

HOW TO CONTROL BEAD DURING BUTT FUSION WELDING OF LARGE DIAMETER PE PIPES

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Visual and dimensional inspection (VDI) of welded connections is a major quality control component for butt fusion of plastic pipes. The principles of VDI are used by welders to discard faulty joints immediately after welding. VDI is also used by construction company and customer quality controllers as well as representatives from the Technical Supervision Authority. Despite some differences in approach to VDI in various countries, a common visual evaluation of the appearance of the PE pipes welded joints can be highlighted based on American recommendations (pic. 1).

German DVS [2], which for many decades have been the source for Soviet and Russian developments in butt fusion joint control, contain more detailed descriptions of defects found during VDI, e.g. cracks, scratches, reduced cross-sections near the welded joints, asymmetry, unevenness of bead and other defects.

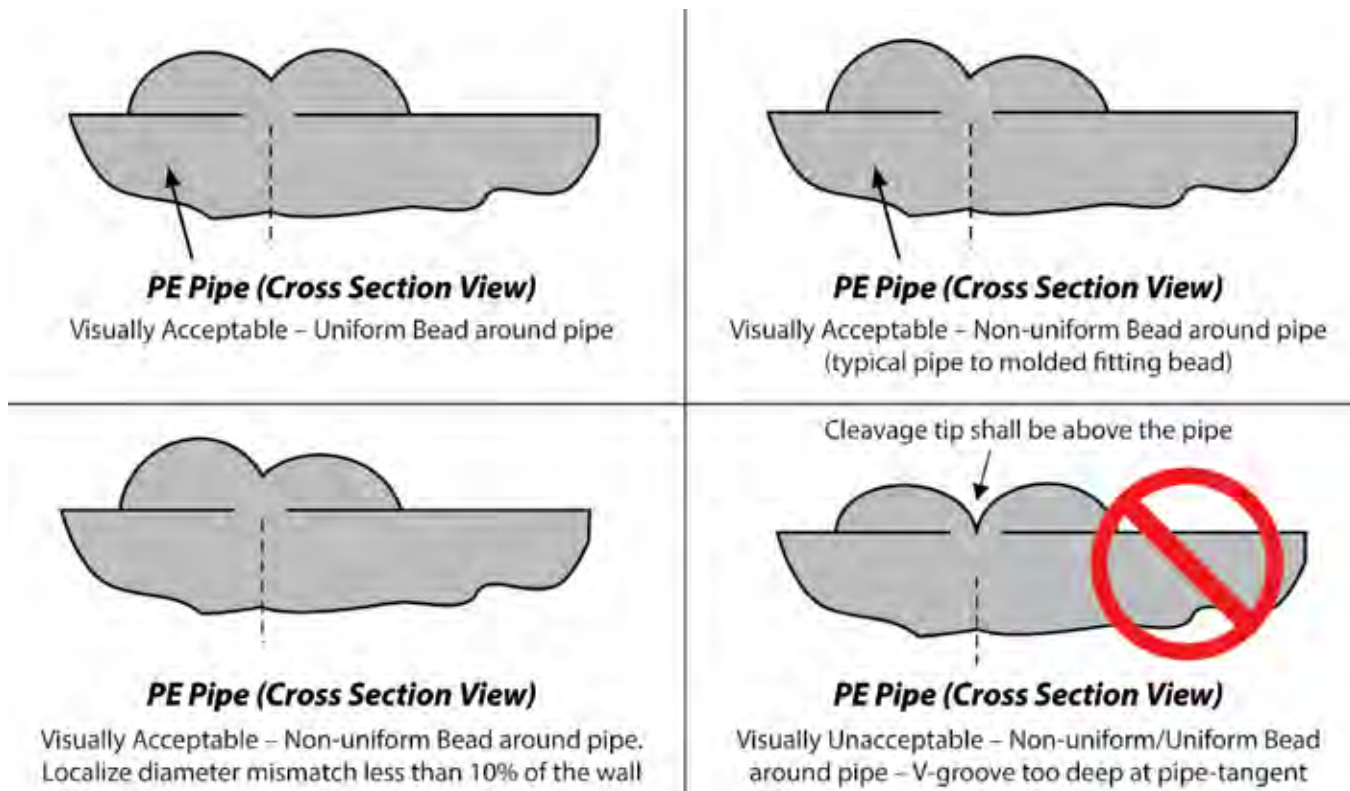
GOST R 54792-2011 [3] contains satisfactory traditional criteria of rejecting defective welded joints based on their appearance. GOST R 54792-2011 VDI conditions should be applied for PE joints made by butt fusion with a nominal outer diameter d_n from 63 to 225 mm and nominal wall thickness e_n from 3.6 to 20 mm.

