Seventh Framework Programme
Marie Curie Action "International Research Staff Exchange Scheme"

Paton Welding Institute
Kiev, Ukraine

Protocols of static internal pressure test of specimens I1, I2, I3 and I4 made of pipe 219×6 (Steel 20)

Contents

Roman Dmytriienko dri1@ukr.net, www.dri1.cc.ua November 2015

Data common to specimens I1 ... I4.

Table 1. Results of tensile testing of specimens from the pipe 219×6 material (steel 20), cut in the circumferential and axial direction in the state of delivery (tension up to formation the neck in the working portion of the specimen).

measurement #		Direction of the specimen				
		circumferential			axial	
		strain	stress		strain	stress
		e	σ, MPa		e	σ, MPa
1		2	3		4	5
1		0	0		0	0
2		3.26E-05	8		0.000151	19.98938
3		0.000106	24.0249		0.000185	29.54951
4		0.000144	29.18004		0.000215	38.62682
5		0.000162	34.33518		0.00025	48.38009
6		0.000192	39.19852		0.000293	58.42306
7		0.000218	43.96459		0.000336	67.88663
8		0.000239	48.6334		0.000384	78.02617
9		0.000252	53.69128		0.000436	87.29661
10		0.000269	58.74915		0.00047	96.56704
11		0.000278	62.83435		0.000531	106.3203
12		0.000308	67.79496		0.000608	116.653
13		0.000338	73.5337		0.000652	125.5372
14		0.000347	78.20251		0.000708	135.7733
15		0.000368	82.19045		0.000755	145.43
16		0.000398	87.63739		0.000816	154.4107
17		0.000415	92.598		0.000885	164.2605
18		0.00045	97.75314		0.000932	174.3035
19		0.000476	102.0329		0.001002	183.6705
20		0.000471	106.7017		0.001066	192.9409
21		0.000527	112.635		0.001148	203.2736
22		0.00054	116.5256		0.001205	212.7372
23		0.00057	122.2644		0.001313	222.7802
24		0.000587	126.7386		0.001421	232.5334
25		0.000648	137.0489		0.001511	241.9004
26		0.000695	146.0947		0.001667	251.4606
27		0.000759	155.4324		0.001831	260.9241
28		0.00082	165.6454		0.001973	271.0637
29		0.000876	175.372		0.002198	280.141
30		0.000944	185.5851		0.002453	289.7977
31		0.001005	194.6309		0.002552	294.0466

Table 1 (continued)

1		2	3		4	5
32		0.001065	204.0658		0.002729	299.8407
33		0.001151	214.6678		0.002889	304.1862
34		0.001228	223.6164		0.003183	309.3042
35		0.001336	233.1485		0.003351	313.4566
36		0.001452	243.2643		0.003589	313.9395
37		0.001602	252.8937		0.003874	316.933
38		0.001805	263.204		0.004181	317.0296
39		0.00205	272.5416		0.004583	318.285
40		0.002355	282.0737		0.005066	318.7678
41		0.002794	292.0922		0.006237	319.0575
42		0.003314	301.5271		0.006656	317.9953
43		0.003921	311.4483		0.00819	320.6026
44		0.004725	320.8832		0.011499	320.8923
45		0.005757	330.9017		0.015542	323.6927
46		0.007193	340.4338		0.017745	324.755
47		0.009408	350.6468		0.020838	328.7142
48		0.011533	359.8872		0.022587	331.9009
49		0.01444	369.7111		0.024453	335.7636
50		0.017718	379.5351		0.026272	340.9782
51		0.021524	388.9699		0.029499	348.607
52		0.026328	399.183		0.032933	357.2981
53		0.03228	408.5206		0.036134	364.8303
54		0.039015	418.5391		0.039469	372.7488
55		0.047381	428.2657		0.042907	379.605
56		0.058571	437.8951		0.046303	383.7574
57		0.073362	447.6218		0.049823	389.648
58		0.080588	452.3879		0.053223	395.1523
59		0.091503	457.154		0.056679	399.7876
60		0.097529	460.072		0.060117	404.1331
61		0.105741	462.0173		0.063465	407.6095
62		0.108982	462.99		0.066908	412.4378
63		0.117461	465.908		0.070454	416.0108
64		0.124447	468.0479		0.074001	418.6181
65		0.130565	469.2151		0.077547	422.4808
66		0.14166	470.8686		0.080865	425.4744
67		0.147745	471.8413		0.084342	428.0817
68		0.156018	472.3276		0.087906	430.4959
69		0.162021	473.4948		0.091496	433.1032
70		0.166767	473.6893		0.095129	434.938
71		0.170957	474.1757		0.09874	437.4487
72		0.176682	474.3702		0.100277	438.5109
73		0.182505	474.5647		0.103498	438.9938

Table 1 (continued)

1		2	3		4	5
74		0.18944	474.7593		0.107119	441.9873
75		0.195191	474.1757		0.110619	442.3736
76		0.200817	474.7593		0.113921	443.7256
77					0.117327	445.6569
78					0.120642	447.1054
79					0.124086	448.4573
80					0.127466	450.9681
81					0.131035	450.6784
82					0.134522	452.1269
83					0.138117	454.0582
84					0.141712	454.0582
85					0.145332	454.4445
86					0.148975	455.4102
87					0.152737	456.7621
88					0.156409	457.1484
89					0.16015	458.6934
90					0.163857	458.5969
91					0.167697	459.9488
92					0.171201	459.3694
93					0.175067	459.466
94					0.178881	459.7557
95					0.182759	460.142
96					0.186672	460.9145
97					0.190461	460.6248
98					0.19409	461.3008
99					0.198306	460.142
100					0.201531	460.9145
101					0.20485	460.2385
102					0.208101	460.6248
103					0.211481	461.3973
104					0.214718	460.8179
105					0.217873	461.1076
106					0.221137	460.0454
107					0.2244	461.3973
108					0.227659	461.0111
109					0.230819	460.9145

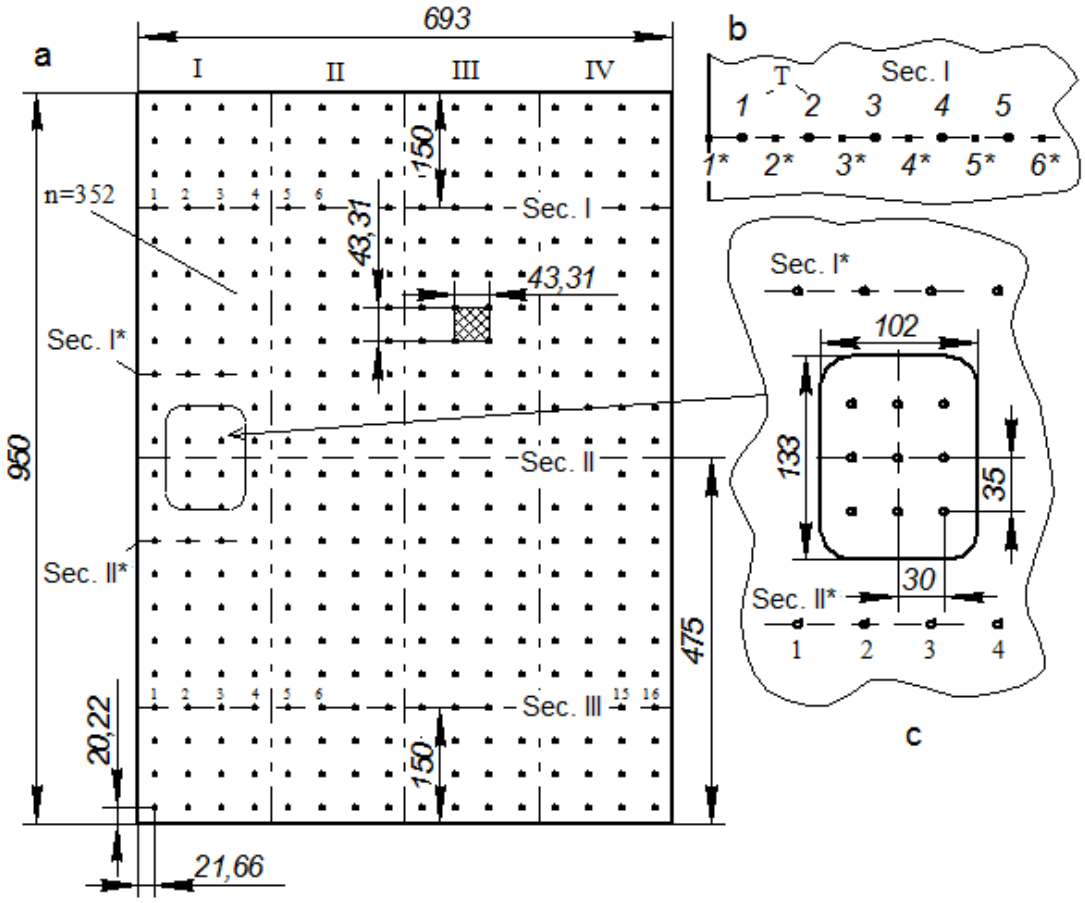


Fig. 1. Schemes of specimens I1 ... I4 wall thickness measurement (sweep of the cylindrical part): a – location of perimeter measurement sections I, II, III; b – location of the punching points 1* ..16 * in sections I, II, III, 1 ... 16 - point of wall thickness measurement; c - wall thickness measurement in defects of specimens I2, I3. (Dimensions in mm).

Measuring of the wall thickness and perimeter of specimens I2 and I3 (with defect) was done only in sections I * and II *.

For the perimeter determination was used tape line with thickness of 0.2 mm. The wall thickness of cylindrical portion of the specimens was measured by ultrasonic thickness gauge TUZ-2.

Two end plates were used for specimen hermetic sealing (Fig. 2).

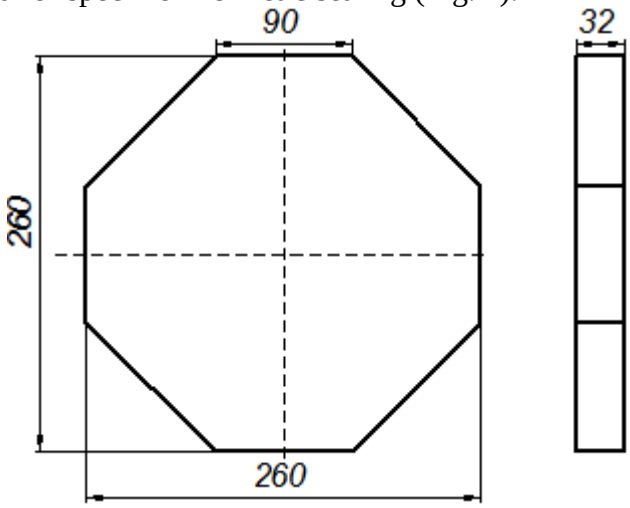


Fig. 2. Steel plates for specimens I1 ... I 4 sealing. (Dimensions in mm).

Protocol of specimen I1 (without defect).

For the manufacture of the specimen was used piece of pipe #8, weight 33.2 kgf (Fig.3a). Sections I, II, III had punched points (marked with "*" on Fig.1). Distance between points was used as the base for measuring residual deformation in circumferential and axial direction before and after destruction (Fig 1b, Table.2, 4).

Table 2. Length of cylindrical portion of specimen I1 and base axial dimensions in the original state.

#	Linear size, mm	Sector				
		I	II	III	IV	average
1	length of the pipe piece, l_o	949	949	946	946	947.5
2	length between the inner surfaces of the plates (bottoms) after welding	954	954	952	952	953
3	distance between the sections I-III	646.5	646.5	645	644	
4	distance between the sections I-II	325	325	324	323	
5	distance between the sections II-III	321.5	321.5	321	321	
Dimensions 3, 4, 5, after the destruction of the specimen did not change, indicating the absence of residual deformation in the axial direction.						

Note: The measurements were done in the middle of the sectors I ... IV, (Fig. 1). The distance between the cross sections was determined by the punching points.

Table 3. Specimen I1 perimeter before (P_H) and after destruction (P_K).

Cross section →	I (150 mm from the top)	II (in the middle)	III (150 mm from the bottom)	average
Perimeter, P_H, mm	693.5	693.5	693.5	693.5
Perimeter, P_K, mm	744	753	741	746

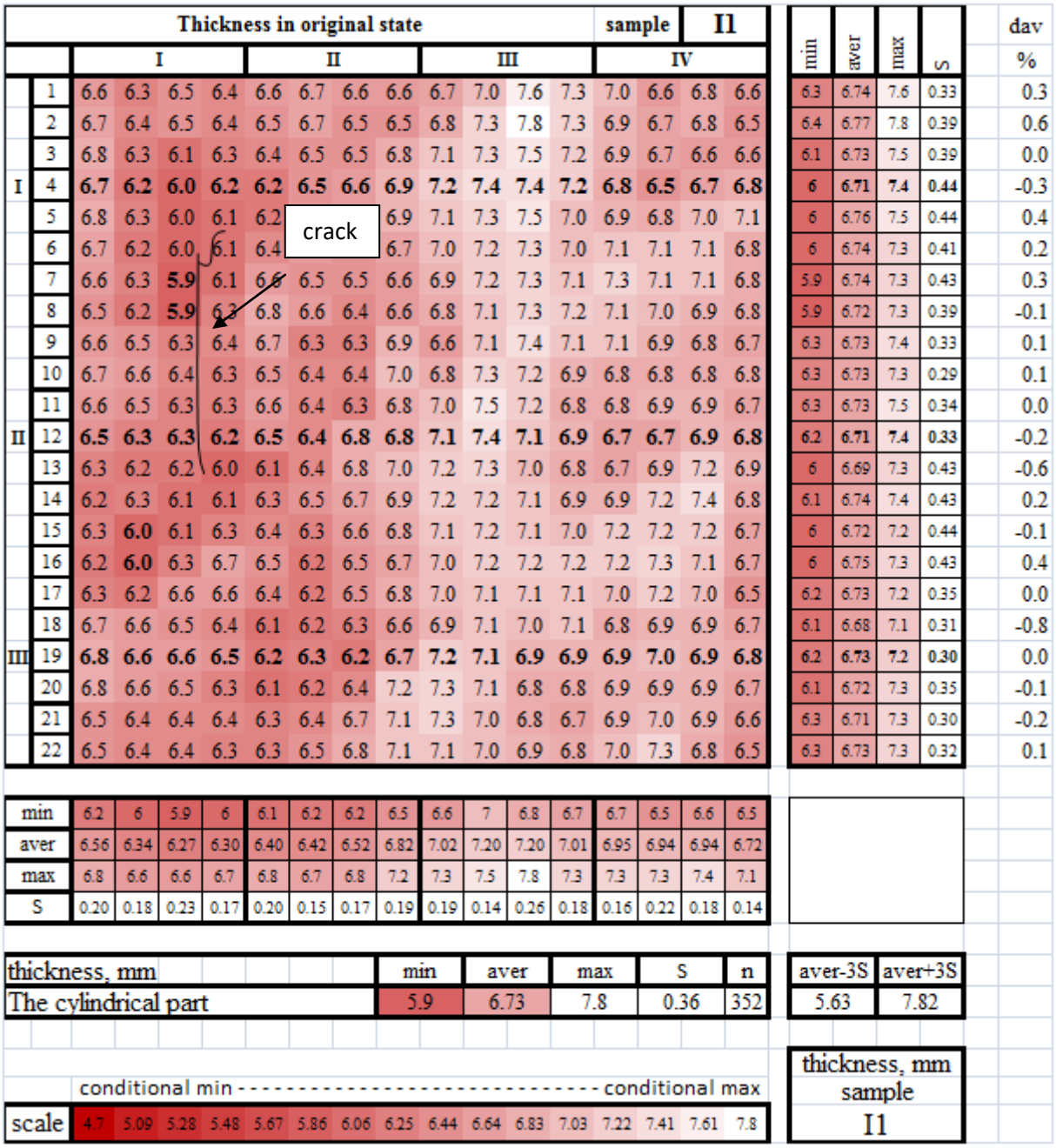
Table 4. Specimen I1. Base length and the wall thickness in the sections I, II, III before (l_H, s_H) and after destruction (l_K, s_K), (mm).

