Make things happen. HOBAS®

HOBAS® CC-GRP Pipes
Features, Tests and Benefits

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Contents

0. Over 50 Years Experience

Fig. 1: **GFP diffuser built in 1991**

The unique HOBAS® Process had its beginnings in Switzerland during the 1950s when Basle's Stückfärberei, a textile processing company, was trying to find a replacement for the wooden cylinders on which the cloth was wound during the dyeing operation. In the course of time the wood became splintered and discolored causing damage to expensive fabrics.

A solution to the problem was sought in the new – at that time – plastics polymers using glass reinforced polyester resin. The already established filament winding process was investigated, as the material produced exhibited corrosion resistant qualities. However, since it was essential for the outside surface to be smooth to prevent damage to the cloth, this type of product was unsuitable.

The idea of manufacturing the cylinder using a centrifugal molding technique was explored first by using a simple lathe. Following the success of these initial trials, casting machines were made and the manufacturing techniques mastered.

The glass reinforced cylinders proved to be an outstanding success. A request for a lightweight pipe suitable for a steep gradient stimulated the company to venture into the manufacture of pipes using the new process. The process was developed further by automation and patent applications were made.

By the early seventies, the process had been improved and sales grown to such an extent that the pipe manufacturing operations became self sufficient. All this led to a joint worldwide sales system for the new manufacturing technology, HOBAS Engineering. Ever since, the process has been developed further and the progressive technological changes of the computer age have been incorporated into the manufacturing systems.

Pipe factories and sales organizations are now operated by the HOBAS® Group all over the world. As a result, it has gained a worldwide reputation for excellence in quality and workmanship.

HOBAS® and partners contribute to the work of various national standardization organizations as well as the European and international standardization committees (CEN, ISO) concerned with the application and use of plastics pipes for water and sewage. These activities, together with the ongoing commitment to research and development both in the company and at several external research establishments, ensure that HOBAS® continues to maintain its technical strength.

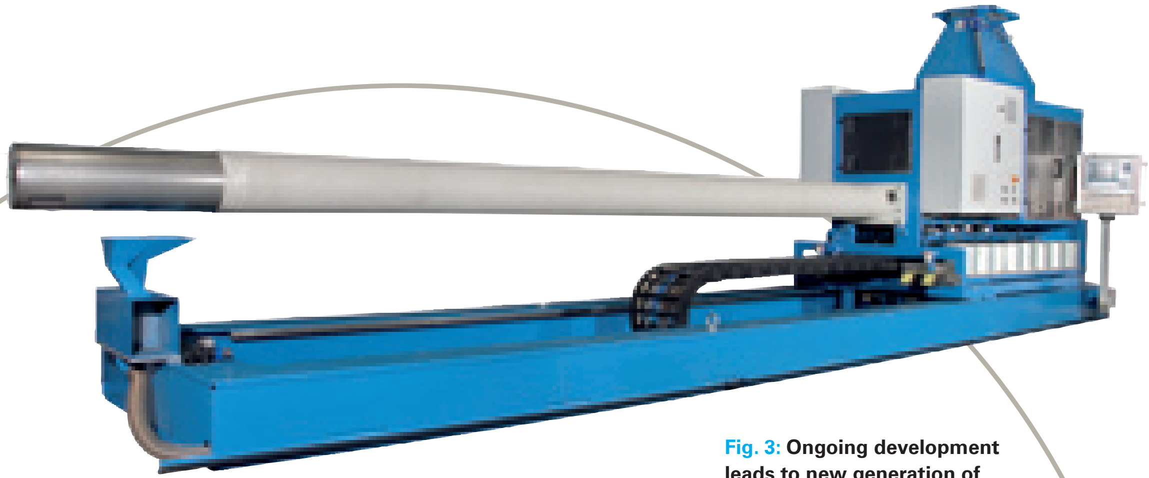


Fig. 3: **Ongoing development leads to new generation of production equipment (feeder)**

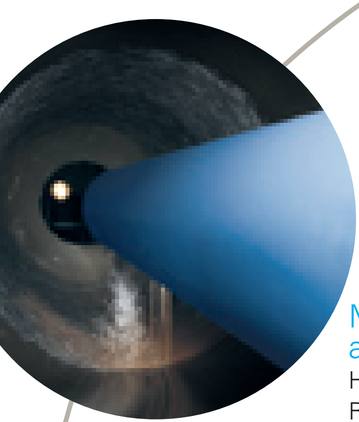


Fig. 4: **Feeder in mold**

Material Composition and Production Process

HOBAS® CC-GRP (Centrifugally Cast Glassfiber Reinforced Plastics) is a special compound made of unsaturated polyester resins (UP), chopped glass fiber and mineral reinforcing agents. These raw materials are progressively fed into a rotating mold, thus building up the wall structure from its exterior surface. The sophisticated manufacturing process is described in brief below.

Raw materials **(see Fig. 2)** undergo stringent incoming inspection and laboratory testing before being approved for use. They are then stored in special tanks to ensure that sufficient quantities are available at all times.

Computer-controlled pumps and high-precision metering systems guarantee that the right amounts of raw materials for the relevant product go to the HOBAS® Feeder **(see Fig. 3)**. A 100% control of production process is assured. Roving stored on spools is chopped to the required length and added. The feeder now deposits the predefined quantities of raw materials layer by layer with each pass of the feeder arm in the six-meter-long rotating mold **(see Fig. 4)**.

Centrifugal casting is important for the quality of HOBAS® Pipes. The preset mold speed with centrifugal acceleration of up to 70 g causes the layers to be bonded into a compact, void free fibre composite.

Spraying hot water onto the outside of the mold accelarates the polymerization process. Resin solidification is irreversible as a result of the three-dimensional chemical bonding. GRP is thus a thermosetting plastic which retains its dimensional stability in any environment.

Cold water is used to cool the mold and after the pipe is removed finishing includes trimming and bevelling the pipe ends. Finally a coupling is mounted onto one end of each pipe.

Fig. 2: **Raw materials**

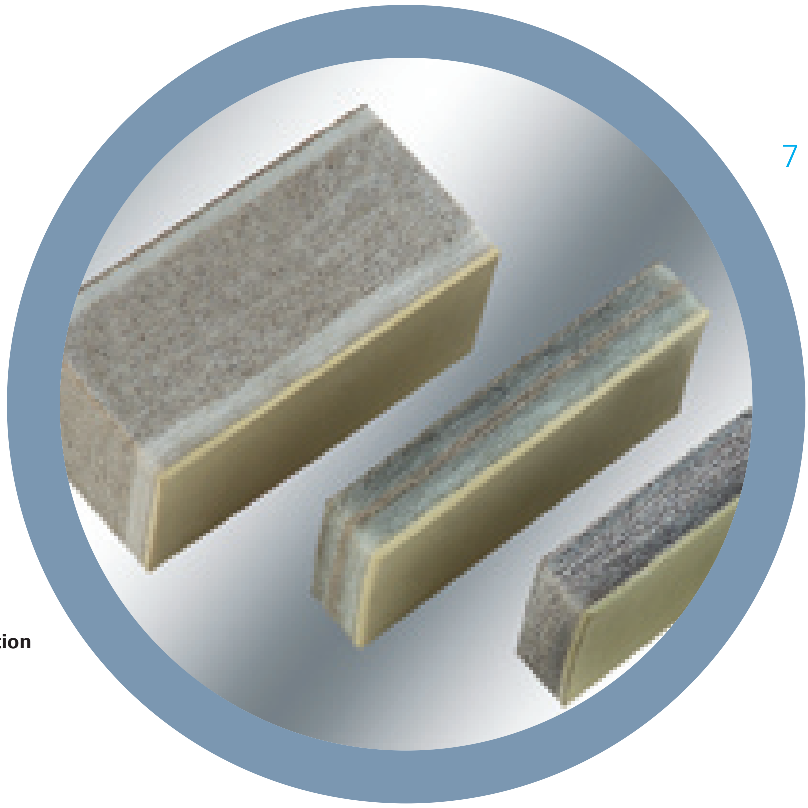


Fig. 5: **Pipe cross section**

Benefits of the HOBAS® Product

For the past 50 years the name HOBAS® has been synonymous with centrifugally cast GRP Pipe Systems.

The centrifugal casting process produces a product with unique features. Users in the water and sewage industries immediately see the benefits of HOBAS® Pipe Systems:

- Manufactured in many countries and supplied in quantities to satisfy most construction requirements.
- **Smooth, accurately dimensioned exterior.** This provides a positive sealing surface for the elastomeric seals used to join the pipes. Additionally, the smooth surface extends along the whole length enabling the **pipe to be cut at any position** for a joint.
- High-density wall. Produced by high compaction of the solid materials during the centrifugal spinning process, the density is responsible for the product's **extreme impermeability**. This feature results in a structure **(see Fig. 5)** that displays **minimal water infiltration**.
- Process particularly suitable for the **economical production** of pipes for buried and trenchless applications. The advantages of using higher stiffness pipes in areas with weaker soils or where it is difficult to guarantee correct installation and good backfill compaction are well known.
- Fully automated HOBAS® Production System enables a product **to be manufactured with the specific properties for its application**, e.g. sewage system, pipe jacking, bore casing, above ground installation or pressure pipe project.
- Resin-rich internal lining layer resulting in a highly corrosion resistant structural wall across a wide pH range. This liner is backed by a resin-rich corrosion barrier layer to give added protection to the structure. Long-term strain corrosion testing has demonstrated that this system significantly exceeds the standards **(see Chapter 8)**.
- **Ability to withstand the high compressive loads** occurring during pipe jacking. This enables HOBAS® CC-GRP Pipe Systems to be used in major trenchless installations in both Europe and the USA.
- No corrosion in conditions which are detrimental to traditional materials. HOBAS® Pipes are **not subject to electrolytic corrosion** and require **no cathodic or other type of protection**.
- **Low coefficient of linear thermal expansion.**
- **Light weight** combined with a standard length of 6 meters offering considerable savings to users through reduced transport, handling and installation costs.
- Smooth bore, giving excellent **hydraulic flow characteristics** with **significantly lower friction losses** than other products of similar dimensions.
- **Internal surface not prone to tuberculation and encrustation.**
- Used and accepted by major water and sewage authorities all over the world.
- **Advanced design and safety concept combined** with a **sophisticated quality control system**. No other pipe material undergoes **four different types of long-term tests** to assure performance for an operational service life of more than 50 years.

Fig. 6: **HOBAS® Jacking Pipe project**

Uses and Applications

HOBAS® CC-GRP Pipe Systems' qualities of high strength combined with flexibility and corrosion resistance make them very attractive for use in numerous applications. Amongst others, they have been successfully installed in the following:

- Sewage (HOBAS® SewerLine®)
- Drainage (HOBAS® BridgeLine®)
- Potable water (HOBAS® WaterLine®)
- Raw water and irrigation (HOBAS® WaterLine®)
- Hydro power (HOBAS® HydroPowerLine)
- Cooling (HOBAS® ThermaLine®)
- Industry (HOBAS® ChemLine®)
- HOBAS® ShaftLine®
- HOBAS® Retention Systems

Furthermore, HOBAS® CC-GRP Pipe Systems have been installed using all the various pipe laying methods:

- Open cut
- Above ground
- Sliplining/Relining (HOBAS® Relining Pipes, HOBAS® NC Line®)
- Microtunneling/Pipe Jacking (HOBAS® Jacking Pipes, **see Fig. 6**)

For the International HOBAS® Reference Database including HOBAS® Projects all over the world from 1961 till now, please contact info@hobas.com or see www.hobas.com/en/projects/ref-database.html.

Quality Assurance

During the course of manufacture, the qualities and quantities of materials and parameters that are important to process performance are constantly monitored and recorded. Regular product sampling and testing is also conducted to check compliance with the manufacturing standards. For more details, please **see Chapter 13**.

1. Pipe Material Properties

As the wall construction of HOBAS® CC-GRP Pipe Systems varies according to the required pressure class and stiffness, the material parameter ranges are only given as a guide. More detailed information on a particular pipe design may be obtained by contacting your HOBAS Sales Engineer at info@hobas.com. Please see the following table for the characteristic short- and long-term material constants for HOBAS® CC-GRP Pipe System wall laminates.

Pipe Performance

Long-Term Type Testing
The standards for plastics products, both reinforced and unreinforced, are formulated on the assumption that the materials display visco-elastic behavior when they are subjected to stress, and these results change in relation to their physical properties over time. Product design is usually based on the projected values of the material's strength at 50 years.

To determine the long-term properties of the pipe, such as ring deflection failure or tensile hoop strength, a statistically significant number of test specimens is prepared and loaded sufficiently to obtain a series of ultimate values, spread across a time span of at least 10,000 hours. The results obtained are evaluated using a log load versus log time regression line of best fit which is projected to obtain the 50 year value.

Procedures and strict guidelines are defined in the regulating Standards. As HOBAS® CC-GRP pipes can be designed according to relevant loads and requirements, material properties may vary from the values given in **Table 1**.

Table 1: Characteristic short-term material constants for HOBAS® CC-GRP Pipe wall laminates

No	Material Property (mechanical properties refer to structural laminate without liner)	Unit	Orientation circumferential	longitudinal
1	Density[1]	kg/m³		~2000
2	Tensile elastic modulus[2] [3] at 23°C	MPa	10000–15000	10000–12000
3	Tensile strength (uniaxial design)[2] [4]	MPa	90–130	15–40
4	Tensile strength (biaxial design)	MPa	200	80–100
5	Tensile strain at break: < PN 10 ≥ PN 10[2] [3]	%	1.2–1.5 1.8–2.0	0.25 1.0–1.4
6	Poisson's ratio[2]	–	~ 0.3	~ 0.25
7	Compressive modulus at 23°C[5] [16]	MPa	12000–18000	12000–18000
8	Compressive strength[5] [16]	MPa	130–140	90–100
9	Compressive strain at break[5] [16]	%	1.2–1.5	1.8–2.0
10	Apparent flexural modulus	MPa	10000–15000	–
11	Flexural strength[6] [7]	MPa	120–140	15 –40
12	Flexural strain at break (extreme fiber)[3] [7]	%	1.6–2.2	1.0
13	Circumferential strain at PN[8] [15]	%	0.2–0.3	–
14	Circumferential strain at 1.5 x PN[8] [15]	%	0.3–0.4	–
15	Temperature resistance[9]	°C	≤ 40 (temp. up to 80°C on request)	
16	Chemical resistance (pH range)[9]	pH	1–10 (higher/lower pH values on request)	
17	Coefficient of linear thermal expansion[10] [14]	1/K		26–30 x 10^{-6}
18	Thermal conductivity[11]	W/m/K		0.5–1.0
19	Thermal capacity[12]	kJ/kg/K		1–1.4
20	Sound celerity[13]	m/s		~450
21	Surface resistance[17] Liner layer Liner layer with 20 m-% graphite filler	Ω		9.6 x 10^{9} 0.4–1.6 x 10^{3}
22	Volume resistance[17] Liner layer Liner layer with 20 m-% graphite filler	Ω		> 30 x 10^{9} 1.3–1.5 x 10^{3}
23	Roughness liner layer – Colebrook White k-value	mm		0.01–0.016

[1] TÜV-Untersuchungsbericht: Ergänzungsprüfung zur Allgemeinen Bauaufsichtlichen Zulassung für Kanäle und Abwasserrohre aus UP-GF der Prüfgruppe 1 und 2, p. 6, Auftragsnr. 2405 5741, 5/98

[2] HOBAS® FFF Project; New Structural Analysis Method for HOBAS® CC-GRP Pipe Systems – Performance Test and Presentation of Results, Report No. JR-KUN-003 Rev. 5; p. 5, 8/18/99

[3] ISO 10467; ISO 10639

[4] TÜV-Untersuchungsbericht; Centrifugally cast and filled pipes of glass fibre reinforced polyester resin in accordance with DIN 16869 as well as fittings and joints, Annex 3; calculated from the extrapolated long-term failure pressure after 50 years, Order no. 2402 4749, 3/96

[5] HOBAS® FFF Project; High Performance Pipe Systems – Report No. HO-FFF-001-05 Determination of the compressive modulus EC with various methods of strain measurement, 5/25/05

[6] Evaluation of QM Data of HRA; Calculation of the extreme fiber bending strength from the short term ultimate ring-deflection test; AN; evaluated according to ISO 10467 (strain) and ÖNORM B 5012-2 (strength), 1999

[7] TÜV-Untersuchungsbericht; Ergänzungsprüfung zur Allgemeinen Bauaufsichtlichen Zulassung für Kanäle und Abwasserrohre aus UP-GF der Prüfgruppe 1 und 2, p. 5, Auftragsnr. 2405 5741, 5/98;

[8] TÜV-Untersuchungsbericht; Ergebnisse der Dehnungsmessungen in Rohr-Umfangsrichtung über die ersten 24 Stunden Prüfdauer, S. 3, Auftragsnr. 2404 3514, 8/98

[9] Values valid for standard body/liner resins

[10] FFF Project; High Performance Pipe Systems – Report No. N 156 – Linear Thermal Expansion of HOBAS® CC-GRP Pipe Material 11/2004

[11] Dominighaus – Kunststoffe und ihre Eigenschaften – 4. Auflage Seite 732 ff, and Test report of Polymer Competence Center Leoben GmbH about thermal conductivity (02/2010)

[12] HOBAS Engineering Report BE023_05 – Specific heat capacity of filler and resin, 3/22/05
Report HOBAS Engineering BE 066_99 – Influence of graphite fillers on physical, chemical and electrostatic properties on HOBAS® standard liner resins 7/23/99

[13] Kurt Moser – Universität Innsbruck – Bescheinigung der Betriebsrauigkeit und Druckwellenfortpflanzungsgeschwindigkeit (Wert abhängig von Rohrgeometrie und Design)

[14] HOBAS Engineering Report BE014_05 – Determination of thermal expansion of a DN 300 PN 1 SN 10000 HOBAS® CC-GRP Pipe, 2/16/05

[15] HOBAS Engineering Report BE004_06 – Abschätzung der Betriebssicherheit einer HOBAS® CC-GRP Kraftwerksleitung DN 1600 PN 16 nach 24-stündiger Druckprüfung bei 24 bar, 22/01/06

[16] BFB – Aachen – Bericht Forschungsprojekt – Bestimmung des Belastungszustands von Vortriebsrohren für den Lastfall „Vorpressen" unter realitätsnahen Randbedingungen, 02/06

[17] Bericht – Österreichisches Kunststoffinstitut – Linerharzplatten mit Graphitzusatz zur Bestimmung des Oberflächen- und Durchgangswiderstandes, ÖKI-Auftr.-Nr. 41.102

Table 2: Summary of important pipe/material parameters for structural design and static calculations

Table 2 shows short- and long-term material properties which are required for static calculations.

No	Material Property	Unit	Short-term	Long-term
1	Stiffness[1]	N/m²	$S_0 \geq SN$	$S_2 = 0.5–0.7 \times S_0$ $S_{50} = 0.3–0.6 \times S_0$
2	Apparent flexural modulus[1]	MPa	E_0 = 10000–15000	$E_2 = 0.5–0.7 \times E_0$ $E_{50} = 0.3–0.6 \times E_0$
3	Pressure resistance (static)[2,3]	bar	$p_0 \sim 4$ xPN	$p_{50} \sim 2 \times$ PN
4	Dynamic pressure resistance[4,5]			
4.1	Dynamic pressure resistance 10^6 pressure cycles between 0.75 x PN and 1.25 x PN	bar	~ 3.5 x PN after 10^6 pressure cycles	
4.2	Dynamic pressure resistance 10^6 pressure cycles between 0.75 x (1.5 x PN) and 1.25 x (1.5 x PN)	bar	~ 3 x PN after 10^6 pressure cycles	
5	Ultimate ring deflection[6,7]			
5.1	SN 2500	%	23.9	14.3
5.2	SN 5000	%	18.9	11.3
5.3	SN 10000	%	15.0	9.0
5.4	SN > 10000	%	$Y_{0B} = \frac{324}{\sqrt[3]{S_0}}$	$Y_{0B50} = \frac{194}{\sqrt[3]{S_0}}$
6	Flexural strain at break[6,7] < PN 10 ≥ PN 10	%	 1.6–2.0 2.0–2.2	 1.0 1.2
7	Flexural strain at break[8,9] (strain corrosion pH 0.1 and pH 10)	%	–	1.0
8	Circumferential strain at break < PN 10 ≥ PN 10	%	 1.2–1.5 1.8–2.0	 0.6–0.7 1.0–1.2
9	Axial compressive strength (pipe sample)[10]	MPa	90–100	–
10	Abrasion after 500,000 cycles[11]	mm	–	< 1.0
11	Compression set (gasket)[12]	%	100	70–80

1) HOBAS Engineering report BE122_03 – Determination of the long-term specific ring creep stiffness under wet conditions and calculation of the wet creep factor of HOBAS® CC-GRP Pipes

2) HOBAS Engineering report BE013_06 – Long-term failure pressure of HOBAS® CC-GRP Pipes DN 600 PN 6, DN 300 PN 10, DN 600 PN 10 and DN 300 PN 16

3) TÜV report 1 397610-2; Long-term failure pressure of HOBAS® CC-GRP Pipes DN 300 PN 10 SN 10000

4) HOBAS Engineering report BE051_03 – Resistance to cyclic internal pressure of HOBAS® CC-GRP Pipe Systems

5) ITC test report 4625 00128/4; HOBAS® CC-GRP Pipes DN 300 PN 16 – Determination of the resistance to cyclic internal pressure

6) HOBAS Engineering report BE050_04; Long-term ultimate ring deflection of an unfilled HOBAS® CC GRP Pipe DN 500 PN 10 SN 10000; Tests carried out at EMPA Switzerland

7) HOBAS Engineering report BE106_02; Long-term ultimate ring deflection of HOBAS® CC GRP Pipe Systems

8) TÜV report 290176; Carrying out of strain corrosion tests on centrifugally cast pipes DN 500 PN 1 SN 10000 made from glass fibre reinforced polyester resin (GRP) with filler combination.

9) HOBAS Engineering report BE048_02 – Long-term strain corrosion performance of HOBAS® CC-GRP Pipe Systems

10) HOBAS Engineering report BE022_06 – Compression tests on HOBAS® CC-GRP jacking pipe samples DN 450 VT produced by HRD

11) HOBAS Engineering report: Abrasion resistance of HOBAS® CC-GRP Pipe Systems

12) Bericht – Österreichisches Kunststoffinstitut – Langzeit-Dichtverhalten von Rohrleitungssystemen mit Elastomeren Dichtverbindungen.

