DOI: http://dx.doi.org/10.15407/tpwj2018.05.05

APPLICATION OF LEAK BEFORE BREAK CRITERION FOR PREVENTION OF AVALANCHE FRACTURE OF THE WALL OF VERTICAL WELDED TANKS

A.Yu. BARVINKO, Yu.P. BARVINKO, A.N. YASHNIK and **V.N. MIRYANIN**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

The paper deals with the possibility of improving the performance of oil storage tanks of 50–120 thou m^3 capacity through application of normalized sheet steel 09G2SYuch-U390 and 09KhG2SYuch-U440 for design rings of tank wall. A relationship between the length of through-thickness fatigue crack in the butt welded joint of the studied steel and number of tank loading cycles was derived experimentally under the conditions of plane deformation at the initial stage of through-thickness crack propagation. Based on the obtained relationship, it was established that after formation of a through-thickness crack in the welded joint of the wall and appearance of oil leakage, there is sufficient time and conditions for its visual detection and taking measures for elimination of the detected defect. The possibility of application of this method to detect the through-thickness crack is proof of the fact that tanks with design rings from the studied steel satisfy the leak before creak criterion. 19 Ref., 5 Tables, 4 Figures.

Keywords: *oil storage tanks, fatigue crack, cyclic loading, butt welded joint, avalanche fracture, leak before break criterion*

Development of industrial production requires constant increased attention to environment protection. This publication shows in the case of construction of tanks for storage of oil and oil products (V = 50–120 thou m^3) the possibility of improvement of environmental safety of these facilities by prevention of development of avalanche fractures in welded joints of the wall at application of normalized sheet steel of C390, C440 strength class with lower carbon content for design rings. In keeping with Ukrainian standards [1], the above facilities belong to the highest criticality class CC3, that is taken into account by introducing the reliability factor γ_r = 1.25 into the strength condition. Alongside strength increase, seismic impact accounting standards at construction of new facilities were made more stringent. In the standards [2], some regions of the Carpathian mountings and Odessa region have the seismicity of 8–9 points with the middle (second) category of soils in the construction site, and one point higher at higher category, respectively. Alongside the above provisions, the standard [3] was complemented by an additional requirement for tanks with a protective wall: design of working tank wall should prevent the possibility of its avalanche fracture. Requirements to the quality of rolled sheets and their welded joints were increased. Ultimately, the adopted changes and additions to the normative acts are aimed at ensuring the normative efficiency and ecological safety of the constructed tanks during their entire design operating life. One of the main issues at achievement of the requirements made is ensuring the high performance of butt welded joints of the wall.

New quality normalized steels of C390 and C440 strength class for critical building structures have been developed and put into industrial production in recent years. Assessment of the correspondence of their mechanical characteristics to the requirements of valid standards on tank construction, performed by the E.O. Paton Electric Welding Institute of the NAS of Ukraine (PWI), allowed finding and proposing new approaches to solving a number of issues on improvement of the wall performance. Table 1 also gives the main characteristics of rolled sheets 16–40 mm thick of 390, 440 strength class, recommended by the USA, EU and Ukrainian standards [3–6] for the main metal structures of tanks of 20–120 thou m^3 capacity. The main requirements of the standards for sheet steel are also given there: sheet delivery condition, carbon content, impact toughness KCV_{-40}, σ_y/σ_t ratio.

One can see from the Table data, that API 650 standard [4] presents two steels: A537 and A678 with delivery of quenched and tempered (QT) sheet. Steels meet all the requirements, except for rather high carbon content: 0.24; 0.20 %. Eurostandard is represented by steels after normalizing rolling C420 and C460 [5] with carbon content of 0.18–0.22 % and σ_y/σ_t ratio equal to 0.81–0.62 at not more than 0.75 norm [3]. The Table also gives an example of application of normalized steel 18G2AV/E440R-N, improved by ladle treatment (LT), for the wall of 75

Table 1. Recommended steel grades for the main metal structures of large capacity tanks in keeping with USA, EU and Ukrainian standards

