High Pressure Pipe System for pipes up to DN 4000

Hochdruckrohrsystem für Rohre bis zu DN 4000

Polyethylene (PE) pressure pipes have been used for water for several decades. Their penetration in the market of plastics pipes is still increasing to the decrement of steel and concrete pipes due to its excellent performance. As a consequence the market is requesting increasing pipes and fittings diameters and higher pressures for novel applications. In order to fulfil these requests new production techniques using fibre-reinforced compounds have been developed. Krah AG's (Germany) 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 of 10 bar and more. The pipe material is a compound of polyethylene (PE 80 pipe grade), fibres and a bonding material.

These pipes are produced by the direct extrusion, winding the pipe in cross layering on the production tool. The pipes are jointed together by the electrofusion jointing technique. The complete range of fittings rounds up this technology.

Moreover, other pressure classes 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.

Becetel has evaluated several mechanical properties of production runs on three pipe diameters: ø 315 mm, ø 560 mm and ø 900 mm and on specimen produced with the same glass fibre content as the pipes. They were subjected to a range of tests to assess their quality compared to contemporary standard PE-pipe production.

Druckrohre aus Polyäthylen (PE) sind seit einigen Jahrzehnten zur Förderung von Wasser im Einsatz. Dank einem ausgezeichneten Leistungsbild nimmt ihr Marktanteil weiterhin auf Kosten von Stahl- und Betonrohren zu. Der Markt fordert daher zunehmend sowohl für Rohre als auch für Armaturen und Fittings größere DNs und höhere PNs für neuartige Anwendungen. Zur Erfüllung dieser Forderungen wurden neue Herstellungsmethoden entwickelt, die den Einsatz faserverstärkter Mischungen vorsehen. Die neueste Entwicklung der Krah AG (Deutschland) ist eine Maschine zur Herstellung von Druckrohren, die in der Lage ist, vollständige Rohrleitungen bis zu einem maximalen Durchmesser von 4000 mm mit einer Rohrlänge von 6 m zu erzeugen. Diese Rohre sind für einen Betriebsdruck von 10 bar und höher ausgelegt. Das benutzte Rohrleitungsmaterial ist eine Kombination aus Polyäthylen (PE 80 Rohrleitungsqualität), Fasern und einem Binder.

Diese Rohre werden mit der Methode der direkten Extrusion hergestellt, wobei die Rohre durch wiederholtes kreuzweise Auflegen der Elemente auf das Herstellungswerkzeug gewickelt werden. Verbunden werden die einzelnen Rohre durch E-Schweißung. Diese Technik wird durch ein komplettes Programm von Armaturen und Zubehör abgerundet.

Es ist außerdem möglich, noch andere Druckklassen zu erzeugen, wobei die hauptsächliche Anwendung in der Förderung von Roh- sowie von Trinkwasser besteht. Die größten Vorteile dieses Rohrleitungssystems finden sich in der langen Lebensdauer, der zuverlässigen Verbindungstechnik, den langen Verlegungsstrecken, den guten hydraulischen Eigenschaften, der hohen Biegsamkeit, dem Korrosionswiderstand sowie in dem sehr niedrigen Gewicht.

Becetel hat einige mechanische Eigenschaften an Rohren der Durchmesser 315 mm, 560 mm und 900 mm aus der laufenden Produktion sowie an Proben, die mit dem gleichen Gehalt an Glasfasern wie die Rohre hergestellt wurden, ausgewertet. Diese Prüfkörper wurden verschiedenen Versuchen unterzogen, um deren Qualität im Vergleich zu herkömmlichen PE-Rohren aus der gegenwärtigen laufenden Produktion bestimmen zu können.

Philippe Vanspeybroeck
General Director of Becetel, Prof.
University of Gent
Tel. +32(0)9/272 5072
E-Mail: philippe.vanspeybroeck@
becetel.de

A battery of tests has been selected to evaluate the pipe and fitting performance of the Krah Pressure Pipe System (KPPS) pipes. This selection is based on the testing methods as required by the actual ISO and CEN standards for (pressure) pipes.

