Strength assessment of polyethylene pipes

Marius Cocard, Angela Câneparu, Marian Iacob
ISIM Timişoara, Romania
Tel: +40-0256-491828; Fax: +40-0256-492797; e-mail: cocardm@isim.ro, acaneparu@isim.ro

Abstract
The paper presents an analysis of the high density polyethylene pipelines welding process using the electrofusion welding. Experimental researches performed on pipes of 32mm diameter and 3mm thickness, dealt with the simulation of several noncorresponding situations which can appear when joining by welding high density polyethylene pipelines of PE 80, SRD 11 type. The assessment of welded joint strength was made by testing and specific analyses.
Keywords: Electrofusion welding, testing, assessment, welded joints, high density polyethylene

1. Introduction

The development of thermoplastic materials (polyethylene, polypropylene, vinyl chloride) has known special amplitude in the last 50 years. One of the most important fields thermoplastics have applications is that of pressure pipelines.

At present, both on national and European plan, the polyethylene pipes and fittings used are the PE 80 and the PE 100.

In the period 1993 - 2002 the consumption of polyethylene pipes, meant for the distribution of drinking water and natural gasses, used for low and medium pressure pipes in Europe is presented in figures 1 and 2.

It shows that on the background of keeping roughly constant the quantity of PE 80 type pipes used, the PE 100 type pipes quantity increased continuously, both for those distributing drinking water and those distributing natural gasses [1].

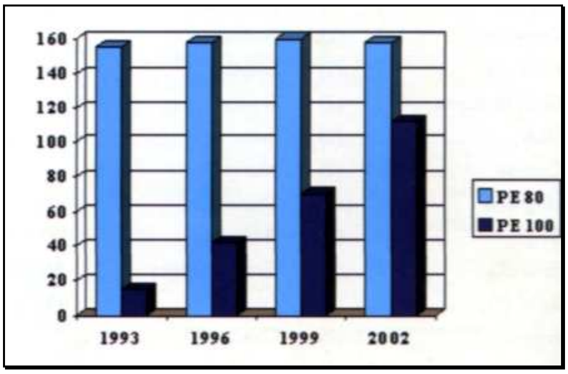


Figure 1. PE 80, PE 100 pipes for drinking water

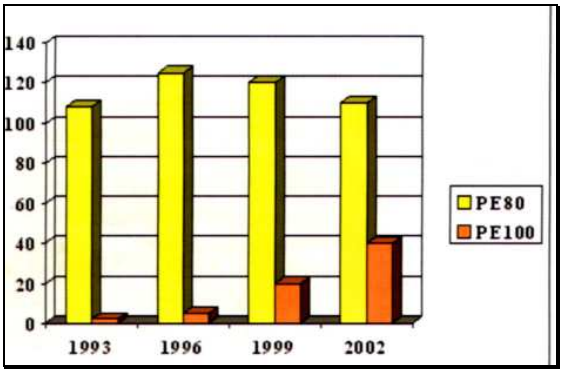


Figure 2. PE 80, PE 100 pipes for gas

For example, the length of polyethylene pipelines for natural gases made in different European countries is presented in percentage, as compared with their total length, in table 1 [1].

Table 1

Country	Gas pipeline total length (Km)	Gas pipeline length - PE (Km)	Ponderosity gas pipeline - PE (%)
Great Britain	252 000	110 000	44
Belgium	40 100	17 700	44
France	137 000	63 500	46
Holland	108 000	12 000	11
Germany	270 000	93 000	34
Denmark	16 000	1 400	9
Spain	14 800	11 700	79
Italy	165 000	7 000	4

It can be mentioned that, only in Great Britain the total length of polyethylene pipelines working from 1969 is about 300 000 Km [2].

Considering the special interest for this field and for the joining by welding of these pipelines, the paper presents an analysis of the PE 80, SDR 11 type high polyethylene welding process using the electro fusion welding.

2. Research and experimental results

Electrofusion welding is a modern welding process which uses special fittings, having incorporated a resistive element; it generates the necessary heat to weld components.

Welded joints made within the experiments were of the socket type – diameter 32 mm, standard dimensional ration SDR11, with pipes (meant for the transport of natural gases) of the PE 80 type and fittings of the PE 100 type (figure 3).

