PE PRESSURE PIPE SYSTEMS

NPG Nordiska Plaströrgruppen
The Nordic Plastic Pipe Association

Content

1. General information on PE pressure pipe systems

A PE pressure pipe system is a highly corrosion resistant pipe system, which is able to transfer axial forces, which results in only a limited need for anchoring. A PE pipe system consists of many components, which might be manufactured by different companies. In order to achieve a system which functions well, a good knowledge of PE pipes, fittings and jointing methods is required. The aim of this publication is to give design engineers access to an overview of the available components for PE pressure pipe systems, and to provide general information on issues which ought to be considered when designing PE pipe systems.

PE pipes are manufactured from different kinds of PE materials. The most commonly used PE resin designations in Europe are PE 80 and PE 100. Material properties are described briefly in section 2.1.

PE pipes are available as standardised solid wall pipes, and as co-extruded multi-layer pipes. The most important pipe properties are summarized in 2.2-2.3.

There are a number of different types of fittings which can be used for PE pipes. Fittings are often manufactured by specialized companies. Different types of fittings are generally described in 2.6.

Jointing methods used for PE pipes are:

- butt welding
- electrofusion
- flanged joints
- mechanical couplings

Butt welding is the most common jointing method for PE pipes and is the method which normally provides the strongest joints, see item 3.

For electrofusion purposes, electrofusion sockets are used with heating wire incorporated into them – which looks visually like a screw thread - in the socket. By connecting the heating wire to an electrical supply, the wire will be heated and will melt the adjacent PE material on the inside of the socket and the outside of the pipe spigot end. The heating of the socket provides a fused connection of the socket and the pipe spigot end, please see item 4 for further information.

Flanged joints are mainly used to connect PE pipes to valves, pumping stations or pressure pipes made of other materials. For further information, please see item 5.

Mechanical couplings can be used for jointing of small sized PE pipes. Mechanical couplings transfer axial forces by means of friction, for further information see item 6.

Different jointing methods have various advantages and disadvantages. In general, all jointing methods are able to transfer axial forces, thus facilitating a limited need for anchoring in the system. For further information please see item 7.

A PE pipe system may comprise a variety of different components. It is important that the design engineer/pipe system supplier has a good understanding of the materials and products, thus enabling him to provide a good system design.

It is the designer/pipe system supplier who selects the components in the system, and who ought to give instructions for the assembly of the system.

2. PE pipes and fittings

2.1 PE materials

The PE pipe properties are to a large extent determined by the PE resin of which the pipe is manufactured. The pipe manufacturers normally use compounded PE materials from the resin suppliers, and do not add on any additives at the manufacture of the pipes.

PE materials for pipe manufacture are available in different material designations (PE 40, PE 63, PE 80 and PE 100). A PE material of lower density like PE 40 is softer and has lower strength properties than a PE material of higher density.

The expected lifetime of a PE pipe is determined by:

- The PE material properties
- The stress level
- The loading time
- The temperature
- The environment

PE materials for pipe manufacture is classified in different strength classes, see table 1.

Table 1: Strength properties of different PE materials

Material designation	Minimum required strength +20 °C (MPa)	Design stress (MPa) Design factor* C= 1.25
PE 40**	4	3.2
PE 63**	6.3	5
PE 80	8	6.3
PE 100	10	8

* To determine the design stress of a PE material, a safety factor is applied on the 50 years minimum required strength value.
** These materials are no longer used in the Nordic countries.

The allowable design stress in the pipe wall of a PE pipe is calculated by reducing the minimum required strength value by a design factor of 1,25 according to EN 12201. Therefore, a PE 100 pipe, which is subjected to an internal pressure corresponding to its PN designation (see 2.2) will be subjected to a pipe wall stress of 8 MPa, and at this stress level a lifetime exceeding 100 years at the temperature +20 °C is expected.
If the pipe is to be subjected to a higher pressure than its PN designation for short periods, this may not necessarily lead to decreased lifetime expectancy. A PE pipe has a rather high short-term strength compared to its long-term strength (approx. 23-24 MPa at a few minutes of loading approx. 13-15 MPa at 1 hour of loading). At short-term loading the real design factor is thus significantly higher. A PE pipe is therefore able to withstand higher pressures than its PN designation for brief periods, see further item 2.4 Resistance against water hammer.

A PE pipe, designed by using a design factor of 1.25, is expected to get a lifetime exceeding 100 years at a temperature of +20 °C or less. An increased design factor will further increase the expected lifetime.

The strength properties of a PE pipe are dependant on the temperature, and the properties given in table 1 refer to a temperature of +20 °C. Higher temperatures will result in reduced strength, and conversely, lower temperatures will result in increased strength. For PE pipes to be used at higher temperatures than +20 °C, the reduction factors given in table 2 can be used.

Table 2: Strength reduction coefficients

Temperature (°C)	Reduction factor
20	1.00
30	0.87*
40	0.74*

* The value may be higher for certain PE resins. Please contact the pipe manufacturer for further information.

The elongation properties of a PE pipe are determined by the E-modulus of the PE material. The E-modulus is influenced by the temperature, the loading time and stress level in the material. A higher temperature will give a slightly decreased E-modulus; a lower temperature a slightly increased E-modulus.

Representative E-modulus values for pipes of PE 80 and PE 100 resins are given in table 3. The values given in table 3 are related to a stress level of 3 MPa in PE 80 pipes and 4 MPa in PE 100 pipes respectively. At higher stress levels, lower E-modulus values apply. At lower stress levels, higher E-modulus values apply.

At lower temperatures than +20 °C, which normally applies for buried pressure pipes in northern Europe, E-modulus values will increase slightly. However, increased E-modulus values and increased strength properties are not normally taken into consideration for the design of the pipe. Increased properties are instead utilized as a contribution to an increased design factor, and a further prolonged service life.

Table 3: Typical E-modulus values for different types of PE pipe at +20 °C and different loading times

Type of material	E-modulus* (MPa)						
	3 min	1 h	10 h	100 h	1000 h	1 year	50 year
PE 80 MD** (At stress level 3 MPa)	600	425	325	250	200	150	100
PE 80 HD*** (At stress level 3 MPa)	800	550	425	325	250	200	150
PE 100 (At stress level 4 MPa)	800	550	425	325	250	200	150

* The E-modulus value depends on the stress level in the pipe wall and the loading time.
** Medium density
*** High density

The relationship between stress and strain in a pipe is steered by Hooke's law:

$$\sigma = E \times \varepsilon$$

Where σ = stress in the pipe wall

E = the E-modulus of the pipe material

ε = the strain in the pipe wall

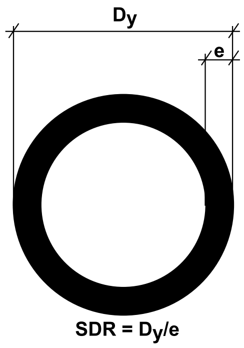
The strain is thus the ratio: σ/E. The material properties given above can be used for calculations of stresses, strains and forces in a PE pipe system, see further item 7 Anchoring.