2. Stiffness

The stiffness of a pipe indicates its ability to resist external soil, hydrostatic, traffic loads, and negative internal pressures. It is a measure of a pipe's resistance to ring deflection determined by testing, being the value obtained by dividing the force per unit length of the specimen by the resulting deflection at 3 percent deflection (5% according to ASTM standards).

$$S = \frac{F \cdot f}{L \cdot d_v} \tag{2.1}$$

S	Specific ring stiffness, N/m²
F	Force, N
L	Length of the test specimen, m
d_v	Vertical ring deflection, m
f	A deflection coefficient for ovality of the deformed specimen, obtained as follows:

$$f = \left(1860 + 2500 \cdot \frac{d_v}{d_m}\right) \cdot 10^{-5} \tag{2.2}$$

d_m	Mean diameter, m

The stiffness measured in the deflection test according to equation (2.1) is equivalent to:

$$S = \frac{E \cdot I}{d_m^3} \tag{2.3}$$

where:

$$I = \frac{e^3}{12} \tag{2.4}$$

S	Specific ring stiffness, N/m²
E	Apparent flexural modulus of elasticity, Pa
I	Second moment of inertia per unit length of the pipe wall section, m⁴/m
d_m	Mean diameter, m
e	Wall thickness, m

Initial Specific Ring Stiffness

Introduction

The initial specific ring stiffness is determined using a special test method, as it cannot be accurately obtained by calculation using the nominal values for elastic modulus (E) and wall thickness (e). There are other terms in common use to describe pipe stiffness.

According to the German DIN standards and the ATV code, the ring stiffness is defined as:

$$S_R = \frac{E \cdot I}{r_m^3} \tag{2.5}$$

S_R	Ring stiffness, N/mm²
E	Apparent flexural modulus of elasticity, N/mm²
I	Second moment of inertia per unit length of the pipe wall section, mm⁴/mm
r_m	Mean radius, mm

The specific ring stiffness according to equation (2.3) can be derived from S_R using the following equation:

$$S = 125000 \cdot S_R \tag{2.6}$$

According to the American ASTM Standards, the ring deflection is expressed as:

$$S_{ASTM} = \frac{F}{d_v} \tag{2.7}$$

S_{ASTM}	Ring stiffness, psi
F	Load per unit length, lb/in
d_v	Vertical ring deflection, in

Stiffness class SN 2500 N/m² or less is not normally recommended for buried applications. Higher stiffness classes can be manufactured for use in unusual loading conditions or weak native soils e.g. peat, etc. For more details, contact your HOBAS Sales Engineer at info@hobas.com.

Table 3: Conversion of SN according to various standards

Nominal	SN 2500	SN 5000	SN 10000	SN 15000	SN 16000	SN 20000	SN 32000	SN 40000	SN 50000
S, N/m² (ISO, EN)	2500	5000	10000	15000	16000	20000	32000	40000	50000
S_R, N/mm² (DIN)	0.02	0.04	0.08	0.12	0.128	0.16	0.256	0.32	0.4
F/d_y, psi	18	36	72	108	115	144	230	288	360
Nominal	**SN 64000**	**SN 80000**	**SN 100000**	**SN 128000**	**SN 160000**	**SN 200000**	**SN 320000**	**SN 640000**	**SN 1000000**
S, N/m² (ISO, EN)	64000	80000	100000	128000	160000	200000	320000	640000	1000000
S_R, N/mm² (DIN)	0.512	0.64	0.8	1.024	1.28	1.6	2.56	5.12	8
F/d_y, psi (ASTM)	461	576	720	922	1152	1440	2304	4608	7200

Long-Term Specific Ring Stiffness

Introduction

Long-term specific ring stiffness tests on HOBAS® CC-GRP Pipes for non-pressure as well as pressure applications have been conducted in order to determine the creep factor for an operational lifetime of 50 years.

The main objectives of this investigation are:

- To summarize and evaluate these results
- To calculate the long-term creep factor
- To compare the results of lab testing with the results from pipelines in operation (tests on excavated pipes)

Tests

The tests and data evaluation were based on the following standards:

- EN 1228 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of initial specific ring stiffness]
- ISO 7685 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of initial specific ring stiffness]
- EN 1225 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of the creep factor under wet conditions and calculation of the long-term specific ring stiffness]
- ISO 10468 [Glass-reinforced thermosetting plastics (GRP) pipes – Determination of the long-term specific ring creep stiffness under wet conditions and calculation of the wet creep factor]
- DIN 53769-3 [Testing of glass fibre reinforced plastics pipes – Determination of initial and long-term ring stiffness]
- EN 705 – and ISO 10928 – [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes and fittings – Methods for regression analyses and their use]

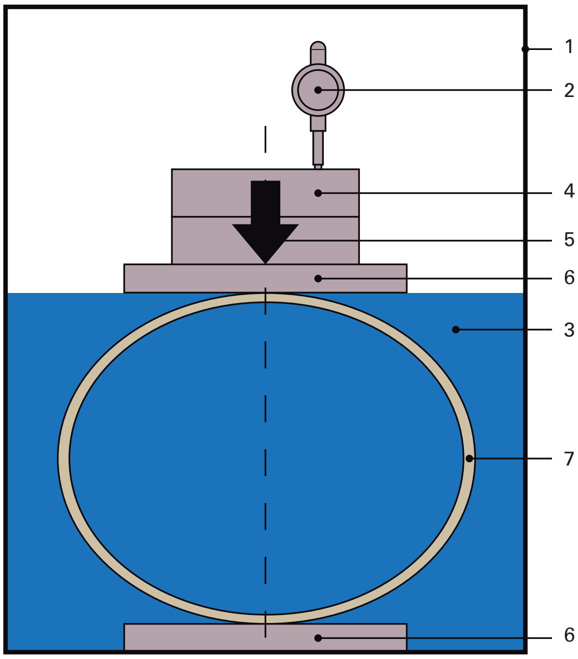
All tests were carried out following the procedures in standards for GRP piping systems.

Samples

HOBAS® CC-GRP Pipes DN 200 to DN 1400 PN 1-PN 16 SN 5000-SN 40000, made of unsaturated polyester resin (UP), silica sand, glass fiber and reinforcing filler materials.

Key
1 water container
2 deflection-measuring device
3 water
4 deadweights
5 direction of compressive force, F
6 bearing plate
7 test piece

Fig. 7: Test setup



Test Procedure

A cut length of a pipe supported horizontally is loaded throughout its length to compress it diametrically to a specified vertical deflection. The pipe is immersed in water (pH 7 ± 2) at a specified temperature (T = 23°C) for the period of the test during which the load remains constant and the vertical deflection is measured at intervals. From this deflection and load the long-term specific ring stiffness is calculated. The wet creep factor is then determined from the long-term wet specific ring stiffness and the initial specific ring stiffness of the same test specimen. The data obtained is evaluated within 0.1 to 10000 hours as well as within 1 to 10000 hours.

Evaluation

The time-dependent change in pipe deflection, which is due to the visco-elastic nature (time-dependent elastic modulus) of the pipe material and ageing (environmental dependant) can be linked to an apparent change in stiffness (Eqn. 2.8).

$$S(t) = \frac{E(t) \cdot e^3}{12 \cdot d_m^3} = \frac{F \cdot f}{l \cdot d_v(t)} \tag{2.8}$$

S(t)	Time-dependent stiffness, N/m²
E(t)	Time-dependent apparent flexural modulus, Pa
e	Wall thickness, m
d_m	Mean ring diameter, m
F	Load, N
f	Geometrical correction factor depending on d_v
$d_v(t)$	Time-dependent ring deflection, m
l	Specimen length, m

where:

$$f = [1860 + (2500 \cdot \frac{d_v}{d_m})] \cdot 10^{-5} \tag{2.9}$$

The deflection data expressed in a log-log scale are extrapolated to 50 years in order to calculate a 50-year ring deflection $d_{v,50}$ and an apparent 50-year long-term stiffness $S_{50,wet}$:

$$S_{50,wet} = \frac{F \cdot f_{50}}{l \cdot d_{v,50}} \tag{2.10}$$

$S_{50,wet}$	Specific ring creep stiffness after 50 years, N/m²
$d_{v,50}$	Extrapolated deflection after 50 years, m

where:

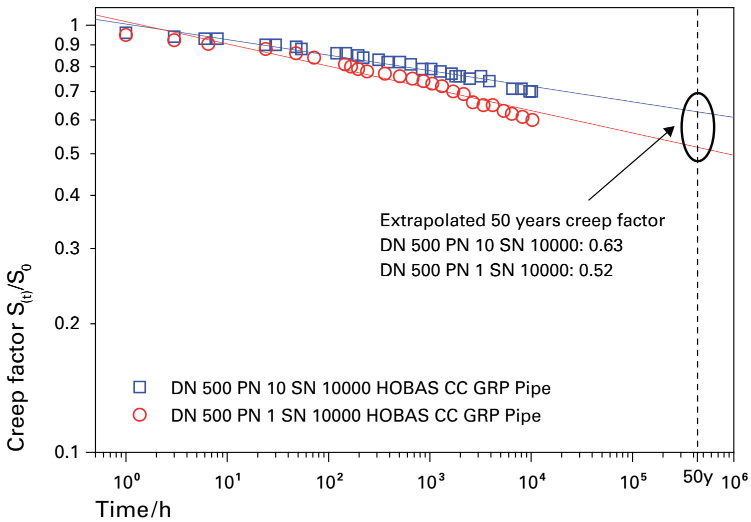
$$f_{50} = [1860 + (2500 \cdot \frac{d_{v.50}}{d_m})] \cdot 10^{-5} \tag{2.11}$$

The wet creep factor $\alpha_{50,creep,wet}$ (Eqn. 2.12) is the ratio of the extrapolated 50-year stiffness $S_{50,wet}$ and the initial stiffness S_0.

$$\alpha_{50,creep,wet} = \frac{S_{50,wet}}{S_0} \tag{2.12}$$

$\alpha_{50,creep,wet}$	Wet creep factor for 50 years
S_0	Initial specific ring stiffness, N/m²

Fig. 8: **Example of long-term creep factors for HOBAS® CC-GRP Pipes**

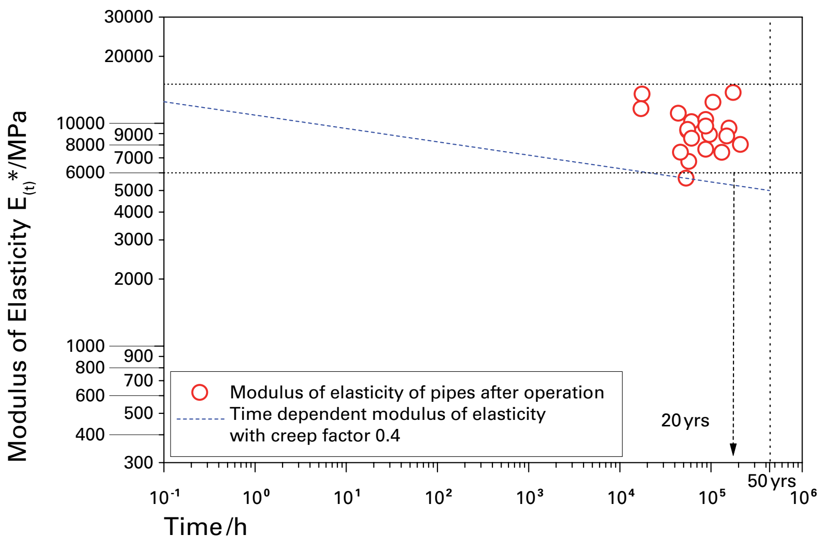


Results

The long-term ring stiffness tests were performed on various CC-GRP-UP pipes DN 200 – DN 1400 PN 1 – PN 16 SN 5000 – SN 40000 by independent certification bodies (TÜV, Det Norske Veritas, Austrian Polymer Institute). Compliance of the long-term ring stiffness with the requirements was assessed and confirmed according to the most relevant national and international standards: EN 1796, EN 14364, ISO 10467, ISO 10639, DIN 19565, DIN 16869, BS 5480, ASTM D3262, ASTM D3517, ASTM D3754, AS 3571, AS 3572.

The typical values for long-term specific ring stiffness S_{50} evaluated for an operational lifetime of 50 years can be taken as approx. 35–65% of initial stiffness SN, depending on pipe classification and various national requirements.

Fig. 9: **Apparent flexural modulus after operation and excavation**



Tests on Excavated Pipes

The test method according to EN 1225 and ISO 10468 represents a worst case scenario, as the specimen under test is fully immersed in water and freely deflectable without any support at the springline. The creep factor is normally used for static calculations. Therefore it was an interesting experiment to excavate pipes after several years of operation to re-determine the specific ring stiffness and apparent flexural modulus, and to compare it to the initial values measured at the time of production. The results are shown in **Fig. 9**.

Conclusions

The creep factors for HOBAS® CC-GRP Pipes resulting from the time-dependent, reversible, visco-elastic material behavior were determined and reported. Comparisons between laboratory tests according to EN 1225 and ISO 10468 and pipes tested after several years in operation indicate significantly lower creep for buried pipes. Using creep factors for static calculations determined in the laboratory therefore ensure additional safety, as the decrease in the specific ring stiffness of the pipe when properly buried is considerably lower than predicted by the creep test.

Finally it has to be mentioned that the time-dependent vertical ring deflection is also closely related to the initial specific ring stiffness. When directly buried, low stiffness pipes tend to deflect more when the soil moves than high stiffness pipes. This affects parameters such as creep, strain corrosion or hydraulic properties. HOBAS® therefore recommends nominal stiffness of SN 5000 (in very stable soils) or SN 10000 and above when soil conditions and quality of installation are not predictable.

3. Long-Term Ultimate Ring Deflection of HOBAS® CC-GRP Pipe Systems

Introduction

Several ring deflection test series have been conducted to establish the ultimate long-term (50, 60 and 100 years) ring deflection of HOBAS® CC-GRP Pipe Systems. Data on two different pipe types tested by TÜV Süd Germany and EMPA Switzerland were evaluated by HOBAS Engineering GmbH: The main objectives of this report are

- to summarize and evaluate these results
- to calculate the long-term failure strains and the long-term ultimate ring deflection

Tests

The tests and data evaluation were based on the following standards:

- EN 1227 and ISO 10471 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of the long-term ultimate relative ring deflection under wet conditions]
- ASTM D5365-93 [Long-term ring bending strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe]
- EN 705:1994 AC:1995 – Method A and ISO 10928 – Method A [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes and fittings – Methods for regression analyses and their use]

All tests were carried out following the procedures in standards for GRP piping systems.

Samples

- Pipe 1: HOBAS® CC-GRP Pipe DN 500 PN 10 SN 5000, tested by TÜV Süd Germany
- Pipe 2: HOBAS® CC-GRP Pipe DN 500 PN 10 SN 10000, tested by EMPA Switzerland

Test Procedure

The test procedure follows the standards mentioned above. Each of several cut lengths of pipe, supported horizontally under water, is subjected to a vertical load over its entire length such that each test piece is subject to a different load to any of the others. The resulting vertical deflections are recorded at given times. Depending upon the level of deflection and the time elapsed, cracks will occur and propagate to failure. The results are used to calculate the long-term ultimate ring deflection and flexural strain under mechanical loading for a defined service life of 50 years. Beyond the requirements of various standards, the deflection and strain values for an operational life time of 60 and 100 years were deduced.

Evaluation

Additionally to the evaluation of long-term ring deflection for various pipe types, the flexural strain at break was calculated following Eqn. 2.11.

$$\varepsilon_b = \frac{428}{\left(1+0.5\cdot\frac{d_v}{d_m}\right)^2}\cdot\frac{d_v}{d_m}\cdot\frac{e}{d_m} \qquad (2.11)$$

ε_b	Flexural strain, %
d_v	Ring deformation, mm
d_m	Mean ring diameter, mm
e	Wall thickness, mm

Based on the failure points measured, a statistical evaluation of the deflection and strain behavior could be performed according to EN 705 and ISO 10926 (method A – covariant method). Additionally the 97.5% lower confidence level for the mean regression as well as the 97.5% prediction interval for individual measurements was calculated. The long-term ultimate ring deflection for both pipe DN 500 PN 10 SN 5000 and DN 500 PN 10 SN 10000 was determined and compared to the requirements of ISO 10467, ISO 10639, EN 1796 and EN 14364.

Results

Laboratory Tests

The results of the various long-term ring deflection test series are presented in **Figures 10–11**.

The long-term regression was calculated according to method A of EN 705 and ISO 10928 including failure points of both pipes and led to extrapolated deflection values as described in **Table 4 and 5**.

Fig. 10: Ultimate ring deflection – HOBAS® CC-GRP Pipes DN 500 PN 10

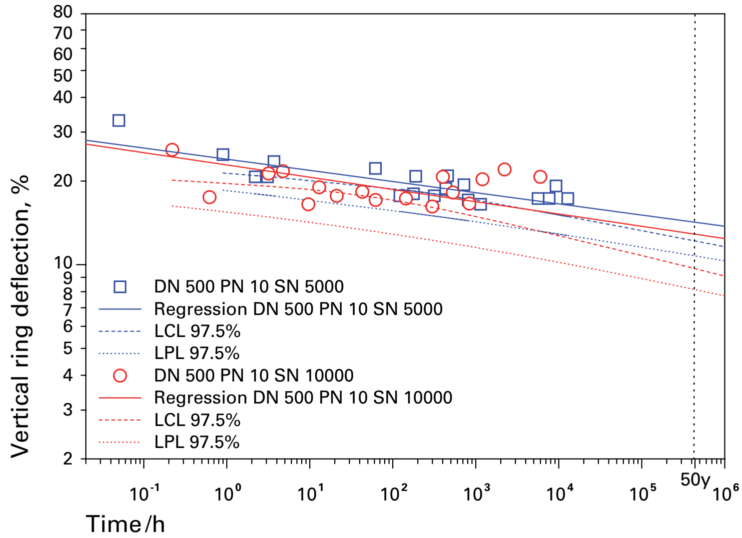
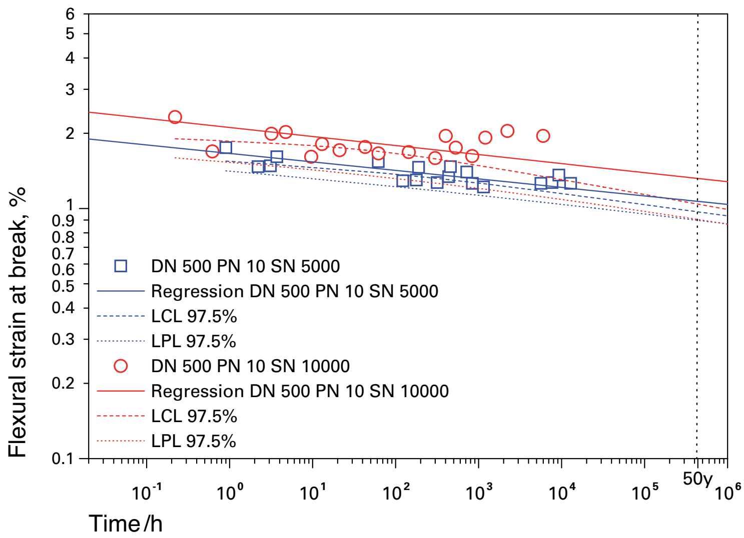


Fig. 11: Flexural strain at break – HOBAS® CC-GRP Pipes DN 500 PN 10



Tests on Excavated Pipes
The test method according to EN 1227 and ISO 10471 represents a worst case scenario, as the specimens under test are fully immersed in water and freely deflectable without any support at the springline (e.g. by the soil). Therefore it was an interesting experiment to excavate pipes after several years of operation, re-determine the ultimate ring deflection and compare it with regression performance. The test results are illustrated in **Fig. 12**.

Conclusions

The requirements of product standards ISO 10467, ISO 10639, EN 14364 and EN 1796 are fulfilled.

Ultimate ring deflection tests on excavated pipes show that the measured values are far above the requirements. Using the extrapolated flexural strain at break (ring deflection) from laboratory tests for static calculations provides additional safety, as the long-term deflection behavior of HOBAS® CC-GRP Pipes when properly buried is considerably better than predicted by the laboratory tests.

Fig. 12: Ultimate ring deflection – HOBAS® CC-GRP Pipes after excavation

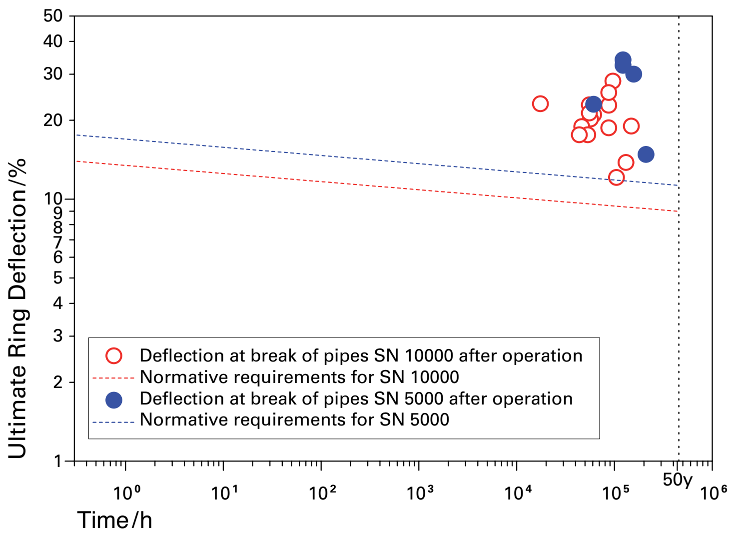


Table 4: Ultimate ring deflection

	Ultimate Ring Deflection, %			
	Requirements SN 5000	DN 500 PN 10 SN 5000	Requirements SN 10000	DN 500 PN 10 SN 10000
50 years	Min. 11.3	14.23	Min. 9	12.9
60 years	–	14.1	–	12.8
100 years	–	13.8	–	12.5

Table 5: Long-term flexural strain at break

	Flexural Strain at Break, %	
	DN 500 PN 10 SN 10000	DN 500 PN 10 SN 5000
50 years	1.10	1.32
60 years	1.06	1.31
100 years	1.04	1.30

4. Hoop Tensile Strength

Introduction

Several series of long-term failure pressure tests have been conducted to establish the long-term (50, 60 and 100 years) hydrostatic pressure design basis for HOBAS® CC-GRP Pipe Systems and to assess the resistance to internal hydrostatic pressure. Data for typical pressure classes PN 6, PN 10, PN 12.5, PN 16 and PN 20 were tested and evaluated. The main objectives of this report are:

- To summarize and statistically analyze these test results
- To extrapolate the long-term failure pressures and evaluate the lower confidence and prediction limits
- To derive the pressure design basis
- To derive the design and minimum safety factors for short-term pressure testing

Tests

The tests and the data evaluation were based on the following standards:

Product standards

- ISO 10467 [Plastics piping systems for pressure and non-pressure drainage and sewerage - Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin]
- ISO 10639 [Plastics piping systems for pressure and non-pressure water supply – Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin]
- EN 1796 [Plastics piping systems for water supply with or without pressure – Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP)]
- EN 14364 [Plastics piping systems for drainage and sewerage with or without pressure – Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP) – Specifications for pipes, fittings and joints]
- DIN 16869 [Centrifugally cast filled glass fibre reinforced unsaturated polyester resin (UP-GF) pipes]
- ASTM D3517 [Standard Specification for "Fiberglass" (Glass-Fibre-Reinforced Thermosetting-Resin) Pressure Pipe]

Test standards

- ISO 8521 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Test methods for the determination of the apparent initial circumferential tensile strength]
- EN 1447 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of long-term resistance to internal pressure]
- DIN 53769-2 [Testing of glass fibre reinforced plastics pipes; long-term hydrostatic pressure test]
- ASTM D2992 [Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" Pipe and Fittings] → procedure B

Standards for data evaluation

- EN 705: Method A and ISO 10928 – Method A [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes and fittings – Methods for regression analyses and their use]
- ASTM D2992 [Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" Pipe and Fittings] → procedure B

Samples

The test specimens were cut from pipes produced by the HOBAS® Centrifugal Casting Process using approved raw materials according to the HOBAS® design requirements. Results of the following HOBAS® CC-GRP Pipes produced in different international production plants were used for the evaluation of the test results:

- DN 300 PN 10 SN 10000
- DN 300 PN 16 SN 10000
- DN 300 PN 20 SN 10000
- DN 400 PN 20 SN 10000
- DN 600 PN 6 SN 5000
- DN 600 PN 6 SN 10000
- DN 600 PN 10 SN 5000
- DN 600 PN 12.5 SN 10000
- DN 800 PN 10 SN 10000

Test Procedure

A cut length of pipe is subjected to a specified internal hydrostatic pressure at ambient temperature (~23°C) to cause a state of stress in the pipe wall, which depends upon the loading conditions. The pressure is kept constant until failure of the specimen. The test is repeated at several internal pressure levels, using a fresh test specimen each time and recording the time to failure (any kind of leakage – however bursting is the typical failure mode of HOBAS® CC-GRP Pipes, as the internal liner and dense, compact pipe wall prevents weeping, which is the typical failure if fibres and resin are not bonded properly). The results are used to calculate an extrapolated failure pressure for a specified period of time. A typical test configuration is shown in **Fig. 13**.

