CUSTOM-MADE PLASTIC PIPES AND FITTINGS PRODUCED FROM POLYETHYLENE MONOCOPOSITE OPEN NEW APPLICATIONS

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ABSTRACT

The use of plastic pipes is very common in many applications such as pressure less sewer pipes as well as pressure pipes up to a limited pressure level. This limit is naturally given by the moderate strength of plastic materials compared to metallic materials such as steel. Corrosion resistance and the high flexibility of polyethylene combined with fibre reinforcement give a synergy and open the way to new applications. Therefore custom-made multilayer pipe structures are state of the art products for high pressure applications.

An up-coming approach is to use self-reinforced high pressure pipes, which are known as monocomposites and consist to 100% of one material e.g. polyethylene. The secret of the monocomposite structure is an integrated layer of highly oriented polyethylene tapes. This allows operating pressures twice as high compared to common polyethylene pipes without losing the beneficial properties such as lightweight, easy weldability, high flexibility and corrosion resistance. The modular structure of PE 100-RC inner layer, reinforcing tape and weldable outer layer enables to design the pipe for different operation requirements such as point load resistance, increased pressure rates and elevated temperatures. The strength of the composite pipe can be varied in a wide range by the ratio of reinforcement.

New applications for the monocomposite high pressure PE pipe are high pressure gas or water pipes or industrial applications e.g. onshore pipelines or salt water applications. A whole system including welding couplers, mechanical transition pieces in connection to steel is approved by the third party inspection of TÜV Süd in Germany and several projects in Europe have proven the excellent handling benefits in practice and on the commercial point of view the capability of competing against traditional materials was reported. For this a technological and economical benchmark of plastic and steel pipeline systems for high pressure gas distribution networks done by KIWA Gastec proved this competitiveness by comparing realistic case studies.
Requirements on plastic pipes for high pressure application

Polyethylene pipes have been in service for over 50 years now. They are easy to handle because of their low weight and being very flexible they can be formed into coils which are highly convenient during installation work. The high ductility, resistance to corrosion and the easy and safe weldability allow long service lives of over 100 years [1, 2].

In order to aware polyethylene pipe systems for high pressure applications and markets some basic requirements need to be fulfilled:

- resistance to constant operating pressure for a reasonable time span e.g. 10, 25, 50 or even 100 years,
- in case of compressible fluids, a good resistance to Rapid Crack Propagation,
- fittings and connectors suitable for the required operating pressure rates to sustain all axial, hoop and bending stresses,
- economic worthwhile with regard to materials, installation, and maintenance costs,
- suitable for modern installation e.g. no-dig techniques.

General properties of self-reinforced PE pipes due to the monocomposite design

Compared to steel, the strength of polyethylene is low. Consequently, integrating materials with a higher strength e.g. polyester, aramide, or even steel fibres to reinforce the polyethylene pipe wall seems like an obvious solution. However, the strength of polyethylene pipe grades can also be increased by stretching, i.e. by specifically optimising the microstructure during processing. If such high-strength structures are used to reinforce a component of one and the same material, this is referred to as self-reinforcement or monocomposites. One advantage of monocomposites is that the strength of a component can be increased without impairing the other properties (see fig. 1).

The balanced proportion of properties has been maintained and accordingly users and planners are able to produce high-pressure polyethylene lines without noticing any changes in the familiar properties of PE 100 pipes. In addition, the remaining pieces can be recycled at any time in an environmentally compatible manner.
Monocomposite pipes produced by extrusion in accordance with the HexelOne® process are generally composed of three functional layers. The materials used for each layer are the well-established PE 100 and PE 100-RC grades that fulfill all the requirements of DIN EN 12201-1 and 1555-1 for drinking water and gas respectively [3, 4].

To reach a higher performance compared to standard PE100 pipes the monocomposite pipes incorporate a reinforcement layer made from highly oriented tapes of polyethylene, whereas the overall wall thickness equals that of the standard PE100 pipes. Due to the oriented structure the strength of PE 100 tapes can be increased to breaking strength > 250 MPa. This is because the micro-structure of the tapes is precisely optimised during processing by applying a combined stretching and heat treatment, resulting in a pure physical modification of the original PE 100 material. Following this procedure tailor-made high strength morphology can be realized [5, 6]. Finally these monooriented tapes can be used for reinforcement of PE100 pipes.

As previously mentioned the main advantage of this polyethylene monocomposite is that the consistent multilayer structure (integrating the reinforcement layer using stretched
polyethylene) does not impair any other positive properties, for example the good welding property, the low specific weight and the flexibility necessary to produce spoolable pipes.

