FRACTURE CRITERIA FOR 18Cr-10Ni-Ti STAINLESS STEEL PIPING

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ABSTRACT

The influence of notches and cracks upon the 18Cr-10Ni-Ti stainless steel specimens and pipes strength is investigated. The techniques and experimental results are discussed. The fracture criteria for damaged pipes made of 18Cr-10Ni-Ti stainless steel are proposed.

KEYWORDS

Stainless steel piping, axial and circular notches, fracture criteria, J_c-integral, ultimate strength, residual strength.

During the exploitation of the main circular water-water reactor's pipings Di-500 the cracks of various types may occur that will lead to the considerable loss of piping strength and increase the possibility of hazard. To predict piping reliability and estimate its residual strength even at the presence of variously oriented cracks one should posses the fracture criteria for the piping material that is 18Cr-10Ni-Ti stainless steel(type AISI 304 steel). The criteria should be investigated under normal and exploitation conditions of staticloading.

The results of the 18Cr-10Ni-Ti stainless steel fracture toughness researches are presented here. The results of the experiments involving the fragments of steel pipes having the defects of various orientation and shape exposed to internal pressure and bending loading are also considered.

SPECIMENS AND THE RESULTS OF THE EXPERIMENTS

The experiments with the smooth specimens cut out of the Di-500 in circular and axial directions do not reveal the difference in their mechanical properties ($\sigma_{0.2}$=327MPa, σ_B=571 MPa, δ=54%, ψ=74%) that confirms the absence of anisotropy in the mechanical properties of the material.

Different specimen types were used to asses rupture behavior of the material in three directions as the crack grows (Fig. 1).

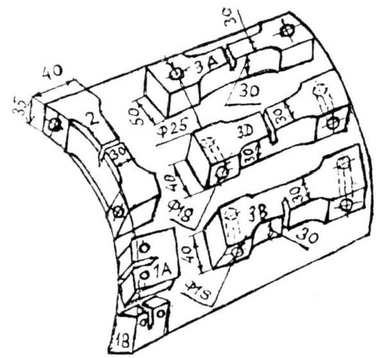

Fig. 1.Types of fracture specimens

The compact tensile specimens of 1A and 1B series differ in the direction of the primary notch. In 1A specimens exposed to tension the primary notch and the direction of crack growth coincide with the pipe axis. (The dimensions of the compact specimens corresponded to standard No 25.506-85, maximum thickness were 30 mm.) Straightline specimens (series 3A, 3B, 3D) differ in crack growth direction and in the direction of loading pin axis. C-shape specimens (series 2) representing the part of pipe shell were used to estimate the rupture strength, when the crack growth direction is towards the wall thickness. The peculiarity of the straightline and C-shape specimens is that the section notch tensile strength distribution corresponds to that of the piping wall even when it is exposed to the bending loading. The C-shape specimens were exposed to uniform axial tension. As it became obvious in the course of the experiments, destruction of the compact specimen is accompanied by the slow crack growth, the crack can be controlled up to the perfect destruction of the specimen, the loading reduces up to zero. The tensile loading of straightline and C-shape specimens showed that the perfect destruction occurs practically at the maximum value of loading, while the crack growth extension is small, that corresponds to the piping destruction conditions due to internal pressure. This fact confirms the importance of specimen type selection for the rupture strength estimation and the fracture criteria formulating.

Being plastic material 18Cr-10Ni-Ti could not be characterized by the stress intensity factor K_{1c} so, the elastic-plastic fracture toughness J_c-integral and crack tip opening displacement δ_c, estimated at the moment of crack initiation were chosen to characterize the fracture behavior of 18Cr-10Ni-Ti steel. The moment of crack initiation was detected with the impedance technique. J_c-integral was calculated also using J_R-curves (Fig.2), the satisfactory coincidence of the results obtained by the two techniques being observed.

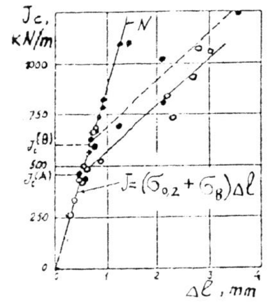

Fig. 2.J_r- curves for 18Cr-10Ni-Ti steel

J_c-integral and δ_c for axial and circular directions with respect to the pipe axis of the crack growth in the compact specimen are presented in the following table.