Figure 3. Electrofusion welded joint – socket type

Two of the most important characteristics for the materials it is taking about are:

- lower confidence limit (LCL);
- minimum strength (MRS).

Table 2, according to ISO 4437 standard [3], presents the lower confidence limit (LCL) and that of the minimum required strength (MRS) for PE 80 and PE 100, respectively which were used within experiments.

Table 2

Material	LCL (20 ^{o}C, 50 year) (MPa)	MRS (MPa)
PE 80	8,0...9,99	8,0
PE 100	10,0...11,19	10,0

2.1 Realization of welded joints

From the experience gained till the present different non corresponding situations have been found which can appear when realizing welded joints on site. The multitude of factors involved in the realization of a welded joint: welding personnel, equipment, welding procedure, material compatibility of components used etc., can influence its quality.

From this reason, welded joints have been made by selecting different values for the heating time, unworked components before welding and respectively the assembling of components in order to be welded with different penetration depths of the pipe in the socket interior (table 3).

Table 3

No.	Experiment	Parameters / Conditions	Sample mark
1	E 1.1	t_i = 70 s	E 1.1.1 - E 1.1.9
2	E 1.2	t_i = 60 s	E 1.2.1 - E 1.2.9
3	E 1.3	t_i = 50 s	E 1.3.1 - E 1.3.9
4	E 1.4	t_i = 40 s	E 1.4.1 - E 1.4.9
5	E 1.5	t_i = 30 s	E 1.5.1 - E 1.5.9
6	E 1.6	t_i = 80 s; unworked pipes	E 1.6.1 - E 1.6.9
7	E 1.7	t_i = 80 s; penetration depth 25mm	E 1.7.1 - E 1.7.9
8	E 1.8	t_i = 80 s; penetration depth 20mm	E 1.8.1 - E 1.8.9
9	E 1.9	t_i = 80 s; penetration depth 15mm	E 1.9.1 - E 1.9.9
10	E 1.10	t_i = 80 s	E 1.10.1 - E 1.10.9

On the bases of these welding regimes and in the given conditions, according to table 3, there have been made 9 welded samples from pipes meant for the transport of natural gases, of the PE 80, ø 32 x 3 mm with PE 100 type fittings, ø 32 mm SDR 11, for each case in part.

2.2 Tests and analyses

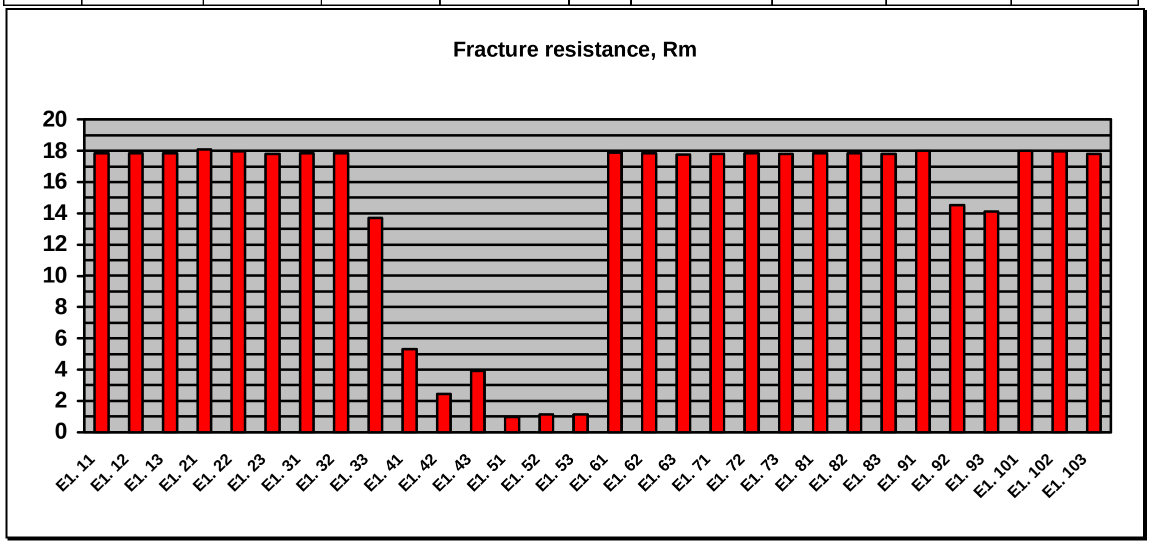
Samples made within each set of parameters/conditions, from E 1.1 to E 1.10 have been subjected to short time, respectively long time tests for macroscopic examination, as it follows:

- welded joints from number 1 to number 3 were tensile tested;
- welded joints from number 4 and 5 were detachment tested;
- welded joints from number 6 to 8 were interior pressure tested;
- welded joints numbers 9 were macroscopically examined.