2.2 Solid wall PE pipes

PE pipes are standardised in accordance with EN 12201-2 (water) and EN 1555-2 (gas) with regard to:

- type of PE material (i.e. PE80, PE100)
- outside diameter (D_y)
- SDR-ratio = outside diameter/wall thickness

PE pipes are standardised in the SDR-classes: 6, 7.4, 9, 11, 13.6, 17, 21, 26, 33 and 41.



The most common classes are 11, 17 and 26.

Table 4: Standardised PE pipes in accordance with EN 12201-2

SDR-Class	SDR 6	SDR 7,4	SDR 9	**SDR 11**	SDR 13,6	**SDR 17**	SDR 21	**SDR 26**	SDR 33	SDR 41
PE 80	**PN 25**	**PN 20**	**PN 16**	**PN 12,5**	**PN 10**	**PN 8**	**PN 6***	**PN 5**	**PN 4**	**PN 3,2**
PE 100	-	**PN 25**	**PN 25**	**PN 16**	**PN 12,5**	**PN 10**	**PN 8**	**PN 6****	**PN 5**	**PN 4**
Nominal stiffness				**SN 64**	**SN 32**	**SN 16**	**SN 8**	**SN 4**	**SN 2**	**SN 1**
Outside diameter (mm)	Minimum wall thickness e (mm)									
16	3,0	2,3	2,0							
20	3,4	3,0	2,3	2,0						
25	4,2	3,5	3,0	2,3	2,0					
32	5,4	4,4	3,6	3,0	2,4	2,0				
40	6,7	5,5	4,5	3,7	3,0	2,4	2,0			
50	8,3	6,9	5,6	4,6	3,7	3,0	2,4	2,0		
36	10,5	8,6	7,1	5,8	4,7	3,8	3,0	2,5		
75	12,5	10,3	8,4	6,8	5,6	4,5	3,6	2,9		
90	15,0	12,3	10,1	8,2	6,7	5,4	4,3	3,5		
110	18,3	15,1	12,3	10,0	8,1	6,6	5,3	4,2		
125	20,8	17,1	14,0	11,4	9,2	7,4	6,0	4,8		
140	23,8	19,2	15,7	12,7	10,3	8,3	6,7	5,4		
160	26,6	21,9	17,9	14,6	11,8	9,5	7,7	6,2		
180	29,9	24,6	20,1	16,4	13,3	10,7	8,6	6,9		
200	33,2	27,4	22,4	18,2	14,7	11,9	9,6	7,7		
225	37,4	30,8	25,2	20,5	16,6	13,4	10,8	8,6		
250	41,5	34,2	27,9	22,7	18,4	14,8	11,9	9,6		
280	46,5	38,3	31,3	25,4	20,6	16,6	13,4	10,7		
315	52,3	43,1	35,2	28,6	23,2	18,7	15,0	12,1	9,7	7,7
355	59,0	48,5	39,7	32,2	26,1	21,1	16,9	13,6	10,9	8,7
400		54,7	44,7	36,3	29,4	23,7	19,1	15,3	12,3	9,8
450		61,5	50,3	40,9	33,1	26,7	21,5	17,2	13,8	11,0
500			55,8	45,5	36,8	29,7	23,9	19,1	15,3	12,3
560			62,5	50,8	41,2	33,2	26,7	21,4	17,2	13,7
630			70,3	57,2	46,3	37,4	30,0	24,1	19,3	15,4
710			79,3	64,5	52,2	42,1	33,9	27,2	21,8	17,4
800			89,3	72,6	58,8	47,4	38,1	30,6	24,5	19,6
900				81,7	66,1	53,3	42,9	34,4	27,6	22,0
1000				90,8	73,4	59,3	47,7	38,2	30,6	24,5
1200					88,2	71,1	57,2	45,9	36,7	29,4
1400					102,9	83,0	66,7	53,5	42,9	34,3
1600					117,5	94,8	76,2	61,2	49,0	39,2
1800						106,6	85,8	68,8	55,1	44,0
2000						118,4	95,3	76,4	61,2	48,9
2250							107,2	86,0	68,9	55,0
2500							119,1	95,5	76,5	61,2

* The real pressure rating is PN 6.3 ** The real pressure rating is PN 6.4

EN 12201-2 and 1555-2 state tolerances for the pipes. All PE pipes have a calibrated outside diameter (D_y) and are round at the manufacturing stage.

The following tolerances apply:

D_y:	-0 mm / +0.006xD_y rounded off to nearest higher 0.1 mm for pipes < 710 mm
	-0 mm / +0.009xD_y rounded off to nearest higher 0.1 mm for pipes ≥ 710 mm
Out-of-roundness:	Allowable difference between largest and smallest diameter measurement:
	0.02xD_y for pipes 90-250 mm
	0.035xD_y for pipes 280-800 mm.
	For pipes ≥ 900 mm the maximum out-of-roundness shall be agreed between the manufacturer and the purchaser.

The above tolerances are valid for supply of pipes in straight lengths from the manufacturer. Depending on how, and for how long time the pipes have been further stored, and increased out-of-roundness may apply. PE pipes in small sizes, supplied in coils, may incur an increased out-of-roundness. For such pipes tolerances on out-of-roundness are to be agreed between the manufacturer and the purchaser.

A PE pipe will at the stage of manufacture be cooled from the outside, and due to the non-uniform cooling characteristics during the extrusion process, frozen-in stresses will be achieved in the pipe wall. When a PE pipe is cut, the pipe end will bend inwardly somewhat within a short time, and this phenomenon is due to the frozen-in stresses (sometimes referred to as barrelling or toe-in), see photo below. To eliminate this effect at the measurement of pipe tolerances, measurements should be made at a distance ≥ 0,5xD_y from the pipe end.

The inward bending effect is hardly noticeable in the case of small PE pipes, but it is clearly evident in the case of large diameter pipes. The inward bending is small (normally significantly less than 1 % av D_y) and has normally no negative influence on the jointing procedure.

In order to ensure that the pipe will meet the requirements of the standard, testing needs to be carried out by the manufacturer and/or by an independent testing institute. In the Nordic countries, practically all PE pipes available on the market have the voluntary quality mark Nordic Poly Mark. Such pipes are tested by the manufacturer and audit tested by an independent testing institute.

CE marking does not provide a corresponding level of control (the manufacturer is only obliged to limited testing without any supervision from an independent institute). To ensure a high pipe quality it is recommended to specify quality marked PE pipes, i.e. pipes marked with the Nordic Poly Mark, or third party certified pipes to a corresponding level.

For PE pipes marked with Nordic Poly Mark it is furthermore required that the pipes shall be manufactured using certified PE resins only.

Therefore in order to ensure high pipe quality, always use pipes having a quality mark.