Pipe wall build-up and wall thickness

The pipe wall of the ø 315 mm pipe consists of 2 parts:

- a stress bearing glass fibre reinforced PE part and
- an internal PE coating of 0,8 mm.

The surface of the stress bearing part consists of a rather rough surface and contains furthermore a small spiral wound glass fibre reinforced PE band.

The wall thickness of the pipe is determined on the rough surface of the stress bearing glass fibre reinforced PE part including the internal PE coating, at minimum 6 places, regularly spread over the circumference of the pipe, by means of a dial gauge. The thickness of the internal PE coating is measured separately under the microscope after cutting out 6 pieces out of the wall at the position where the total wall thickness has been determined.

The outside diameter varies between 314,9 mm and 316,3 mm, whereas the total wall thickness amount 6,1 mm with a standard deviation of 0,3 mm.

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.

During cooling of the PE material e.g. post-processing, the macromolecules are likely to arrange in crystallites, the size of which is dependent upon both thermal history and chain characteristics (e.g. branching, ...). The degree of such arrangement leads to a more or less complete packing. The higher the packing, the higher the crystallisation and in turn the higher the density.

Because of additives, pigments and fibres, the density measured on compound is different from the density measured on the base polymer.

The density of the base polymer will affect the mechanical properties of the product.

The density has been determined on a ø 315 mm pipe according to ISO 1183/1 ("Plastics – Methods for determining the density and relative density of non-cellular plastics" – method A: immersion method) on the pipe material.

Due to the contents of glass fibres the density of the PE-pipe varies between 1,04 g/m^3 and 1,08 g/cm^3.

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 can 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 standard allows the determination of the long-term behaviour (e.g. 50 or 100 years) of the pipes under constant pressure at a constant temperature (e.g. 20 °C). Moreover, the mathematical procedure of ISO 9080 allows extrapolations at other temperatures and other times. Extrapolation of the relationship between logarithm of the stress and logarithm of the failure times determine the long-term strength.

According to ISO 9080, for each selected temperature, a minimum of 30 observations is required, regularly spread over more than five internal pressure levels. Moreover, the internal pressure levels are selected such that at least one observation will occur above 9.000 h and three observations will occur above 7.000 h.

Testing

Based on the obtained pressure tests (according to ISO 1167 for the internal pressure tests at 20 °C and 80 °C and to ASTM D 1599 for the burst test at 20 °C) on ø 315x5,8 mm and on ø 900x45 mm pipes (see **Table 1**) a provisional regression curve based on ISO 9080 is established. An extrapolation until 50 years, based on "Model 3" (a four-parameter model), which consists of variable slopes of the regression lines at different temperatures, is conducted.

Calculations of the regression curves

For this provisional calculation only 16 samples, from two pipe diameters, have been taken into account.

Table 1

Pipe ø and no.	Temperature (°C)	Hoop stress (MPa)	Test pressure (bar)	Results
ø315/1 ø315/2 ø315/3	20 20 20	26,8 29,8 35,8	9,0 10,0 12,0	Brittle failure after 2.134 h Brittle failure after 128 h Brittle failure after 5,4 h
ø315/4	20	39,1	14,5	Burst pressure test within 1 min
ø315/5 ø315/6 ø315/7 ø315/8	80 80 80 80	10,4 11,9 14,8 17,9	3,5 4,0 5,0 8,0	Brittle failure after 1.457 h Brittle failure after 603 h Brittle failure after 45,4 h Brittle failure after 5,4 h
ø900/1 ø900/2 ø900/3 ø900/4	20 20 20 20	25,0 27,0 29,0 31,0	23,8 25,7 27,6 29,5	Under pressure Under pressure Under pressure Under pressure
ø315/5 ø315/6 ø315/7 ø315/8	80 80 80 80	9,2 10,4 11,5 13,1	12,0 13,0 15,0 17,0	Under pressure Under pressure Brittle failure after 603 h Brittle failure after 159 h

Table 2

	C	Std. Error
(1)	-132,184	28,178
(2)	51.639,876	9.526,425
(3)	76,181	20,591
(4)	-30.644,730	6.802,259

