Failure Resistance Evaluation for Pipings of NPP with BWR

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ABSTRACT

In the present investigation the fracture resistance test results of modern structural steels of the grades 22K (USSR), Creselso 330E(France), 19MN5(Japan) and their weldments have been extensively studied under the test conditions simulating the service operation of Dy752 pipings of NPP with reactors of BWR type. The materials low cycle fatigue resistance and crack growth kinetics have been evaluated in the operation temperature range of 20-350°C, and the fracture toughness values - with the use of brittle crack initiation criterium. It has been shown that all the characteristics of the investigated materials reflecting the various stages of fracture process are very close in their values and to predict the service life of pipings the correspondent correlations of the expanded in the USSR standard PNAE G-7-002-86 may be used.

1 INTRODUCTION

The low alloyed steels of the grades 22K, Creselso 330E, 19MN5 with nearly the same chemical compositions and mechanical properties are suitable for manufacture of pipings, collectors and separating drums of forced circulating circuit of BWR type. The steels similarity permitted the investigators not to perform certification tests of steels, manufactured abroad in compliance with the "Rules of arrangement and safe operation of NPP equipment and piping". Therefore the service life estimation of forced circulation circuit components was conducted in conformity with the "Strength calculation standard PNAE G-7-002-86" with the use of low alloyed 22K steel characteristics (though there was no experimental confirmation). However, by the service operation of forced circulating circuit components during 3 years a somewhat higher degree of damage was found Creselso 330E steel (at Smolenskaja NPP with BWR RBMK-1000 type) and 19MN5 steel (at Ignalinskaja NPP with BWR RBMK-1500 type) as compared with damaged weldments of Dy752 piping (826x38mm) fabricated from 22K steel. This fact made it necessary to perform certification tests of Creselso 330E and 19MN5 steels in complience with the rules of PNAE G-7-008-89 standard.

2 MATERIALS AND EXPERIMENTAL PROCEDURE

The fracture resistance of Creselso 330E and 19MN5 steels have been examined on one melt, and their weldments (produced by manual welding with the electrodes of ETNA 52HR grade) - with the use of one patch. The chemical composition of investigated materials is given in Table 1 and the mechanical properties - in Table 2.

Table 1. Chemical composition of investigated metals

Material	Type	C	Si	Mn	S	P	Cr	Ni	Cu
Base metal	Creselso330E	0.205	0.266	1.02	0.005	0.004	0.188	0.198	0.129
Weld metal	ETNA52HR	0.06	0.32	1.71	0.03	0.03	0.10	0.09	0.18
Base metal	19MN5	0.22	0.39	1.23	0.003	0.007	0.30	0.22	0.067
Base metal	22K(TY)	0.19-0.26	0.20-0.40	0.75-1.00	0.025	0.025	0.40	0.30	0.30
Base metal	Creselso330E (TY)	0.23	0.20-0.40	0.90-1.20	0.025	0.025	0.40	0.30	0.30
Base metal	19MN5(TY)	0.17-0.23	0.20-0.60	1.00-1.30	0.020	0.025	0.30	0.30	0.30

Table 2. Mechanical properties of investigated metals

Material	Type	T_{test} °C	UTS MPa	YS MPa	A %	Z %	T_{cr} °C
Base metal	Creselso330E	20	556	343	29.0	66.5	-10
		275	483	225	28.4	58.4	-10
		350	507	218	32.0	61.5	
Weld metal	ETNA52HR	20	514	358	24.7	65.5	-10
		275	516	390	19.9	60.5	
		350	468	239	35.0	65.8	
Base metal	19MN5	20	598	375	33.4	67.3	-20
		275	548	321	23.8	57.0	
		350	556	345	25.5	64.4	
Base metal	22K(TY)	20	440	220	20	45	+40
		350	360	190	18	45	
Base metal	19MN5(TY)	20	431	216	20	45	
		350	372	196	18	43	