Evaluation

The results were used to calculate the ultimate failure pressure for an operational life time of 50 years (Hydrostatic Design Basis, HDB). Beyond the requirements of various standards, failure pressure for an operational life time of 60 and 100 years was additionally calculated. 19 specimens were tested for pressure level PN 16 and PN 20 within 0.1 and 11,000 hours. For PN 10, a total of 58 specimens ranging from less than 3 min to over 33,000 hours were used for the analysis. The regression line for pipes PN 6 was established on the basis of 33 data points between 0.3 and 10,000 hours.

Fig. 13: Long-term hydrostatic pressure tests

The pressure class PN is related to the long-term failure pressure or HDB for the pipe as follows (Eqn. 2.12).

$$PN \leq \frac{HDB_{50}}{F_{SD}} \tag{2.12}$$

HDB_{50}	50-year failure pressure, bar
F_{SD}	Design factor of safety (EN/ISO – F_{SD} depending on PN class)
PN	Nominal pressure, bar

This approach is in line with the relevant standards of ISO, EN, DIN and ASTM.

Results

The test results of the various long-term failure pressures are presented in **Fig. 14** and **Table 6**. The regressions were calculated according to method A of EN 705 and ISO 10928 including all failure points of the relevant pipes PN 20, PN 16, PN 10 and PN 6.

Applying a statistical extrapolation model to the test data plotted in a log-log scaled pressure-time diagram **(Figure 14)** results in a projected safety factor after 50 years operational life time. For CC-GRP-UP pressure pipes this safety factor is around 2 related to the nominal pressure PN. The pressure strength (hoop tensile strength) is predominantly accounted for by the (inner and outer) reinforced composite layers. By varying ratio and thickness of glass fiber reinforced UP-resin layers within the pipe wall, the pressure resistance of CC-GRP-UP pipes can be customized.

Fig. 14: Test results for long-term failure pressure with HOBAS® CC-GRP Pipes PN 6, PN 10, PN 12.5 and PN 16

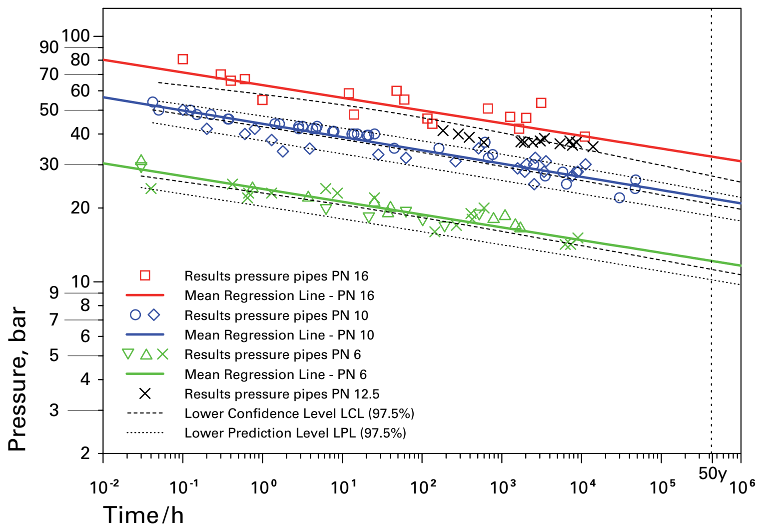


Table 6: Results of long-term hydrostatic pressure tests for HOBAS® CC-GRP (current test results)

	PN 6	PN 10	PN 16	PN 20
Failure pressure (50 years) – PDB, bar	12.2	21.8	32.4	57.6
Safety factor (50 years)	2.03	2.18	2.03	2.9
Failure pressure (60 years), bar	12	21.6	32	57.3
Safety factor (60 years)	2	2.16	2	2.87
Failure pressure (100 years), bar	11.7	21	31.2	56.5
Safety factor (100 years)	1.95	2.1	1.95	2.8

Tests on Biaxially Loaded Pipes

The above test was also performed on pipes designed to carry axial loads. The results of the test series are used for the hydrostatic pressure design basis (HDB) for biaxially loaded pipes. The tests were carried out on DN 500 specimens with butt wrap laminates as well as GRP flanges and end caps. Results with long-term safety factors > 2 are presented in **Fig. 15** below.

Tests on Excavated Pipes

As described above, the pressure design concept for CC-GRP pipe systems is based on the requirement that the pipes have to withstand approximately an internal pressure of 2 × PN for a mean elapsed time of 50 years without failing. In the field however CC-GRP Pipe Systems are generally operated at nominal pressure PN or lower. Thus, from an engineering perspective, it is of fundamental interest to see how the hydrostatic design basis (HDB) derived from long-term tests as described above corresponds to the system performance experienced in the field. To establish this correlation and to prove the validity of the HDB concept, individual buried pressure pipes were excavated after many years in operation and tested to assess their residual performance. Special focus was placed on the resistance of the pipe specimens to failure pressure. The pipe longest in operation was chosen from a penstock DN 500 PN 35 in operation for approx. 25 years when the pipe sample was taken. All samples were pressurized and the ratio of failure pressure p_b to nominal pressure (PN), indicated as the safety factor, was calculated. In the following figure the residual safety factor of several pipe samples after x years' operation (expressed in hours) under buried conditions is plotted as a function of time in a log-log scale diagram.

Fig. 15: Test results of ongoing long-term failure pressure tests with biaxially loaded HOBAS® CC-GRP Pipes PN 10

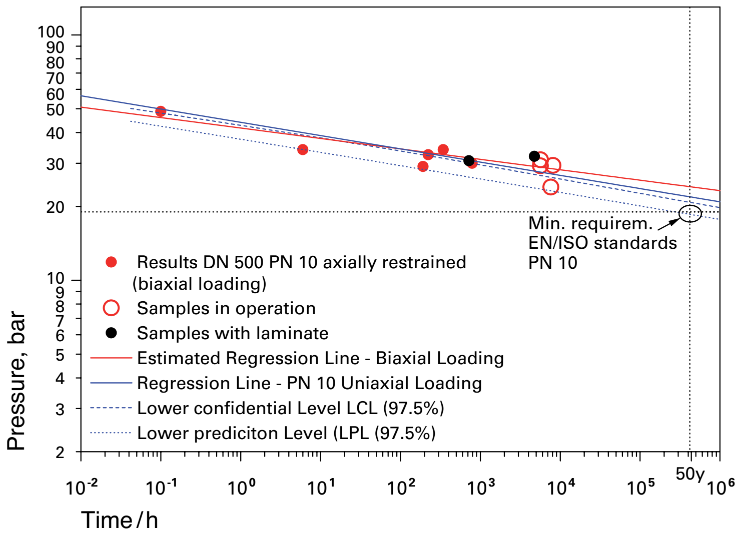
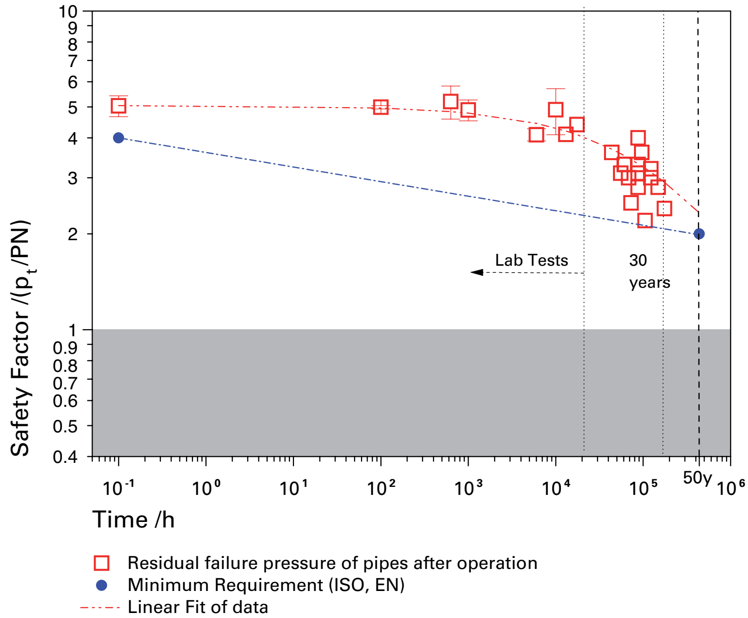


Fig. 16: Residual failure pressure depending on operation time in comparison to the hydrostatic design basis



Biaxially loaded pipe with laminate

Conclusions

- The requirements of product standards ISO 10467, ISO 10639, EN 1796, EN 14364, DIN 16869, ASTM 3517 and ASTM 3754 are fulfilled.
- The pressure pipes PN 6, PN 10, (PN 12.5), PN 16 and PN 20 show long-term safety factors of ~ 2.
- The same safety factor was determined on biaxially loaded pipes DN 500 PN 10.
- No joint tested together with pipes under sustained internal pressure showed sign of failure or leakage.
- A comparison of the long-term failure pressure of different pipes from different international factories shows comparable results in the slope of the regression line. This corresponds to the fact that all pipe types are made from high-performance composite materials, designed and manufactured according to the advanced design algorithm and production technology used worldwide for HOBAS® CC-GRP Pipe Systems.
- The evaluation of results from long-term tests as well as the experience with pipes in operation allows the conclusion that safety factors after 50 years of operation will provide a higher safety margin than actually assumed for the structural design of the pipeline.

5. Resistance to Cyclic Internal Pressure HOBAS® CC-GRP Pipe Systems

Introduction
In order to assess the resistance of HOBAS® CC-GRP Pipe Systems, several series of cyclic internal pressure tests were carried out at external certified institutes. The main objective of this report is to summarize the test data.

Tests
The tests were performed referring to the requirements of the following standards:
- EN 1638 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Test method for the effects of cyclic internal pressure]
- ISO 15306 [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of the resistance to cyclic internal pressure]
- In accordance with ASTM D2992 [Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings]
- ISO 10639 [Plastics piping systems for pressure and non-pressure water supply, – Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin]
- ISO 10467 [Plastics piping systems for pressure and non-pressure drainage and sewerage - Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin]

Samples
- DN 200 PN 10 SN 10000 HOBAS® CC-GRP pipe (4 specimens) tested by TÜV Bau und Betrieb.
- DN 400 PN 10 SN 5000 HOBAS® CC-GRP pipe (1 specimen) tested by Johnston Pipes and witnessed by WRc (Water Research center), United Kingdom
- DN 300 PN 16 SN 10000 HOBAS® CC-GRP Pipe (2 specimens) tested by ITC Zlin Czech Republic

Test Procedure
A test piece is subjected to a specified cyclic internal hydrostatic pressure for at least 1 million cycles **(see Table 7)**. The mean pressure during the test must be equal to the nominal pressure expressed in bars and the pressure amplitude must be equal to ± 0.25 times the nominal pressure expressed in bars i.e. the specimen must be cycled between(0.75 x PN) and (1.25 x PN). Additionally to the described test sequence, one pipe (DN 300 PN 16) was also cyclically pressurized at a higher stress level between 0.75 times (1.5 x PN) and 1.25 times (1.5 x PN). After cyclic testing, the sample is tested to evaluate the residual circumferential tensile strength (failure pressure).

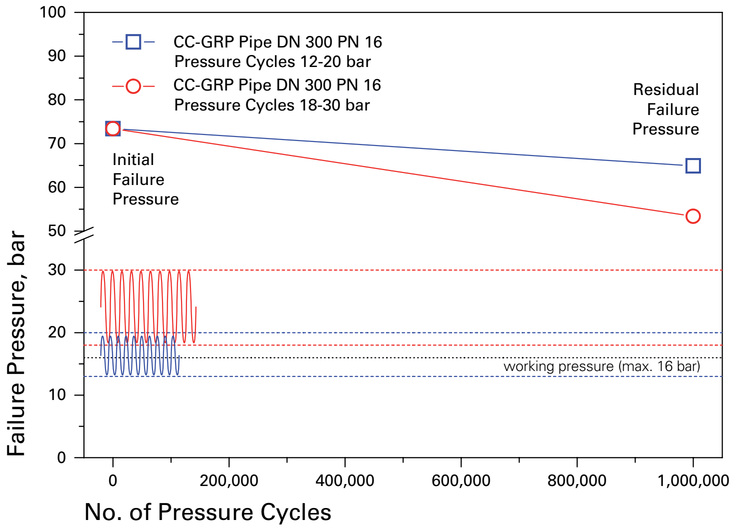
Test pressures

PN 10	1 million cycles between 7.5 and 12.5 bar
PN 16	1 million cycles between 12 and 20 bar
PN 16	1 million cycles between 18 and 30 bar

Table 7: **Cycle frequency**

Nominal diameter DN	Minimum cycle frequency, cycles/min
≤ 150	16 ± 4
> 150 and ≤ 350	8 ± 2
> 350 and ≤ 500	4 ± 1

Fig. 18: **Pressure resistance of HOBAS® CC-GRP Pipes PN 16 after 10^6 pressure cycles**



Results

Cyclic Pressure Test

The test samples DN 200 PN 10 SN 10000, DN 400 PN 10 SN 5000 and DN 300 PN 16 SN 10000 successfully completed 1 million pressure cycles and displayed no signs of weeping or leakage throughout the test period.

Hoop Tensile Strength (Failure Pressure)

Following the cyclic pressure tests, the specimens were pressurized to failure (hoop tensile strength), **see Table 9**.

Table 8: **Results of cyclic pressure tests**

Pipe sample	Number of cycles between	Results
DN 200 PN 10 SN 10000 Sample 1–4	10^6 between 7.5–12.5 bar	No leakage or signs of failure
DN 400 PN 10 SN 5000	10^6 between 7.5–12.5 bar	
DN 300 PN 16 SN 10000 Sample 1	10^6 between 12–20 bar	
DN 300 PN 16 SN 10000 Sample 2	10^6 between 18–30 bar	

Fig. 17: **Test setup DN 300 PN 16**

Table 9: **Results of hoop tensile strength**

Pipe sample	Initial failure pressure (p_b), bar	Failure pressure (p_b) after 10^6 cycles, bar	Safety factor after 10^6 cycles (p_b/PN
DN 200 PN 10 SN 10000 Sample 1–4 (7.5–12.5 bar)	–	41.5	4.2
DN 400 PN 10 SN 5000 (7.5–12.5 bar)	51.1 ± 4.2[1)]	48	4.8
DN 300 PN 16 SN 10000 Sample 1 (12–20 bar)	73.4	64.9	4.1
DN 300 PN 16 SN 10000 Sample 2 (18–30 bar)	73.4	53.4	3.3

1) Mean of 4 single results

Conclusions

- The requirements of of ISO 10639 and ISO 10467 are fulfilled. Subjecting HOBAS® CC-GRP pipes to 1 million cyclic pressure variations between (0.75 x PN) and (1.25 x PN) and even 0.75 times (1.5 x PN) and 1.25 times (1.5 x PN) did not lead to leakage or any signs of failure.
- The DN 200 and DN 400 PN 10 as well as the DN 300 PN 16 pipe types show a residual pressure safety of more than 4 after 1 million cycles between (0.75 x PN) and (1.25 x PN). A safety factor of 3 was even measured after 1 million cycles between 0.75 times (1.5 x PN) and 1.25 times (1.5 x PN).

References

- TÜV Test report AW5/7895-4-95 – Prototype testing to obtain a quality certificate issued by RAL for sewer and pressure GRP pipelines
- Johnston Pipes Test Report 001/00/CM – The Effect of Cyclic Internal Pressure on GRP Pipes
- ITC Test Report ref. No. 4625 00128/4 – Determination of the resistance to cyclic internal pressure

6. Buckling Resistance

The resistance of HOBAS® CC-GRP pipes to internal pressure is required and specified by product standards. The requirements and specifications for resistance to internal negative pressure (vacuum) or external water pressure are not sufficient.

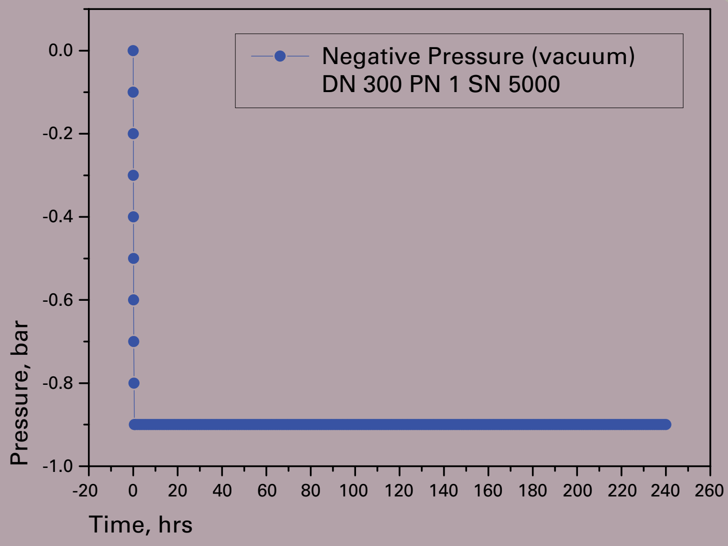
Buckling due to internal negative pressure may occur e.g.:
- In pressure pipelines due to sudden closure or opening of valves (water hammer)
- In tanks and pipelines with insufficient ventilation
- In pipelines with gradients after sudden filling or flushing

To determine the effect of internal negative pressure, a test was conducted as described below.

Samples
A pipe DN 300 PN 1 SN 5000 with a length of 6 meters is jointed with FWC couplings on both ends to short pipes (approx. 500 mm). The system is closed at both ends with laminated blind flanges **(Fig. 19)**. On one of the blind flanges the vacuum pressure pump and a pressure sensor are connected.

Test and Procedure
The sample pipe DN 300 PN 1 SN 5000 is tested for resistance to internal negative pressure. The test is conducted at room temperature. After it reaches the maximum negative pressure without failure, pressure is maintained for 240 hours (10 days).

Fig. 20: **Record of pressure test on pipe DN 300 PN 1 SN 5000**



Results
The pipe DN 300 PN 1 SN 5000 resisted the internal pressure of –0.9 bar (0.1 bar absolute) for a period of 240 hours without failure. The test was then stopped. A pressure of –1.0 bar could not be achieved with this pump and test equipment.

Conclusions
- The pipe DN 300 PN 1 SN 5000 resists the pressure of –0.9 bar (0.1 bar absolute) for 240 hours without failure.
- Full vacuum could not be obtained due to test equipment limitations.
- As GRP pipes have time-dependent material properties resulting in a reduction in stiffness over time, HOBAS® recommends a pipe with a stiffness of SN 10000 for an application with permanent full vacuum conditions when not buried.
- With the presence of groundwater or negative internal pressure the maximum allowable buckling pressure has to be determined taking into consideration the actual height of water above ground, actual pressure and installation conditions.

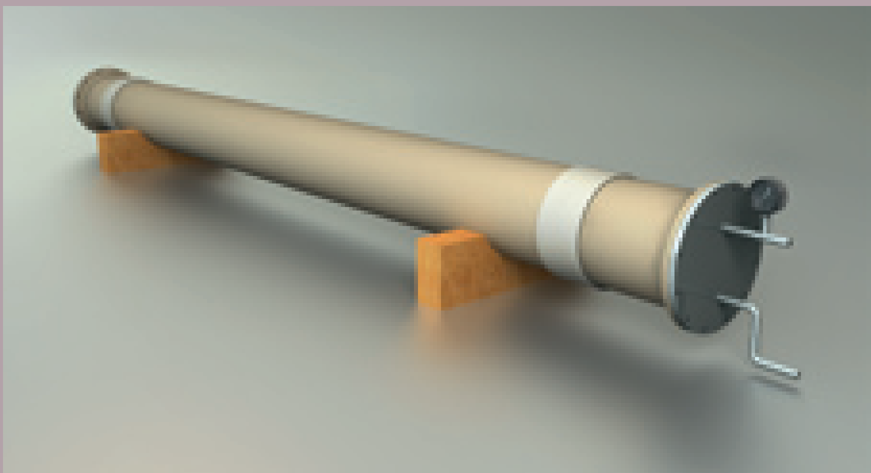


Fig. 19: **Test configuration**

7. Couplings and Fittings

HOBAS® GRP Coupling

Standard HOBAS® CC-GRP Pipes are jointed to each other and to fittings using HOBAS® GRP Couplings. The coupling is mounted on one end of the pipe at the factory and thus joining two HOBAS® CC-GRP Pipes on site is very simple and no special equipment is needed. Additionally the central register provides high safety against overpushing when evenly loaded **(see Fig. 21)**.

The FWC couplings (also called collars or sleeves) have a full width EPDM (ethylene propylene diene monomer) or NBR (nitrile butadiene rubber) elastomeric gasket with a Shore A hardness of 50–60 as an integral part of the coupling, are easily fitted and produce a totally impervious joint equivalent to the performance of the pipe.