Distance	Measuring point #	Sec. I		Sec. I		Sec. II		Sec. II		Sec. III		Sec. III	
		l_H	s_H	l_K	s_K	l_H	s_H	l_K	s_K	l_H	s_H	l_K	s_K
1*-2*	1	43.2	6.7	46.1	6.3	46.2	6.5	51.4	5.8	42	6.8	44.8	6.4
2*-3*	2	43.7	6.2	48.4	5.7	44	6.3	51.2	5.5	42.4	6.6	45.3	6.2
3*-4*	3	44	6.0	51	5.1	44.5	6.3	-	5.4	43.2	6.6	46.4	6.0
4*-5*	4	41.6	6.2	46.3	5.6	44.5	6.2	51.5	5.2	44.5	6.5	47.8	5.9
5*-6*	5	42.6	6.2	46.8	5.8	42.8	6.5	47	5.9	43.2	6.2	48	5.6
6*-7*	6	44	6.5	47.1	6.0	41.7	6.4	46.8	5.6	42.6	6.3	47	5.7
7*-8*	7	43	6.6	46	6.1	43	6.8	47.2	6.1	42.1	6.2	46.2	5.7
8*-9*	8	45.5	6.9	48.2	6.5	40.8	6.8	43.6	6.4	44	6.7	47	6.2
9*-10*	9	43	7.2	45	6.9	43.5	7.1	45.8	6.8	42.8	7.2	45	6.8
10*-11*	10	42.8	7.4	44.2	7.1	42.8	7.4	44.6	7.1	42.4	7.1	44	6.9
11*-12*	11	44	7.4	45.8	7.2	43.7	7.1	45.5	6.9	43	6.9	45	6.6
12*-13*	12	41.5	7.2	43.2	6.9	41.6	6.9	44	6.6	43.5	6.9	45.4	6.5
13*-14*	13	44.3	6.8	46.8	6.5	42	6.7	45	6.6	43.8	6.9	46	6.6
14*-15*	14	42.7	6.5	45.5	6.2	44	6.7	47	6.4	43.4	7.0	45.4	6.6
15*-16*	15	43	6.7	46	6.2	42.4	6.9	45.4	6.8	44.8	6.9	47.2	6.7
16*-1*	16	42.8	6.8	45.3	6.4	44.4	6.8	47.2	6.5	43.4	6.8	46	6.3
Σ	-	691.7	-	741.7	-	691.9	-	703.2	-	691.1	-	736.5	-
average	-	43.23	6.71	46.36	6.28	43.24	6.71	46.88	6.23	43.19	6.73	46.03	6.29

Weight of welded specimen: 61.2 kg. Weight of the specimen filled with water: 93.2 kg. Water temperature: 18 ^{o}C. Water weight: 32 kg. Internal volume of the specimen 32 liters.

Fig. 3. Specimen I1 (points indicate places of the measurement thickness): a – pipe piece #8; b - specimen before the test; c - welding of the pipe; d - top bottom with the fittings.

Results of measuring of wall thickness of the sample before and after the test are given at Fig.4 and Fig.5, correspondingly.



thickness, mm	min	aver	max	S	n	aver-3S	aver+3S
The cylindrical part	5.9	6.73	7.8	0.36	352	5.63	7.82

Fig. 4. Map of the wall thickness of the specimen I1 in original state.

On the right of the map the deviation of the mean cross-sectional thickness from the average thickness of the cylinder (dav) is specified. The figure indicates the location of the crack formed after the destruction of the specimen; min, aver, max - the minimum, average and maximum values, respectively; S - standard deviation; n - number of measurements.

Table 5. The wall thickness of the specimen I1 in original state, mm.

Section	# of the point number in cross-section															
#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	6.6	6.3	6.5	6.4	6.6	6.7	6.6	6.6	6.7	7.0	7.6	7.3	7.0	6.6	6.8	6.6
2	6.7	6.4	6.5	6.4	6.5	6.7	6.5	6.5	6.8	7.3	7.8	7.3	6.9	6.7	6.8	6.5
3	6.8	6.3	6.1	6.3	6.4	6.5	6.5	6.8	7.1	7.3	7.5	7.2	6.9	6.7	6.6	6.6
4	**6.7**	**6.2**	**6.0**	**6.2**	**6.2**	**6.5**	**6.6**	**6.9**	**7.2**	**7.4**	**7.4**	**7.2**	**6.8**	**6.5**	**6.7**	**6.8**
5	6.8	6.3	6.0	6.1	6.2	6.5	6.6	6.9	7.1	7.3	7.5	7.0	6.9	6.8	7.0	7.1
6	6.7	6.2	6.0	6.1	6.4	6.6	6.5	6.7	7.0	7.2	7.3	7.0	7.1	7.1	7.1	6.8
7	6.6	6.3	**5.9**	6.1	6.6	6.5	6.5	6.6	6.9	7.2	7.3	7.1	7.3	7.1	7.1	6.8
8	6.5	6.2	**5.9**	6.3	6.8	6.6	6.4	6.6	6.8	7.1	7.3	7.2	7.1	7.0	6.9	6.8
9	6.6	6.5	6.3	6.4	6.7	6.3	6.3	6.9	6.6	7.1	7.4	7.1	7.1	6.9	6.8	6.7
10	6.7	6.6	6.4	6.3	6.5	6.4	6.4	7.0	6.8	7.3	7.2	6.9	6.8	6.8	6.8	6.8
11	6.6	6.5	6.3	6.3	6.6	6.4	6.3	6.8	7.0	7.5	7.2	6.8	6.8	6.9	6.9	6.7
12	**6.5**	**6.3**	**6.3**	**6.2**	**6.5**	**6.4**	**6.8**	**6.8**	**7.1**	**7.4**	**7.1**	**6.9**	**6.7**	**6.7**	**6.9**	**6.8**
13	6.3	6.2	6.2	6.0	6.1	6.4	6.8	7.0	7.2	7.3	7.0	6.8	6.7	6.9	7.2	6.9
14	6.2	6.3	6.1	6.1	6.3	6.5	6.7	6.9	7.2	7.2	7.1	6.9	6.9	7.2	7.4	6.8
15	6.3	**6.0**	6.1	6.3	6.4	6.3	6.6	6.8	7.1	7.2	7.1	7.0	7.2	7.2	7.2	6.7
16	6.2	**6.0**	6.3	6.7	6.5	6.2	6.5	6.7	7.0	7.2	7.2	7.2	7.2	7.3	7.1	6.7
17	6.3	6.2	6.6	6.6	6.4	6.2	6.5	6.8	7.0	7.1	7.1	7.1	7.0	7.2	7.0	6.5
18	6.7	6.6	6.5	6.4	6.1	6.2	6.3	6.6	6.9	7.1	7.0	7.1	6.8	6.9	6.9	6.7
19	**6.8**	**6.6**	**6.6**	**6.5**	**6.2**	**6.3**	**6.2**	**6.7**	**7.2**	**7.1**	**6.9**	**6.9**	**6.9**	**7.0**	**6.9**	**6.8**
20	6.8	6.6	6.5	6.3	6.1	6.2	6.4	7.2	7.3	7.1	6.8	6.8	6.9	6.9	6.9	6.7
21	6.5	6.4	6.4	6.4	6.3	6.4	6.7	7.1	7.3	7.0	6.8	6.7	6.9	7.0	6.9	6.6
22	6.5	6.4	6.4	6.3	6.3	6.5	6.8	7.1	7.1	7.0	6.9	6.8	7.0	7.3	6.8	6.5

Table 6. The wall thickness in the sections I, II, III, of I1 specimen in original state, mm.

Section	# of the point number in cross-section																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**average**
I	6.7	6.2	6.0	6.2	6.2	6.5	6.6	6.9	7.2	7.4	7.4	7.2	6.8	6.5	6.7	6.8	**6.71**
II	6.5	6.3	6.3	6.2	6.5	6.4	6.8	6.8	7.1	7.4	7.1	6.9	6.7	6.7	6.9	6.8	**6.71**
III	6.8	6.6	6.6	6.5	6.2	6.3	6.2	6.7	7.2	7.1	6.9	6.9	6.9	7.0	6.9	6.8	**6.73**
average																	**6.71**

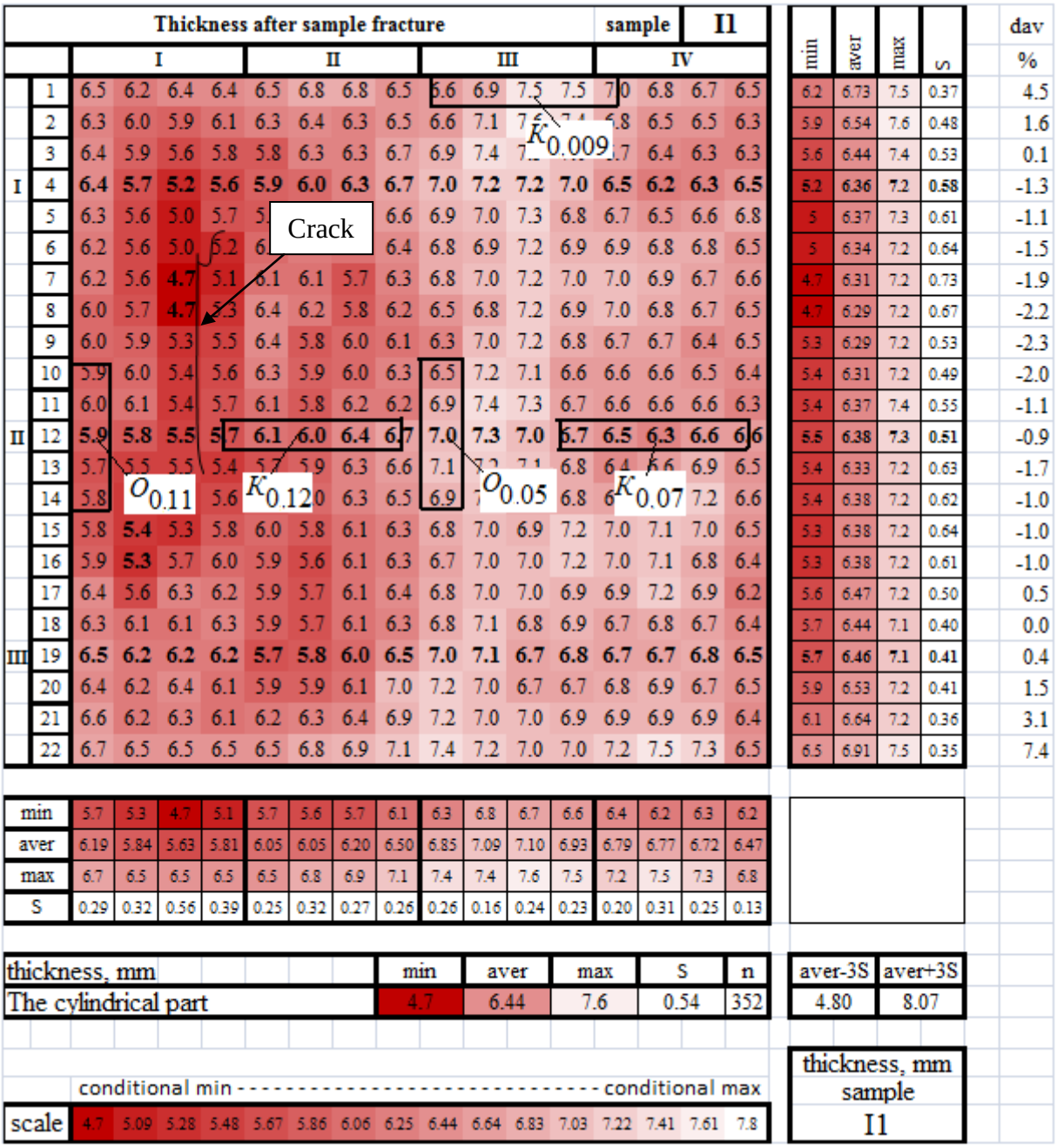


Fig. 5. Map of the wall thickness after specimen destruction and places of tensile samples 30 mm × 180 mm cutting. K, O – samples in circumferential and axial direction, respectively; low index – value of residual deformation in the hoop direction after failure. All other symbols - are the same as in Fig. 4.

Table 7. The wall thickness in the sections I, II, III, I1 after specimen fracture, mm.

Section	# point number in the cross-section																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**average**
I	6.4	5.7	5.2	5.6	5.9	6.0	6.3	6.7	7.0	7.2	7.2	7.0	6.5	6.2	6.3	6.5	**6.36**
II	5.9	5.8	5.5	5.7	6.1	6.0	6.4	6.7	7.0	7.3	7.0	6.7	6.5	6.3	6.6	6.6	**6.38**
III	6.5	6.2	6.2	6.2	5.7	5.8	6.0	6.5	7.0	7.1	6.7	6.8	6.7	6.7	6.8	6.5	**6.46**
average																	**6.40**

Note: The wall thickness in the places of fracture was measured with a caliper: 4.5 - 4.8 mm.

Loading of the specimen by internal pressure was done stepwise (Fig. 6), after each step the pressure was released to 0. Steps 1...20 were held in the water jacket, and steps 21..25 out of it. Loading in steps 1...20 was made by holding max pressure during 0.5...3 min. For reducing pressure fluctuations 2 additional high pressure receivers were included in the hydraulic system.

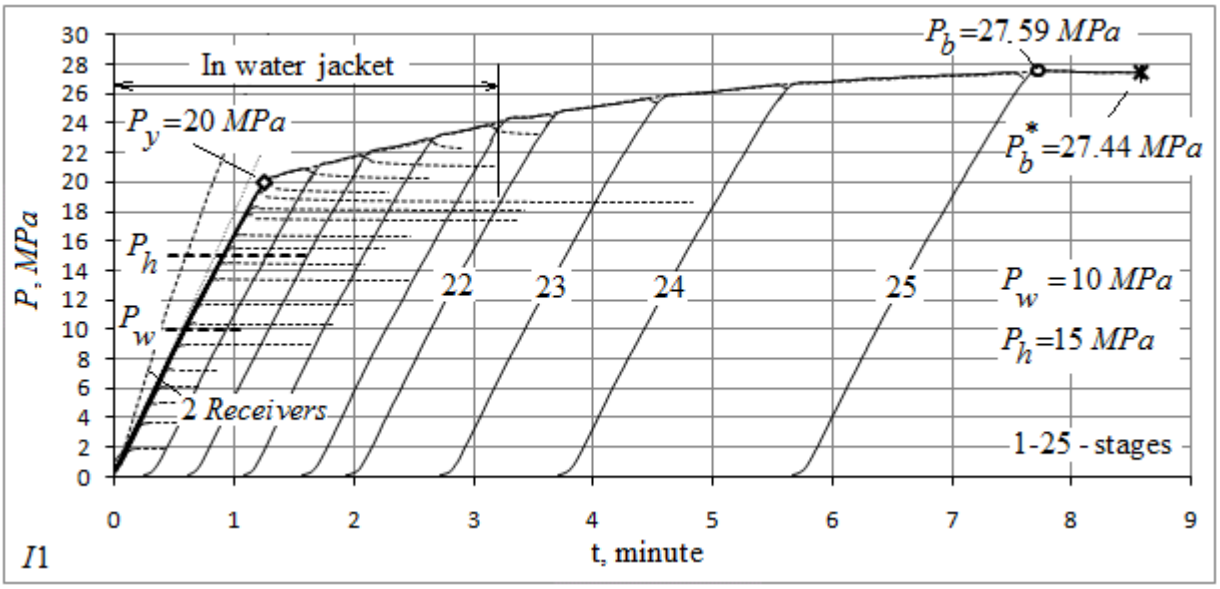


Fig. 6. Steps of internal pressure loading of the specimen I1. P_w, P_h - working pressure and test pressure; P_y - yield pressure; P_b, P_b^* - the maximum pressure that sustained the specimen and the pressure at which the failure occurred; 2 receivers - the pressure in the two paired receivers connected without the specimen.

According to test results of the sample I1:
P_y=20 MPa, P_b=27.59 MPa, P_b^*=27.44 MPa.

Judging by the nature of crack and loading diagram (Fig.6), fracture of specimen I1 had ductile character.

Table 8. Change in the volume of specimen I1 during test in the water jacket, (WJ). Steps 1 ... 20.

