The influence of liquid Pb-17Li eutectic on the mechanical properties of structural materials

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ABSTRACT

The structural materials - martensitic steel X18 CrMoVNb 12 1 and vanadium alloy V3Ti1Si - are studied in respect to their mechanical properties in the Pb-17Li eutectic. Tensile tests at 240 and 300°C do not indicate any liquid metal embrittlement effect.

Creep-rupture tests of the martensitic steel at 550°C in the liquid metal are running, first results indicate a reduction of creep life by corrosion action of the liquid metal. Further tests and examinations after exposure have to approve the first results and to develop a mechanistic model of the liquid metal effect.

The creep-rupture tests with the vanadium alloy are under preparation.

1. INTRODUCTION

The candidate structural materials for application in a liquid metal blanket of a fusion reactor which are under consideration are a martensitic steel X 18 CrMoVNb 12 1 (no. 1.4914) or a vanadium alloy of a composition V 3Ti 1Si. These materials should be compatible with the liquid alloy Pb-17Li and this compatibility should not be significantly influenced by the superimposure of stresses or cycling stresses. The mechanical strengths of the two materials at high temperatures should not be reduced by the corroding liquid metal.

The cycling operation mode of a fusion reactor blanket has two aspects in respect to material behavior and compatibility. One aspect is that the materials are undergoing a thermal cycling which causes a strain controlled cycling of the material. Thus, low cycle fatigue behavior of the materials is of importance, and the fatigue strength should not be reduced by the wetting with the liquid alloy. The temperatures of blanket and secondary system may cause a cooling down of the blanket fluid at the shut-down period to a temperature close to the melting point of the eutectic alloy. The materials contected with the liquid alloy pass the temperature range above the melting point. Within this range, the conditions for an occurance of "Liquid Metal Embrittlement" are fulfilled.

An influence of liquid metals on the creep-rupture behavior of structural materials has been observed in tests which have been performed in a liquid sodium environment /1/. Thus, such detrimental effects may also occur in Pb-17Li. Tests to evaluate the influence of the molten metal on the creep-rupture behavior of the two materials have been started in our laboratory.

The influence of liquid lithium metal on the fracture of the martensitic steel has been detected in an earlier study /2/. These tests have also indicated the importance of a pre-corrosion of the specimens in the liquid metal.

2. EXPERIMENTS

2.1 MATERIALS

The martensitic steel X 18 CrMoVNb 12 1, the composition of which is listed in Table 1, has received a three step heat treatment. The sequence of 2 h at 950-980°C, 0.5 h at 1075°C, fast cooling, and 2 h at 750°C produces a homogenized, fully martensitic and δ-ferrite free structure /3/. The vanadium alloy V 3Ti 1Si has been fabricated by Metallgesellschaft AG, Frankfurt, Germany. The specimens which are made of rods of 12 resp. 20 mm diameter are finally heat treated in vacuo in the presence of zirconium getter at 1150°C for 1 h.

2.2 THE EXPERIMENTAL SETUP

The eutectic alloy Pb-17Li has been delivered by Metallgesellschaft AG, Frankfurt, Germany. The composition is in the range 0.66-0.68 wt-% Li very close to the eutectic point. The melting point is also measured before each test and is 235°C. The handling of the liquid metal and the procedure to fill and close the capsules for mechanical testing has been described earlier /2/.

The equipment is developed on the basis of preceding work of the liquid metal laboratory in the KfK. The material specimens are immersed in the liquid metal inside of stainless steel capsules the principle of which is described in ref. /2/. The capsules have a provision to mount the specimens of their bottom. The upper end of them is connected to the load bar. Stresses or strain are imposed on the material by means of material testing machines. The strain is measured outside of the capsules. The arrangement of strain measurements in low cycle fatigue tests is made in a way that the tests can be made under strain control.

The testing temperature is maintained at constant level by means of electric heating jackets with electronic power regulation. A creep machine for four parallel tests has been constructed. The experimental data of these tests which last more than twothousand hours in some cases are collected in a data logger.

