Steel Tape-Armored Polyethylene Pipe for Gas Transmission (II)
— Development of Mechanical Fitting —

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ABSTRACT A mechanical end fitting for steel tape-armored polyethylene pipe for gas transmission has been developed, together with the pipe --a flexible, earthquake-resistant pipe suitable for long-distance installation. The basic structure of the end fitting adopted a sealing scheme that was applied to conventional pipes including steel pipes for gas transmission and low-pressure polyethylene pipes, placing particular emphasis on developing a structure that enables secure clamping of the steel tape reinforcement layer at the end, and on ease of assembly in a short time. This report presents the design of the end fitting, along with the results of various performance evaluation tests.

1. INTRODUCTION

The design of a flexible pipe for gas transmission with composite structure that enables long-distance, joint-less installation along meandering open-cut routes or in underground conduits has been reported in another paper [1]. Since the flexible pipe for gas transmission necessitates, at its ends, jointing with existing gas conduit pipes and various piping systems for gas transmission, the development of end fitting has been carried out simultaneously with the development of the pipe. The design and performance of a mechanical end fitting for steel tape-armored polyethylene pipe (hereinafter called STAPP) will be presented in this report.

2. DESIGN OF END FITTING FOR STAPP

2.1 Design Concept

Mechanical fittings have an established track record in jointing polyethylene pipes for gas transmission currently in use for low-pressure ranges below 0.1 MPa. Expansion of application of the polyethylene pipes for gas transmission to the medium-pressure range of 0.3 MPa or lower is in prospect [2], so that development of medium-pressure mechanical fittings similar to those for low-pressure pipes for gas transmission is under way.

In this development program, the design has been reviewed for higher pressures to make the fittings applicable to the range of 1-MPa gas pressure or higher. Major design improvements aimed at include: first, upgrading the surface pressure at the sealing portion; and secondly, clamping mechanism for the end portion of the reinforcement steel tape layer. In terms of the latter objective, given the fact that the pressure resistance of the pipe strongly depends on the integrity of the steel tape layer, a simple and robust clamping mechanism was developed and was incorporated into the fitting structure, thus preventing the end portion of the steel tape reinforcement layer from getting loose.

2.2 Sealing Structure

Figure 1 shows a schematic of the gas sealing structure. The structure, comprised of a stop ring, a rubber gasket with rounded top and square bottom and a retainer, has a mechanism such that by thrusting down the retainer using the locking bolts, surface pressure is applied onto the gasket placed in the tapered space between the main body of the fitting and the inner polyethylene pipe, thereby sealing the structure against the internal gas pressure. The stop ring in front of the gasket functions as a preventive against cold flow of the gasket.

Since sealing function has to be maintained for a long time, the initial surface pressure was designed, in view of

