KAWASAKI STEEL TECHNICAL REPORT
No.9 (March 1984)

A Large Diameter Pipe Epoxy Powder Coating Line and Product Quality

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Synopsis :
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A Large Diameter Pipe Epoxy Powder Coating Line and Product Quality*

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An epoxy powder coating line has been in operation since April 1983 at the UOE pipe mill plant of Chiba Works. The line serves for an external coating of the world's largest class pipe with its diameters ranging from 12" to 64" and its length 60' at max, particularly for enduses requiring good corrosion resistance and good coating adhesion.

A unique chemical treatment of pipe exterior for an improved corrosion resisting property; a dual-layer application of paint—one for adhesion and the other for impact resistance; an effective use of preheating and postheating; a computer-aided quality assurance system in temperature control and automatic film thickness measurement; all these technical developments assure good adhesion and toughness of the coating against damages to surface during transportation, handling and construction, thus opening up a new horizon unattainble by the conventional single layer coating method.

This paper discusses these new technical developments mainly from the viewpoint of coating materials and coating conditions.

1 Introduction

A large number of pipelines have been constructed or planned as a means of efficient transport of crude oil, natural gas, water and other fluids. Since these pipelines are laid under the assumption that they endure normally for 20 years or longer, and in some cases for 40 years or longer, it is a very important task to protect the pipelines from corrosion throughout.

Anti-corrosive coating material for pipeline is required to have corrosion-preventive properties and excellent mechanical properties such as strength and toughness. Furthermore, it must have adequate adhesive strength to steel pipe and, besides, any flaws inflicted during transport and handling up to the completion of laying must be easily repairable.

Though bitumen materials such as asphalt or coal tar were frequently used previously as outer coating material for steel pipe, they have recently been replaced with plastic materials such as polyethylene or epoxy resin to meet the quality requirements described above. Moreover, since the working conditions for coating in the field are not always favorable, it has been desired to have coating work carried out in the factory.

Under these circumstances, Kawasaki Steel Corporation installed a T-die method[1] polyethylene-coated pipe manufacturing line in the Large Diameter Pipe Plant, Chiba Works, in April, 1979, and produced pipes for natural gas pipe line in USSR, for trans-Mediterranean pipeline, and for fresh water pipeline in Saudi Arabia, all being favorably approved.

In these days, gas is pressured and oil heated to 60°C or higher for an improved transport efficiency.

While polyethylene-coated pipe can be used at temperatures up to 60–70°C owing to softening of polyethylene, epoxy resin does not soften up to around 100°C; therefore, epoxy-coated pipe is suited for the pipeline operated at such higher temperature range, enjoying increasing demands. In order to respond to these demands, Kawasaki Steel Corporation installed an epoxy powder-coated pipe manufacturing line in the neighborhood of the polyethylene-coated pipeline.

As one of its features, the new line is designed to form an integral double-layer coat, primarily with a high-adhesive epoxy resin over steel pipe and secondarily with another resin of high impact-resistance. This is a noticeable improvement in resistance to impact and bending strain where the conventional epoxy coat has been criticized.

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The present report outlines coating techniques employed in the new line, and the properties of epoxy-coated pipe manufactured by it.

2 Coating Process and Line

The coating line can process various types of steel pipe, such as UOE pipe, spiral-weld pipe, and electric resistance-weld pipe of outside diameter from 12 inches (318.5 mm) to 64 inches (1 626 mm) at a rate up to 6 m^2/min.

The coating process is illustrated in **Fig. 1**. The process is divided into three steps.

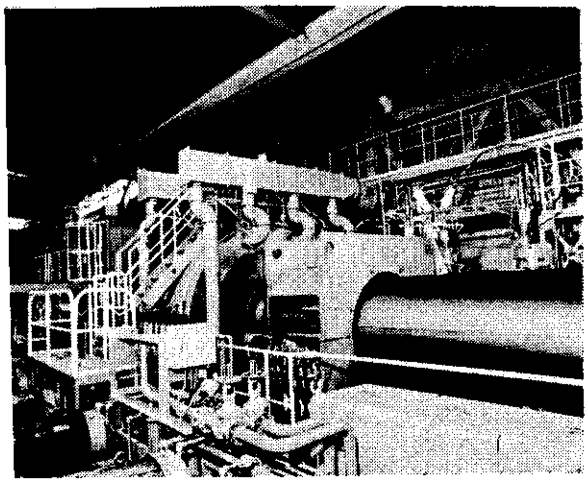

Photo 1 Veiw of coating line

Table 1 Main equipment for epoxy powder coating

Equipment	Type and Capacity
Blasting	Rotary type Capacity : 1 000 kgf/min
Pre-heating	Electric induction heater Capacity : Max. 3 100 kW
Fusion bond epoxy coating	Spray guns : electrostatic guns Inner Layer : 6 sets Outer Layer : 18 sets Capacity ot coating : Max. 6 m^2/min
Post-heating	Electric induction heater Capacity : max 3 100 kW
Film thickness test	Ultrasonic water jet type Measuring range : 150–1 000 μm Accuracy : ±10 μm
Pinhole test	High voltage pulse arc type Discharging voltage : 2–10 kV

