w w w . k r a h . n e t

Characteristics

PE-GFR pressure pipes

Krah pressure pipe system (KPPS)

Polyethylene (PE) pressure pipes have been used for water transportation for several decades. Their penetration in the market of plastics pipes is still increasing to the decrement of steel and ductile pipes due to its excellent performance. As a consequence the market is requesting increasing numbers of pipes and fittings in all kinds of diameters and higher pressurerates for novel applications.

In order to fulfill these requests new production techniques using fibre-reinforced compounds have been developed.

Krah AG`s latest development is the pressure pipe production machine to produce complete pipe systems up to a maximum diameter of 4000 mm, with a pipe length of 6 m. The pipes are designed for a working pressure up to 10 bar, with a safety factor C=1.25.

The pipe material is a compound of polyethylene (PE 80 or PE 100 pipe grade), fibres and a bonding material. These pipes are produced by the direct extrusion, winding the pipe in cross layers on the production tool. The pipes are jointed together by the electro fusion jointing technique. The fittings are fabricated by using butt-fusion and electro fusion technology. The complete range of fittings round up this technology.

Moreover, other pressure classes, up to 16 bar – depending on the diameter, can be produced. The main application is the conveyance of raw and potable water. The major advantages of this pipe system are the long lifetime, the reliable jointing technique, long installation lengths, good hydraulic properties, high pipe flexibility, the resistance against corrosion and a very low weight of the pipe.

All tests have been carried out by Becetel vzw, Gontrode Heirweg 130 – 9090 Melle (Belgium) on request of KRAH AG, Germany. Becetel is accredited according to EN ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories", certificate no. 242-T (see: *www.beltest.fgov.be*).

Becetel has evaluated several mechanical properties of the pipes. A hugh amount of tests has been selected to evaluate the pipe and fitting performance of the KPPS pipes. This selection is based on the testing methods as required by the actual ISO and CEN standards for (pressure) pipes.

The pipe system is produced and designed according to ISO/AWI 29561 (Plastics piping systems - Glass fibre reinforced polyethylene (PE-GFR) piping systems for water supply).

Production process

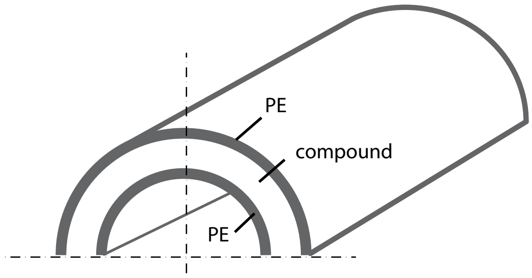
KPPS-pipes are produced according to the Krah spiral cross winding extrusion process. The extrusion unit is mixing all components and extruds them directly. During the production process the pipe is extruded seamless and all sub processes are controlled continuously by an integrated CPV and visualizing software.

The first layer is produced cross-over on a pre-heated calibration mandrel, the next layers are produced accordingly on the previous layers.

The orientation of the molecules is in radial direction, which has a positive effect on the internal pressure behavior. Another great advantage in quality is, due the slow and always rotating cooling process, that the pipe wall has no frozen stresses and no sagging.

Pipe wall build-up and color

The pipe wall of the KPPS pipes consists of three parts: a stress bearing compound of glass fibre reinforced polyethylene and an internal and external polyethylene layer.



Usually the internal and external layers have a coloured surface, e.g. blue – and the middle compound layer is white or black.

Density

Conventional density is a measure for the level of packing of the macromolecules, induced by post-processing crystallisation under cooling or annealing at moderate temperature.

Production technology

KPPS pipe DN/ID 2000 mm - 10 bar, including the integrated electro fusion joint

Butt fusion joint - DN/ID 1400 mm

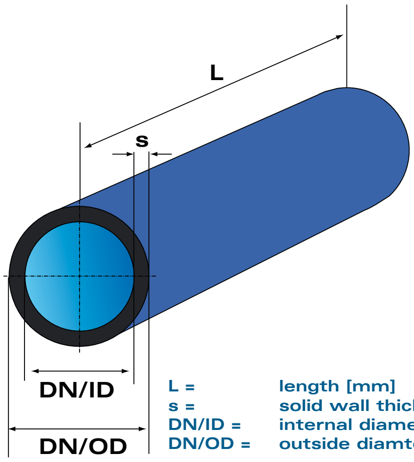
Bend 90° - DN/ID 1600 mm

Related to additives, pigments and fibres, the density measured on compound is different to the density measured on the base polymer.
The density of the base polymer will affect the mechanical properties of the product.

