Reinforced thermoplastic pipe: standardised composite solution for oilfield flowlines

Reinforced Thermoplastic Pipe (RTP) is increasingly gaining acceptance in oilfield applications. RTP is a flexible pipe, supplied on long length coils, which can be installed easy and quickly at very low cost. Combining the corrosion resistance of High Density Polyethylene (HDPE) and the high tensile strength, impact resistance and temperature resistance of high strength synthetic fibre, these pipes are ideally suited for oilfield flowlines, waste water disposal lines, and injection line applications.The first RTP has been installed offshore for water injection risers and oil flowlines.

Introduction

"Composites" is the buzzword in materials science these days, and challenge the engineer's imagination. Numerous new ideas and products are launched, but few are being used in the day to day practice in oil and gas exploration and production (E&P). The reason for the slow acceptance of composites in the oil and gas industry is a lack of track record, lack of engineering practice and standards, and as a consequence lack of trust.

In principle, composites would be ideal construction materials for oilfield applications. They show an interesting combination of properties, which are not found in any single component material like metal. Composites, if properly engineered, combine corrosion resistance, high strength, light weight, longevity and ease of maintenance. However, due to the complex nature of their composition, it is often not possible to make easy to understand unambiguous design guidelines and engineering standards. This usually restricts the use of composites to special applications, like aerospace, where products are tailor engineered to solve problems which can only be solved at prohibitively high cost by other solutions.

Pipelines are the first examples of composite products, covered by recognized international standards, used for E&P. Everybody in the industry knows about Glass fibre Reinforced Epoxy (GRE) pipe, which is used extensively for highly corrosive fluids. GRE is covered by numerous national, international and industry standards. For highly demanding operations in E&P, the application of GRE is still limited, due to the complexity and the cost of installation, and its relatively low impact strength.

With Reinforced Thermoplastic Pipe (RTP), this situation has changed. RTP is a flexible pipe, supplied on long length coils, which can be installed easy and quickly at very low cost. Combining the corrosion resistance of High Density Polyethylene (HDPE) and the high tensile strength, impact resistance and temperature resistance of high strength synthetic fibre, these pipes are ideally suited for oilfield flowlines, waste water disposal lines, and injection line applications. Meanwhile the fist RTP has been installed offshore for water injection risers and oil flowlines.

The application of RTP in E&P is covered by API RP 15S [1]. Since the introduction of this standard, early this year, pipeline engineers have an easy to understand document to specify these exciting and cost effective new materials for corrosion resistant pipeline systems. RTP has an extensive 6 years track record in E&P applications in the Middle East, SE Asia and Europe.

Construction of reinforced thermoplastic pipe and fittings

RTP is a three layer pipe construction (Fig. 1):

1. A high density polyethylene (HDPE) liner pipe to provide a leak tight containment for the fluid
2. A reinforcement layer, consisting of an even number (usually 2) helically wrapped layers of fibre reinforcement. Most commonly, high strength aramid fibre (Twaron®, Kevlar®) is utilised, as these synthetic fibre materials show the unique combination of a very high tensile strength, low creep, absolute corrosion resistance, and high impact strength, not found in any other fibrous material, like, for instance, glass fibre. Aramid fibre also has a very good high temperature and fire resistance.
   The aramid fibres are applied as uniaxially reinforced HDPE strips, which are heat bonded to the HDPE liner pipe to form a strong monolithic composite construction.
   Alternatively, instead of aramid fibre, high tensile strength steel cords may be used to reinforce RTP. At the cost of a slightly increased risk of corrosion, even higher maximum operating pressure may be obtained.
3. A protective outer HDPE layer to protect the fibre reinforcement from damage, abrasion and ultraviolet (UV) radiation. Usually, the outer layer is a white heavily UV stabilised compound, which reflects sunlight and prevents solar heating. This allows the RTP to be installed on the surface in desert and tropical conditions, and ensures a maintenance free operation up to 20 years. In buried installation, the life expectancy is as much as 50 years.