Fig. 21: Jointing forces for HOBAS® symmetric GRP couplings

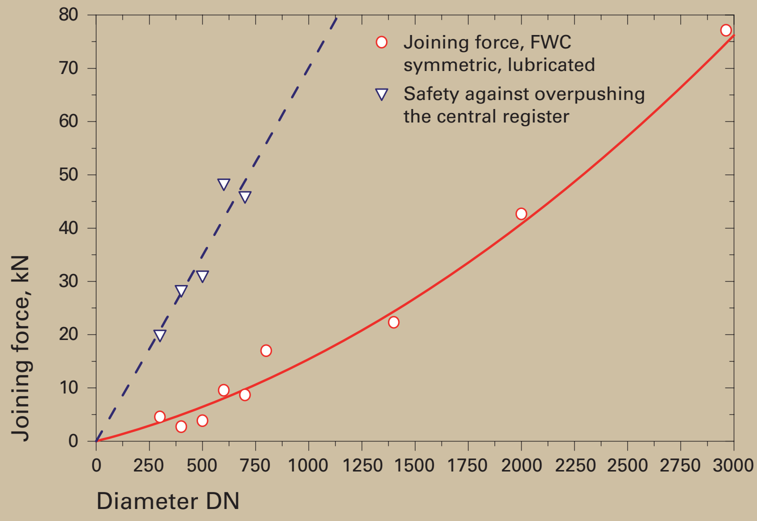
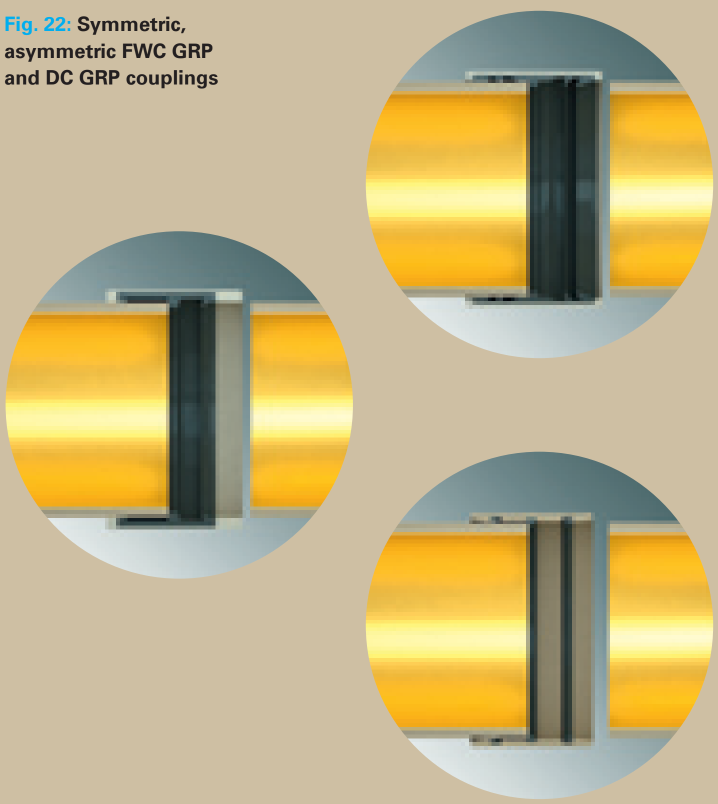


Fig. 22: Symmetric, asymmetric FWC GRP and DC GRP couplings



The HOBAS® FWC joint meets the compliance requirements of EN 691-1, ISO 8639, EN 1119, and DIN 4060, which ensures that they remain sealed even when deflected and subjected to externally applied lateral loading and/or internal and external hydrostatic pressure, or a combination of those loads. The high contact pressure of the seal on the pipe also may also prevent tree root penetration.

The smooth external surface and constant outside diameter of the HOBAS® CC-GRP Pipe Systems, together with the availability of separate GRP couplings, means that the pipe can be cut and jointed anywhere along its 6 meter length. This permits easy installation of fittings at any desired location without the need for supplying specially cut pipes and the re-use of off-cuts without the need for special adjustment pipes gauged to verify tolerance.

Special Joints

Special jointing systems are available for specific applications where the joint is designed to be locked to the pipe spigots. These include the HOBAS® laminated Butt Wrap as well as DC and FWC locked joints **(see Fig. 23)**. These joints are e.g. used in submarine pipelines subject to towing forces during installation or for vertical installations such as shaft linings or bore casing. Pipes for use in these applications need to be designed to withstand axial loading.

Axial movement, ground strains in mine subsidence areas or earthquake zones can be accommodated by variations of the HOBAS® jointing system using shorter pipes or special extended length couplings such as used in Japan. Jointing systems for pipe jacking or relining applications are also produced.

GRP Fittings

HOBAS® GRP Fittings can be produced in both standard and non-standard forms to customer specification and are available for pressure and non-pressure applications. Protected ductile iron, coated steel or stainless steel fittings are compatible and may be used with all classes of HOBAS® CC-GRP Pipes. Diameters up to and including DN 600 are also compatible with ductile iron pipes. HOBAS® Fittings can be laminated for connecting to a large number of other piping materials.

Joint	Locked
FWC Coupling	X
FWC-L Coupling	√
Mechanical Coupling	X
Flanged Joint	√
Laminates	√

The range of fittings includes:

- Bends: To any specified angle
- Tapers: Concentric and level invert
- Tees and branches: Equal and unequal square or angled

HOBAS® Product catalogs show the standard range of HOBAS® GRP Fittings, special fittings can be manufactured to order.

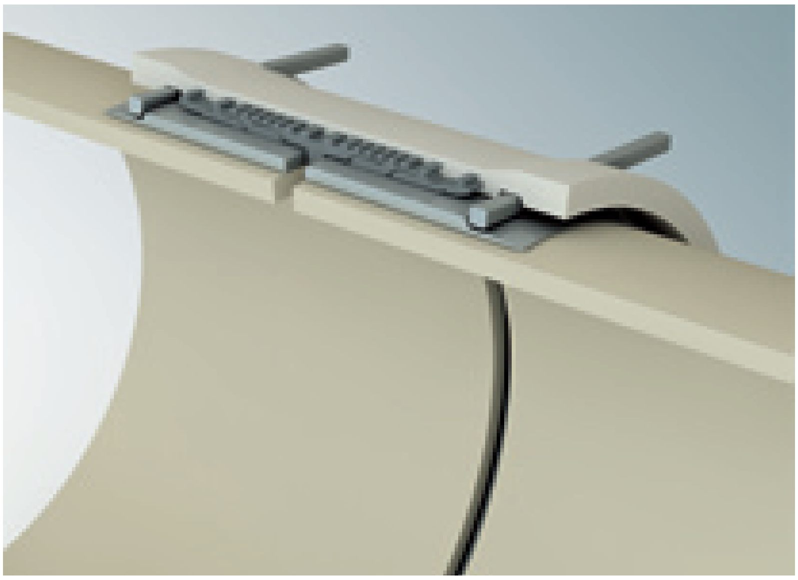
Non-Pressure Fittings

A full range of HOBAS® GRP bends, tees, junctions, flanges, reducers, manholes and connectors are available for sewerage, drainage and other low head applications.

Pressure Fittings

For water supply, sewerage rising/force mains, and other pressure applications, in addition to HOBAS® GRP Pressure Fittings, cast or ductile iron fittings or valves can in some cases be used with HOBAS® CC-GRP Pipe Systems. Steel fittings may also be used. As the HOBAS® Pipe is flexible, flexible tapping bells, manufactured from gun metal or stainless steel may be used for service conditions.

Fig. 23: **HOBAS Locked Joint System FWC-L**



Performance Testing of HOBAS® Joints

Tightness and System Tests

Introduction

Leak-tightness and pressure type tests on centrifugally cast (DC) and filament wound (FWC) couplings were carried out for the HOBAS Engineering pipe system in the material development department. The tests were witnessed by TÜV Industrie Service Germany and aimed to prove the conformity of HOBAS® GRP couplings for various national and international standards. The test sequences complied with the requirements of the following standards:

Test Standards
- EN 1119
- ISO 8639
- Based on ASTM D4160 (loading conditions according to EN and ISO standards are more stringent, e.g. 2 x PN/24 h instead of 1 x PN/10 min and higher shear loads)

Product Standards
- EN 1796
- EN 14364
- ISO 10639
- ISO 10467
- ASTM D3262
- ASTM D3517
- ASTM D3754

Purpose

The test series aimed to prove the conformity of HOBAS® GRP Couplings to the above standards.

Samples

HOBAS® FWC and DC Couplings **(see Fig. 22)**

Tests

Leak-tightness and pressure tests according to the above standards and regulations. The test sequences are shown in **Table 10**. The system has to prove tight under draw and angular deflection, and resist misalignment under shear load and angular deflection **(see Fig. 25–26)**.

Fig. 24: **Test for misalignment by shear load and draw on HOBAS® locked joint system DN 1200 PN 6**

Table 10: Test conditions – leak-tightness and pressure tests

Test Sequence	Pressure, bar	Duration	Requirement/ Results
Draw of 18 mm	Min. 1.5 x PN	15 min	No leakage during test sequence
	Negative pressure –0.8 bar (vacuum 0.2 bar absolute)	≥ 1 hour	
Angular deflection and draw of 18 mm	Min. 1.5 x PN	15 min	No leakage during test sequence
	Min. 2 x PN	24 hours	
Misalignment by shear load (20 x DN, N) and draw of 18 mm	Min. 1.5 x PN	15 min	No leakage during test sequence
	Min. 2 x PN	24 hours	
	Cycles 0–1.5 x PN	10 cycles of 1.5 to 3 min each	

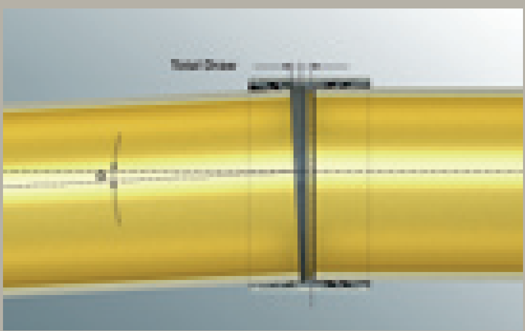


Fig. 25: **Test sequence for angular deflection and draw**

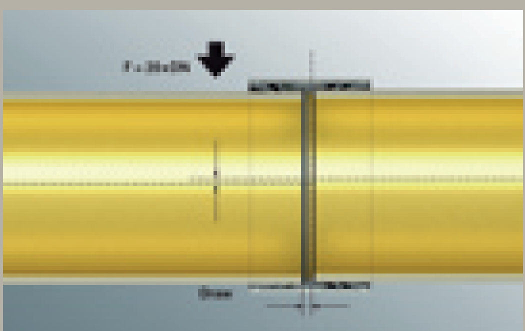


Fig. 26: **Test sequence for misalignment by shear load and draw**

Conclusions

Type tests were performed on all HOBAS® GRP Couplings at regular intervals. As they comply with ISO and EN standards, they also meet ASTM D 4161 requirements.

The test series under draw, hydrostatic and cyclic pressure were positive. No leakage could be observed during the test sequences with angular deflection and misalignment by shear load.

The tests with negative pressure were positive (0.2 bar absolute pressure), no increase in pressure was detected during the test period.

Leak Tightness Under External Pressure

Introduction

In order to prove that HOBAS® filament wound (FWC) and centrifugally cast (DC) GRP Couplings are leak tight when subjected to external water pressure, HOBAS Engineering GmbH performed a test series which was witnessed by TÜV Industrie Service Germany.

Samples

- HOBAS® asymmetric filament wound coupling type FWC DN 250 PN 16
- HOBAS® symmetric filament wound coupling type FWC DN 300 PN 16
- HOBAS® centrifugally cast coupling type DC DN 300 PN 1

Tests

Determination of system leak tightness under external pressure. To perform the leak tightness test, HOBAS® CC-GRP pipes with a length of approximately 0.5 m each were connected with the test coupling. A sleeve tube with larger diameter (HOBAS® CC-GRP) and laminate end caps formed an annular test chamber for external pressure tests **(see Fig. 27)**. The annular chamber was filled with tap water to perform pressure tests with the following procedure:

- Min. 2 bar for 24 hours
- Pressure increase until failure (burst, leakage, etc)

Fig. 27: Sample cut after testing

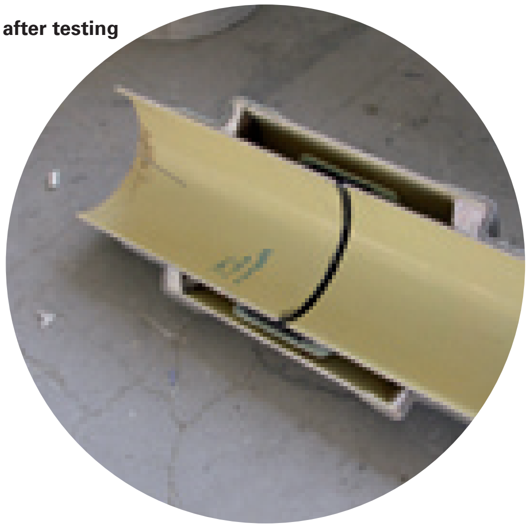
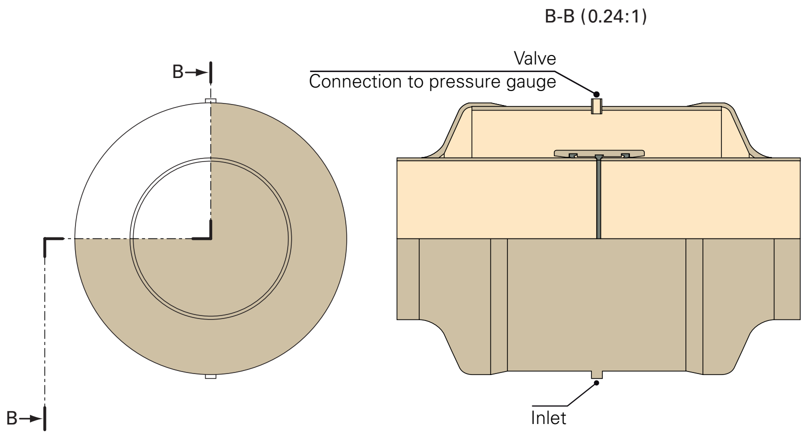


Fig. 28: Test configuration



Results

Coupling	Test	Pressure, bar	Test duration	Results
DN 250 Asymmetric FWC Type GRP	External pressure	Min. 2	24 hours	No leakage during test period
		–	Increase to failure	Tight for pressure < 10 bar
DN 300 Symmetric FWC Type GRP	External pressure	Min. 2	24 hours	No leakage durgin test period
		–	Increase to failure	Tigth for pressure < 11 bar (laminate rupture at 11 bar)
DN 300 Symmetric DC Type GRP	External pressure	Min. 2	24 hours	No leakage during test period
		–	Increase to failure	Tight for pressure < 8.3 bar (laminate rupture at ~ 8.3 bar)

Table 11: Results of leak tightness test under external pressure

During the test series at minimum 2 bar with a dwell time of 24 hours no leakage was detected in HOBAS® coupling systems. The asymmetric FWC showed gasket failure at approx. 10 bar. The test specimens (annular chamber laminate) failed at ~8.3 bar (DC coupling) and 11 bar (FWC symmetric). No gasket failure was observed.

Conclusions

Leak tightness under external pressure for HOBAS® Coupling Systems was measured and reported. No leakage during the test period of 24 hours at min. 2 bar could be detected.

The asymmetric FWC is tight up to an external pressure of 10 bar (gasket failure occurred at >10 bar). The symmetric FWC and the DC coupling showed short-term leak tightness of more than 11 and 8.3 bar respectively. In both test series the laminate on the end caps failed.

Long-Term Gasket Compression and Resistance to Root Infiltration

Introduction

In order to prove long-term gasket compression and resistance to root infiltration in HOBAS® filament wound (FWC) and centrifugally cast (DC) GRP Couplings, a test series was carried out by the Austrian research institute for plastics (OFI). The test series was performed according to the requirements of EN 14741 [Thermoplastics piping and ducting systems – Joints for buried non-pressure applications – Test method for the long-term sealing performance of joints with elastomeric seals by estimating the sealing pressure].

Samples

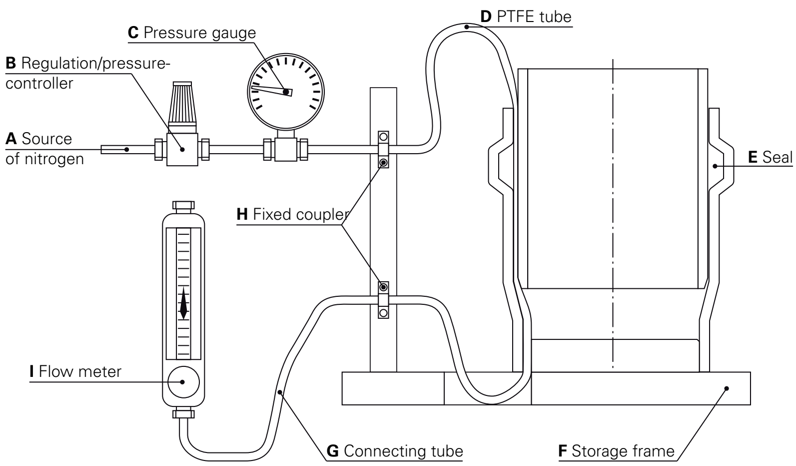
- HOBAS® asymmetric filament wound coupling type FWC DN 300 PN 16
- HOBAS® symmetric filament wound coupling type FWC DN 300 PN 16
- HOBAS® centrifugally cast coupling type DC DN 300 PN 1

Fig. 29: Test configuration – long-term sealing pressure

Tests

Determination of the long-term sealing pressure and resistance to root infiltration. The sealing pressure of the coupling is estimated by measuring the pressure necessary to lift the seal in a PTFE tube located between the rubber seal and the outside wall of the spigot in a joint. In a temperature-controlled environment and at increasing time intervals, a constant flow rate of 120 ml/min nitrogen is forced through the PTFE tube. The nitrogen pressure necessary to achieve the flow is measured. The extrapolated regression lines for the pressure are used to calculate the long-term sealing pressure of the gasket.

Fig. 30: Typical test setup



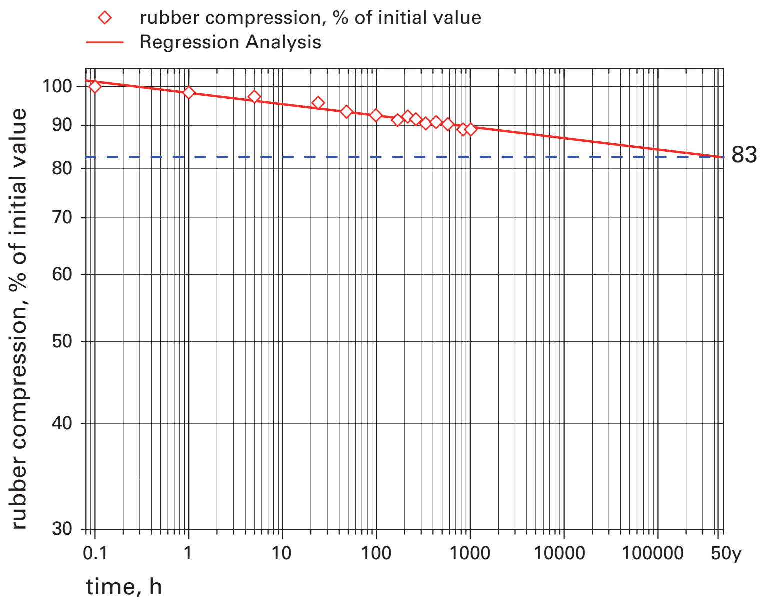
Results

Fig. 31 shows typical results for HOBAS® GRP coupling systems. A residual long-term (>50 years) sealing pressure of more than 80% was calculated.

Conclusions

The HOBAS® GRP Coupling systems show an excellent long-term sealing pressure of > 80% of their initial value. This performance also ensures high safety against root infiltration.

Fig. 31: **Long-term sealing compression of HOBAS® GRP Couplings**



Chemical Resistance

HOBAS® CC-GRP Pipe Systems' resistance to attack by chemical agents has been determined throughout years of research and field experience. In general, HOBAS® CC-GRP Pipe Systems are impervious to attack from chemicals found in typical water and sanitary sewer systems. Details can be found in **Chapter 8 (Chemical Resistance)**. Additionally to the performance tests on HOBAS® CC-GRP Pipes, strain corrosion tests on couplings over more than 5 years have proven the excellent corrosion resistance of the entire pipe system.

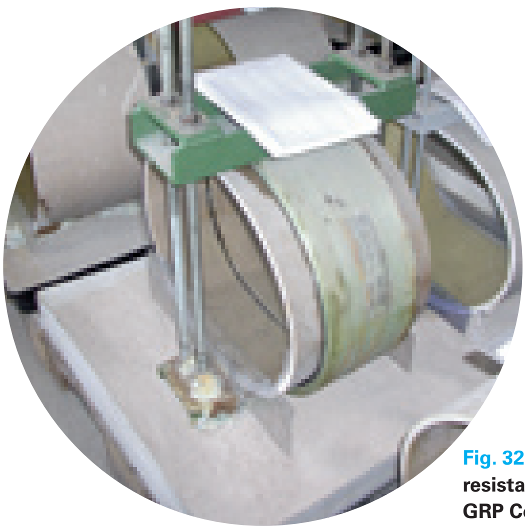


Fig. 32: **Long-term chemical resistance of HOBAS® GRP Couplings**

Performance Testing of HOBAS® Fittings

Tightness and System Tests – Example GRP Spool DN 1600 PN 10

Introduction

In order to assess the internal hydrostatic pressure resistance of GRP fittings, several spools were tested. One of these spools had a diameter DN 1600 PN 10 bend manufactured according to HOBAS® design guidelines. The GRP spool consisting of two elbows (45 and 22.5°, 4 butt wrap laminates and 2 GRP flanges) was tested by HOBAS Engineering GmbH according to a defined test configuration **(see clause tests)**.

Samples

- 1 Bend DN 1600 PN 10 45° (2 miters of CC-GRP)
- 1 Bend DN 1600 PN 10 22.5° (1 miters of CC-GRP)
- 4 Butt Wrap laminate (coupling laminate)
- 2 Laminate stub flanges DN 1600 PN 10

Fig. 33: Spool DN 1600 PN 10

Tests

The long-term pressure tests were based on ISO 14692-2 but conducted at room temperature. The test conditions were in line with the normative requirements for survival tests for GRP spools. The pressure was 24 bar which exceeds the LCL 97.5% for HOBAS® CC-GRP Pressure Pipes (22.6 bar). It has also to be mentioned that ISO 14692-2 actually specifies a service life of only 20 years. The LCL 97.5% however was derived from a pressure regression line based on a 50-year safety factor of 1.9 (ISO 10639, ISO 10467, EN 1796 and EN 14364).

Test sequences:
Leak-tightness tests according to ON B5161 (1.5 times PN for min. 15 min).

Pressure tests in accordance with ISO 14692-2, EN 1394, ISO 8521, ISO 8533 and ASTM D1599-B.