Name of the standard for tank design (country of the standard validity)	Designation of recommended steel, sheet thickness	Normative document for steel delivery	As-received condition*	Carbon content, % (max)	σ_y, MPa	σ_t, MPa	δ_5, %	*KCV* in keeping with normative document for steel delivery, J/cm²/T_{test}, °C	σ_y/σ_t
API 650 11th edition (USA)	A537M class 2, C415, $t \le 45$ mm	Specification ASTM A537/A537M	Q/T	0.24	415	550–690	22	34/–68	0.75–0.60
	A678M grade B, C415, $t \le 45$ mm	Specification ASTM A678/A678M	Q/T	0.20	415	550–690	22	34/–68	0.75–0.60
	A841M grade B class 2, C415, $t \le 40$ mm	Specification ASTM A841/A841M	TMCR	0.15	415	550–690	22	34/–68	0.75–0.60
EN 1993-4-2:2007 EN 14015:2004 (EC countries)	EN 10025-3-S420N, C420, $16 < t \le 40$ mm	EN 10025-3:2004	N	0.22	420 400	520–680	19	25/–20	0.81–0.62
	EN 10025-3-S420NL, C420, $16 < t \le 40$ mm	EN 10025-3:2004	N	0.22	420 400	520–680	19	34/–20 25/–40 20/–50	0.81–0.62
Steels not included into the list of recommended ones, but which are applied in tank construction	18G2AV/E440R-N, C440, $16 < t \le 30$ mm	PN-86/H-84018	LT, N	0.20	430	560–720	18	83/–40 — factory certificate data	0.77–0.60
	06GB C390, $8 < t \le 50$ mm	TU Y 27.1-05416923-085:2006	LT, Q/T	0.08	390	490	22	123/–40 98/–60 74/–70	0.80
	06G2B C440, $8 < t \le 50$ mm			0.08	440	540	22		0.81
	09G2SYuch-U C390, $8 < t \le 50$ mm	TU 14-1-5065:2006 Modification No.1 of 01.03.2012	LT, N	0.13	390	530	18	60/–40 30/–70	0.74
	09G2SYuch-U C440, $20 < t \le 32$ mm C440, $32 < t \le 60$ mm			0.11	440 410	590 570	18	60/–40 30/–70	0.75 0.72

*Designations of as-received condition of steel: Q/T — quenching plus tempering; LT — ladle treatment; TMCR – thermomechanical controlled rolling; Q/HT — quenching with high tempering; N — normalizing; TH — thermal hardening.

thou m³ tanks [7]. After improvement, KCV_{-40} values were equal to not less than 96 J/cm² that is almost two times higher than the initial values. Ukraine is represented by 06GB rolled sheets with $\sigma_y/\sigma_t = 0.90–0.85$, delivered in QT condition, and two normalized steels 09G2SYuch-U390 and 09KhG2SYuch-440 [8] with carbon content of 0.11–0.13 % and σ_y/σ_t ratio of not more than 0.75.

Steels 09G2SYuch and 09KhG2SYuch [9] were developed in 1982-1984 by PWI initiative, together with Metallurgical Works «Azovstal» (Ukraine) and «Severstahl» (Russia). Sheet steel 09G2SYuch was developed at the first stage. By its properties it should correspond to general purpose steels and should be an alternative of steels 09G2S, 16GS, 20K in fabrication of high pressure vessels. The main requirements to the new steel were higher strength (390 class), high cold resistance ($KCV_{-40} \ge 60$ J/cm²), low sensitivity to overheating at electroslag welding of 40–120 mm thick sheets. Development of the new steel was based on low-alloyed general-purpose steel 09G2S. The advantages of the new steel were ensured by its optimum alloying and production technology: increased manganese content, additional alloying with aluminium and cerium, in combination with ladle treatment. The process of new steel development, its production technology and results of its successful application for manufacture of high pressure welded vessels of 40–110 mm thickness are quite fully described by the steel developers in [10]. The achieved positive effect of application of steel 09G2SYuch allowed the authors to optimize its composition further on by additional alloying of steel with approximately 1 % chromium. New steel 09KhG2SYUch of C440 strength class [11] was produced. Increase of chromium content in the steel significantly increased its impact toughness, improved its strength and cold resistance in the heat-affected zone (HAZ) at electroslag welding that allowed replacing post-weld normalizing of the vessels by high tempering [10, 11]. New steels of improved modification have been designated 09G2SYuch-U and 09KhG2SYuch-U, 390 and 440 strength classes, and they were produced to TU specification [9]. In 2011, by the initiative of PWI and FGUP «I.P. Bardin TSNIIchermet» Modification No.1 to this specification was developed that allowed achieving mechanical properties of steels [8] in full compliance with the requirements of standards [3–5] for tanks for storage of oil and oil products.