Step #	P_{max}, MPa	P_{min}, MPa	ΔV_{ti}, cm^3	ΔV_{pi}, cm^3
0	0	0	0	0
1	1.85	1.85	9.815	0
2	3.63	3.62	19.472	0
3	5.02	5	26.912	0
4	6.1	6.06	32.611	0
5	7.26	7.18	38.785	0
6	8.99	8.91	47.650	0
7	10.43	10.32	55.566	0.1583
8	11.69	11.64	63.006	0.4749
9	13.47	13.35	73.455	1.7414
10	14.54	14.46	79.787	1.8997
11	15.54	15.43	86.120	2.8495
12	16.46	16.34	92.610	4.2743
13	17.75	17.45	105.117	9.9734
14	18.34	18.03	107.807	9.1818
15	19.25	18.67	140.894	36.0941
16	19.95	19.28	174.760	66.0511
17	20.9	20.22	357.089	236.6833
18	21.81	21.03	425.892	293.7900
19	22.86	22.33	536.666	389.4266
20	23.87	23.27	501.920	343.3284

Fig.7. The water jacket

Note: ΔV_{ti} - the maximum (full) change of volume at each step was determined at the end of exposure to max pressure; ΔV_{pi} - residual change of volume at the appropriate step after pressure release. Changing the volume was determined by burettes of water jacket (Fig.7) as the difference between levels of the liquid columns multiplied by a calibration coefficient and with the addition of 7.4% taking into account the error of the burette A, and 1.78% for burettes B.

Table 9. Perimeters (Pp mm) of the specimen I1 and change of its weight (with water) after steps 20...25 (out of the water jacket).

Step #	P_{max}, MPa	Perimeter designation		Section #			average		The change in weight, kg
				I	II	III			
0	0	$Po=P_H$		693.5	693.5	693.5	693.5		
20	23.87	P_{20}		708.0	708.2	707.8	708		1.475
21	24.62	P_{21}		711.2	711.3	710.4	710.97		1.658
22	25.71	P_{22}		717	717.6	716.2	716.93		2.225
23	26.6	P_{23}		725.4	726.1	723.3	724.93		3.100
24	27.41	P_{24}		738.6	743.1	734.4	738.7		4.525
25	27.59	$P_{25}=P_K$		744	753	741	746		-

Results of perimeter changing are given at Fig. 8 (in accordance with Table 9).

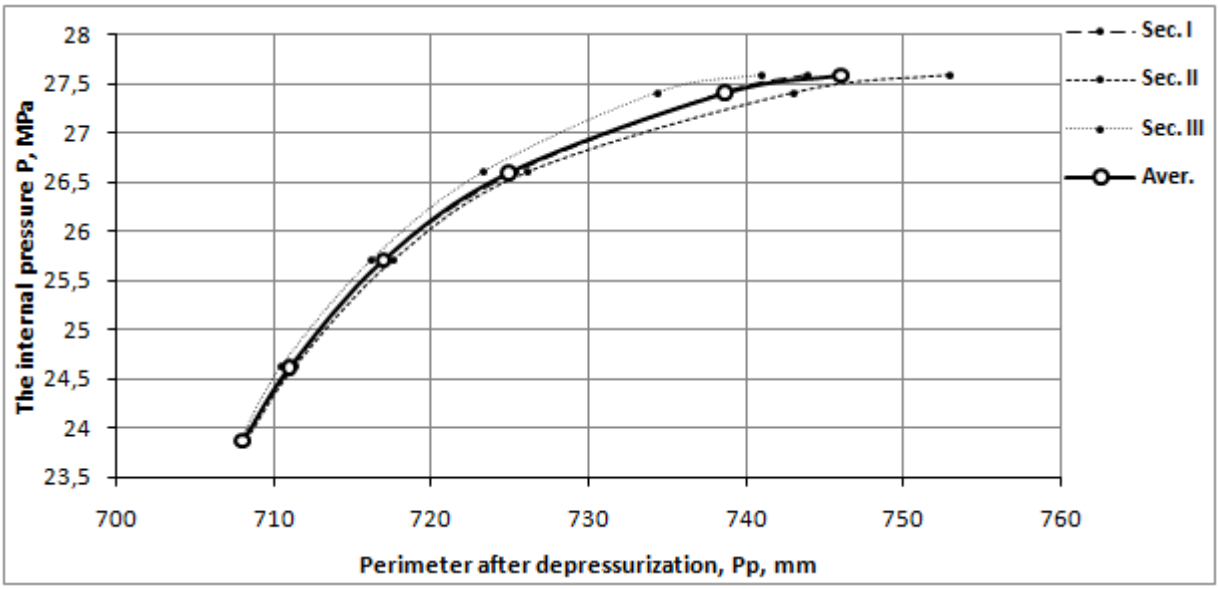


Fig.8. Perimeter (Pp) of specimen I1 measured in sections I, II, III after steps 20-25.

Table 10. Perimeter (P_K) after specimen destruction.

Section # *		P_K, mm.
	1	699.6
	2	719.5
	3	732.4
Sec. I	4	742.5
	5	749.5
	6	-
	7	-
	8	-
	9	-
	10	-
	11	-
Sec. II	12	-
	13	753.8
	14	753
	15	751.2
	16	748.8
	17	745.6
	18	741.4
Sec. III	19	737.8
	20	730.5
	21	720
	22	702

Fig. 9. Specimen I1. a - after step 24; b - after failure (step 25).

* - Perimeter was determined in the sections of wall thickness measurements (Fig.1a).

Fig.10. Sample for tensile test cut out the specimen I1 after its destruction.

Protocol of specimen I2 (with defect).

For the manufacture of the specimen was used piece of pipe #7, weight 32.7 kgf (Fig.12).

Table 11. Axial dimensions of the specimen I1 in the original state.

#	Linear size, mm	Sector				
		I	II	III	IV	average
1	length of the pipe piece, l_o	948	948	946	947	947.25
2	length between the inner surfaces of the plates (bottoms) after welding	954	954	952	953	953.25

Note: The measurements were made in the middle of the sectors I ... IV, (Fig.1).

Table 12. Specimen I1 perimeter before (P_H) and after destruction (P_K).

The cross section →	I*	II*	average
P_H, mm	692.3	692.3	692.3
P_K, mm	692.3	692.3	692.3

Table 13. Wall thickness of the specimen in original state, mm.

Section #	Point #																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**average**
I*	7.1	6.7	6.6	6.6	6.8	6.6	6.4	6.4	6.5	6.8	6.8	6.8	6.6	7.0	7.1	7.3	**6.76**
II*	6.8	6.5	6.5	6.9	6.6	6.1	6.1	6.2	6.9	6.9	7.2	7.2	7.1	6.9	7.3	6.9	**6.76**
average																	**6.76**

Note: After the destruction of the specimen the thickness of the wall in sections I* and II* has not changed.

Weight of welded specimen: 60.7 kg. Weight of the specimen with water: 92.6 kg. Water temperature: 12.5 ^oC. Water weight: 31.9 kg. Internal volume of the specimen 31.9 liters. Weight of specimen filled with water and hydraulic armature: 93.3 kg. The initial linear dimensions of the defect: 133×102 mm. Length of arc A (Fig,11): A = 586 mm.

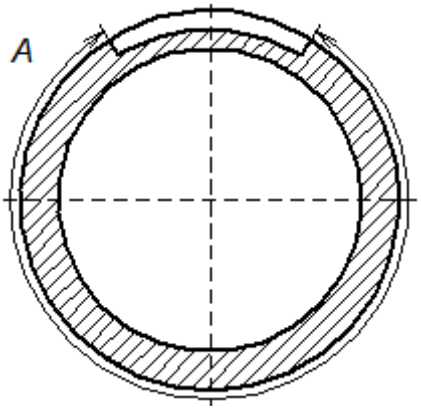


Fig. 11. Arc A.

Fig.12. Specimen I2: a - before the test, b – pipe edge prepared for welding; c, d - welding of the lower bottom; e - top end of the specimen; f - defect (numbers near the points indicate the wall thickness).

Loading of the specimen by internal pressure was done stepwise (Fig.13), after each step the pressure was released to 0. Loading in steps 1...20 was made by holding max pressure during the time necessary for reading of strain gauges mounted on the specimen surface (Fig.14).

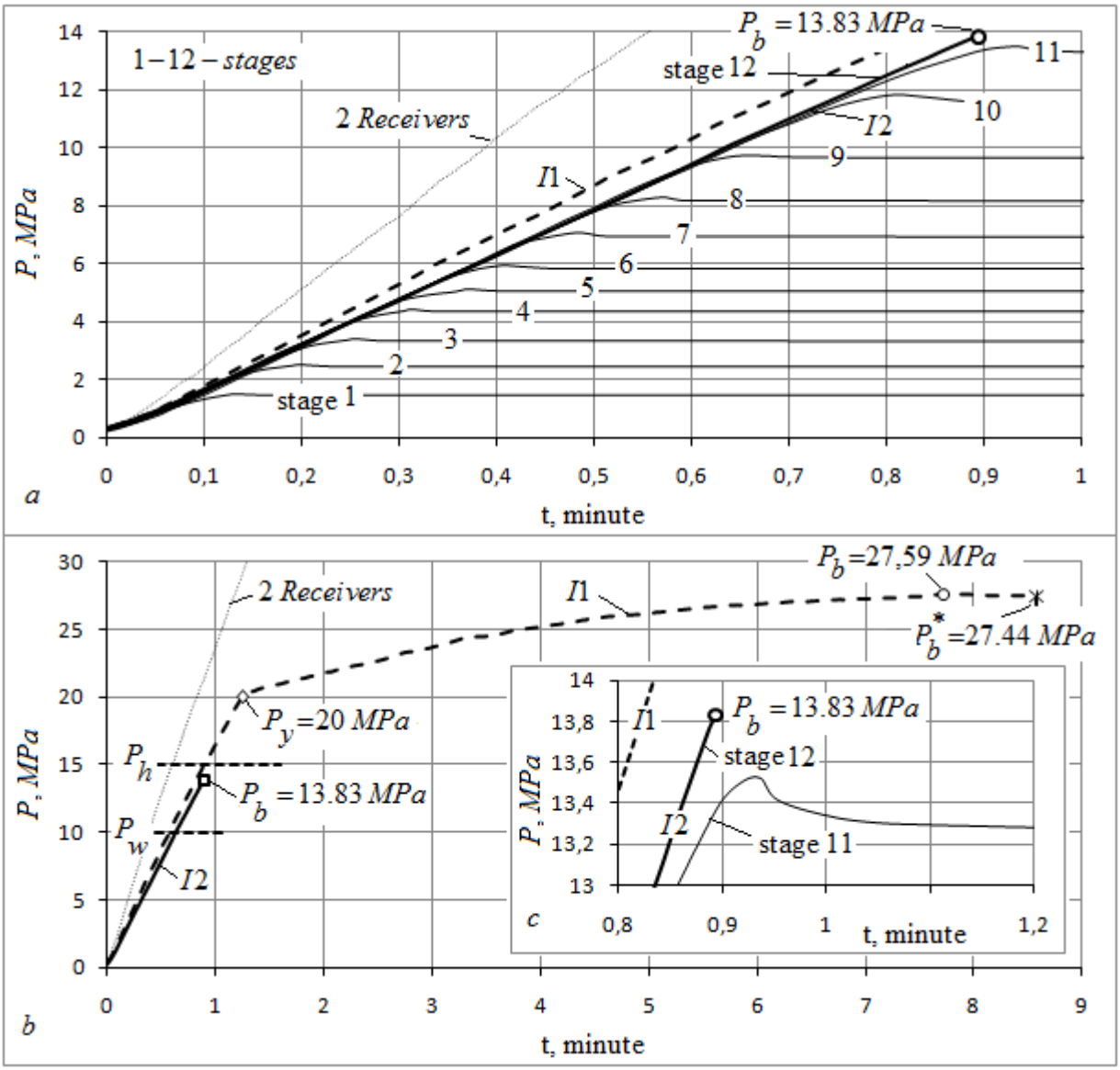


Fig.13. Loading of the specimens I2 and I1 by internal pressure: a - loading steps of the specimen with defect (I2); b - I1 and I2 loading; c- before the last and last steps (enlarged). Designations as in Fig.6.

Table 14.Experimental strains (gauges 1..8, Fig.14).

Step #	P, MPa	Defect		Defect		Pipe		Pipe	
		axial strain		hoop strain		axial strain		hoop strain	
		1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0	0
1	1.45	7.79E-05	7.34E-05	0.00033	0.00033	2.29E-05	2.29E-05	0.00011	0.00011
2	2.45	9.17E-05	0.000115	0.000532	0.000536	3.21E-05	3.67E-05	0.000193	0.000188
3	3.34	0.000128	0.000147	0.000724	0.000734	5.5E-05	4.58E-05	0.000257	0.000266
4	4.32	0.000174	0.000193	0.000935	0.000935	6.42E-05	6.42E-05	0.00033	0.000339
5	5.04	0.000193	0.000211	0.001119	0.001119	7.34E-05	6.42E-05	0.00039	0.000385
6	5.83	0.000229	0.000284	0.001394	0.001366	8.25E-05	8.25E-05	0.000449	0.000445
7	6.9	0.000541	0.000633	0.001907	0.001816	0.000101	0.000101	0.000523	0.000523
8	8.12	0.000779	0.001522			0.000133	0.000128	0.000601	0.000605
9	9.64					0.00017	0.000174	0.000697	0.000692

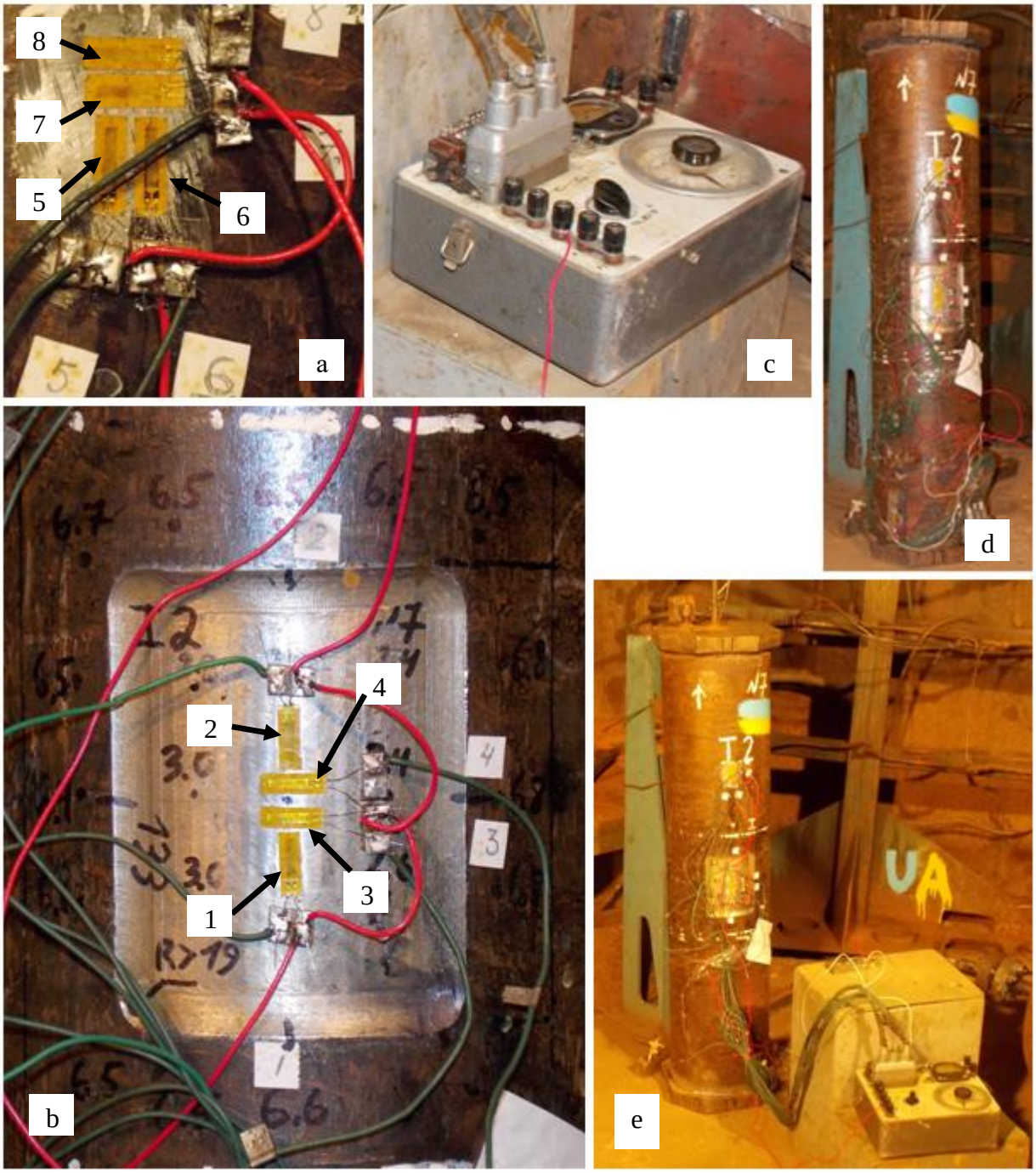


Fig. 14. Measurement of specimen I2 strains: a - gauges 5, 6, 7, 8 location; b - gauges 1, 2, 3, 4 location; c - ISD-3 measuring device, d, e - specimen during the test.