The GRP spool was pressurized for approximately 16 hours to 1.5 times PN (15 bar). Afterwards the pressure was increased to 24 bar for more than 1000 hours. After this sequence, the pressure was released to check for any visual defects. As no visual defects could be found, the GRP spool was pressurized again, however this time to min. 25 bar for more than 100 hours. To meet the requirements of test standard ISO 8533, the spool was additionally pressurized to 30 bar for 0.5 hours (the standard requires min. 6 minutes). As the GRP spool was still tight, pressure was increased to failure. The complete test sequence is summarized in the following table **(Table 12)**.

Table 12: Test sequences

Sequence No.	Pressure, bar	Time, hours	Time, days
1	15	16	0.67
2	24	1140	47.5 (~6.8 weeks)
3	Pressure release	–	–
4	25	124	5.2
5	30	0.5	0.021
6	Increase to burst	–	–

Results

Table 13: Test results

Sequence No.	Pressure, bar	Time, hours	Results
1	15 (1.5 x PN)	16	No leakage
2	24 (2.4 x PN)	1140	No leakage
3	Pressure release	–	No signs of failure
4	25 (2.5 x PN)	134	No leakage
5	30 (3 x PN)	0.5	No leakage
6	Increase to burst	–	Burst at 35 bar

Conclusions

- The purpose of the test series was to check the HOBAS® laminate design by long- and short-term hydrostatic pressure testing.
- The long-term pressure sequences of 24 bar and 1140 hours were positive: The GRP spool meets the requirements of ON B 5161 EN 1796, EN 14364, ISO 10639 and ISO 10467.
- Also the test sequence based on ISO 14692-2 was positive (test was carried out at room temperature instead of 65°C as required by ISO 14692-2).
- The GRP spool meets the short-term pressure requirements of ISO test standard ISO 8533 (min. 6 min at 3 x PN).
- On smaller diameter fittings also tests at 65°C were successfully carried out.

8. Chemical Resistance

Resistance to Chemicals

HOBAS® CC-GRP Pipe Systems' resistance to attack by chemical agents has been determined throughout years of research and field experience. In general, HOBAS® CC-GRP Pipe Systems are impervious to attack from chemicals found in typical water and sanitary sewer systems.

Chemical reactions can be very complex. There are so many factors affecting the reaction of a piping system to chemical attack that it is impossible to produce charts to cover all the possibilities. Some of the major factors affecting chemical resistance are:

- Temperature
- Chemical (or mixture of chemicals) present
- Concentration of chemicals
- Duration of exposure
- Frequency of exposure

For more details, please see the chemical resistance guide for HOBAS® CC-GRP Pipe Systems in the Annex.

Corrosion Resistance

The polyester resins used in the HOBAS® production process fully enclose the other pipe constituents to prevent their contact with aggressive media. HOBAS® CC-GRP Pipes therefore display outstanding resistance to corrosion from industrial wastewater and sewerage. Under certain circumstances related to the temperature, velocity, retention time and waste water composition, hydrogen sulfide gas can be generated and this will form sulfuric acid which corrodes cement, concrete and ferrous materials. The resins used in HOBAS® CC-GRP Pipes are not affected by these corrosive agents and extensive tests have been performed to demonstrate the pipe's high chemical resistance.

Polyester resins are also non-conductors of electricity, hence the HOBAS® Pipe System is not subject to electrolytic corrosion. It can occur with metallic pipe systems, where stray electric currents exist generated by either chemical reactions or adjacent power lines.

No Corrosive Build-Up (Incrustation)

The resistance of the internal pipe surface to chemical attack enables the product to satisfy the requirements for the conveyance of water and different types of sewage. There has been no failure of HOBAS® CC-GRP Pipe Systems or loss of hydraulic capacity as a result of build-up on the interior wall of the pipe.

Strain Corrosion

Introduction

A series of strain corrosion tests with acidic and alkaline chemicals was conducted on pipes of different types and manufactured at various production plants to establish the long-term (50, 60, and 100 years) resistance of HOBAS® CC-GRP Pipe Systems to acid strain corrosion.

The main objectives of this report are:

- To summarize and evaluate these results
- To calculate the long-term failure strains

Standards

Pipe System Standards

- EN 14364 [Plastics piping systems for drainage and sewerage with or without pressure – Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP) – Specifications for pipes, fittings and joints]
- ISO 10467 [Plastics piping systems for pressure and non-pressure drainage and sewerage – Glass-reinforced thermo-setting plastics (GRP) systems based on unsaturated polyester (UP) resin]
- ASTM D3262 [Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe]
- ASTM D3754 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe]

Test Standards

- EN 1120 and ISO 10952 [Plastics piping systems – Body resin reinforced thermo-setting plastics (GRP) pipes and fittings – Determination of the resistance to chemical attack from the inside of a section in a deflected condition]
- ASTM D3681 [Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermo-setting-Resin) Pipe in a Deflected Condition]

Standards for Data Evaluation

- EN 705: Method A and ISO 10928 – Method A and B [Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes and fittings – Methods for regression analyses and their use]

Samples

Glass fiber reinforced, filled thermosetting resin pipes manufactured with HOBAS® CC-GRP Pipe technology. The pipes were produced at different international production plants.

Test Procedure

The test procedure follows the above mentioned standards. The interior of a specimen for tests in acidic media is exposed to a corrosive test liquid [1N sulfuric acid (0.5 mol H_2SO_4/l); pH ~ 0.1] at room temperature while being maintained in a fixed diametrically deflected condition. For the test series with alkaline media, the sulfuric acid is substituted by sodium hydroxide [sodium hydroxide with min. pH 10;0.5 mol NaOH/l]. The test is repeated at several deflection (strain) levels inducing flexural strain/stress in the pipe wall exposed to the sulfuric acid or sodium hydroxide. Each test is carried out using a fresh test piece and recording the time to leakage at each deflection (strain). The results are used to calculate the ultimate ring deflection and flexural strain under combined mechanical loading and chemical attack for a defined service life of 50 years. Beyond the requirements of various standards, the deflection and strain values for an operational lifetime of 60 and 100 years was deduced.

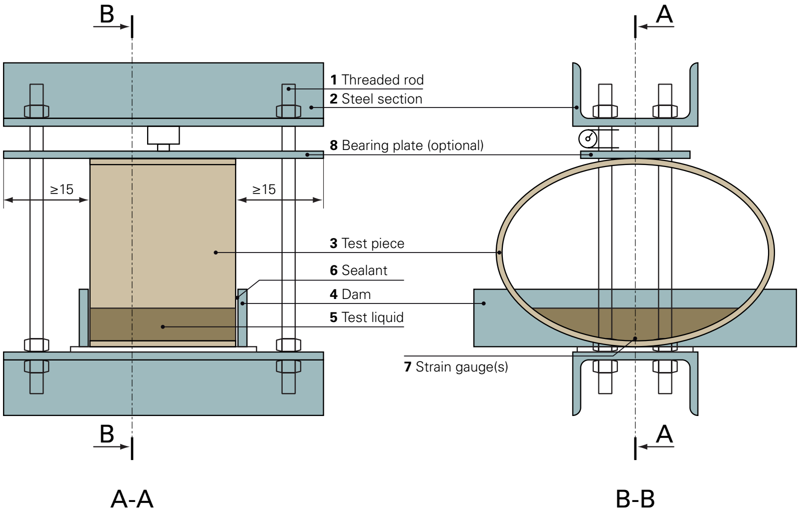


Fig. 34: **Strain corrosion – test setup**

Fig. 35: Strain corrosion tests

Data Evaluation

In order to establish a master curve containing test series of various pipe types, manufactured in different international plants, increasing the number of data points and the statistical relevance, the flexural strain was calculated according to Eqn. 2.13.

$$\varepsilon_b = \frac{428}{\left(1+0.5\cdot\frac{d_v}{d_m}\right)^2}\cdot\frac{d_v}{d_m}\cdot\frac{e}{d_m} \quad (2.13)$$

ε_b	Flexural strain at break, %
d_v	Ring deformation, mm
d_m	Mean ring diameter, mm
e	Wall thickness, mm

Apart from this master curve, a statistical evaluation of the strain corrosion behavior including more than 60 data points (instead of the usual 18 failure points) was performed according to EN 705 and ISO 10928 method A (covariant method) resulting in a higher statistical relevance. Additionally the 97.5% lower confidence level for the mean regression and the 97.5% prediction interval for individual measurements were calculated.

Results

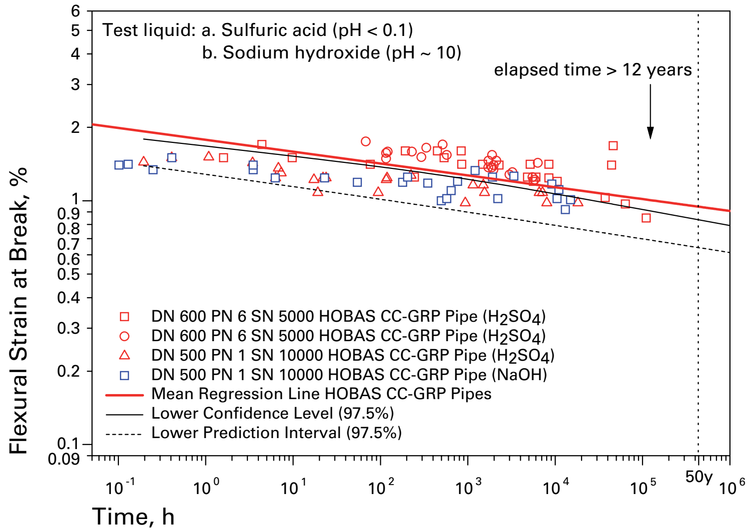
The results of the various strain corrosion test series are presented in **Fig. 36**. The long-term regressions were calculated according to method A in EN 705 and ISO 10928 including failure points of all pipes and led to the following long-term flexural strain at break **(Table 14)**.

Conclusions

The requirements of product standards ISO 10467, EN 14364 and ASTM D3262 are fulfilled for acidic and alkaline environments.

After more than 12 years of strain corrosion testing, HOBAS® CC-GRP Pipe Systems, including the standard joint **(see also couplings chapter)** prove their superior behavior under combined mechanical loading and chemical attack. The highly advanced design of the HOBAS® CC-GRP Pipe System leads to significant advantages compared to other products.

Fig. 36: **Strain corrosion test results**



Maximum Service Conditions

Standard HOBAS® CC-GRP Pipe Systems are intended for continuous use with water, wastewater and controlled industrial wastes at temperatures up to 40°C in pH ranges from 1.0 to 10.

For temperatures and chemical conditions in excess of these values, HOBAS® should be consulted for advice on more resistant resins at info@hobas.com.

In the case of industrial effluents, with the exception of chlorinated or aromatic solvents, HOBAS® CC-GRP Pipe Systems have excellent resistance to chemical attack. Furthermore, special resin systems can be used to improve the chemical resistance especially at elevated temperatures. The flexibility of the HOBAS® process allows the use of vinyl esters based on novolacs and epoxies when resistance to solvents is required. Pipes with high temperature resistant liners should be handled and installed more carefully than standard pipes.

Recommendations and experience show acceptable continuous environments for satisfactory long-term pipe performance, however individual project conditions should be considered when selecting the appropriate product characteristics. Also pressure and stiffness ratings may be reduced at elevated temperatures. HOBAS® will assist the design engineer when making these evaluations.

Table 14: **Calculated long-term properties**

	Flexural strain at break Acidic environment (low pH)	Flexural strain at break Alkaline environment (high pH)
50 years	1.1	0.92
60 years	0.95	0.91
100 years	0.93	0.89

Tailor Made Pipes for Special Applications

A variety of liner resins are available with HOBAS® CC-GRP Pipe Systems to suit various exposure conditions. Special linings such as epoxy, vinyl ester or special isophthalic resins can be specified to protect against crude oil, alkalis, acids, chlorides, sulfates, natural gas, soils and critical atmospheres. Thus every project is considered separately in terms of the chemicals occurring.

For detailed information, please see the chemical resistance guide in the Annex.

9. Abrasion Resistance

Years of experience and a large number of abrasion-wear tests series have shown that HOBAS® CC-GRP Pipe Systems have a wear resistance comparable to thermoplastic pipes. Several different methods have been used to investigate the abrasion resistance of various pipe materials. The nature of the testing methods precludes any specific comparisons, but nevertheless, in every case it is clear that HOBAS® CC-GRP Pipe Systems display superior resistance to abrasion. The excellent internal abrasion resistance of HOBAS® CC-GRP Pipe Systems is due to a specially formulated resilient liner resin.

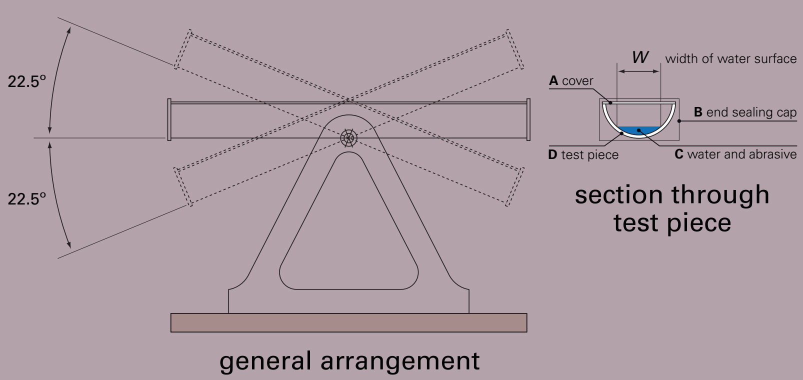
Introduction

Pipe systems for sewer and pressure applications can be stressed continuously by mechanical abrasion. In order to determine the abrasion resistance of HOBAS® CC-GRP Pipe Systems, several Darmstadt rocker tests were performed.

The main objectives of this report are:

- to summarize and evaluate the results
- to calculate the long-term abrasion safety factor of HOBAS® CC GRP Pipe Systems

Fig. 37: Abrassion test principle



Samples

Segments of HOBAS® CC-GRP Pipes DN 200 – DN 600.

Tests and Procedure

The Darmstadt Rocker test is based on DIN 19565 [Centrifugally cast and filled polyester resin glass fibre reinforced (UP-GF) pipes and fittings for buried drains and sewers – Dimensions and technical delivery conditions] and EN 295-3 [Vitrified clay pipes and fittings and pipe joints for drains and sewers – Test methods].

The test method is based on the guideline given in DIN 19565 which is considered to be the most sophisticated, relevant and stringent method to assess the abrasion resistance and durability of pipes. A semi-circular channel pipe with a length of approx. 1 m is closed at both ends by end plates to form watertight seals. The test piece is filled with a specified water/gravel mixture (sand or corundum) and then covered with a plate. The channel pipe test piece is tilted alternately at a uniform rate in the longitudinal direction at an angle of ± 22.5° to the horizontal axis per cycle, i.e. a total of 45° over two tilts/cycles **(see Fig. 37)**. During each tilt, the abrasive slides from one end of the test piece to the other over the channel's inner surface at the invert and thereby causes wear on the inner surface. After 50,000 cycles the water and abrasive is removed and measurements are taken over the central 700 mm of the invert at 20 mm intervals to determine the amount of wear which has occurred. The test piece is then refilled with the abrasive and clean water to continue the test for a further number of cycles until a total of at least 200,000 cycles or more are completed.

Evaluation
In order to calculate the abrasion safety factor for HOBAS® CC-GRP Pipe Systems the minimum liner thickness of 1 mm was divided by the relative abrasion value determined (Eqn. 2.14).

$$SF_a = \frac{e_l}{a} \qquad (2.14)$$

SF_a	Abrasion safety factor
e_l	Liner thickness, mm
a	Abrasion, mm

Results
Fig. 38 illustrates the abrasion wear as a function of the number of cycles for various pipes. According to DIN 19565, the average abrasion wear of pipe samples after 100,000 cycles (calculated and stated in **Table 15**) corresponds to an operational life time of 50 years.

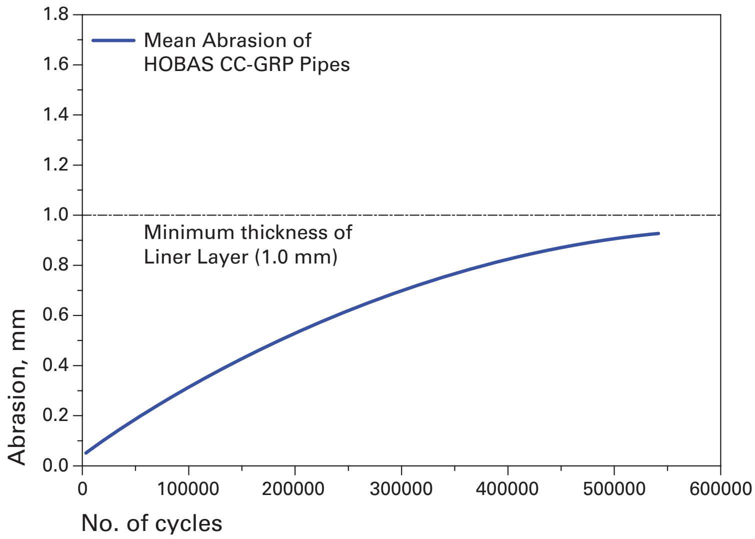
HOBAS® CC-GRP Pipes have an inner protective layer (liner) with a thickness of at least 1 mm. Given this protective layer, a safety factor of 4.3 against complete abrasion applies even after 50 years in operation **(see Table 15)**.

Table 15: Average abrasion of HOBAS® CC-GRP Pipes

No. of cycles	Abrasion, mm	Abrasion safety factor
100,000	0.31	4.3
200,000	0.49	2.6
500,000	0.90	1.5

TÜV report 1192706 Abrasion resistance of a HOBAS CC-GRP pipe DN 350 PN1 SN 10000

Fig. 38: Mean abrasion wear of HOBAS pipes (average value of 10 samples)



Conclusions
The test results show that the abrasion resistance requirements for HOBAS® CC-GRP Systems are fulfilled. The minimum abrasion safety factor is 4.3 after 100,000 cycles, which is considered to be equivalent to an operational lifetime of 50 years according to DIN 19565. Even after 200,000 and 500,000 cycles, the reinforced structural layers are still entirely covered by the liner resin.

Experience with flush lines carrying water in conjunction with highly abrasive glacier rubble for hydropower stations has proven the outstanding abrasion resistance of HOBAS® CC-GRP Pipe Systems over many years (e.g. flush line KW Wald Austria DN 1600 PN 1). After 20 years of operation and approximately 2000 flushes with high abrasive glacier rubble, the HOBAS® pipes perform with an excellent inner surface.

The excellent abrasion resistance is assured due to the production technology of HOBAS® CC-GRP Pipe Systems. A highly protective abrasion-resistant liner layer is applied with a sufficient thickness of at least 1 mm in order to protect the reinforced structural layers of the pipe wall.

10. Hydraulic Roughness

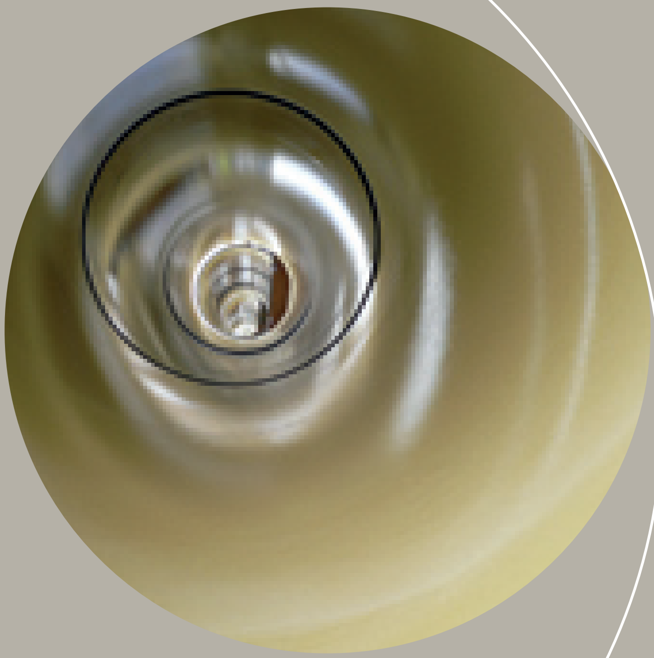
Introduction

GRP pipes with a smooth bore have excellent hydraulic flow characteristics with significantly lower friction losses than other products of similar dimensions. The resin rich internal lining layer provides protection against highly corrosive media and the internal surface is not prone to tuberculation and encrustation.

There are numerous formulae available for the estimation of head loss in pipes and fittings. The most commonly used empirical formulae are the based on Darcy-Weißbach (Colebrook) with the friction factor k, Hazen-Williams and Manning.

The actual roughness of the internal liner layer has been verified both in pipelines installed for several years and at test institutes.

Fig. 39: Smooth internal liner layer gives excellent flow characteristics



Samples (Projects Studied)

- DN 800 PN 1 pipes in Prague-Ruzyne after over 20 years of operation.
- DN 200 PN 6 and PN 10 SN 10000 of about 1.4 km at Rakovnik-Brno after over 5 years of operation."
- DN 400 PN 1 SN 5000 HOBAS® CC-GRP pipe tested at IRO institute/Germany

Test Procedure

According to the standard DIN 19565-1 the hydraulic roughness k must be determined in a hydraulic test, in which the pressure losses along a test pipeline are established for different flow rates Q and the resistance coefficients λ calculated as follows:

$$\lambda = g \cdot \pi \cdot d_{im}^5 \cdot (h_1 - h_2)/(8 \cdot Q^2 \cdot l) \qquad [1]$$

Where

λ	resistance coefficient, –
g	acceleration due to gravity, m/s²
d_{im}	mean internal diameter, m
h_1	pressure head at point 1, m
h_2	pressure head at point 2, m
Q	flow rate, m³/s
l	length between point 1 and 2, m

The parameter d_{im}/k is determined by plotting the values calculated as a function of the Reynolds number R_e. From the d_{im}/k values thus obtained the factor k is determined (in mm).

Results

The roughness factor (Colebrook-White) of k has been verified by external test institutes. Apart from friction losses in straight pipes, fittings may cause head losses if they are numerous or the pipeline short. The standard formula for head loss is:

$$H = \frac{K \cdot v^2}{2 \cdot g} \quad [2]$$

Where

H	head loss, m
K	head loss coefficeint, –
v	flow velocity, m/s
g	acceleration due to gravity, m/s²

Typical values for "K" for normal water supply systems, where the Reynold´s number exceeds 2 x 10^5 are given in **table 16**. Recommended values by the AWWA M45 same as specific HOBAS values are shown.

Conclusions

Excellent roughness values were experimentally verified in situ on pipes in service for several years, both on sewer and pressure pipes. These measurements show that HOBAS® CC-GRP Pipe Systems have a hydraulic wall roughness of k ~ 0.01 mm.