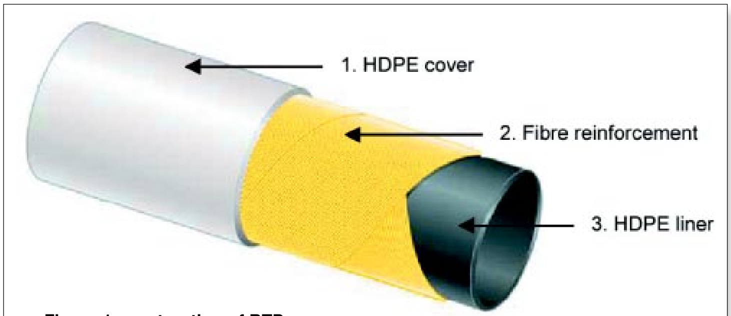

Figure 1 construction of RTP

The winding angles of the aramid fibre or steel cord reinforcement are chosen such that a maximum hydrostatic burst resistance is combined with optimum axial flexibility. Typically, this angle is close to ± 54°. At the optimum winding angle, the RTP shows minimum axial expansion under varying pressure, and also minimum axial thermal expansion. At the same time, the axial stiffness of RTP is low, and very close to a non-reinforced standard HDPE pipe.

The optimum reinforcement geometry may be estimated by simple composite "netting theory" [2]. For more accurate results, the netting theory must be modified to include bi-axial load conditions etc. The modified netting theory is described in detail in ref. [3, 4]. Based on this theory, Pipelife has developed an RTP design calculation model, which is approved by Det Norske Veritas (DNV), according to the requirements in API 17J.

Thanks to the high flexibility, low axial stiffness, and low thermal expansion, an RTP pipe can be installed very easily, without the need for expansion loops. Also thanks to its high flexibility, RTP is supplied on long length road transportable coils.

Several options for connecting fittings on RTP exist. Basically two fittings are required, one pipe-to-pipe coupler, and an end-fitting to connect RTP to existing steel pipe. Several metallic crimp-on and bolt-on options are feasible, and do exist. However, metallic fittings are still prone to corrosion, and still would require regular inspection and maintenance. Pipelife has opted for a plastic composite fitting design based on the electrofusion principle, quite similar to electrofusion systems for standard low pressure HDPE-pipe.

To make a RTP to RTP pipe connection, a two stage thermoplastic welding process is used. First the butt-ends of the liner pipe are connected by standard thermoplastic pipe butt welding technique. This provides a 100% leak free connection, while the fluid in the pipe does not come into contact with any foreign materials like metal or elastomeric seals. However, such connection would not be strong enough to transfer the very high axial loads due to hydrostatic pressure (which may be as high as 150 Bars). After butt welding, a reinforced composite electrofusion sleeve, called the "in-line coupler", is slid over the butt-weld area, and welded in place. While the electrofusion sleeve transfers mechanical loads, the butt-weld ensures leak tightness.

The electrofusion sleeve consists of an inner HDPE sleeve, which is weldable on the HDPE surface of the RTP. Inside the HDPE sleeve is a

Figure 2 RTP composite in-line electrofusion coupler

copper heating coil, which is electrically energized to melt the sleeve to pipe interface, and provide a strong monolithic weld. The HDPE sleeve mechanically interlocks in an outer fibreglass/epoxy sleeve, which provides strength (Fig. 2).

The RTP pipe to steel pipe interface connector ("end fitting"), basically consists of half an in-line electrofusion sleeve. The steel parts and flange mechanically interlock in the outer fibreglass/epoxy shell. An elastomeric seal ensures a leak free connection between the RTP liner pipe and the steel flange. This elastomeric seal at the very end of the RTP pipe is the only element in the pipe system that requires some kind of regular inspection. Even if the elastomeric seal fails, due to the positive effect of the internal pressure, no catastrophic failure occurs, and the leakage of fluid will be controlled and limited (Fig. 3).

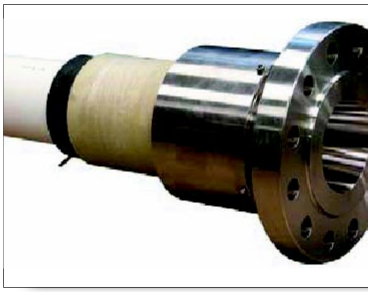

Figure 3 RTP electrofusion end-coupler provides interface with ANSI 6" #600 RF flange, to connect RTP pipe to steel pipe.

The design of the composite in-line and end-fitting system has been supported by advanced finite element analysis, to prevent stress concentrations in any part of the system. The fitting design has been verified by Det Norske Veritas.

The butt-welding and electrofusion welding process is performed with fully automated CNC computer controlled equipment, to avoid human interference and error. The equipment keeps record of the welding parameters of every separate weld. Any welding error is detected automatically.