![Monocomposite pipe structure](image)

**Fig. 2:** Monocomposite pipe structure

**Pressure rating of monocomposite high pressure pipes**

It is well known that the long-term pressure resistance of polyethylene (MRS = Minimum Required Strength) is the decisive dimensioning parameter according to which the required pipe measurements of a specified material such as PE 100 are determined and normatively fixed to satisfy stipulated operating conditions (pressure, temperature and time) [7, 8]. The method applied to gain the MRS value is fully described in the ISO 9080 [9] standard.

The strength of the monocomposite pipes was proven in the same way and in addition to that a second method, the so-called constant linear pressure increase method (in short LPI), was applied and compared to the results coming from the ISO 9080 procedure [10, 11].

The LPI-method was published by Barth et al. [12], whereby the influence of different water/chemicals mixtures on the pressure resistance was studied. A detailed description of the background of the LPI-method was recently published by Dr. Hessel [13]. When using the LPI-method the main advantage is a less scope of testing, since a significant decrease of statistical spread of the test results could be observed compared to standard hydrostatic pressure tests described in the ISO 9080 standard. Following the LPI-method a very reliable prediction of the long-term hydrostatic strength can be provided for the tested pipe construction. The resultant long-term strength was also determined following the common methods described in
the ISO 9080 by KIWA Gastec as well as SKZ on a 110x10 pipe for comparison purpose. It was found out and evaluated by third party that the LPI is capable to predict at least a minimum hydrostatic pressures strength line and is leading to similar results as the ISO standard. As for example the long-term strength of the monocomposite polyethylene pipe OD 110x10 mm was found to be twice as high as that of an standard PE100 pipe although both pipes had the same overall wall thickness and were made of the same original materials. This was evaluated by both methods. However, it was the first time reported that a PE100 SDR 11 pipe (OD 110x10mm) is able to withstand hydrostatic pressures of 40 bars (20°C, water) for more than 50 Years.

**Resistance to Rapid Crack Propagation**

Although rapid crack propagation (RCP) is not used for qualifying the lifetime of a plastic pipe, it is an essential property of gas pipes. This failure mechanism, also known for steel pipes, can cause severe damage and result in highly dangerous situations. As a rule of thumb one can say that the higher the operating pressure, the higher the risk of pipe failures due to RCP. The risk of RCP caused failures are also known to be higher for a larger wall thickness. The resistance of pipe-materials against RCP can be tested using full scale tests according to ISO 13478 [14], but for thermoplastic pipes a small scale steady-state (S4) test according to ISO 13477 [15] has also been developed, in order to quantify RCP in a standardized way.

Generally when testing RCP by the S4 test method a critical pressure ($P_c$) above which RCP can occur as well as a critical temperature ($T_c$) below that RCP has to be considered were determined. It is understood that the fact that a material exhibits RCP sets limits on the combination of wall thickness and applied pressure.

For a given application this means that due to lifetime and strength, most plastic materials can withstand higher pressures when using larger wall thicknesses, but due to RCP the use of the material is restricted to a maximum value equal to $P_c$ ($T_c$). If for example standard PE 100 gas pipes are pressurized above 10 bar and an excavator would locally cause a third party damage the initiated crack could rip metres of pipe length as a result of rapid crack propagation. An example of a massive crack caused by RCP is shown in figure 3a. and figure 3b shows a crack arrest as the opposite of rapid crack propagation.
To go beyond the common S4 test conditions for PE100 the monocomposite pipes were tested to determine their critical pressure and critical temperature. Due to the limitation of 55 bar of test pressure rig used for the tests and a minimum applicable test temperature of -55°C the report ends up in its summary [17]:
- the critical temperature $T_{cs4}$ is lower than -55°C at a testing pressure of 24.6 bar
- the critical pressure $p_{cs4}$ is to be higher than 24.6 bar at testing temperature of -55°C

It is remarkable that under this test conditions all test samples showed crack arrest, in other words no rapid crack propagation could be observed.

**Third party approval for high pressure pipe and fitting system**

In the case of solid wall pressure pipes the long-term hydrostatic strength of the material e.g. PE 100 is the standard dimensioning characteristic which decides today’s usual operating pressures of maximum 16 bar for drinking water and 10 bar for gas pipes (at 20 °C and safety factors of 1.25 or 2 respectively) for the SDR 11 pipe series. The materials used as well as the pipe dimensions fit ISO 4437 [18], EN 1555 [8], ISO 4427 [19] and EN 12201 [7] respectively for gas and water distribution. EN 1555 specifies polyethylene (PE) piping systems in the field of the supply of gaseous fuels to be used with a maximum operating pressure up to and including 10 bar. It also specifies the test parameters for the test methods referred to in the current standard. It is applicable to PE pipes, fittings, valves, their joints and to intended joints with components of other materials.