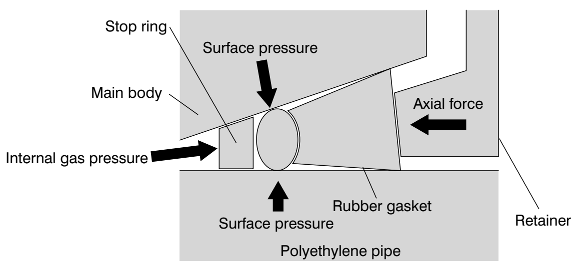

Figure 1 **Schematic of gas sealing structure.**

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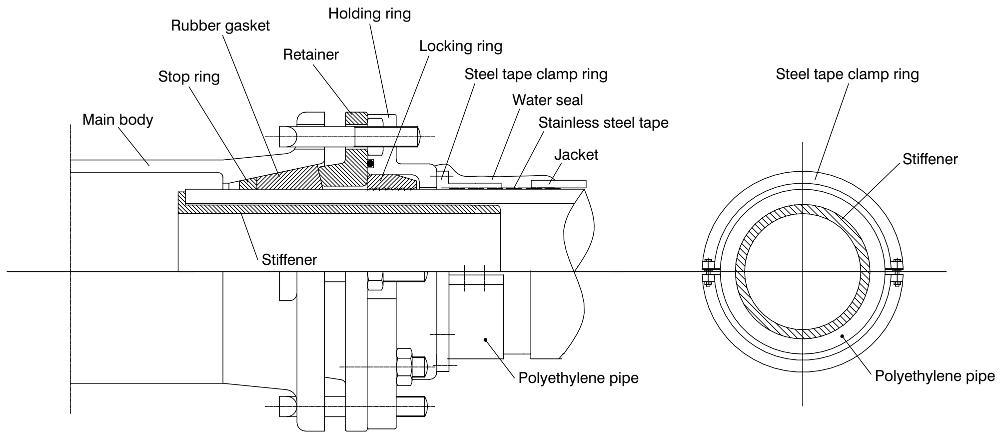

Figure 2 Structure of mechanical fitting for STAPP.

Table 1 Function and material of the constituting parts of mechanical fitting.

Parts	Function	Material
Main body	Provision of protection, waterproofing, and resistance against axial tension	Cast iron
Retainer	Generation of surface pressure for rubber gasket with the help of locking bolts	Steel or polyoxymethylene
Holding ring	Position setting of locking ring	Steel
Locking ring	Holding of inner pipe	Polyoxymethylene
Stiffener	Protection of inner pipe against collapse due to external force	Steel
Rubber gasket	Sealing of gas	Acrylonitrile-butadiene rubber (NBR)
Stop ring	Protection against the cold flow of rubber gasket	Cotton cloth + NBR
Steel tape clamp ring	Holding of steel tape ends	Steel
Jacket	Anticorrosion layer	Acrylate resin

providing a surface pressure that is sufficiently high for upgrading gas transmission pressure, to secure a service life of 50 years.

Figure 2 shows the basic structure of the mechanical fitting for STAPP, and Table 1 shows the function and material of the constituting parts.

Figure 3 shows the test results of surface pressure retention characteristics for the gas-sealing rubber gasket. It can be seen from the Figure that the surface pressure estimated to remain after 50 years is 5.4 MPa, thus achieving the retention of a long-term surface pressure, i.e. required surface pressure multiplied by the safety factor equaling to 1.0 x 4 = 4.0 MPa.

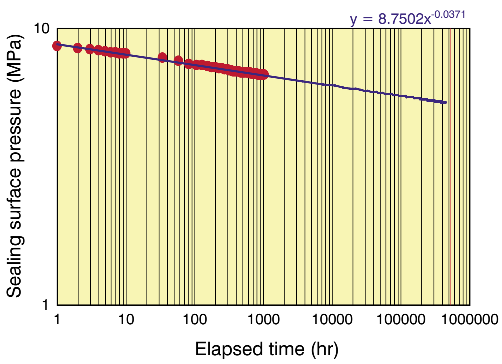

Figure 3 Relaxation curve of sealing surface pressure.

2.3 Steel Tape Clamping Structure

Since stress is generated in the steel tape of a STAPP when an internal pressure is applied to the pipe, the tapes have to be clamped at the joints to counteract the tensile stress accumulating at the steel tape end.

In the steel tape clamping structure shown in Figure 4, a steel tape locking ring (Photo 1) and a steel tape clamp ring (Photo 2) were introduced in order to clamp the steel tape end both circumferentially and axially. The former is a half-opened fitting with a slit for steel tapes, and the latter is a flange fitting with two halved collars.

It was decided to clamp the steel tape end using the steel tape clamp ring, whereby the steel tapes are folded after passing through the slit on the locking ring, the steel tape clamp ring with halved collars is set around the folded steel tapes, and the bolts are tightened to clamp the collars circumferentially, thus fastening by friction the locking ring with the steel tapes.

The design of the steel tape clamp structure was carried out in accordance with the procedures set forth in Figure 5.