Length measuring the of bases K and O in circumferential and axial direction, correspondingly, was done after steps 9...12 (Table.15). Measurement was carried out by a ruler.

After the step #10 maximal residual deflection in the defect had reached a depth of the defect (Fig.15).

Table 15. Base lengths in the defect and specimen weight

Step #	P, MPa	Linear dimension, mm			Arc A length, mm	Weight of specimen with the armature, kg
		K	O	(length x width) of the defect		
9	9.64	44.8	44.6	133×102	586	93.3
10	11.78	45.9	44.6			-
11	13.49	47.2	44.6	133×107.2	586	93.3
12 (last)	13.83	47.2	44.6	133×110	586	-

Fig.15. Defect after step #10.

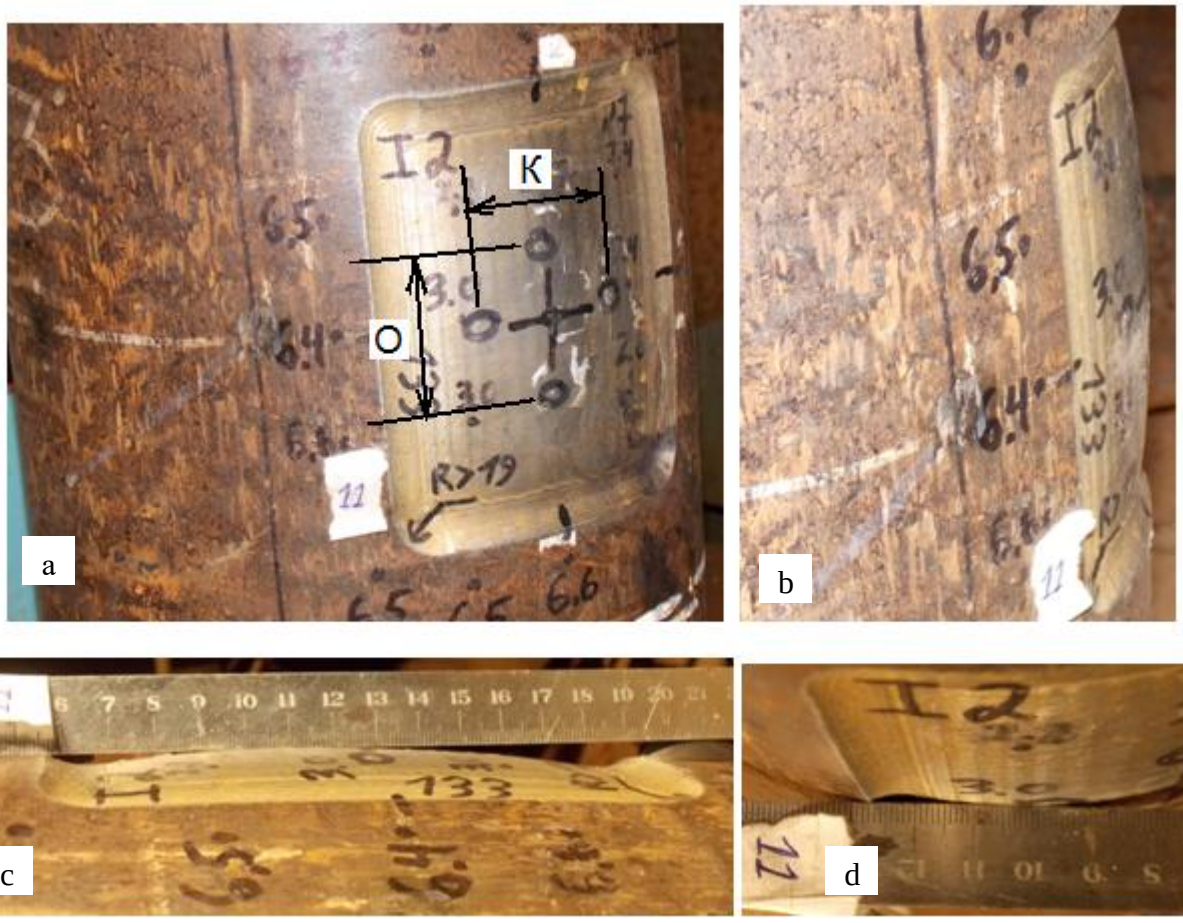


Fig.16. Defect after step #11.

Some general views of specimen after destruction are given at Fig. 17...19.

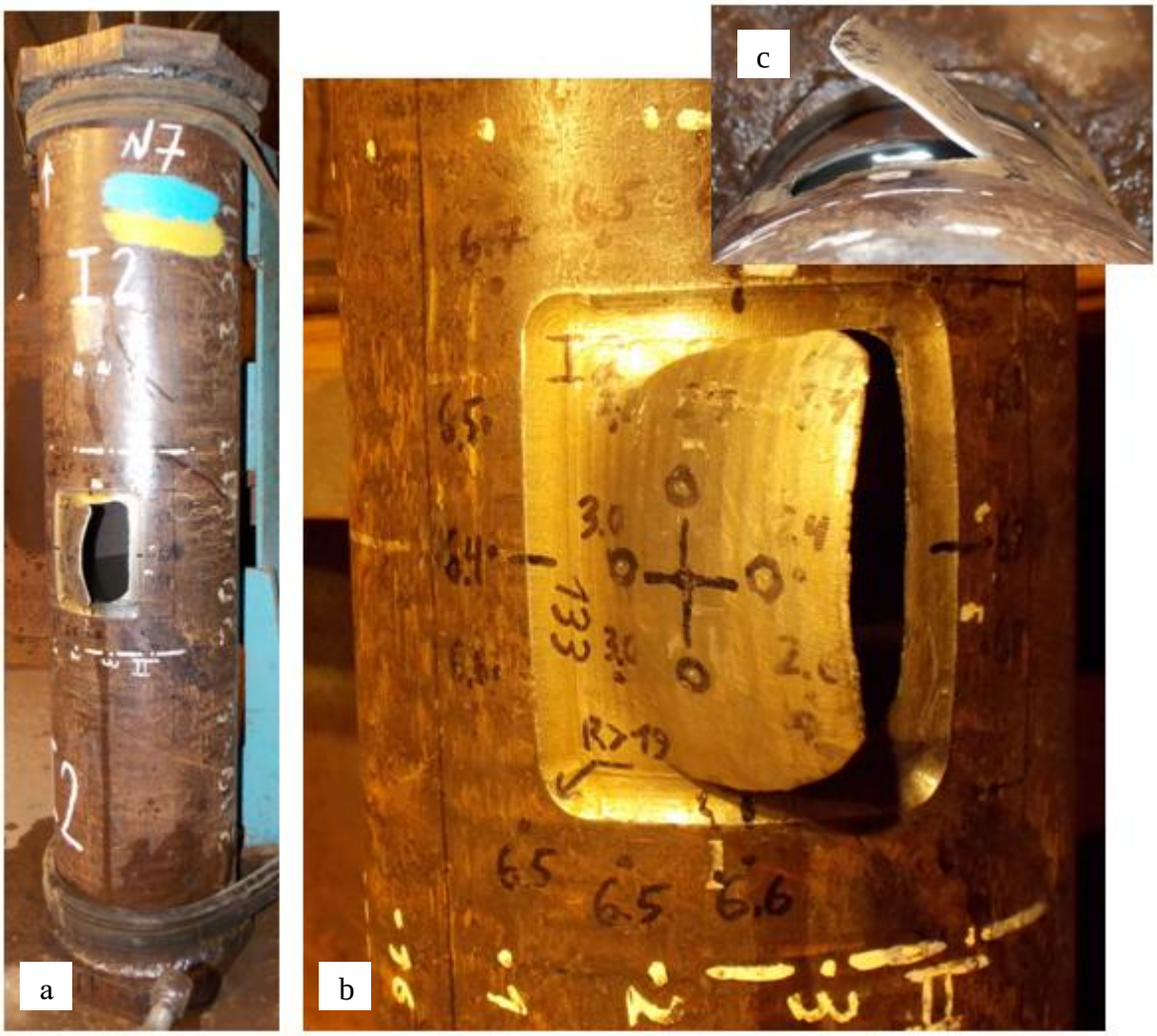


Fig.17. Destruction of the specimen: a - general view; b, c - the destruction in the defect.

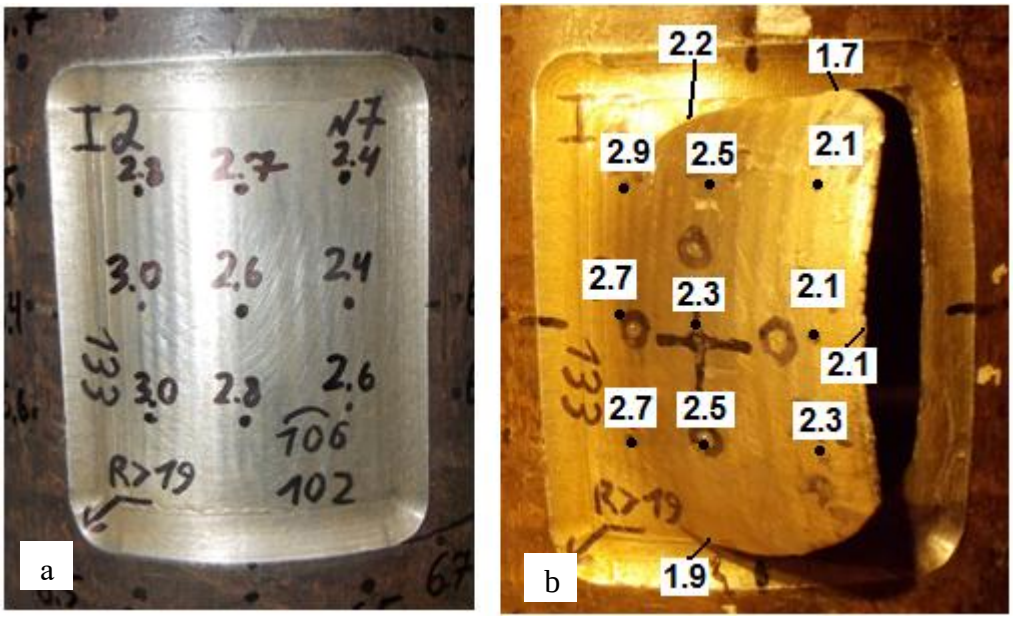


Fig.18. Defect wall thickness before (a) and after (b) destruction. (Dimensions in millimeters).

At Fig. 18b also is given the thickness at the contour of the destruction measured with a caliper.

Fig. 19. Fracture in defect zone.

Protocol of specimen I3 (with defect and bandage).

Loading of the specimen by internal pressure was done stepwise, after each step the pressure was released to 0.

The chronology of measurements and loading of the sample by internal pressure is given below:

- stage 1 ... 5 - measurement of strain using strain gauges installed in the defect and regular part of the pipe, before the start of plastic deformation in the defect (without bandage).
- installation of thebandage.
- stage 1 ... 13 - measurement of strain using strain gauges installed in the defect, regular part of the tube and on the surface of the bandage.
- stage 14 ... 18 - measurement of the perimeter of the pipe reinforced by bandage, determination of changes in specimen weight.

For the manufacture of the sample was pipe section #6 (Fig. 22a). Weight of the pipe section ith defect - 32.7 kgf.

Table 16. The length of the cylindrical portion of the sample I3 and axial dimensions in the original condition and after the destruction.

#	Linear size, mm	Sector				
		I	II	III	IV	average
1	length of the pipe section, l_o	947	946	946	947	946.5
2	length between inner surfaces of the sealing bottoms before test	954	955	953	956	954.5
3	length between inner surfaces of the sealing bottoms before test	954	955	953	956	954.5

Note: The measurements were done in the middle of the sectors I ... IV, (Fig. 1).

Table 17. The perimeter of the I3 sample in its original state, during the test, and after destruction mm.

Sec. →	4	5	6	8	9(I*)	9(I*)	9,5	10	11,5	13	14(II*)	18	19
Phase ↓					Transition								
0	693.5	693.5	693.5	693.5	693.5						693.5	693.0	693.0
0						**731.6**	**732.6**	**735.8**	**737.5**	**736.5**	**735.0**		
									W	W	W		
13	698.8	698.7	698.8	697.2	695.2	**731.6**	**733.2**	**736.0**	**738.8**	**737.8**	**735.0**	699.8	699.4
14	703.2	703.0	703.8	700.4	697.0	**732.4**	**733.6**	**736.8**	**738.8**	**737.6**	**735.5**	704.2	704.2
15	711.0	710.6	710.8	705.2	700.0	**733.5**	**734.5**	**737.0**	**739.0**	**737.6**	**735.5**	714.2	714.0
16	723.2	723.0	722.0	711.0	702.8	**734.6**	**734.8**	**737.0**	**739.0**	**737.8**	**735.5**	726.8	726.0
17	738.2	739.6	737.0	717.2	705.8	**735.8**	**735.2**	**737.0**	**739.4**	**737.8**	**736.0**	743.0	741.8
18	761.2	764.0	760.0	729.0	709.2	**736.2**	**735.2**	**737.0**	**739.4**	**737.8**	**736.0**	<u>764.0</u>	<u>764.0</u>
18**					699.0			695.0		694.8	695.0		

Notes: After installation of the bandage the perimeter of the pipe at areas not covered with bandage has not changed. W - wire strain gauges on a bandage. Bold values relate to the bandage. Underlining values relate to measurements at the area of destruction. The sample is divided into 22 conditional sections (see. Fig. 1). Cross-section 9.5 is located between the 9th and 10th sections. Transition – the area of the beginning of the bandage (see. Fig. 24).

* - one value for the pipe other for the bandage.

** - After removal of the bandage.

In the middle of the defect in the ring (R) and axial (A) directions were punched measuring bases (see. Figure 22b): R = 44.8 mm, A = 45.0 mm. After the destruction of the sample and removal of the bandage: R = 45.4 mm, A = 45.0 mm. The measurement was made by the metal ruler. The length and width of the defect in the initial state, measured in the middle by caliper: 133.2 × 102.2 mm. After the destruction of the sample and removal of the bandage length and width amounted: 133.3 × 103.2 mm.