The checking of welded joints was made firstly by tensile testing according to PT ISCIR CR 7/3 [4] requirements. Results of tensile testing made on section sample are presented in table 4.

Table 4

No.	Sample mark	F_{max} (N)	R_m (N/mm^2)	Fracture position	No.	Sample mark	F_{max} (N)	R_m (N/mm^2)	Fracture position
1	E1.11	5430	17,83	MB	**16**	E1.61	5450	17,90	MB
2	E1.12	5440	17,86	MB	**17**	E1.62	5430	17,83	MB
3	E1.13	5430	17,83	MB	**18**	E1.63	5410	17,77	MB
4	E1.21	5420	18,10	MB	**19**	E1.71	5420	17,80	MB
5	E1.22	5400	17,97	MB	**20**	E1.72	5430	17,83	MB
6	E1.23	5420	17,80	MB	**21**	E1.73	5420	17,80	MB
7	E1.31	5440	17,86	MB	**22**	E1.81	5440	17,86	MB
8	E1.32	5430	17,83	MB	**23**	E1.82	5430	17,83	MB
9	E1.33	4100	13,69	SUD	**24**	E1.83	5420	17,80	MB
10	E1.41	1600	5,32	SUD	**25**	E1.91	5410	18,00	MB
11	E1.42	750	2,46	SUD	**26**	E1.92	4420	14,51	SUD
12	E1.43	1200	3,94	SUD	**27**	E1.93	4300	14,12	SUD
13	E1.51	300	0,99	SUD	**28**	E1.101	5410	18,00	MB
14	E1.52	350	1,15	SUD	**29**	E1.102	5400	17,97	MB
15	E1.53	350	1,15	SUD	**30**	E1.103	5420	17,80	MB



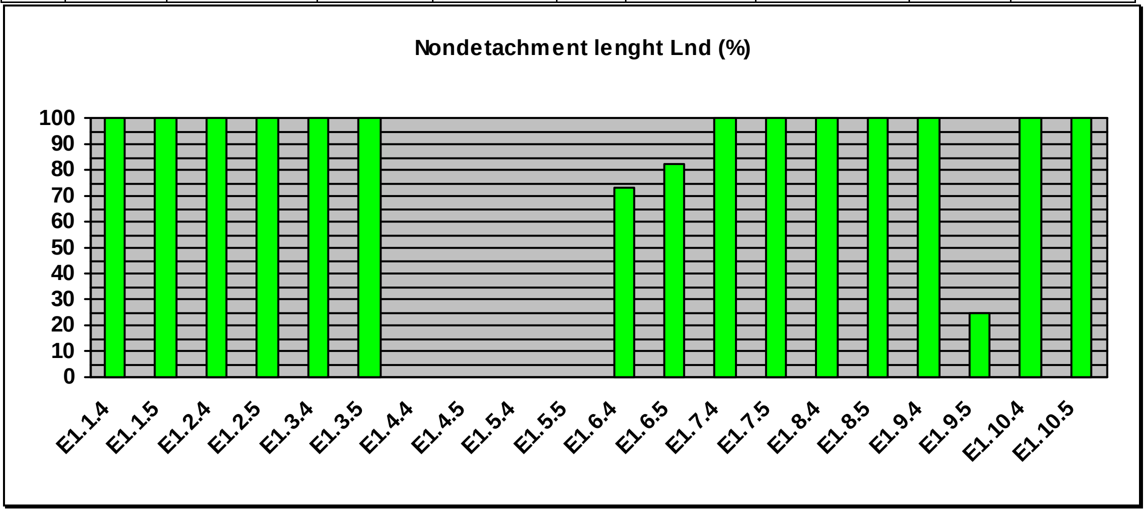
Non corresponding results, with fracture in the weld have been recorded at the following samples: E1.3.3, E1.4.1, E1.4.2, E1.4.3, E1.5.1, E1.5.2, E1.5.3, E1.9.2 and E1.9.3, value of the fracture resistance R_m are in the range 0.99 and 14.51 N/mm^2 (figure 4).