Due to the relation of the thicknesses of the three layer the density of the KPPS-pipe varies between 1.04 kg/dm³ and 1.08 kg/dm³.

Nominal pipe diameter

The nominal pipe diameter for KPPS pipes, is the internal (hydraulic) diameter (DN/ID), different pressure classes have the same nominal diameters.



L = length [mm]
s = solid wall thickness [mm]
DN/ID = internal diameter [mm]
DN/OD = outside diamter [mm]

Pipe length

The standard nominal pipe length (L) is 6 m, to guarantee an easy handling, storing and installation. The nominal pipe length is the laying length of the pipe, the overall pipe length includes spigot/socket end.

Integrated sockets

In general every pipe and every fitting has an integrated electro fusion socket and spigot. So no additional coupling elements are needed. The length of the socket can vary depending of the requested pressure class. Another jointing possibility for the KPPS-components is the butt-fusion technology.

Regression analysis

As a viscoelastic material, PE and its related products, exhibits time dependent properties under stress (pressure). This time dependency is frequently related to an age dependency as the traditional regression curves are often interpreted as a loss of strength with time. As a matter of fact the downward slope reflects the ability of the viscoelastic material to withstand lower stresses for longer periods than it to withstand higher stresses for short times.

For pressure applications one of the most important test is the determination of the regression curves according to ISO 9080 ("Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation") based on the Arrhenius equations.

This preliminary calculation demonstrates:

The KPPS-pipe has a MRS (minimum required strength at 20°C) value of > 20 Mpa. Compared to an extruded PE 100 pipe, according to DIN 8074, the pipe wall can be decreased by approx. 50%.

Short-term burst pressure

The short-term burst pressure according to ASTM D1599, procedure A was done to find out the maximum hoop stress of KPPS pipes.

The test result was a hoop stress at burst pressure of 39.1 MPa.

Slow crack growth (SCG)

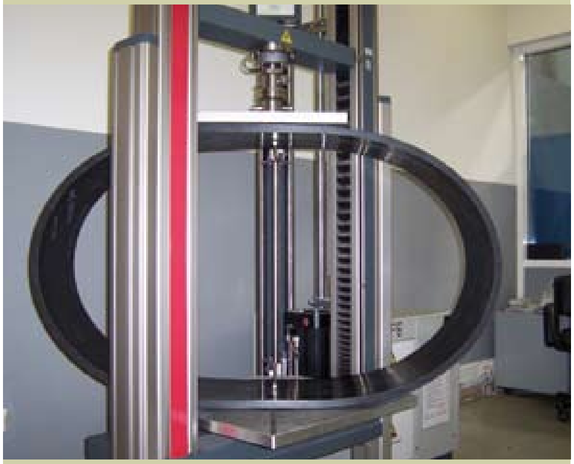
Slow crack growth (SCG) can be defined as the relatively stable growth of a crack through the wall of a component over a long period of time. The initiation and growth of the crack requires a stress concentration and a driving force.

Storage, handling and installation in severe conditions could result in scored or notched pipes. This damage can initiate SCG failures.

The use of PE reinforced materials with high SCG resistance minimizes such effects, including occasional scoring and notching created during renovation and even trenchless installation. In a pipeline system SCG usually starts at the notch in combination with internal pressure, residual stresses from processing, installation stresses, ground and traffic loading.

The tests are performed in accordance with EN ISO 13479 "Polyolefin pipes for the conveyance of fluids - Resistance to crack propagation - Test method for slow crack growth on notched pipes (notch test)"

Stiffness test of a KPPS pipe



Deflection test according to EN 1440

A KPPS T-piece

Infrared heating system

The pipe (length 1200 mm, with a free length of 800 mm between the end-caps) has been notched (4 equidistant notches, length 315 mm) with a milling cutter (60° included angle, "V" cutter).

Test was stopped after 2500 hours, without any failure of the pipe.

Rapid crack propagation (RCP) S4

Rapid crack propagation (RCP) is the generation of a low ductility (brittle) crack running at high speed (approximately 300 m/s) over long lengths along an internally pressurised pipeline.

