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Development of Manufacturing Techniques for ERW-SR Pipe in Coil

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Abstract:

There have been active requirements for long-length pipe and tube products in several industrial fields. For example, in the field of hollow parts for industrial equipment, primarily in the automobile industry, electric resistance welded (ERW) pipe and tube are adopted for the parts as a means to reduce cost, lighten car bodies, and streamline continuous and automatic manufacturing. Further, for construction of facilities with long piping as freezer piping for ice skating rinks and underground piping for snow melting systems, a pipe laying using extra-long-length pipe products without welding has been devised to reduce costs through improvement their fabrication efficiency and paring down in the number of the welding joints. To cope with those requirements, Nippon Steel's Hikari Works has developed a new coiled pipe product called "PIC" (Pipe In Coil), an ERW hot reduced pipe. This PIC is manufactured by a combined process technology in which the winding technique in the wire manufacturing process is introduced into the rolling process for continuous hot reducing of the electric resistance welded pipe and tube. In order to make the trailblazing PIC product a commercial product, several new techniques, for example, a defect-less processing technique for electric welded portions, a PIC hot-reducing and winding technique, and a quality assurance technique for the long-length materials, have been established for combined use with PIC secondary processing techniques such as continuous cold drawing and straightening, a coating technique for the inner surface of the PIC, etc. By applying these techniques, the PIC product with a good cold workability, superior corrosion resistance, excellent performance, and superior economic efficiency has been successfully put onto market. In this paper, these manufacturing and secondary processing techniques are introduced.

1. Introduction

In recent years, continuous operation and labor saving in the secondary working process of steel products have enabled extensive improvements in productivity and cost reduction. On the other hand, in the field of hollow parts for industrial machines and equipments, primarily in the automobile industry, there have been accelerated requirements for higher-grade and higher-function steel merchandise[1,2].

To cope with these requirements, Nippon Steel's Hikari Works has been engaged since 1987 in developing a manufactur-

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ing technology for an ERW hot-reduced pipe in a coil shape, a new coiled pipe product called "PIC" (Pipe In Coil). PIC is manufactured by a combined process technology in which the winding technique in the wire manufacturing process is introduced into the rolling process for continuous hot reducing (SR; stretch reducing) of the electric resistance welded (ERW) pipe and tube.

In order to make the trailblazing PIC product a commercial product, several new techniques which include these PIC manufacturing techniques, for example, a defectless processing technique for electric welded portions, a PIC hot-reducing and winding technique, and a quality assurance technique for the long-length materials, have been established for combined use with PIC secondary processing techniques such as continuous cold drawing and straightening technique, a coating technique for the inner surface of the PIC, etc. By applying these techniques, an electrically welded long-length pipe, or PIC, with good cold workability, superior corrosion resistance, excellent performance and superior economic efficiency has been successfully put onto market.

This paper introduces the trailblazing PIC manufacturing techniques, the quality assurance technique for the long-length pipe and its characteristics, and the secondary processing technique.

2. PIC Manufacturing Process and Its Features

2.1 Manufacturing process

The PIC manufacturing process has enabled the manufacture of ultra-long-length pipes by combining the technique to reduce the diameter of straight pipe and lengthen it, a technique which has accumulated through the existing ERW + SR, together with the high-level and highly efficient inspecting technique and wire-winding technique. The outline of the process is shown in **Fig. 1**.

The manufacturing process comprises process 1 through process 3.

Process 1: A 100m-long electric resistance welded (ERW) pipe is manufactured by forming a steel strip into the shape of a pipe and applying high-frequency induction welding. Then, the outside and inside beads are cut off and the inside beads are removed from the inside of the pipe by high-pressure air blowing.

Process 2: The pipe, which is called mother pipe, is heated up to about 1,000°C by a high-frequency induction heater and then reduced in diameter and lengthened by a stretch reducer.

Process 3: After being stretch-reduced, the steel pipe is hot-wound into a coil shape by a garret-reel type coiler.

In this process, seamless pipe or TIG welded pipe can be applied as the mother pipe.

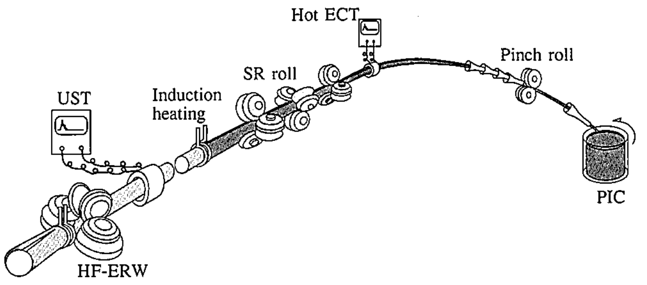

Fig. 1 PIC manufacturing process

2.2 Features

PIC has the features shown in **Table 1**. Since it can be continuously subjected to processes such as pipe drawing, straightening, and U-bending, its productivity and performance surpass that of conventional short-length pipe to a remarkable degree. Further, the decreases in the number of base-fitting works, omission of the primary heat treatment, etc., PIC manufacturing can be expected to lead to cost reduction and improvements in yield.

