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A Study on the Deformation of O.D 245mm Off-shore Plant Pipe by Induction Bending

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고주파 벤딩을 통한 직경 245㎜ 해양플랜트 배관의 변형에 관한 연구

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ABSTRACT

Bending using high-frequency induction heating is used to bend pipes and sections, and is currently widely applied in industrial fields such as power generation facilities, ships, onshore plants, and offshore plants. The purpose of this study is to study the manufacturing process and design technology of high-frequency bending of pipe to make the best pipe design arrangement. Although various studies are being conducted in the field of high-frequency bending, more research is needed on high-frequency bending of pipes for ship building and offshore plants. The purpose of this study is to review the feasibility of production design using 3D model tool of S3D and AM(PDMS), and to review and improve bending thickness reduction, reduction rate, and roundness.

Keywords : Induction Heating(유도 가열), High-frequency Induction Bending(고주파 벤딩), Offshore Plant(해양 플랜트)

1. Introduction

High-frequency bending is extensively used to manufacture products that are used in offshore plants. In this study, we aim to construct the best pipe layout by investigating the fabrication process and design techniques of high-frequency pipe bending. Although considerable amount of research has been performed in the field of high-frequency bending, there is a need for additional research in high-frequency pipe bending for shipbuilding and offshore plants. In this study, we investigated the validity of production design using 3D modeling tools, such as S3D and AM (PDMS), and attempted to improve the roundness of pipes and the amount

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and rate of decrease in thickness, etc. Designing high-pressure pipes and cable pipes with the knowledge of the characteristics of high-frequency bending can strengthen the competitiveness in the field of shipbuilding and offshore plants. In this study, the pipe bending mechanism was first analyzed theoretically to obtain the best pipe bending design that improves the installation productivity and satisfies the production design requirements. Additionally, pipe bending tests were conducted to confirm the ovality and amount of thickness reduction due to high-frequency bending.

2. Pipe Design for High-Frequency Bending

2.1 Purpose of high-frequency bent pipes

High-frequency bent pipes are used to mitigate the thermal expansion and shock that occur when a fluid with high temperature and pressure flows through a pipe. Furthermore, high-frequency bending is applied to cable pipes to prevent damage to the cables as shown in Fig. 1 because several cables and sensors are installed together.

2.2 Definition and characteristics of high-frequency bending

High-frequency bending(pipe bending by high-frequency local induction heating) is a hot working technology that uses high-frequency induction heating to bend steel components, such as a pipes, I-beams, channels, and H-steel, as shown in Fig. 2. Unlike the cold bending process, high-frequency bending has lower ellipticity and thickness reduction rate. Moreover, the bending angle and radius can vary. Comparatively, three-dimensional bending and multiple bending are easy, and they are advantageous because of the low-cost and high productivity, as they do not require a separate mold compared to pipe bending products that use molds. As high-frequency bending is a hot working bending process, it is possible to bend pipes with large outer diameters (ODs) while maintaining a small forming load. Particularly, it can be used to produce special alloy steel bending products, which are difficult to manufacture at room temperature. Additionally, high-frequency bent pipes can replace elbows in curved pipe sections, thereby reducing the number of welding areas significantly.

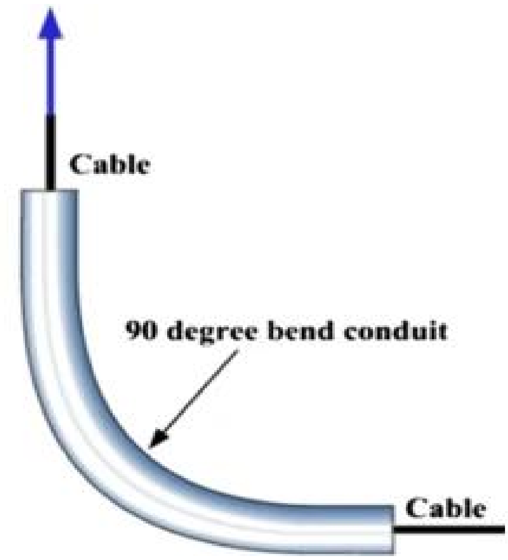

Fig. 1 Pulling cable through cable pipe (Conduit)

Fig. 2 Equipment of induction bending

2.4 Thickness reduction rate and ovality

The rate of thickness reduction is expressed in Equation (1):

$$Tr = \frac{T_0 - T_1}{T_0} \times 100\% \qquad (1)$$

where,

T_0 is the pipe thickness before bending,

T_1 is the minimum pipe thickness after bending, and T_r is the thickness reduction ratio (%).

Ovality is expressed in Equation (2):

$$Ovality = 2 \times \frac{(A-B)}{(A+B)} \times 100\% \qquad (2)$$

where, A and B are illustrated in Fig. 3.

A is the maximum O.D(Outer diameter) Max and B is the minimum O.D(Outer diameter) Min.