In order to avoid damage due to this phenomenon gas and water supply systems are designed taking into account the critical pressure, below which RCP does not occur.

Ongoing progression of the crack is dependent upon the balance between the strain energy potentially available for release at the crack tip as the crack further extends and the energy required to create new crack surfaces. Crack arrest is achieved when the strain energy for release is less than the energy required for the creation of new crack surfaces. The strain energy is influenced primarily by the internal pressure of the fluid exerted locally at the pipe bore adjacent to the crack tip; which in turn is affected by the rate at which the fluid decompresses relative to the crack speed. Secondary influences include the possible deformation of the pipe behind the crack tip induced by the pressure of the internal fluid as it exits from the pipe.

The initiation of RCP could be the result of impact damage, through wall SCG or a poor fusion. The phenomenon of RCP has been reported for different materials e.g. steel, plastics, etc.

The parameters that govern RCP are
- internal pressure
- pipeline temperature
- rate of decompression of the conveyed fluid
- fracture toughness of the pipe material

The susceptibility to RCP of pipes in a particular material increases with increasing pipe diameter and wall thickness and is assessed experimentally to allow the system to be designed to eliminate the risk.

The tests on the PE reinforced pipes are performed in accordance with EN ISO 13477: "Determination of the resistance to Rapid Crack Propagation (S4 test)".

Temperature (°C)	0
Pressure (bar)	5
Crack length *a* (mm)	300
a/d_n	1.0
Results	Crack arrest

Test conditions

The crack length in the above-mentioned table is measured from the centre of the knife impact. The crack length is also given in relation to the nominal diameter of the pipes DN.

The S4 tests on the KPPS pipe ø 315 x 5.8 mm result in the following critical pressure: pc, S4 > 5 bar at 0°C.

Decohesion of an electro fusion joint

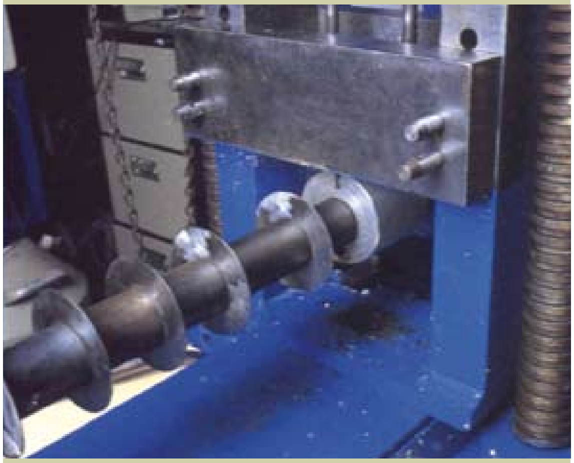
The purpose of this test is to assess the cohesion of PE pipe/electro fusion socket assembly by examination of the decohesion of the assembly by a tensile stressing of a strip test piece under conditions which cause progressive peeling of the fused interface.

The tests on the PE reinforced pipes are performed in accordance with ISO 13954: "Plastics pipes and fittings - Peel decohesion test for polyethylene electro fusion assemblies".

The specification following EN 1555 (Gas) and EN 12201 (Potable Water) limits the percentages of brittle decohesion to 33 %. This limit was not extended.

Interpretation of results and fracture patterns:

If the fracture of the test specimen occurs in the pipe stroke than the corresponding bending stress has been calculated. This bending stress varies between 64 MPa and 71 MPa.



Rapid crack propagation - S4 test

Indicator for density test

Electro fusion spigot of a DN/ID 1200 - 10 bar

Electrofusion coupler ø 560 mm

Thermal stability

Determination of the oxidation induction time (OIT) is performed according to EN 728.
It is a measure of how well stabilised the material is against thermal degradation during processing, storage welding, and operation. If the material is not well stabilised, it could start to degrade during extrusion, moulding, storage, welding, or use at elevated temperature, resulting in a shorter lifetime.

Thermal stability is measured according to ISO TR 10837 and is expressed by OIT.
The OIT, during which the antioxidant additive in the PE material significantly reduces oxidation of the material in the presence of oxygen at an elevated temperature, is measured in minutes.

The OIT is in this case measured after processing.

The test pieces was checked from outside and inside of the pipe for > 55 min and the appearance of the piece did not change.