Table 3

Temperature	Stress in MPa at 50 years	
°C	σ_{LTHS}(1) σ_{LPL}(2)	
20	22,48	18,77
80	6,21	2,65

(1) σ_{LTHS} long-term hydrostatic strength (MPa), represents the predicted mean strength at a temperature T and a time t = 50 years

(2) σ_{LPL} represents the 97,5 % lower confidence limit (LPL) of the predicted strength for a single value with a probability level - which has a value of 0,975 at a temperature T and a time t = 50 years

Fig. 1

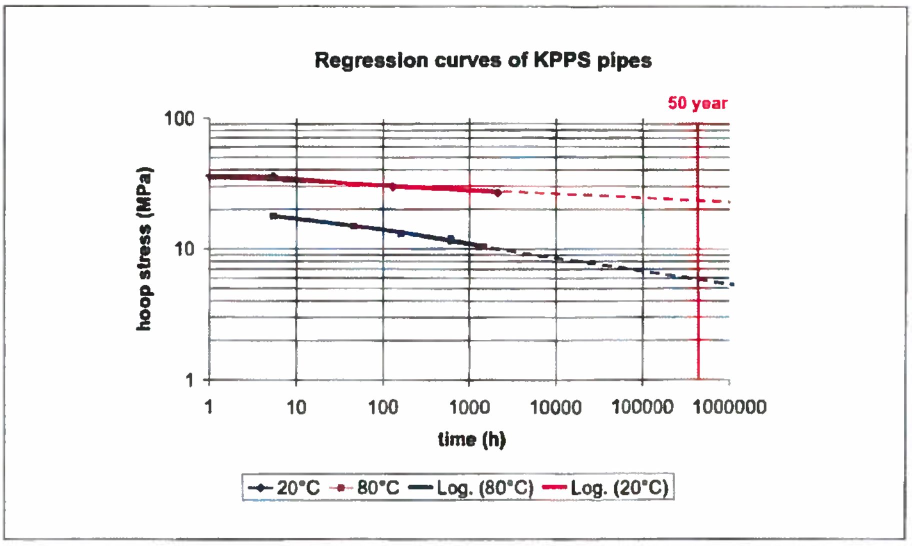

Table 4

Test piece ø (mm)	Wall thickness e_y (mm) at notch position				d_{em} (mm)
	A = $e_{y,min}$	B	C	D	
315	5,90	6,10	6,15	6,00	315,8

d_{em} = mean outside diameter (mm); e_y = wall thickness (mm); $e_{y,min}$ = minimum wall thickness (mm)

Table 5

Temperature (°C)	Hoop stress (MPa)	Test results
80	4,6	> 2.500 h, test stopped

Model 3 (4 parameter)

The following results are achieved by applying the regression procedure on the failure data set as mentioned in the Table 1. The regression analysis, based on the PC computer program prepared by Becetel, as mentioned in ISO 9080, is reported hereafter.

The "Model 3" uses the following equation to calculate the long-term hydrostatic strength, according to ISO 9080.

$$\log t = C(1) + \frac{C(2)}{T} + C(3)\log\sigma + \frac{C(4)}{T}\log\sigma$$

σ = hoop stress, stress in circumferential direction (MPa); t = time (h); T = temperature (K); C(1), C(2), C(3), C(4) =coefficients of the equation, to be determined by regression on the stress rupture data.

These calculations permit to predict the 20 °C regression line and the lower confidence limit (LPL 97,5 %) of the stress at 50 years.

Determination of the "brittle" slope

As the pipes present a no ductile failures, only the "brittle failure slope" has been used in the calculation.

The following statistical values are determined after 50 years.

- coefficient of the equation log t = f (log σ, T), (**Table 2**)
- extrapolated stress levels at different temperatures (**Table 3, Figure 1**).

Conclusion

This preliminary calculation demonstrates that the reinforced PE pipes have an LTHS > 22,5 MPa and an LPL > 18,8 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 minimises 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 on the PE reinforced ø 315 mm pipe 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)".

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); (**Tabel 4** and **5**).

Rapid Crack Propagation (RCP)

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.