3. EXPERIMENTAL RESULTS

The tensile tests of the two materials in molten Pb-17Li eutectic at 240 and 300°C do not indicate a significant embrittling action of the liquid metal on the tensile properties of the specimens. As shown in Table 2, the values of the yield strength R_p, the ultimate tensile strength R_m and the elongation A which are measured in the liquid metal environment are very close to those of reference tests. Even a pre-corrosion of the specimens up to 1500 hours in the stagnant Pb-Li melt at 550°C does not cause a more brittle behavior in the tensile tests within the whole range of strain rates and temperatures applied in the test series.

The examination of specimens does not exhibit any embrittling liquid metal effect on the surfaces of the specimens. The ductile fracture zones are free from any intercrystalline surface cracks in accordance with the reduction of area.

The tensile properties of the V 3Ti 1Si alloy in Pb-17Li are different from those of the martensitic steel. The ultimate tensile strength is lower and the ductility is higher. The behavior is only slightly changed by a pre-corrosion in the molten metal. The most of the specimens exhibit small increases of strength and small losses of ductility. A few specimens show, however, significant changes which are under examination.

The series of creep-rupture tests of the martensitic steel X 18 CrMoVNb 12 1 at 550°C in the liquid metal are not yet finished, first results have been received, as is shown in Table 3. The first results indicate a ductile fracture behavior of this steel in the molten eutectic mixture. The creep curves, for instance, show a well defined region of secondary creep in which the creep rate remains at its minimal value for a longer period of time. An extended tertiary creep range follows, and this is in accordance with the strain-to-fracture values.

It is not yet possible to construct a creep-rupture curve of this steel for its behavior in Pb-17Li. It is, however, obvious from a comparison of the first results with the behavior of this steel (commercial quality) in creep-rupture tests in the atmosphere, that the liquid metal has an influence on the creep-rupture life of the material. The result of such a comparison is shown in Fig. 1, the reference data are taken from ref. /4/. The data of table 3 support the preliminary creep-rupture curve of X 18 CrMoVNb 12 1 as shown in this diagram.

Creep-rupture tests of V 3Ti 1Si specimens are in preparation.

4. DISCUSSION OF THE RESULTS

The insensitivity of the two materials in contact with the Pb-17Li eutectic at temperatures just above its melting points to liquid metal embrittlement is somewhat surprising. Lithium has been shown to cause some embrittlement of the martensitic steel after pre-corrosion /2/. The lithium content of the eutectic should improve the poor wetting behavior of molten lead. The heavy metal belongs to the group of molten metals which develop an embrittling activity against several solid alloys. The two tested alloys, the martensitic steel and the vanadium alloy as well, seem to stand with such activities. In every case, we have fulfilled all conditions which are necessary to get a more or less complete wetting. This has been shown by means of metallographic examinations of the specimens. One aspect of the embrittling molten metal is its capacity to dissolve components of the solid alloy. Low solubility is assumed as favorable for embrittling action. The capacity of lead to dissolve transition metals is, however, larger than that of the alkali metals as lithium. Thus, dissolving corrosion reactions may suppress local effects at grain boundaries which are necessary for the embrittling action.

The NET batch of the steel X 18 CrMoVNb 12 1 which has received an optimizing heat treatment should have a better creep-rupture strength than the commercial batch, the properties of which /4/ we have used for comparison. However, the creep-rupture life seems to be reduced in our tests in the molten metal, the running tests are supporting the preliminary curve. The ductile behavior of the specimens indicate that there should not occur a drastic local corrosion effect at grain boundaries. The inspection of the specimens exhibits a corrosion layer the depth of which has not yet been determined. The fact that the reduction of creep life increases with the growing duration of the exposure is an argument for corrosion induced reducing of the life time. Some parallel tests with our specimens in air have to bring out the effects of the liquid alloy.

The detailed examination of failed specimens will produce a better understanding of the results of these tests.