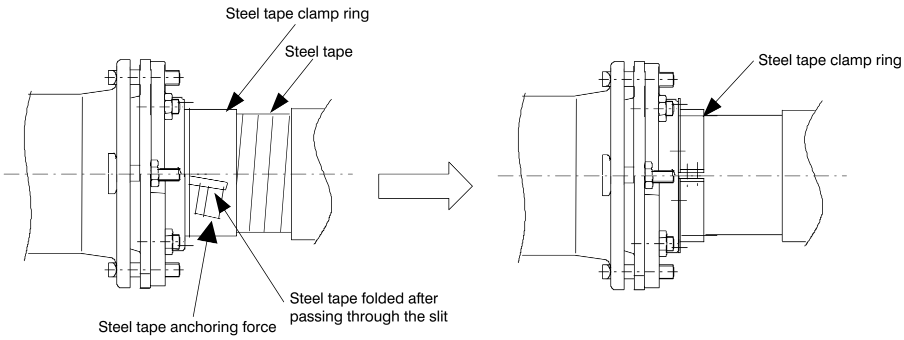

Figure 4 Steel tape clamp structure.

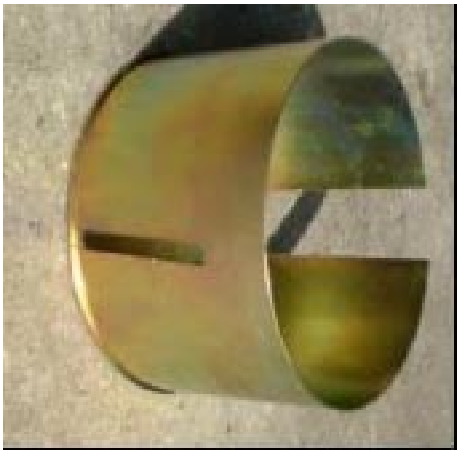

Photo 1 Steel tape locking ring.

Photo 2 Steel tape clamp ring.

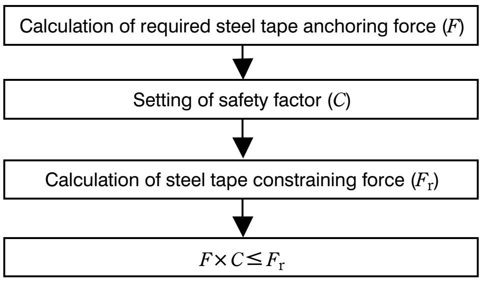

Figure 5 Procedures for designing steel tape clamp structure.

2.3.1 Steel Tape Anchoring Force

The steel tape anchoring force at the end F is represented by Equation (1).

$$F=\left(\frac{P(D-t)}{2t\cdot F_f\cdot \sin^2\phi}\right)\times w\times t \qquad (1)$$

where: P is the maximum working internal pressure, D is the outside diameter of steel tape reinforcement layer, w is the steel tape width, t is the thickness of steel tape, F_f is the reinforcement efficiency of steel tape, and ϕ is the steel tape wrapping angle.

2.3.2 Safety Factor

The safety factor was set as 4 over the tensile strength, the same as for the steel tape.

2.3.3 Steel Tape Constraining Force

Steel tape constraining force F_r refers to the frictional fastening force between the steel tape locking ring and the steel tapes, which is generated by fastening the clamp ring circumferentially using the locking bolts, and is calculated by Equation (2)

$$F_r=\frac{\mu\cdot \mathrm{N}\cdot P}{2}\left(\frac{\varphi+\sin\varphi}{\sin(\varphi/2)}\right) \qquad (2)$$

where: μ is the friction coefficient between the steel tape and the steel tape locking ring, N is the number of bolt, P is the bolt fastening force, and ϕ is the contact angle between the fastening cleat and the steel tape locking ring.

3. VERIFICATION OF STEEL TAPE STRESS

Since steel tape clamping is the most important technique in the design of the mechanical fitting for STAPP, the stress generated at the steel tape end was measured experimentally.

3.1 Experimental Method

The end portion of a STAPP sample of about 1.2 m in length was removed of its jacket over a length of about 150 mm to expose the steel tape ends, while constraining the steel tape ends using a metallic belt. Strain gages were attached on the steel tapes parallel to the tape axis to measure the hoop stress as shown in Figure 6 and Photo 3. As for the steel tapes underneath the jacket, windows were made in the jacket so as to attach strain gages on the center areas of the steel tape on the upper layer. Thus 21 measurement points were prepared in total including one point for the steel tape end, and 20 points for the steel tapes underneath the jacket.