As it is evident from the listed properties they agree with the requirements of specifications for 22K steel and sometimes they are higher (the value of T_{cr}). The specimens were machined out from the tube wall of 38mm thickness along the vessel axis. The specimens for low cycle fatigue investigation with the diameter of 10mm and length of 120mm were tested in tension and compression mode at the same temperature range as CT1 specimens used to estimate the fatigue crack growth rates. The test temperatures were 20, 275 and 350°C (20°C is the minimal operation temperature; 350°C is the maximal operation temperature; 275°C is the temperature of possible strain aging effect for low-carbon steels). Fracture toughness tests were performed both on CT1 specimens and on bend specimens of 15x30x360mm dimension. The low-cycle fatigue, fatigue crack growth kinetics and fracture toughness test methods agree with the requirements of the standards of the USSR (GOST 25.506-85 and PNAE G-7-002-86).

3 THE INVESTIGATION RESULTS

The obtained results permittedto estimate the temperature effect on steels fracture resistance. They illustrate a monotonous decrease of Creselso 330E and 19MN5 steels fracture resistance with temperature increase in range of 20-350°C. For example, by the deformation amplitude of 0.5% the 19MN5 steel

lifetime before a crack generation is approximately two folds decreased by the temperature increase from 20 to275°C and is about 4 times decreased by the temperature increase up to 350°C. At the same time the low-cycle fatigue curve of 22K steel is located lower on the graph at 275°C that at 350°C. This effect was attributed to the strain aging influence on the as-produced 22K base metal and welds (produced by manual electric arc welding with YONI-13/45 and YONI-13/55 electrodes). Figure 1 shows the low cycles fatigue curves, obtained for 22K, Creselso 330E and 19MN5 steels.

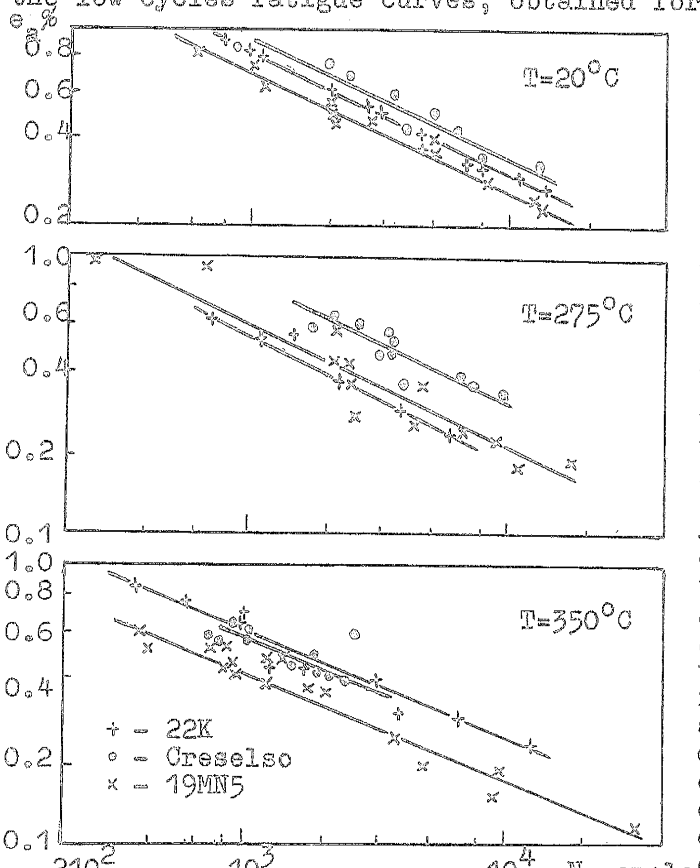

Fig.1. Low cycle fatigue resistance of low carbon steels used for forced circulation circuit pipings.

