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Durability of Three Layer Polypropylene Coated Steel Pipe at Elevated Temperatures

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Abstract:

The authors investigated corrosion resistance of polypropylene coating newly developed for pipelines operating at elevated temperatures and obtained the following results. 1) The polypropylene coating has an excellent indentation resistance, a larger impact strength and peel strength compared with the polyethylene coating even at 100°C. 2) The polypropylene coating with special antioxidants has an excellent resistance to thermal oxidation, and the life time of about 25 years at 100°C is estimated. 3) The polypropylene coating with the excellent resistance to thermal oxidation has a property to prevent residual internal stress cracking due to defects in the coating in the temperature range from 23°C to 100°C, even though the coating on steel pipe has a larger residual stress compared with the polyethylene coating. It is considered from the results mentioned that the newly developed polypropylene coated steel pipe has an excellent durability at 100°C.

1. Introduction

In recent years, operating temperatures of pipelines have been increasing as a result of three factors: the increase in oil temperatures due to the trend towards greater oil well depth, the increasing oil specific gravity, and an improvement in transportation efficiency. From the viewpoint of world environmental protection, because the implementation of district air- conditioning systems are primarily increasing in Europe, operating temperatures of piping are also increasing[1]. Polyethylene coating is normally used as the heavy duty protective coating for pipelines, and has shown high reliability in Europe and Japan. However, a durable heavy duty protective coating for elevated temperatures was required as the operating temperatures of pipeline and piping increased.

The authors have already improved the durability of the polyethylene coating at an operating temperature of 80°C with which continuous coating of steel pipe is possible through the use of existing extrusion coating equipment, and the coating is reliable in long-term operation[2,3]. Polypropylene coating for pipelines with an operating temperature of over 80°C was then developed, and its corrosion resistance was investigated[4,5]. This development was carried out to meet the basic requirements of the coating properties shown below.

The mechanical properties required for coating during the installation of pipes are indentation resistance and impact resis-

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tance. Adhesion strength is also an important property for the polypropylene coating to ensure that the coating material strongly adheres to the external surface of the steel pipe and remains stable over an extended period. T. Arai et al.[6], G.P. Guidetti et al.[7] and G. Connelly et al.[8] reported on three layer polypropylene coatings and their durability. However, no study has been conducted concerning the diffusion of the antioxidants from the coatings to underground soil or the residual internal stress cracking from the presented defects in the coatings. The most important chemical property is the resistance of coatings to oxidation in sand and in the atmosphere at elevated temperatures. To meet the requirements of these mechanical properties and the chemical properties, a new polypropylene coating material containing special antioxidants was developed. Furthermore, the difference between the material strength and residual internal stress in polypropylene coatings are quite important in preventing residual internal stress cracking from the defects that exists in the coating at elevated temperatures.

2. Experiments

2.1 Specimens

Polypropylene (MI=0.90, ρ =0.896) combined with special antioxidants[9] was employed as the polypropylene coating material. High density polyethylene (MI=0.23, ρ =0.945) was used as the control material. Three layer polypropylene coated steel pipe and three layer high density polyethylene coated steel pipe were used as specimens. A steel pipe (216 mm outside diameter, 5.8 mm wall thickness, 5500 mm in length) was coated with a solvent free epoxy primer and an adhesive coating. It was coated with polypropylene or high density polyethylene with a thickness of 3 mm by the extrusion coating method. **Fig. 1** shows the coating layers of polypropylene or high density polyethylene on the steel pipe.

2.2 Experimental method

2.2.1 Mechanical properties

The mechanical properties of the coating were investigated through the use of indentation and impact tests. The test methods and specimens are summarized in **Table 1**. The indentation and impact tests on the polypropylene coating were conducted at temperatures of 40°C to 100°C and -30°C to 100°C, while those for high density polyethylene coating were conducted at temperatures of 40°C to 80°C and -45° C to 80°C.

2.2.2 Adhesion strength

The adhesion strength of the coating was measured through the use of the peel test. The test method and specimen details are summarized in **Table 2**. The peel test was conducted on the polypropylene coating at temperatures of 20°C to 100°C, and for the high density polyethylene coating at temperatures of 20°C to 80°C.

2.2.3 Chemical property

The oxidation resistance of the polypropylene coating was evaluated using an accelerated oven test. The test methods and specimens are summarized in **Table 3**. The brittleness time for the coating with a standard amount of antioxidants was measured at temperatures of 120°C to 160°C, while that for the free film with 1% of the standard amount of antioxidants as the control material was measured at temperatures of 100°C to 160°C. Arrhenius plots were developed and extrapolated to estimate the life of the polypropylene coating.

The hot sand immersion test was also conducted on the high density polyethylene free film to observe the basic phenomena of antioxidant diffusion from the free film to sand at 120°C. The residual antioxidants in the high density polyethylene free film were primarily extracted using cyclohexane, and the amount was normally measured by gel permeation chromatography.