2.3 Available manufacturing range

An external appearance of PIC is shown in **Photo 1**, and the practically manufacturable PIC dimensions in **Fig. 2**. In the case of low-carbon steel (0.15%C grade), pipe with an extra small-diameter down to 10.5mm or heavy-wall pipe with a 26% t/D (thickness/outside diameter) can be manufactured. In this connection, since the diameters of the products are all almost the same as those of BIC (Bar In Coil), working installations for wire products can be applied. Further, a rich assortment of products ranging from carbon steel (0.04 ~ 0.45%C) to the higher grades such as low-alloy steel, stainless steel, etc., are kept in stock.

3. PIC Manufacturing Techniques

One technical problem in manufacturing long-length PIC is how to maintain a stable level of quality over its full length. In developing PIC, a quality assurance system for the process has been established together with methods to stabilize the forming and welding. Further, a non-flattening coiling technique to suppress deformation while hot-winding, a technique which did not exist in the traditional fields of pipe, bar, and wire, has also been developed.

3.1 Forming technique

In the manufacturing process for base pipe materials, a process which plays an important role in stabilizing the quality of

Table 1 Features of PIC

① Ultra-long lengthening can be achieved.
② Electric resistance welded (ERW) pipe with an extra-small diameter and a higher t/D can be manufactured.
③ Welded pipe of a higher quality with extremely small outside and inside beads can be manufactured.
④ Since PIC is hot-finished, it has a uniform micro structure and the primary heat treatment at the customers can be omitted.
⑤ A wide range of steel grades from carbon steel to low-alloy steel, stainless steel, etc., can be manufactured.

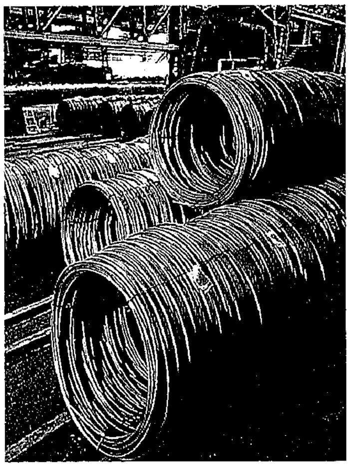

Photo 1 External appearance of PIC

PIC, the forming technique is nearly as important as the welding technique. Particularly, since the mother pipe has an outside diameter of 89.1mm, PIC is required to secure the stability of forming in a wide range of wall thicknesses from 1.6mm to 7.0mm. To cope with this subject, a technique to design an optimal-caliber forming roll has been developed on the basis of the spring-back amounts when bending sheet steel, thus enabling the stable fomation of the base pipe in the said wide range of wall thickness.

3.2 Welding technique

To obtain stabile quality at the weld zones of carbon steel and stainless steel, techniques for (1) controlling the welding atmosphere, (2) optimizing the welding heat input, and (3) controlling the welding heat input, have been established.

3.2.1 Technique for controlling the welding atmosphere

In our investigations seeking to suppress the generation of oxides which could possibly develop into impurities during the electric welding PIC of high-grade metals such as stainless steel, low alloy steel, high carbon steel, etc., we have clarified now the effects of the oxygen concentration and of the dew point in the welding atmosphere on the amount of oxides to be generated by heating in welding. The results of the investigation are shown in **Fig.** 3. The figure demonstrates that the non-oxidation region is in the range under 0.1% of the oxygen concentration and below -30°C of the dew point. In order to realize these conditions using the actual equipment, a squeeze-roll-integrated sealing apparatus was devised as shown in **Photo** 2.

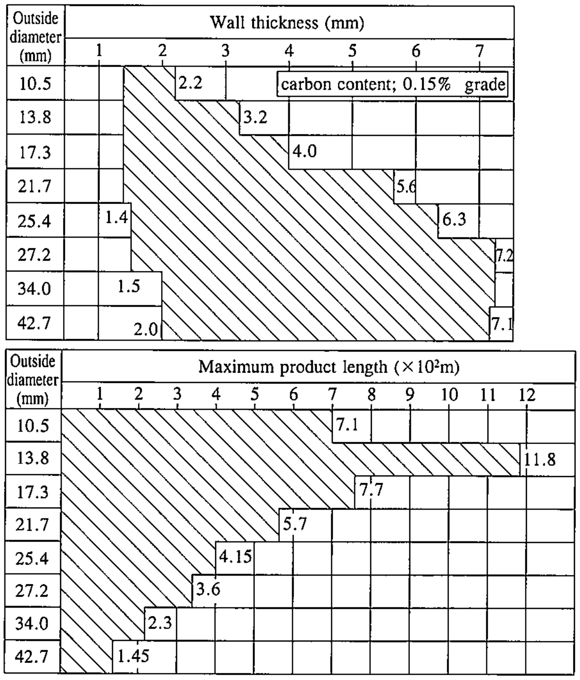

Fig. 2 Range of manufacturable dimensions

3.2.2 Technique for optimizing the welding heat input

The optimum welding conditions can be confirmed by a condition phenomenon defect diagram (CPD diagram) showing the relationship between the welding heat inputs, the welding phenomena, and the welding defects[4]. When manufacturing PIC, a CPD diagram of actual operation was drawn up for each steel grade and each size to ascertain the optimum welding conditions. An example of the CPD diagram for carbon steel is shown in **Fig.** 4.