Table 16: Typical roughness coefficients and head loss coefficients for GRP pipes and fittings

	Description	AWWA M45	HOBAS
Roughness Coefficients for Pipes			
Pipe	Colebrook-White k	0.00518	0.01–0.016
Pipe	Hazen-Williams C	150	155
Pipe	Mannings n	0.009	0.008–0.01
Head Loss Coefficents for Fittings			
Bend	11.25°, single miter		0.03
Bend	22.5°, single miter		0.06
Bend	30°, single miter		0.12
Bend	45°, double miter		0.15
Bend	60°, double miter		0.3
Bend	90°, Standard	0.5	
Bend	90°, single miter	1.4	
Bend	90°, double miter	0.8	
Bend	90°, triple miter	0.6	0.45
Bend	180°, return bend	1.3	
Tee	Straight flow	0.4	0.2
Tee	Flow to branch	1.4	1.9
Tee	Flow from branch	1.7	1.6
Reducer	Single size reduction	0.7	
Reducer	Double size reduction	3.3	
Wye (45°)	Straight flow		0.2
Wye (45°)	Flow to branch		0.9
Wye (45°)	Flow from branch		0.7

Fig. 40: Test set-up at IRO institute

11. Environmental Effects

Designed for high corrosion resistance

The unique production method and the multi-functional layer design allow HOBAS CC-GRP Pipes to be tailored according to the individual requirements of a specific application. Generally CC-GRP-UP pipe wall composites are designed as sandwich structures with different functionalities of their layers **(Fig. 41)**. An outer protective layer containing high amount of sand aggregates provides high environmental resistance in respect of UV, chemicals, ground water, weathering and any type of mechanical attack. The thickness of the outer protective layer is at least 1 mm and prevents degradation of the structural integrity of the pipe, thus allowing the pipe even to be installed above ground without any further protection.

Fig. 41: **Structural design of HOBAS® CC-GRP Pipes**

Fig. 42: **Above ground installation**

Aggressive Ground Conditions

HOBAS CC-GRP Pipe Systems can be used without any external protection when buried directly in highly acidic or alkaline soils, or soils of low resistivity. Cathodic protection due to nearby steel structures is of no concern where a HOBAS Pipe System is used.

Weather resistance

HOBAS CC-GRP Pipes can be stored outside or installed above ground for long periods of time without any detrimental effects on the structure of the pipe or coupling. Some superficial roughening may occur. Extensive exposure to UV radiation of the inner pipe layer while on stock however shall be avoided. When pipes shall be stored over a longer period, HOBAS recommends to cover the ends e.g. with end caps for protection of the inner liner layer.

Permanent above ground installations are made using HOBAS CC-GRP Pipe Systems e.g. penstocks or HOBAS BridgeLine®. Advice regarding the need for protection in any particular installation can be obtained from your HOBAS Sales Engineers under info@hobas.com.

Biological Attack

Biological attack is defined as degradation caused by the action of living microorganisms. Microorganism that attack organic materials are such as fungi and bacteria. Macroorganisms that can affect organic materials located underground include tree roots, insects and rodents. The pipe material of HOBAS CC-GRP Pipe Systems has proven itself to be immune to biological attack. HOBAS CC-GRP Pipe Systems do not serve as a nutrient for micro or macro-organisms.

Epoxy modified vinyl-ester resins are used where special resistance against solvents is required. Extensive tests were carried out to assess the pipe material performance in a temperature range a HOBAS CC-GRP Pipe System usually is installed and operated. Mechanical tests such a Charpy, Flexural and Tensile tests did not significantly influence the material behaviour of the structural pipe wall within a temperature range of –40 to +40°C.

12. Potable water

HOBAS CC-GRP Pipe Systems are widely used for potable water and have been tested and approved by the water authorities in many countries. This test information can be obtained from HOBAS Engineering under info@hobas.com.

HOBAS CC-GRP Pipe Systems are officially approved for potable water in most countries such as:

- Austria
- Bulgaria
- Czech Republic
- Germany
- Hungary
- Italy
- Moldavia
- Norway
- Poland
- Romania
- Slovak Republic
- Spain
- Sweden
- Switzerland
- Turkey
- USA

SVGW
Schweizerischer Verein des Gas- und Wasserfaches
Grütlistrasse 44
CH- 8027 Zürich

Zertifizierungsstelle Wasser

SVGW SSIGE

Zertifizierungsantrag:

vom:

Gestützt auf das Prüf- und
zertifiziert der SVGW die

Rubrik:

Bezeichnung:

Modelle / Typen:

Zertifizierungsgrundlage:

Gültigkeit:

Der Auftraggeber ist berei
das SVGW-Konformitätsze

Bemerkungen:

Zürich, 17. Oktober 2005

DVGW CERT GMBH

DVGW-Baumusterprüfzertifikat

DVGW type examination certificate

Anwendungsbereich field of application	Produkte der Wasserversorgung products of water supply
Zertifikatinhaber owner of certificate	Hobas Rohre GmbH Gewerbepark 1 / Hellfeld, D-17034 Neubrandenburg
Vertreiber distributor	Hobas Rohre GmbH Gewerbepark 1 / Hellfeld, D-17034 Neubrandenburg
Produktart product category	Kunststoff-Druckrohre für erdverlegte Leitungen: Druckrohr, Formstück u. Rohrverbindung aus UP-GF, Part.-Gr. 2 (8416)
Produktbezeichnung product description	Rohre aus GFK (UP-GF), Druckstufe PN 10/ PN 16 (SN 5000/10000)
Modell model	GFK-Rohr "Hobas"
Prüfberichte test reports	Kontrollprüfung Labor: 1046043-3 vom 27.10.2008 (TKS) Kontrollprüfung Labor: 1046043-2 vom 27.10.2008 (TKS) Mechanikprüfung: BB6/5691-1-2-99 vom 06.11.2002 (TKS) KTW-Prüfung: 261407 vom 17.12.2007 (TZW) Mikrobiologische Prüfung: MO 104/08 vom 09.05.2008 (TZW)
Prüfgrundlagen basis of type examination	DVGW VP 615 (01.07.1996) BGA KTW (07.01.1977) DVGW W 270 (01.11.2007)
Ablaufdatum / AZ date of expiry / file no.	14.10.2011 / 08-0608-WNI

13. Quality Assurance

The HOBAS Group Plants have quality management systems designed to satisfy the exact requirements of the ISO 9001 Standard. Each pipe manufactured by the computer controlled production process is marked with a unique number that permits complete traceability of the product with respect to the origin, quality and quantity of raw materials, the manufacturing conditions and batch conformance test results. Even before the pipe is produced, the quality approved raw materials are tested in the laboratory in order to ensure that they meet the strict internal standards.

Fig. 43: Raw Materials

HOBAS® Raw Materials

The HOBAS Group Plants only use approved raw materials from qualified suppliers which meet detailed specified requirements. Each type of raw material has to pass process, compound and service relevant requirements set up in the central research department. The detailed raw material specifications are available from HOBAS Engineering GmbH under info@hobas.com.

Glass fibres

Every HOBAS CC-GRP Pipe System has to meet structural, mechanical and chemical requirements according to its type and has to comply with relevant standards. The major reinforcing material used for HOBAS CC-GRP Pipe Systems to achieve the recommended mechanical properties in the axial and circumferential direction is fibre glass. There are some layers in the wall structure of a HOBAS Pipe in which the fibres are the main component and responsible for the excellent mechanical performance of every HOBAS CC-GRP Pipe System.

Standard roving tests are performed on every batch delivered (tex number, roving stiffness, moisture content, size content, styrene solubility, etc.) to check the quality and uniformity of an approved glass fibre. In the Research and Development Department more tests are carried out, especially during the approval process. The bulk density test simulates the fibre compaction, also the process performance such as filamentation and electrostatic charging can be observed during the high speed chopping test. The values optioned for these tests provide important figures for the HOBAS design calculations.

Already during the early stage of the product development long-term product assessments such as hydrostatic pressure tests and investigations to prove corrosion resistance are being started. Only if values are satisfying and meet relevant normative requirements the glass fiber type is approved for the HOBAS process. This procedure allows that only reinforcing products are used which have been assessed for the long-term product application.

Resins

Very detailed specifications have been developed for the unsaturated polyester and vinyl ester resins intended for use in pipe production by centrifugal casting in order to ensure the process ability (reaction times, peak exotherm, viscosity and solid matter content), the compound performance (elastic modulus, tensile and flexural strength/strain, glass transition temperature and temperature stability) and the service performance (chemical resistance, heat deflection temperature, molecular weight, acid number) of the pipe during its life cycle.

Reinforcing filler materials and aggregates

Generally it is possible by the HOBAS Manufacturing Technology to mix unsaturated polyesters with various reinforcing fillers and aggregates from natural or synthetic origin. These also so called active fillers are used to achieve certain mechanical (stiffness, compressive strength) and service properties (chemical resistance, UV light resistance, fire resistance, etc.) and do not adversely influence the process and product performance.

Sealing material

Filling the gap between the pipe and joint requires a material which can be compressed to ensure durable tightness of the pipeline, even if there is relative movement between the pipe and the joint.

The material must have a high water and chemical resistance and shall be thermally stable. For that purpose EPDM (ethylene propylene diene monomer) or NBR (nitrile butadiene) rubber are the perfect choice. Their excellent ability to restore their shape after having been compressed and their good chemical resistance make them ideal sealing elastomers and used in a large number of applications.

The rubber materials used for HOBAS CC-GRP Pipe System must be approved according to EN 681-1 and various potable water requirements. The material is specified in detail and is tested at regular intervals by HOBAS Quality Control and at external accredited institutes.

HOBAS® CC-GRP Pipe Systems

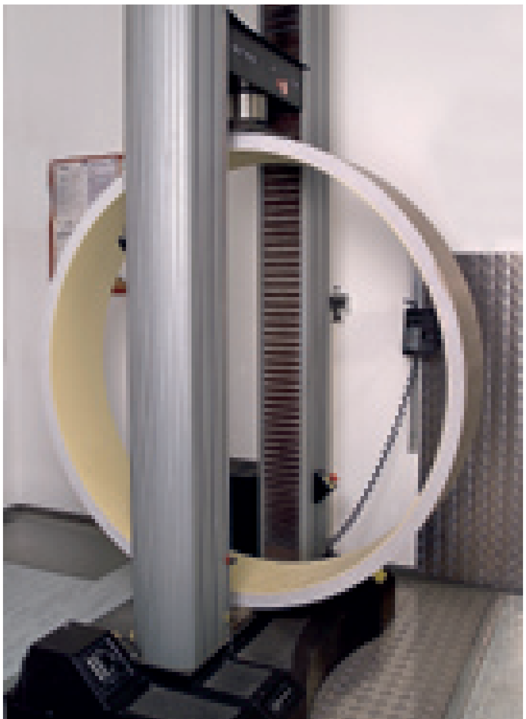
Quality Assurance of Pipe Systems

In addition to the raw material and process control tests, every finished product has to be checked if it meets the dimensional requirements calculated in the HOBAS® Design. The raw material consumption is observed for each pipe and any unacceptable deviation can be detected during the manufacturing process. Additionally to the 100% product control the finished products are sampled and mechanically tested according to a systematic, statistically based scheme.

Pipe Stiffness

The method for the stiffness test is defined in e.g. ISO 7685 and EN 1228. A ring of 300 mm length is cut from a pipe sampled from the batch of pipes being checked. The specimen is loaded to compress it diametrically to a defined deflection and the resulting load is determined. The stiffness is calculated from geometry, load and deflection. The initial specific ring stiffness must not be less than the designated nominal stiffness (SN) of the pipe batch.

Fig. 44: **Ring deflection test**



Initial Ring Deflection

The test method for initial ring deflection is defined e.g. in the ISO 10466 and EN 1226. The pipe ring previously used for the ring stiffness is deformed to specified levels **(see table 17)** and must not show any signs of failure to a certain level.

Table 17: **Deformation Levels**

SN	Level A	Level B
2500	14,3	23,9
5000	11,3	18,9
10000	9,0	15,0
12500	8,4	14,0
15000	7,9	13,1
16000	7,7	12,9
20000	7,1	11,9

Table	Minimum test deflection (%) calculated according to ISO and EN standards
Level A	No visible damage to inside layer at specified deflection
Level B	No structural damage at specified deflection

For intermediate stiffness values, the deflection levels can be calculated:

$$\text{Level A} = \frac{194}{\sqrt[3]{S_0}} \qquad \text{(Eqn. 2.15)}$$

$$\text{Level B} = \frac{324}{\sqrt[3]{S_0}} \qquad \text{(Eqn. 2.16)}$$

Failure Pressure – Initial Circumferential Tensile Strength (Pressure pipes only)
The test procedure is specified in e.g. ISO 8521 and EN 1394. When subjected to short-term hydrostatic pressure, the pipe must satisfy the minimum burst/hoop tensile strength required by relevant product standards (EN 1796, EN 14364, ISO 10639, ISO 10467, DIN 16869). These requirements are based on statistical safety factors after an operational lifetime of at least 50 years and long-term failure pressure regression analysis to assess the time dependent mechanical strength properties of CC-GRP Pipe Systems.

Longitudinal Tensile Strength
Longitudinal tensile strength is monitored in specified intervals. The tests are defined in ISO 8513 and EN 1393 and values must meet the requirements of the relevant product standards.

Surface qualities
The external surface of the pipe shall be smooth and free of exposed fibre projections and indentations so that a gasket can effectively seal anywhere on the pipe surface.

The internal surface of the pipe shall be smooth and free of exposed glass fibres and having resin hardness not less than the manufacture's minimum specification.

Fig. 45:
TÜV Süd Octagon

Additional Requirements – The TÜV Octagon
The product standards for pipes – ISO 10639, ISO 10467, EN 1796 and EN 14364 – state the requirements for GRP (glass reinforced unsaturated polyester resins) irrespective of the manufacturing process used (e.g. centrifugal casting or filament winding). However, to define the product properties in more detail, a special quality specification for centrifugally cast GRP pipes was subsequently introduced. The requirements in this quality specification do not contradict the minimum ones given in the latest versions of the ISO and EN pipe system standards but define requirements over and above them for ensuring a high level of quality.

Application
This quality specification shall apply to centrifugally cast GRP pipe systems that meet the basic requirements of ISO 10639, ISO 10467 EN 1796 and EN 14364. It cannot be applied to GRP pipe systems that do not comply with ISO 10639, ISO 10467 EN 1796 and EN 14364.
The requirements of this quality specification provide the basis for the TÜV quality mark MUC-KSP-A 2000 (for pipes) and MUC-KSP-A 2100 (for fittings).

Mechanical testing
Beside the mechanical short and long-term tests required by the product standards following tests are specified in the TÜV Work Instruction:
- Fire resistance performance
- Cyclic resistance to internal pressure for pressure pipes 1 million pressure cycles according to ISO 15306
- Chemical resistance for sewer pipes (The chemical resistance shall be tested according to the requirements of ISO 10467 and EN 14364 using the strain corrosion test with sulphuric acid (pH < 0.5) and a sodium hydroxide solution (pH $= 10 \pm 0.5$) to EN 1120.)
- Abrasion resistance for sewer pipes on the basis of DIN 19565
- Axial compressive strength test procedure (for jacking pipes and pipes used for manholes)

Internal and third-party quality control

To ensure controlled, consistent quality in fabrication, the scope of testing and inspection described in the HOBAS product documentation shall be observed in internal and third-party quality control. Within the scope of annual third-party quality control the above tests and inspections are carried out by means of random sampling.

Qualification of personnel applying the laminate

To ensure the high level of quality, employees working on relevant parts and pressure fittings must furnish proof of their qualifications in form of a certificate as per DVS 2220. The DVS is a technical-scientific non-profit-making society with its headquarters in Düsseldorf/Germany promoting welding and allied processes for the benefit of the general public. It sets standards for research and development, training, certification, quality assurance, advice and assessment, standardisation, safety at work and health. The technical standard DVS 2220 contains basic knowledge of thermo sets – especially GRP. Employees certified as per DVS 2220 are qualified in manipulation of GRP laminated and glued connections. Alternatively qualification certificates as per similar standards or codes are also accepted.

Branding and Marking

All products are branded with a serial number (enabling product traceability even after many years of services), the nominal diameter, series, pressure and stiffness class as well as specific quality marks relating to approvals by various associations and third party certifications (DVGW, SVGW, ÖVGW, GRIS, KIWA, TÜV, CSTB, etc.).

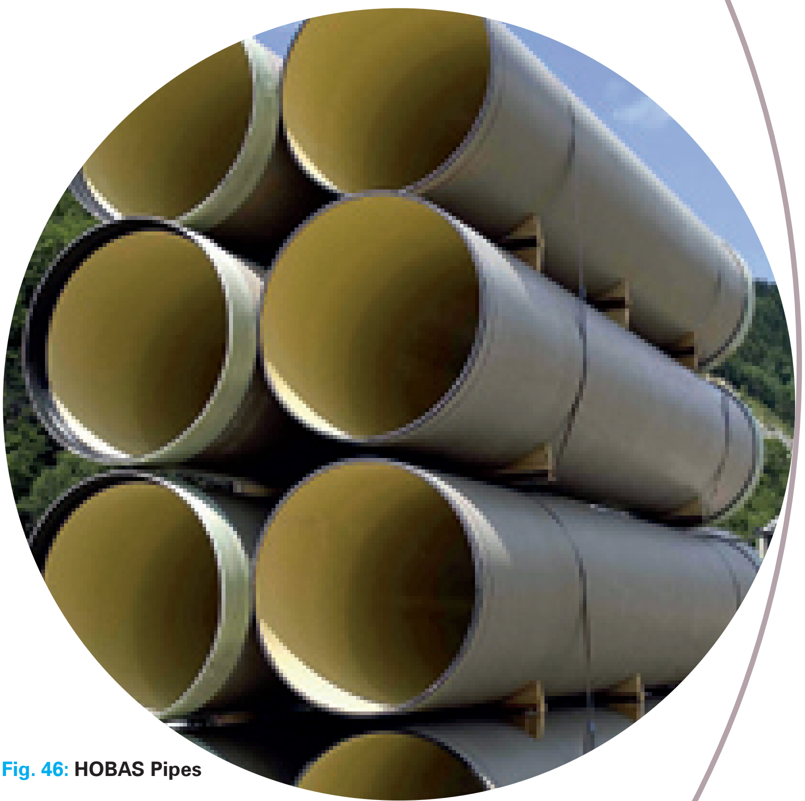


Fig. 46: **HOBAS Pipes**

Environmental Care

HOBAS is committed to continual improvement of environmental performance. Our Group Environmental Policy is defined in accordance with the international ISO 14001 standard. HOBAS focuses on continuous improvement, year by year. This includes cost and energy efficient management of raw materials and of production processes as to minimize consumption of resources and environmental impact.

Environmental Care is a part of our corporate social responsibility and represents a global expression of our continuous efforts to advance our environmental stance.

ISO 14001 is the most acknowledged international standard that enables a strategic approach to our environmental policy, plans and actions. Operating according to the ISO 14001 requirements brings the following benefits:

- Answer clients requests regarding environmental compliance;
- Be up to date with increasingly stringent legislation;
- Enhance existing environment protection measures (i.e. energy, air, water and waste management);
- Increase suppliers and employees environmental awareness

Fig. 47: Selection of ISO 14001 Certificates

Environmental Care throughout the Product Life Cycle
For more than 50 years the name HOBAS has been synonymous with centrifugally cast CC-GRP Pipe Systems. The centrifugal casting process generates a product with unique features, answering clients' requests around the world for innovative solutions for water and wastewater pipelines.

Environmental protection is embedded in the production process, pipe transportation, and installation and use phases as well as in everyday life of HOBAS Employees. HOBAS makes sure that not a drop of valuable potable water is lost and not a square meter of soil is contaminated with sewage water.

Pipe Design and Selection of Raw Materials
HOBAS Pipes are designed for a multitude of applications and installation methods. The pipe system design is based on client specifications integrated with environmental protection and a sophisticated, certified quality system. For instance, four different types of long term tests are undergone to assess performance for an operational service life of more than 50 years.

Raw materials are carefully chosen and undertake stringent quality control. HOBAS Pipes' main ingredients are Glass Fiber, Polyester Resin, Sand, Filler and Additives. Sand and Calcium Carbonate are environmentally neutral.

In addition, preference is given to recycled materials in the choice of raw materals if of equal or greater performance. For instance the use or resins based on recycled PET has been tested and approved.

Fig. 48: Raw materials

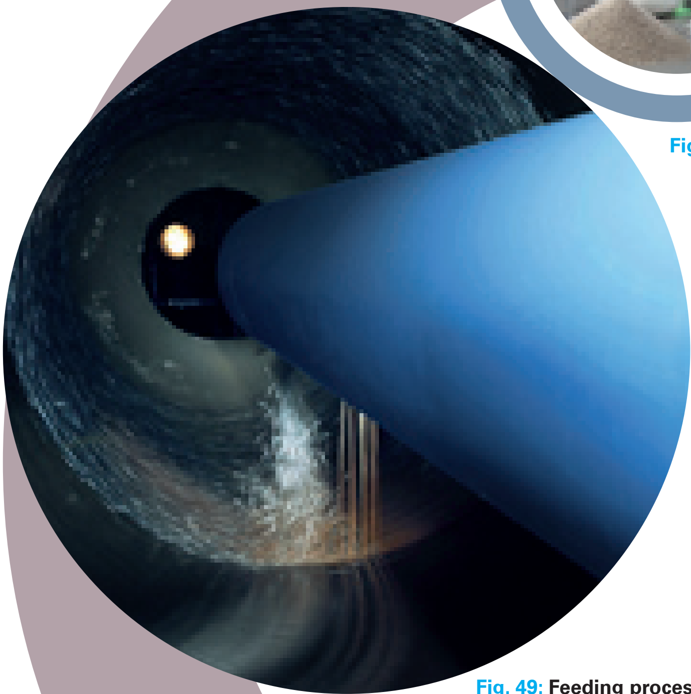


Fig. 49: Feeding process

Fig. 50: **Light-weight Pipes**

Production Process
Through the centrifugal casting process, the raw materials are fed into a rotating mold. Special attention is given to minimizing resource consumption and to reducing waste. For example, the electronic programming instructs the feeder arm exactly how much material should be released at different production stages. In addition, much of the energy used in the production process is recuperated and reused. Process improvement aims to enhance production according to desired specifications and in line with environmental care. A pipe comes out of the machine with perfect roundness, constant wall thickness and a completely smooth outer and inner surface.

Pipe Transport and Installation
HOBAS Pipes have a standard length of 6 meters and a reduced outer diameter in relation to the inner diameter as compared to other materials such as concrete or iron. In addition, HOBAS Pipes are lighter and, as a result, smaller pipes can be nested inside bigger ones during transport thus resulting in reduced transportation costs and less CO_2 generation.

With its ideal inner/outer diameter ratio, HOBAS Pipes can be installed with narrower trench widths, using less bedding material and less backfilling, thus resulting in less material movement. Furthermore, less storage space, less use of heavy machinery and easier handling enables faster construction while reducing costs.

