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Development of Embossed Plastic and Concrete Coated Pipe for Offshore Pipelines*

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The strong demand for corrosion resistant offshore steel pipelines in recent years has led to the making of pipes coated with polyethylene or epoxy resin. Furthermore, for minimizing buoyancy of the pipes during the laying work and for protecting them on the sea bottom, concrete-coated pipes have begun to be used. Recently, the authors have successfully developed a new product whose concrete coating is fast bonded to the polyethylene coating for a remarkable increase of the adhesive strength of concrete. This new coated steel pipe is embossed with a rugged pattern on the outer surface of the polyethylene coating to achieve a perfect bond between polyethylene and concrete so as to prevent peeling-off of concrete and damages of pipe during pipe laying and to improve pipe protection on the sea bottom. Embossing the outer surface of polyethylene coating has achieved, at the concrete coating interface, an adhesive strength of more than 12 kgf/cm² which is about 30 times that for the non-embossed pipe.

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1 Introduction

Pipelines play an important role in the world energy industry by effectively transporting gas, petroleum, water, etc. Steel pipes for these pipelines are subjected to various corrosion protection treatments according to their applications. A combination of anticorrosive coating and cathodic protection has so far been considered the most economical and effective means of corrosion protection.

Bituminous materials, such as asphalt and coal-tar enamel, were mainly used as external protection coatings in the past. In recent years, however, plastic materials, such as polyethylene resin and epoxy resin, have been mainly used in this application. Especially in the case of offshore pipelines, high-quality pipe that ensures high safety is required because the corrosive environment is severe and besides it is almost impossible to check and repair pipe after laying.

The Chita Works of Kawasaki Steel has so far produced large amounts of polyethylene-coated steel pipes for offshore pipelines as well as those to be laid on land by the round die method at its coated pipe mill. Based on techniques thus accumulated, the Chita Works developed coated steel pipe with increased safety for offshore pipelines by applying a concrete coating to the external surface of polyethylene-coated steel pipe excellent in long-term corrosion resistance. In this coated steel pipe (hereinafter called embossed polyethylene-coated pipe), embossing are applied to the external surface of a polyethylene coating to increase the bond between polyethylene and concrete. This increase in the bond is aimed at preventing troubles during pipe laying, such as peeling-off of concrete and pipe damage, and improving pipe protection at the sea bottom. This concrete coating has the following two purposes:

(1) Prevention of the pipe floating due to buoyancy during pipeline laying
(2) Prevention of impact damages to laid pipes due to anchoring from ships, by otter boards of fishing trawls, etc.

This paper describes the development of the embossed polyethylene-coated pipe and results of various performance tests conducted to investigate the mechanical characteritics for practical use.

Incidentally, this embossed polyethylene-coated pipe is used in principal parts of a gas transportation offshore pipeline (total length: 42 km) laid in Japanese waters by a major oil company.

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2 Progress of Development

2.1 Preliminary Investigation and Analysis

Because of its very smooth external surface, the conventional polyethylene-coated steel pipe has a low bonding strength with concrete, leading to various troubles during pipeline laying. For this reason, how to increase the bond between the external surface of polyethylene and concrete is one of the most important problems.

The following two methods may be used to this end:

(1) Mechanical shear connectors are installed at the interface as with composite girders used in bridges.

(2) Protrusions are made on the steel surface as with deformed bars.

The latter method is favorable from the standpoints of workability, material cost, etc., and examination was made with a view to finding a good method of making surface protrusions. There are the following two conventional methods of embossing the external surface of polyethylene:

(1) Tape wrapping

(2) Hot plate stamping

It was decided to make, as trial, four patterns which were deemed typical and possible to make by these two methods, and to select the best one in terms of the bonding strength with concrete.

Used as the test material was steel pipe under API 5LX52 (406.4 mmϕ, 7.9 mm$t$, 4000 mm$L$), with a 2.4 mm thick high-density polyethylene coat applied to the external surface. The embossed patterns given in **Table 1** were made by the above-mentioned two methods. The concrete used had a specific gravity of 2.2 and a compressive strength of 350 kgf/cm^2, reinforced with chicken wire nets (38 mm) of steel wires #17.