(1) Pretreatment,
(2) Coating,
(3) Inspection and preparation for shipping.

The principal operations for these steps are outlined below. The specifications for these equipments and the outer views of coating line are shown in **Table 1** and **Photo 1**, respectively.

2.1 Pretreatment Line

The pretreatment line includes a dryer to improve blasting efficiency, a blasting machine and a chemical treatment unit.

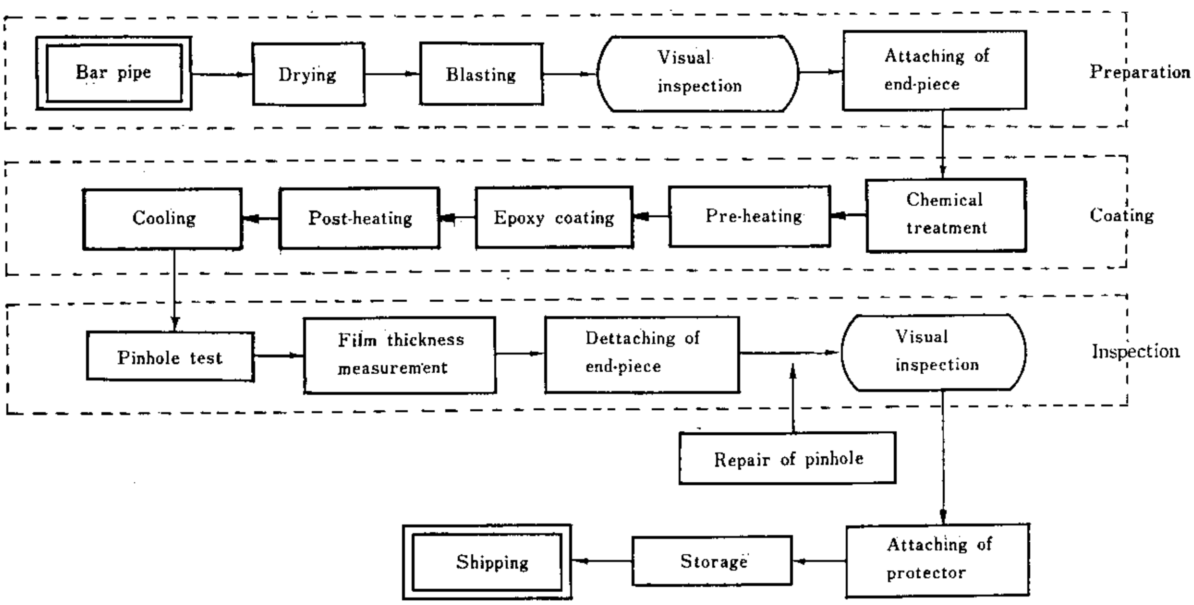

Fig. 1 Manufacturing process of epoxy powder coated pipe

Blasting is applied for the purposes of removing rust, giving appropriate anchor pattern to the pipe surface, thereby improving adhesiveness of coating film and promoting flexibility and impact resistance. Therefore, whenever a flaw detected in the surface inspection after blasting is retouched by grinder and the like, the portion is subjected to blasting again. The anchor pattern is measured as a standing operating procedure and constantly controlled.

The chemical treatment unit which is to noticeably improve the cathodic disbonding resistance and salt water resistance, is installed immediately before the preheating furnace so that the treated surface can be coated with the least possibility of touching the conveyor roller or other objects.

2.2 Coating Line

The coating line consists of preheating furnace, electrostatic powder coating unit, post-heating furnace and water-cooling system.

The preheating furnace is to heat up steel pipe before wating to a specified temperature. Since the heating of pipe must be done quickly so as to prevent the reoxidation of pipe surface from which rust is removed, the electric induction heater is adopted, with care taken to use a relatively low frequency so as to avoid heating the pipe surface to an unnecessarily high temperature through the skin effect of high frequency current.