The smooth outer diameter of HOBAS Pipe Systems allows trenchless installation methods such as Jacking. The power consumption during the jacking process is reduced due to the smooth surface and the lower pipe weight since less jacking forces are needed as compared to other materials.

These advantages result in not only reduced installation costs but also in a cleaner and more environmentally friendly installation site. Furthermore, HOBAS CC-GRP Pipe Systems show excellent resistance to UV light and are therefore widely chosen for above ground installations.

Operation Phase

The operational service life of more than 50 years and the absence of corrosion and abrasion reduce maintenance costs with HOBAS CC-GRP Pipes Systems to a minimum. The smooth inner surface and greater internal diameter as compared to other materials provide HOBAS Pipes with a significantly lower roughness coefficient and superior flow characteristics. As a result, less energy is needed to pump the water through the pipe system throughout its life time. This is not only a cost reduction advantage but also minimizes resources consumption and lowers CO_2 generation for decades of product use. In case of Relining, when new pipes are inserted into an old corroded pipeline, similar or even superior flow characteristics can be obtained even though the HOBAS Pipe diameter is smaller than that of the older pipe.

An installed HOBAS CC-GRP Pipe System is well integrated and has a neutral impact on the surrounding environment while preserving its functional quality.

Recycling

Finding ways to efficiently reuse pipe waste-material represents a key concern for HOBAS. Today recycling thermosetting plastics mainly consists of energetic recycling. At HOBAS, GRP waste is shredded and – as one way to reuse it – transported to cement plants where it is energetically recycled in a furnace, thus replacing fossil fuels (coal).

As use of fiber reinforced plastics e.g. in automotive, aviation, windmill and pipe industry results in continuously growing composite waste, the GRP industry as a whole is driven to find cost-effective and sustainable alternatives of recycling. HOBAS is naturally part of this commitment.

Fig. 51: Pipe integrated in surrounding environment

Annex

14. Chemical Resistance Guideline

Maximum Recommended or Tested Temperatures, °C

The numbers in the columns of “structural wall”, ”inner surface“ and “elastomer” state the maximum temperature up to which the corresponding part of the HOBAS CC-GRP Pipe System is resistant relating to the chemical effluent described in the first column.

Special resin pipes according to media analyses for special applications are available on request. For media where nothing is indicated, HOBAS engineers will carry out individual research according to your specifications in order to check the resistance of HOBAS® CC-GRP Pipe Systems. Where critical effluents, especially mixtures, are used, the suitability of raw materials will be checked separately.

Values stated for elastomer resistance to chemicals are according to ISO/TR 7620 and to DIN EN 12115/appendix. The chemical resistance tests were mainly performed at room temperature. Therefore applications at temperatures > 35°C must be checked separately.

Abbreviations

EPDM	Ethylene propylene diene monomers
NBR	Nitrile butadiene rubbers
NR	Not recommended
R	Recommended
Sat	Saturated
Information regarding empty fields is available on request	

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Brines (inorganic salt solutions – non oxidizing)	Sat	45	80	40	80	70	70
Hot Air + Hot Moisture	100	50	80	40	80	110	80
Potable Water	100	45	80	30	80	100	
Raw Water	100	45	80	35	80	100	80
Domestic wastewater	100	35	80	35	70	70	80
Sea Water, Brakish Water	100	50	80	40	80	100	80
Thermal Spring Water, Spa	100	45	80	30	80	100	80
Acetaldehyde	100	NR	NR		NR	R	NR
Acetic Acid	0–25	NR	100		100	NR	NR
Acetic Acid	25–50	NR	80		80	NR	NR
Acetic Acid	50–75	NR	60		60	R	
Acetic Acid, Glacial	100	NR	NR		NR	R	NR
Acetone	10	NR	80		80	R	NR
Acetone	100	NR	NR		NR	R	NR
Acetonitrile	100	NR	NR		NR	NR	NR
Acetophenone	100	NR	NR		NR	R	NR
Acetyl Chloride	ALL	NR	NR		NR	NR	NR
Acrylic Acid	0–25		40		40	R	
Acrylic Latex	ALL		50		50		
Acrylonitrile	100	NR	NR		NR	NR	NR
Alkyl Benzene Sulfonic Acid	92		50		50	NR	NR
Allyl Alcohol	100	NR	NR		NR	NR	R
Allyl Cloride	ALL	NR	NR		NR		
Alpha Methyl Styrene	100	NR	NR		NR	NR	NR
Alpha Olefin Sulfates	100		50		50		
Alum	ALL		100		100		
Aluminum Chloride	ALL	40	100	30	100	R	R
Aluminum Chlorohydrate	ALL		100		100		
Aluminum Citrate	ALL		100		100		
Aliminum Fluoride	ALL	NR	27		27	R	R
Aluminum Hydroxide	ALL		80		80		
Aluminum Nitrate	ALL		80		80	R	R
Aluminum Potassium Sulfate	ALL		100		100	R	R
Aluminum Sulfate	ALL	40	100	30	100	R	R
Amino Acids	ALL		40		40		
Ammonia, Liquified	ALL	NR	NR		NR	R	R
Ammonia, Aqueous (see Ammonium Hydroxide)							
Ammonia (Dry Gas hot)	ALL	NR	40		40	NR	NR
Ammonia (Dry Gas cold)	ALL					R	R
Ammonium Acetate	65		40		40	R	R
Ammonium Benzoate	ALL		80		80		
Ammonium Bicarbonate	ALL		70		70	NR	NR
Ammonium Bisulfite (Black Liquor)			80		80		
Ammonium Bromate	40		70		70		
Ammonium Bromide	40		70		70	R	R
Ammonium Carbonate	ALL		65		65	R	R
Ammonium Chloride	ALL	40	100	30	100	R	R
Ammonium Citrate	ALL		70		70		
Ammonium Fluoride	ALL		65		65		

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Ammonium Hydroxide	1	NR	90		90	R	R
Ammonium Hydroxide	5	NR	80		80	R	
Ammonium Hydroxide	10	NR	65		65	R	
Ammonium Hydroxide	20	NR	65		65	R	
Ammonium Hydroxide	29	NR	40		40	R	
Ammonium Lauryl Sulfate	30		50		50		
Ammonium Ligno Sulfonate	50		70		70		
Ammonium Nitrate	ALL		90		90	R	R
Ammonium Persulfate	ALL		80		80	R	NR
Ammonium Phosphate (Mono or Di Basic)	ALL		100		100	R	R
Ammonium Sulfate	ALL	25	100	20	100	R	R
Ammonium Sulfide (Bisulfide)	ALL		50		50	R	R
Ammonium Sulfite	ALL		65		65		
Ammonium Thiocyanate	20		100		100		
Ammonium Thiocyanate	50		45		45		
Ammonium Thiosulfate	60		40		40		
Amyl Acetate	ALL	NR	NR		NR	R	NR
Amyl Alcohol (Vapor)			65		65		
Amyl Alcohol	ALL	NR	50		50	R	R
Amyl Chloride	ALL		50		50	NR	NR
Aniline	ALL	NR	NR		NR	R	NR
Aniline Hydrochloride	ALL		80		80	NR	NR
Aniline Sulfate	Sat		100		100		
Aqua Regia (3:1 HCl-HNO3)	ALL	NR	NR		NR	NR	NR
Arsenic Acid	80		45		45	R	R
Arsenious Acid	20		80		80	R	
Barium Acetate	ALL		80		80		
Barium Bromide	ALL		100		100		
Barium Carbonate	ALL	NR	100		100		
Barium Chloride	ALL	40	100	30	100	R	R
Barium Cyanide	ALL		65		65		
Barium Hydroxide	ALL		65		65	R	R
Barium Sulfate	ALL		80		80	R	R
Barium Sulfide	ALL		80		80	R	R
Beer			50		50	R	R
Beet Sugar Liquor	ALL		80		80	R	R
Benzaldehyde	100	NR	NR		NR	R	NR
Benzene	100	NR	NR		NR	NR	NR
Benzene, HCl (wet)	ALL	NR	NR		NR	NR	
Benzene Sulfonic Acid	30		100		100	NR	NR
Benzene (Vapor)	ALL	NR	NR		NR	NR	
Benzoic Acid	ALL	25	100	20	100	NR	R
Benzoquinones	ALL		65		65		
Benzyl Alcohol	ALL		NR		NR	R	NR
Benzyl Chloride	ALL		NR		NR	NR	NR
Black Liquor (pulp mill)	ALL		80		80		
Bleach Solutions:							
Calcium Hypochlorite	ALL		80		80	NR	
Chlorine Dioxide		NR	70		70	NR	

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Chlorine Water	ALL	NR	80		80	NR	
Chlorite	50		40		40		
Hydrosulfite			80		80		
Sodium Hypochlorite	0–15	NR	50		50	NR	
Borax	ALL		100		100	R	R
Boric Acid	ALL	40	100	30	100	R	R
Brake Fluid			45		45	R	NR
Bromine	Liquid	NR	NR		NR	NR	NR
Bromine Water	5		80		80	NR	NR
Brown Stock (pulp mill)			80		80		
Bunker C Fuel Oil	100	25	100	20	100	NR	R
Butanol	ALL		50		50	R	R
Butyl Acetate	100	NR	NR		NR		NR
Butyl Acrylate	100	NR	NR		NR	NR	NR
Butyl Amine	ALL	NR	NR		NR	NR	NR
Butyl Benzoate	100					R	
Butyl Benzyl Phthalate	100		80		80		
Butyl Carbitol	100		40		40	R	
Butyl Cellosolve	100		40		40	R	NR
Butylene Glycol	100		70		70		
Butylene Oxide	100	NR	NR		NR		
Butyraldehyde	100	NR	NR		NR		NR
Butyric Acid	50	NR	100		100		NR
Butyric Acid	85	NR	27		27		NR
Cadmium Chloride	ALL		80		80	R	R
Calcium Bisulfite	ALL		80		80	NR	NR
Calcium Bromide	ALL		90		90		
Calcium Carbonate	ALL		80		80		
Calcium Chlorate	ALL	40	100	30	100		
Calcium Chloride	Sat	40	100	30	100	R	R
Calcium Hydroxide	ALL	NR	80		80	R	R
Calcium Hypochlorite	ALL	NR	80		80	R	NR
Calcium Nitrate	ALL		100		100	R	R
Calcium Sulfate	ALL		100		100		
Calcium Sulfite	ALL		80		80	R	R
Cane Sugar Liquor/Sweet Water	ALL		80		80	R	R
Capric Acid	ALL		80		80		
Caprylic Acid (Octanoic Acid)	ALL		80		80		
Carbon Disulfide	100	NR	NR		NR	NR	NR
Carbon Tetrachloride	100	NR	40		40	NR	NR
Carbowax	100		40		40		
Carbowax Polyethylene Glycols	ALL		65		65		
Carboxyethyl Cellulose	10		65		65		
Carboxymethyl Cellulose	ALL		65		65		
Castor Oil	ALL		70		70	R	R
Chlorinated Pulp			80		80		
Chlorination Washer Hoods/Ducts			80		80		
Chlorinated Waxes	ALL		80		80		
Chlorine (liquid)	100	NR	NR		NR	NR	NR
Chlorine Dioxide			70		70	NR	NR
Chlorine Gas (wet or dry)		NR	100		100	NR	NR

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Chlorine Water	ALL		80		80	NR	NR
Chloroacetic Acid	25	NR				R	NR
Chloroacetic Acid	100	NR	NR		NR	R	
Chlorobenzene	100	NR	NR		NR	NR	NR
Chloroform	100	NR	NR		NR	NR	NR
Chloropyridine	100	NR	NR		NR		
Chlorosulfonic Acid	ALL	NR	NR		NR	NR	NR
Chlorotoluene	100	NR	NR		NR	NR	NR
Chrome Plating Solution			50		50	NR	NR
Chromic Acid	5	NR	45		45		
Chromic Acid	20	NR	NR		NR	NR	NR
Chromium Sulfate	ALL		65		65		
Chromous Sulfate	ALL		80		80		
Citric Acid	ALL	25	100	20	100	R	
Cobalt Chloride	ALL		80		80	R	R
Cobalt Citrate	ALL		80		80		
Cobalt Naphthenate	ALL		65		65		
Cobalt Nitrate	15		50		50		
Cobalt Octoate	ALL		65		65		
Coconut Oil	ALL		80		80	NR	R
Copper Acetate	ALL		100		100	R	R
Copper Chloride	ALL	40	100	30	100	R	R
Copper Cyanide	ALL	25	100	20	100	R	R
Copper Fluoride	ALL		100		100		
Copper Nitrate	ALL		100		100		
Copper Sulfate	ALL	40	100	30	100	R	R
Corn Oil	ALL		90		90	NR	R
Corn Starch	ALL		100		100		
Corn Sugar	ALL		100		100		
Cottonseed Oil	ALL		100		100	NR	R
Cresylic Acids	ALL	NR	NR		NR	NR	
Crude Oil, Sour or Sweet	100	30	100	25	100		
Cyclohexane	100		50		50	NR	R
Cyclohexanone	100	NR	NR		NR	NR	NR
Decanol	100		50		50	R	NR
Dechlorinated Brine Storage	ALL		80		80		
Deionized Water		35	90	25	90	R	R
Demineralized Water		35	90	25	90	R	R
Detergents, Organic	100		70		70		
Detergents, Sulfonated	ALL		90		90	R	R
Diallylphthalate	ALL		80		80		
Diammonium Phosphate	65		100		100		
Dibromophenol		NR	NR		NR		
Dibromopropanol	ALL	NR	NR		NR		
Dibutyl Ether	100		40		40	NR	NR
Dibutylphthalate	100	25	80	20	80	R	NR
Dibutyl Sebacate	ALL		90		90	R	NR
Dichlorobenzene	100	NR	NR		NR	NR	NR
Dichloroethane	100	NR	NR		NR		
Dichloroethylene	100	NR	NR		NR		NR
Dichloromethane (Methylene Chloride)	100	NR	NR		NR	NR	NR

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Dichloropropane	100	NR	NR		NR		
Dichloropropene	100	NR	NR		NR		
Dichloropropionic Acid	100	NR	NR		NR		
Diesel Fuel	ALL	25	80	20	80	NR	R
Diethanolamine	100		27		27		
Diethyl Amine	100	NR	NR		NR	NR	NR
Diethyl Ether (Ethyl Ether)	100	NR	NR		NR	NR	NR
Diethyl Formamide	100	NR	NR		NR		
Dietyl Ketone	100	NR	NR		NR	R	NR
Diethyl Maleate	100	NR	NR		NR		
Di 2-Ethyl Hexyl Phosphate	100						
Diethylenetriamine (DETA)	100	NR	NR		NR		
Diethylene Glycol	100	40	90	30	90	R	R
Diisobutyl Ketone	100	NR	NR		NR	R	NR
Diisobutyl Phthalate	100		50		50		
Diisobutylene	100					NR	
Diisopropanolamine	100		45		45		
Dimethyl Formamide	100	NR	NR		NR	NR	NR
Dimethyl Phthalate	100	25	65	20	65	R	NR
Dioctyl Phthalate	100		80		80	R	NR
Dioxane	100	NR	NR		NR	R	NR
Diphenyl Ether	100		27		27		
Dipiperazine Sulfate Solution	ALL					NR	NR
Dipropylene Glycol	ALL	40	90	30	90		
Distilled Water	100	35	90	25	90	R	
Divinyl Benzene	100	NR	NR		NR		
Embalming Fluid	ALL		45		45		
Epichlorohydrin	100		NR		NR	NR	NR
Epoxidized Soybean Oil	ALL		65		65		
Esters of Fatty Acids	100		80		80	NR	NR
Ethanolamine	100	NR	NR		NR	R	
Ethyl Acetate	100	NR	NR		NR	R	NR
Ethyl Acrylate	100	NR	NR		NR	NR	
Ethyl Alcohol (Ethanol)	10	25	50	20	50	R	R
Ethyl Alcohol (Ethanol)	50		40		40	R	R
Ethyl Alcohol (Ethanol)	95–100	NR	27		27		
Ethyl Benzene	100	NR	NR		NR	NR	NR
Ethyl Benzene/Benzene Blends	100	NR	NR		NR	NR	NR
Ethyl Bromide	100	NR	NR		NR		
Ethyl Chloride	100	NR	NR		NR		NR
Ethyl Ether (Diethyl Ether)	100	NR	NR		NR	NR	NR
Ethylene Chloride	100	NR	NR		NR	NR	NR
Ethylene Chloroformate	100		NR		NR		
Ethylene Chlorohydrin	100		40		40		NR
Ethylene Diamine	100	NR	NR		NR	R	
Ethylene Dibromide	ALL	NR	NR		NR		
Ethylene Dichloride	100	NR	NR		NR	NR	NR
Ethylene Glykol	ALL	40	90	30	90	R	R
Ethylene Glykol Monobutyl Ether	100		40		40	R	R
Ethylene Diamine Tetra Acetic Acid	100		40		40	R	
Ethylene Oxide	100	NR	NR		NR	R	NR

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Eucalyptus Oil	100		60		60		
Fatty Acids	ALL	25	100		100	R	R
Ferric Acetate	ALL		80		80		
Ferric Chloride	ALL	40	100	30	100	R	R
Ferric Nitrate	ALL	30	100	25	100	R	R
Ferric Sulfate	ALL	40	100	30	100	R	R
Ferrous Chloride	ALL	30	100	25	100	R	R
Ferrous Nitrate	ALL	30	100	25	100	R	R
Ferrous Sulfate	ALL	40	100	30	100	R	R
Fertilizer, 8,8,8			50		50		
Fertilizer, URAN			50		50		
Fluoboric Acid	10		100		100	R	R
Fluoride Salts & HCl	30:10		50		50		
Fluosilicic Acid	10		65		65	R	NR
Fluosilicic Acid	35		40		40		
Fluosilicic Acid	Fumes		80		80		
Formaldehyde	25–56		65		65	R	R
Formic Acid	10	NR	80		80	R	NR
Formic Acid	50	NR	40		40	R	NR
Freon 11	100					NR	R
Fuel Oil	100	25	100	20	100	NR	R
Furfural	10		40		40		NR
Furfural	50–100	NR	NR		NR		
Gallic Acid	Sat		40		40	NR	NR
Gasoline, Regular Leaded	100	25	45	20	45		
Gasoline, Regular Unleaded	100	25	27	20	27	NR	R
Gasoline, Alcohol Containing	100					NR	
Gluconic Acid	50		80		80		
Glucose	ALL		100		100	R	R
Glutaric Acid	50		50		50		
Glycerine	100		50		50	R	R
Glycolic Acid (Hydroxyacetic Acid)	10		80		80		
Glycolic Acid (Hydroxyacetic Acid)	35		60		60	R	R
Glycolic Acid (Hydroxyacetic Acid)	70		27		27		
Glyoxal	40		40		40		
Green Liquor (pulp mill)			80		80		
Heptane	100	25	90	20	90	NR	R
Hexane	100		65		65	NR	R
Hydraulic Fluid	100		65		65	NR	R
Hydrazine	100	NR	NR		NR	R	NR
Hydrobromic Acid	18		80		80	R	NR
Hydrobromic Acid	48		65		65	R	NR
Hydrochloric Acid	10	30	100	25	100	R	
Hydrochloric Acid	15	25	100	20	100	R	
Hydrochloric Acid	25		70		70		
Hydrochloric Acid cold	37	NR	45		45	R	NR
Hydrochloric Acid hot	37					NR	NR
Hydrochloric Acid & Organics		NR	NR		NR	NR	
Hydrocyanic Acid	10		80		80	R	NR
Hydrofluoric Acid	1		50		50		
Hydrofluoric Acid	10	NR	50		50		

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Hydrofluoric Acid	20	NR	40		40	NR	NR
Hydrofluosilicic Acid	10		65		65	NR	R
Hydrofluosilicic Acid	35		40		40	NR	R
Hydrogen Bromide, gas	ALL		80		80		
Hydrogen Chloride, dry gas	100		100		100		
Hydrogen Fluoride, gas	ALL		65		65		
Hydrogen Peroxide (storage)	5	NR	65		65	R	R
Hydrogen Peroxide (storage)	30	NR	40		40	R	R
Hydrogen Sulfide, gas	ALL	NR	100		100	R	NR
Hydriodic Acid	10		65		65		
Hypophosphorus Acid	50		50		50		
Iodine, Solid	ALL		65		65		
Isoamyl Alcohol	100		50		50		
Isobutyl Alcohol	ALL		50		50	R	R
Isodecanol	ALL		50		50		
Isononyl Alcohol	100						R
Isooctyl Adipate	100		50		50		
Isopropyl Alcohol	ALL	NR	50		50	R	R
Isopropyl Amine	ALL		40		40		
Isopropyl Myristate	ALL		90		90		
Isopropyl Palmitate	ALL		90		90		
Itaconic Acid	ALL		50		50		
Jet Fuel		20	80	NR	80		
Jojoba Oil	100		80		80		
Kerosene	100	NR	80		80	NR	R
Lactic Acid	ALL	25	100	20	100	R	R
Latex	ALL		50		50	NR	NR
Lauric Acid	ALL		100		100		
Lauryl Alcohol	100		65		65		
Lead Acetate	ALL	30	100	25	100	R	R
Lead Chloride	ALL		90		90	R	NR
Lead Nitrate	ALL		100		100	R	R
Levulinic Acid	ALL		100		100		
Lime Slurry	ALL		80		80		
Linseed Oil	ALL	40	100	30	100	NR	R
Lithium Bromide	ALL		100		100		
Lithium Chloride	ALL		100		100		
Lithium Sulfate	ALL		100		100		
Magnesium Bicarbonate	ALL		80		80		
Magnesium Bisulfite	ALL		80		80		
Magnesium Carbonate	15	25	80	20	80		
Magnesium Chloride	ALL	40	100	30	100	R	R
Magnesium Hydroxide	ALL		100		100	R	NR
Magnesium Nitrate	ALL	30	100	25	100		
Magnesium Sulfate	ALL	40	100	30	100	R	R
Maleic Acid	ALL		90		90	R	R
Maleic Anhydride	100		90		90	R	R
Manganese Chloride	ALL		100		100		
Manganese Sulfate	ALL		100		100		
Mercuric Chloride	ALL	40	100	30	100	R	R
Mercurous Chloride	ALL	40	100	30	100	R	R