The bonding strenth test was conducted using a 50 t universal testing machine. The test pipe was set and loaded as shown in **Fig. 1** and the relative displacement between the external surface of polyethylene and concrete was measured with dial gages. **Table 2** shows the

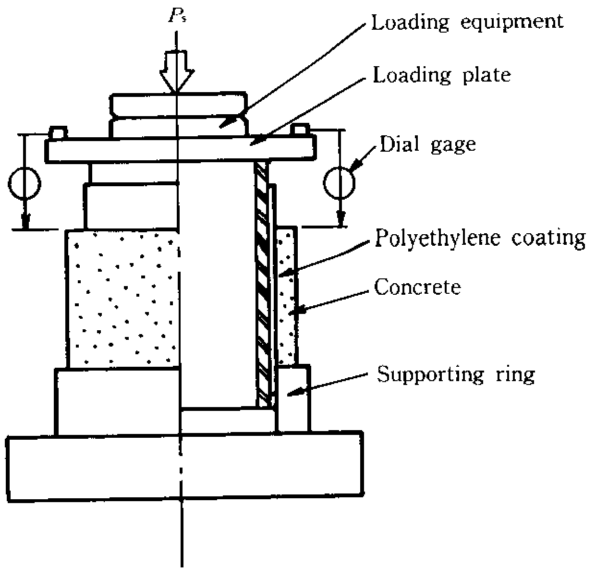


Fig. 1 Schema of method of shear strength test[1)]

Table 2 Shear strength test results

			Maximum load P_{max} (t)	Shear strength $\tau_{B\,max}$ (kgf/cm^2)	Average shear strength $\tau_{B\,max}$ (kgf/cm^2)
A	Chequer	1	4.180	1.08	1.19
		2	5.030	1.30	
B	Straight line	1	5.650	1.46	1.44
		2	5.480	1.41	
C	Tape wrapping (Single)	1	1.575	0.41	0.38
		2	1.350	0.35	
D	Tape wrapping (Double)	1	1.465	0.38	0.37
		2	1.365	0.35	
E	Non embossed	1	1.610	0.42	0.38
		2	1.295	0.33	

Table 1 Embossed patterns

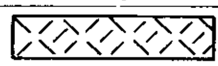
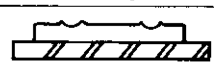
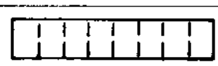
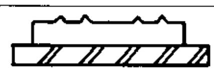
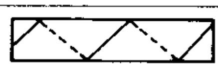
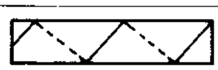
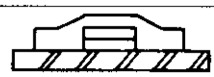
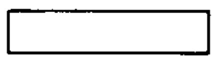
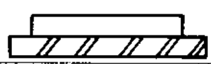
Item	Type of pattern	Surface pattern	Cross-cut pattern
A	Chequer		
B	Straight line		
C	Tape wrapping (Single)		
D	Tape wrapping (Double)		
E	Non embossed		

Table 3 Mechanical Resistance Stress

	Straight line	Chequre
τ_B (max)	1.44 kgf/cm^2	1.19 kgf/cm^2
A	56.9 cm^2	44.5 cm^2
τ_m (max)	72.5 kgf/cm^2	70.5 kgf/cm^2

results of the test. The bondig stess τ_B is generally given by the following equation:

$$\tau_B = \frac{P}{\pi D L} \quad \cdots\cdots (1)$$

where P: applied load (kgf)
D: outside diameter of pipe, including polyethylene coating (cm)
L: concrete coating width (cm)

The bonding strength τ_B is given by a resultant stress of adhesive stress τ_a frictional stress τ_f and mechanical resistance stress τ_m, i.e., $\tau_B = \tau_a + \tau_f + \tau_m$. If τ_a of non-embossed pipe is taken as 0.4 kgf/cm^2 and it is supposed that $\tau_f = 0$ because normal stress does not act and that τ_m is proportional to the area of embossed surface A (cm^2), then the following equation is introduced:

$$\tau_m = \frac{DL}{A}(\tau_B - \tau_a) \quad \cdots\cdots (2)$$

Table 3 gives results obtained by inserting experiment data into the above-mentioned two equations.