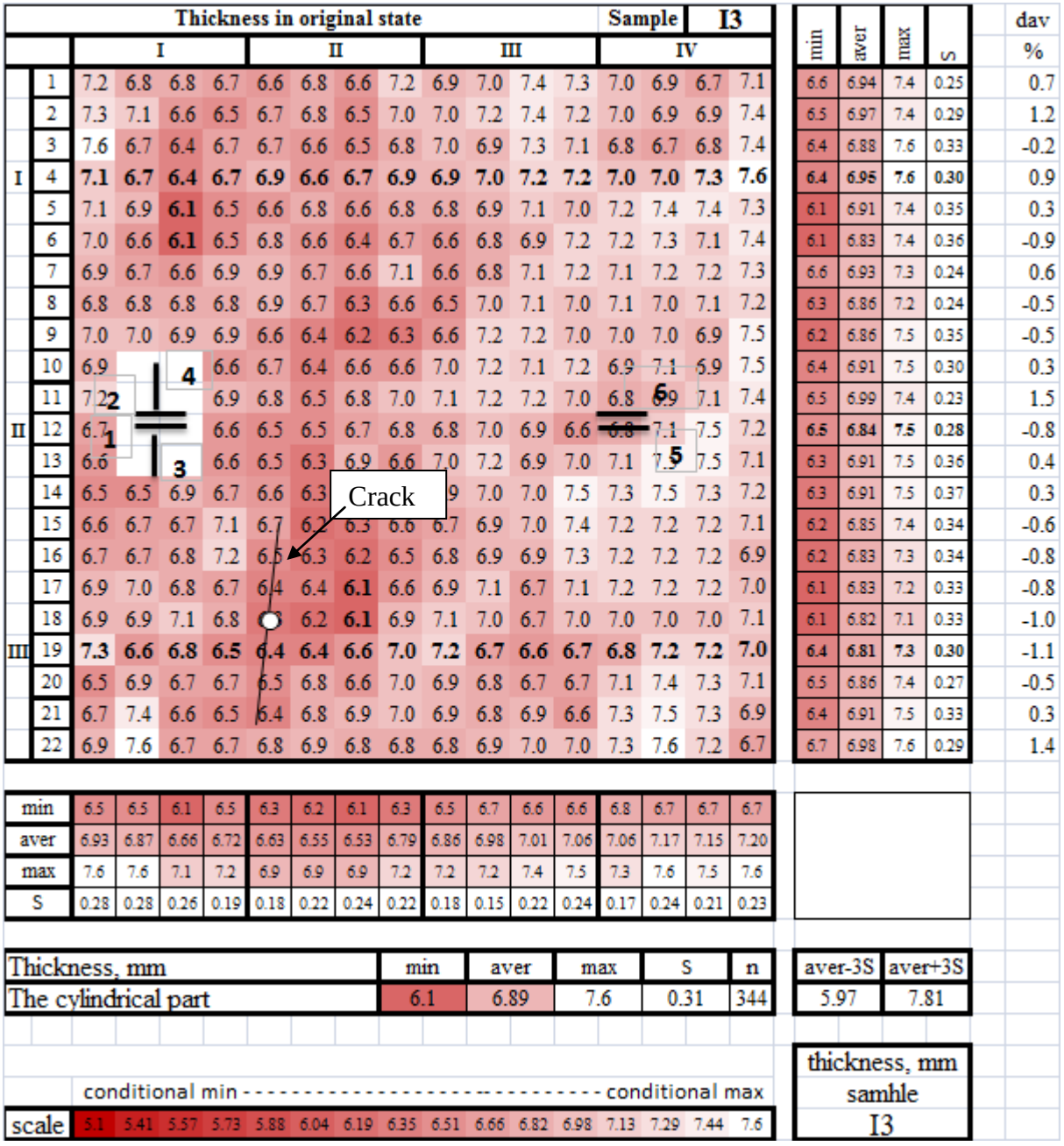


Fig. 19. The map of the wall thickness of the specimen I3 in its original condition, mm. The diagram shows the position of the crack, resulting in the destruction of the specimen, the white dot indicated the start point of the destruction. Bold horizontal and vertical lines present mounted on the specimen strain gauges. All other designations as in Fig. 4.

Weight of empty specimen: 60.6 kgf. Weight of the specimen filled with water: 92.5 kgf. Water temperature: 23 ^{o}C. Weight of water: 31.9 kgf. Internal volume of the specimen - 31.9 liters.

Table 18. Strains ($\times 10^{3)}$, in the annular and axial directions, measured by strain gauges 1...6 mounted on the sample I3[1)].

gage number		1	2	3	4	5	6
Regulations		Defect	Defect	Defect	Defect	Tube	Tube
Direction		Ring	Ring	Axial	Axial	Ring	Ring
Step	P, MPa						
0	0	0	0	0	0	0	0
1	2.12	0.367	0.367	0.092	0.092	0.110	0.110
2	3.13	0.541	0.495	0.128	0.138	0.156	0.165
3	3.84	0.679	0.633	0.165	0.165	0.202	0.211
4	5.05	0.926	0.899	0.211	0.220	0.266	0.275
5	5.93	1.164	1.073	0.257	0.257	0.312	0.321

[1)] The measurements were performed before the installation of the bandage.

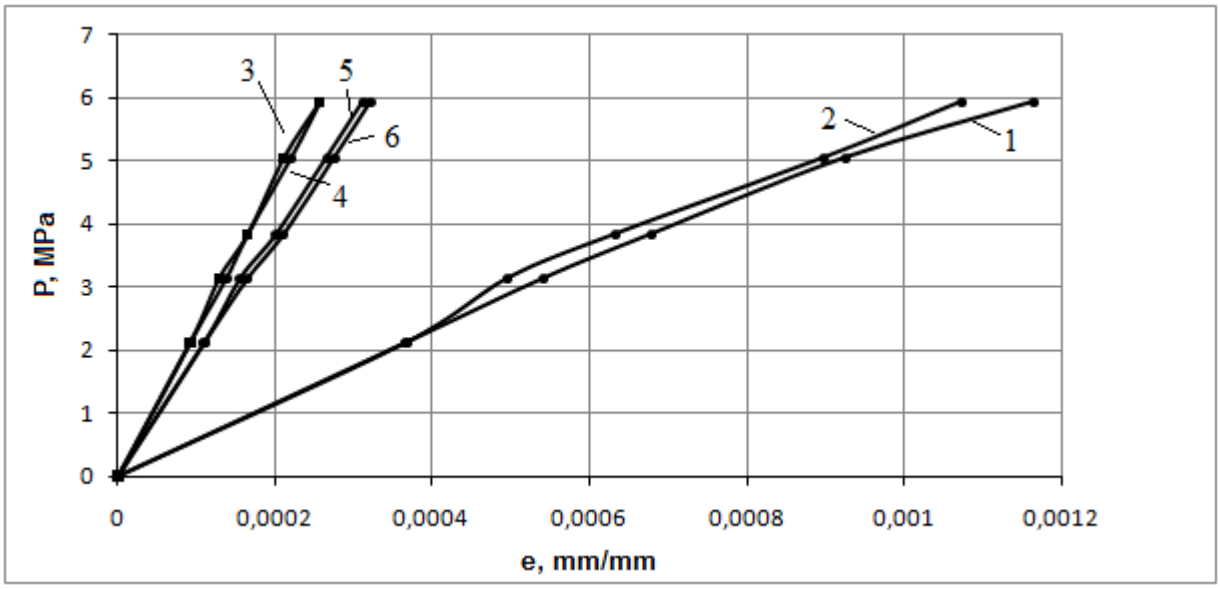


Fig. 21. Strains measured by gauges 1 ... 6.

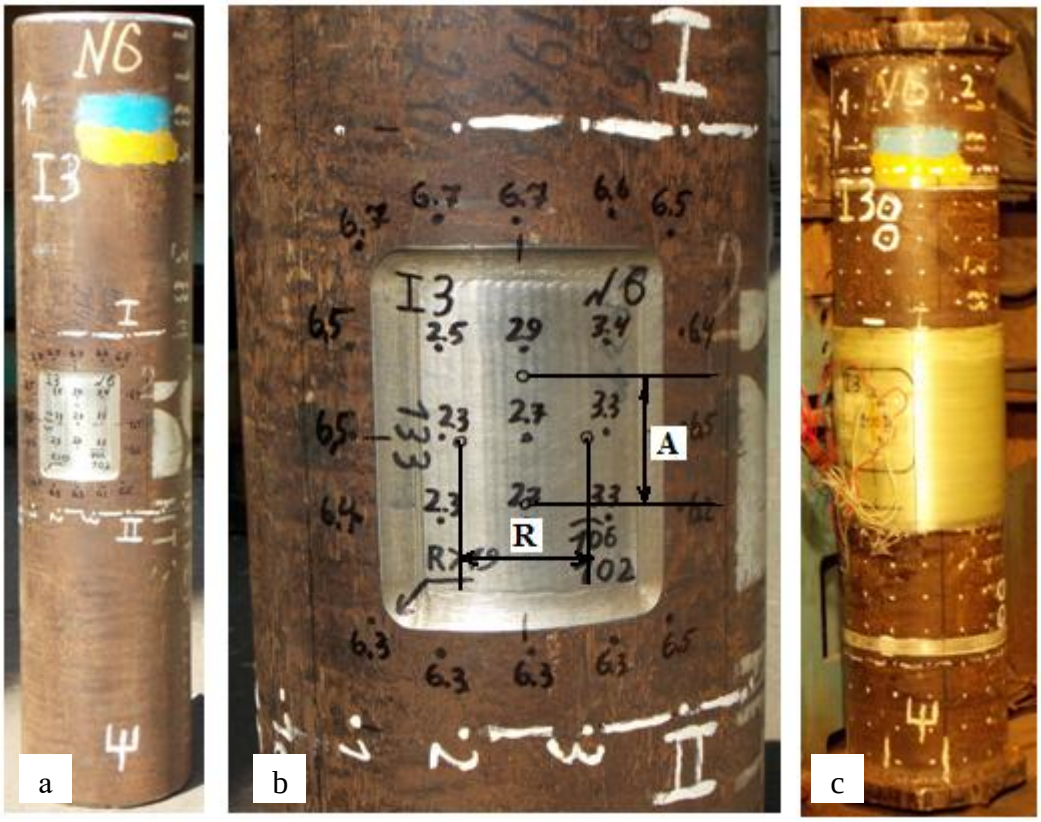


Fig. 22. Sample I3: a – pipe section #6 with defect; b - defect; c - sample I3 with a bandage.

The average remaining wall thickness in the defect - 2.82 mm, average wall thickness around the defect - 6.46 mm. After destruction, the average thickness of the wall around the defect and in the defect has not changed. The length of the weld along the axis of the tube is about 10 mm.

In order to align the outer surface of the pipe the cavity of the defect before installation of the bandage was filled with blend consisting of chopped to pieces roving (pieces of about 15 mm length) mixed with epoxy binder of cold hardening ("Himkontakt - Epoxy" TU-U 24.6-2558309112-006-2006).

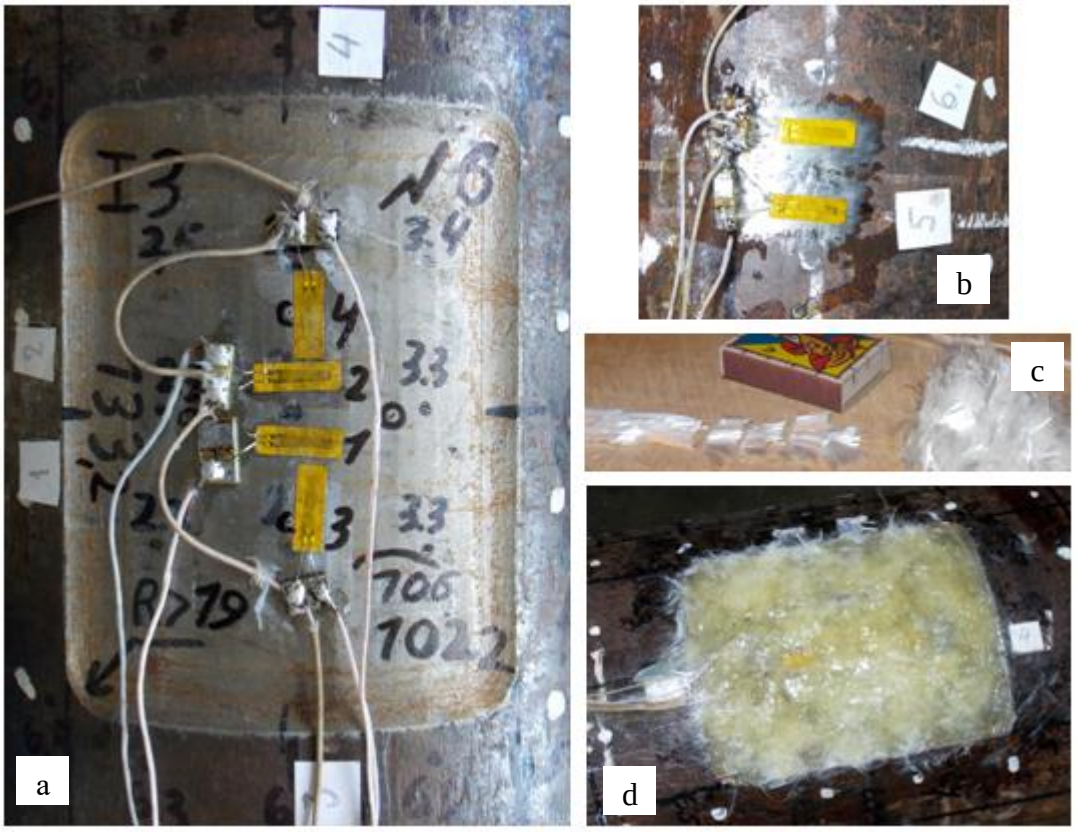


Fig. 23. Installation of strain gauges in the defect (a) on the tube (b); roving for preparation the filling (c); defect filled with bland (d).

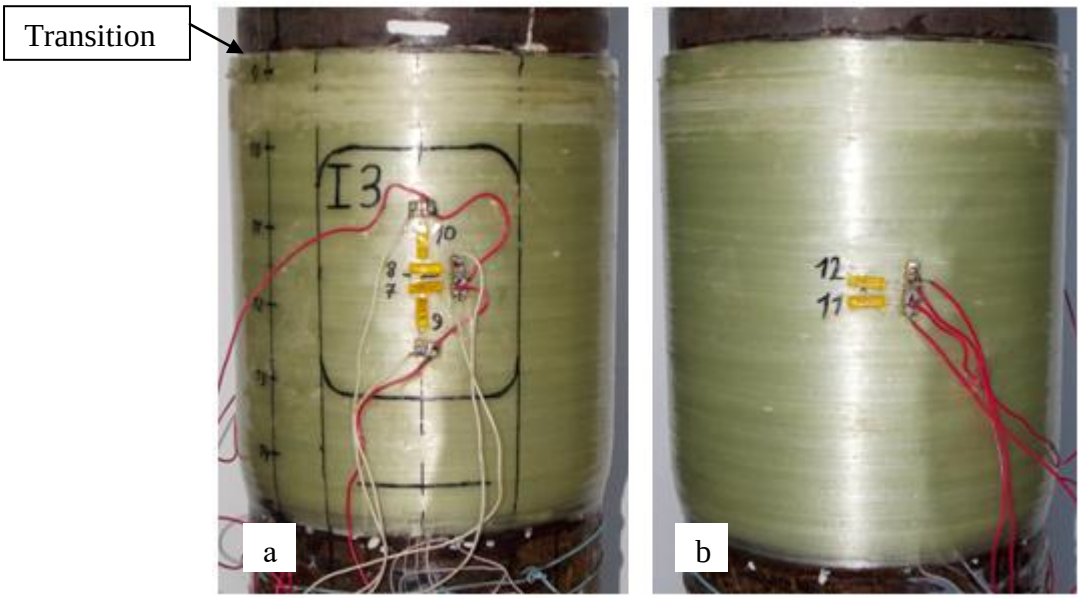


Fig. 24. Installation of strain gages on the bandage: a - in the area of the defect; b - in the regular part.

Strain gages, mounted on a bandage, were located over the strain gauges mounted on a metal pipe.

The bandage on the sample I3 consisted of 16 layers. Step of bandage winding - 2.36 mm / turn, the tension of the roving during bandage winding ~ 4.6 kgf. General thickness of the bandage

~ 6.22mm. The width of the bandage ~ 263 mm, excluding a bevel on one side ~ 234 mm. Bandage is located between the 9th and 15th sections.

Table 19. Temperature during polymerization of the bandage.

Day	Heating	Excerpt
	from-to, °C / min	°C / min
1	20-120 / 90	120 / 120
2	20-130 / 90	130 / 90
2	130-140 / 30	140 / 180
3	20-150 / 90	150 / 180

Table 20. Strains ($\times 10^3$), measured by strain gauges 1...6 mounted on a metal area and 1*…6 * - on bandaze[1)].