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Mercury			100		100	R	R
Methyl Alcohol (Methanol)	100	NR	NR		NR	R	R
Methyl Ethyl Ketone	ALL	NR	NR		NR	R	NR
Methyl Isobuthyl Ketone	100	NR	NR		NR	R	NR
Methyl Methacrylate	ALL	NR	NR		NR	R	NR
Methyl Styrene	100	NR	NR		NR	NR	NR
Methylene Chloride	100	NR	NR		NR	NR	NR
Milk and Milk Products	ALL	25		20		R	R
Mineral Oils	100	30	100	25	100	NR	R
Molybdenum Disulfide	ALL		90		90		
Monochloroacetic Acid	80	NR	NR		NR		
Monochlorobenzene	100	NR	NR		NR	NR	NR
Monoethanolamine	100	NR	NR		NR		
Monomethylhydrazine	100	NR	NR		NR		
Morpholine	100	NR	NR		NR		
Motor Oil	100	30	100	25	100	NR	R
Myristic Acid	ALL		100		100		
Naphta, Aliphatic	100	NR	80		80	NR	
Naphtalene	ALL	30	80	25	80	NR	NR
Nickel Chloride	ALL	40	100	30	100	R	R
Nickel Nitrate	ALL	40	100	30	100		
Nickel Sulfate	ALL	40	100	30	100	R	R
Nitric Acid	2	NR	70		70		
Nitric Acid	5	NR	65		65		
Nitric Acid	15	NR	50		50	NR	NR
Nitric Acid	35	NR	40		40	NR	NR
Nitric Acid	50	NR	NR		NR	NR	NR
Nitrobenzene	100	NR	NR		NR	NR	NR
Nitrogen Tetroxide	100	NR	NR		NR	NR	NR
Octanic Acid (Caprylic Acid)	ALL		80		80		
Octylamine, Tertiary	100	30		25			
Oil, Sweet or Sour Crude	100	30	100	25	100		
Oleic Acid	ALL	40	100	30	100	R	R
Oleum (Fuming Sulfuric Acid)		NR	NR		NR	NR	NR
Olive Oil	100		100		100	NR	R
Orange Oil (limonene)	100		100		100		
Organic Detergents, pH < 12	ALL		70		70		
Oxalic Acid	100	NR	100		100	R	
Ozone (< 4 ppm in water phase)			27		27	R	NR
Palm Oil	100		100		100	NR	R
Palmitic Acid	100		100		100	R	R
Pentasodium Tripoly Phosphate	10		100		100		
Perchloroethylene	100		40		40	NR	NR
Perchloric Acid	10	NR	65		65		
Perchloric Acid	30	NR	40		40	NR	NR
Phenol (Carbolic Acid)	5		NR		NR	R	NR
Phenol (Carbolic Acid)	> 5	NR	NR		NR	R	NR
Phenol Formaldehyde Resin	ALL		40		40		
Phosphoric Acid	80	NR	100		100	R	
Phosphoric Acid Vapor & Condensate			100		100		
Phosphorous Trichloride		NR	NR		NR	NR	NR

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Phthalic Acid	100		100		100	R	R
Phthalic Anhydride	100	30	100	25	100	R	R
Plating Solutions, Cadmium Cyanide			80		80	R	R
Plating Solutions, Chrome			50		50	R	
Plating Solutions, Gold			40		40	R	R
Plating Solutions, Lead			80		80	R	R
Plating Solutions, Nickel			80		80	R	R
Plating Solutions, Platinum			80		80	R	R
Plating Solutions, Silver			80		80	R	R
Plating Solutions, Tin Fluoborate			90		90	R	R
Plating Solutions, Zinc Fluoborate			80		80	R	R
Polyphosphoric Acid			100		100		
Polyvinyl Acetate Emulsion	ALL		50		50	R	
Polyvinyl Alcohol	ALL		50		50		
Potassium Aluminum Sulfate	ALL		100		100	R	R
Potassium Bicarbonate	10	25	65	20	65		
Potassium Bicarbonate	50	25	60	20	60		
Potassium Bromide	ALL		100		100	R	R
Potassium Carbonate	10	NR	65		65	R	R
Potassium Carbonate	50		60		60	R	R
Potassium Chloride	ALL	40	100	30	100	R	R
Potassium Dichromate	ALL	25	100	20	100	R	R
Potassium Ferricyanide	ALL	40	100	30	100		
Potassium Ferrocyanide	ALL	40	100	30	100		
Potassium Hydroxide	10	NR	65		65	R	
Potassium Hydroxide	25		45		45	R	
Potassium Iodide	ALL					R	R
Potassium Nitrate	ALL	40	100	30	100	R	R
Potassium Permanganate	ALL	NR	100		100	R	NR
Potassium Persulfate	ALL		100		100	R	R
Potassium Sulfate	ALL	40	100	30	100	R	R
Propionic Acid	20		90		90		
Propionic Acid	50		80		80		
Propylene Glycol	ALL	40	100	30	100	R	R
Pyridine	100	NR	NR		NR	NR	NR
Salicylic Acid	ALL		60		60	R	R
Sea Water		50	100	40	100	R	R
Sebacic Acid	ALL		100		100		
Selenious Acid	ALL		100		100		
Silicic Acid (hydrated silica)	ALL		120		120		
Silver Cyanide	ALL		90		90	R	R
Silver Nitrate	ALL	NR	100		100	R	R
Sodium Acetate	ALL	40	100	30	100	R	R
Sodium Alkyl Aryl Sulfonates	ALL		80		80		
Sodium Aluminate	ALL		50		50	R	R
Sodium Benzoate	ALL		80		80		
Sodium Bicarbonate	ALL	30	80	25	80	R	R
Sodium Bifluoride	100		50		50		
Sodium Bisulfate	ALL	30	100	25	100	R	R
Sodium Borate	ALL		100		100	R	R
Sodium Bromide	ALL		100		100		

Chemical/Effluent	Conc./%	Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
		Standard Body UP	VE-Epoxy	Standard Liner UP	VE-Epoxy	EPDM	NBR
Sodium Carbonate (Soda Ash)	10	NR	80		80		
Sodium Carbonate (Soda Ash)	35	NR	70		70		
Sodium Chlorate	ALL		100		100	R	
Sodium Chloride	ALL		100		100	R	R
Sodium Chlorite	10		70		70	R	
Sodium Chlorite	50		40		40	R	
Sodium Chromate	50		100		100		
Sodium Cyanide	5	NR	100		100	R	R
Sodium Cyanide	15	NR				R	R
Sodium Dichromate	ALL		100		100		
Sodium Diphosphate	100		100		100		
Sodium Ethyl Xanthate	5		65		65		
Sodium Ferricyanide	ALL		100		100		
Sodium Ferrocyanide	ALL		100		100		
Sodium Fluoride	ALL		80		80		
Sodium Fluorosilicate	ALL		50		50		
Sodium Hexametaphosphate	10		65		65		
Sodium Hydrosulfide	20		70		70	R	R
Sodium Hydroxide	1	NR	65		65	R	
Sodium Hydroxide	5	NR	65		65	R	
Sodium Hydroxide	10	NR	65		65	R	
Sodium Hydroxide	25	NR	65		65	R	
Sodium Hydroxide	50	NR	90		90	R	
Sodium Hypochlorite	15	NR	50		50	R	
Sodium Hyposulfite	20		70		70		
Sodium Lauryl Sulfate	ALL		80		80		
Sodium Monophosphate	ALL		100		100	R	R
Sodium Nitrate	ALL	40	100	30	100	R	R
Sodium Nitrite	ALL		100		100		
Sodium Oxalate	ALL		80		80		
Sodium Persulfate	20		55		55		
Sodium Polyacrylate	ALL		65		65		
Sodium Silicate, pH < 12	100	NR	100		100	R	R
Sodium Silicate, pH > 12	100	NR	100		100	R	R
Sodium Sulfate	ALL	40	100	30	100	R	R
Sodium Sulfide	ALL	NR	100		100	R	R
Sodium Sulfite	ALL	NR	100		100		
Sodium Tetraborate	ALL		90		90		
Sodium Thiocyanate	57		80		80		
Sodium Thiosulfate	ALL		80		80		
Sodium Triphosphate	ALL		100		100		
Sorbitol	ALL		80		80		
Soybean Oil	ALL		100		100	NR	R
Stannic Chloride	ALL	40	100	30	100	R	R
Stannous Chloride	ALL	40	100	30	100	R	R
Stearic Acid	ALL	25	100	20	100	R	R
Styrene	100	NR	NR		NR	NR	NR
Styrene Acrylic Emulsion	ALL		50		50		
Styrene Butadiene Latex	ALL		50		50		
Succinonitrile, Aqueous	ALL		40		40		
Sucrose	ALL		100		100	R	R

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Sulfamic Acid	10		100		100		
Sulfamic Acid	25		65		65		
Sulfanilic Acid	ALL		100		100		
Sulfite/Sulfate Liquors (pulp mill)			90		90	NR	NR
Sulfonyl Chloride, Aromatic		NR	NR		NR	NR	NR
Sulfur Dichloride		NR	NR		NR		
Sulfuric Acid	0–25	25	100	20	100	R	NR
Sulfuric Acid	26–50	25	80	NR	80		
Sulfuric Acid	51–70	NR	80		80	R	NR
Sulfuric Acid	71–75	NR	50		50	NR	NR
Sulfuric Acid	76–93	NR	NR		NR	NR	NR
Sulfuric Acid	Fumes		100		100	NR	NR
Sulfuric Acid/Ferrous Sulfate	10/Sat'd		90		90		
Sulfuric Acid/Phosphoric Acid	10:20		80		80		
Sulfuryl Chloride	100	NR	NR		NR	NR	NR
Superphosphoric Acid (105%H_3PO_4)	100		100		100		
Tall Oil	ALL		65		65		
Tannic Acid	ALL	35	100	25	100	R	R
Tartaric Acid	ALL		100		100	NR	R
Tetrachloroethane	100	NR	NR		NR	NR	NR
Tetrachloroethylene	100		40		40	NR	NR
Tetrachloropentane	100	NR	NR		NR		
Tetrachloropyridine		NR	NR		NR		
Tetrapotassium Pyrophosphate	60		50		50		
Tetrasodium Ethylenediamine	ALL		60		60		
Tetracetic Acid Salts							
Tetrasodium Pyrophosphate	60		50		50		
Textone			90		90		
Thioglycolic Acid	10		40		40		
Thionyl Chloride	100	NR	NR		NR	NR	
Tobias Acid (2-Naphthylamine Sulfonic Acid)			100		100		
Toluene	100	NR	NR		NR	NR	NR
Toluene Diisocyanate (TDI)	100	NR	NR		NR	R	
Toluene Diisocyanate (TDI)	Fumes	NR	27		27		
Toluene Sulfonic Acid	ALL		100		100		
Transformer Oils	100		100		100	NR	R
Tributyl Phosphate	100					R	NR
Trichloroacetic Acid	50		100		100	NR	NR
Trichloroethane	100	NR				NR	NR
Trichloroethylene		NR	NR		NR	NR	NR
Trichloromonofluoromethane	ALL		27		27		
Trichlorophenol	100	NR	NR		NR		
Tridecylbenzene Sulfonate	ALL		100		100		
Triethanolamine	ALL					R	R
Triethylamine	ALL	NR				R	NR
Triethylene Glycol	100					R	R
Trimethylamine Chlorobromide		NR	NR		NR		
Trimethylamine Hydrochloride	ALL		55		55		
Triphenyl Phosphite	ALL	NR					
Trisodium Phosphate	50	NR	80		80		

		Structural Wall (Body Resin)/°C		Inner Surface (Liner Resin)/°C		Elastomer Gaskets/°C	
Chemical/Effluent	**Conc./%**	**Standard Body UP**	**VE-Epoxy**	**Standard Liner UP**	**VE-Epoxy**	**EPDM**	**NBR**
Turpentine			65		65	NR	R
Urea	30		65		65	R	
Vegetable Oils	ALL		100		100	NR	R
Vinegar	ALL		100		100	R	
Vinyl Acetate	ALL	NR	NR		NR	R	NR
Vinyl Toluene	100	NR	27		27		
Water, Deionized	ALL	45	90	30	90	R	R
Water, Destilled	ALL	40	100	30	100	R	R
Water, Sea	ALL	50	80	40	80	R	R
White Liquor (pulp mill)	ALL	NR	80		80		
Xylene	ALL	NR	NR		NR	NR	NR
Zinc Chlorate	ALL		100		100		
Zinc Chloride	ALL	40	100	30	100	R	R
Zinc Nitrate	ALL	40	100	30	100		
Zinc Sulfate	ALL	40	100	30	100	R	R
Zinc Sulfite	ALL		100		100		

15. Comparison of GRP Pipe Standards

Introduction

This document contains a comparison of the requirements of important GRP pipe standards (product standards).

Standards

ASTM D3262	[Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe]
ASTM D3517	[Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe]
ASTM D3754	[Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe]
ASTM D2997	[Standard Specification for Centrifugally Cast "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe]
ISO 10467	[Plastics piping systems for pressure and non-pressure drainage and sewerage – Glass-reinforced plastics (GRP) systems based on unsaturated polyester (UP) resin]
ISO 10639	[Plastics piping systems for pressure and non-pressure water supply – Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin]
EN 1796	[Plastics piping systems for water supply with or without pressure – Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP)]
EN 14364	[Plastics piping systems for drainage and sewerage with or without pressure – Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP) – Specifications for pipes, fittings and joints]
DIN 16869-2	[Centrifugally cast filled glass fibre reinforced unsaturated polyester resin (UP-GF) pipes]
DIN 19565-1	[Centrifugally cast and filled polyester resin glass fibre reinforced (UP-GF) pipes and fittings for buried drains and sewers – Dimensions and technical delivery conditions]

Abbreviations

CF	Creep factor (wet)
NR	No requirements
PN	Nominal pressure class
R	Requirement mentioned in the standard
REG	According to long-term regression
SN	Nominal stiffness
S_0	Initial specific ring stiffness
Table	Values tabled (mainly depending on diameter and pressure class)
TS	Test standard (relevant test method)
Y_{0A}	Deflection level for liner cracks
Y_{0B}	Deflection level for structural failure
Tightness	Leak tightness test

Comparison of Pipe Standards

See table

16. Abbreviations

Abbreviation list

In this HOBAS® document abbreviations are generally explained as they occur. Additional repeated abbreviations are listed below.

Symbol	Common Unit	Meaning
a	mm	Abrasion
d_e	mm, m	External pipe diameter
d_i	mm, m	Internal pipe diameter
d_m	mm, m	Mean pipe diameter [$d_e - e$]
d_v	mm	Vertical deflection
d_v/d_m	%	Vertical deflection
E, E_t	N/m²	Apparent flexural moduli of pipe wall
e	mm	Pipe wall thickness
e_L	mm	Liner thickness
F	N	Load
F_{SD}, FS	–	Design safety factor
f	–	Deflection coefficient for ovality of the deformed specimen
g	m/s²	Acceleration due to gravity
H	m	Head loss
HDB, HDB_{50}	bar	50 years failure pressure
I	m⁴/m	Second moment of inertia per unit length (of a pipe)
k	mm	Roughness coefficient
l	m	Length
P, p, p_w	bar	Internal/operating pressure
PDB	bar	Pressure design basis
PN	bar	Nominal pressure
Q	l/s	Discharge flow
q_c	MPa	Critical buckling pressure
R_e	–	Reynold's number
r_m	m	Mean pipe radius
r	–	Rerounding coefficient
S_0	N/m²	Initial pipe ring stiffness, relating to pipe diameter
S	N/m²	Specific ring stiffness
S_{50}, S_t	N/m²	Time-dependent pipe stiffness
S_R	N/mm²	Ring stiffness, relating to pipe radius
α	°	Bending angle (e.g. of fittings, couplings)
$\alpha_{(t)\ creep,\ wet}$	–	Wet creep factor
ε_b	%	Calculated flexural strain in pipe wall
ε_{50}	%	Long-term ultimate ring bending strain
λ	–	Colebrook White friction factor
μ	–	Poisson's ratio
ρ	kg/m³	Density
σ	MPa	strength
σ_{50}	MPa	Long-term strength

Parameter/Standard	ASTM D3262		ASTM D3517		ASTM D3754		ASTM D2997	
	R	TS	R	TS	R	TS	R	TS
Initial and long-term ring stiffness								
Initial specific ring stiffness	$S_0 \geq$ SN @ 5% deflect.	ASTM D2412	$S_0 \geq$ SN @ 5% deflect.	ASTM D2412	$S_0 \geq$ SN @ 5% deflect.	ASTM D2412	$S_0 \geq$ SN @ 5% deflect.	ASTM D2412
Long-term specific ring stiffness	NR	–	NR	–	NR	–	NR	–
Initial and long-term ring deflection								
Liner cracking Y_{0A} SN 2500 (~18 psi)	15%	ASTM D2412	15%	ASTM D2412	15%	ASTM D2412	NR	–
Liner cracking Y_{0A} SN 5000 (~36 psi)	12%		12%		12%			
Liner cracking Y_{0A} SN 10000 (~72 psi)	9%		9%		9%			
Structural failure Y_{0B} SN 2500 (~18 psi)	25%		25%		25%			
Structural failure Y_{0B} SN 5000 (~36 psi)	20%		20%		20%			
Structural failure Y_{0B} SN 10000 (~72 psi)	15%		15%		15%			
SN 2500 (~18 psi) 50-year Y_{50B}	NR	–	NR	–	NR	–	NR	–
SN 5000 (~36 psi) 50-year Y_{50B}								
SN 10000 (~72 psi) 50-year Y_{50B}								
Strength								
Beam Strength	Table	ASTM D3262	Table	ASTM D3517	Table	ASTM D3754	NR	–
Longitudinal tensile strength	Table	ASTM D638	Table	ASTM D638	Table	ASTM D638	Table	ASTM D2105
Longitudinal tensile strain at break (mean)	Min. 0.25%	ASTM D638	Min. 0.25%	ASTM D638	Min. 0.25%	ASTM D638	NR	–
Longitudinal tensile modulus	NR	–	NR	–	NR	–	Table	ASTM D2105
Longitudinal compressive strength	Table	ASTM D695	Table	ASTM D695	Table	ASTM D695	NR	–
Initial and long-term circumferential tensile strength (failure pressure)								
Initial failure pressure	NR	–	Table hoop tensile strength Leak tightness 2 x PN	ASTM D2992 (ASTM D1599)	Table hoop tensile strength Leak tightness 2 x PN	ASTM D2992 (ASTM D1599)	Table hoop tensile strength Leak tightness 2 x PN	ASTM D2992 (ASTM D1599)
Long-term failure pressure Safety factor	NR	–	1.8		1.8		HDP ASTM D2992	
Chemical resistance (strain corrosion)								
Chemical resistance	50-year strain 0.34–0.6%	ASTM D3681	NR	–	50-year strain 0.34–0.6%	ASTM D3681	NR	–
Abrasion resistance								
Abrasion resistance	NR	–	NR	–	NR	–	NR	–
Tightness of flexible joints								
Loading conditions	1xPN/ 10 min	ASTM D4161	1xPN/ 10 min	ASTM D4161	1xPN/ 10 min	ASTM D4161	NR	–
Shear load	17.5xDN /N		17.5xDN /N		17.5xDN /N			
Angular deflection DN ≤ 500 (~ 20")	3°		3°		3°			
Angular deflection 500 < DN ≤ 900 (~ 20"–36")	2°		2°		2°			
Angular deflection 900 < DN ≤ 1800 (~ 39"–75")	1°		1°		1°			
Angular deflection DN > 1800 (~ 75")	0.5°		0.5°		0.5°			
Negative pressure	–0.8 bar/ 10 min		–0.8 bar/ 10 min		–0.8 bar/ 10 min			

ISO 10467		ISO 10639		EN 1796		EN 14364		DIN 16869-2		DIN 19565-1	
R	TS	R	TS	R	TS	R	TS	R	TS	R	TS
$S_0 \geq SN$ @ 2.5–3.5% deflect.	ISO 7685	$S_0 \geq SN$ @ 2.5–3.5% deflect.	ISO 7685	$S_0 \geq SN$ @ 2.5–3.5% deflect.	EN 1228	$S_0 \geq SN$ @ 2.5–3.5% deflect.	EN 1228	$S_0 \geq SN$ @ 3% deflect.	DIN 53769	$S_0 \geq SN$ @ 3% deflect.	DIN 53769
NR	ISO 10468 ISO 14828	NR	ISO 10468 ISO 14828	NR	ISO 10468 ISO 14828	NR	ISO 10468 ISO 14828	Gravity, CF: 0.4 Press., CF: 0.5	DIN 53769	Gravity, CF: 0.4 Press., CF: 0.5	DIN 53769
14.3%	ISO 10466	14.3%	ISO 10466	14.3%	EN 1226	14.3%	EN 1226	15%	DIN 53769	15%	DIN 53769
11.3%		11.3%		11.3%		11.3%		12%		12%	
9%		9%		9%		9%		9%		9%	
23.9%		23.9%		23.9%		23.9%		25%		25%	
18.9%		18.9%		18.9%		18.9%		20%		20%	
15%		15%		15%		15%		15%		15%	
14.3%	ISO 10471	14.3%	ISO 10471	14.3%	ISO 10471	14.3%	ISO 10471	15%	DIN 53769	15%	DIN 53769
11.3%		11.3%		11.3%		11.3%		12%		12%	
9%		9%		9%		9%		9%		9%	
NR	–	NR	–	NR	–	NR	–	NR	–	NR	–
Table	ISO 8513	Table	ISO 8513	Table	EN 1393	Table	EN 1393	Table	DIN 53455	Table	DIN 53455
NR	–	NR	–	Min. 0.25%	EN 1393	Min. 0.25%	EN 1393	NR	–	NR	–
NR	–	NR	–	NR	–	NR	–	NR	–	NR	–
NR	–	NR	–	NR	–	NR	–	NR	–	NR	–
Acc. to REG	ISO 8521	Acc. to REG	ISO 8521	Acc. to REG	EN 1394	Acc. to REG	EN 1394	Burst min. 4 x PN and REG	DIN 53758	Burst min. 4 x PN and REG	DIN 53758
1.6–2.1	ISO 7509	1.6–2.1	ISO 7509	1.6–2.1	EN 1447	1.6–2.1	EN 1447	1.78–2.08 and REG	DIN 53769	1.9 for PN 6	DIN 53769
$Y_{0B50}=\frac{194}{\sqrt[3]{S_0}}$	ISO 10952	NR	–	NR	–	$Y_{0B50}=\frac{194}{\sqrt[3]{S_0}}$	ISO 10952 EN 1120	NR	–	Table	DIN 53769
NR	–	NR	–	NR	–	NR	–	NR	–	Barrier layer co-vered after 100000 cycles	DIN 19565 (Darm. rocker test)
2xPN/24 h	ISO 8639	2xPN/24 h	ISO 8639	2xPN/24 h	EN 1119	2xPN/24 h	EN 1119	2xPN/24 h	Guided by GKR 1.8 1/8	2xPN/24 h	Guided by GKR 1.8 1/8
20xDN /N		20xDN /N		20xDN /N		20xDN /N		20xDN /N		20xDN /N	
3°		3°		3°		3°		3°		3°	
2°		2°		2°		2°		2°		2°	
1°		1°		1°		1°		1°		1°	
0.5°		0.5°		0.5°		0.5°		0.5°		0.5°	
−0.8 bar/ 1 h		−0.8 bar/ 1 h		−0.8 bar/ 1 h		−0.8 bar/ 1 h		−0.8 bar/ 1 h		−0.8 bar/ 1 h	

HOBAS® Group Worldwide
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