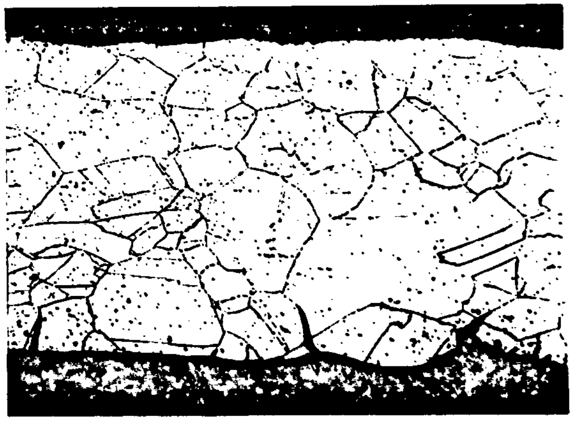
8 (b)

Fig. 8. Structures of stress rupture samples of Incoloy 800 within the region of the fracture zone. Testing temperature 700°C. Samples a,c,e and g: without Na; samples b,d,f and h: in the presence of Na; samples a + b: G = 6kp/mm²; c + d: G = 8kp/mm², e + f: G = 10kp/mm², g + h: G = 12kp/mm². x 200.

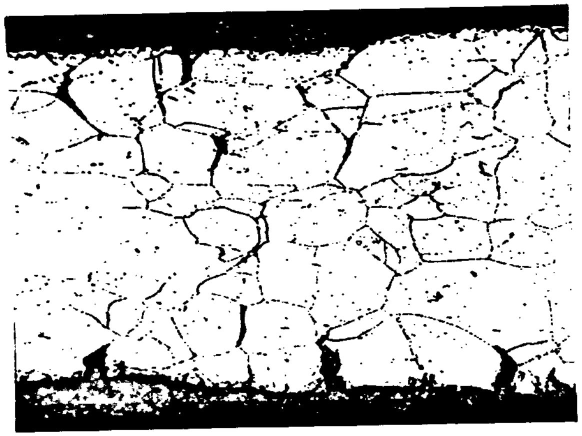
8 (c)

8 (d)

8 (e)



8 (f)



8 (g)

8 (h)

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