2.2 Determination of Embossed Pattern

From the results of the preliminary investigation so far conducted, it was revealed that the straight line has the greatest effect on bonding strength among the four types of pattern. Therefore, the relation between the bonding shear strength and the projected area A_e of the embossed part and the relation between the average shear stress and the slippage were clarified, and an embossed height of 1.7 mm was determined in consideration of the stability of embossing work.

The rolling method and the pressing method were then examined as embossing methods. An experiment was conducted on coated pipe of 89.1 mm outer diameter by the rolling method and it was found that this method had the following problems:

(1) The embossed pattern becomes partially nonuniform due to a difference in the circumferential speed of rolls. **Photo 1** shows a deformed embossed pattern.
(2) It is difficult to heat rolls uniformly.
(3) The embossing speed of rolls (1 m/min) is too low to keep up with the polyethylene coating speed (3 to 5 m/min).

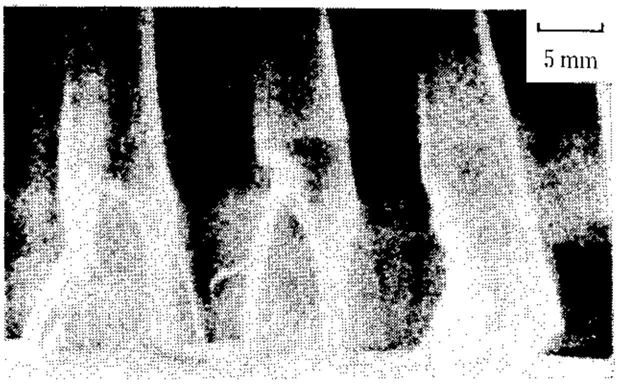


Photo 1 Deformation of embossed pattern

Next, the press method was examined by conducting an experiment using a mold with a heater. There was no basic problem, and optimum embossing conditions were obtained after trying various changes in the pressing temperature, pressure and time.

The degree of deterioration of polyethylene by the effect of heat during embossing was determined by the Fitz-Simol test. It was found from the results of intrinsic viscosity (η) measurement that polyethylene is stable at contact temperatures up to 270°C and begins to deteriorate above 300°C. Results of an investigation of the texture of lowered molecular polyethylene with a polarizing microscope also show that polyethylene is stable below 270°C and begins to deteriorate above 350°C.

Furthermore, it was found that at 200 to 300°C polyethylene is not influenced at all in mechanical and physical properties such as tensile strength, impact strength, dielectric strength and density.

2.3 Embossing Equipment

Photo 2 shows the embossing equipment. There is a portal-type embossing machine at the center of the line. A traveling carriage is installed on the entry side and

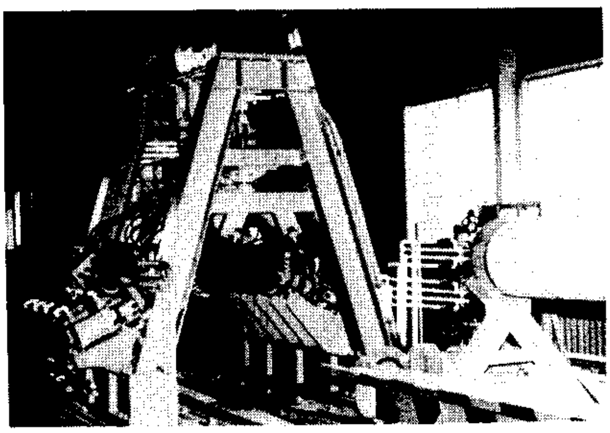


Photo 2 Embossing machine[1)]

embossing is conducted by advancing this carriage through a tunnel-like heater by pitches corresponding to the heater width. Embossing are made as profiles incorporating a sheathed heater are pressed at the same time from three directions.