3.2.3 Technique for controlling the welding heat input

A feedback controlling method which paired an apparatus to monitor the welding phenomena with a radiation thermometer was adopted. Further, a process computer (P/C) was introduced to perform the correction calculation for the heat input using the wall thicknesses and pipe manufacturing speeds in order to realize highly precise heat input control. As a result, the quality of weld zones has been considerably improved.

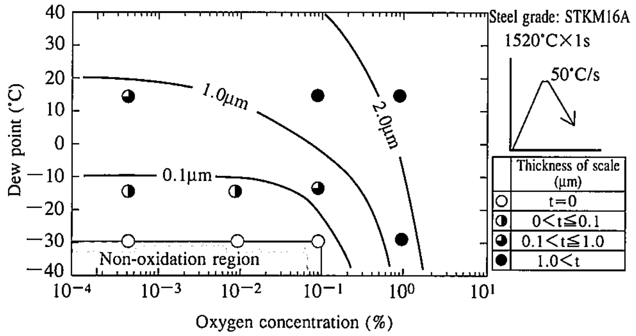

Fig. 3 Effects of dew point and oxygen concentration on generation of scale when induction heating

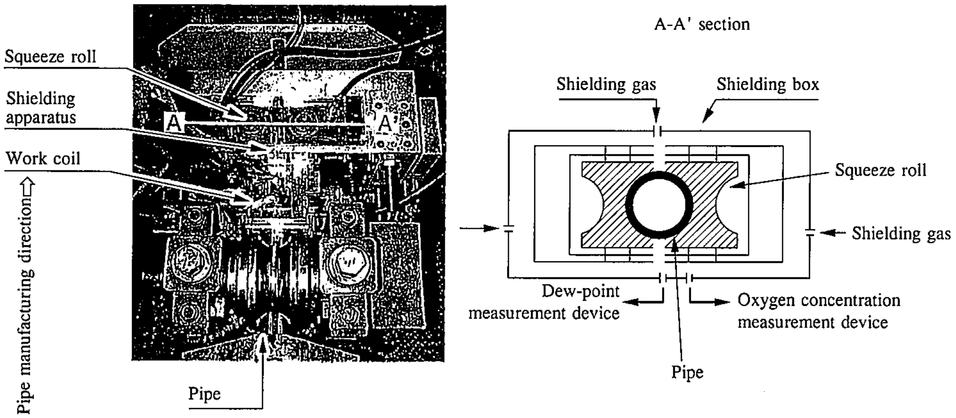

Photo 2 Squeeze roll integrated sealing apparatus

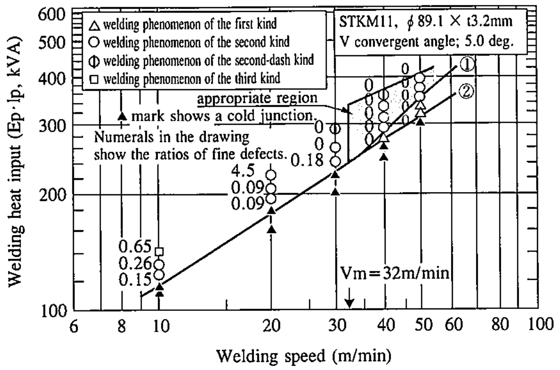

Fig. 4 CPD diagram for carbon steel

3.3 Stretch reducing (SR) technique

One of features of PIC is that both thin-wall pipe with a low t/D and heavy-wall pipe with a high t/D can be manufactured. Previously, there were technical problems caused by overlap of buckling into the inside surface of the thin-wall pipe, during its manufacture, as well as unsatisfactory accuracy of wall thickness in the case of the thick-wall pipe. To cope with these problems, operational conditions such as the SR conditions, the pattern of the area reduction for each stand, the shape of caliber, heating temperature, and so on were optimized, thereby enabling the SR in a wide range of dimensions.

On the other hand, when the pipe is hot-wound in a coil shape, deteriorations in the dimensional accuracy, such as a flattening in the vertical direction against the bending radius direction, non-uniformity of thickness, etc., are generally observed. To cope with these problems, a deformation-added winding technique has been established to improve the roundness. Flattening the pipe in advance in the horizontal direction against the direction of the bending radius with pinch rolls arranged just in front of the coiler.

3.4 Technique for assuring the quality in full length

The main quality requirements for the PIC are its weld zone properties, external surface properties, dimensional precisions, and material characteristics.