In [12] it is shown that high ductility properties of normalized sheet steel 09G2SYuch-U allow eliminating high tempering of assemblies for tapping branch pipes and manholes at tank wall thickness of up to 30 mm, and detecting through-thickness fatigue cracks at the initial stage of their propagation with application of leak before break criterion. In this publication, based on the results of performed experimental studies of welded joints of normalized sheet steel 09KhG2Syuch-U, including base metal, it is shown that similar capabilities are also available in the tank wall at application of this steel for design rings.

In Ukraine steel production in keeping with the specification [8] has been mastered by MW «Azovstahl», and PWI developed welding technology provides their mechanical properties on the level of those of base metal. Standard values of impact toughness of rolled sheets are $KCV_{-40} \geq 60$ J/cm^2 for 20–32 mm thickness. At delivery of sheets t = 26 mm of steel 09G2Yuch-U for two tanks of 50 thou m^3 capacity, KCV_{-40} certificate data were not lower than 148 J/cm^2.

The need for additional technical proposals for guaranteed prevention of avalanche fractures of welded joints of the wall of inner tank (for tanks with a protective wall) in the standard [3] is the consequence of the arisen need for construction of a considerable number of such tanks of 50–100 thou m^3 capacity. Elimination of dyking around the tanks in the absence of actual data on fulfillment of this function by the protective wall, necessitated envisaging additional measures on improvement of performance of the wall of the main (inner) tank. Allowing for new requirements of the normative documents, this work gives an analysis of the results of research performed at PWI of the possibility of prevention of avalanche fractures through application of leak before break criterion for design rings of the wall of tanks of 20–120 thou m^3 capacity at application of normalized rolled sheets of steel 09Kh2SYuch-U.

Theoretical fundamentals of the possibility of elimination of avalanche fracture of the wall in metal tanks for liquid storage by its outflowing from the formed crack are given in [13], and an overview of the current status of this issue — in [14]. Work [13] deals with a surface fatigue crack of approximately 2t length, which grows during cyclic loading, and reaches the wall opposite side. A leak of the stored liquid through the through-thickness crack develops, that allows visually detecting the defect. It is important to have enough time to detect the formed through-thickness crack before it has reached its critical size, and to take measures to eliminate the detected defect, i.e. prevent the avalanche fracture. Such an elimination of avalanche fracture was called «by the leak before break» criterion. In [14] it is noted that the literature data do not give sufficient information on the considered criterion as regards its application in tanks for storage of oil and other structures. In each individual case special experimental studies should be performed.

Reference [12] gives the results of investigation of welded joints of steel 09G2SYuch-U and their testing program. Considered investigations of welded joints