Tensile strength, yield, elongation and E-modulus

Tensile strength, yield, elongation and E-modulus are major properties of the material and represent its capability to sustain a given range of applied short-term load conditions. During installation and service, the PE system is subjected to different sources of secondary stresses generated by installation techniques, bending and soil subsidence. It is necessary to ensure that the system is capable of withstanding the induced stresses and strains.

Tensile strength, yield, elongation and E-modulus are influenced by test temperature, strain rate and test piece geometry and are important considerations when undertaking structural design analysis.

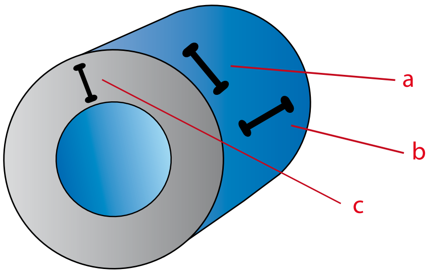
The tensile properties of reinforced PE are normally determined by the conduct of uniaxial tensile tests at constant temperature and a given strain rate, on dumbbell test pieces moulded from material pellets or machined from pipes or fusion joints.

The major characterising features of the test are yield point stress and strain, elongation at break and E-modulus. The ductility of reinforced PE creates the conditions for exceptional resistance to loads induced by ground movement and external loads (traffic) applied to pipes.

The tensile properties are quality control parameters used in the quality assessment of materials and pipes. It is sensitive to significant changes in molecular structure, glass content, extrusion conditions, etc. leading to material and pipe deterioration.

The mean value of the E-modulus, according to ISO 527-4 was 2355 N/mm^2.

We carried out the evaluation of the tensile properties in longitual, radial and circumferential directions.



The mean results were:

Direction	Stress at yield	Strain at break
(a) Circumferential	66.8 N/mm²	7 %
(b) Longitual	34.7 N/mm²	19 %
(c) Radial	31.1 N/mm²	6 %

Determination of flexural E-modulus

The flexural E-modulus is an important property of the material and demonstrates if the behaviour of compression zone of the reinforced specimen is different from the tensile zone by comparing it to the overall tensile modulus.

The flexural E-modulus is determined at 23°C, according to EN ISO 178 (Plastics – determination of flexural properties of rigid plastics).

The mean value was 2566 MPa. The result demonstrates that the E-modulus in tension and in flexion are nearly equal.

Tensile test specimen preparation

Test specimen after tensile test

KDR-700 pipe production line

Burstpressure test of a KPPS pipe DN/ID 900 by 80°C

Linear thermal expansion coefficient

The linear thermal expansion coefficient (α) has been determined on a rectangular reinforced PE specimen ($120 \times 10 \times 4\,mm^3$) produced with the same glass fibre content as the pipes according to a proper Becetel method.
The α is between the α of glass ($0.9 \times 10^{-5}/K$) and the α of HDPE ($18 \times 10^{-5}/K$).

$$\alpha = 5 \times 10^{-5} \frac{1}{K}$$

(measured between –20°C and 50°C)

Deflection test

The deflection is done according to EN 1440. The test results on the tested pipes fulfilled the requirements by far.

Determination of ring stiffness

The ring stiffness is determined by measuring the force and the deflection while deflecting the pipe at a constant rate according to EN ISO 9969: “Thermoplastics pipes – Determination of the ring stiffness”. We did several ring stiffness tests (deformation of 3%), and the results was always as expected (calculated). Even after a second deformation of the test pieces no failures have been recorded and the aimed stiffness was reached. A deformation of 60 % did not lead to any failures.

Determination of creep ratio

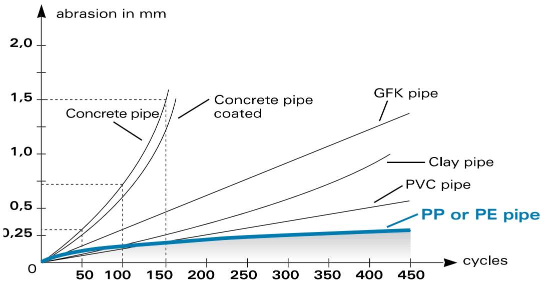
The creep ratio on thermoplastics pipes having a circular cross-section is measured according to EN ISO 9967: “Thermoplastics pipes – Determination of creep ratio”.