Figure 4. Tensile tested sample

For tests made on welded joints subjected to Peel tests results are presented in table 5.

Table 5

No.	Sample mark	Lack of penetration (%)	Weld length Ls (mm)	Detachment length Ld (%)	No.	Sample mark	Lack of penetration (%)	Weld length Ls (mm)	Detachment length Ld (%)
1	E1.1.4	-	11	-	**11**	E1.6.4	-	11	27
2	E1.1.5	-	11	-	**12**	E1.6.5	-	11	18
3	E1.2.4	-	11	-	**13**	E1.7.4	10	11	-
4	E1.2.5	-	11	-	**14**	E1.7.5	10	11	-
5	E1.3.4	-	11	-	**15**	E1.8.4	29	9	-
6	E1.3.5	-	11	-	**16**	E1.8.5	29	9	-
7	E1.4.4	-	-	100	**17**	E1.9.4	46	4	-
8	E1.4.5	-	-	100	**18**	E1.9.5	46	4	75
9	E1.5.4	-	-	100	**19**	E1.10.4	-	11	-
10	E1.5.5	-	-	100	**20**	E1.10.5	-	11	-



The testing was performed according to SR EN 12814-4:2003 [5], and the results interpretation was made according to the requirements of SR EN 13067: 2004 [6].

Each welded joint was longitudinally cut in two equal parts. Samples obtained in this way were fixed in a pressing device, so that the length between the device bit and the fitting is 5 mm.

The testing was realized by tightening the sample till the two parts of the pipe wall reached contact. An analysis was made to see if fractures were recorded in the weld plan, measuring the length of the longitudinal part detached from the weld – Ld (figure 5).

Figure 5. Samples subjected to detachment testing

In the case of samples E1.4.4, E1.4.5, E1.5.4, E1.5.5, E1.6.4 and E1.9.5 the length of detached longitudinal weld was 25% bigger, the respective joints were not corresponding. In the diagram afferent to table 5 the length of the nondetached part of the tested welded joints - Lnd is presented.

Welded joints from number 6 to number 8 of each set of samples were subjected to interior pressure according to the SR ISO 1167 standard [7].

From data presented in the technical literature, after using finite element modelling [8], there resulted that in the case of electrofusion welded joints zones where maximum stresses appear, depend on the test type the sample is subjected. From figure 6 it can be seen that for the creep testing (figure 6 a), the maximum stress appears in the pipe, in the fitting, respectively – when subjecting the sample to hydrostatic pressure (figure 6 b).

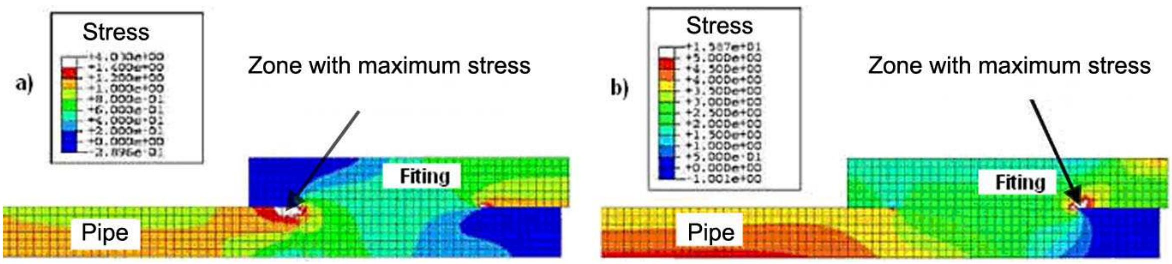


Figure 6. Stress state in the welded joint:
a) creep testing; b) hydrostatic pressure testing

Interior pressure testing was realized at 80 ^oC, water was both conditioning environment (exterior) as well as testing environment (interior). Results are presented in table 6.