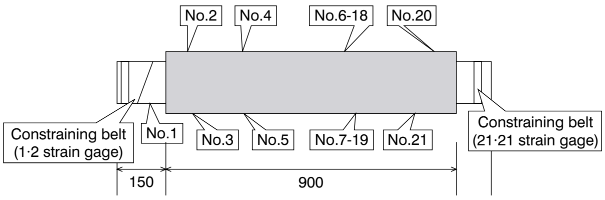

Figure 6 Setup for stress measurement on steel tape ends.

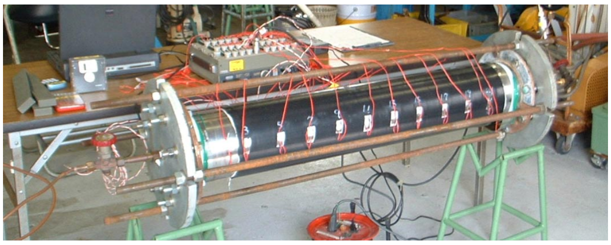

Photo 3 Stress measurement for steel tape ends.

The sample was pressurized with an internal pressure of 2 MPa, and the constraining belts on the both steel tape ends were undone to measure the stress changes over time.

3.2 Experimental Results

Figure 7 shows the stress on the steel tape after the constraint on the steel tape ends was released.

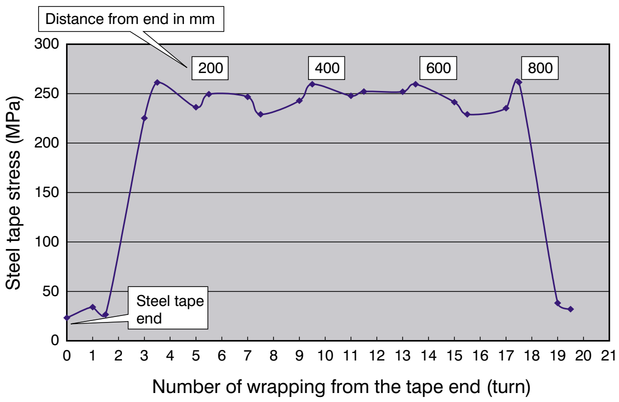

Figure 7 Stress on steel tape after the constraint on the steel tape ends was released.

The stress on the steel tape ends decreases due to loosening as the steel tape ends are released, together with its counterpart underneath the jacket, but it has been confirmed that the influence of the steel tape release spreads only as far as the first turn of wrapping from the end of the remaining jacket, and beyond there, the loosening of the steel tape is suppressed due to the frictional force from the jacket.

3.3 Verification by FEM Analysis

The finite element method (FEM) was used to analyze the stress on the steel tape end, where the steel tapes were modeled using spiral shell elements to simulate the stress distribution on the steel tapes under the conditions of constrained steel tape end, and as of released steel tape end.

3.3.1 Constrained Steel Tape End

The result of analysis is shown in Figure 8. The steel tape stress of 120 MPa with a uniform distribution is in good agreement with the experimental result.

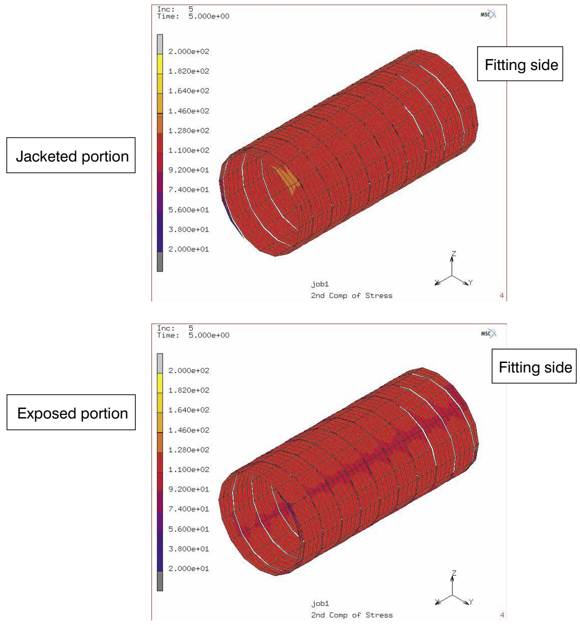

Figure 8 Stress distributions on the steel tape with constrained end.

