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Research article

Experimental study on the thermostable property of aramid fiber reinforced PE-RT pipes

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Abstract

Flexible composite pipes are advantageous in ultra high strength, high modulus, pH and corrosion resistance and light weight, but there are still some hidden safety troubles because they are poorer in thermostable capacity. Therefore, test samples of flexible composite pipes were prepared with high-temperature polythene (PE-RT) as the neck bush and aramid fiber as the reinforcement layer. Experimental study was conducted by using HPHT vessel and differential thermal scanner for different working conditions, different temperatures, whole-pipe pressure-bearing capacity and 1000 h viability. It is shown by the environmental compatibility test that high temperature has little effect on the weight, Vicat softening temperature, mechanical properties and structures of neck bush PE-RT, but exerts an obvious effect on the tensility and whole-pipe water pressure blasting of the reinforcement aramid fiber. Besides, the drop of whole-pipe pressure-bearing capacity is caused by deformation and breaking of aramid fibers when the reinforcement layer is under the force of internal pressure. Finally, disorientation and crystallization of molecular thermal motion occur with the rise of temperature, so amorphous orientation reduces, crystallinity factor and crystalline orientation factor increase gradually, thus, disorientation of macromolecular chains increases and tensile strength decreases. It is concluded that this type of flexible composite pipe can smoothly pass 1000 h viability test. And it is recommended that it be used in the situations with temperature not higher than 95 °C and internal pressure not higher than 4 MPa.

Keywords: Flexible composite pipe; Aramid fiber; Heat resistant polythene; Thermostable; Water pressure blasting; Pressure bearing capacity

Flexible composite pipes, also known as reinforced thermoplastic pipes (RTP), contain three layers, among which, neck bush and reinforcement layer are keys to determine mechanical and thermal properties of these pipes. In recent years, some high-performance thermo-plastics have been deployed as lining materials for flexible pipes. Accordingly, products with cross-linked polyethylene (PEX), heat-resistant polythene (PE-RT), polyvinylidene fluoride (PVDF) and polyamide (PA) as neck bush have been developed. Most of these products have polyester, aramid fiber or steel wire as reinforcing materials in the reinforcement layer [1–5]. Through copolymerization of polythene and octane, PE-RT can be produced. By controlling the quantity and distribution of side chains, unique molecular structures can be obtained to enhance the thermostable properties of PE pipes. Besides, these unique structures may significantly enhance mechanical properties, creep resistance against external stress, thermal stability, long-term hydrostatic strength, resistance to slow crack growth (SCG) and rapid crack propagation (RCP) of these materials. Aramid fibers in the reinforcement layer are characterized by ultra high strength, high modulus, pH and corrosion resistance, light weight and other outstanding properties. In addition, they have strengths 5–6 times that of

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steel wire, modulus twice to three times that of steel wire or glass fiber, and ductility twice that of steel wire, but weight only approximately 1/5 that of steel wire. At 560 °C, they do not decompose or melt [6–10]. With excellent insulation and aging-resistance performances, they have long life cycles. Applications of flexible composite pipes in harsh environmental conditions in oil or gas fields are confined. Heat-resistance capacities of flexible pipes are poorer than metallic pipes, and majority of flexible pipes are used in temperatures below 90 °C [11–14]. Furthermore, these pipes are characterized by a downtrend of pressure-bearing capacities with the temperature increase. Nominal pressure correction factors for different application temperatures have been proposed in relevant standards, but most of these factors are a series of fixed references determined through only limited tests (mostly with fresh water as the test medium). Consequently, these factors may not fully reflect accurate changes in temperature resistance of such pipes.

In fact, pressure correction factors for flexible composite pipes with different structures, sizes and different application media are all different [15]. Most users select reinforced thermoplastic pipes through experiments, which mainly focus on pressure-bearing capacity of pipes subject to relevant standards. For thermostable properties of pipes, only those standards for Vicat softening temperatures of thermoplastic neck bush have been applied for judgment, but performance degradation induced by variations of temperatures and pressures in later applications are not considered. Such negligence may present severe potential threats to the safe and long-term operation of such pipelines [16].

In view of this, the authors explored the thermostable properties of various layers and the whole flexible composite pipes with PE-RT as neck bush and aramid fiber as reinforcement layer. Focus was placed on the impacts of changes in temperatures on compositions and mechanical properties of neck bush and reinforcement layer.

1. Experiment

1.1. Selection of samples

Product name: aramid reinforced flexible composite pipe;

Specifications: Diameter: 100 mm; Pressure endurance: 4 MPa;

Material of neck bush: PE-RT;

Material of reinforcement layer: aramid;

Material of external protection layer: PE.

1.2. Experimental procedures

1.2.1. Performance test of material of the neck bush

By using HPHT vessel, assessments were made on materials of polythene neck bush under different working conditions, predominantly including normal temperatures and pressures, HTHP and simulated field conditions, in accordance with NACE TM 0298-2003 "Standard test method for evaluating the compatibility of FRP pipe and tubular with oilfield environments". See Table 1 for more details related to corrosion environment and media.

Table 1
Conditions for experiments related to corrosion-resistance performances of non-metallic neck bush materials.

S/N	Test environment	Gas pressures/MPa	NaCl concentration/(mg.L^{-1})	Temperature/°C	Duration time/h
F1	Simulation of H_2S-containing conditions in an oilfield	Total pressure: 10 H_2S partial pressure: 0.60 CO_2 partial pressure: 0.25	140000	70	10 100 1000

First of all, a pipe ring with a width of approximately 15 mm was taken out of the non-metallic pipe to serve as the sample used in the experiment. The HPHT vessel was deployed to simulate the environmental conditions expected in oilfields to determine changes in weight and apparent tensile strength of the sample with different periods of test time. The apparent tensile strength can be calculated by using the following equation:

$$\sigma_a = \frac{P_b}{2A_{\min}} \tag{1}$$

in which, σ_a is the tensile strength, MPa; P_b is tensile strength at break, N; $A_{\min}$ is the sectional area of the sample, mm^2.

UTM 3505 electronic universal testing machine was used to determine changes in tensile strengths of the pipe ring at different duration time (10 h, 100 h, 1000 h). Changes in weights of the samples were assessed to determine the applicability of the selected pipe in a simulated oilfield environment. XRD-300DL thermal deformation tester and Vicat softening temperature tester were used to determine the Vicat softening temperature of neck bush under the load of 50 N and at a rising room temperature rate of 50 °C/h as required in GB/T 8802-2001. Finally, Nicolet Avatar 360 Fourier Transform Infrared Spectrometer (IR) was used to determine the structures and compositions of the sample.

1.2.2. Performance test of material of the reinforcement layer

The AQ200 differential thermal scanner was used in DSC analysis. According to GB/T 14337-2008, high and low temperature test chamber was used to determine the tensile strength of the aramid fiber under different temperatures to determine the impacts of temperatures on tensile strengths.