The steel pipe transportation carriage is of the self-traveling type. Steel pipe is received by V-type supports and speeds are automatically changed by a frequency-changing motor to increase the accuracy of stop position.

The embossing machine proper has the following features:

(1) Pipe ends usually have a curvature of about 1/1000 and the mold is longitudinally divided into four portions in order to eliminate the effect of this curvature.

(2) The out of roundness (difference between long diameter and short diameter/nominal diameter) of steel pipe is expected to be about 0.5% maximum. The mold is circumferentially divided into three portions to cope with the out of roundness.

(3) To prevent the excessive thrust of the mold, a stopper is installed so as to prevent excessive biting of the mold.

3 Production of Embossed Polyethylene-Coated Pipe

The Chita Works produced about 1 000 t of embossed polyethylene-coated pipe for a major oil company. The specifications of the pipe and the manufacturing procedure are described in the following.

3.1 Specifications of Pipe

The material pipe used is seamless steel pipe API 5LX52. **Table 4** gives the chemical composition and mechanical properties of the material pipe. NACE, ASTM and DIN standards were applied as the coating specifications. **Figure 2** shows the coating composition. **Table 5** shows principal specifications and results.

Table 4 Specifications of pipe

Chemical composition (wt%)					Mechanical properties			
C	Mn	Si	P	S	Tensile strength (kgf/mm²)	Yield strength (kgf/mm²)	Elongation (%)	Charpy (kg·m)
≦0.31	≦1.35	0.15~0.35	≦0.04	≦0.05	≧46.4	≧36.6	≧27.0	(−26°C 2 mmV) ave. ≧2.07 any. ≧1.55

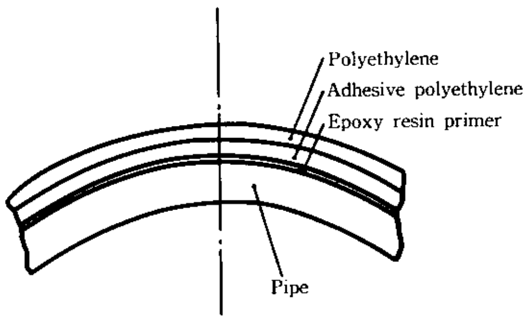


Fig. 2 Schema of adhesive polyethylene coated pipe[1)]

Table 5 Properties of polyethylene compound

	Specification	Typical result
Polyethylene coating thickness	2.0 mm or above	3.0 mm
Adhesive strength	7.5 kgf/cm or above	15~20 kgf/cm
Tensile break strength	200≧ kgf/cm²	302 kgf/cm²
Dielectric strength	40≧ kV/mm	44 kV/mm
Pinhole detector	12 kV	20 kV
Density	0.93 gm/ml	0.952 gm/ml

Table 6 Concrete specifications

	Category I	Category II
Concrete thickness (mm)	53.0	25.4
Nominal density (gm/cm³)	3.04	2.35
S/C*1)	3.0	2.26*3)
W/C*2)	22.3	21.2
Cement (kg/m³)	833	765
Water (kg/m³)	186	162
Iron ore (kg/m³)	2 499	432
Sand (kg/m³)	none*4)	1 297
Compressive strength (7 days) (kgf/cm²)	≧210	≧210

Note
*1) S/C means aggregate-cement ratio.
*2) W/C means water-cement percentage.
*3) The ratio of iron ore and sand is about 1 : 3.
*4) Small amount of sand might be used to adjust density.

The coating process is described in the following. Rust is removed by shot blasting the external surface of pipe to SIS Sa $2\frac{1}{2}$ or more. After the application of epoxy resin primer (target thickness: 20 μm), adhesive polyethylene (target thickness: 0.5 mm) is extruded and high-density polyethylene (target thickness: 3.0 mm or more) is then extruded, followed by the embossing process and further by the concrete coating process.

ASTM specifications are applied to the concrete material. **Table 6** shows main specifications of concrete. The concrete thickness, nominal density, etc., are changed properly depending on the place of pipe laying. The compressive strength is 350 to 500 kgf/cm^2 and satisfies the specifications. **Figure 3** schematically shows the section of a polyethylene-coated pipe which is further coated with concrete.