Table 6

Pipe no.	Temperature (°C)	Pressure (bar)	Crack length a (mm)	a/d_n	Results
1	0	5	300	1,0	Crack arrest

Table 7

Fusion conditions	Test piece no.	Aspect of the failure	Peel force (N)	Bending force (N)	Stress at pipe rupture (N)	% brittle failure
KRAH AG	1	Pipe failure	-	2459	71	0
	2	Pipe failure	-	2230	65	0
	3	Pipe failure	-	2456	71	0
	4	Pipe failure	-	2194	64	0
	5	Pipe failure	-	2374	69	0
	6	Decohesion	1465	-	-	0
	7	Pipe failure	-	2218	64	0
	8	Decohesion	2317	-	-	0
	9	Decohesion	2081	-	-	0
	10	Pipe failure	-	2201	64	0

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,....

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 pipe are performed in accordance with EN ISO 13477: "Determination of the resistance to Rapid Crack Propagation (S4 test)".

The crack length in **Table 6** is measured from the centre of the knife impact. The crack length is also given in relation to the nominal diameter of the pipes d_n.

The S4 tests on the PE pipes ø315x5,8 mm result in the following critical pressure: $p_{c,S4}$ > 5 bar at 0 °C.

Determination of the decohesion resistance of a PE pipe/electrofusion socket assembly

The purpose of this test is to assess the cohesion of PE pipe/electrofusion 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 pipe are performed in accordance with ISO 13954: "Plastics pipes and fittings – Peel decohesion test for polyethylene electrofusion assemblies".

An electrofusion assembly ø 560, which consists of a male and a female part, is fused together by Krah AG.

10 parallel samples of 40 mm width are milled alongside the assembly, containing the pipe (male) / electrofusion (female) coupler. The coupler is peeled from the PE pipe with a tensile speed of 25 mm/min at 23 °C.

The specification following EN 1555 (Gas) and EN 12201 (Potable Water) limits the percentages of brittle decohesion to 33 %.

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 and taken up in the Table. This bending stress varies between 64 MPa and 71 MPa. If the fracture occurs by "pure" decohesion than the corresponding decohesion force has been used in the **Table 7**.

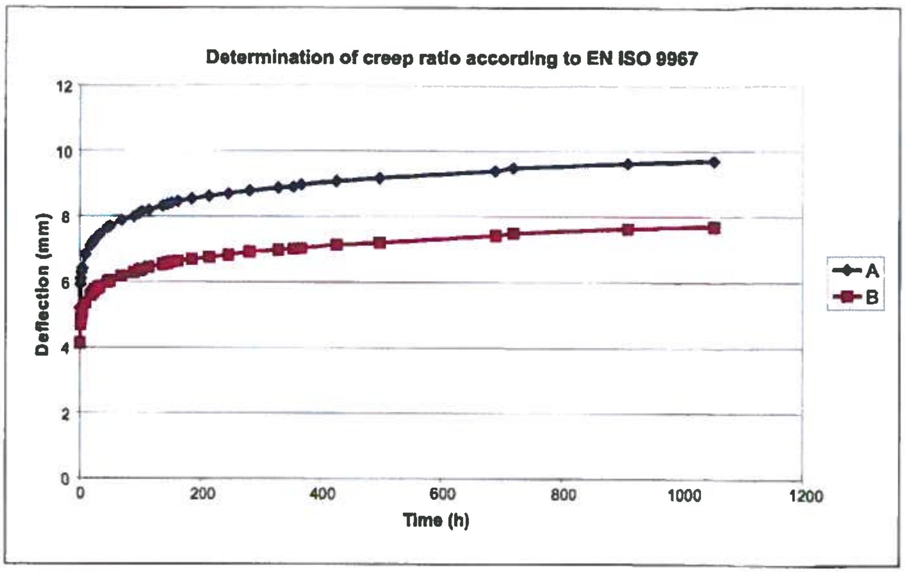

Fig. 2

Table 8

Position	Mass of test piece (mg)	OIT at 200 °C (min.)	Test piece appearance
outside of the pipe	15,6	>55	No change
inner side of the pipe	15,7	>55	No change

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 degradation causes modification of the molecular structure. This effect is more pronounced at high temperatures (e.g. processing at 200 °C) and is insignificant at lower temperatures (e.g. operation at 20 °C) and is reduced by the addition of relevant stabilisers. The presence of stabilisers is monitored by the measurement of the oxidation induction time (OIT).