For the weld zone properties, authors developed a system to inspect the weld zones in full length using supersonic flaw detection after electric welding and to cut automatically and remove defective portions.

As it is very difficult to inspect the overall length of the external surface of PIC since it is wound in a coil shape, the inspection must be carried out on the way from the SR process to the winding process. To cope with this in manufacturing, a hot eddy-current-flaw-detection employing high-power mutual induction (HPMI) has been put to practical use for the first time in the world, and the eddy-current-flaw-detection in the vicinity of Curie temperature, a measurement which had been difficult to carry out in the past, has been realized.

For the dimensional accuracy and the material characteristics, SR conditions and winding conditions have been optimized, the manufacturing process is assured by controlling the SR temperature, and batch inspections are carried out by measuring the dimensions of both pipe ends and carrying out mechanical testing to assure the accuracy and characteristics.

4. Secondary Working Techniques for PIC

The PIC manufacturing techniques have thus far been described. To achieve the features of the ultra-long length PIC at its maximum in each application field, the development of secondary working techniques is also inevitable. These various secondary working techniques will be descrived in the coming pages together with their quality characteristics after they are performed.

4.1 Continuous pipe drawing techniques

4.1.1 Technique for treating the inside surface of the pipe

In the pipe drawing work, scales have to be removed from the inside and outside surfaces of the pipe and treatment has to be made to form a lubricating film on the surfaces. In general, the treatment of the inside and outside surfaces of the straight pipe is carried out by dipping the pipe into a pickling tank, film-forming tank, and so on.

In the case of the long-length pipe in a coil shape, the outside surface can be easily treated by applying any dipping method, but it is difficult to treat its inside surface over the full length due to the residual air. Thereupon, authors developed a technology to treat the inside surface by forcedly and continuously feeding a treating liquid through the pipe with a pump. An outline of the treating equipment is shown in **Fig. 5**.

Fig. 6 shows an example of the results obtained by checking the coating mass of a film-forming agent adhered by the above said method onto the inside surface of PIC extending 600m longitudinally. The coating mass is stable in the longitudinal direction. Therefore, when pipe drawing work is carried out in the next process, the PIC can be drawn very stably.

4.1.2 Technique for drawing pipe using a floating plug

In general, methods of core grid drawing, plug drawing, and floating plug drawing are used for the pipe drawing work. Among them, plug drawing, a method in which a plug is overhung by a rod is generally adopted. However, if long-length pipe in a coil shape is drawn, it is very difficult to insert the rod. Therefore, floating plug drawing should be applied for the case shown in **Fig. 7**, which does not require any rod.

The theory of floating plug drawing work explicates the floating conditions based on the geometrical and mechanical considerations, that is, the design data for both the plug and the dies[5].

However, in actual drawing operation even in cases when the plug and dies satisfy the equilibrium equation of floating,the pipe drawing work is sometimes disrupted due to material characteristics, surface properties, film forming state, and even the surface properties of the tools. Thereupon, to clarify a potential pipe drawing region, a number of pipe drawing tests were carried out, and the data thus obtained were pigeonholed by the ratio of the reduction in wall thickness to the reduction in outside diameter and the area reduction ratio. The relation of the said ratios is shown in **Fig. 8**. By designing the pipe-drawing-pass schedule based on the results obtained from these tests, authors have been able to attain a stable pipe drawing work. When PIC with a length of 600m is worked by this pipe drawing method, the dimensional accuracy obtained fully satisfies the allowances described in JIS G 3445, an example of which is shown in **Fig. 9**.

4.2 Technique for continuously straightening PIC

In traditional methods to construct piping, pipes of about 5 to 6 meters in length are connected by joints or welding. Further,

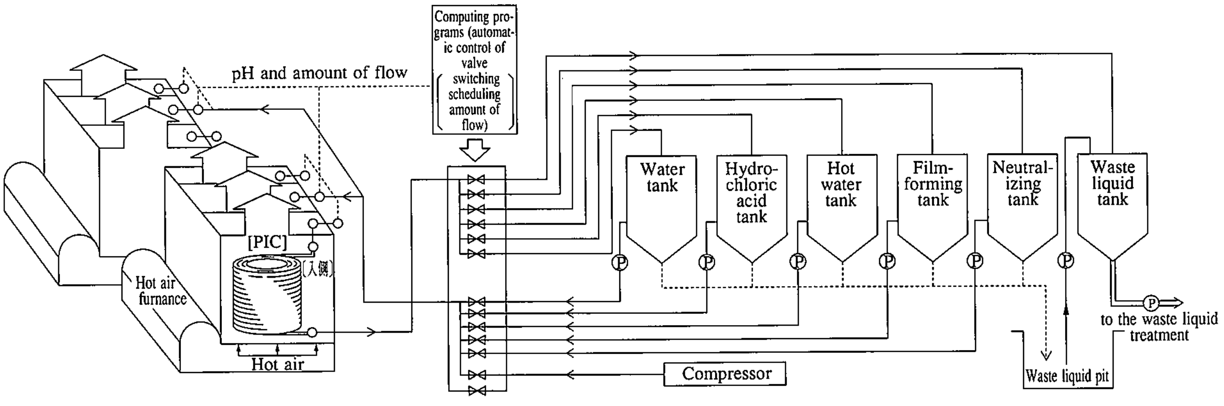

Fig. 5 Schematic diagrams of the equipment for continuous and automatic treatment of the inside surface of PIC