The pipe is coated by the electrostatic powder process with 24 spray guns, of which 6 for prime coat are installed at the fore part of coating booth, and 18 for top coat at the rear part.

There are two sets of powder feeding system, one for 6 guns for prime coat and the other for 18 guns for top coat, allowing the supply of two different types of powder.

These unique designs opened the way, as explained later in more detail, for the use of prime coating specially designed for strong adhesion to steel pipe, and the use of rubber-modified high-elastic top coating, thereby making it possible to obtain coated film having corrosion resistance and mechanical properties such as resistance to bending force and impact to a level unattained by the conventional single-layer coating.

The coating booth is made from non-conductive materials so as to improve coating efficiency. It permits a high coating efficiency for pipes of any diameter, from large to small, without being affected by pipe diameter, backed by an in-booth air stream control and a gun layout arrangement. The thickness of coated film ranges from 300 μ, the minimum thickness to secure specified film characteristics to as thick as 700 μ by lower temperature coating tobe described later.

The post-heating furnace is to allow the film to complete the curing reaction so as to exhibit the full performance.

Epoxy resin is of thermosetting type, and coated film with inadequate curing has extremely inferior flexibility and impact resistance[2)]. Generally, inadequate curing is avoided by heating uncoated pipe to a temperature higher than that required for completing curing. However, if coating temperature is higher than necessary, a melting time of powder becomes so short that a number of problems take place; such as a lowered mechanical strength of film by air void inclusion, and nonconformances in appearance such as curing before the smoothing of film surface (orange peel), and incomplete mixing of late-coming powder with the main coated film (dust coating).

In order to solve these troubles, the post-heating furnace is designed to make a more positive function in the present line than simply keeping heat as in the conventional line.

That is, as shown in the heating cycle in **Fig. 2**, the pre-heating furnace provides temperature required for melting powder to adapt itself to the anchor pattern, while the post-heating furnace heats up the film as required for curing. Particularly, when coating two different types of powder in a staggered-timing as described above, it is essential to carry out coating at a relatively low temperature, for making two layers into one integral film without causing defects to both bottom and top layers.

In order to ensure positive functioning of the post-heating furnace, the induction heating ensuring ready control is adopted.

The heating temperatures at the pre- and post-heating furnace are controlled automatically by the computer based on pipe temperatures measured at three respective points before and after the coating booth and at the inlet of post-heating furnace, jointly with pipe size and line speed. In this way, complete curing

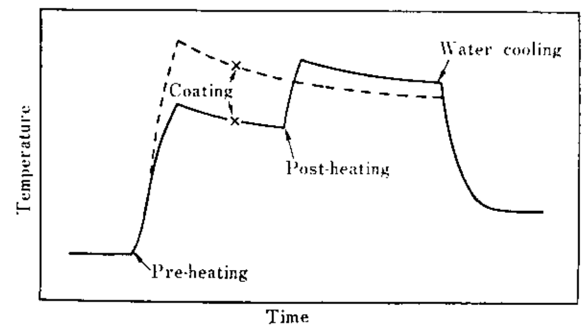

Fig. 2 Heat pattern in epoxy powder coating

of coating is ensured for every possible combination of conditions such as resin type, pipe size and line speed.

In addition, the coating line is equipped with safety devices. Powder epoxy resin has a possibility of causing dust explosion or fire hazard depending upon the concentration of floating particles. For this reason, the anti-explosion devices are provided at places where the powder concentration is high, such as coating booth, powder recovering duct and dust collector. While epoxy resin itself is not toxic, some resin powder contains hardening agent of amine derivative, and hence, should be kept away from the skin. In order to avoid toxic effects, a special device has been developed and installed to supply resin powder automatically from a drum to the powder feeding system.

2.3 Inspection Line

For a sufficient quality assurance for customer requirements, an automatic pin-hole detector and an automatic thickness gage are installed on-line so as to check the entire film for pin-holes and to measure the film thickness.

These on-line instruments are located immediately after the water-cooling units, and the inspection results are quickly taken into operation: for instance, thickness data are constantly displayed in the digital form to the operator of the coating line. The automatic pin-hole detector gives an alarm whenever a pinhole is detected and marks its position with a seal so that it will retouched in the subsequent repairing process without fail.

Besides, the process includes various types of test, such as adhesion test and hardness and cure test. The specifications and frequency of these tests are fed into the computer, and when the arrival of particular pipe at the inspection site is indicated to an inspection personnel through CRT, the inspection results are inputted and the judgement for approval is displayed.

The strict process control and inspection system ensure the product quality, as described in the above.