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2.3 Co-extruded PE pipes

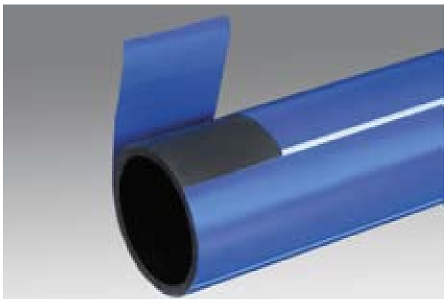
PE pipes are also available as co-extruded, i.e. pipes containing different material layers. There are two main types of co-extruded pipes (further described in annex B and C of EN 12201):

- Pipes containing different material layers, where the different layers are inseparable (pipes with co-extruded layers)
- Pipes having an outer material layer such as PP, which does not strongly adhere to the inner core pipe (pipes having a peelable layer)

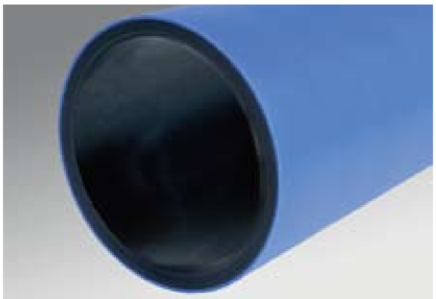
The latter type of pipe is the most common co-extruded pipe in the Nordic countries. The main pipe is a standardised PE pipe. The material of the outside layer and the thickness of the layer vary between pipes from different suppliers.

A peelable outer layer on a PE pipe may provide a certain additional protection against scratches, and an outer layer also serves as a mechanical protection for an aluminium layer which in rare occasions is used as a diffusion barrier on small sized PE pipes intended for use in heavily contaminated ground, see further 2.4.

It should however be noted, that scratches on PE pipes seldom cause problems, see further 2.4.



A PE pipe with peelable outer layer



A co-extruded PE pipe

For further information on properties of co-extruded pipes contact the respective manufacturer.

2.4 PE pipe properties

Hydraulic losses

PE pipes have a smooth internal surface and a low hydraulic roughness coefficient, k. For PE pipes < 200 mm the k-value is 0,01 mm. For pipes > 200 mm a k-value of 0,05 mm can be used. Butt welded PE pipes get small weld beads at each joint, see photo.

Weld beads on a PE pipe; cross section through a joint

The beads, which are usually left on the pipes, have normally a height corresponding to approximately 2 % of the pipe diameter and will only give a minor increase of the head loss in the pipe system. In thick-walled PE pipes the internal bead will be cooled slowly and will then show a tendency to stand out more from the pipe wall, which thus could give a slightly increased head loss. It is possible to remove weld beads, but this ought to be done at the welding operation when the bead still is hot.

Special equipment is required to remove internal beads. To assess the total head loss in a PE pipe system a roughness coefficient of 0.1-0.2 mm can be used. When using the latter roughness coefficient all additional losses from weld beads, bends, etc can be neglected, and the estimated head loss will normally be on the safe side. When pumping untreated sewage water, a thin surface growth may appear on the inside of the pipe which sometimes could give a somewhat increased hydraulic roughness.

Resistance against water hammer

When designing PE pressure pipe systems, pressure surge needs normally not to be considered. The reason is that a PE pipe has a relatively high short-term strength compared to its long-term strength, see 2.1. Frequent pressure surge up to 1.5 times the PN-rating of the pipe has been found not to influence on the long-term strength of the pipes.

Furthermore, the low E-modulus of the PE material results in a much lower pressure wave velocity in the system, and thus a lower surge, than in pipe systems made of other materials, for further information see /ref.1/. For thin-walled PE pipes (SDR $\geq$26) the risk for buckling due to under pressure at pressure surge, ought to be taken account of.

Diffusion

PE pipes are not completely diffusion tight against low molecular organic substances. The permeability differs for different types of PE materials, and increases with increasing temperatures. On rare occasions, a taste and odour effect on the water has been found for small-sized PE pipes in heavily contaminated ground.

Reported problems are almost exclusively related to house connections of LDPE (low density polyethylene). PE80 and PE100 materials have a significantly higher diffusion resistance compared to earlier LDPE materials. The penetration time for a substance to pass the wall of PE pipes of same SDR-ratio is directly proportional to the square of the pipe wall thickness. It thus takes 100 times longer to notice taste and odour influence in a 250 mm pipe than in a 25 mm pipe of the same PE material and pressure rating, /ref.2,3/. Furthermore, stagnant water is much more frequent in house connections than in distribution lines. The circumference/volume ratio of the pipe will also affect the risk for taste and odour problems.

For small diameter pipes with a large surface related to the pipe volume, the concentration of permeating substances will be higher than in larger pipelines. The above circumstances explain why taste and odour problems are really only found in small diameter PE pipes. If small diameter PE pipes are to be installed in contaminated ground, pipes with a diffusion barrier can be chosen, but in most cases larger PE pipes do not need any additional protection even if installed in contaminated ground.

Measuring device for scratches

Notch sensitivity

PE pipes are relatively soft and can be scratched if carelessly handled. Normal handling will only result in the occurrence of minor scratches, which however will not influence the strength properties of the pipes. Scratches on PE pipes may appear visually worse than they are in reality. The real depth of a scratch can be measured by using a measuring device, see photo.

Scratches up to a depth of 10 % of the pipe wall thickness have been found not to affect the strength properties of a PE pipe, /ref.4/. Therefore, in most cases it is of little consequence which type of PE pipe is used (a co-extruded pipe or just a standard one). In most cases standard solid wall PE pipes can be used for most applications without any disadvantages.

Development of new PE resins has implied that PE materials are today available for which scratches have even less influence on the strength properties of the pipes as mentioned above. If for special applications it is desired to minimize possible influence of scratches, such resins can be used for the manufacture of the pipes.

Squeeze-off equipment

2.5 Squeeze-off of PE pipes

A method used to quickly decrease or stop the flow in a PE pipe is to squeeze-off the pipe. The method was originally developed for small sized PE 80 gas pipes with low working pressure, but the method has in recent years also started to be used for PE 100 water pipes.

Equipment for squeeze-off of PE pipes is available on the market, but the effect of the squeezing on the long-term strength of PE 100 water pipes is still not fully studied.

2.6 PE fittings

Most PE pipe manufacturers make segment welded (mitred) fittings, while electro fusion fittings, injection moulded fittings and swept bends normally are manufactured by specialized fitting manufacturers. The fitting design will influence the wall thickness needed for the fitting. Some fittings may need a thicker wall than required for a straight pipe of the corresponding PN-class. Recommendations for the design of fittings are given in EN 12201-3:2010.

Mitred (segment welded) fittings

Bends and tees can be segment-welded from mitred PE pipe pieces. The final size of the fitting depends on the sizes and number of the mitred pipe pieces. The pressure rating of the fitting (PN-class) depends on the SDR-ratio of the pipe pieces and the type of fitting. Recommendations for PN-classification of mitred fittings are given in EN 12201-3, annex B.