Thermal stability is measured according 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 (**Table 8**).

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

Table 9

Test piece no.	Thickness mm	Width mm	Stress at yield N/mm^2	Tensile strength N/mm^2	Strain at break %
1	4,07	10,05	37,2	37,2	4,7
2	4,01	10,19	37,2	37,2	5,6
3	4,08	10,17	38,3	38,3	6,4
4	4,08	39,68	39,7	39,7	4,9
5	4,12	40,45	40,5	40,5	5,5
Mean			38,6	38,6	5,4
Standard deviation			1,5	1,5	0,7

Table 10

Test piece no.	Thickness mm	Width mm	E-modulus N/mm^2
1	4,10	10,17	2462
2	4,11	10,16	2580
3	4,10	10,14	2396
4	4,09	10,11	2333
5	4,09	10,10	2002
Mean			2355
Standard deviation			217

Table 11

Test piece no.	h (mm)	b (mm)	F (N)	y (mm)	E_f (MPa)
1	4,09	10,12	30	1,10	2581
2	4,01	10,15	30	1,17	2568
3	4,04	10,08	30	1,16	2549
Mean					2566

Table 12

Test piece	y (m)	F (kN)	S (kN/m^2)
a	0,00903	0,555	3,99
b	0,00906	0,498	3,56
c	0,00907	0,536	3,83
Mean value			3,8 kN/m^2

Where F the load at 3 % deformation of the inside diameter d_1 (kN);
y the deflection at 3 % deformation of the inside diameter di (m);
S the ring stiffness of the pipe $= \left(0{,}0186 + 0{,}025\frac{y}{d_i}\right)\frac{F}{L \cdot y}$ (kN/m^2)
L the mean length of the test pieces (m).

Table 13

Test piece	M	B	R	Y_2 (mm)
a	1,5595	4,9856	0,9989	11,60
b	1,4914	3,2126	0,9983	9,54

Where M, B the coefficients of the equation $Y_t = B + M \log_{10} t$;
Y_t the calculated deflection at time t (mm);
t the time (h);
R the correlation coefficient;
Y_2 the calculated two-year deflection, calculated deflection at 17520 h (mm).

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 tensile strength, yield and elongation are measured at 23 °C, according ISO 527-4 (1997) "Plastics: Determination of tensile properties – Part 4 : Test conditions for isotropic and orthotropic fibre reinforced plastics components", on dumbbell test pieces (type 1B) produced with the same glass fibre content as the pipes, with a tensile speed of 50 mm/min (**Table 9**).

The tensile stress at yield is determined from the recorded stress-strain diagrams. The strain and elongation at break is recorded using a long travel extensometer with an initial gauge length of 50 mm.

The tensile E-modulus is measured at 23 °C, according ISO 527-4 (1997) "Plastics: Determination of tensile properties – Part 4 : Test conditions for isotropic and orthotropic fibre reinforced plastics components", on dumbbell test pieces (type 1B) with a tensile speed of 1 mm/min (**Table 10**).

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 test pieces with a length l of 120 mm are placed flat wise on a three-point flexural creep rack. The distance l_v between the supports is 64 mm.

The flexural E-modulus is determined at 23 °C, at a crosshead speed of 2 mm/min on rectangular reinforced PE specimen (120x10x4 mm^3) produced with the same glass fibre content as the pipes. The flexural E-modulus is calculated from the plot, time versus deflection, at mid span.

The results (**Table 11**) demonstrate that the E-modulus in tension and in flexion are nearly equal.

Linear thermal expansion coefficient

The linear thermal expansion coefficient (α) has been determined on a rectangular

Table 14

Test piece	Creep ratio „ι
A B	2,17 2,25
Creep ratio „	2,21

reinforced PE specimen (120x10x4 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 10^{-5}/K) and the α of HDPE (15 10^{-5}/K).

$$\alpha = 5 \cdot 10^{-5} \cdot \frac{\text{mm}}{\text{mm} \cdot \text{K}}$$

(measured between –20 °C and 50 °C)

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".