Table. Mean values of 18Cr-10Ni-Ti stainless steel fracture toughness in axial and circular directions.

direction	K_Q MPa$\cdot\sqrt{m}$	δ_c mm	J_c kN/m
axial	52	0.75	450
circular	52	0.95	600

The analysis of the results depicted in Fig.2 shows that the considerable variance and overlapping of J_c and δ_c values for 1A and 1B series allows to state the absence of anisotropy of rupture behavior of 18Cr-10Ni-Ti steel in axial and circular directions. This fact is quite agree with the results of smooth specimen tests. The values of δ_c and J_c-integral could be taken as minimum: δ_c=0.75mm, J_c=450 kN/m.

3A, 3B, 3D and C-shape specimens were exposed to tension loading, the P-v diagrams were registered. The destruction of these specimens occurs practically at the maximum of loading. Besides strength · characteristics estimation using dividing grids technique (Novikov et al,1979) the maximum deformation distribution along the width of the specimens at the tip of the notch at the moment of crack initiation were investigated. The dividing grids with square cells 1x1 mm are formed by photolithography technique. When exposed to tension loading at the considerable crack tip opening the 3A, 3B, 3D specimens were deformed in the notch area so that loading line became closer to the centroid of the section weakened by the notch. This fact shows the considerable bending effect almost in all 3A, 3B, 3D specimens that could be illustrated by Fig.3. The axial loading of the C-shape specimens lead to the double reduction of displacement v_{max} and the minimal bending effect.

The more uniform distribution of maximum deformation at the tip of the notch at the moment of crack initiation in the C-shape specimens were obtained using dividing grids technique. Fig.4 shows general results of 3A, 3B, 3D, and C-shape specimens tests. These results also shows the absence of anisotropy in rupture strength at axial and circular crack growth. Besides, one may conclude that 18Cr-10Ni-Ti steel responds weakly to the stress concentration as the destructive nominal stress σ_n demonstrates linear dependence upon section dimensions.

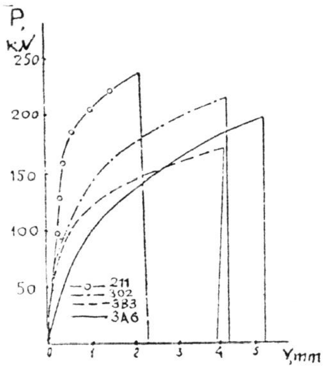

Fig. 3. Fracture diagrams for different specimen types

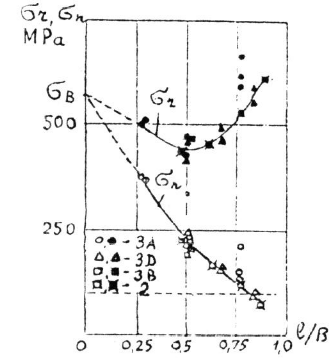

Fig. 4. The diagram of residual strength 18 Cr-10Ni-Ti steel

PIPING TESTS RESULTS

Fragments of 18Cr-10Ni-Ti steel pipes Di-80 with the internal diameter equal to 80 mm and wall thickness of 5 mm were used as the model specimens. The width-to-internal diameter ratio of these pipes is equal to 0.0625 that practically corresponds to that of Di-500 pipes (0.068), so Di-80 can be regarded as the six times smaller model of Di-500. The mechanical properties of Di-80 material are: $\sigma_{0.2}$=337 MPa, σ_B=644 MPa, δ=51%. They were estimated in the course of flat and ring specimens cut out of pipes tests. The rupture strength characteristics of Di-80 material were estimated using specimens with primary defects mentioned above.

Pipe specimens were 250-300 mm long and possessed axial or circular surface notches of various depth **a** and length 2c and were exposed to internal pressure and bending loading.

The destruction of pipes with long and not deep notches occur with the considerable displacement of the crack edges δ_K in the middle. The tearing length $2c_K$ on the surface exceeds the length of 2c of the primary notch. The square of the tearing is large enough (up to 400 mm) and is approximately equal to the effective circular hole of Di-20. The value of distructive pressure in this case exceeds 20 MPa. The increase of the notch depth **a** to the value of (0.8 - 0.9)s changes the nature of tearing. It leads to the reduction of plastic deformation and thus small tearing square. The value of the destructive