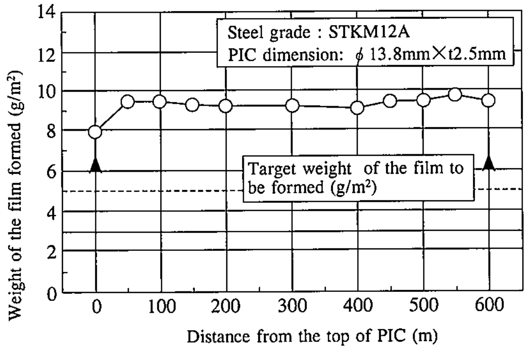

Fig. 6 Coating mass of the film-forming agent in the PIC longitudinal direction

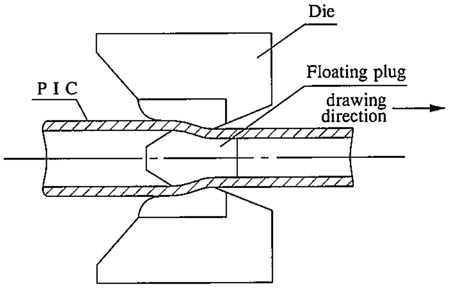

Fig. 7 Pipe-drawing method using the floating plug

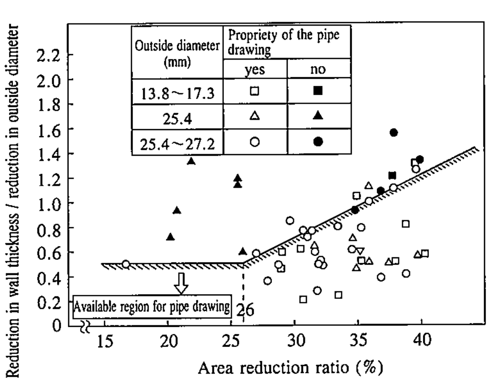

Fig. 8 Available region for pipe drawing

the process takes longer than that employed for PIC, and the welding requires a great deal of skill. However, if long-length and straight pipes are applied, especially in the case of piping works for facilities such as skating rinks and plants where long-length, straight pipes or high-curvature pipes are used, the term required for piping works could be expected. Thereupon, a technique has been developed to continuously straighten PIC to make it into a long, straight pipe.

Photo 3 shows the continuous-straightening machine thus developed. The machine has a VH roller straightening mode to straighten pipe without rotating it, and its roll clearance is made variable to provide optimum straightening conditions for a variable range of other pipe diameters. In addition, to cope with the site piping works, the machine is compactly designed with an overall length of only 3 meters and weight of about 5 tons. Further, a simulation program which has been developed for the residual curvature due to repeated bendings makes it possible to adjust the roll positioning without having to apply any special skill.

Measurements of the accuracy of curvature and the accuracy of outside diameter at intervals of 10 meters made directly after continuous straightening of PIC are shown in **Fig. 10** and **Fig. 11**, respectively. The straightening accuracy sufficiently satisfies the target value of 1mm/m for the general straight pipe, and the accuracy of the outside diameter after straightening the pipe fully satisfies the piping allowance described in JIS G 3452.

Photo 4 shows an example of application of the PIC continuous-straightening technique to refrigerant piping for a 400m skating rink. The considerable decrease in the number of welding points is evident in the photograph

4.3 Technique for continuously U-bending PIC

Among other applications, long-length piping is used as the meandering paneling for large refrigerating machines. Since such panels used to be manufactured by bending and joining together 5- to 6- meter-long welding pipes, the same problem as that was experienced in the case of long-length piping arose. Thereupon, a technique for continuously U-bending PIC, which can continuously bend the long length straight pipe in a U shape has been developed.