Table 6

No.	Sample mark	$P_{testing.}$ (bar)	t (ore)	Fracture position	No.	Sample mark	$P_{testing}$ (bar)	t (ore)	Fracture position
1	E1.1.6	11	461	-	**16**	E1.6.6	11	167	-
2	E1.1.7	11	461	MB	**17**	E1.6.7	11	167	-
3	E1.1.8	11	461	-	**18**	E1.6.8	11	167	-
4	E1.2.6	11	646	MB	**19**	E1.7.6	11	167	-
5	E1.2.7	11	738	MB	**20**	E1.7.7	11	167	-
6	E1.2.8	11	183	-	**21**	E1.7.8	11	167	-
7	E1.3.6	11	183	-	**22**	E1.8.6	11	168	-
8	E1.3.7	11	183	-	**23**	E1.8.7	11	168	-
9	E1.3.8	11	183	-	**24**	E1.8.8	11	168	-
10	E1.4.6	11	183	-	**25**	E1.9.6	11	168	-
11	E1.4.7	11	183	-	**26**	E1.9.7	11	168	-
12	E1.4.8	11	183	-	**27**	E1.9.8	11	168	-
13	E1.5.6	11	-	-	**28**	E1.10.6	11	168	-
14	E1.5.7	11	-	-	**29**	E1.10.7	11	168	-
15	E1.5.8	11	-	-	**30**	E1.10.8	11	168	-

By this testing the aim was to establish zones and time up to the fracture of the sample. From results presented in table 6 it can be seen that up to a minimum time considered as being 165 hours, no fractures appeared in the samples subjected to the test. The joints of samples with the mark E1.5.6, E1.5.7 and E1.5.8 which are not tight, no testing can be done.

For samples E1.1.7, E1.2.6 and E1.2.7 the fracture produced in the base material, in the aria near the fitting (figure 7). For the other samples the testing continues.

.

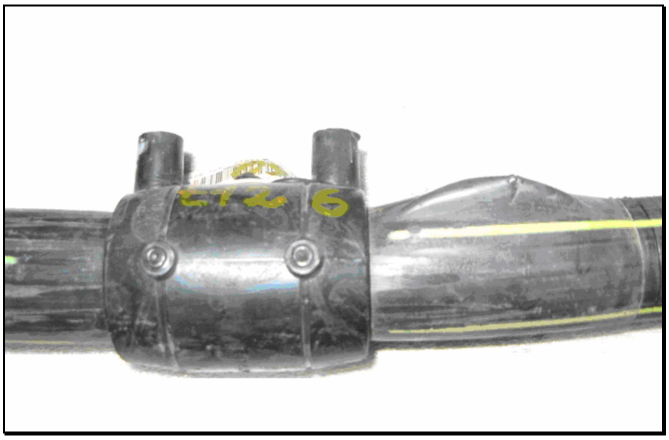


Figure 7. Sample E1.2.6

The following figures present the most representative macroscopic examined samples [9].

