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Calculated and experimental determination of permissible defect sizes in metal of repair welding

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ABSTRACT. The paper presents an approach to the assessment of permissible defect sizes in welded joints of pipelines from pearlitic low carbon steel,the repair of which was carried out with the use of austenitic welding materials. Also, the sizes and location of defects, which can be permitted after their detection for future operation without decreasing serviceability, were deterined.

1 INTRODUCTION

During the operation of pipilines Dy-752 of the repeated forced circulation circuit of NPP with RBMK-1000 and RBMK-1500 reactors there occurred some damages both at the earlier stage (before the planned preventive repairs) owing to technological defects during manufacture or assembly and after long-term operation (5 - 10 years) owing to operation effects (repeated loading, temperature and corrosion environment). As a rule, all such damages occurred in the area of weld joint, in a weld root, because of the violation of the welding procedures during the assembly of cladded low carbon steel. Because of their fast growth during operation the repair should be performed if the UST revealed the defect sizes exceeding 10 mm. CRISM "Prometey" has developed the technology to repair the damaged sections of pipelines,which includes identification of a zone with defects and its further welding up with austenitic welding materials. Therewith, the electrodes EA-395/9 (25% Nickel) with high margin of austenitic properties have been used for the first weld layer, and the electrodes EA-400/10Y (11% Nickel) - for the next ones. This technology has been successfully applied when repairing pipelines made from the low carbon steel 22K (Crezelso 330E and 19MN5) at the Sosnovyi Bor, Smolensk, Ignalina and Chernobyl NPPS. The pipeline components repaired according to the stated technology,have been operating for over 10 years. At the same time by repairing with austenitic welding electrodes (due to their decreased technological characteristics) the generation of defects is possible and very often it is necessary to solve the problem if they are permissible in operation. In this connection this study aimed at evaluating the permissible sizes of defects in the pipeline sections repaired by welding.

2 MATERIALS AND RESEARCH METHODS

As defects like cracks appeared, as a rule, in the weld root area close to anticorrosion cladding (Timofeev 1992), it was foreseen, during the repair at the assembly stage, to remove the weld outside throughout the pipeline thickness around the whole perimeter. The sequense of beading is shown in Fig.1. It is necessary to consider the distribution of residual stresses in the repaired joint as they, together with the working stresses from inner pressure, shall determine, the serviceability of pipeline. As it's seen in the sketch of the repaired weld joint,the joint is dissimilar and contains both pearlitic low carbon steel and austenitic welding and cladding materials dissimilar in their composition and properties and it should be certainly taken into account when evaluating the nature of residual stress distribution and service life during operation. Physical and mechanical properties of repaired weld joints are given in Table.

Experimental and calculation methods have been used to assess the permissible sizes of defects in repaired weld joints. As specified in the Ref (Karzov 1982), all three stages of defect development, namely the initiation of corrosion crack, its growth up to the critical size during the cyclic loading and damage at the maximum applied loading, have been taken into account. But the permissible defects sizes have been calculated only by considering the two latter stages (Rivkin 1989) and using the parameters of static and cyclic fracture toughness for materials of the stated weld joint taken from the other investigations. In experiments, using specimens with gauge cross-section of 25x20 mm, the effects of some defects (slag inclusions, lack of fusions with the sizes from 4 up to 20 mm) have been evaluated only at the stage of crack initiation. Tests have been performed on the scheme of rigid symmetrical loading with the frequency of 0.2 - 0.5 Hz. The consideration of this stage, makes it possible to evaluate the lower boundaries of the band of spattering of low cyclic fatigue resistance of the given weld joint containing technological defects of various types. Using such conservative dependence in calculations, we'll have safety margin on lifetime.

3 MAIN RESULTS AND THEIR DISCUSSION

Experimental data (Petrov 1994) concerning the influence of defects in repaired weld joints on low cycle fatigue proved that practically they do not affect lifetime (Fig.2). In some cases even in the presence of slag inclusions, oriented perpendicular to the direction of the applied load, fracture took place on base metal,and consequently for a given welded joint it is unnecessary to introduce the the coefficient of fatigue strength reduction even in the presence of technological defects.