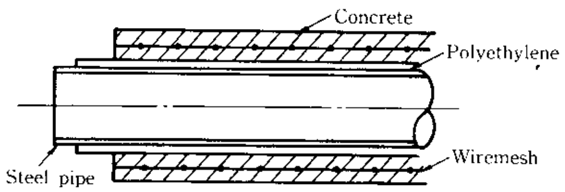


Fig. 3 Schema of concrete and polyethylene coated pipe[1)]

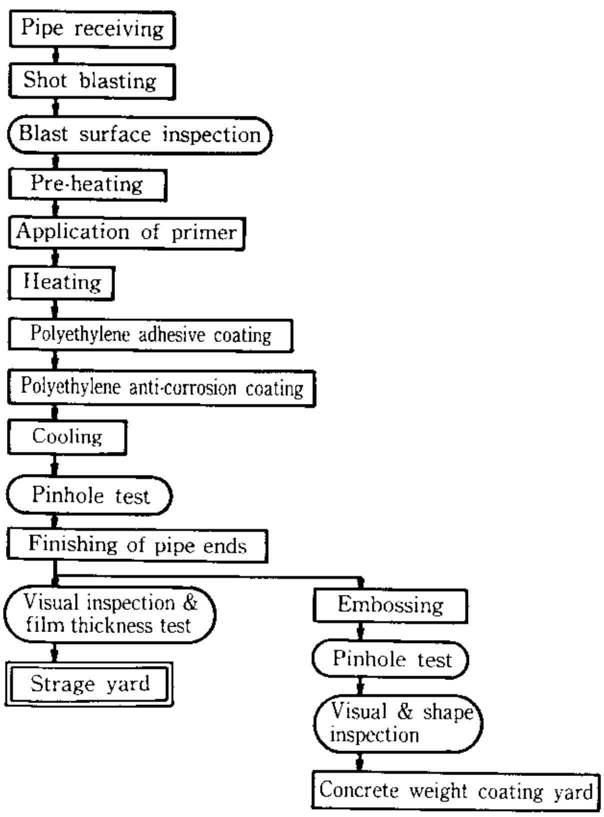


Fig. 4 Manufacturing and inspection procedure of external coating[1)]

The bonding strength between polyethylene and concrete of a composite pipe made by the above-mentioned process is 12 kgf/cm^2 (specified strength: 2.5 kgf/cm^2 or more) and is 20 to 30 times that of coated steel pipe not embossed (hereinafter called general coated pipe) in the range of 0.4 to 0.6 kgf/cm.[1)]

Incidentally, the polyethylene coating process and concrete coating process are shown in **Figs.** 4 and 5, respectively. **Photo 3** shows embossed polyethylene and concrete coated pipes.

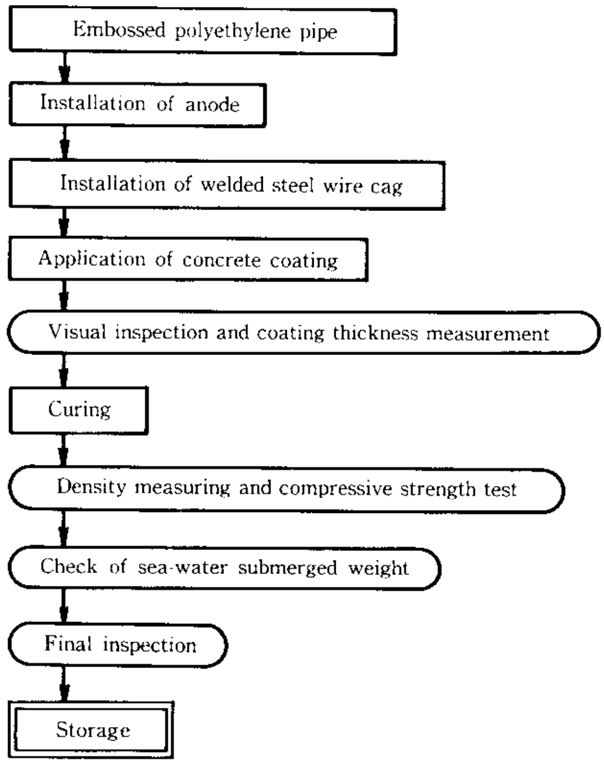


Fig. 5 Manufacturing process of concrete coating[1)]