Three pipe test pieces (ø315x5,8 mm) with a length of (300±10) mm are placed in a tensile machine at 23 °C, between two parallel flat horizontal plates, with the longitudinal axis of the pipe test pieces parallel to the plates. These test pieces are submitted to a deflection at constant speed of 10 mm/min until minimum 3 % deformation of the inside diameter is reached.

The test pieces nos. b and c are turned over an angle of 120° and 240° with respect to the position of test piece no. a (**Table 12**).

Remark: The test pieces a and b have been deformed for a second time after the ring stiffness has been determined. No failures have been recorded on test pieces a and b after a deformation of respectively 60 % and 50 %.

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".

Two pipe test pieces (ø315x5,8 mm) with a length of 300 mm are placed between two parallel flat horizontal plates at 23 °C and are submitted to a constant compressive force for 1000 h. This loading force is determined as the force which generates a deflection of the test piece of 1,5 % ± 0,2 % within 6 minutes.

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.

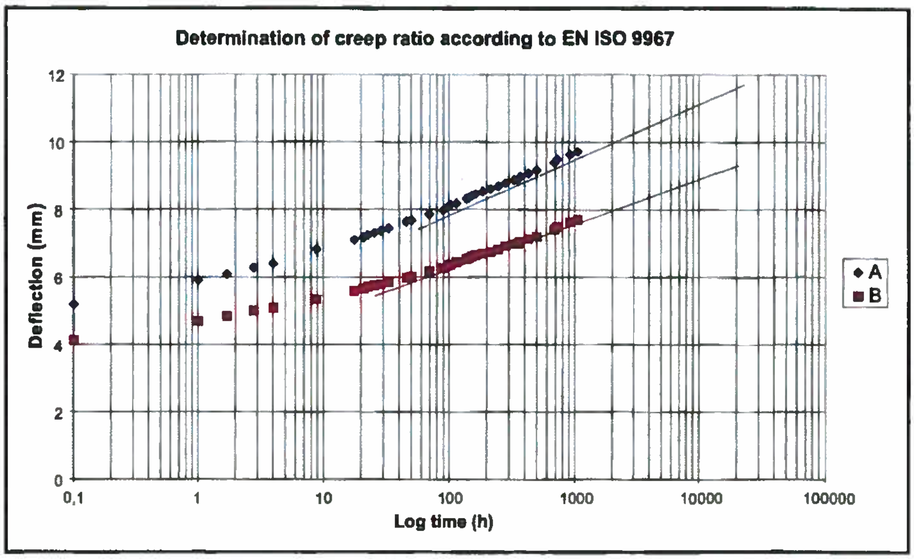

Fig. 3:

Table 15

Specimen no.	$E_{1\,min}$ (N/mm^2)	E_{24h} (N/mm^2)	E_{2000h} (N/mm^2)	E_{50y} (N/mm^2)
1 (at σ 2 MPa)	2515	1979	1685	1406
2 (at σ 4 MPa)	2605	1804	1477	1134

Calculation of the two-year deflection and calculation of the creep ratio

The measured deflection for each test piece is plotted against the logarithm of the time. By linear regression (Excel calculation), a straight line is fitted onto the data points. Based on the criteria included in EN ISO 9967, the following equations of those straight lines were determined, together with the extrapolated two-year deflection Y_2 (**Table 13**).

The creep ratio, γ_i, for each test piece is calculated using the following equation:

$$\gamma_i = \frac{Y_2\left(0{,}0186 + 0{,}025\frac{y_0}{d_i}\right)}{y_0\left(0{,}0186 + 0{,}025\frac{Y_2}{d_i}\right)}$$

γ_i = the creep ration for each test piece a or b; Y_2 = the calculated two-year deflection (mm); y_0 = the initial deflection, 6 min. after application of the full load (mm); d_i = the mean value of the initial internal diameter (mm).

The creep ratio of the pipe, γ_i is then calculated as the arithmetic mean of the values of the individual test pieces (**Table 14, Figure 3**).