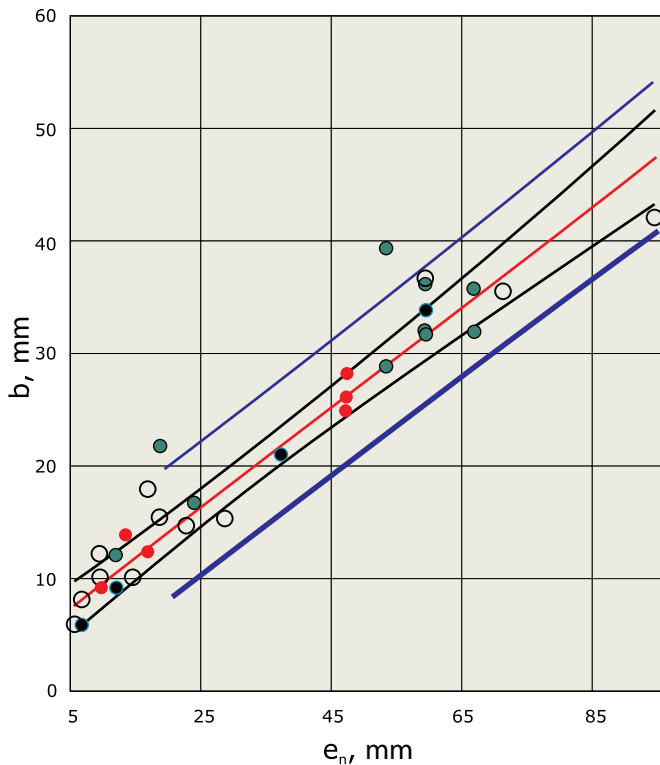
Welded objects i.e. plastic pipes and fittings are increasing in geometrical sizes and new types of polymeric materials are being applied. Some butt fusion problems observed in practice are due to the fact that generally accepted technological norms are far behind pipe production innovations.

Traditional DVS technical codes contain bead sizes. Deviation from the norm mean improper pipe preparation for welding and a deviation of the major welding parameters from the optimal values.

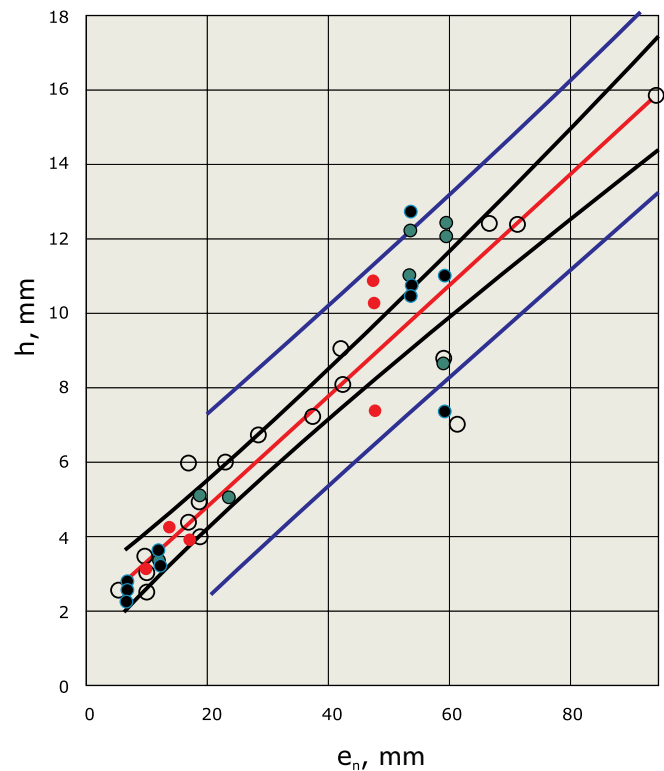


Pic. 1. Visual evaluation of allowable and disallowable bead shape





Pic. 2. Bead width to pipe wall thickness dependency (Single Low Pressure procedure, summer). White points – unknown material. Black points – PE100 2HT11-9. Green points – Sabic P6006. Red points – PE 100 6949C. Red line is the trend line, black lines is confidence interval for the function.