3.3.2 Released Steel Tape End

Figure 9 shows the result of stress analysis when the steel tape end is released. It can be seen that the region where steel tape stress decreases corresponds to a small section of about one turn of spiral wrapping from the end, showing good agreement with the experimental result.

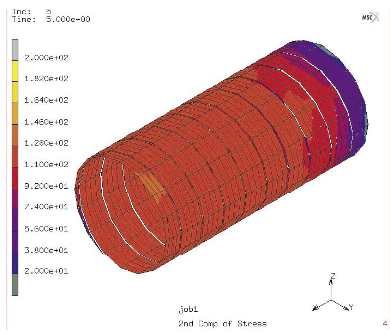

Figure 9 Stress distributions on the steel tape with released end.

4. PERFORMANCE OF END FITTING

The end fitting for the STAPP has been tested in compliance with the tests for mechanical fittings specified in ISO 10838 (Mechanical fittings for polyethylene piping systems for the supply of gaseous fuels) and in Technical Data for Polyethylene Pipe for Gas Transmission [3]. In the tests, the test pressure has been set so as to correspond to an internal pressure of 1 MPa.

Table 2 shows a summary of a series of tests carried out for the end fitting for STAPP with 1-MPa rating. Since there are no problems in any of the tests, it is believed that the end fitting developed here is amply suitable for use in practical applications with 1-MPa rating.

Photo 4 Tensile test.

5. EASE OF INSTALLATION

It has been confirmed that the end fitting developed here can be assembled simply by fastening the parts, and thus has superior ease of installation at the site. For reference's sake, the assembly of an end fitting is finished by one worker in about one hour.

Photo 5 Bending test.

6. CONCLUSION

As described above, a mechanical end fitting for steel tape-armored polyethylene pipe applicable to a working pressure of 1 MPa or higher has been developed, and its design methodology was upgraded and its performance was evaluated. Hereafter, it is hoped that the end fitting will be widely used for flexible, earthquake resistant, long-distance installation piping systems for gas transmission.

Table 2 Summary of tests for end fitting.

Test item	Content	Result
Appearance	Checking of any defects of practical importance	No abnormalities
Internal pressure resistance	Checking of internal pressure resistance	No leak up to 9.6 MPa
Air tightness	Checking of any leak or deformation	1.5 MPa x 24 hr, no abnormalities
Internal pressure creep at elevated temperatures	Checking of any leak or deformation under specified conditions	5-MPa circumferential stress x 1000 hr x 80°C, no abnormalities
Bending fatigue	Checking of fatigue resistance against vibrations corresponding to 50 years	±2.6 cm x 2.3×10^6, no abnormalities
Tensile test at RT	Checking of any leak or deformation under specified conditions (Photo 4)	12 MPa x 1 hr, no abnormalities
Tensile test at HT	Checking of any leak or deformation under specified conditions	3.54 MPa x 500 hr, no abnormalities
Bending	Checking of any leak or deformation under specified conditions (Photo 5)	Cantilever 35 cm in length, no abnormalities
Heat cycle	Checking of heat cycle resistance against seasonal changes corresponding to 50 years	–5~40°C x 50 cycles, no abnormalities
Sealing surface pressure	Checking of retention of specified surface pressure after 50 years (Photo 6)	Figure 3. Estimated surface pressure after 50 years: 5.4 Mpa

Photo 6 Test for the relaxation of sealing surface pressure.

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1) Takeuchi et al.: "Steel Tape-Armored Polyethylene Pipe for Gas Transmission (I) --Development of Pipe--," Furukawa Review, 26, 17 (2004).
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