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REFERENCES

/1/ Huthmann, H., Menken, G., Borgstedt, H.U., Tas, H.; "Influence of Flowing Sodium on the Creep Rupture and Fatigue Behavior of Type 304 ss at 550°C", Proc. 2nd Intern. Conf. on Liquid Metal Technology in Energy Production, Ed. J.M. Dahlke, National Technical Information Service, Springfield, VA, 1980, Vol. 2, Chapter 19, 33-40

/2/ H.U. Borgstedt and M. Grundmann; The Fracture of Austenitic and Martensitic Steel in Liquid Lithium, Nuclear Engng. and Design / Fusion, 3 (1986) 273-286

/3/ C. Wassilew, personal communication

/4/ M. Schirra, personal communication

Table 1: Chemical compositions of the NET-heat X 18 CrMoVNb 12 1

1.4914 (Heat 53645)	C	Cr	Ni	Mo	V	Nb
wt-%	0.13	10.6	0.87	0.77	0.22	0.16

Si	Mn	S	P	B	N	Others
0.37	0.82	0.04	0.005	0.0085	0.020	Al 0.054 Co 0.01 Cu 0.015 Zr 0.053

Table 2: Tensile test results of steel X 18 CrMoVNb 12 1

Temp. (°C)		Pre-exposure (h)	R_m (MPa)	A (%)
Air	RT	-	800-830	18-19
	300	-	670-720	15-16
Pb-17Li	240	-	700-715	14,9-15,6
	300	-	660-680	
Pb-17Li	240	500	670-690	15,5-16,5
	300	500	630-650	
Pb-17Li	240	1000	~640	16-18
	300	1000		
Pb-17Li	240	1500	640-660	16-18
	300	1500		

Table 3: Creep-rupture tests of steel X 18 CrMoVNb 12 1 in liquid Pb-17Liat 550°C

Stress (MPa)	Min. Creep Rate (s^{-1})	Time-to-Rupture (h)	Elongation (%)	Reduction of Area (%)
180	$5.0 \cdot 10^{-9}$	still running		
200	$7.2 \cdot 10^{-9}$	1152	20.0	78.64
210	$7.5 \cdot 10^{-9}$	997	19.0	76.10
230	$2.5 \cdot 10^{-8}$	still running		
240	still running	still running		

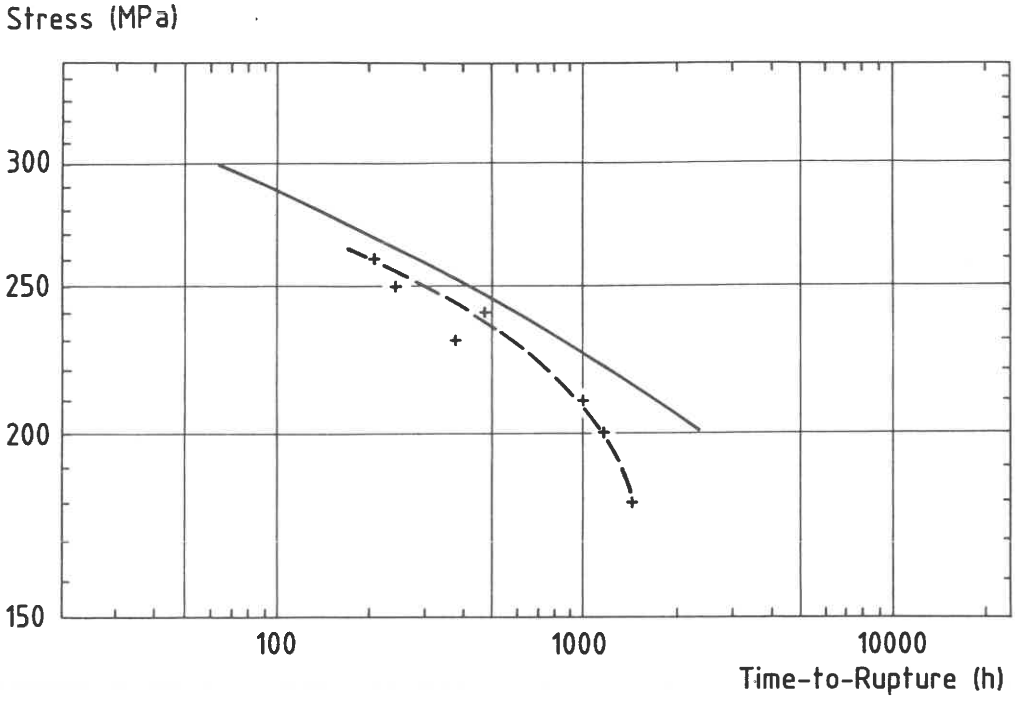

Fig. 1: State and first results of creep-rupture tests with X 18 CrMoVNb 12 1 in Pb-17Li at 550°C