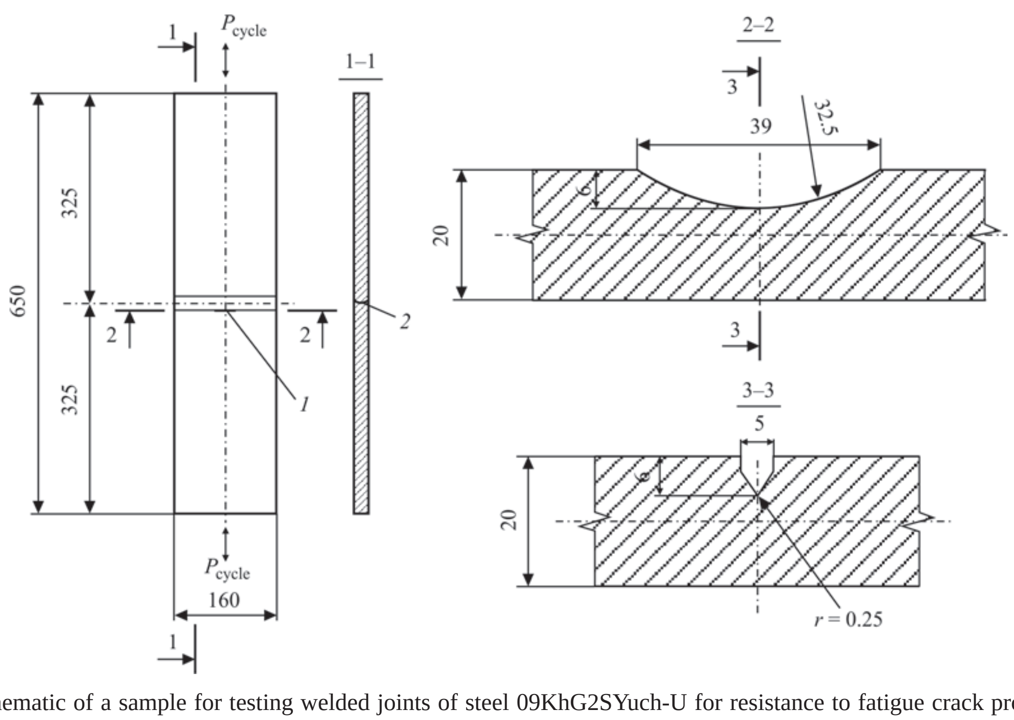

Figure 1. Schematic of a sample for testing welded joints of steel 09KhG2SYuch-U for resistance to fatigue crack propagation: *1* – notch in the HAZ; *2* – weld reinforcement was removed on both sides

Table 2. Chemical composition of studied steel 09KhG2SYuch-U, wt.%

Steel grade	C	Si	Mn	Cr	Al	S	P	Cu	Ni
						Not more than			
09KhG2SYuch-U TU 14-5065-2006 (modification No.1)	0.10–0.13	0.50–0.80	1.9–2.2	1.0–1.30	0.04–0.08	0.030	0.030	0.30	0.30
09KhG2SYuch-U (studied)	0.10	0.50	1.84	0.96	0.03	0.002	0.002	0.05	0.12
09G2SYuch-U TU 14-5065-2006 (modification No.1)	0.08–0.11	0.30–0.60	1.9–2.2	Not more than 0.30	0.04–0.08	0.030	0.030	0.30	0.30
09G2SYuch-U (data from [12])	0.11	60	2.1	0.11	0.08	0.011	0.015	0.05	0.21

of steel 09KhG2SYuch-U were also performed by this program with addition and allowing for some features of the tested steel. The program included testing at cyclic loading of three samples with a transverse butt weld (Figure 1). Transverse butt weld simulated the vertical butt weld of the joint of 20 mm wall sheets with K-shaped groove. The composition and mechanical properties of sheet steel 09KhG2SYuch-U are given in Tables 2, 3. When making the weld, the root pass was welded with LB52U electrodes of 2.5 mm diameter, and filling passes — with FOX EV63 electrodes of 3.0 mm diameter. Cooling rate $w_{5/6}$ was equal to 10–15 °C/s. KCV_{-40} values in as-welded condition were equal to: 113.5–116.5 (fusion line) and 104.9–156.7 J/cm^2 (weld metal). For comparison the Tables give similar data for steel 09G2SYuch-U from [12].

The objective of the research consisted in establishing a relationship between the crack length and number of cycles of tank filling-emptying in the initial section of formation and propagation of a through-thickness fatigue crack in the vertical butt welded joint of steel 09KhG2SYuch-U of the tank wall and showing that the obtained relationship of fatigue crack propagation in the wall of an oil-filled tank allows safely detecting a fatigue crack by leak before break criterion before fracture, and timely taking measures on liquidation of the defected defects.