Fig. 12 shows the actuation flow of the PIC continuous U-bending machine. The pipe continuously delivered by a fixed length from the straightening machine is bent by two devices serving both as a cramp and dies. Just as the bending work finish-

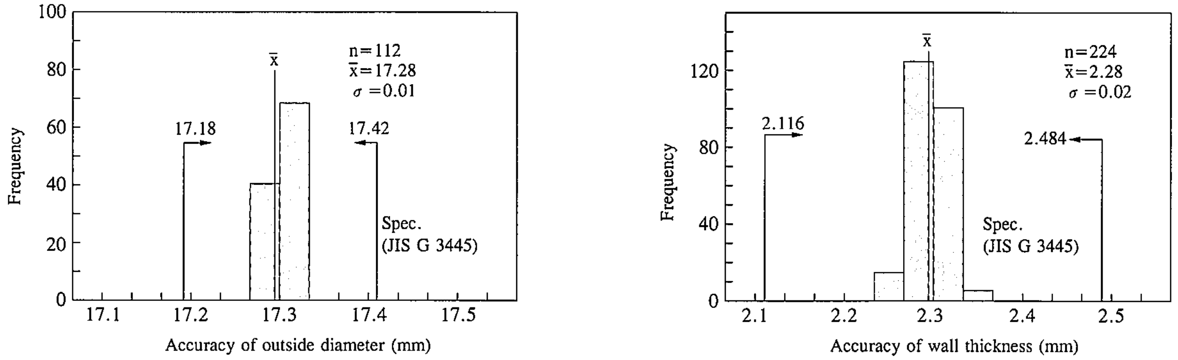

Fig. 9 An example of the dimensional accuracy after floating plug drawing

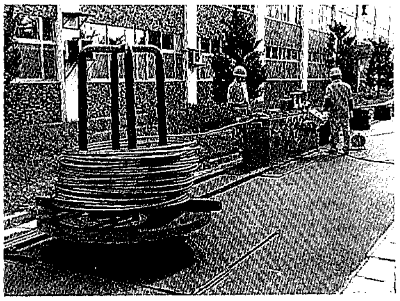

Photo 3 External appearance of the PIC continuous-straightening machine

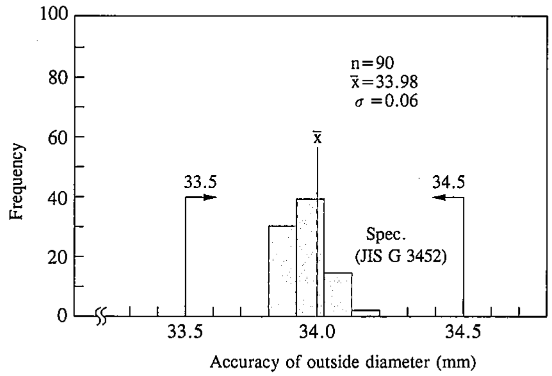

Fig. 11 Accuracy of outside diameter after straightening PIC

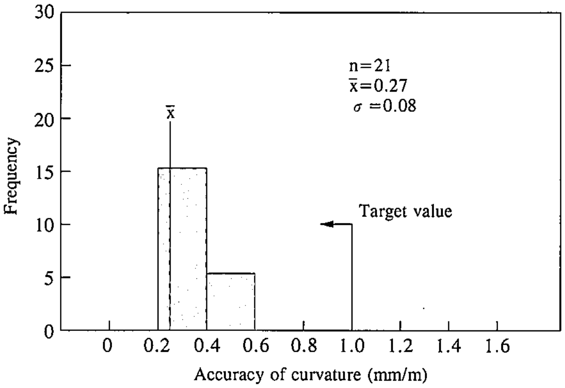

Fig. 10 Accuracy of curvature after straightening PIC

Photo 4 General view of a skating rink

es, the pipe is delivered once again, and the bending head is turned reversely to bend the pipe in the opposite direction. The machine can carry out the above said operation automatically, and the panel size can be freely set to up to 3.5 meters both in width and length.

Photo 5 shows the meandering bending panels of a heat-exchange freezer manufactured by applying the technique for continuous U-bending of PIC.

4.4 Cold forging property

When manufacturing machine parts using steel bar and wire through cold forging, the cold forging property of the material as an index of its workability has been hitherto valuated by compression test[6]. However, when the compression test is carried out a simple hollow PIC, buckling is generated on the PIC and the test cannot be applied.

Thus, we developed an end-face locking and compressing test[6] in which a "core" is inserted in a cutting test piece of PIC, and used. An example of evaluation of the cold forging property of PIC by this test is shown in **Fig. 13**. From the figure, the stretch-reduced PIC has a limit compressibility of up to 50% which can be raised up to 75%, the same level of bar and wire through spheroidal heat treatment.

Further, to establish a method for evaluating cold forging property of PIC[9], its propriety was analyzed by the performance analysis system[8] for cold forging steel in which the rigid and plastic FEM[7] was used.