RTP properties, testing and qualification

The thermoplastic materials, of which textile fibre reinforced RTP is composed, show "regressive" strength behaviour. This means that, unlike for instance steel, the time to failure is a function of the magnitude of the applied load. This is most easily depicted in the so called "regression curve". At selected hydrostatic pressures, the time to failure (on a logarithmic scale) is measured, to obtain data points in the range of about 1 hour to more than 10,000 hours (1 year). The data points are recorded at the maximum operating temperature, which is 65°C (150 °F) for HDPE-based RTP pipe.

Subsequently, the curve of the statistical 97.5% Lower Confidence Level (LCL) of the hydrostatic bust pressure is drawn through the data points. The procedure to do so is standardised in, for instance ASTM2992, and ISO9080. By extrapolating the regression curve to the anticipated operational lifetime of the pipe system (usually 20 years for oilfield operations, and 50/ years for utility applications), the LCL of the long term hydrostatic pressure is obtained. Pressurising the pipe to LCL would be irresponsible, as there would remain a 2.5% chance of failure during the lifetime of the pipe. Therefore the applicable standards prescribe multiplying LCL with a safety factor, S_f, to obtain the safe Maximum Allowable Operating Pressure (MAOP).

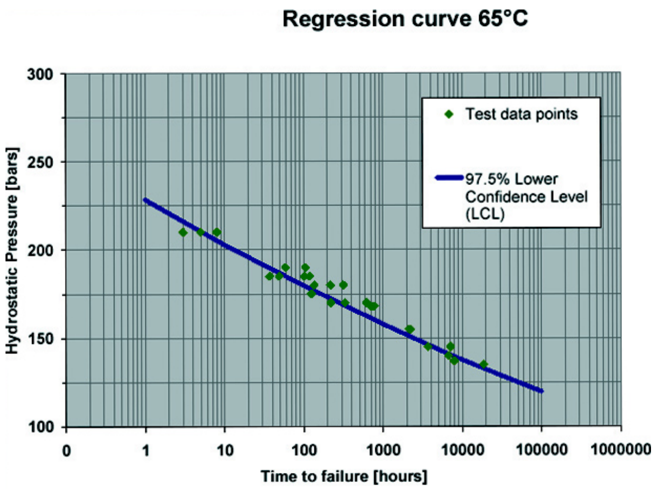

Figure 4 Regression curve of Soluforce M480 RTP, determined at maximum operating temperature of 65°C according to ASTM2992

$LCL_{20\ years}$ = 115 Bars

$MAOP_{water\ service}$ = 90 Bars

$$MAOP = S_f \times LCL$$

S_f depends on the type of fluid (and the associated risk), transported. According to API RP 15 S, $S_f = 0.67$ for water service, and $S_f = 0.50$ for hydrocarbons.

Figure 5 (A & B) Special mechanical testing of RTP.
Left: 4" RTP subjected to bending test, no failure at a bending radius of 300 mm
Right: “Flexirig” test bench for simultaneous dynamic tensile, bending, and torsional load testing.

A typical regression curve for a 4" Soluforce M480 RTP pipeline is given in Figure 4.

While the determination of the regression curve is the key important test in the standards for RTP pipe, API RP 15S (oilfield service), ISO/TS 18226 (gas service) and DVGW VP 642 (German standard for RTP gas service), some other important tests have to be done to qualify RTP fully. These tests relate for instance to the integrity and strength of the fitting system (1000 hours elevated temperature and pressure test), tensile strength tests, and tests of the bending flexibility (Fig. 5).

Aramid fibre reinforced RTP shows a remarkably good resistance against fire. RTP has been tested to survive a 1100 °C jet fire test, under full operating pressure, for a period of 6 minutes. Although the outer cover burns during the test, the thermal insulating properties of the reinforcing layer and polyethylene prevent a quick deterioration of strength of the aramid fibre reinforcement. This good fire behaviour suggests future use of RTP in fire sensitive areas.

Steel wire cord reinforced RTP does not show regressive behaviour. It is now sufficient to determine the hydrostatic pressure at which the steel wire reinforcement breaks or yields. This pressure is than multiplied with an appropriate safety factor to obtain the MAOP. The procedure to qualify steel wire reinforced RTP is given in API 17J. The basic requirements in API 17J are a verified and qualified model to calculate the pipe hydrostatic strength, and a verified and qualified model to predict the corrosion of the reinforcement in the anticipated operational environment. The hydrostatic strength design procedure of Pipelife Soluforce Heavy steel wire reinforced RTP is verified and qualified by Det Norske Veritas, while the verification of the corrosion model, on the hand of results from an actual field test of a water injection pipeline, is well under way.