The pipe deflection is measured at regular intervals, the linearity of the plot of pipe deflection against time is analysed and the creep ratio is calculated.

The mean creep ratio was 2.21.

Abrasion behavoir

Polyethylene and polypropylene pipes are among the most abrasion proof pipes. This was tested and proofed in the so-called Darmstadt-procedure and the results are shown in the diagram and conform the quality of the KPPS pipes.

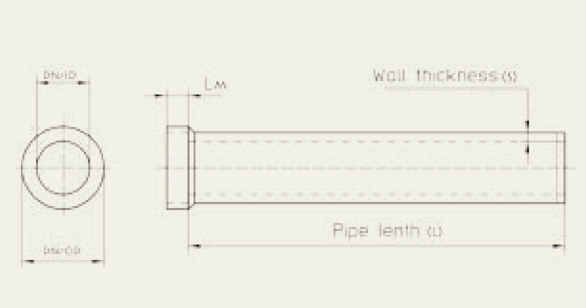


Abrasion curve of various pipe materials according to the Darmstadt procedure

The inner surface of KPPS pipes are made out of virgin high quality PE, so the abrasion behavior is like PE pipes.

Delivery Program

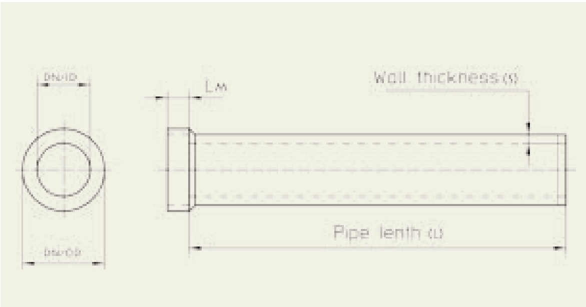
Pipes 6 bar



DN/ID [mm]	s [mm]	DN/OD [mm]	Section of distance [mm²]	Section of pipe wall [mm²]	Weight per pipe [kg]	Socket lenght [mm]
500	10	520	1963.49	160.22	15	156
600	12	624	2827.43	230.72	22	156
700	14	728	3848.45	314.03	30	156
800	15	830	5026.54	384.06	39	156
900	17	934	6361.72	489.74	50	163
1000	19	1038	7853.98	608.24	61	163
1200	23	1246	11309.73	883.70	88	169
1300	25	1350	13273.22	1040.66	104	248
1400	27	1454	15393.80	1210.42	120	248
1500	29	1558	17671.45	1393.02	138	254
1600	31	1662	20106.19	1588.42	157	254
1700	33	1766	22698.00	1796.65	177	267
1800	35	1870	25446.90	2017.68	198	267
1900	37	1974	28352.87	2251.55	221	267
2000	39	2078	31415.92	2498.23	245	267

Standard pipe length of 6 m - shorter length on request
All technical subject to change.

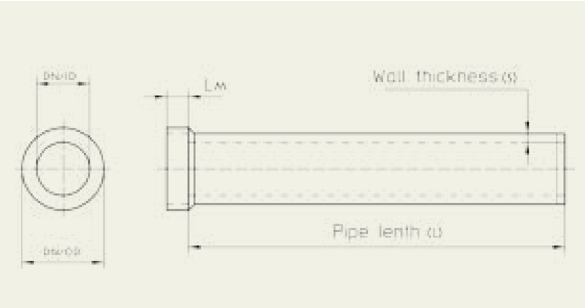
Pipes 10 bar



DN/ID [mm]	s [mm]	DN/OD [mm]	Flow cross-section [mm²]	Section of pipe wall [mm²]	Weight per pipe [kg]	Socket lenght [mm]
500	16	532	1963.49	259.37	26	156
600	19	638	2827.43	369.48	38	156
700	23	746	3848.45	522.41	51	156
800	26	852	5026.54	674.69	66	156
900	29	958	6361.72	846.38	85	163
1000	33	1066	7853.98	1070.93	105	163
1200	39	1278	11309.73	1518.05	151	169
1300	42	1384	13273.22	1770.73	177	248
1400	46	1492	15393.80	2089.66	205	248
1500	49	1598	17671.45	2384.50	235	254
1600	52	1704	20106.19	2698.75	268	254
1700	55	1810	22698.00	3032.42	303	267
1800	59	1918	25446.90	3445.73	339	267
1900	62	2024	28352.87	3821.56	378	267
2000	65	2130	31415.92	4216.80	419	267

Standard pipe length of 6 m - shorter length on request
All technical subject to change.