If the angle between mitred segments in bends does not exceed 15 degrees (7.5 degree cutting angle on each mitred piece), the bend will get the same PN-rating as the pipe pieces of which it is made. Mitred T-fittings need to be manufactured from segments with a thicker wall (lower SDR-ratio) than the pipe for which it is intended to be used.

Mitred T-fittings will thus normally get a somewhat smaller internal diameter than the pipe for which the fittings are intended to be used. As an alternative to mitred tees, T-fittings can also be manufactured from specifically made thick-walled pipes. The latter type of T-fittings has normally the same inside diameter as the pipe.



Injection moulded fittings

Injection moulded fittings have normally a local externally increased wall thickness in order to get a pressure rating equal to the pipes for which the fittings are intended, see figure. The internal diameter of the fittings is the same as for the pipes for which the fittings are intended to be used.

Electrofusion fittings

Electrofusion fittings are mostly injection moulded and have heating wire laid in the form of a metal thread placed at the inside surface of the fitting. There is a variety of different brands of electrofusion fittings on the market, and significant differences between products manufactured by different suppliers may apply. Requirements on all measurements and tolerances for the fittings are not stated in EN 12201-3. Neither are any requirements on thread area, thread length, voltage, current, fusion time, etc specified. The latter means that it is the manufacturer of the fitting who specifies the fusion parameters which are to be used for his brand of fittings.

When electrofusion fittings are used, it is important that the tolerance between the pipe spigot end and the electro fusion socket is kept sufficiently small. Tolerance problems are less common for sizes up to 250 mm, but for larger sizes tolerance problems may apply. The problem increases with increased sizes, and it depends basically on procedure problems (bad workmanship) or on the fact that the permissible out-of-roundness for the pipes according to EN 12201 is greater than the required tolerance for the fitting. For further information, see item 4.

Due to limited requirements in EN 12201-3 electrofusion fittings from different manufacturers may show significant differences. Seen against this background and the workmanship and tolerance problems related to the use of large electrofusion fittings, the Nordic Plastic Pipe Association recommends a restrictive use of large diameter electrofusion fittings.

Swept bends

Swept bends are less common than mitred bends. Swept bends are manufactured from straight pipes which are heated up, bent and cooled down. Swept bends get normally a larger bending radius than injection moulded or mitred bends. The bending implies that the bend might get a slightly increased out-of-roundness and that the wall thickness on the outside of the bend will be somewhat decreased.

If the bending radius is not kept too small, the decrease of the wall thickness will be limited, and swept bends are normally made of pipes with the same SDR-ratio as for the pipes which they are intended to be used with. The tolerances on the degree of swept bends may be somewhat larger than for injection moulded or mitred bends.

Bending of the pipe instead of using prefabricated bends

Instead of using prefabricated bends, a PE pipe could be bent and laid in a curvature. When laid in curvature the bending radius should preferably not be less than $100xD_y$. Such a pipe, placed on a pipe bed of friction material, will in most cases stay in curvature without external supports.

It is also possible to bend the pipe down to $50xD_y$, or in certain cases even more, but at such bending the pipe needs to be securely anchored, and significant forces are needed to keep the pipe in the intended curvature. The forces may be released if the pipe looses its anchoring, which must be prevented to avoid risk for injuries on the working staff in the trench. Sharp bending of PE pipes should therefore be avoided where possible.

3. Butt welding

3.1 Welding principle

Butt welding means that the end surfaces of the pipe are heated up and subsequently pressed together using a controlled pressure. The pressure causes the molten material to flow and mix, resulting in a butt weld. To achieve a high quality weld, the end surfaces must be clean and the melting and compression correctly performed.

The welding procedure is defined by a number of so-called welding parameters, which mainly depend on the pipe diameter and the pipe wall thickness.

3.2 Welding parameters and welding standards

There are different standards which describe the welding procedure and define the welding parameters to be used. Some common standards in Europe are:

DS/INF 70	Plastic pipes. Butt fusion of polyolefin pipe systems.
ISO 21307	Plastics pipes and fittings – Butt fusion jointing procedures for PE pipes and fittings used in the construction of gas and water distribution systems
DVS 2207-1	Schweissen von thermoplastischen Kunstoffen. Heizelementschweissen von Rohren und Tafeln aus PE-HD.

The above standards and specifications have minor differences with regard to welding parameters to be used. At butt welding it is important that a sufficient amount of material is melted, and that the pipe ends are pressed together with a suitable force (so that not all of the molten material is pressed out of the fusion zone into the beads).

Furthermore, the weld is not to be subjected to stresses before it has cooled down and obtained a sufficient strength. It is thus important that the heat soak time and the cooling time is sufficiently long.

The NPG member companies recommend the use of welding parameters as given in /ref.5/.

For pipes with a low SDR-ratio the cooling time may need to be further prolonged. For such pipes contact the pipe manufacturer for suitable welding parameters.

3.3 The welding operation

It is important that the welding operation is carried out by an experienced and qualified welder with sufficient knowledge, and that the welding machine is checked before welding work is started (welding equipment needs to be calibrated at least once a year by testing institute or specialized company).

Welding parameters are to be stated and followed during the entire work. All welding operations are to be recorded.

In many countries it is required that welding work is to be performed by licensed welders only. The butt welding operation is described in detail in /ref.5/.

3.4 Quality assurance

Determination of the strength properties of a butt fusion joint can only be made by means of destructive testing methods, which means that test joints have to be taken out from the pipeline for testing purposes. A correctly performed butt weld will have practically the same strength properties as the pipe. If testing of welds is required, it is important the testing is executed at an as early stage as possible (preferably as procedure testing before main work on site is commenced). During welding operation on site, it is imperative that the details of the welding work is recorded, and that records show the welding parameters which were used, the name of the welder, and when the welding was executed.