4.5 Technique for coating the inside surface of PIC

Spray coating, dip coating, electrodeposition, and etc., have been applied as coating methods for various workpieces taking the corrosion resistance into consideration. However, it is very difficult to uniformly coat and to adhere the film closely to the inside

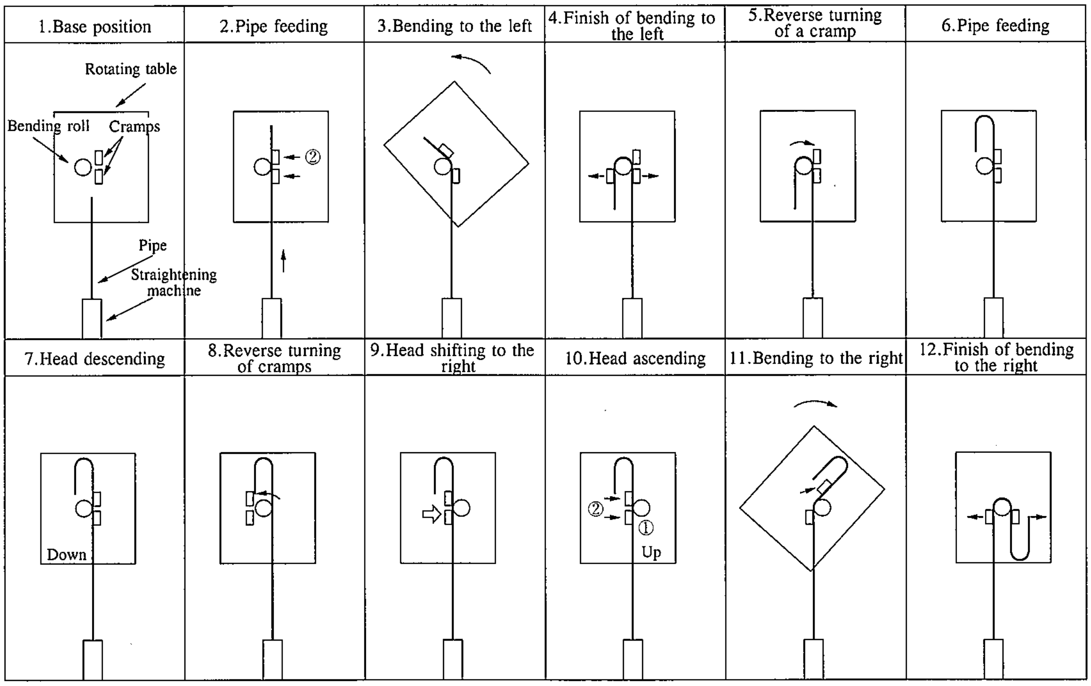

Fig. 12 Actuation flow of the PIC continuous U-bending machine

surface of long-length pipes such as PIC.

Thereupon, turning our attention to the self-precipitating aqueous coating method[10-13] in which a paint film is formed on a metallic surface by chemical reactions, we have established a technique for coating the inside surface of PIC which gives a heightened corrosion-preventive property to the inside surface by optimizing the inside surface properties of the long length pipe, the speed with which the coating liquid is supplied, the washing speeds, and so forth.

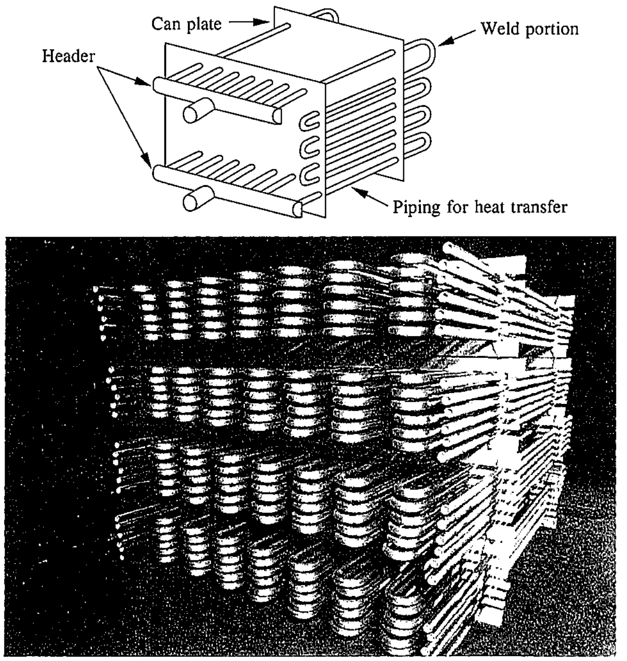

Photo 5 General view of the freezer's meandering piping for heat exchanging

This self-precipitating aqueous coating to the inside surface of PIC is carried out by the inside surface coating unit shown in **Fig. 14**. The coating properties obtained after coating are shown in **Photo 6**, and the thickness distribution of the film coated in **Fig. 15**. The results of a salt spray test (using samples with line-cuttings at the coated portion) perfomed according to JIS Z 2371 for accelerated corrosion testing, on straightened pipes and U-bended parts are shown in **Photo 7**. The coated portions other than the portions with line-cuttings exhibit no signs of rusting and have good corrosion resistance.