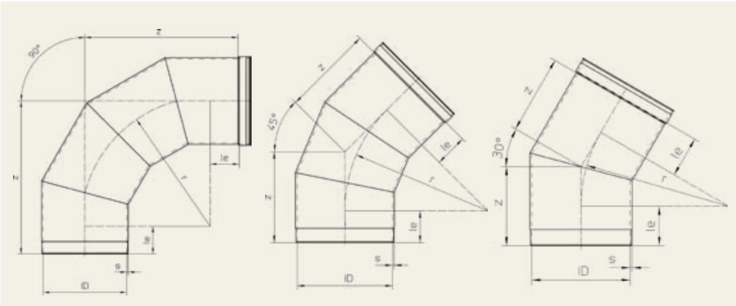
Pipes 16 bar



DN/ID [mm]	s [mm]	DN/OD [mm]	Section of distance [mm²]	Section of pipe wall [mm²]	Weight per pipe [kg]	Socket lenght [mm]
500	26	552	1963.49	429.64	44	156
600	32	664	2827.43	635.35	63	156
700	37	774	3848.45	856.68	85	156
800	42	884	5026.54	1111.00	111	156
900	48	996	6361.72	1429.55	141	163
1000	53	1106	7853.98	1753.29	174	163
1200	64	1328	11309.73	2541.42	251	169
1300	69	1438	13273.22	2967.58	294	248
1400	74	1548	15393.80	3426.72	341	248
1500	79	1658	17671.45	3918.86	392	254
1600	85	1770	20106.19	4499.54	446	254
1700	90	1880	22698.00	5061.11	504	267
1800	95	1990	25446.90	5655.65	565	267
1900	100	2100	28352.87	28352.87	630	267
2000	106	2212	31415.92	7013.17	697	267

Standard pipe length of 6m - shorter length on request
All technical subject to change.

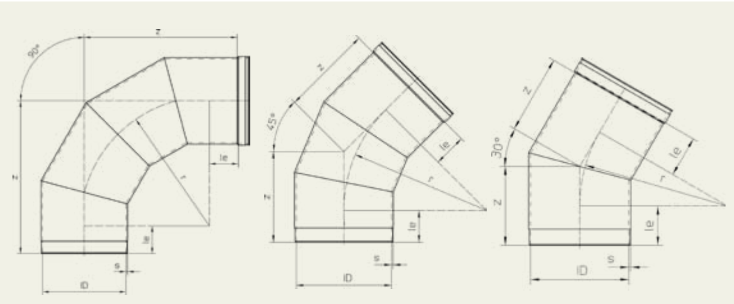
Segmented bends 6 bar



Angle	DN/ID	s	DN/OD	le	r	z
30°	1000 mm	27	1054	603	1500	802
	1200 mm	32	1264	715	1800	882
	1400 mm	38	1476	868	2100	1063
	1600 mm	44	1688	1020	24000	1243
	1800 mm	49	1898	1072	2700	1323
	2000 mm	55	2110	1226	3000	1504
45°	1000 mm	27	1054	699	1500	1022
	1200 mm	32	1264	758	1800	1146
	1400 mm	38	1476	918	2100	1370
	1600 mm	44	1688	1077	2400	1594
	1800 mm	49	1898	1137	2700	1718
	2000 mm	55	2110	1297	3000	1943
60°	1000 mm	27	1054	665	1500	1266
	1200 mm	32	1264	718	1800	1440
	1400 mm	38	1476	870	2100	1712
	1600 mm	44	1688	1023	2400	1986
	1800 mm	49	1898	1076	2700	2159
	2000 mm	55	2110	1229	3000	2432
90°	1000 mm	27	1054	802	1500	1900
	1200 mm	32	1264	883	1800	2200
	1400 mm	38	1476	1063	2100	2600
	1600 mm	44	1688	1243	2400	3000
	1800 mm	49	1898	1323	2700	3451
	2000 mm	55	2110	1504	3000	3700

Bends are being welded from pipe segments -
Other diameters an/or pressure classes on request.
All technical subject to change.