The first monocomposite polyethylene pipe system, the HexelOne® system, was certified for high pressure applications by TÜV SÜD. The approval of TÜV specifies a variety of different
tests that have to be passed and are originating from standards like DVGW VP 642 [20] and DVGW VP 600 [21], whereby the testing conditions were tightened to justify the use of higher operating pressures. These tests were performed by independent testing institutes e.g. KIWA Gastec, SKZ, TGM, HESSEL Ingenieurtechnik etc. Recently the HexelOne® pipeline system has already been certified for SDR 11 pipes with outer diameters of 90, 110, 125 and 160 mm.

**Economical Benchmarking**

The higher material prices of some advanced plastic pipeline systems compared to steel systems can be compensated by cost-effective installation methods. Therefore, in certain cases advanced plastic pipeline systems are really competitive to steel pipeline systems. This follows from a benchmark based on a real case study comparing different plastic pipe systems to steel pipe systems as well as different installation techniques in an economical benchmarking. The benchmarking was done by KIWA Gastec on behalf of GERK (The European Gas Research Group).

It was shown that monocomposite PE pipes and solid wall polyamide pipes are competitive to steel pipeline systems both in the case of installation by digging and installation by ploughing. The cost effectiveness of the different pipe systems is compared by calculating the capital (installation, damage and repair, testing and commissioning, project and material) and operational expenditure (maintenance and inspection).

The materials costs of the plastic pipeline systems have been provided by the resin and pipeline manufacturers. The costs of plastic pipeline fitting materials have been provided by Friatec Germany. The materials costs of steel pipelines have been provided by E.ON Ruhrgas (Germany) and Gas Natural (Spain). E.ON Ruhrgas and Gas Natural have also provided the costs of installation, damage repair, testing & commissioning, project and maintenance. The costs of installation, damage repair, testing & commissioning, project and maintenance for plastic pipeline systems are based on German prices provided by E.ON Ruhrgas.

The higher material prices of some advanced plastic pipeline systems compared to steel systems can be compensated by cost-effective installation. This was clearly revealed from the economic analysis of typical reference projects (See fig. 4). The case was worked out for the outer pipe diameters of Ø160 and Ø110 mm.
Fig. 4: Total expenditure of the reference case installed by digging and ploughing when possible (Ø110 mm). Steel pipelines are installed by digging only, since steel pipeline systems cannot be installed by ploughing.

Projects
Due to significant cost savings several projects with monocomposite pipes were installed. The presentation will demonstrate some examples:

Fig. 5a: E.ON Thüringer Energie AG
4.5 km, HexelOne® Gas pipe OD 110 mm, MOP 16 bar

Fig. 5b: Stadtwerke Bad Langensalza
13 km, HexelOne® Gas pipe OD 110 mm, MOP 16 bar
Perspective

Advanced plastic pipe systems like the presented monocomposite pipe system proved to fulfill the technical as well as the economical requirements for high pressure pipelines. With the currently known results, plastic pipe systems technically show good future perspectives. The required essential technical properties can be met or even be exceeded. In order to optimize the economic advantages some steps will be to optimize the monocomposite pipes for the alternative no-dig technologies. Therefore egeplast will develop high pressure pipe systems with protective and barrier layers, which provide the possibility of integrity check and permanent leakage monitoring and ware suitable for no-dig installation. Monocomposite reinforcement can also be used to develop electrofusion couplers and other pipe equipment.

![a) b)](image)

**Fig. 5:** a) High pressure plastic pipe with barrier and permanent leakage monitoring  
b) Electrofusion coupler produced from monocomposite reinforced sleeve

List of references


Plastic pipeline systems for water supply, and for drainage and sewerage under pressure – – polyethylene (PE) – Part 2: Pipes

Plastic pipeline systems for gas supply – polyethylene (PE) – Part 2: Pipes

Plastic pipeline and protective pipe systems – determination of internal pressure creep test behaviour of thermoplastic pipe materials through extrapolation


[17] TGM Report TGM – VA 24 069: RCP – S4 Test according EN ISO 13477 on samples pipe dn 160 x 14,6 mm HexelOne