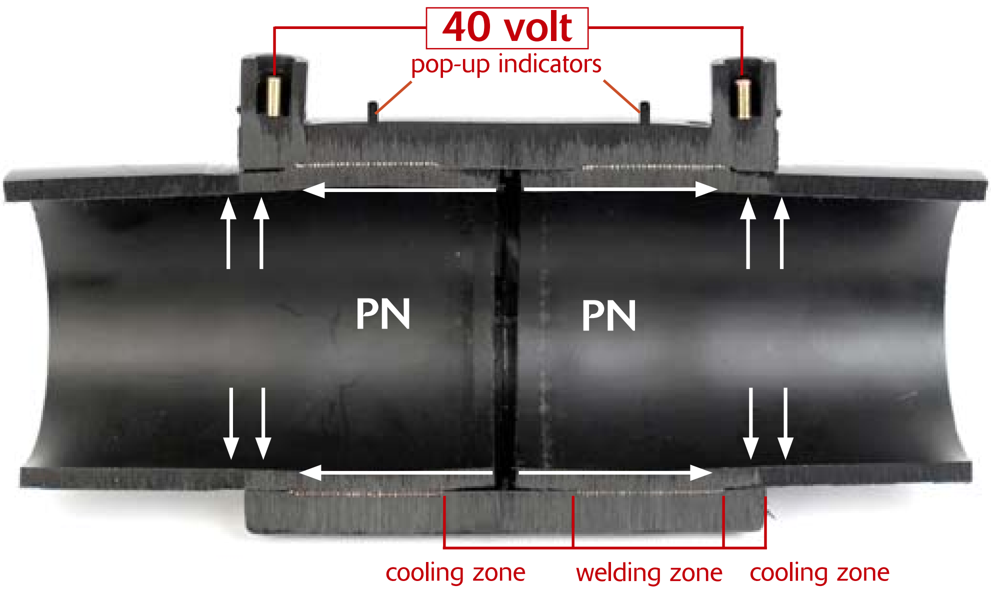
Visual inspection of the bead appearance may give certain information on possible faults, but can not be used for a reliable assessment of the strength properties of the welds. Visual inspection is therefore mainly a method for selection of welds with doubtful appearance for supplementary testing.

Testing procedures for butt welding of PE pipes are also given in EN 12201-5 (fitness for purpose of the system).

4 Electro fusion

4.1 Fusion principle

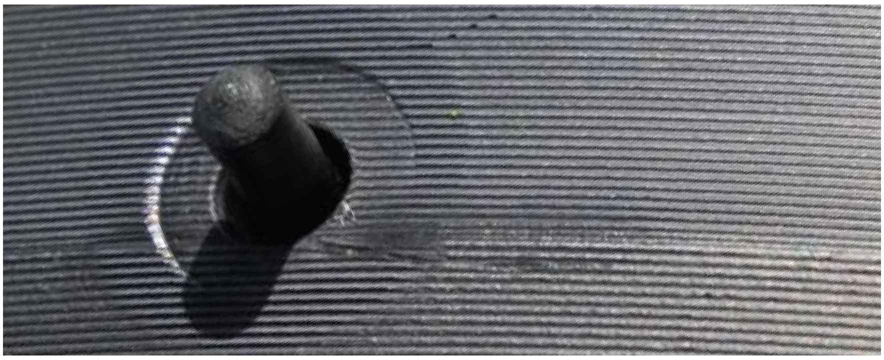
All electrofusion fittings have heating wire in the form of a metal thread placed at the inside surface of the fitting. When the thread is connected to an electricity supply, the thread will be heated up and will cause adjacent PE material to melt, thus also causing fusion between the pipe spigot end and the electrofusion socket. An electrofusion joint shall be able to withstand radial forces caused by the internal pressure as well as axial forces, see figure.



The electrofusion joint shall in principle to able to withstand the same level of axial forces as the pipe itself. In order to be able to achieve a high quality electrofusion joint, the tolerance between the pipe and the socket needs to be small, the weld zone surfaces clean, and the pipe spigot end scraped.

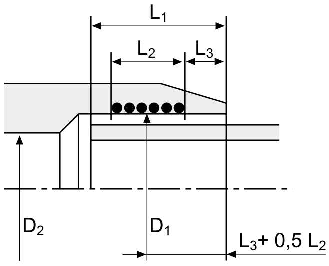
It is the heat from the heating wire which melts the PE material on the inside of the socket and the material on the outside of the pipe. The molten material will slowly start to flow, but the melt flow will stop when the material has reached the cooling zone of the fitting. During further heating, more material will melt in the weld zone and expand due to the heat. Since the cooling zones are blocked by cooled down material, the material expansion caused by the heating will build up a pressure in the welding zone.

The pressure reaches its optimal value at the end of the fusion period. An indication that a sufficient pressure has been built up is given when molten material is pressed out through indicator holes on the socket, so-called pop-up indicators, see photo.



Electrofusion enables jointing of pipes of different SDR-ratios. However, it must be checked that the electrofusion sockets are suitable for use together with pipes of the respective SDR-class.

4.2 Standard requirements for electrofusion fittings



EN 12202-3 states for electrofusion fittings that the internal diameter of the socket (D_1) shall be equal or greater than the nominal pipe diameter, i.e. D_y min.

The standard only specifies minimum value for the D_1- and L_2-measurements and minimum and maximum value for the L1-measurement, see figure.The fitting manu-facturer shall state D_1-, L_1-, L_2- och L_3-measurements for the fitting. The manufacturer should also state the smallest acceptable diameter for the down scraped pipe spigot end to ensure an acceptable joint quality. It ought to be noted that EN12201-3 does not set any requirements on thread area, thread length, voltage, current, fusion time, etc, thus indicating that fusion parameters will be set by each manufacturer of fittings.

4.3 Tolerances spigot - socket

Electrofusion sockets from different manufacturers may have different tolerance ranges, which may affect the assembly of the sockets. Difficulties at the assembly stage usually increase with increased sizes.

A large tolerance facilitates assembly, but makes it more difficult to build up a sufficient pressure during the fusion process. There are different methods in use to alleviate the problem. Some sockets could have a certain shrinkage at heating built into the socket, or by applying an outside pressure sleeve, the sockets could be prevented from expanding during the fusion process.

Some sockets have two optical reading codes on the sockets. By reading the first one, the pipe and socket are pre-heated to reduce tolerances. By reading the second one, the fusion process is started.

Reading of optical code

External pressure sleeve

External pressure sleeve

4.4 Differences between different suppliers

Electrofusion fittings are normally manufactured from PE 100 material, but the fittings are intended for use with both PE 80 and PE 100 pipes. Since many fitting properties are not covered by EN 12201-3, see 4.2, there are significant differences between fittings from different manufacturers, and it is in fact the manufacturer of the fitting who sets the welding parameters for the respective fitting.

4.5 Use of large diameter electrofusion fittings

The tolerance between pipe and socket must always be kept narrow to enable a sufficient welding pressure to be built up during the electrofusion process. This means increased problems with increased pipe sizes. Necessary tolerances needed for the assembly of a socket on a large diameter pipe, therefore often need to be reduced in order to ensure a reliable fusion. The manufacturers of electrofusion sockets have tried to solve this problem in different ways, see 4.3. A problem is that PE pipes may develop an increase in their out-of-roundness in time during the storage stage. The permissible out-of-roundness for PE pipes in sizes 280-630 mm is according to EN 12201-2 3.5 % of the diameter, (see 2.2), which exceeds the allowable tolerances for most electrofusion fittings. In order to get pipes to fit with large electrofusion fittings it is often necessary to reduce the out-of–roundness of the pipes by using a re-rounding tool, see photo. Difficulties at assembly are often due to tolerance problems (the fitting requires smaller tolerances than what EN 12201-2 allows for the pipes).