Maximum force P_{max} of cyclic loading of the sample was assumed, taking into account that the stress in the sample $\sigma = 2/3\ \sigma_y$ of steel, and $P_{min} = 0.1P_{max}$. Stress 2/3 σ_y corresponds, according to [3, 4], to maximum design hoop stresses in the tank wall. Actual dimensions of the cross-section were allowed for in each sample. Initiation of a fatigue crack along the fusion line was induced by application of a sharp notch of more than 6 mm depth and 39 mm length (Figure 1). During its growth through the wall thickness, according to fatigue fracture diagram (FFD) (see Figure 2), the macrocrack passed the section of its stable development, moved to the unstable propagation section, and reached the opposite side. The latter section of critical propagation of a through-thickness crack under plain strain conditions (Figure 3, *a*), is characterized by a high rate of its propagation (see Figure 2). In the used samples the length of this section is limited by the extent of plane strain zone. One can see from Figure 3, *b*, that after the crack has reached the length of approximately 35 mm, lines of steel contraction across the thickness (of the type of moiré fringes) appear at its tips that is indicative of transition of metal ahead of the crack into the plain stress state. This is the consequence of σ_{max} value abruptly becoming close to σ_y value of steel at reduction of the area of the sample net cross-section. Development of the surface fatigue crack in the vertical welded joint on the real tank wall will proceed at an actually constant level of hoop stresses, right up to the formed through-thickness fatigue crack reaching its critical length $l_{cr} = 2a_{cr} \approx 250$–300 mm. For this testing it is important for the process of initial growing of the crack through the thickness, its reaching the opposite surface of the sample and the initial stage of through-thickness crack propagation under the conditions of plane strain to be largely similar to running of this process in the

Table 3. Mechanical characteristics of rolled sheets of steel 09KhG2SYuch-U440 23 mm thick

Number	Melt number	Sheet thickness, mm	σ_y, MPa	σ_t, MPa	δ_5, %	ψ_z, %	σ_y/σ_t	KCV_{-40}, J/cm^2
1	Studied steel 09KhG2Yuch-U	23	472.1 472.9	768.6 768.2	22.5 22.7	47.8 41.0	0.61	205.0/135.7** 196.4/100.1** 199.0/121.1**
2	To TU 14-1 5065-2006 Modification 1. Delivery type: normalizing 09G2SYuch-U	20–32	440	590	18	–	≤ 0.75	60 not less than
3		20–32	390	530	18	–	≤ 0.75	60 not less than
4	09G2SYuch-U* Data from [12]	20	415	550	29	56	0.75	156

*Data for steel 09G2SYuch-U390 are given for comparison. **Transverse/longitudinal samples. 1. Steel is subjected to ladle treatment with argon purging. 2. Weight fraction of cerium in steel should be within 0.001–0.050 %. 3. Ce content in the studied steel is 0.004.

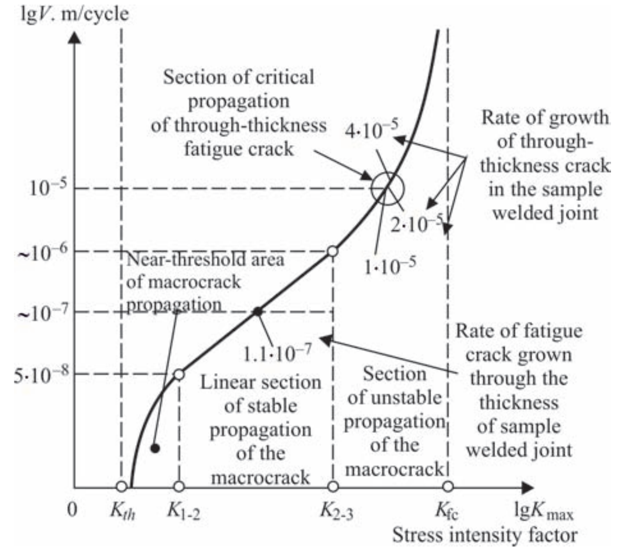

Figure 2. Sections of macrocrack propagation on fatigue fracture diagram [15]