3 Properties of Epoxy-coated Pipe

The anti-corrosive coating of steel pipe for pipeline is required to have adequate impact resistance to prevent flaws in the course of pipe transport to the installation site, bendability to fabrication strain at the time of pipe laying, as well as cathodic disbonding resistance and electric insulation resistance to prevent corrosion for a long period. These properties are extensively affected by the nature of powder resin, and the methods of pretreatment and coating.

In this section, the properties of epoxy-coated steel pipe-manufactured by the present line are described, together with the effects of pretreatment, powder resin and coating method.

3.1 Impact Resistance and Flexibility

When using epoxy powder-coated pipe for pipeline, the impact resistance and the flexibility come into question first. Since these properties deteriorate at lower temperatures, the pipes destined for cold countries are required to have particularly excellent performance.

Kawasaki Steel Corporation has developed powder resin to fulfil these requirements in corporation with the paint manufacturer, and a new coating method to fully exhibit its performance, allowing the manufacture of coated pipe of excellent quality.

Generally speaking, the cracking resistance of epoxy-resin film improves in proportion to the content of rubber-like substance in resin, though the adhesiveness of film to steel pipe deteriorates as the content is increased, causing film to peel off from the pipe surface in the impact test. Consequently, the addition of rubber-like component fails to improve the impact energy reading beyond a certain level.

In order to ensure the improvement of film's cracking resistance by adding rubber-like substance, and to maintain firm adhesion of film to steel pipe, a method of double coating has been developed to make a film consisting of two layers of different characteristics. That is, coating of composition design with enhanced

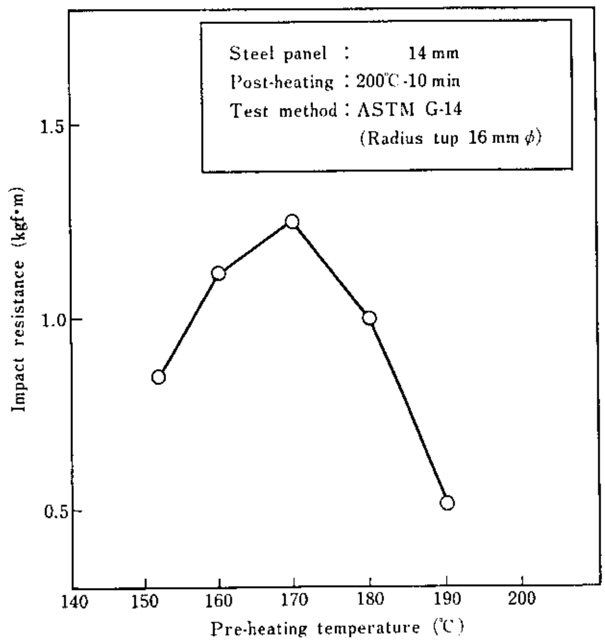

Fig. 3 Change of impact resistance with pre-heating temperature

Table 2 Impact resistance of new developed coating method

Coating material and method		Test temperature 23°C	Test temperature −40°C
Newly developed epoxy powder and method	One layer coating using the powder for under-layer	0.4-0.5 kg·m	0.2-0.3 kg·m
	One layer coating using the powder for top-layer	0.8-1.2	0.5-0.7
	Double-layer coating	1.3-1.8	0.6-0.8
Conventional epoxy powder (One layer Coating)		0.3-0.5	0.2-0.3

Film thickness : 360 μ
Test method : ASTM G14 (Radius tup : 16 mm φ)
Wall thickness of pipe : 12.7 mm

Table 3 Results of bending test

Material (epoxy powder)	Test temperature 23°C	Test temperature −20°C
Newly developed epoxy powder (Double-layer coating)	>5°/P.D.	3°/P.D.
Conventional epoxy powder	>5°/P.D.	1.5°/P.D.

Table 4 Effects of chemical treatment on cathodic disbonding and salt resistance

Test	Chemical treatment	Non-treatment
Cathodic disbonding (5.5 V 20°C 3% NaCl solution 30 days)	6 mm	16 mm
Hot salt resistance (adhesive strength after immersing in 80°C 3% NaCl solution for 30 days)	220 kg/cm²	90 kg/cm²

Film thickness : 350 μ
Initial adhesive strength : 230 kg/cm²

adhesiveness to steel pipe is adopted for the bottom layer, while coating with rubber-like substance added to improve the impact resistance for the top layer. Besides, the coating conditions for securing double coating consisting of two layers of different characteristics have been examined.