The calculation scheme to determine the reliability of welding repair of defects involves the calculation of critical defect sizes (depth $a_{cr}$and length b_{cr}) in conformity with various operation conditions. The permissible defect sizes are equal to:

$$[a] = [a]_i - \Delta a,$$
$$[b] = [b]_i - \Delta b,$$

where $[a]_i = a_{cr}/n_a$ and $[b]_i = b_{cr}/n_b$ (n_a, n_b - safety margins for defect depth and length);
Δa and Δb - defect growth in depth and length for the operation period.

The critical defect sizes are determined by means of interpolation, the two-criteria, approach R6 as well as by the method of the ultimate state - plastic collapse. Moreover, in all cases, except the latter, it's necessary to have a distribution of residual welding stresses. Welding stresses have been calculated by FEM by solving the problem of thermoelastic ductility for the conditions of welding process simulation during repair. The distribution character of residual welding stresses in the repair zone is given in Fig.3. The given information shows that the highest stresses are acting in the circumferential direction on the weld centre close to the outer surface of the pipeline. The value of such stresses exceeds the yield strength of weld metal (σ_b= 600 MPa, YS = 416 MPa).

At the pipeline inner surface the residial stresses, though being tensile ones, are by 2 times lower, than at the outer surface The level of residual welding stresses in the zone where defects like lack of fusion and cracks are the most probable, namely fusion lines of pearlitic base metal and austenitic weld, is lower as it's shown in Fig.3. The highest welding stresses are acting in the axial direction in the vicinity of the outer pipeline surface (σ_z= 390 MPa,YS = 456 MPa),circumferential stresses are slightly lower and equal to 340 MPa.

Having the information about residual and operating stresses under maximum design loading, equal to 200 MPa,the critical defect sizes by statical loading and their growth (Δa,Δb) have been calculated for the whole survice life under transient operating conditions (1000 cycles) with the predetermined amplitude of cyclic stresses which took into consideration both operating and technological stresses. The value $a_0$equal to 2-4 mm,i.e. the height of the welded metal bead during manual electroarc welding has been adopted as the initial defect size. The calculation results of the critical defect on two criteria sizes are given in Fig.4. Here it is shown the range of permissible defect sizes (height) which could be accepted without correction.

The minimum sizes have been taken from the critical defect sizes calculated for various zones of the repaired weld joint. The calculation proved, that the most dangerous are the defects repaired in the circumferential direction. The critical sizes of defects, located in base metal (near weld zone), are smaller than those located in the other zones of weld joint (facing layer performed with the electrodes EA-395/9 and weld performed with the electrodes EA-400/10Y). It's due to the fact that fracture on HAZ metal of of low carbon steel has,as a rule,a quasi-brittle nature.

When selecting the permissible defect sizes, besides the knowledge of initial and critical defect sizes, and determination of their size increments during the operation period, the safety factor has to be established. In this case along with the calculated and experimental data, sensitivity of the applied inspection methods,as well as the level of technological discipline and defect location shall be taken into account. The permissible defect sizes have to be not less than the sensitivity threshold of the applied method,which are multiple to it. The defect with the permissible sizes [a] = 4 mm and [a]/[b] = 2/3, and by the consideration of the ultrasonic method on sensitivity [a] = 4 mm and [b] = 15 mm meet these requirements for the considered repaired weld joint of the pipelines Dy-752 (wall thickness 38 mm). The results presented in Fig.5 prove clearly this fact.

4 CONCLUSIONS

1. In repaired weld joints defects like slag inclusions and lacks of fusion of the sizes up to 4 mm don't pratically effect serviceability under cyclic loading.

2. Permissible sizes of defects for dissimilar weld joints (pearlitic steel and austenitic repaired weld) shall be determined on a less alloyed component of the joint, i.e. on pearlitic steel.

3. For the considered type of weld joint of the pipeline Dy-752 the size of a permissible inner defect after repair is 4 mm on depth and 15 mm on length.