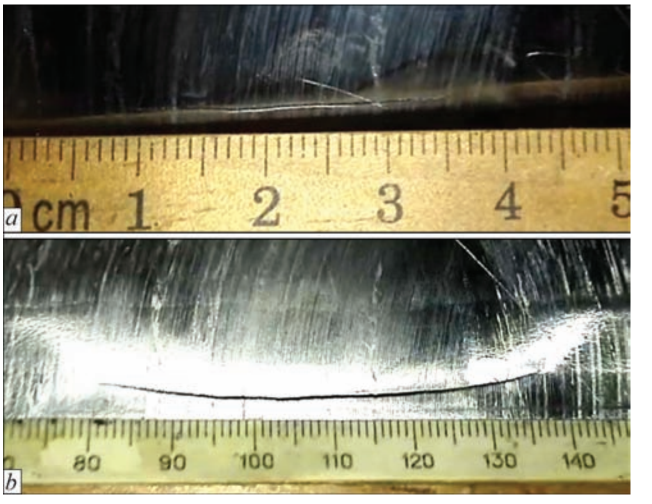

Figure 3. Fatigue crack propagation: growth under plane strain conditions (*a*) and formation of steel contraction across the sample thickness at the tips of through-thickness crack at its length $2a \geq 35$ mm (*b*)

welded joint on the tank wall. The accepted condition can be fulfilled at performance of 100 % ultrasonic (UT) (radiographic) testing of the length of vertical design welds on the tank wall.

Results of measurements of the number of loading cycles and respective values of the surface crack length are given in Tables 4, 5.

Table 4 shows that at the initial notch length ($l_{in.surf.cr}$) of 39 mm, at the moment of through-thickness crack formation the length of surface ($l_{fin.surf.cr}$) crack was equal to 53 mm. «Whiskers» formed on both sides (Figure 4) had the length of 6–7 mm. Moment of through-thickness crack formation was preceded by appearance of surface instability along the line of the crack reaching the surface. The zone of crack propagation was under plain strain condition. On the sample mirror surface elastic wave deformations were observed along the line of its appearance at each cycle of opening of the approaching crack. The through-thickness crack formed as a rupture of 5–7 mm length ($l_{in.thr.cr}$). Release of potential energy accumulated in the sample with stopping of crack propagation occurred at 5–7 s. that is equal to 20–30 loading cycles. This was followed by the start of the process of growing of the length of already through-thickness crack up to critical size for this sample. This is the time of action of the leak before break criterion. As noted above, this time is limited on the sample also by the extent of plane strain zone. Data given in Tables 4, 5 on propagation of a crack from the notch and propagation of the through-thickness crack can be regarded as two successive stages. Given below is brief analysis of the data in Tables 4, 5 as regards propagation of the considered defect in the welded joint of steel 09KhG2SYuch-U.

First stage. According to the data in Table 4, the fatigue crack along the entire length (39 mm) of the sharp notch (Figure 1), initiated at the number of cycles $N_{init.surf.cr}$ = 10.3 thou (average from three samples). Taking into account the assumed safety factor for the loading cycle number n_Z = 10 [16], we have 1000 cycles. At the annual number of tank filling-emptying cycles N_{an} = 100 [3], we have 10 years. At the assumed periodicity of technical and expert examination of tanks (5 and 10 years) [17], such a defect should be detected visually or at performance of ultrasonic testing and repaired. If the initial crack is overlooked, it will continue to propagate in the direction of wall (sample) thickness. One can see from Table 4

Table 4. Dependence of length $2a$ of through-thickness crack from the side opposite to the notch, on the number of loading cycles N (steel 09KhG2SYuch-U440, t = 200 mm)

Sample number	Steel grade, conditions of making the welded joint	Initial crack length $2a$, mm, N = 0.00	Number of loading cycles N						
			100	150	200	250	300	400	600
			Length of through-thickness crack $2a$ (mm), allowing for initial length						
1	09KhG2SYuch-U, normalized	7	10	–	14	–	6	20	26
2		7	10	–	14	–	16	18	20
3		4	8	–	12	–	14	15	17
4	09G2SYuch-U390*, normalized	8	10	11	12	11	14	20	25
5		10	12	–	14	–	16	20	30
6		12	14	–	18	–	24	27	32

*Data on steel 09G2SYuch-U390 are given for comparison.