2.2.4 Residual internal stress

The material strength and residual internal stress of the polypropylene coating were measured to evaluate whether it cracked as a result of the defects. The test methods and specimens are summarized in **Table 4**. The residual stress was calculated using the tensile modulus of elasticity of the material and the shrinkage strain of the coating measured at temperatures of 23 C to 100 C, and compared with the tensile strength of the coating material with various defects at each temperature.

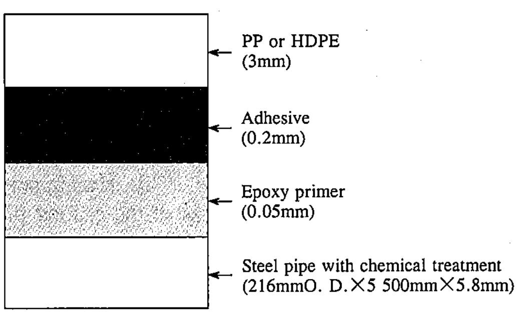


Fig. 1 Coating layers of polypropylene or high density polyethylene on the steel pipe

Table 1 Mechanical property test methods and specimens

Properties	Standard	Specimens
Indentation	DIN 30670	Cut specimen from coated pipe Size : 50mm×50mm×5.8mm Coating thickness : 3mm
Impact strength	ASTM G14	Cut specimen from coated pipe Size : 216mmO.D.×100mm×5.8mm Coating thickness : 3mm

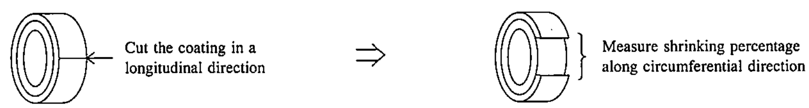
Table 2 Adhesion strength test method and specimen

Property	Standard	Specimen
Peel strength	DIN 30670	Cut specimen from coated pipe Size : 75mm×150mm×5.8mm Coating thickness : 3mm

Table 3 Chemical property test methods and specimens

Property	Methods	Specimens
Brittleness time	Measurement of time when coating cracked after accelerated oven test	Cut specimen from coated pipe Size : 216mmO.D×30mm×5.8mm Coating thickness : 3mm
	Measurement of time when free film cracked by bending after accelerated oven test	Cut specimen from free film Size : 35mm×65mm×2.5mm

Table 4. Evaluation test methods and specimen with residual internal stress cracking

Properties	Methods	Specimens
Tensile strength	ASTM D638	Cut specimen from free film Type : IV Film thickness : 2mm
Modulus of tensile elasticity	ASTM D638	
Shrinkage strain	Measurement of shrinking percentage along circumferential direction when it was constant after cutting the coating in a longitudinal direction	Cut specimen from coated pipe Size : 216mmO.D×20mm×5.8mm Coating thickness : 3mm
		

3. Results and Discussions

3.1 Mechanical properties

A comparison of the indentation test results for the polypropylene coating with those for the polyethylene coating is shown in **Fig. 2**. The indentation results for both materials increased with an increase in temperature. The indentation of the polyethylene coating was only 0.18 mm at 80°C, which was too small to have any effect on the corrosion protection. Even at 100°C, the indentation of the polypropylene coating was only 0.16 mm. It has excellent indentation resistance at temperatures above 80°C.

Next, a comparison of the impact test results for the polypropylene coating with those for the polyethylene coating is shown in **Fig. 3**. Both impact strength decreased with an increase in temperature. The impact strength of the polyethylene coating was still approximately 8J at 80°C, which for practical purposes could be considered high. Even at 100°C, the impact strength of the polypropylene coating was still approximately 22J, meaning that it had a large impact strength at temperatures above 80°C. Neither coating cracked at any of the test temperatures.

Therefore, it was clarified the polypropylene coating of coated steel pipe is not significantly damaged by sand or gravel in underground piping environments at 100°C. It has a high resistance to impact during handling, and has excellent mechanical properties.

3.2 Adhesion strength

A comparison of the peel test results for polypropylene coating with those for the polyethylene coating is shown in **Fig. 4**. Both peel strengths decreased with an increase in temperature. The peel strength of the polyethylene coating was still approximately 50 N/cm at 80°C. Even at 100°C, the peel strength of the polypropylene coating was still approximately 130 N/cm. It had a large peel strength at temperatures above 80°C. Therefore, the polypropylene coating was found to strongly adhere to the external surface of steel pipe, and remain stable over an extended period at an elevated temperature of 100°C.