Use of a re-rounding tool to facilitate electrofusion

4.6 Execution of welding

Good workmanship is of utmost importance to achieve high quality electrofusion joints. Inferior joint quality will mostly be due to bad workmanship or insufficiently tolerances between pipe and socket. Furthermore, it is important only to use equipment specifically intended for the electrofusion fittings used.

Electrofusion may seem simple, but is in reality often more complicated than butt welding. At butt welding, the welder has full control over the welding parameters and the welding procedure. For electrofusion, the welding parameters are set by the fitting manufacturer, and it is the fusion parameters, the tolerances spigot/socket and the cleanliness of the welding surfaces which together contribute to the strength of the joint. More information on electrofusion is given in /ref.6/.

4.7 Quality assurance

Determination of the strength of the joint can only be made by means of destructive testing, meaning that the electrofusion fitting is cut off from the pipeline and tested to failure. Large electrofusion fittings are expensive, and are therefore tested only seldomly. At more comprehensive electrofusion jointing operations, destructive testing of fittings could preferably be executed as procedure testing, i.e. the testing is carried out before site work is commenced.

As a routine check during electrofusion operations, it should be checked that pop-up indicators are up and that no threads or too much molten material have come out at the ends of the socket. It should further be checked that it can be seen on both sides of the socket that the end of the pipe have been scraped (preferably by a rotating scraping tool) and that the mark of the spigot length show that no sliding has occurred during the fusion process, see photo.

Testing procedures for electro fusion joints are also given in EN 12201-5 (fitness for purpose of the system).

5 Flanged joints

Flanged joints are normally used to connect PE pressure pipelines to valves, pumping stations and pipelines of other pipe materials. A flanged joint to be used for PE pipes consists of different components, manufactured by different companies. The joint must be able to transfer long-term axial forces with maintained tightness, which requires use of suitable components and a correct assembly.

5.1 Flanged joint components

The components in a flanged joint for PE pipes are:

- Stub-ends or flanged adapters of PE
- Back-up flanges
- A gasket
- Bolts for connection of back-up flanges

Stub-ends and flanged adapters

Stub-ends and flanged adapters are flanged items made of PE, see 5.2. Stub-ends have shorter lengths than flange adapters, but the flange dimensions are the same for both. Dimensions for stub-ends and flanged adapters are standardised in ISO 9624:1997, see further 5.2.

Back-up flanges

Dimensions for back-up flanges are standardised in ISO 9624, see 5.2. Back-up flanges are manufactured of different material and are available in different designs. Flanges are normally made of steel, but also of ductile iron or glass fibre reinforced PP. Several corrosion protection systems also apply.

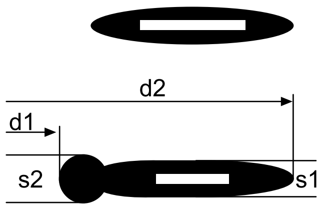
Gaskets

Gaskets are often made of rubber materials, but some other materials are also approved for use. The gasket material shall be chemically and thermally compatible with the fluid in the pipe, and have an appropriate hardness. Gaskets of soft materials need to be oversized with holes for the bolts and centred by the bolts (so called full face style, see photo) to facilitate assembly. Soft or too thick gaskets could show a tendency to blow out at high pressures. Gaskets made of harder materials and rubber gaskets with a steel core are usually designed as drop-in gaskets (centred by bolts placed at 3-, 6- and 9-o'clock position).

Full face rubber gasket centred on the bolts

Plane drop-in gasket

Drop-in steel core rubber gasket



Steel core rubber gasket profiles

Drop-in steel core rubber gaskets have shown significantly better performance than other types of gaskets when used for large diameter flanged joints. The best sealing function is achieved for steel core rubber gaskets with an integrated o-ring on the inner edge of the gasket.

Bolts

Number of bolts and bolt sizes are standardised in ISO 9624. Bolts of steel are available in several material qualities. Corrosion aspects ought to be considered at the selection of bolt material.

5.2 Flanged joint standard

Standardized dimensions for stub-ends and back-up flanges are given in ISO 9624:1997, which is the standard to which SS-EN 12201-3 refers. Table 5 shows the measurements which are given in ISO 9624 for flanged joints of pressure class PN 10. Flanged joints for pressure class PN 16 require increased bolt sizes and other dimensions for the back-up flanges.

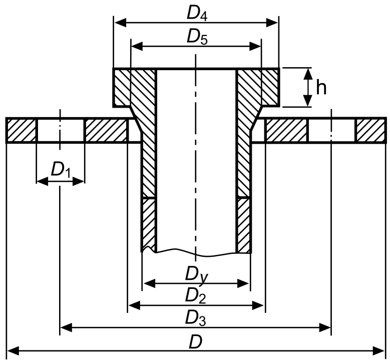
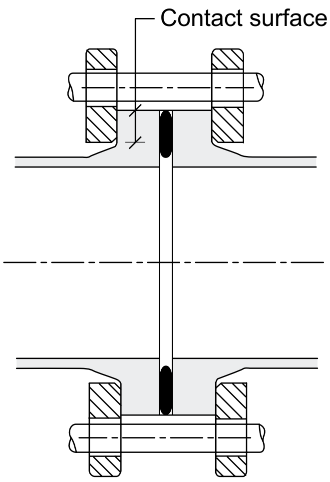


Table 5: Dimensions for components in flanged joints for PE pipes of pressure class PN 10

Pipe diameter D_y (mm)	Stub-end dimensions (mm)		Back-up flange dimensions (mm)				Bolts	
	D_4	D_5	D	D_2	D_3	D_1	Number	Size
20	45	27	95	28	65	14	4	M 12
25	58	33	105	34	75	14	4	M 12
32	68	40	115	42	85	14	4	M 12
40	78	50	140	51	100	18	4	M 16
50	88	61	150	62	110	18	4	M 16
63	102	75	165	78	125	18	4	M 16
75	122	89	185	92	145	18	4	M 16
90	138	105	200	108	160	18	8	M 16
110	158	125	220	128	180	18	8	M 16
125	158	132	220	135	180	18	8	M 16
140	188	155	250	158	210	18	8	M 16
160	212	175	285	178	240	22	8	M 20
180	212	180	285	188	240	22	8	M 20
200	268	232	340	235	295	22	8	M 20
225	268	235	340	238	295	22	8	M 20
250	320	285	395	288	350	22	12	M 20
280	320	291	395	294	350	22	12	M 20
315	370	335	445	338	400	22	12	M 20
355	430	373	505	376	460	22	16	M 20
400	482	427	565	430	515	26	16	M 24
450	585	514	615	470	565	26	20	M 24
450	585	514	670	517	620	26	20	M 24
500	585	530	670	533	620	26	20	M 24
560	685	615	780	618	725	30	20	M 27
630	685	642	780	645	725	30	24	M 27
710	800	737	895	740	840	30	24	M 27
800	905	840	1015	843	950	33	24	M 30
900	1005	944	1115	947	1050	33	28	M 30
1000	1110	1047	1230	1050	1160	36	28	M 33
1200	1330	1245	1455	1260	1380	39	32	M36

A value for the thickness of the flange of the stub-end (the h-measurement, see figure) is not given in ISO 9624. Therefore, different manufacturers of stub-ends may have different measurements, which will thus influence the length of the bolts.