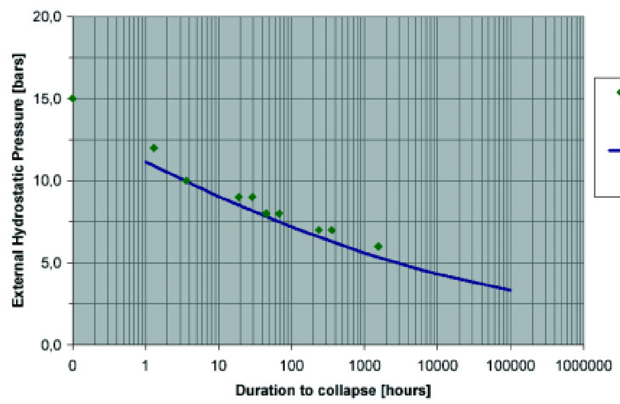

Figure 7 Hydrostatic Collapse Resistance of 5" Soluforce M570 RTP, determined at 20°C according to ASTM2992.

Apart from the tests required by standard or "recommended practice" (API RP 15 S, API 17J, ISO/TS 18226 and DVGW VP 642), special applications may require special testing. For instance practical tests regarding traffic impact resistance, the resistance against digging machine backhoe impact, or even "squeezability" (Fig. 6) for emergency shut down procedures. All these tests show a sturdiness of RTP equal to, or even better than steel pipe, and superior to rigid glassfibre epoxy piping.

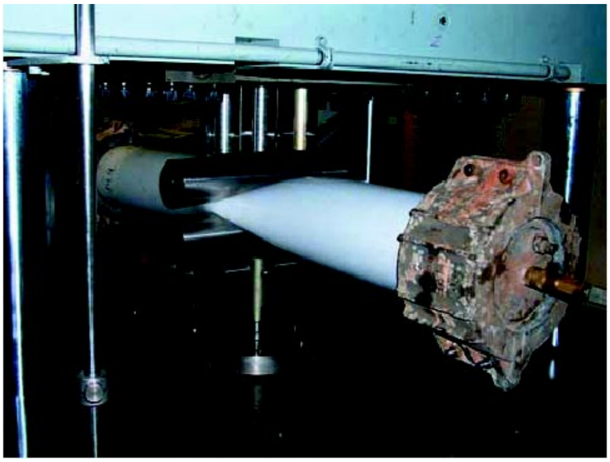

Figure 6 Test simulating squeezing of a 5" RTP for emergency shutdown purposes. No failure occurs at full operating pressure. After squeezing and re-rounding the reinforcement sleeve must be utilised to restore full strength. (courtesy SKZ, Germany)

Recently, Soluforce RTP has also been used for flowlines and water injection risers in shallow waters. The collapse resistance due to external hydrostatic load is a key element in designing such pipelines. Since the reinforcing fibres hardly contribute to the ring stiffness of the pipe, RTP possesses about the same collapse resistance as HDPE pipe of the same diameter/wall thickness ratio ("SDR ratio"). In unpressurised condition, RTP may be installed in water depths up to about 30 meters, depending on the pipe diameter and wall thickness. If the unpressurised condition lasts for only short time, like for instance during installation only, the water depth may be increased accordingly. The hydrostatic collapse resistance of a typical 4" Soluforce RTP pipe, as a function of duration is depicted in Fig.7.

Figure 8 Uncoiling RTP from disposable wooden reel by simple installation trailer behind a 4WD vehicle.

Installation, field experience and track record

Thanks to its flexibility, RTP is supplied on 400 meter coils. This allows a very economical and fast installation, both if the pipe is installed on the surface, or buried (Fig 8).

Normally, no supports or "sleepers", nor prefabricated bends are required (Fig. 9) Speeds

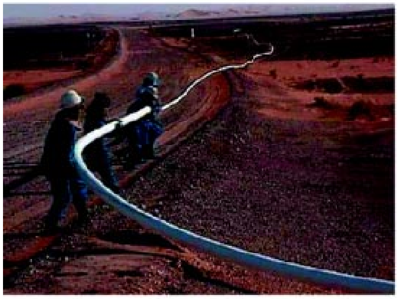

Figure 9 (A & B) Installation of RTP on the desert surface in Oman, and a trenched installation on Sumatra.

Figure 10 Installation of RTP by trenching machine at 1.5 m depth and a speed of 400m/hour

up to 1 km/hour have been reached installing RTP on the ground surface.