Table 5. Dependence of the length of surface fatigue crack in butt welded joint on the number of loading cycles (steel 09KhG2SYuch-U440, t = 20 mm)

Sample number	Steel grade	$N_{surf.init.cr}$, thou	$l_{in.surf.cr}$, mm	$N_{thr.cr}$, thou	$l_{fin.surf.crf}$, mm	$l_{in.thr.cr}$, mm
1	09KhG2SYuch-U440, normalized	10200	39	8100	53	7
2		10500	39	11800	53	7
3		7500**	39	13500	51	4
4	09G2SYuch-U390*, normalized	12100	41	11400	61	8
5		13300	38	9400	56	10
6		14600	47	5800	56	12

*Data on steel 09G2SYuch-U390 are given for comparison. **Technical stoppage of the machine occurred with re-starting and going into the mode.

that about 11.4 thou loading cycles $N_{thr.cr}$ are required up to formation of a through-thickness crack. At the initial depth of the fatigue crack of 2 mm the rate of crack growth by depth was equal to $1.1.10^{-7}$ m/cycles. One can see from FFD (see Figure 2) that the growing process occurred in the section of stable crack propagation at constant increase of growth rate. Here there is also the possibility of timely visual detection of the crack at tank wall examination. Analysis of the process of initial development of fatigue crack in the welded joint of steel 09KhG2SYuch-U shows that presence of the crack through the entire wall thickness can be the consequence of only gross violation of the periodicity of tank examination, or its poor performance. Figure 4 shows a fatigue crack formed before reaching the opposite side from the notch tip, and its propagation in the form of «whiskers» at the notch tips.

Second stage. Table 5 gives the data of increase of the length of a through-thickness crack formed in the welded joint of the sample under plane strain conditions. Judging by the rate of its propagation on FFD (see Figure 2), this is the final stage of unstable propagation of a fatigue macrocrack. As noted above, the length of plane strain zone is substantially limited on the sample. At relatively high rate of through-thickness crack growing, here the cycle count goes to hundreds. By the data of Table 5, it can be stated that a crack grew from 7 up to 16 mm during 300 loading cycles. After 300–400 loading cycles signs of deformation began appearing on the surface of crack tips (Figure 3, *a*), which at more than 35 mm crack length developed into a contraction across sample thickness (Figure 3, *b*). The obtained good convergence of crack growth on the three samples is attributable, allowing for [18], to practically the same KCV_{-40} values for all the welded joint zones.

It should be noted that the possibilities of application of leak before break criterion to detect through-thickness fatigue cracks in metal walls of tanks are quite limited. As applied to pressure vessels, defects of the type of through-thickness fatigue macrocrack are inadmissible [16]. Welded cylindrical tanks belong to those few facilities, the design of which and operating modes create the conditions for visual detection of a through-thickness fatigue macrocrack on the surface of welded joints of the wall by oil flowing out of it. The tank wall has a smooth cylindrical surface, completely open for visual examination. At up to 22 m wall height the stored product pressure on the wall is not more than 0.2 MPa, oil temperature in the tank is not higher than 50 °C. Oil and oil products feature a high permeability. Practical experience shows that already at the length of through-thickness crack of 3–5 mm their seeping through the crack is observed, with formation of dark spots (wetted areas) on the wall surface. Such oil spots are readily detectable on the open surface at examination. Proceeding from operating conditions, it was necessary to consider in greater detail the duration of the cycle of tank filling-emptying. For tanks of 50–100 thou m^3 capacity, full cycle duration is equal to about 10 h (rate of oil rise in the tank is up to 4 m/h). Maximum number of cycles per year is not more than 100 [3], i.e. 1 cycle every 3.5 days or about 8 cycles per month. Number of cycles, at which plane strain was clearly recorded on the sample, can be assumed to be 300. Through-thickness crack length $2a$ = 16 mm corresponded to this number. Allowing for safety factor n_Z = 10 [16], we have 30 cycles of controlled loading, that amounts to $30{\cdot}3.5 \approx 100$ days. In connection with the fact that the scope of experimental and laboratory data on the considered issue is limited [14], we believe it is possible to compensate the formed gap by applying n_Z = 10. Eventually, we get the estimated controlled time of not more than 10 days. This time is quite sufficient for visual detection of the oil spot, performance of welded