3.3 Chemical properties

Arrhenius plots for the brittleness times of polypropylene coatings and free films measured in accelerated oven tests are summarized in **Fig. 5**. The polypropylene free film with 1% of the standard amount of antioxidants shows good linearity at tem-

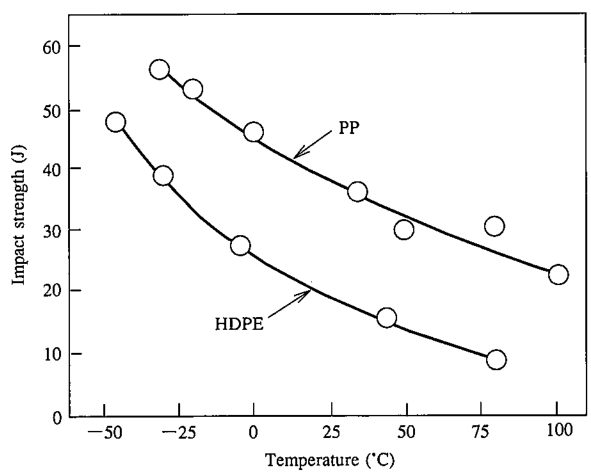


Fig. 3 Effect of temperature on the impact strength of coating

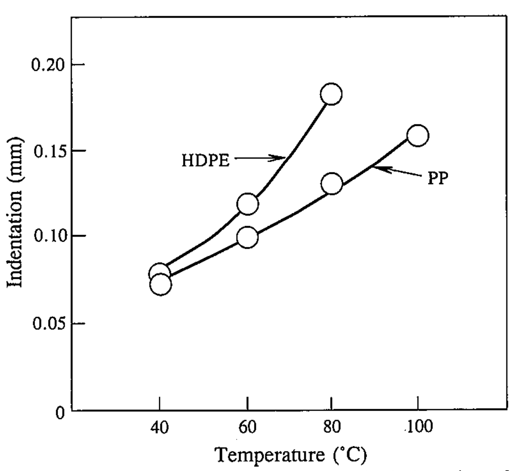


Fig. 2 Effect of temperature on the indentation of coating

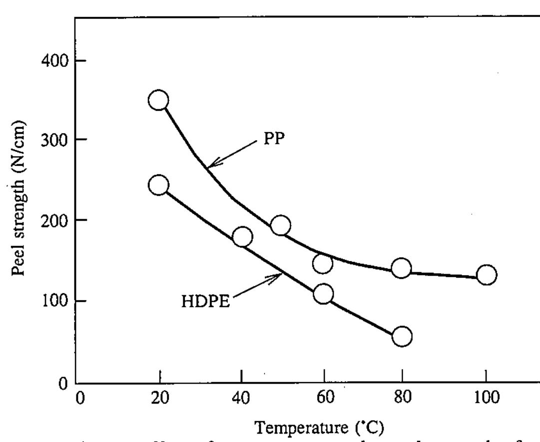


Fig. 4 Effect of temperature on the peel strength of coating

peratures in a range between 100°C and 160°C. The polypropylene coating with the standard amount of antioxidants had an estimated life of approximately 25 years at 100°C, which translates into excellent resistance to thermal oxidation.

The rate of decrease for antioxidants in the high density polyethylene free film decreases with an increase in the molecular weight in hot sand. Therefore, the authors used large molecular-weight antioxidants to prevent the oxidation deterioration of polypropylene coating in sand and in the atmosphere at elevated temperature[9].

3.4 Residual internal stress

A comparison between the residual internal stress of polypropylene coating and the tensile strength of the coating material is shown in **Fig. 6**. The residual stress was smaller than the tensile strength at temperatures between 23°C and 100°C. Polypropylene coating without any defects can prevent the occurrence of residual internal stress cracking until the coating undergoes thermal oxidation.

Next, a comparison between the tensile strength of the polypropylene with various notch depths and several pinhole shapes and the residual stress is shown in **Figs. 7** and **8**. The tensile strength with a surface notch of 50% of thickness of the coating decreased by approximately 56%, and the reduced tensile strength was still larger than the residual stress at 100°C. The tensile strength with a round pinhole decreased by approximately 51%, while the tensile strength with a square pinhole decreased by approximately 58%. The tensile strength reduced by the presence of the above defects was still larger than the residual stress at 100°C.

It is considered polypropylene coating has excellent resistance to thermal oxidation and is able to prevent residual internal stress cracking resulting from various defects on the coating at temperatures of 23°C to 100°C.

4. Conclusions

The newly developed polypropylene coatings have excellent indentation resistance, large impact strength and peel strength compared with high density polyethylene coatings at 100°C. The polypropylene coatings containing special antioxidants also have excellent resistance to thermal oxidation and will prevent residual internal stress cracking resulting from defects at elevated temperatures. Polypropylene coated steel pipes are suitable for pipelines and district air-conditioning piping systems operating at elevated temperatures of 100°C.