Determination of the flexural creep modulus by a four point loading flexure test according to RAL Richtlinie R 14.3.1. AW (January 1998) and DIN 54 852 (1986)

Two test pieces (ø315x5,8 mm) with a length of 300 mm are placed between two parallel flat horizontal plates at 23 °C and are submitted to a constant compressive force for 1000 h. This loading force is determined as the force which generates a deflection of the test piece of 1,5 % ± 0,2 % within 6 minutes.

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.

Two rectangular reinforced PE specimen (120x10x4 mm^3) produced with the same glass fibre content as the pipes are placed edgewise on a four-point flexural creep rack (23 °C). The distance l_v between the supports is 110 mm and the length of the zone of constant flexural moment is 60 mm. The applied stress is σ 2 MPa / 4 MPa.

The specimen deflection is measured at mid span and measured at regular intervals.

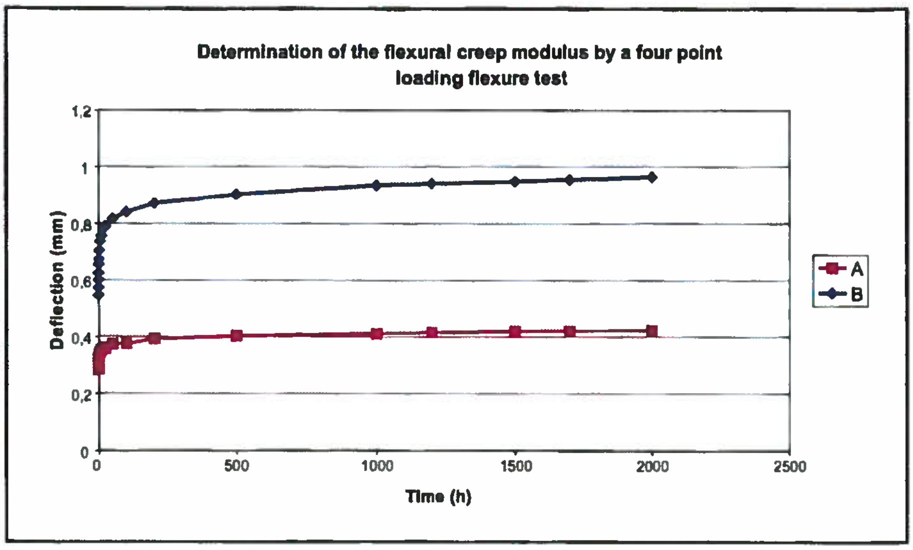

Fig. 4

The flexural creep modulus $E_{1\,min}$, $E_{24\,h}$ and $E_{2000\,h}$ is calculated from the plot, time versus deflection, at mid span (**Figure 4, Table 15**).

Calculation of creep moduli

$$E_{1min} = \frac{1}{\delta_{1min}} \cdot \frac{\sigma b h^2}{6} \cdot \frac{3}{2h}\left[\frac{l^2}{h^2} - \mu\right]$$

$$E_{24\,h} = E_{1min} \cdot \frac{\delta(1min)}{\delta(24h)}$$

$$E_{2000\,h} = E_{1min} \cdot \frac{\delta(1min)}{\delta(2000h)}$$

$$E_{50\,y} = E_{1min} \cdot \frac{\delta(1min)}{\delta(50y)}$$

E_{1min} = creep modulus after 1 min (N/mm^2); δ_{1min} = deflection after 1 min. (min); δ_{24h} = deflection after 24 h (h); σ = flexural stress ($\sigma 2$ or $\sigma 4$) (N/mm^2); b = specimen thickness (mm); h = specimen height of specimen (mm); l = load distance (mm); = coefficient : 0,4.

Conclusions

Becetel has evaluated a production run on the ø 315 and ø 900 glass fibre reinforced KPPS pipes and KPPS electrofusion assembly ø 560. They were subjected to a range of tests to assess their quality compared to contemporary standard PE-pipe production.

The findings of this initial investigation support the idea of Krah AG (Germany) to produce this kind of reinforced PE pipes up to 10 bar for pipes up to DN 4000.

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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).