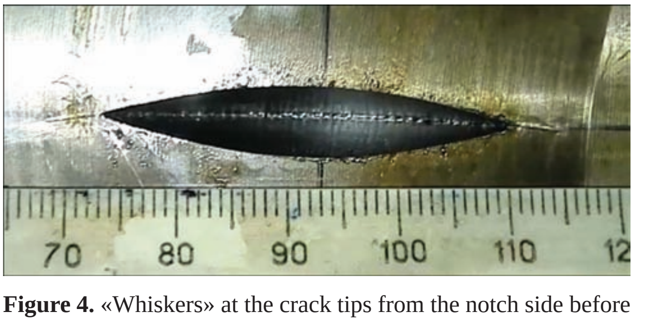

Figure 4. «Whiskers» at the crack tips from the notch side before reaching the opposite surface

joint UT in the section of oil seepage, and taking measures on prevention of further crack growth. Detection and stopping of crack growth in the weld is a reliable method of prevention of avalanche fracture in the wall of tanks, both those with a protective wall and of conventional design, required by the standards [3].

Note that alongside sheet steels considered in this publication and in work [12], national metallurgy has recently mastered production of a number of new structural steels, in particular, C420M and C460M. These steels are manufactured in the condition after normalizing rolling, which allows producing rolled sheets with σ_y/σ_t ratio of not less than 0.78 for C420 and not less than 0.83 for C460.

When considering the issue of application of these steels for tanks, the features of stressed state of the wall should be taken into account. Tank wall is a thin-walled cylindrical shell. At the diameter of 60–72 m and lower ring thickness of 26–28 mm, radial displacements of the wall reach 40 and 50 mm at the level of 1.0 m, respectively. At these displacements, the welded assembly of wall-to-bottom transition is plastically deformed, that is allowed for by $\gamma_n = 1.2$ coefficient during design. In addition, one should take into account that welding in the branchpipes and manholes into the lower ring is performed in a rigid contour. Under such conditions, in order to eliminate cold cracking in circumferential welds it is important for the steel to have a sufficient ductility margin. In view of what is stated in the standard [3], a requirement to $\sigma_y/\sigma_t \leq 0.75$ ratio was introduced for steels with $\sigma_y \leq 440$ MPa. It is also important for the rolled sheets to be delivered after normalizing, that ensures good quality of sheet rolling and eliminates angular deformations in the vertical welded joints of the wall. Considering all the above factors, the authors believe that at present, sheet steels of C390 and C440 strength class proposed for tanks by the standards [3–5], do not offer any acceptable alternatives to steels 09G2SYuch-U and 09KhG2SYuch-U.

The given investigation results lead to the following conclusions:

1. Mechanical properties of normalized sheet steels 09G2SYuch-U and 09KhG2SYu-U fully meet the requirements of standards for cylindrical steel tanks. Application of these steels essentially improves the efficiency and ecological safety of tanks.

2. Application of normalized sheet steels 09G2SYuch-U and 09KhG2SYuch-U for design rings of the wall of tanks of up to 20 thou m^3 and greater capacity for storage of oil and oil products enables preventing avalanche fractures of the wall by visual detection of a through-thickness fatigue crack formed in the welded joint, by leak before break criterion (outflowing oil spot).

3. In the case of the considered steels, there are not less 10 days of safe operation for visual detection of the crack by leak before break criterion and taking measures to eliminate its possible propagation.

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Received 05.03.2018