BEND DURABILITY PREDICTION IN THE DESIGN AND OPERATION OF POWER PLANT PIPES

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ABSTRACT

This paper introduces a brief review of the works performed by the authors to predict piping bend durability and service reliability in power plants using statistics of service material characteristics and stresses. Prediction involved the application of mechanic-static models for crack growth kinetics and durability estimation taking into account pipe bend stress state, pipe steel short and long-term strength characteristics and ductility, resistance to cracking and working fluid induced corrosion. It is shown that a prior design estimate may be obtained by probabilistic modelling of reliability, proper material and production process choice, criteria and methods of in service pipe bend diagnostics. Results of probabilistic estimates are used to validate strength margins, calculated service characteristics and stresses allowable for a service life of 200000-300000 hours rated for power plant safety margins.

KEYWORDS

Durability, piping, probabilistic modelling , strength , ductility , fatigue and stress-corrosion crack.

INTRODUCTION

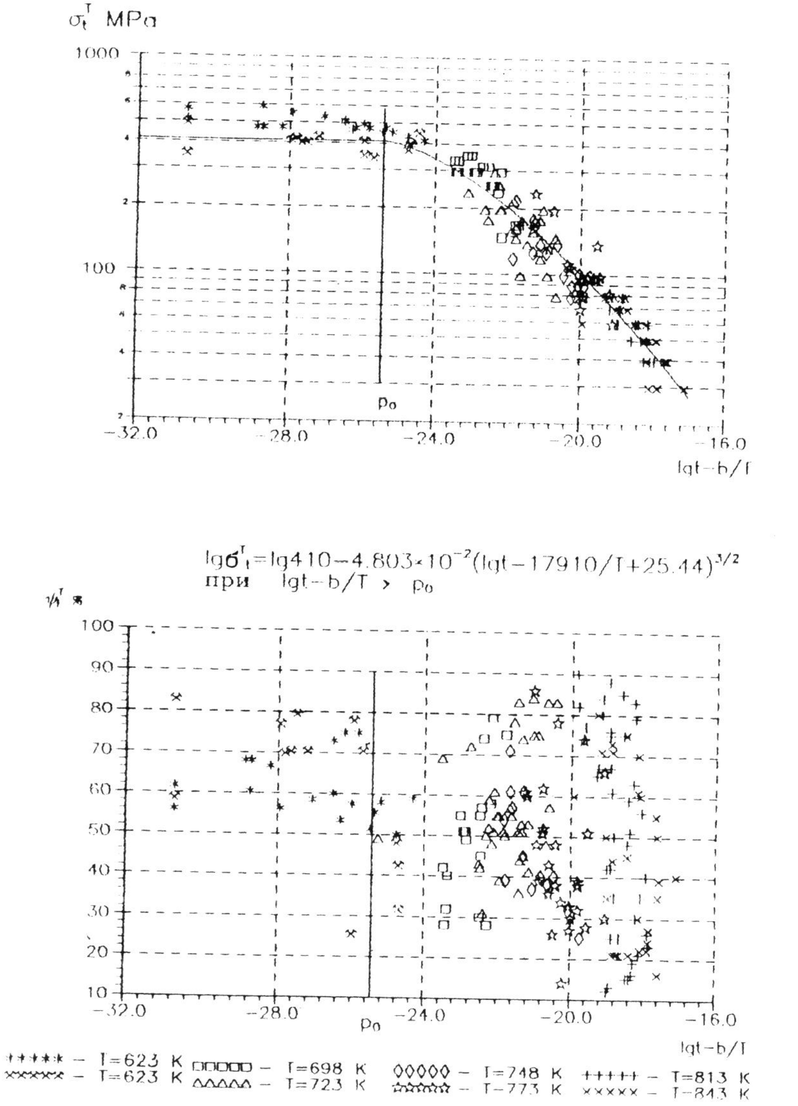
Piping bends are the most stressed and critical power plant components working under power loading and corrosion attack by working fluid. A large bulk of data on their performances, bench test results, statistics of working stresses and operation failures allows to use piping bends as representative objects for validating various durability and service reliability prediction methods in the design of power plant components. The probabilistic estimation seems to be the most efficient prediction method used here (Bolotin V.V.,1984,Machutov N.A.,1991, Novogilov V.V., 1988).

This paper presents a brief analysis of works based on probabilistics prediction in the design of piping bend reliability,proper choice of material, production process, criteria and methods of in-service diagnostics.