The analysis of the results shows that there is a slight decrease in low cycle fatigue fracture resistance of 19MN5 steel as compared with 22K and Creselso 330E steels which ehxibit the nearly same fracture resistance (with the exception of 275°C temperature range, when the strain aging effect of 22K steel takes place). At the same time the cyclic strength of 19MN5 steel and also 22K and Creselso steels, estimated by the fatigue crack initiation moment, agree with the standard requirements conformably to the operation conditions of forced circulation circuit pipings with BWR. As regards Creselso 330E weldment, produced by manual welding with

ETNA-52HR electrodes, the low cycle fatigue resistance of this material at all test temperatures is lower that of base metal. The investigation results showed a slight tendency of 22K steel base metal to strengthen at all test temperatures (though this steel is considered to be a cyclically stable material). A loss of strength was found for an as-produced weldment produced with electrodes of the grades ETNA-52HR, YONI-13/45 and YONI-13/55 by cyclic elastic-plastic deformation.

The materials fatigue crack growth rates have been evaluated by the performance of tests in air in the temperature range of 20-350°C with the use of loading cycle asymmetry coefficients R=0.1 and R=0.7. The compact specimens of 25mm thickness were tested in the tensile mode on a servohydraulic machine "Hydropulse 400 KN" with the frequencies of 5-30 Hz (that is in compliace with the recommendations RD50-345-82 standard). The crack propagation was measured on specimen polished surface using MBS-9 optical microscope (measurement error did not exceed the value of 0.014 mm). Then the data entry into the computer database was performed. The developed application package provided experimental data processing and output of kinetic fatigue fracture diagrams in graphic and table display. Figure 2 illustrates the kinetic fatigue fracture diagrams for Creselso 330E and 19MN5 steels and weldments produced with ETNA-52HR electrodes in the coordinates "fatigue crack growth rate - stress intensity factor range". In the diagram section with middle values of stress intensity factor the experimental results are related to Paris equation $dl/dN=C(\Delta K)^m$, where $m=2.9$ and $C=3\cdot10^{-11}$, they are constants for low carbon materials, used in nuclear power of the USSR. The obtained results confirm the possibility of these values application to estimate production defects growth and to predict the component remaining service life because the fatigue crack growth rate in the investigated materials is somewhat lower. By the investigation of temperature effect on the fatigue crack growth kinetics it is evident that with temperature increase from 20 to 350°C the crack growth rate in base metal of Creselso 330E and 19MN5 steels is slightly increased, and in weld metal, it does not practically change. The loading cycle asymmetry change influence on the fatigue crack growth resistance is also negligible; with its increase from the value of 0.1 to 0.7 the crack

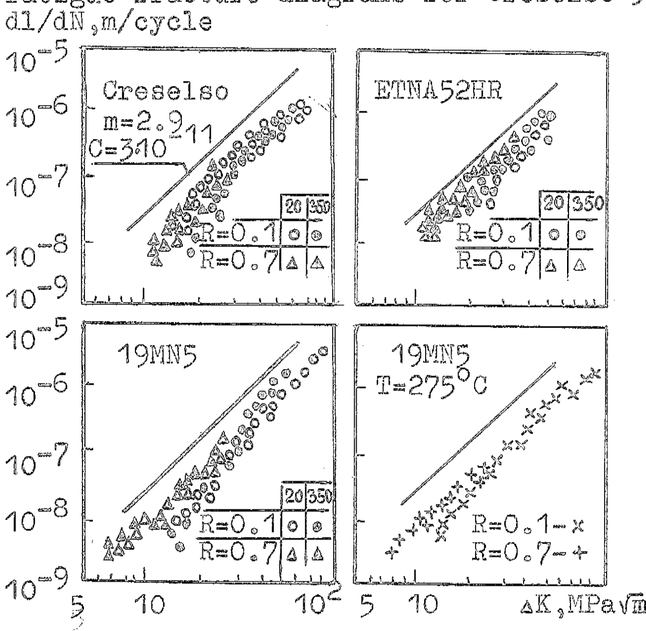

Fig.2. Fatigue crack growth resistance of low carbon steels.

growth rate is only slightly increased.