Step	P, MPa	1	2	3	4	5	6	1*	2*	3*	4*	5*	6*
0	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
1	3.13	0.532	0.541	0.128	0.147	0.165	0.147	0.128	0.101	0.156	0.046	0.138	-
2	5.35	0.770	0.807	0.220	0.202	0.275	0.257	0.330	0.293	0.238	0.110	0.229	-
3	6.40	0.899	0.935	0.275	0.229	0.330	0.312	0.422	0.385	0.275	0.138	0.266	-
4	7.53	1.027	1.054	0.321	0.266	0.385	0.367	0.513	0.477	0.330	0.193	0.321	-
5	8.99	1.210	1.201	0.403	0.312	0.468	0.449	0.706	0.651	0.403	0.266	0.376	-
6	10.36	1.375	1.357	0.523	0.358	0.523	0.513	0.990	0.917	0.513	0.358	0.431	-
7	12.92	1.568	1.540	0.752	0.440	0.651	0.642	1.632	1.495	0.770	0.477	0.532	-
8	14.69	1.605	1.770	0.908	0.972	0.743	0.734	2.127	1.962	-	-	0.605	-
9	16.65	1.944	2.274	1.091	1.229	0.844	0.844	2.677	2.494	-	-	0.688	-
10	18.38	2.613	2.934	1.302	1.495	0.954	0.963	3.182	2.998	-	-	0.770	-
11	19.90	3.237	3.952	1.595	1.742	1.064	1.036	3.613	3.393	-	-	0.889	-
12	20.65	3.897	-	1.953	2.054	1.164	1.128	3.787	3.585	-	-	0.963	-
13	21.21	4.447	-	2.219	2.375	1.265	1.220	3.961	3.732	-	-	0.981	-

[1)] The measurements were performed after installation of the bandage. Strain gages 1* ... 6* installed on the bandage over the strain gages 1 ... 6.

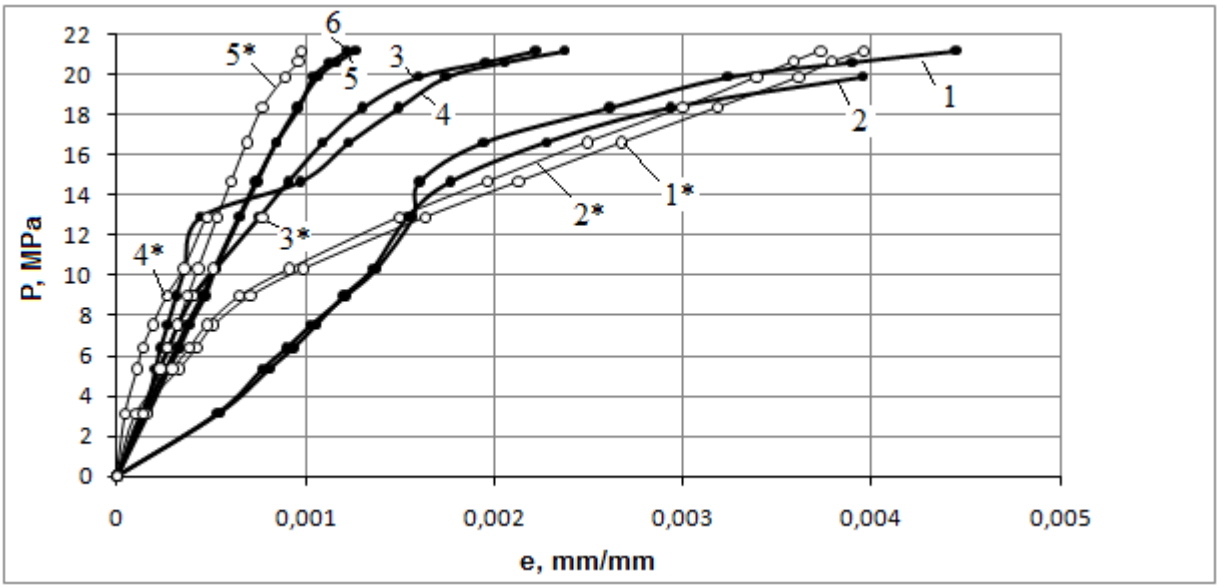


Fig. 25. Strain measured by gauges 1 ... 6 mounted on a metal area and 1*... 6* on the bandage.

Table 21. Changes in weight of the specimen I3.

after step	P, MPa	Weight G, kgf	Δ G, g
0	0	96.2*	0
13	12.21	96.5*	
13	21.21	96.4	300
14	22.76	96.7	600
15	24.81	97.2	1100
16	26.74	97.85	1750
17	27.90	98.65	2550
18	29.03	-	-

Notes: * - Weight with bandage and strain gauges. Further, without strain gages. The water temperature during the test 23 °C.

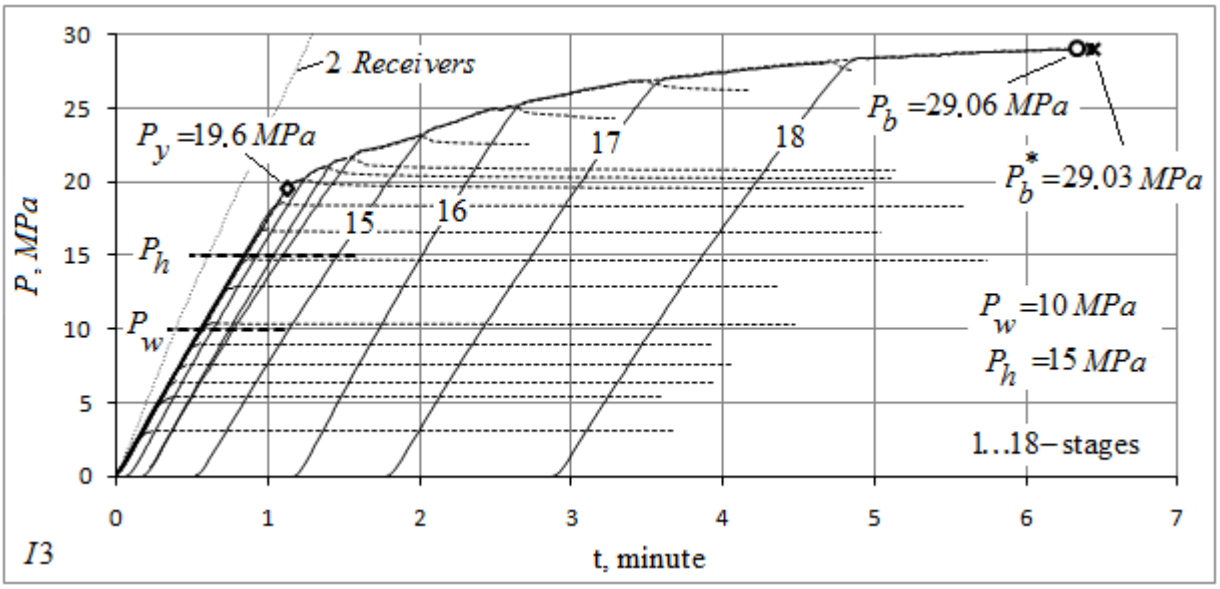
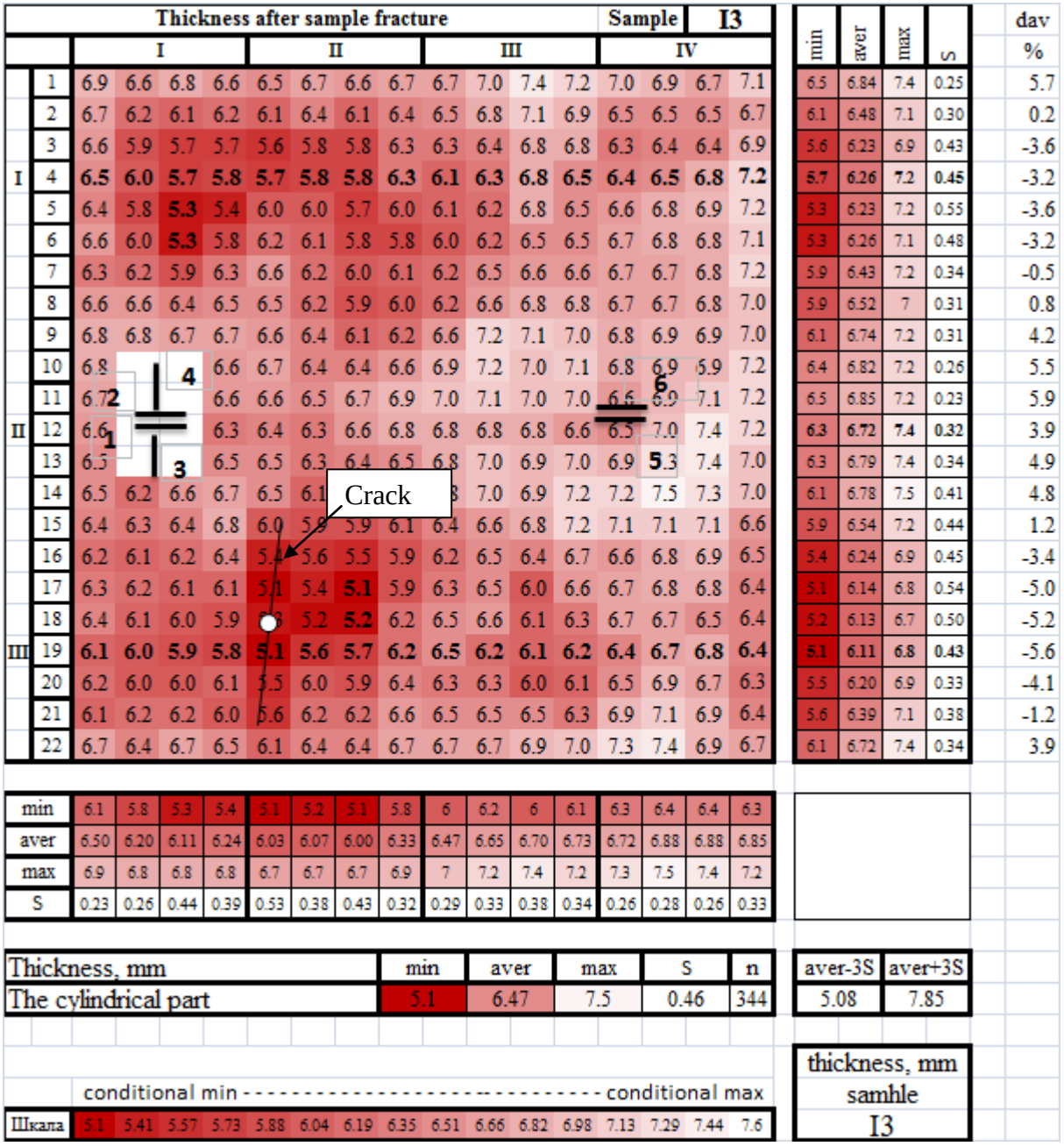


Fig. 26. Stages of internal pressure loading of the sample I3.

P_w, P_h - work and test pressure; P_y - yield pressure; P_b, P_b^* - the maximum pressure that sustained the specimen and the pressure at which the failure occurred; 2 receivers - the pressure in the two paired receivers connected with the specimen.



Thickness, mm	min	aver	max	S	n
The cylindrical part	5.1	6.47	7.5	0.46	344

aver-3S	aver+3S
5.08	7.85

Fig. 27. The map of the wall thickness of the sample after the destruction, mm. The diagram shows the position of the crack, resulting in the destruction of the sample, the white dot indicates the beginning of the destruction. Bold horizontal and vertical lines present ring and axial strain gauges. All other designations as in Fig. 4.

The nature of the destruction of the metal sample was plastic. Wall thickness at the area of fracture, measured with a caliper ~ 4.5 mm. The maximum crack opening ~ 35.5 mm. Crack length ~ 280 mm. After cutting the band in an axial direction and separation it from the metal pipe the gap between cut ends of the bandage ~ 4 mm.

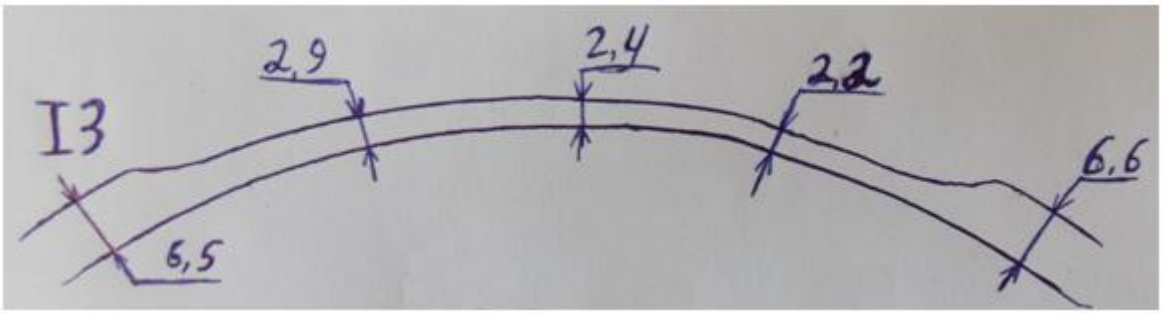


Fig. 28. Defect section contour in the circumferential direction after the destruction of the sample I3.

Fig. 29. Specimen I3 after the destruction:
a sample after the test; b - in the process of disclosure of the defect; c - after the complete opening of the defect; d - filling of the defect; e – the cut area of the defect.

Protocol of specimen I4 (bandage, no defects)

Loading of the specimen by internal pressure was done stepwise, after each step the pressure was released to 0.

The chronology of measurements and loading of the sample by internal pressure is given below:

- stage 1 ... 7 – measurement of change of the specimen volume prior to the plastic deformation (without bandage) in the water jacket;
- stage 1 ... 5 - measurement of deformations on the surface of the pipe by strain gauges (without bandage);
- installation of the bandage;
- stage 1 ... 6 - measurement of deformation on the surface of the pipe and bandage by the strain gages;
- stage 1 ... 19 - – measurement of change of the specimen volume in the water jacket;
- stage 20 ... 26 - measurement of change of the bandage perimeter and of change of the specimen weight.

For the manufacture of the specimen was used the pipe section # 5 with weight: 33.2 kgf.

Table 22. The length of the cylindrical portion of the specimen I4 and other axial dimensions in the original condition and after the destruction.

#	Linear size, mm	Sector				
		I	II	III	IV	average
In the initial state						
1	length of the pipe piece, l_o	948,5	951	952	950	950,38
2	length between sealing bottoms	954	957	959	956	956,50
3	distance between the sections I-III	646	648	648,5	645	646,88
4	distance between the sections I-II	322	321,5	320	321,5	321,25
5	distance between the sections II-III	324	327,5	328	323,5	325,75
After the destruction						
2	length between sealing bottoms	964	965	965	962	964,00
3	distance between the sections I-III					
4	distance between the sections I-II	337,0	325,5	324,0	325,5	328,00
5	distance between the sections II-III	326,5	329	330	325,5	327,75

Note: The measurements were done in the middle of the sectors I ... IV, (Fig. 1). The distance between the cross sections was determined by the punched points. The distances between the sections I-II after the destruction was measured along the bulging surface.

Table 23. Specimen I4 perimeter before (P_H) and after destruction (P_K).

Cross section →	I	II	III	average		Sec. 7
Perimeter, P_H, mm	693,2	692,8	693	693,00		692,9
Perimeter, P_K, mm	700,5	703,0	700,5	701,33		759

Note: For the designation of sections see. Fig. 1.

Table 24. Distances between points of measure in initial state (l_H) and after fracture (l_K), (mm).

Distance	Measuring point #	Sec. I		Sec. II		Sec. III	
		l_H	l_K	l_H	l_K	l_H	l_K
1^*-2^*	1	42.6	42.8	42.8	43.5	42.8	43.0
2^*-3^*	2	43.7	44.5	43.3	43.8	44	45.0
3^*-4^*	3	44.2	44.8	43.4	44.0	44	44.6
4^*-5^*	4	42.6	43.0	43	43.8	43	43.5
5^*-6^*	5	42.2	42.6	43	43.5	43	43.6
6^*-7^*	6	43.6	44.0	44.8	45.0	43.5	44.0
7^*-8^*	7	44.6	45.0	45	45.8	44.3	45.0
8^*-9^*	8	42.4	42.8	42.5	43.0	42.8	43.4
9^*-10^*	9	42.5	43.2	42.8	43.4	42.6	42.8
10^*-11^*	10	44.7	45.0	43.3	43.6	42.4	42.6
11^*-12^*	11	44.5	44.8	43.5	44.0	42	42.2
12^*-13^*	12	42.2	42.6	42.5	43.0	42.8	43.0
13^*-14^*	13	43.2	43.6	42.8	43.2	43.2	44.0
14^*-15^*	14	43.6	44.0	43.6	44.0	44.2	44.4
15^*-16^*	15	44	44.6	43	43.8	44.8	45.2
16^*-1^*	16	42	42.8	42.8	43.4	43	43.6
Σ	-	692.6	700.1	692.1	700.8	692.4	699.9
average	-	43.29	43.76	43.26	43.80	43.28	43.74

Note: For the designation of sections see. Fig. 1.