Results of works performed have been used to validate strength margins and criteria of operation reliability and to develop statistical methods of estimation of design strength and ductility properties and allowable stresses for boiler and piping materials with a rated service life of 200000-300000 hours,which are realized by now in current specifications (Adamovich V.K. et al., 1984, Adamovich V.K., Zverkov B.V.,1986).

RESULTS AND DISCUSSION

Mechanism of Temperature-Time Factor Influence on Material Strength and Ductility Materials Characteristics. Kinetics of damage accumulation in power plant components is largely determined by time and temperature effects on strength and ductility of materials used for component production. For type 20 steel,Fig.1 shows curves for long-term creep rupture (σ^T_t) and contraction of area (ψ^T_t) dependence on Dorn parameter (p=lgt-b/T ,



$$\lg\sigma^T_t=\lg 410-4.803\cdot10^{-2}(\lg t-17910/T+25.44)^{3/2}$$
при $\lg t-b/T>p_0$

Fig.1 Parametric dependence of long-term strength σ^T_t and contraction of area ψ_t for type 20 steel

t -time before fracture, T - temperature). The proposed curves represent characteristic time-temperature influence on material strength and ductility in power engineering equipment, that is confirmed by results of material tests and investigations in a wide range of varying internal and external factors (the alloying degree varying from carbon steel to nickel-based alloys, steel structure from ferritic to austenitic one with a volume fraction of strengthening phase changing from 0.01 to 0.4 , test time from a thousandth part of second to 80000 hours and exposure times under laboratory or working conditions from 1 to 200000 hours) (Adamovich V.K.,1969,1970,1989).

Three major intervals can be discerned on the curves in Fig.1: the interval I (p<p0), in which no remarkable time dependence of strength is observed, the interval II (p0<p<pt0), where early reduction of strength due to a time factor takes place and the interval III (p>pt0),in which a value of long-term creep strength decreases below a yield stress level ; hence allowable stresses are determined by long-term creep rupture. Ductility reduction in the first interval of transgranular fracture is caused by dynamic strain ageing,in the second and third intervals - by formation of wedge like cracks and cavities in grain boundaries respectively.

As shown by analysis of perfomance data (Antikain P.A., 1990, Nachalov V.A.,1983, Urvancev V.G.,1988, Minz I.I., Gakomoldina S.A.,1984, Stanukovich B.A.,1989) because of high stresses in intervals I and II , piping bend fracturability is significantly effected by a corrosion factor,which determines the intensity of crack initiation and growth at cyclic loading. In the interval III $(p>p_{to})$ piping bend fracture depends much on the rate of intergranular void accumulation of creep and low-cycle fatique , so the corrosion factor effect either decreases sharply or this effect is not remarkable (Adamovich V.K.,1975, Stanukovich B.A.,1986, Minz I.I., 1991).

For the service life of 100000 hours, parameters p_o and pto correspond to temperatures T and Tt which equal to about 573 K and 673 K for carbon, 623 K and 753 K for chrome-molybdenum and chrome-molybdenum-vanadium, 673-723 K and 773-823 K for austenitic steels respectively (Adamovich V.K. et al.,1981).

Fracture models. Following models to predict durability and service reliability of piping bends have been used :

1). Model V1 . Crack growth from surface flows during starts-up by a solution mechanism along with slip or film spalling in the crack tip (Ford F.P., 1989).

2). Model V2 . Crack growth as a result of oxide film rupture (Wellinger K.,1966).

3). Model V3 . Creep-accelerated crack growth (Stanukovich B.A.,1989).

4). Model V4 . Fracture accumulation due to depletion of long-term ductility at p>pto (Adamovich V.K.,1975).

Calculation Methods. In models V1,V2, and V3 a half-elliptical surface crack with a depth to half-width ratio, equaling to 0.1, has been used as hypothetical one. The ratio corresponds to the depth of specified flaw. Statistics of maximum elastic stress σ f max in pipe bends were derived from data of bulk measurements of cross-section area shape and full-scale wall thicknesses (Adamovich V.K., Perez I.M.,1979, Nachalov V.A.,1983). Relaxation of these stresses to a stress level 2 0 a, while correcting bend cross-section shape due to èlastic strain and creep has been taken into account in calculations. Pressure loading cycles (p) from zero to a maximum working value have been also considered. Estimates of stress σ f max and cyclic stress amplitude σ a have been made accounting for wall thickness change at bending and torus effect. The number of cycles N before the crack depth from the wall thickness becomes 0.4 in models V1,V2 and V3 and the time before fracture strain in model V4 have been considered as the design durability.The time before fracture strain in model V4 corresponded to operation and test data on long-term strength of full-scale bends (Adamovich V.K.,1975).