Pic. 3. Bead height to pipe thickness dependency (Single Low Pressure procedure, summer). White points mean unknown materials. Black points – PE 100 2HT11-9. Green Points – Sabic P6006. Red Points – PE100 6949C. Red line is the trend line, black lines are confidence interval for the function.

The criteria for bead sizes in the new DVS [2] codes, containing too great and too small bead volume, are not quantified. These codes require comparison of the evaluated bead with the control samples instead. It is standard practice in Germany to involve experts in the welding of testing samples, which can then be used by other welders. These works are postponed due to the fact that obtaining more universal criteria requires very expensive experiments. To obtain results for welding super large diameter pipes would cost millions of roubles.

The authors have managed to carry out a significant volume of experiments required for obtaining new criteria for VDI of welded joints with wall thicknesses of e_n up to 95 mm.

PE pipes made in Russia and abroad have been used: Sabic P6006, 6949C and PE 2HT11-9. Some pipe types were unidentified.

All joints were welded using butt fusion at a heating plate temperature of 220°C. The welding was done in three different modes according to GOST R ISO 55276-2012. Various welding machines were used for welding: Georg Fischer – Omicron, WIDOS, KWH, BADA, McElroy and USPTPEP.

Alignment of the long (up to 12 m) large and super large diameters pipes was done using adjustable roller supports made by the Kokhanovsky Pipe Plant.

Qualification and skills were not taken into consideration deliberately as the welding was done by experts.

The thickness of the pipe wall is the most obvious factor that influences the bead parameters i.e. volume, height and width. According to GOST R ISO 55276-2012 and generally accepted tradition, the duration of heating, welding pressure increase, and cooling under pressure depends on the thickness of the pipe walls. These dependencies are directly proportional and this makes some process engineers use linear extrapolation of data obtained during welding of thin pipes to big thickness pipes. In fact, bead sizes nonlinearly tend to depend on the thickness of the pipe wall [4], and rheological characteristics of molten mass also need to be taken into account as a dependency factor. Some areas of nonlinear function can be approximated to linear function sections, which are more convenient for the control of welded joints e.g. bead width – wall thickness dependency is quite reasonably approximated to linear sections in small pipe wall thicknesses [3]. Bead height has a linear dependency from e_n with pipe wall thicknesses up to 40 mm.

As a result of statistical processing of experimental data obtained by the authors, the following adequate approximating function for bead size – pipe wall thickness dependencies in e_n range up to 95 mm were derived:

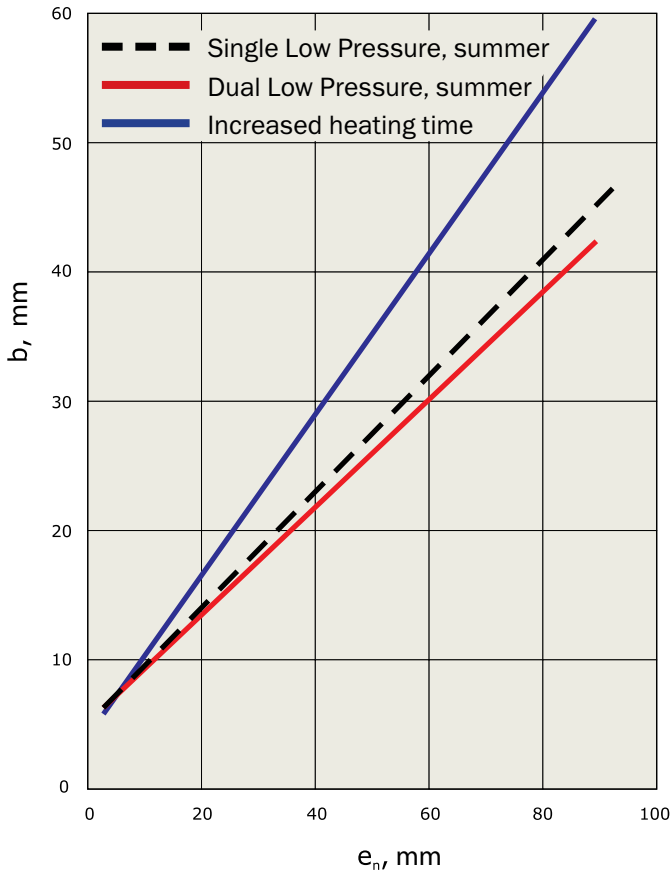


FIG. 4. Bead width to thickness of the pipe dependency, GOST R ISO 55276-2012 procedure and welding conditions.

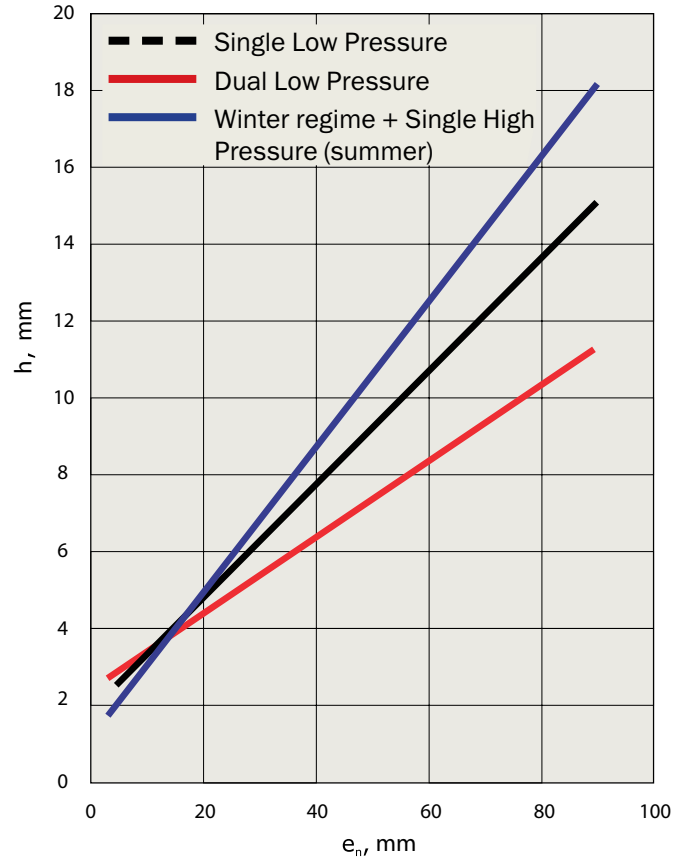


FIG. 5. Bead thickness to wall thickness dependency, GOST R ISO 55276-2012 procedure and welding conditions.

FIG. 6. Welding of 95 mm wall thickness pipe



Table 1. Allowable bead sizes in butt fused welded joints made of PE 100: Single Low Pressure fusion procedure for wall thickness e_n from 20.1 to 45.3 mm

№	e_n , mm	d_n , mm	SDR	Calculated bead size, mm	
				b	h
1	20,1	355	17,6	14,1±5,9	4,9±2,2
2	20,5	225	11	14,3±5,9	4,9±2,2
3	20,6	280	13,6	14,3±5,9	4,9±2,2
4	21,1	355	17	14,5±5,9	5,0±2,2
5	22,7	250	11	15,2±5,9	5,3±2,2
6	23,2	315	13,6	15,5±5,9	5,3±2,2
7	23,7	400	17	15,7±5,9	5,4±2,2
8	25,4	280	11	16,4±5,9	5,7±2,2
9	25,5	450	17,6	16,5±5,9	5,7±2,2
10	26,1	355	13,6	16,8±5,9	5,8±2,2
11	26,7	450	17	17,0±5,9	5,8±2,2
12	28,3	500	17,6	17,7±5,9	6,1±2,2
13	28,6	315	11	17,9±5,9	6,1±2,2
14	29,4	400	13,6	18,2±5,9	6,2±2,2
15	29,7	500	17	18,4±5,9	6,3±2,2
16	31,7	560	17,6	19,3±5,9	6,6±2,3
17	32,2	355	11	19,5±5,9	6,7±2,3
18	33,1	450	13,6	19,9±5,9	6,8±2,3
19	33,2	560	17	19,9±5,9	6,8±2,3
20	35,7	630	17,6	21,0±5,9	7,2±2,3
21	36,3	400	11	21,3±5,9	7,2±2,3
22	36,8	500	13,6	21,5±5,9	7,3±2,3
23	37,4	630	17	21,8±5,9	7,4±2,3
24	40,2	710	17,6	23,1±5,9	7,8±2,3
25	40,9	450	11	23,4±5,9	7,9±2,3
26	41,2	560	13,6	23,5±5,9	8,0±2,3
27	42,1	710	17	23,9±5,9	8,1±2,3
28	45,3	800	17,6	25,3±6,0	8,6±2,3