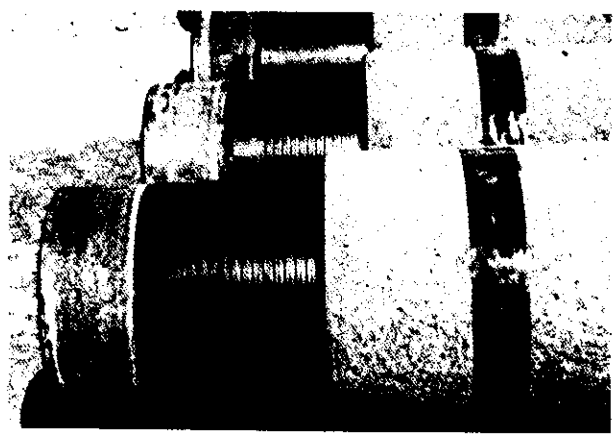


Photo 3 Embossed polyethylene and concrete coated pipes[1)]

ing the peeling-off of concrete.

4 Mechanical Characteristics for Practical Use

Figure 6 shows a representative pipeline laying method using a laying barge[2]. Pipes 12 m in length are continuously welded on board and are delivered into the sea from the stern. The performance of the pipe was investigated by supposing this laying method and the damage at the sea bottom.

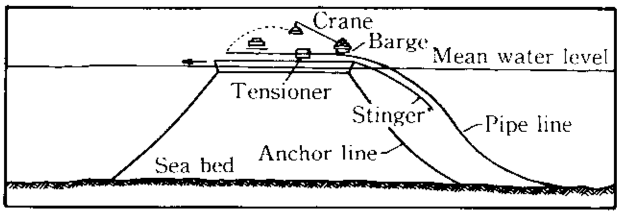


Fig. 6 Method for constructive pipe line (A. H. Mousslli[2])

4.1 Test Material

Highly adhesive polyethylene with a thickness of 3.0 mm was applied to the external surface of steel pipe 324.0 mm in outside diameter and 9.5 mm in wall thickness. The pipe was then embossed and coated with 53.0 mm thick concrete reinforced with steel wires. Pipe thus manufactured was used as the test material.

4.2 Flattening Test

The flattening test was conducted using a 200 t testing machine to investigate the deformation behavior of the pipe when flattening forces are applied from above and below by a pipe fixing device (tensioner). Results of this test are shown in **Fig. 7**. It is apparent that loads applied to the embossed polyethylene-coated pipe until the final concrete cracking and the peeling-off of concrete from polyethylene are about 5 tf larger than those applied to the general coated pipe. This is considered attributable to an increased bond by embossing between the external surface of polyethylene and concrete, thereby suppressing the peeling-off of concrete.

4.3 Flexure Characteristics

The bend radius (R) during pipe-laying was determined and the simple-bending test was conducted. The minimum bend radius for design is given by the following equation:

$$R = \frac{E \cdot D}{2\sigma_0 \cdot D_F} \quad \cdots\cdots (3)$$

where, R: Overbend radius of curvature (ft)
E: Elastic modulus ($= 30 \times 10^6$ psi)
D: Outside steel diameter of pipe (ft)
σ_0: Minimum specified yield stress of pipe
D_F: Design factor, usually 0.85

When the bend radius (R) is calculated by the above-mentioned equation from the specification of the steel pipe made this time, we obtain $R = 110$ m.

Next, the simple bending test was conducted on pipes of actual length (length: 12.2 m) to investigate the yield strength, stiffness, etc. of the embossed polyethylene-coated pipe with this bend radius. **Photo 4** shows the pipe being tested. Loads were applied at two points and were gradually increased until concrete was crushed or peeled off from the external surface of polyethylene.