During tightening of the bolts, forces will be transferred via the back-up flanges to the stub-ends, which in turn will compress the gasket. Unfortunately, the contact area between the stub-end and the back-up flange is not proportional to the diameter of the pipe in ISO 9624.



Specifically for 630 mm pipes but also for PE pipes > 800 mm, the specified dimensions for the stub-ends are probably too small to ensure a good function of the joint. For this reason, some manufacturers have developed there own stub-end designs for certain pipe dimensions.

For large diameter flanged joints, it is important to choose a gasket which is able to seal at a low compression level, and the bolt torque needs to be adjusted to give a suitable gasket compression. For further information contact the pipe manufacturer.

5.3 Flanged joint assembly

At assembly of flanged joints, the flanges and gasket should be centred and angular deviation in the joint corrected. The end surfaces of the stub-ends shall be close to each other before the bolts are tightened in order to avoid elongation of the pipe during joint assembly. Bolts shall be tightened crosswise with the same increment of torque up to the final torque required to achieve the correct tightening pressure in the joint.

Different types of gaskets may require different sealing pressures to ensure joint tightness. The necessary sealing pressure for the gasket is normally proportional to the internal pressure in the pipe. As a rough rule of thumb, the sealing pressure should be at least twice the maximum internal pressure in the pipe.

Re-tightening of bolts will normally decrease the risk for leakage. However, the selection of gasket type is important and will influence the performance of the joint. Drop-in steel core rubber gaskets have shown better performance than other types of gaskets, see further / ref.7.

> It is the design engineer or the joint supplier who has to select suitable components for the flanged joint and should supply instructions for the assembly operation.

6 Mechanical couplings

Mechanical couplings can be used for jointing of small sized PE pipes (normally < 63 mm). There are many different brands, and the joints are mainly made of brass or plastic materials. The mechanical joints have locking rings aimed to grip into the PE pipe and achieve an anchoring.

Certain couplers have also an insert to be placed in the pipe. For PE 100 pipes which are somewhat harder than PE pipes of lower material designations, some mechanical couplings may have difficulties to establish a proper anchoring. Mechanical joints to be used on PE 100 pipes are therefore to be selected with caution for unburied pipelines.

7 Anchoring

Almost all types of joints for PE pipes are restrainable, i.e. are able to transfer axial forces in the pipeline. Such forces are created by the internal pressure in the pipe and by temperature changes in the system.

A pipe system which is able to transfer axial forces does not need thrust blocks, provided the joints are able to transfer the upcoming forces.

Welded joints in PE pipes have practically the same strength as the pipe itself, and welded PE systems therefore do not normally need any further anchoring than:

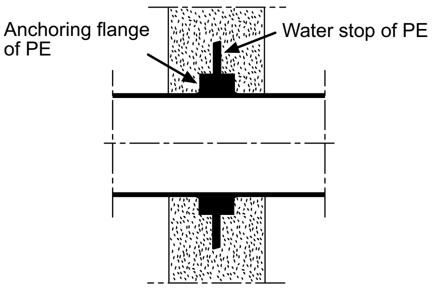
- anchoring of the pipe at connections to valve chambers and pumping stations, and at connec tions to bell and spigot jointed pipe systems
- anchoring at each sides on bends for PE pipes placed on supports

The anchoring of the pipe ends of a PE pipeline with welded joints is needed since the internal pressure will cause a small diameter increase in the pipeline, and a corresponding shortening of the pipe length will occur unless the end points are not anchored. Temperature changes may also give rise to changes in pipe length. The anchoring of the end points is specifically important for PE pipe placed on supports, or laid in ducts.

For a buried pipe, the soil friction will, to a certain extent, contribute to the anchoring of the pipe ends. However, for large diameter PE pipes a certain anchoring of the pipe ends may be needed, since soil friction will not be sufficiently high to prohibit minor movements at the end points.

Axial forces may thus be transferred from the pipe system to valve chambers and pumping stations. Connection points should therefore be designed to resist such forces, which can be large and may need specific anchoring flanges welded on to the PE pipeline, see figure. When anchoring buried PE pipes in concrete walls, the risk for water leakage between the pipe and the surrounding concrete needs also to be taken into account. It is therefore recommended that the cast-in PE pipe section also has a water stop flange welded on to the PE pipe.

Example of anchoring and water stop flanges for PE pipes.



Left. Anchoring and water stop flange for casting in concrete walls.

Right. Anchoring flanges for a PE pipe on supports (the pipe is to be fixed by a steel clamp between the flanges)

Axial forces in the pipe due to forced elongation and prohibited elongation can be calculated by using the following formulas:

Axial force at assembly due to forced elongation of the pipe:

$F = 1000 x A x E x \varepsilon$ (Equation 7.1)

Where
F = axial force in the pipe (kN)
A = cross sectional area of the pipe = $0{,}25\pi\,(D_y^2 - D_i^2)$ (m^2)
E = E-modulus of the pipe (MPa), see table 3.
ε = elongation in the pipe at assembly ($\Delta L/L$)

Axial force due to prohibited thermal expansion:

$F = \alpha x A x E x \Delta T$ (Equation 7.2)

Where
F = axial force in the pipe (kN)
α = thermal expansion coefficient (mm/m°C; normally 0,16-0,18)
A = cross sectional area of the pipe = $0{,}25\pi\,(D_y^2 - D_i^2)$ (m^2)
E = E-modulus of the pipe (MPa), see table 3.
ΔT = temperature change (°C)

Axial forces due to elongation of the pipe at assembly or temperature changes will decrease by time due to relaxation. The initial force is dependant on how fast and to what extent the pipe is elongated during assembly, and how fast a temperature change will occur in the pipe. To calculate initial forces the E-modulus is to be chosen with regard to the above times, see table 3.

PE pipe systems with restrainable joints are able to transfer high axial forces. The axial force which will occur in a pipeline with restrainable joints due to an internal pressure of 10 bar is shown in table 6.

Table 6: Axial force in PE pipes at an internal pressure of 10 bar.

D_y (mm)	Axial force (kN)	D_y (mm)	Axial force (kN)	D_y (mm)	Axial force (kN)
40	1,1	200	28	630	276
50	1,7	225	35	710	351
63	2,8	250	44	800	445
75	3,9	280	55	900	564
90	5,6	315	69	1000	696
110	8,4	355	88	1200	1002
125	11	400	111	1400	1364
140	14	450	141	1600	1781
160	18	500	174	1800	2254
180	23	560	218	2000	2783

For pressures other than 10 bar, the axial force in the pipe can be calculated by using the figures in table 6 in proportion to the actual pressure.