By automated trenching techniques (deep ploughing; deep trenching), speeds up to a few hundred meters per hour are feasible (Fig. 9 & Fig.10).

Recently, Soluforce RTP has been used for offshore water injection risers at an oil platform of Brunei Shell Petroleum to replace corroding steel risers (Fig. 11). Thanks to its light weight, a small and cheap installation vessel could be used, saving considerable cost. No metal welding or "hot work" was required on the platform's topside.

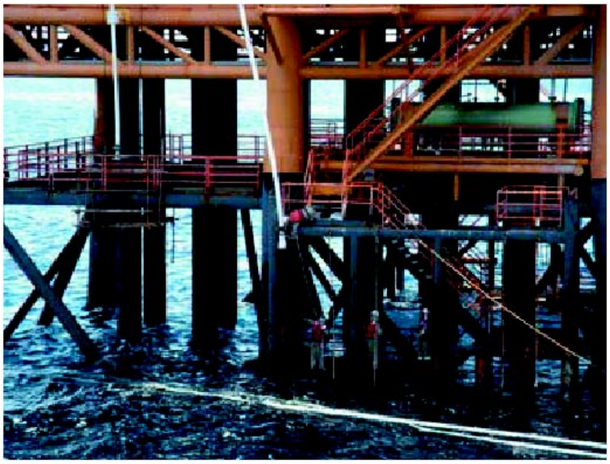

Figure 11 Installation of RTP water injection riser on a platform of BSP. (courtesy: Brunei Shell Petroleum)

Soluforce RTP is now also used for flowlines in shallow water and swamp areas offshore West Africa. The pipe is simply un-reeled from a small installation barge. As RTP floats, even water-filled, weight is added by strapping-on concrete weight blocks, steel wire cable, or anchor chain. Alternatively, the RTP flowline may be pre-assembled with weight blocks and floater cans on the beach and towed out to the installation site. Once arrived, the floater cans are released in a controlled manner to sink the RTP to the seabed.

RTP is used in the oil and gas industry since 2000. The longest track record is in applications like water, oil and gas flowlines, and water injection flowlines. Since April 2006, onshore applications are covered by an internationally accepted "Recommended Practice", API RP 15S. Earlier applications have been realised under oil company in-house standards.

Later applications also include onshore gas transport and distribution. The first gas pipeline was installed in Fayum, Egypt under E-Gas waiver. Later, high pressure gas distribution pipelines were installed in Germany, under TÜV approval. Recently, Soluforce was type approved according to German standard DVGW VP 642, and it may now be used without project specific approval.

The most recent application area of RTP is offshore, to replace corroding steel pipelines in relatively shallow waters.

Conclusions

- RTP is the first successful example of a fibre reinforced thermoplastic composite product, to be used in oil exploration and production.
- The application of RTP in the oil and gas industry is covered by internationally accepted standards and practices, like API RP 15S, and others.
- RTP has a proven 6 years track record in the oil and gas industry
- RTP is an economical solution to do away with corrosion in oilfield pipelines, both onshore, and in shallow waters offshore.
- The installation of RTP is much faster and more

economical than any other pipeline material

- Presently, RTP is only available in diameters up to 6", as this is the limit with regard to economical logistics.
- The pressure rating of RTP is up to about 100 Bars for aramid fibre reinforced products, and about 150 bars for steel wire cord reinforced pipe. The temperature rating is 65 °C.

References

1. API RP 15S, "Qualification of Spoolable Reinforced Plastic Line Pipe", API publication, first edition, March 2006.
2. D. Hull, "An introduction to composite materials", 1981, Cambridge University Press
3. M. P. Kruijer, "Modelling the time-dependent mechanical behaviour of steel reinforced thermoplastic pipes", May 2006, PhD thesis, University Twente,.
4. M. P. Kruijer, L.L. Warnet, R. Akkerman, " Analysis of the mechanical properties of a reinforced thermoplastic pipe (RTP)", Composites part A, 36 (2005), pp 291–300.

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PetroMin thanks Dr. Bert Dalmolen of Pipelife Nederland B.V. for this paper. Bert holds a Ph. D. in Physics, University of Groningen, the Netherlands and has a long experience in the development of fibre reinforced engineered products. He was the inventor of the RTP pipe and fitting system and member of RTP standardisation committees, like API RP15S, and DVGW VP642. He has been a technical marketing manager in Akzo Nobel (1998) and currently working as a technical manager in Soluforce RTP, Pipelife Nederland BV.