Figure 8 shows test results. As is apparent from this figure, the bending yield strength of the general coated

Photo 4 Setup for bending test[1]

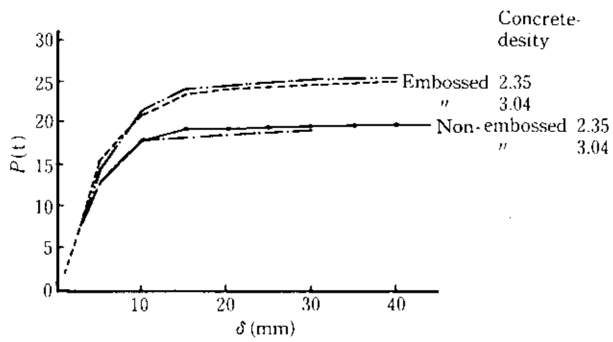


Fig. 7 Relations between press-down load and deformation quantity[1]

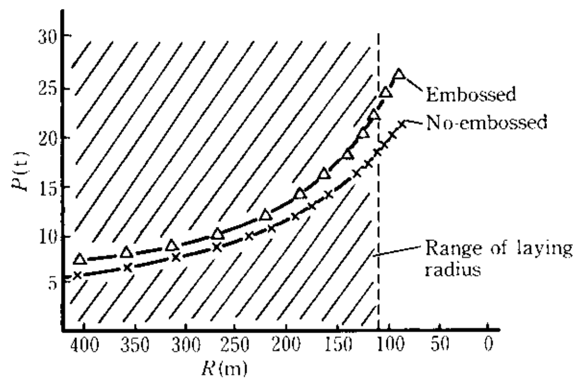


Fig. 8 Relations between load and radius bending[1]

pipe is 21 tf, while that of the embossed polyethylene-coated pipe is 26 tf. It can be seen from this that embossed surface of the coating contribute to the bending yield strength. In the general coated pipe, cracks were formed in a wide area and the gap of the cracks was wide. In the embossed polyethylene-coated pipe, hair cracks were formed and the depth and degree of these hair cracks were small. Similarly, the bending stiffness ($E_s \cdot I_c$) was calculated by the following equation[3]:

$$E_s \cdot I_c = \frac{M_p}{\varrho} \quad \cdots\cdots (4)$$

where, E_s: Elastic modulus
I_c: Geometrical moment of inertia
M_p: Bending moment
ϱ: Curvature ($1/R$)

Figure 9 shows the bending stiffness $E_s \cdot I_c$ at M_p of 40 tf · m ($P = 20$ tf) and at a curvature ϱ of 1/100. It is apparent from this figure that the bending stiffness of the embossed polyethylene-coated pipe is about 1.4 times that of the general coated pipe. Therefore, it is expected that the pipe damage during laying work in rough seas and deep seas can be reduced in the future.

4.4 Otter Board Impact Test

Pipelines on the sea bottom are subjected to various external forces, such as those generated by anchoring from ships and collisions of otter boards of fishing trawls, in addition to external forces from the natural environment, such as tidal currents, movement of sea-bottom soil and ground pressures by earthquakes. To investigate the resistance to these external forces, a drop test was conducted using an otter board (length: 2.0 m, width: 1.5 m, thickness: 0.2 m, weight: 1.5 t) of a fishing trawl used in Japanese waters.

Photo 5 shows the condition of the drop test. The otter board was dropped from heights of 1.0 and 3.0 m onto the axis of pipe placed on a sand mat and the condition of rupture was examined. **Table 7**, **Photos 6**, and 7 show test results. It is evident that embossing increases the composite stiffness of polyethylene coated steel pipes and concrete, thereby reducing concrete damage due to impact.