Data bank of NPO ZKTI short and long-term rupture strength tests of power equipment materials and also analytical and numeric probabilistic approaches have been utilized in calculations (Adamovich V.K.,1973, Adamovich V.K.,Perez M.,1980).

Comparison of Probabilistic Modelling Results with Operation Data. As is shown by operation data analysis, piping bend fracture is typically observed in the region of maximum stresses- on the outer surface of the extended section in the bend top and on the inner surface a little above the bend neutral.

At Dorn parameter value less than pt bend rupture is largerly caused by a corrosion factor that is produced by a contact of inner surface with water heat-transfer agent or by wetting external piping insulation. Probabilistic modelling results,consistent with service data show a considerable increase of crack growth rate (Fig.2) and crack lengths b(Fig.3) and appreciable reduction of durability (Fig.4) with yield strength and hardness increase above values 540-580 MPa and 160-180 HB respectively. Analysis of numeric calculations based on probabilistic models showed that strength improvement for bends made of type 20 steel was attributed to no tempering after cold bending,especially when pipes were normalized from rolling heating without control of final hot forming temperature. The calculated effect of accelerated crack growth because of creep and the transition from trans to intergranular cracking when crack depth achieves 2 mm also agree with investigation data on metal fracture on internal bend surface during operation at temperature 613 K (Stanucovich B.A.,1980).

Analysis of model calculations performed shows that bend fracture intensity reduction with a decrease of short-term strength is a result of stress relaxation σ f max to 2 σ a because of local elastic and creep strains (compare Fig.3a and 3b). Based on probabilistic modelling results and corresponding service data, it is found out that in the temperature-time interval under consideration (p<pt) the piping bend durability as to corrosion crack resistance criteria is by an order or more lower than the durability determined by low-cycle fatique criteria. According to probabilistic prediction data, enchancement of piping bend durability and service reliability can be provided by following measures: proper choice of material and production process that permit to reduce stresses σ a owing to bend metal strenath decrease, more stringent requrements to bend cross section sizes development of diagnostic procedures and techniques for in-service detection of bends with a raised level of 0 a. This is also in agreement with data of many-year operation expirience laboratory and bench test results (Nachalov V.A.,1983, Minz I.I., 1984, et al.).

In contrast to the above temperature-time interval, the dependence of durability and service reliability on pipe steel strength, which is derived from results of mechanic-static modelling for the high-intensive creep interval (p>pt0), is more complicated. For example, the design durability for type 12X1MФ steel decreases both in the interval of raised strength values (σ_b^{20}) 600-650 MPa) because of lower long-term ductility margins and in the interval of its raised values (σ_b^{20}< 450 MPa) due to lower long-term strength margins (Adamovich V.K.,1975), that is in a compliance with operation data (Adamovich V.K.,1976). Thus allowable design strains in straight bend sections depend on both strength properties and structural state of bend metal (after cold bending or with subsequent thermal treatmert, Fig.5).

Factors, revealed by probabilistics modelling and providing safe bend operation life, enable to develop special techniques for individual bend diagnostics during operation (investor' sertificates USSR N 832310 and 1566195 et al.).

In addition to optimizing methods of proper choice of materials and production processes ,diagnostic procedures and criteria, the probabilistic

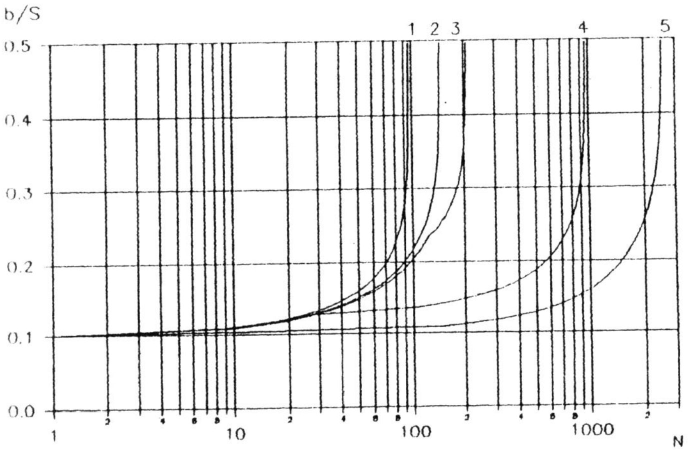


Fig.2 Kinetics of surface crack growth in type 20 steel bends
DxS=159x12 mm , p=15.2 MPa , t=613 K.
Model V1,V2,V3 calculation.
σ_b^{20}, MPa : 1 - 650 ; 2 - 600 ; 3 - 570 ; 4 - 550 ; 5 - 500