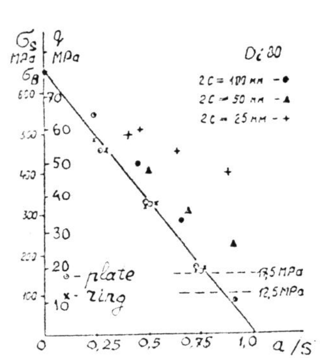

Fig. 5. Dependence of the Di-80 strength on the notch depth

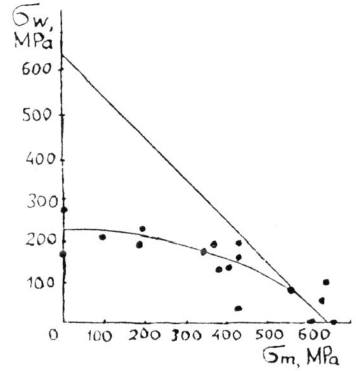

Fig. 6. Dependence of the Di-80 strength on the circular and bend stresses

pressure is 10 - 20 MPa. Decreasing the value of 2c the tearing is modified into honeycomb with the square of the tearing section less then 1 mm^2.

The results of pipe tests involving only internal pressure are shown in Fig. 5. Specimens exposed to internal pressure and bending loading had circular notches of 4 mm depth. The experimental results for these specimens are shown in Fig. 6.

THE DISCUSSION OF THE RESULTS

The analysis of the results depicted in Fig. 5 shows that the circumferential destructive stress can be obtained from

$$\sigma = \sigma_B(1 - a/s) \qquad (1)$$

when the length of the crack or notch 2c considerably exceeds the thickness of pipe and the characteristic dimension $\sqrt{Rs}$, defining the defect influence zone for the pipe with diameter R. In this case the ultimate strength is that very criterion that defines the destructive strength of 18Cr-10Ni-Ti stainless steel with notches. The fact that circumferential destructive stress for Di-80 exposed to internal pressure agrees with that for specimens cut out of this pipe, gives an opportunity to use σ_B as the fracture criterion for Di-80. We should notice that the reduction of axial defect length increases the relative pipe strength especially for deep cracks. This can be probably explained by supporting influence of areas, that are close to the both edges of the defect. So the strength of the pipe with surface crack the length and depth of which is 2c and a respectively may be represented by the strength of the specimen which dimensions depend upon pipe and crack dimensions. Fracture criterion for steel piping at the elastic-plastic state can be formulated as :

$$\frac{\sigma}{\sigma_B} = 1 - \frac{a/s \cdot c/\sqrt{Rs}}{1 - a/s + c/\sqrt{Rs}} \qquad (2)$$

Fig. 7 shows the experimental results for Di-80 combined with those obtained by Henry and Bernard (1972) who had tested AISI

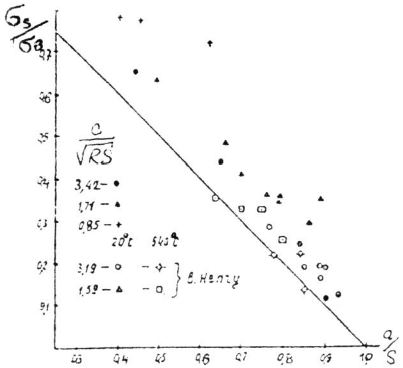

Fig. 7. The results of specimen and pipe tests

304 pipes with external diameter equal to 178 mm and the wall thickness of equal to 6.5 mm at room temperature and at 540 C. The results obtained by Henry and Bernard (1972) quite agree with ours. It makes it possible to state that at the working loading 0.2 σ_B and hydraulic test stress 0.3 σ_B the crack the depth of which does not exceed 0.7s does not reduce the piping strength. Moreover the comparison of the results of specimen and pipe tests (Fig.5 and 7) allows to make the preliminary conclusion that the estimated 18Cr-10Ni-Ti steel pipe strength at the presence of surface crack with the depth of a/s is 1.3 times more than that of the specimens with the same relative depth of notch.

Pipe specimen loading by internal pressure and bending loading gave considerable reduction in destructive pressure at low values of bending moment in comparison with the estimated nominal destructive pressure based on σ_B fracture criterion. This fact is probably connected with the great influence of the circumferential stress upon the strength of the pipes with the deep circular notches.

CONCLUSIONS

Fracture criteria for notched specimens and pipes with circular notches is shown to be based on ultimate strength σ_B. In the case of more complex loading (i.e. simultaneous loading of notched pipes with internal pressure and bending) σ_B criterion may lead to the overestimation of the residual strength.

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