As it has been mentioned above the fracture toughness of Creselso 330E and 19MN5 steels was estimated by testing of compact CT1 specimens and bend specimens with the cross-section of 15x 30mm. It is well known that on such small specimens and with low strength characteristics of investigated materials (YS at 20°C lower 400MPa) it is impossible to obtain the correct values of K_{1C} in the whole range of loading temperatures (from -150 to +20°C). Therefore, in accordance to GOST 25.506-85 the brittle fracture resistance of these steels (at -20 ÷ +20°C) was assessed with the use of K_C parameter. The fracture toughness test results of all investigated materials are shown in Figure 3. For steels of foreign delivery the test results were obtained on specimens of small thickness (30mm) and for 22K steel - on specimens of sufficiently greater thickness (150mm). The data of Fig.3 illustrate that 19MN5 steel fracture toughness is of high standard level, and it higher that of 22K and Creselso 330E steels.

Thus, the fracture resistance of Creselso 330E and 19MN5 steels and their weldments is not inferior to that of 22K steel and its weldments, produced by manual electric arc welding under the conditions of assembling. The investigation of defected zones of piping weldments made from Creselso 330E and 19MN5 steels showed that the increased piping damage by operation was caused by the breaching of welding processing by the production of circumferential welds during assembling. The defects were located mainly in the transition from austenitic cladding to perlitic base metal or weld zone. The dimensions of piping defects were statistically determined (Timofeev et al. 1990; Vaseneve et al. 1990) and the knowledge of materials fracture resistance at various fracture stages permits to assess the piping service life. ZNII KM"Prometey" has developed the welding processing of circumferential welds excluding the appearance of production defects by the manufacture and assembly processes.

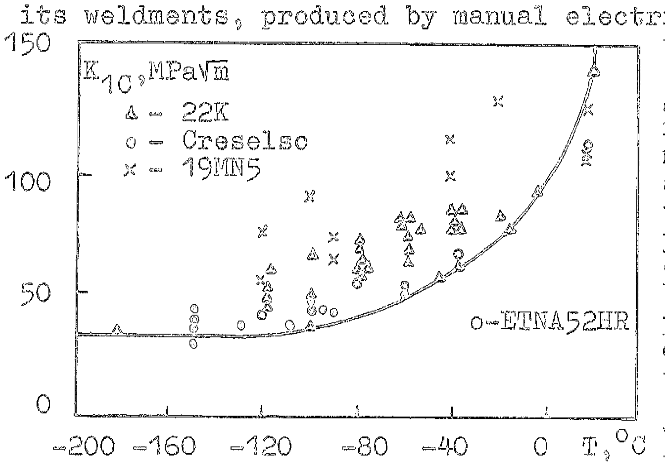

Fig.3. Fracture toughness of low carbon steels.

CONCLUSIONS

1. Creselso 330E (France) and 19MN5 (Japan) steels fracture resistance at the stage of fatigue crack initiation and propagation and fracture toughness are not inferior to analogous characteristics of 22K steel (USSR).

2. The increased damage of cladded weldments from Creselso330E and 19MN5 steels at the service stage is caused by the welding processing breaching by circumferential welds manufacture during assembling.

3. By service life estimation of NPP pipings with water cooled and water moderated boiling reactors, manufactured from Creselso 330E and 19MN5 steels, the corresponding relations for low carbon materials from PNAE G-7-002-86 (USSR) standard may be used.

REFERENCES

GOST 25.506-85. Metals mechanical testing procedure. The estimation of crack resistance (fracture toughness) by static loading. USSR state standard committee, 1985, 61p.

Strength calculation standard for nuclear power plant equipment and piping PNAE G-7-002-86. Moscow, Energoizdat,1989, 528p.

Vaseneva N.V., Timofeev B.T., Chernaenko T.A. Fracture resistance of pipings manufactured from a low carbon steel. Scientific and technical collection "Shipbuilding". Issue Metal Science, Welding, N 10, 1990, pp.14-16.

Timofeev B.T., Vaseneva N.V., Generalova S.P., Chernaenko T.A. Service life estimation of low carbon steel pipings with regard for production quality. Third All-Union Symposium on Fracture Mechanics "Crack resistance of materials and structure components". Zhitomir, 30 October - 1 November, 1990, Part 3, pp93-94.