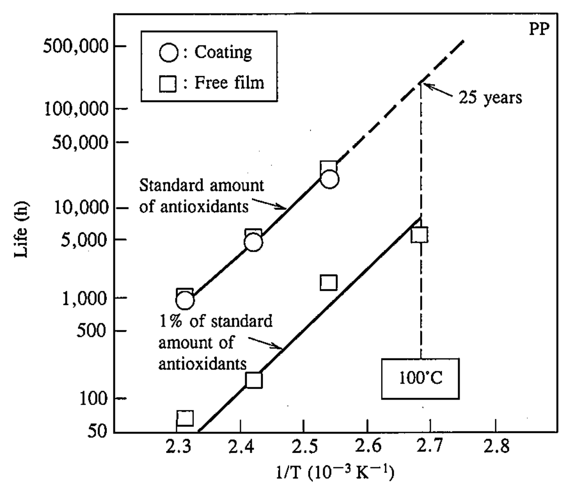


Fig. 5 Extrapolation of Arrhenius plots for brittleness times measured in accelerated oven tests for estimating the life of coatings

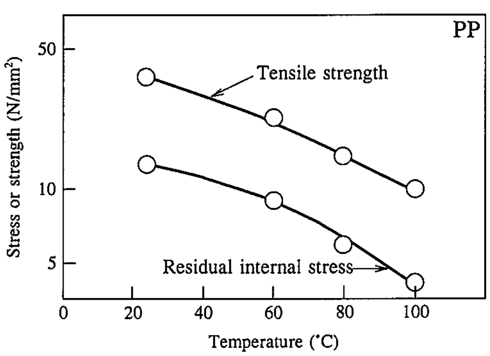


Fig. 6 Relationship between residual internal stress and tensile strength at various temperatures

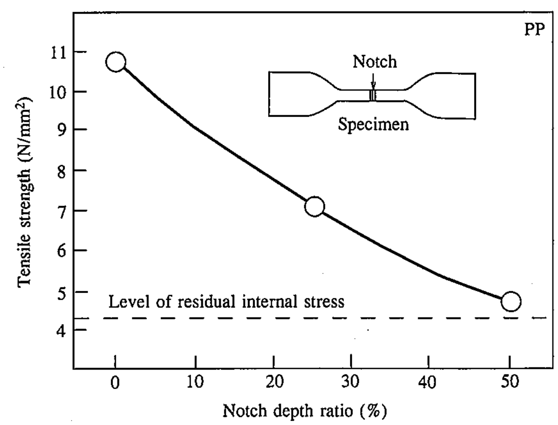


Fig. 7 Effect of the notch depth ratio on tensile strength at 100°C

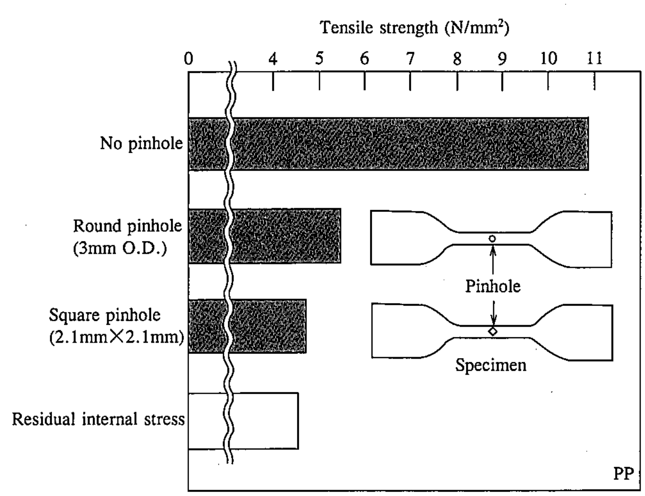


Fig. 8 Relationship between tensile strength at 100°C and pinhole shape

References

1) Raske, D.T. et al. : Energy Conservation-Buildings and Community Systems(UC-95d). ANL-88-6, 1(1988)
2) Miyajima, Y. et al.: CAMP-ISIJ. 3, 1546 (1990)
3) Miyajima,Y. et al. : Proceedings of the 10th International Conference on Pipe Protection. London, Mechanical Engineering Publications Limited, 1993, 183p
4) Funatsu,S. et al. : 11th International Conference on Pipeline Protection. London, Mechanical Engineering Publications Limited, 1995, 227p
5) Sato, H. et al. : CAMP-ISIJ. 8, 1544 (1995)
6) Arai,T. et al. : Proceedings of the 6th International Conference on the Internal and External Protection of Pipes. 1985, 395p
7) Guidetti,G.P. et al. : Proceedings of the 7th International Conference on the Internal and External Protection of Pipes. 1987, 203p
8) Connelly,G. et al. : Proceedings of the 8th International Conference on the Internal and External Protection of Pipes. 1990, 179p
9) Sato, H. et al. : CAMP-ISIJ. 8, 730 (1995)