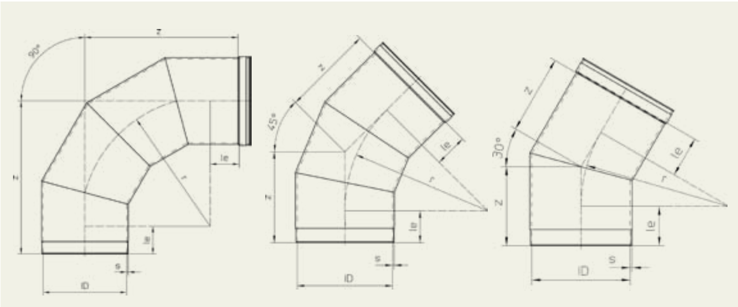
Segmented bends 10 bar



Angle	DN/ID	s	DN/OD	le	r	z
30°	1000 mm	46	1092	659	1500	802
	1200 mm	55	1110	711	1800	882
	1400 mm	65	1530	863	2100	1063
	1600 mm	73	1746	1016	2400	1243
	1800 mm	83	1966	1066	2700	1323
	2000 mm	91	2182	1219	3000	1504
45°	1000 mm	46	1092	699	1500	1022
	1200 mm	55	1110	758	1800	1146
	1400 mm	65	1530	918	2100	1370
	1600 mm	73	1746	1077	2400	1594
	1800 mm	83	1966	1137	2700	1718
	2000 mm	91	2182	1297	3000	1943
60°	1000 mm	46	1092	665	1500	1266
	1200 mm	55	1110	718	1800	1440
	1400 mm	65	1530	870	2100	1712
	1600 mm	73	1746	1023	2400	1986
	1800 mm	83	1966	1076	2700	2159
	2000 mm	91	2182	1229	3000	2432
90°	1000 mm	46	1092	802	1500	1900
	1200 mm	55	1110	883	1800	2200
	1400 mm	65	1530	1063	2100	2600
	1600 mm	73	1746	1243	2400	3000
	1800 mm	83	1966	1323	2700	3451
	2000 mm	91	2182	1504	3000	3700

Bends are being welded from pipe segments -
Other diameters an/or pressure classes on request
All technical subject to change.

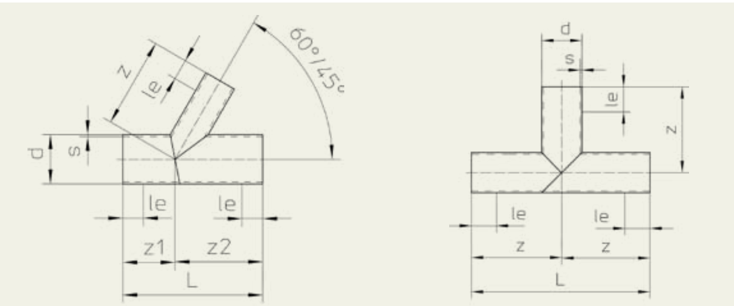
Segmented bends 16 bar



Angle	DN/ID	s	DN/OD	le	r	z
30°	1000 mm	74	1148	659	1500	802
	1200 mm	90	1380	711	1800	882
	1400 mm	104	1608	863	2100	1063
	1600 mm	119	1838	1016	2400	1243
	1800 mm	133	2066	1066	2700	1323
	2000 mm	149	2298	1219	3000	1504
45°	1000 mm	74	1148	699	1500	1022
	1200 mm	90	1380	758	1800	1146
	1400 mm	104	1608	918	2100	1370
	1600 mm	119	1838	1077	2400	1594
	1800 mm	133	2066	1137	2700	1718
	2000 mm	149	2298	1297	3000	1943
60°	1000 mm	74	1148	665	1500	1266
	1200 mm	90	1380	718	1800	1440
	1400 mm	104	1608	870	2100	1712
	1600 mm	119	1838	1023	2400	1986
	1800 mm	133	2066	1076	2700	2159
	2000 mm	149	2298	1229	3000	2432
90°	1000 mm	74	1148	802	1500	1900
	1200 mm	90	1380	883	1800	2200
	1400 mm	104	1608	1063	2100	2600
	1600 mm	119	1838	1243	2400	3000
	1800 mm	133	2066	1323	2700	3451
	2000 mm	149	2298	1504	3000	3700

Bends are being welded from pipe segments -
Other diameters an/or pressure classes on request
All technical subject to change.