Figure 3 shows the result of impact test with double-coated specimens, which are steel plates heated to various temperatures before being coated and cured under a certain curing conditions (post-heating at 200°C for 10 min.). The pre-heating temperature is required to be just adequate to melt powder so as to cause it comply with the anchor pattern of blasting. When the temperature is too high, the top layer coated on the fully cured bottom layer fails to fuse with the latter, and in the impact test, two layers may separate to deteriorate the impact resistance. Moreover, if the temperature is too high, the film tends to trap air voids, thus lowering the impact resistance again.

Tables 2 and **3** show the impact resistance and flexibility of double coating which is 360 μ thick and coated under proper conditions, in comparison with those of conventional films. The double-layer coating permits to improve the impact resistance extensively over that of respective single-layer coatings: 2–3 times as high as the impact resistance of single layer coated at high temperatures. As for the flexibility, a double coated pipe can be bent by 3° per inch pipe diameter at −20°C without affecting coating, clearing 1.5° as required for the fabrication at the time of pipe laying.

3.2 Cathode Disbonding Resistance

The cathode disbonding of coated pipe refers to peeling of coated film under the action of hydrogen and alkali produced by the electrolysis of water due to protective current on exposed steel surface at the flaw site of coating acting as cathode. Therefore, the cathode disbonding resistance depends upon the adhesiveness and water permeability of coating[3]. Naturally, disbonding is required to be minimized in order to keep anticorrosiveness for a long period.

It has been known for long time that the chemical treatment of steel surface after blasting to enhance the adhesiveness of film is effective for improving the cathode disbonding resistance. An example of this effect is illustrated in **Table 4**. Kawasaki Steel has developed a chemical treatment process which effectively improves the cathode disbonding resistance.

Moreover, this chemical treatment has proved to be effective for improving the salt water resistance, since the coated pipe treated in this method has the adhesiveness of film little affected after immersion in an 80°C saline solution for a long period, as shown in Table 4.

3.3 Electric Insulation Resistance

The course of aging in the electric insulation resistance of coated pipe provides a criterion for evaluating the maintenance of anti-corrosive properties of coating film. Particularly, buried or submerged pipelines, which are often affected by the penetration of water, are required to have high electric insulation resistance and minimum aging.

As shown in **Fig. 4**, an accelerated corrosion test of immersing coated steel pipe in 3% NaCl aq. solution for 100 days at 80°C revealed the excellent anticorrosive properties of coating developed by Kawasaki Steel, with the electric insulation resistance as high as 10^8 ohm·cm² and very little aging.

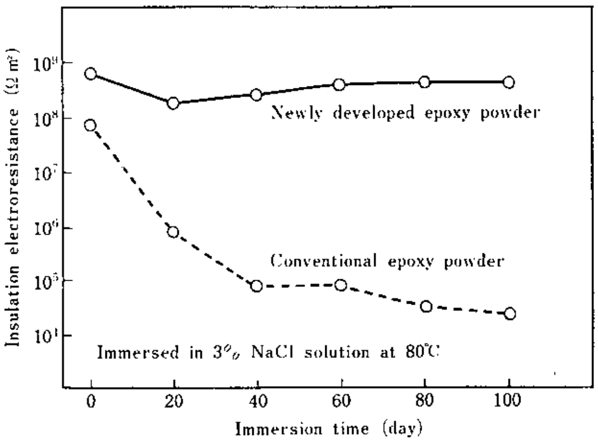

Fig. 4 Change of insulation electroresistance in immersion test

4 Conclusions

The line for epoxy powder coating installed at the Large Diameter Pipe Plant, Chiba Works has been described together with the properties of coated pipe produced by them.

The line features a number of innovative mechanisms such as a chemical treatment unit for processing the steel surface, a double layer coating system to make two films of different characteristics, and computer-controlled furnaces to coat at low temperatures and to cure at high temperatures, so as to manufacture epoxy-coated pipe having not only anti-corrosiveness but also impact resistance, flexibility and other mechanical properties. At the same time, epoxy resin powder suited for this coating process has been developed, allowing the production of epoxy-coated pipes excellent in both anti-corrosiveness and mechanical properties. Moreover, the quality assurance system consisting of a computer system and an automated inspection system has permitted to supply highly reliable steel pipes.

It is expected that the present line will not only contribute to the construction of pipeline requiring high quality pipe, but also exploit new fields of application utilizing excellent properties of products such as structural support and marine piles, thus expanding the demands.

The authors are grateful to Kansai Paint Co., Ltd. and its staff for their cooperation in constructing the present line and developing new coating method.

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