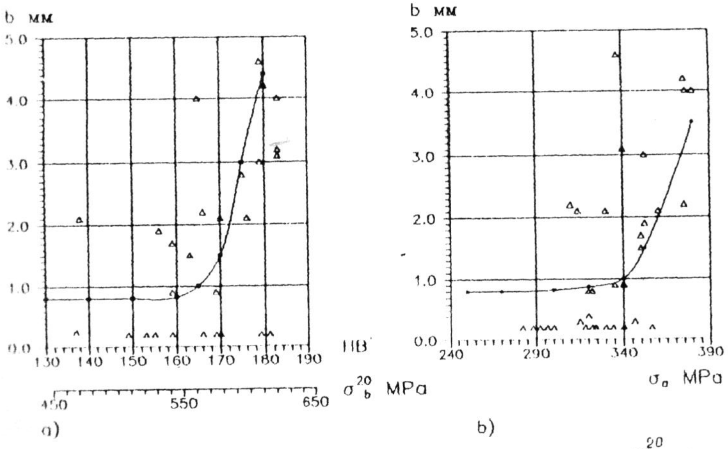


Fig.3 Dependence of crack depth on yield strength σ_b^{20} (a) and stress amplitude σ_a for type 20 steel bends DxS=133x8 mm , p=11 MPa, t=593 K, N=200, t=100000 hours
---- Model V1,V2 calculations for inner surface
Δ - Operation data , Urvancev V.G.,1988

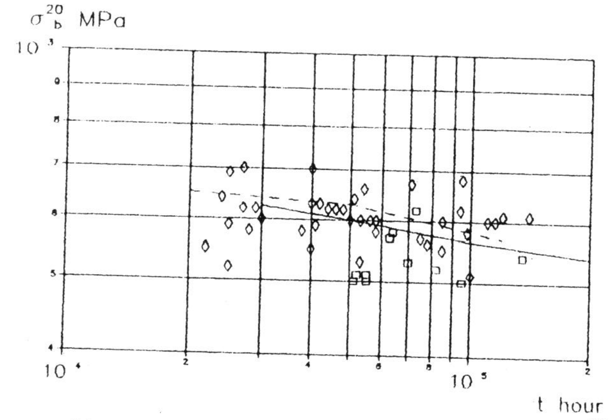


Fig.4 Time to failure vs yield strength σ_b^{20} for type 20 steel bends (DxS=159x12 mm , p=15.2 MPa, t=613 K)
---- Model V1,V2,V3 calculation for inner surface,
– – Model V2,V3 calculation for outer surface
◊,□ – Operation data (Minz I.I.,Zakomoldina S.A.,1984, Urvancev V.G.,1988, NPO ZKTI)
◊ – outer surface , □ inner surface

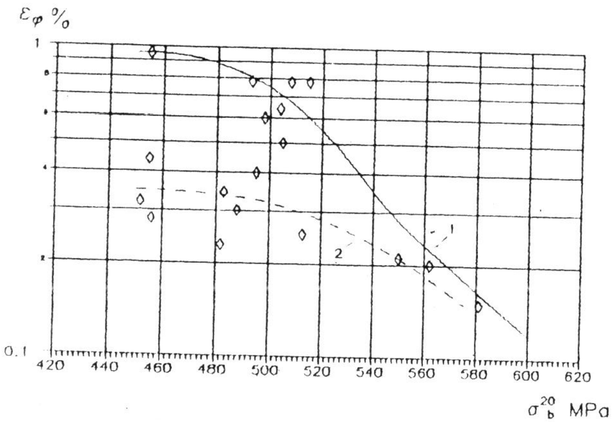


Fig.5 Yield strength dependence of allowable residual strains in straight sections of type CrMoV steel bends.
Calculations for thermally treated (1) and non-treated (2) bends
– operation data for thermally treated and non-treated bends.

modelling enables to design bend service reliability from statistics of material properties and working stresses along with the use of standard analytical or numeric estimates of their realization as a group. In this case results of probabilistic prediction are also in a satisfactory agreement with many-year operation experience data on both bend fracturing and distribution of actual strength margins and residual strains in straight pipe sections (Adamovich V.K.,Perez I.M.,1980).

CONCLUSIONS

Potential of mechanic-static modelling has been analyzed taking into account the working fluid corrosion effect and temperature-time factor in the predicting crack growth rates, fracture accumulation, piping bend safety margins, Validation of proper bend material and production process choice, diagnostic procedures and criteria. Results of a prior probabilitistic prediction agree well with piping bend service data.

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