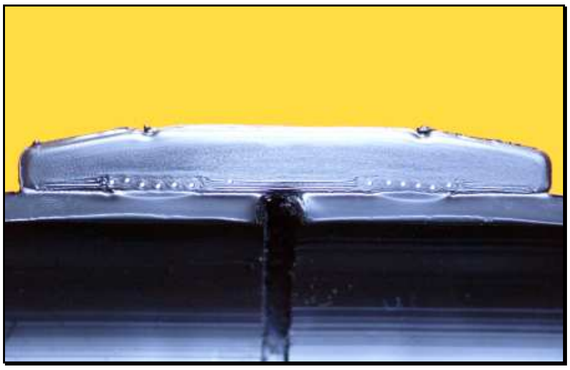


Figure 8. Macroscopic examination - E1.2.9

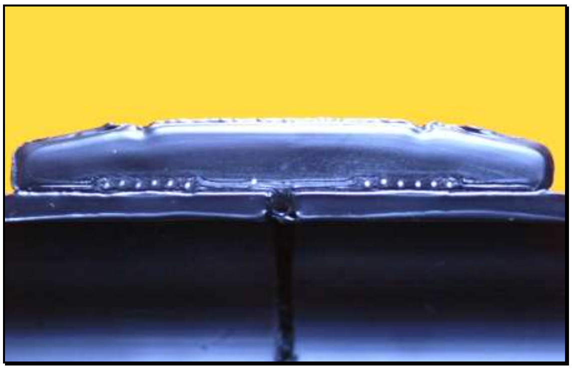


Figure 9. Macroscopic examination - E1.3.9

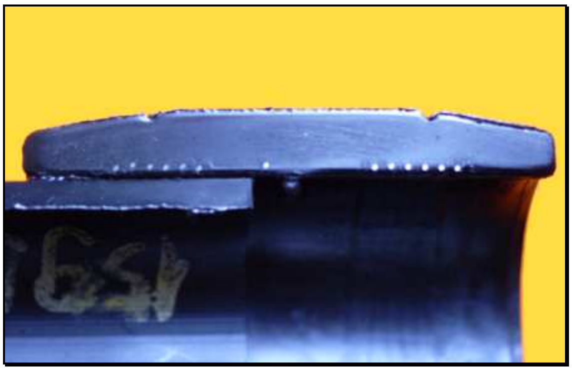


Figure 10. Macroscopic examination - E1.5.9

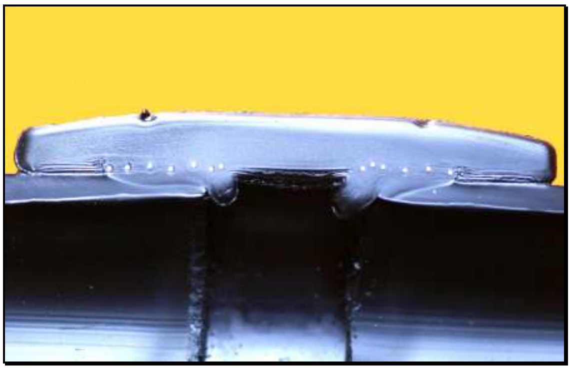


Figure 11. Macroscopic examination - E1.8.9

3. Conclusions

1. The paper aimed to underline some factors that can lead to non corresponding welded joints [10], with the possibility that failure can appear in time, at high density polyethylene pipelines, meant for the distribution of natural gases.

2. The reduction of the heating time to a lower value that 62% versus the recommended and the weld fracture.

3. The abrasion working of the pipes ends on a depth bigger than 0,1 – 0,2 mm determines the reduction of the pipe material strength and the appearance of fracture in that zone. So, it is very important to select some compatible components for welding and from dimensional point of view.

4. After performing interior pressure testing, there resulted that even for major defects welded joints (the penetration depth of the pipe in the socket of only 54 %), failure did not produce up to 165 hours. This evinced the fact that only a pressure test, which is

generally made for the final check of pipes on the site, is insufficient – it is only a tightness test and not a test of the weld quality.

5. The realization of welded joints with the strength and life service at the level of the pipe material (50 years), needs the optimization of electrofusion welding processes qualification and checking by non-destructive methods.

References

1. Leone, G., La crescita del PE nelle reti di distribuzione gas ed acqua in pressione, Rivista Italiana della Saldatura, nr. 4, 2003.
2. www.eltex-pipe.com
3. *** ISO 4437-1997, Canalisation enterrees en polyethylene (PE) pour reseaux de distribution de combustibles gazeaux – Serie metrique – Specifications.
4. *** PT ISCIR CR7/3-2003, "Prescripții tehnice pentru omologarea procedurilor de sudare a țevilor şi fitingurilor din polietilenă".
5. *** SR EN 12814-4:2003, Încercarea elementelor de legătură sudate a produselor semifinite de materiale termoplastice. Partea 4: Încercarea la jupuire.
6. *** SR EN 13067: 2004, Sudori pentru materiale plastice. Testul de evaluare a sudorilor. Îmbinări sudate a materialelor termoplastice.
7. *** SR ISO 1167: 1993, Țevi din materiale plastice pentru transportul lichidelor. Determinarea rezistenței la presiune interioară.
8. Troughton, M., Brown, C., Hessel, J. Piovano, M., Comparison of long-term and short-term tests for electrofusion joints in PE pipes, Plastics Pipes XIII conference, Washington DC, USA, 2-5 October 2006.
9. *** SR EN 12814-5:2001, Încercarea elementelor de legătură sudate a produselor semifinite de materiale termoplastice. Partea 5: Examinarea macroscopică.
10. *** DVS 2202/1 - Defectele îmbinărilor sudate din materiale termoplastice. Caracteristici, descriere, evaluare.