For the bead width b

$$b = 0.447 \cdot e_n + 5.089 \quad (R=0.95), \quad (1)$$

and for the bead height h

$$h = 0.147 \cdot e_n + 1.920 \quad (R=0.92), \quad (2)$$

where R – correlation coefficient.

Confidence limits for the data (yHt, yBt), shown on pictures 2 and 3 (blue curves), are calculated at confidence probability of 95%.

Tables 1 and 2 show allowable bead sizes, calculated for corresponding pipe sizes.

If bead sizes are lower than shown in tables 1 and 2, it can be assumed that welding parameters are not adequate for rheological properties of materials and welding conditions:

- low temperature of the heating plate,
- insufficient heating time,
- low pressure in the welding area,
- process standby is held for too long.

If the bead sizes are greater than shown in tables 1 and 2, it can be assumed that:

- the temperature of the heating plate, heating time and welding pressure are too high.

Based on the data in these tables, welders and controllers can evaluate the quality of 100% of welded joints and take

Table 2. Allowable bead sizes in butt fused welded joint made of PE 100: Single Low Pressure fusion procedure for pipe wall thicknesses e_n from 45.4 to 95 mm

№	e_n , mm	d_n , mm	SDR	Calculated bead size, mm	
				b	h
1	45,4	500	11	25,4±6,0	8,6±2,3
2	46,3	630	11	25,8±6,0	8,7±2,4
3	47,4	800	17	26,3±6,0	8,9±2,4
4	50,8	560	11	27,8±6,0	9,4±2,4
5	51,0	900	17,6	27,9±6,0	9,4±2,4
6	52,2	710	13,6	28,4±6,0	9,6±2,4
7	53,3	900	17	28,9±6,0	9,8±2,4
8	56,6	1000	17,6	30,4±6,1	10,2±2,4
9	57,2	630	11	30,7±6,1	10,3±2,4
10	58,8	800	13,6	31,4±6,1	10,6±2,4
11	59,3	1000	17	31,6±6,1	10,6±2,4
12	64,5	710	11	33,9±6,2	11,4±2,5
13	66,1	900	13,6	34,6±6,2	11,6±2,5
14	66,7	1400	21	34,9±6,2	11,7±2,5
15	68,0	1200	17,6	35,5±6,2	11,9±2,5
16	71,1	1200	17	36,9±6,3	12,4±2,5
17	72,6	800	11	37,5±6,3	12,6±2,5
18	73,5	1000	13,6	37,9±6,3	12,7±2,6
19	81,7	900	11	41,6±6,5	13,9±2,6
20	83	1400	17	42,2±6,5	14,1±2,6
21	88,2	1200	13,6	44,5±6,6	14,9±2,7
22	90,8	1000	11	45,7±6,7	15,3±2,7
23	94,8	1600	17	47,5±6,8	15,9±2,7

decisions on mechanical testing of the joints and optimise the welding mode.

Equations 1 and 2 refer to welding using the Single Low Pressure fusion procedure in favourable weather conditions.

If technicians, in full compliance with GOST R ISO 55276-2012, use American high pressure welding machines, choose a Single High Pressure fusion procedure, or prefer to choose a Dual Low Pressure procedure, then the correction coefficients in pictures 4 and 5 should be used. This also applies if welders extend the heating time due to low ambient temperatures.

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