5 Conclusions

The bond between polyethylene and concrete is markedly increased by embossing the external surface of steel pipe coated with a high-adhesive-type polyethylene excellent in corrosion resistance. The bonding strength of this embossed polyethylene-coated pipe was 12 kgf/cm^2, which is about 30 times that of the general coated pipe. It was ascertained that the embossed polyethylene-coated pipe having this high bonding strength

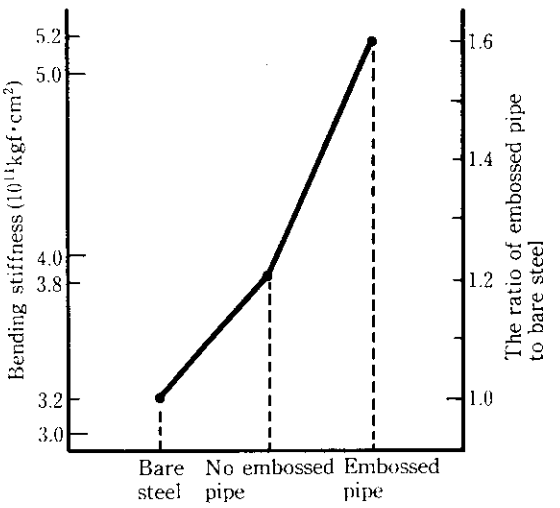


Fig. 9 Bending stiffness[1]

Table 7 Results of impact test[1]

Drop height	Crack length of longitudinal section	
	Embossed	No-embossed
1 m	0.25 m	1.0 m
3 m	0.8 m	rupture of concrete coating

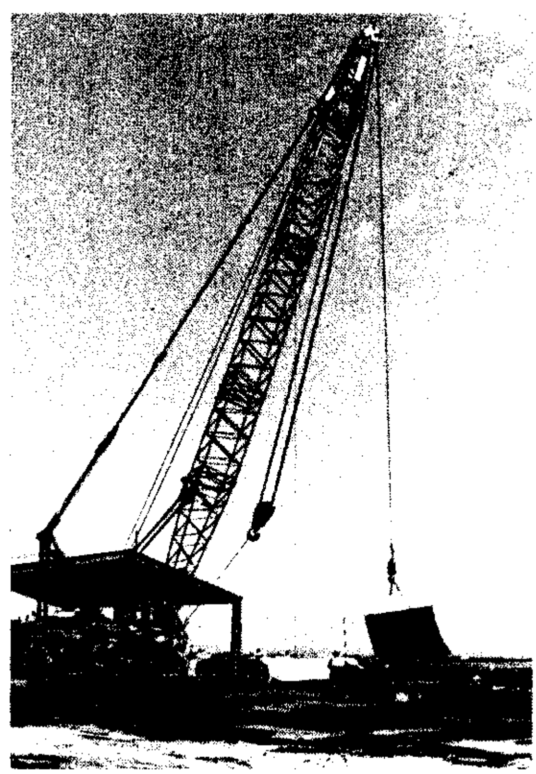


Photo 5 Impact test[1]

Photo 6 Rupture of Non-Embossed pipe after 3 m height impact test[1)]

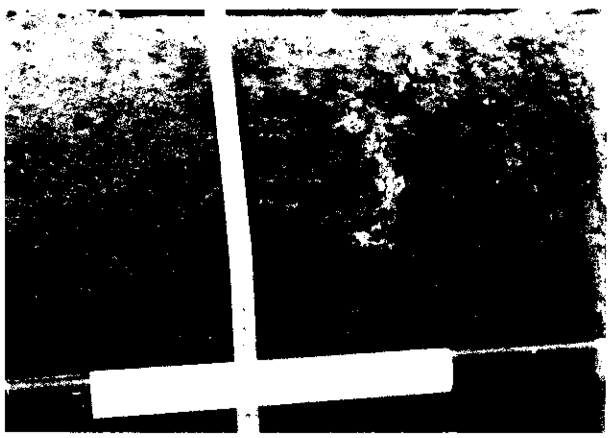


Photo 7 Damage of embossed pipe after 3 m height impact test[1)]

shows excellent resistance to flattening forces, bending stresses, etc. during pipe laying, showing excellent performance in withstanding the impacts at the sea bottom.

About 1 000 t of this embossed polyethylene-coated pipes with these excellent features were used in submarine pipelines of Iwaki Offshore Gas Field, a second commercial gas field in Japan, and the pipeline laying work was successfully completed in the autumn of 1983.

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