5. Conclusion

PIC, a new type of piping manufactured by a method combining the process to manufacture small-diameter electrically welded (ERW) pipe with the wire-manufacturing process has been firmly established as an industrially applied steel product through the development of various trailblazing manufacturing techniques and

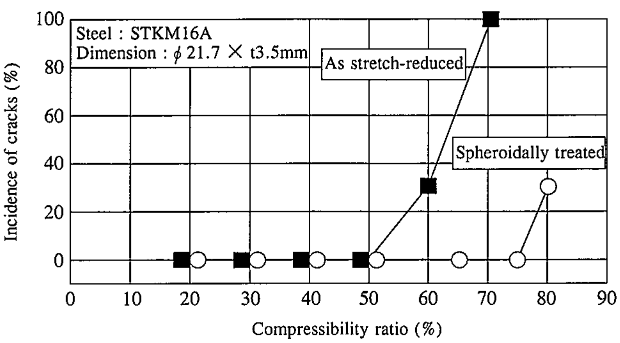

Fig. 13 Characteristics of PIC's compression workability

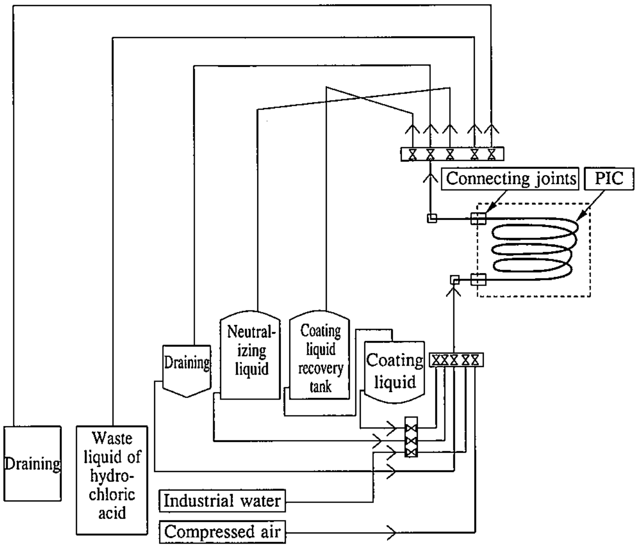

Fig. 14 Model diagram of the unit for coating of the inside surface of PIC

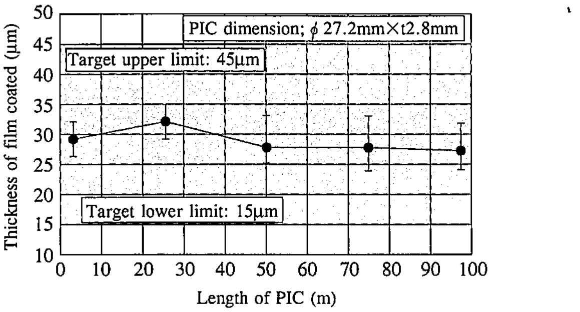

Fig. 15 An example of the thickness distribution of film after coating the inside surface of PIC

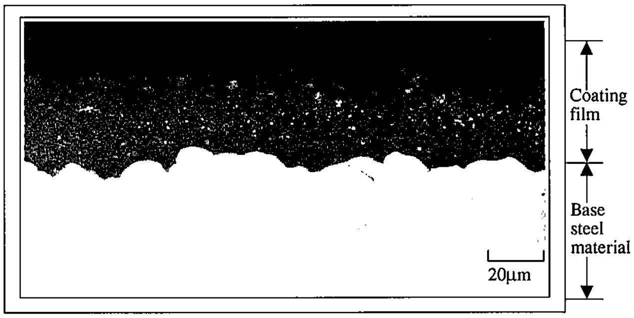

Photo 6 Coating property after coating the inside surface of PIC

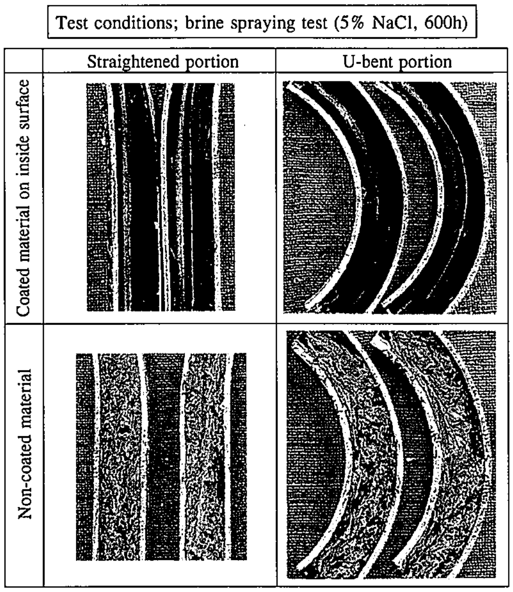

Photo 7 Results of corrosion test

secondary treating techniques. Up to the present, 250,000 tons of PIC have been produced in total.

Steel products will be endowed hereafter with a higher quality, a higher value added, and a lower cost. Moreover, also in the field of secondary working, continuous working and process saving are expected to be pushed forward in an effort to further reduce costs. From the standpoint of its profile features and quality characteristics,PIC is a steel product capable of coping with these needs and Nippon Steel is presently working to open up new avenues for its use and develop working techniques to cope with it through technical cooperations with users.

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