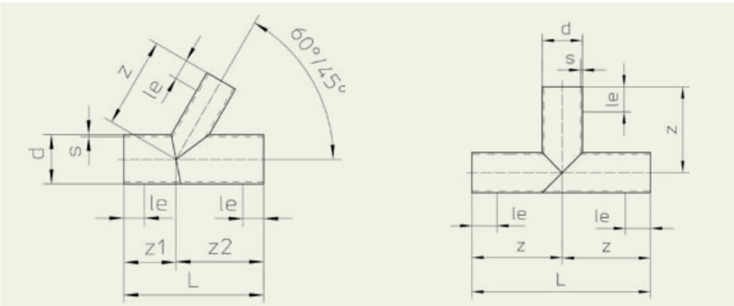
Segmented branches 6 bar



Angle	DN/ID	d [mm]	s [mm]	le [mm]	L	z1	z2
45°	1000 mm	1045	27	400	2070	710	1360
	1200 mm	1264	32	400	2400	860	1540
	1400 mm	1476	38	500	2730	1010	1720
	1600 mm	1688	44	500	3060	1160	1900
	1800 mm	1898	49	600	3590	1410	2180
	2000 mm	2110	55	600	3920	1560	2360
60°	1000 mm	1054	27	400	2070	710	1360
	1200 mm	1264	32	400	2400	860	1540
	1400 mm	1476	38	500	2730	1010	1720
	1600 mm	1688	44	500	3060	1160	1900
	1800 mm	1898	49	600	3590	1410	2180
	2000 mm	2110	55	600	3920	1560	2360

Fittings are being welded from pipe segments -
Other diameters an/or pressure classes on request
All technical subject to change.

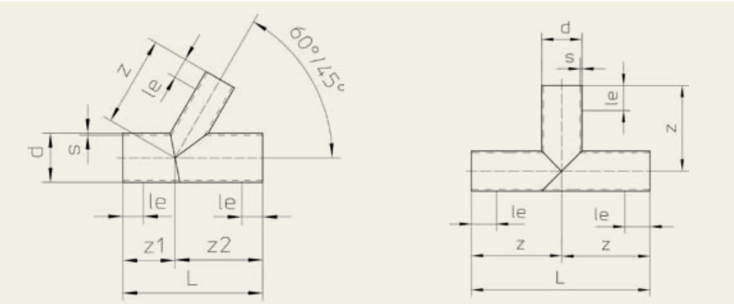
Segmented branches 10 bar



Angle	DN/ID	d [mm]	s [mm]	le [mm]	L	z1	z2
45°	1000 mm	1092	46	400	2070	710	1360
	1200 mm	1110	55	400	2400	860	1540
	1400 mm	1530	65	500	2730	1010	1720
	1600 mm	1746	73	500	3060	1160	1900
	1800 mm	1966	83	600	3590	1410	2180
	2000 mm	2182	91	600	3920	1560	2360
60°	1000 mm	1092	46	400	2070	710	1360
	1200 mm	1110	55	400	2400	860	1540
	1400 mm	1530	65	500	2730	1010	1720
	1600 mm	1746	73	500	3060	1160	1900
	1800 mm	1966	83	600	3590	1410	2180
	2000 mm	2182	91	600	3920	1560	2360

Fittings are being welded from pipe segments -
Other diameters an/or pressure classes on request
All technical subject to change.

Segmented branches 16 bar



Angle	DN/ID	d [mm]	s [mm]	le [mm]	L	z1	z2
45°	1000 mm	1148	74	400	2070	710	1360
	1200 mm	1380	90	400	2400	860	1540
	1400 mm	1608	104	500	2730	1010	1720
	1600 mm	1838	119	500	3060	1160	1900
	1800 mm	2066	133	600	3590	1410	2180
	2000 mm	2298	149	600	3920	1560	2360
60°	1000 mm	1148	74	400	2070	710	1360
	1200 mm	1380	90	400	2400	860	1540
	1400 mm	1608	104	500	2730	1010	1720
	1600 mm	1838	119	500	3060	1160	1900
	1800 mm	2066	133	600	3590	1410	2180
	2000 mm	2298	149	600	3920	1560	2360

Fittings are being welded from pipe segments -
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w w w . k r a h . n e t

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All information subject to change
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