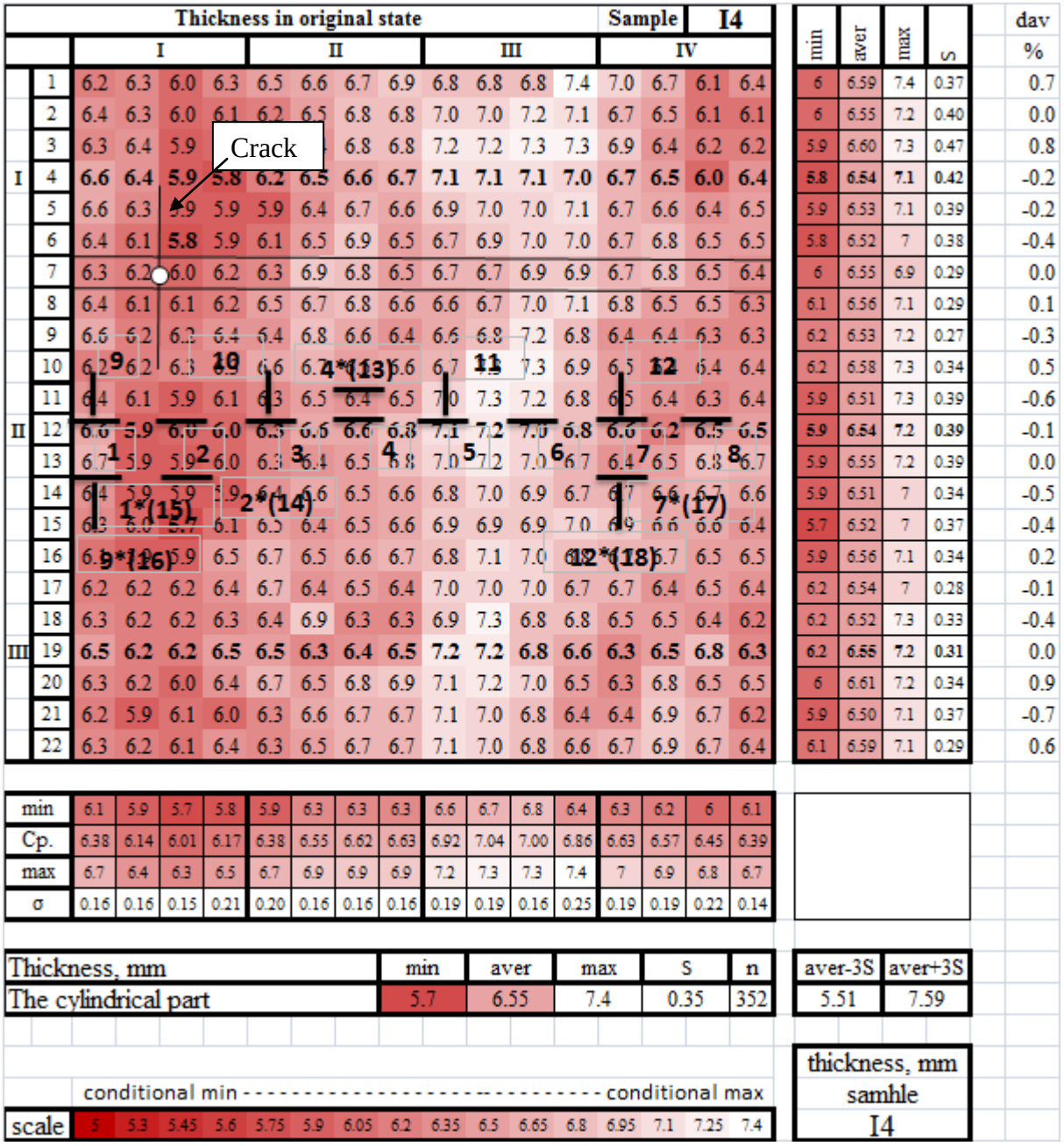


Fig. 30. The wall thickness of the specimen in its original condition, mm.

The cross-section II is between the 11th and the 12th lines, but for measurement of its thickness was taken the 12 line. An asterisk (*) marks gages glued to the bandage. All other designations as in Fig. 4. The diagram shows the position of the crack, resulted in the destruction of the specimen. The white dot indicates the start point of the destruction. By bold horizontal and vertical lines are presented the strain gauges installed on the specimen surface.

Fig. 31.Specimen I4 before the installation of the bandage.
a - general view of the specimen; b – piece of the pipe welded to the sealing bottom to fixing the specimen in the jig of the machine; c - weld of top sealing bottom; d - nuts welded to sealing bottom for fixing specimen in the tailstock of the machine; e – weld of the lower bottom.

Weight of empty specimen: 61.8 kgf. Weight of the specimen filled with water: 93.6 kgf. Water temperature: 10 ^{o}C. Weight of water: 31.8 kgf. Internal volume of the specimen of 31.8 liters. Weight of the bandage -3.6 kgf; general weight of installed strain gauges and connecting wires - 0.1 kgf. Length of the sealing weld along the axis of the pipe -10 mm.

Table 25. Perimeters of the cross-sections in specimen original state - P_H , during the test (after removing from the water jacket) - P and after the specimen destruction - P_K mm.

		P, MPa	Weight G, kgf	ΔG, g	Perimeter, mm.					
Section →					I	II	-	III	7	-
Before installing the bandage	P_H				693.2	692.8		693.0	692.9	
Section →					I*	II*	II**	III*	7	7*
After installing the bandage		0	97.3		709.2	712.8	708.4	710.8	692.9	708.8
After step	19		97.5[1)]							
	19	27.02	98.5	200	711.2	715.2	710.8	712.2	697.6	710.8
	20	28.60	98.5	200	711.6	716.5	711.5	713.0	699.0	711.6
	21	30.10	98.6	300	712.4	717.0	712.4	714.0	700.8	712.8
	22	31.60	98.7	400	713.2	717.8	712.8	714.4	702.0	713.8
	23	33.10	98.8	500	713.6	718.2	713.4	715.2	703.5	714.0
	24	35.10	99.0	700	714.8	719.6	714.5	716.0	705.2	715.2
	25	37.10	99.1	800	715.4	719.8	715.0	716.5	707.2	715.8
	26	39.60	-	-	715.6	720.2	715.2	717.2	759	-
The thickness of the bandage, mm, (approximately)					2.5		2.5	-		
					I	II	-	III	7	-
After removing the bandage	P_K				700.5	703.0		700.5	759	

Notes: Section I is located at a distance of 150 mm from the top of the pipe section, and in welded specimen at distance of 155 mm from the nearest bottom. Cross section II is located in the middle of the pipe section, and in welded specimen at a distance of 475 mm from the nearest bottom. Cross section III is located at a distance of 150 mm from the bottom of the pipe section, and in welded specimen at a distance of 155 mm from the nearest bottom. The cross-section 7 (7th from the top) located in the welded sample at a distance of 280 mm from the nearest bottom. 7* - section of the bandage corresponding to the cross section 7 of the pipe, but located 20 mm below the edge of the bandage. The sections marked with * relate to the bandage. Cross section II ** is shifted above the strain gage in axial direction. Width of roulette tape - 10 mm., its thickness - 0.2 mm. The slot width -25 mm.

[1)] – here, unlike of other cases, weight does not include the fittings.

Table 26. Strains ($\times 10^3$) by the gages installed on the bandage.

		gages											
		hoop direction								axial direction			
Step	P, MPa	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0	0	0	0	0	0	0	0	0	-	0	0
1	3,68	0,269	0,215	0,296	0,153	0,242	0,251	0,188	0,265	0,063	-	0,054	0,054
2	6,56	0,476	0,404	0,520	0,292	0,431	0,458	0,332	0,467	0,117	-	0,099	0,099
3	8,52	0,619	0,529	0,682	0,377	0,547	0,583	0,440	0,610	0,153	-	0,126	0,126
4	11,85	0,843	0,745	0,933	0,538	0,772	0,817	0,619	0,852	0,215	-	0,179	0,179
5	12,57	0,897	0,803	1,000	0,583	0,812	0,875	0,664	0,906	0,229	-	0,188	0,188

Note: strain measurement was made after the preliminaryloading in the water jacket (after step 7).

Installation of the bandage: the tension of roving kgf 4.2 ± 0,6; step of wrapping along the axis of the specimen - 2.36 mm/turn; the number of layers - 8. Weight of the roving bobbin before winding - 6.68 kg, after winding - 3.80 kgf. The weight of the used roving - 2.88 kgf. Polymerization of the bandage: temperature - 120 °C, duration - 20 hours. Polymerization was done in several shifts, each consisted of raising the temperature to 120 °C and subsequent exposure for several hours.

After installing the bandage, it was cut in circumferential direction (at section 7) to form a groove with width -26 mm. The thickness of the carved out ring by according to 18 measurements.- 2 mm ± 2.5. In order to remove the ring from the specimen an axial groove was done. The ring easily separated from the pipe. After removal of the ring the width of the axial groove increased by 3.2 mm.

Fig. 32. Axial groove in the ring (a); bandage after removal of the ring (b).

Fig. 33. Strain gages on the surface of the pipe before installing the bandage (a) and at the bandage surface (b).

Strain gages, mounted on a bandage, were placed over the strain gages on the surface of the pipe.

Table 27. Strain ($\times 10^3$) by gauges after bandage installation

			gages											
			ring direction								axial direction			
Step		P, MPa	1	2	3	4	5	6	7	8	9	10	11	12
0		0	-	0	-	0	-	-	0	-	0	-	-	0
1		2.14	-	0.126	-	0.031	-	-	0.085	-	0.045	-	-	0.027
2		3.83	-	0.229	-	0.063	-	-	0.166	-	0.085	-	-	0.045
3		5.90	-	0.354	-	0.090	-	-	0.260	-	0.126	-	-	0.072
4		8.46	-	0.507	-	0.126	-	-	0.377	-	0.153	-	-	0.081
5		11.66	-	0.700	-	0.188	-	-	0.520	-	0.224	-	-	0.099
6		12.42	-	0.758	-	0.197	-	-	0.556	-	0.229	-	-	0.126
Step		P, MPa	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*
0		0	0	0	-	0	-	-	0	-	0	-	-	0
1		2.14	0.153	0.094	-	0.076	-	-	0.117	-	0.036	-	-	0.031
2		3.83	0.251	0.179	-	0.162	-	-	0.188	-	0.045	-	-	0.045
3		5.90	0.386	0.265	-	0.265	-	-	0.287	-	0.072	-	-	0.072
4		8.46	0.538	0.386	-	0.368	-	-	0.413	-	0.103	-	-	0.103
5		11.66	0.754	0.547	-	0.507	-	-	0.565	-	0.153	-	-	0.135
6		12.42	0.799	0.583	-	0.538	-	-	0.610	-	0.162	-	-	0.148

After removal of the specimen from the water jacket there were revealed small circular cracks around the bandage.

Table 28. Change in the volume of specimen I4 during test in the water jacket, (WJ). Steps 1 ... 19.

Step #	P_{max}, MPa	P_{min}, MPa	ΔV_{ti}, cm^3	ΔV_{pi}, cm^3	burette
without bandage					
0	0	0	0	0	A
1	3,85	3,85	21,926	0	A
2	5,68	5,66	32,295	0	A
3	6,58	6,57	37,440	0	A
4	7,69	7,68	43,851	0	A
5	8,78	8,76	50,025	0	A
6	10,50	10,49	59,999	0,1583	A
7	12,51	12,50	72,347	0,7915	A
with bandage					
0	0	0	0	0	A
1	1,24	1,24	6,015	0	A
2	3,05	3,04	14,881	0	A
3	4,88	3,86	23,983	0	A
4	6,81	6,79	33,561	0	A
5	8,03	8,02	39,735	0	A
6	9,88	9,86	49,155	0	A
7	12,03	12,01	59,840	0	A
8	13,40	13,38	66,806	0	A
9	14,59	14,57	73,138	0	A
10	15,65	15,62	78,996	0	A
11	16,93	16,89	86,752	0,9498	A
12	18,90	18,83	101,000	4,7492	A
13	20,60	20,50	115,565	9,6568	A
14	21,43	21,32	119,522	8,7069	A
15	22,80		146,277	26,4374	A
16	24,00	23,76	164,440	38,5298	B
17	25,00	24,70	173,384	38,5298	B
18	25,92	25,71	192,649	49,5384	B
19	27,02	26,74	201,594	49,5384	B

Fig. 34. The water jacket

Note: ΔV_{ti} - the maximum (full) change of the volume at each step was determined at the end of exposure to max pressure; ΔV_{pi} - residual change of volume at the appropriate step after pressure release. Changing of the volume was determined by burettes of water jacket (Fig.34) as the difference between level of the liquid columns multiplied by a calibration coefficient and with the addition of 7.4% taking into account the error of the burette A, and 1.78% for burette B.

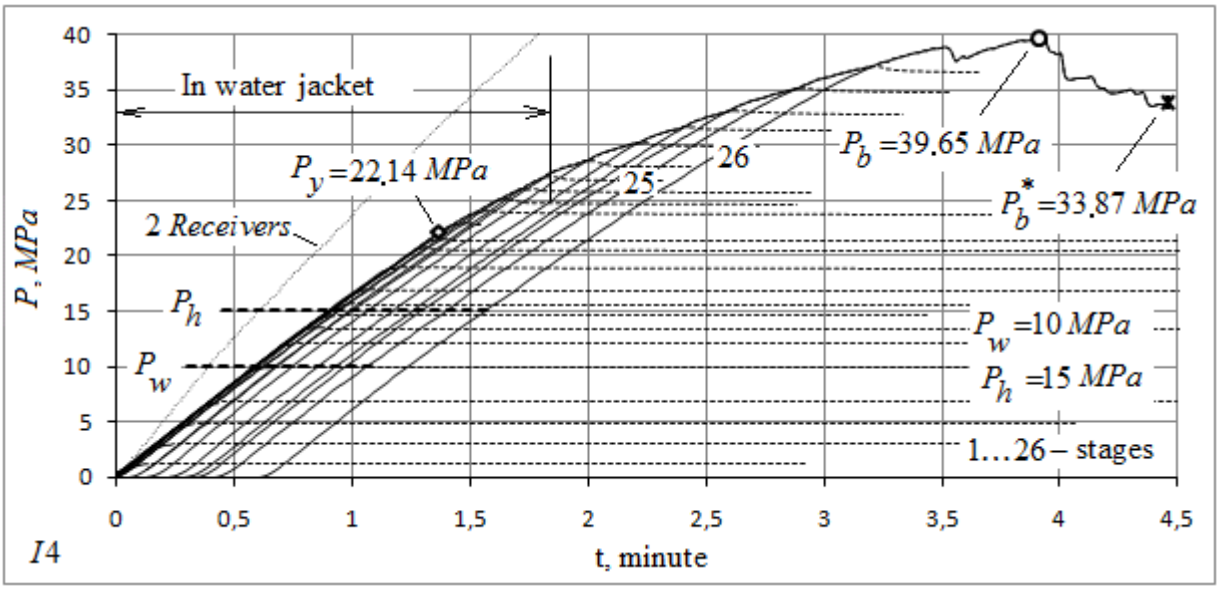


Fig. 35. Internal pressure loading of the specimen.

P_w, P_h - working pressure and test pressure, accordingly; P_y - yield pressure; P_b, P_b^* - the maximum pressure that sustained the specimen and the pressure at which the failure occurred, accordingly; 2 receivers - the pressure in the two paired receivers connected without the specimen.

The length of the broken part of the bandage along the pipe axis ~ 225 mm. The maximum crack opening in the pipe - 36.6 mm. The nature of the destruction of the metal sample was plastic. Wall thickness at the area of fracture, measured with a caliper ~ 4.5 mm. Crack length ~ 280 mm.

Table 29. The wall thickness of the specimen in sections 6, 7, 8, after the destruction mm.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
6	6.1	5.6	5.3	5.4	5.7	6.3	6.6	6.4	6.5	6.8	6.9	7.0	6.5	6.6	6.4	6.2
7	5.8	5.4	5.0	5.1	5.8	6.4	6.4	6.1	6.2	6.5	6.5	6.6	6.2	6.3	5.9	5.8
8	5.7	5.5	5.5	5.6	6.0	6.4	6.3	6.0	6.2	6.4	6.7	6.7	6.4	6.1	6.0	5.7

Note: The wall thickness of cross-section in other cases has not changed significantly.

Fig. 36. Specimen (a) - after the destruction; (b, c) - after removal of the bandage.