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Table

Physical and mechanical properties of repaired weld joints

Material	T °C	UTS MPa	YS MPa	A, %	Z, %	$\alpha \times 10^{6}$ K^{-1}	$E \times 10^{5}$ MPa	λ	Cp, KJ/Kg/K
Steel Creselso 330E	20	548	290	29.1	63.0	12.5	1.99	55.0	0.48
	100	520	280	-	-	13.0	1.87	52.0	0.49
	200	500	255	-	-	13.8	1.76	50.0	0.50
	350	478	220	30.6	62.0	14.2	1.62	45.0	0.52
Weld metal EA-400/10У	20	637	416	42.6	60.8	15.0	1.94	-	0.46
	100	610	400	-	-	16.0	1.84	15.0	0.47
	200	570	390	-	-	16.5	1.78	17.2	0.49
	350	515	380	38.0	59.7	17.0	1.70	18.9	0.50
Weld metal EA-395/9	20	670	456	35.0	58.0	16.3	1.91	-	0.51
	100	650	440	33.0	57.0	16.3	1.87	15.0	0.51
	200	610	430	32.0	57.0	16.5	1.79	16.8	0.52
	350	590	380	31.0	56.0	17.0	1.76	18.4	0.53
Anticorrosive cladding ЗИО-8	20	600	380	28.0	51.0	15.5	1.91	15.0	0.47
	100	580	360	-	-	15.8	1.87	16.0	0.49
	200	540	340	-	-	16.0	1.81	18.0	0.54
	350	500	310	21.0	42.0	16.7	1.69	19.0	0.53
Anticorrosive cladding EA-898/21B	20	620	390	25.0	58.0	15.6	1.87	-	0.48
	100	590	380	-	-	16.2	1.82	15.0	0.49
	200	550	370	-	-	16.6	1.76	17.0	0.52
	350	490	350	25.2	50.7	17.1	1.71	18.5	0.54

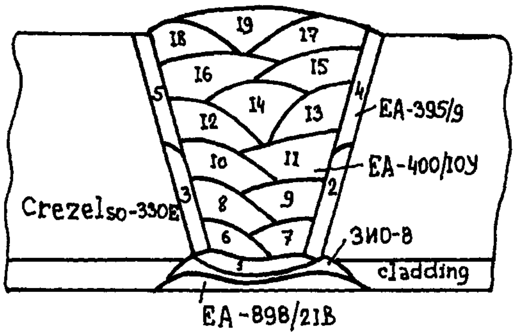

Fig.I.

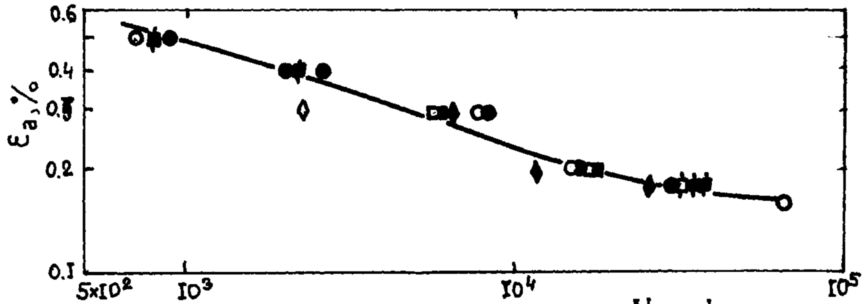

Fig.2.

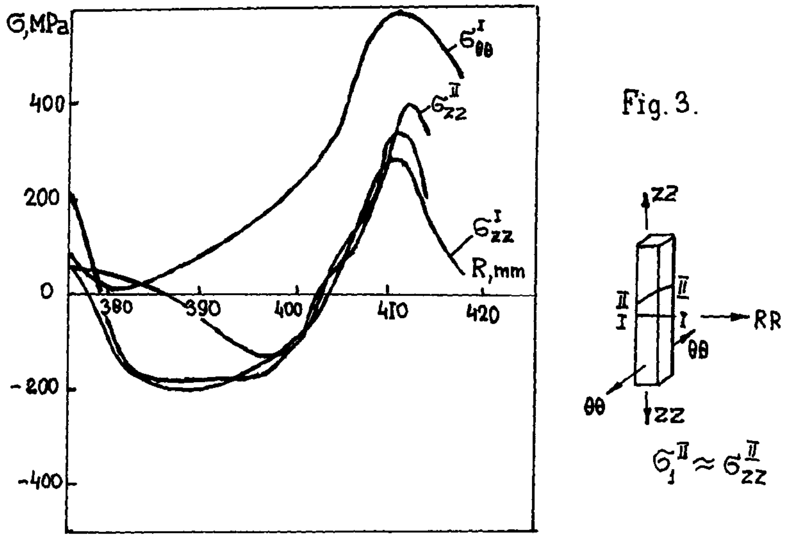

Fig. 3.