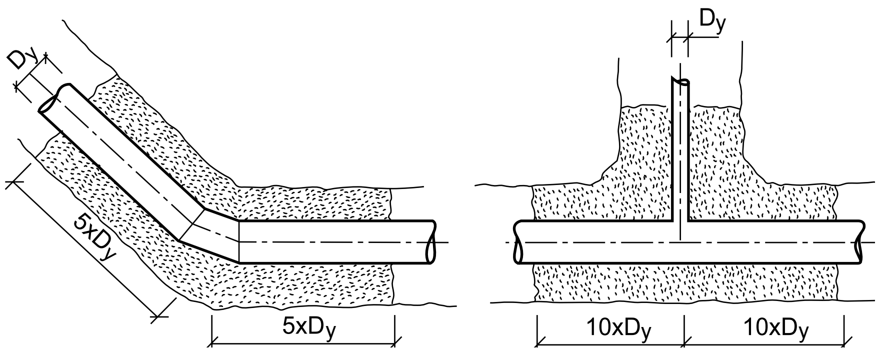
When connecting PE pipelines to valves or pipelines of other pipe materials, the connection point needs to be anchored for a force equal to the corresponding water pressure in the pipeline. Joint assembly and temperature changes may also cause additional forces. Calculation of such forces can be made by using equations 7.1 and 7.2.

In order to minimize movements at bends and tees in buried PE pressure pipe systems, backfill of friction material should be placed as shown below. The backfill material is to be compacted to ≥ 90 % mod. Proctor around:

– all bends >10° at a distance of minimum 5xD_y on each side of the bend (If bends larger than 45° are substituted with two bends of half angle, an improved hydraulic function and a decreased soil pressure around the bend will be achieved.)

– all tees at a distance of minimum 10xD_y around the tee (where D_y is the outside diameter of the branch)

Backfill with compacted friction material around bends and tees to minimize movements in buried PE pressure pipe systems.



If backfill is placed and compacted as described above, movements are expected to be almost negligible (usually less than 1 % of the pipe diameter).

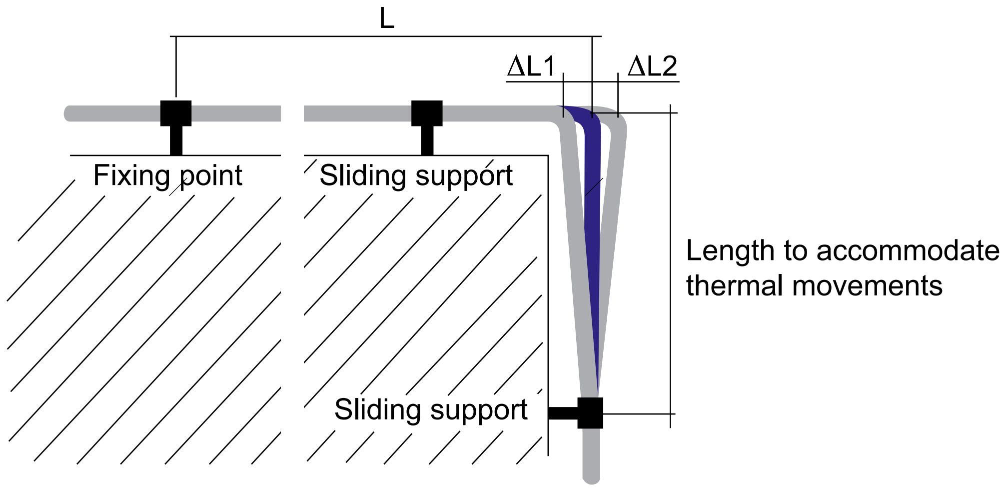
Segment-welded PE tees are sometimes cast in concrete as a protection for the tee fitting. If PE tees are cast in concrete, the surrounding concrete needs to be reinforced to withstand the full internal water pressure in the pipeline.

Temperature changes may give rise to noticeable length changes in PE pipelines, where movements in axial direction are not inhibited. A PE pipeline with restrainable joints on supports can accommodate limited changes in length, thus allowing minor movements and angular deflections in bends.

Fixing points should however be placed on each side of the bend not too far from the bend in order to limit movements and angular deflections, see figure.

A thermal expansion coefficient of 0.16 – 0.18 mm/m °C can be used for calculation of thermal movements.

Thermal movements are inhibited in between fixing points on straight pipe sections, but temperature changes will as a result of the inhibited expansion give rise to axial forces in the pipeline. Axial forces can be calculated by using equation 7.2.



Limitation of movements in bends
due to temperature changes.

8 Tightness testing

At tightness testing of PE pressure pipelines, a volume increase will occur in the pipeline. To maintain the pressure in the pipeline, an additional water volume therefore needs to be pumped in.

At tightness testing of long pipelines, or large diameter pipelines, it is more difficult to distinguish a small leakage from the water volume which needs to be pumped in to compensate for the volume expansion in the pipeline. If a leakage occurs in a PE pipeline, the leakage would most likely be found at a flanged joint, mechanical coupling or faulty electrofusion joint.

When performing tightness testing of long PE pipelines, or large diameter PE pipelines, it could be considered to have such joints available for inspection. A small leakage may otherwise be difficult to find.

The tightness testing procedure for PE pipelines is normally following various national standards or codes of practice.

Examples of some national standards and codes of practice for tightness testing of PE pipelines are:

- VAV P78 (Swedish code of practice)
- SFS 3115 (Finnish standard)
- EN 805 (European standard)
- DVGW W 400-2 (German code of practice)
- WRc A guide to testing of water supply pipelines and sewer rising mains (English code of practice)
- ASTM F2164 (American standard)

Tightness testing against closed valves should be avoided if possible, since minor leakages may occur at the valves.

9 Design

The Nordic Plastics Pipes Association gives in this pamphlet general information on PE pipes, fittings and jointing methods used for PE pressure pipe systems, as well as design issues which ought to be regarded by design engineers.

A PE pressure pipe system usually contains many different components, often manufactured by different companies. Some suppliers of components for the use in PE pipe systems have also their own distribution channels, and it is not always possible for a PE pipe manufacturer to supply all components. When several suppliers are involved, compatibility problems may also occur. It is therefore important that the design engineer/pipe system supplier is well familiar with the range of components available and there limitations to be able to provide suitable pipe system design.

It is the designer/pipe system supplier who selects the components to be used in the system, and who ought to supply instructions for the assembly of the system.

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The Nordic Plastics Pipe Association (NPG) has in this publication compiled information on PE materials, pipes, fittings and jointing systems. In addition, information has also been given on the need for anchoring and tightness testing of PE pipelines. We hope that that the information provided will be of some help to design engineers of PE pipe systems. Further information can be provided from NPG or any of the NPG member companies:

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INEOS
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www.ineos.se

KWH PIPE
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PIPELIFE
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