Summary results of the samples I1 ... I4 and material.

Basic data about the pipe.

Pipe:

dimension - 219×6; material - 20 steel (carbon steel; weight per meter ~ 33.51 kgf.

Quality certificate # 4/4050. The pipe is manufactured in accordance with GOST 8732-78; GOST 8731-74 Clause 1.2. B (with standardization of mechanical properties and chemical composition). Hot rolled seamless steel pipes. The manufacturer: OJSC "Interpipe NTRP plant." Party number 443, # 32416 melt.

Table 30. The mechanical properties of the pipe material.

According to	$\sigma_в$, MPa (kgf/mm^2)	σ_{02}, MPa (kgf/mm^2)	δ_5, %	Flattening
GOST 8731-74, clause 1.2. B.	412 (42)	245 (25)	21	
Melt number 32416	475,78 (48,5)	323,73 (33,0)	32,0	Satisfactorily
	480,69 (49,0)	328,64 (33,5)	33,0	Satisfactorily
Circumferential direction *	474,76	305	33,13	
Axial direction *	461,40	314	40,97	

* - Data obtained at the Problems of Strength Institute by testing of the samples cut from the pipe.
$\sigma_в$ - tensile strength, σ_{02} - yield strength, δ_5 - relative extension,

Table 31. Chemical composition of the pipe material.

According to	Mass fraction of elements, %							
	C	Mn	Si	S	P	Cr	Ni	Cu
By GOST 1050-88	0.17-0.24	0.35-0.65	0.17-0.37	<0.040	<0.035	<0.25	<0.30	<0.30
Melt # 32416	0.19	0.54	0.29	0.02	0.011	0.07	0.05	0.08
Actually*	0.177	0.55	0.289	0.018	0.008	0.078	0.065	0.070

* - the data obtained in the laboratory of the Electric Welding Institute.

According to GOST 8732-78: wall thickness tolerance +12.5/-15.0%; outer diameter tolerance ± 1,0%; curvature of any portion of the pipe with length of 1 m should not exceed 1.5 mm.

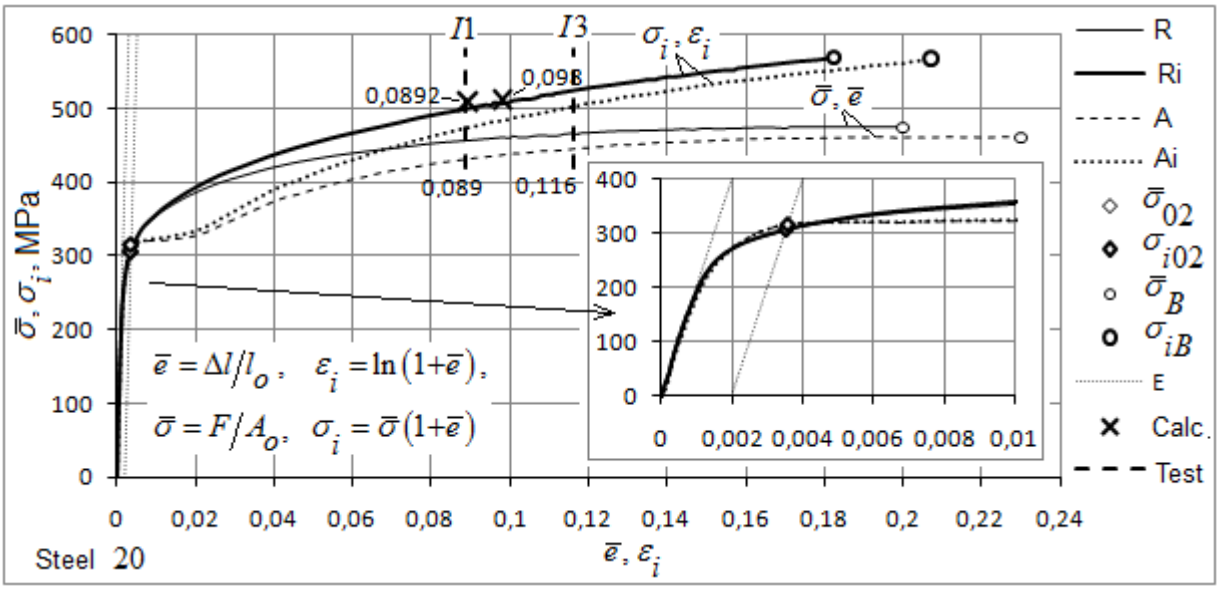


Fig. 37. Tensile diagrams ($\bar{\sigma}, \bar{e}$) of specimens cut in the hoop (R) and axial (A) direction from the pipe in the initial state, and built on their base the actual stress-strain diagram σ_i, ε_i.

At the figure also are shown calculated values of the limit state of the pipe under internal pressure, and the maximum intensity of the strain obtained during tests of samples I1 and I3.

Basic data of the roving

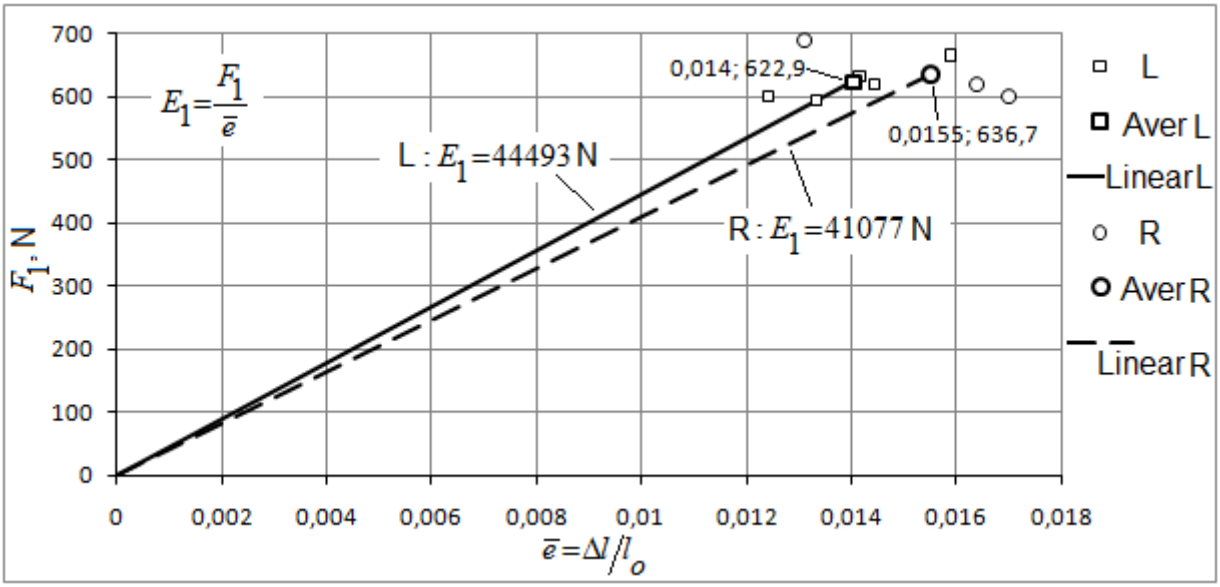


Fig. 38. Effort F_1 per one roving thread (R) (tensile test of loop (L), consisting of a certain amount of roving threads).

Base characteristics of specimens I1...I4

Table 32. The summary characteristics of the specimens I1 ... I4 «INNOPIPES».

Parameter		UM.	sample ID			
			I1	I2	I3	I4
Pipe section						
Outside diameter, D_O		mm	220,15	219,77	220,15	219,99
wall thickness	average, s_o	mm	6,73	6,76	6,89	6,55
	minimal, $s_{\min}$	mm	5,9	6,1	6,1	5,7
Internal volume, W_o		l	32	31,9	31,9	31,8
Distance between the sealing bottoms, l_o		mm	953	953,25	954,5	956,5
Yield pressure, $\left[P_Y\right]$		MPa	10,43	-	-	10,50
Defect						
Remaining wall thickness	average, t_o	mm	-	2,7	2,82	-
	minimal, $t_{\min}$	mm	-	2,4	2,3	-
Linear dimensions (length × width)		mm	-	133× 102	133,2× 102,2	-
Estimated coefficient of strength reduction				0,499	0,493	
Yield pressure, $\left[P_Y\right]$		MPa	-	5,83	5,93	-
Bandage						
outer diameter, D_{O*}		mm	-	-	232,59	225,02
number of layers, n		pcs	-	-	16	8
thickness, s_{o*}		mm	-	-	6,22	2,52
thickness of layer, Δr		mm	-	-	0,389	0,315
Step of winding, Δl		mm/ rev	-	-	2,36	2,36
Yield pressure, $\left[P_Y\right]$		MPa	-	-	16,65	16,93
According loading diagram						
Yield pressure, P_Y		MPa	20	-	19,6	22,14
Maximum pressure, P_b		MPa	27,59	13,83	29,06	39,65
Pressure destruction, P_b^*		MPa	27,44	13,83	29,03	33,87
The actual strength factor, φ		-	1	0,501	1,053	1,437

$\left[P_Y\right]$ - Yield pressure for samples I1 and I4 was determined by water jacket, for samples I2 and I3 by strain gages. P_Y - Yield stress, determined by the internal pressure loading diagram.

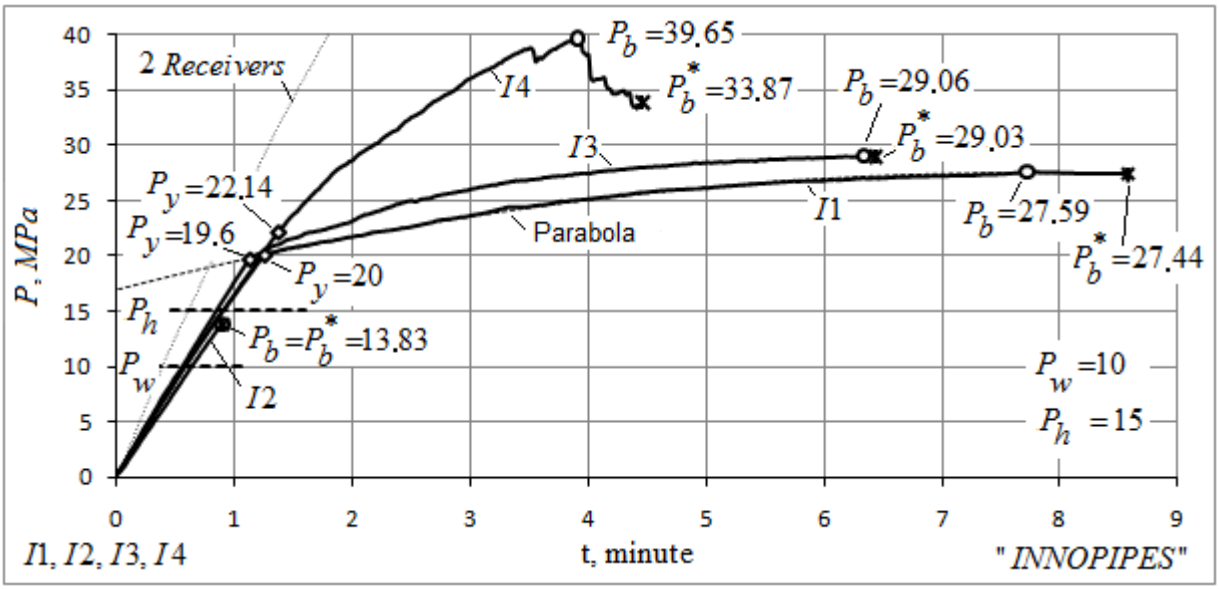
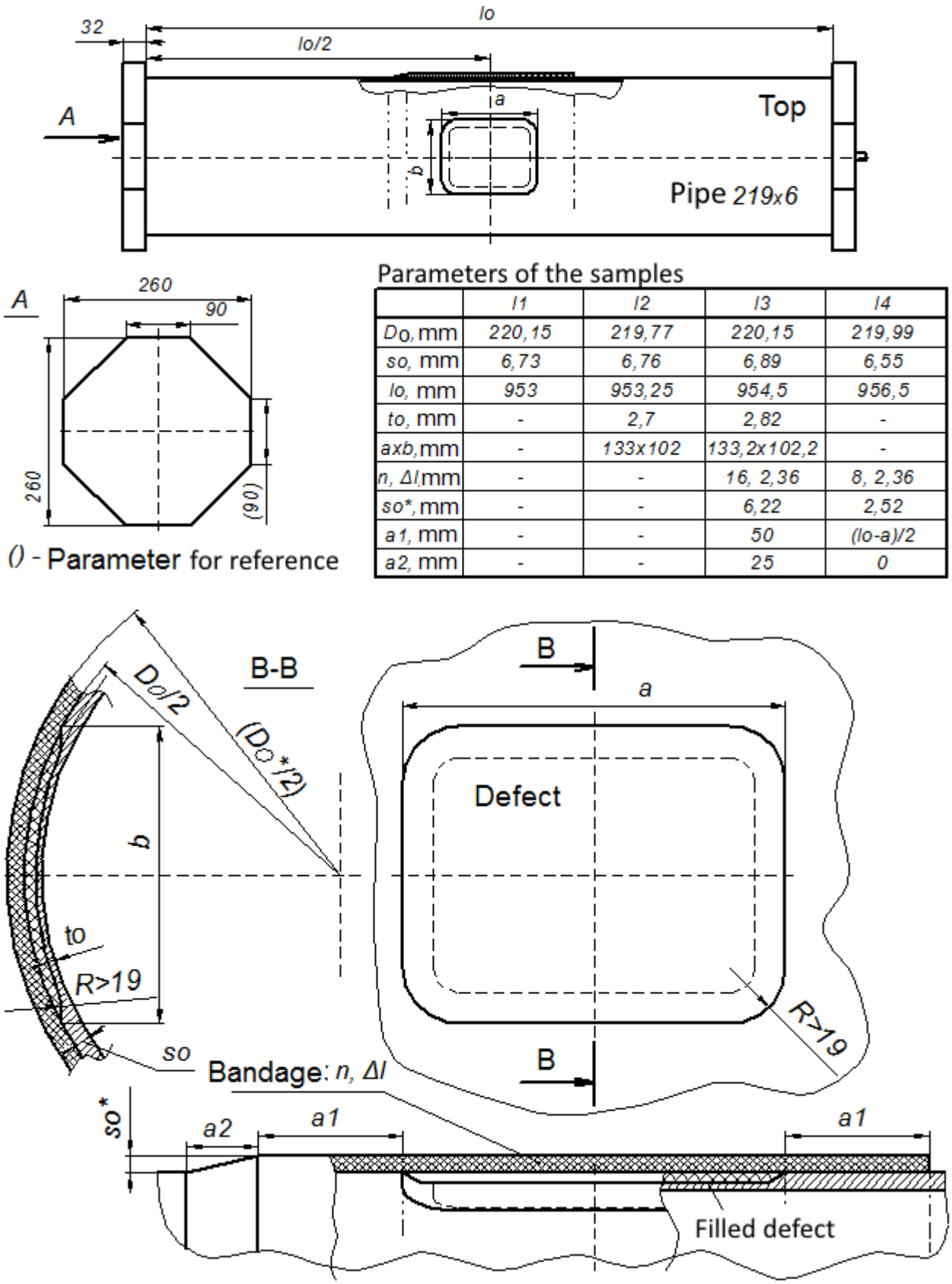


Fig. 39. Internal pressure loading diagrams of specimens I1, I2, I3 and I4.

P_w, P_h - working pressure and test pressure, correspondingly; P_y - yield pressure; P_b, P_b^* - the maximum pressure that sustained the specimen and the pressure at which the failure occurred, correspondingly; 2 receivers - the pressure in the two paired receivers connected without the specimen. Parabola - approximation equation of the second degree.

Fig. 40. Specimens I1, I2, I3 and I4 after the test.



Parameters of the samples

	l1	l2	l3	l4
D_o, mm	220,15	219,77	220,15	219,99
so, mm	6,73	6,76	6,89	6,55
lo, mm	953	953,25	954,5	956,5
to, mm	-	2,7	2,82	-
axb, mm	-	133x102	133,2x102,2	-
n, Δl, mm	-	-	16, 2,36	8, 2,36
so*, mm	-	-	6,22	2,52
a1, mm	-	-	50	(lo-a)/2
a2, mm	-	-	25	0

Fig. 41. Specimen I3 scheme.