Fig.1. Sketch of repair welded joint with anticorrosive cladding.

Fig.2. Low cycle fatigue resistens of austenitic repair weld:
○,● - without defects;□,■- slag inclusions (from 3*1.5 and 12*6 mm),
◊,♦ - a set of lacks of fusion between the cladding and weld metal.

Fig.3. Distribution of residual stresses in repair zone for two section on weld metal and HAZ.

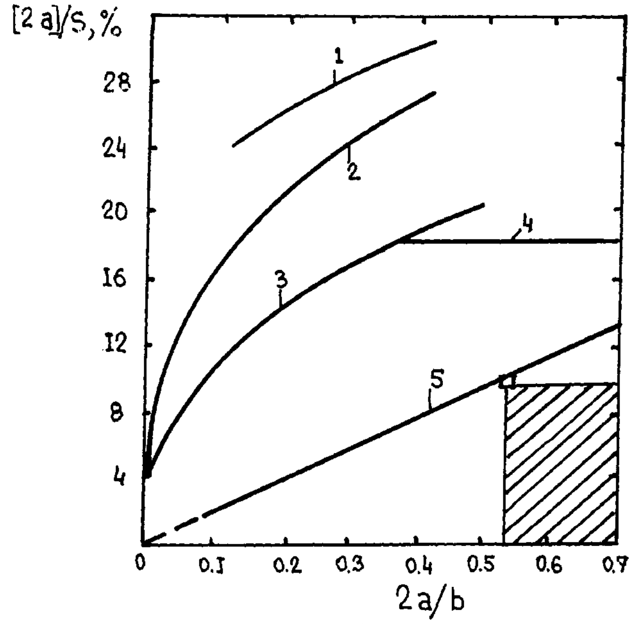

Fig.4.

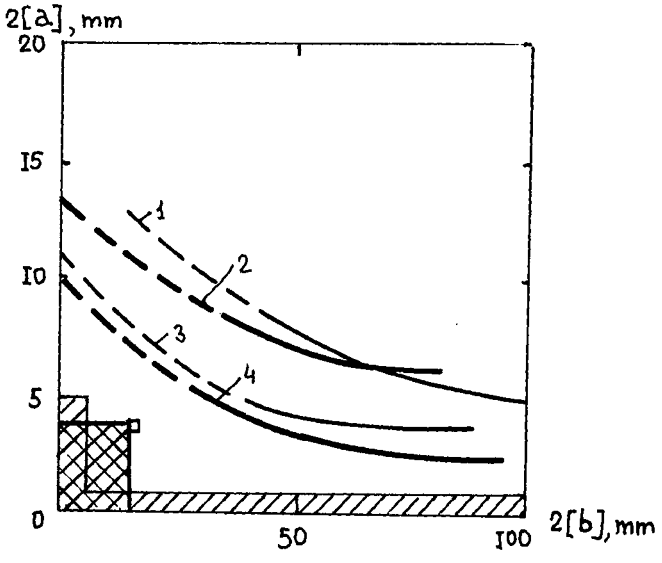

Fig.5.

Fig.4. Permissible defect sizes for repair welds of the primary circuit piping of NPP with RBMK reactor: 1,4-interpolation criterion (base metal 270°C and 20°C); 2,3 - ultimate plastic state criterion weld and base metal, 270°C; 5 - the dependence [2a]/S on the correlating of semiaxes L_{ca}= 15 mm;///-the range of permissible defects [2a] ⩽ 4 mm and L_{ca}= 15mm.

Fig.5. Permissible defect sizes at 270°C:1,3-Creselso-330E,Δσ=200,400 MPA, 2,4 - weld metal,the type EA-400/10Y electrodes ,Δσ=200 and 400 MPA, /// - the range of the sensitivity threshold of the method ; \\\ - the range of permissible defects for [2a] ⩽ 4mm and L_{ca}= 18 mm.