3. Production Defects and Prevention

3.1 High-frequency bending defects in pipes

In the high-frequency bending process, the transfer speed of the pipe is increased to improve productivity, and this results in a non-uniform temperature distribution. This also causes an increase in the deformation resistance of the pipe, an increase in the bending force, and defects, such as buckling and ellipticity. Buckling defects occur owing to the hardness of the material being bent.

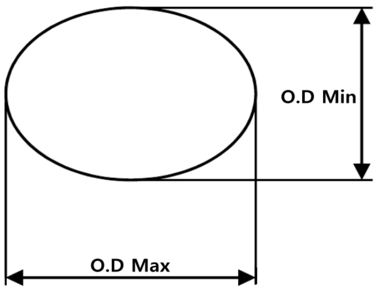

Fig. 3 Definition of ovality

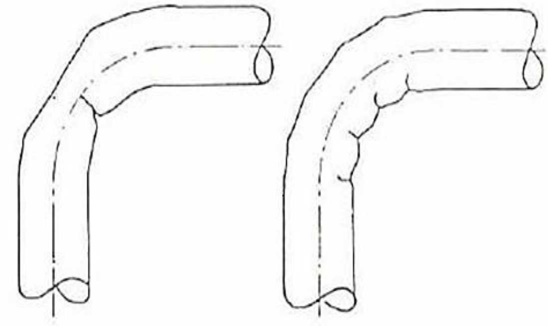

Fig. 4 Buckling defect

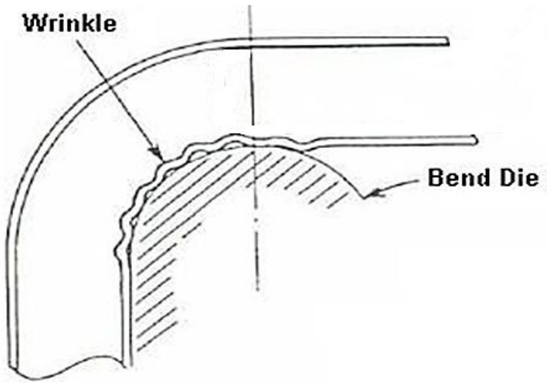

Fig. 5 Wrinkling defect

This can cause deformation, as shown in Fig. 4, if the hard material is not compressed sufficiently at the internal radius of the bend. Wrinkling defects occur when the material undergoes compressive deformation during bending, as shown in Fig. 5.

3.2 Prevention of high-frequency bending defects in pipes

To prevent defects, optimal heating conditions must be designed. This requires heating conditions that consider the induction heating process variables (induction frequency and inductive power), pipe transfer speed for uniform heating, and a coil design for the optimal temperature gradient.

4. Results and Discussion

In this study, a pipe bending test was performed using the API 5L X65 QS PSL2 OD 245mm diameter pipe. The results of the magnetic particle inspection performed before the dimensional measurement of the bending section did not show any problem.

4.1 Dimensional measurement of the fabricated pipe and discussion.

In this study, the dimensional changes that can be observed while performing high-frequency bending at 90°, 80°, 60°, 45°, 30°, and 10° for the API 5L X65 QS PSL2 OD 245mm diameter pipe are represented in several graphs. As shown in Fig. 6, the dimensions of the high-frequency bending section were measured at nine points (1 to 9) and their changes were confirmed.

4.2 Measurement results

The high-frequency bending of the API 5L X65 QS PSL2 OD 245mm diameter pipe was performed at 90°, 80°, 60°, 45°, 30°, and 10° angles. To confirm the changes before and after the bending operation, the dimensional changes of outer, inner, and upper-side thicknesses were measured at nine points on the pipe, as shown in Figs. 7 to 12.

The test results show that the outer thickness of the API 5L X65 QS PSL2 OD pipe (diameter = 245mm) decreased significantly and evenly at Points 2–8. After bending, the average decrease in the outer thickness was 1.55mm. The outer thickness decreased the most with an average of 1.62mm in the case of 45° bending, whereas it decreased the least at an average of 1.44mm in the case of 10° bending. The inner thickness of the pipe increased significantly and evenly at Points 2–8. After bending, the average increase in the inner thickness was 2.82mm. The highest increase in the inner thickness was 2.88mm, which was in the case of 30° bending, whereas the least average increases was 2.79mm in the cases of 10° and 60° bending. The thickness of the upper-side of the pipe increased significantly and evenly at Points 2–8. After bending, the average decrease in the upper thickness was 0.68mm. The maximum average decrease in the upper thickness was 0.90mm in the case of 90° bending, Whereas the minimum average decrease was 0.53mm in the cases of 10° and 45° bending. After bending at 90°, 80°, 60°, 45°, 30°, and 10° angles, the changes in the thickness of the pipes were analyzed. The result confirmed that the

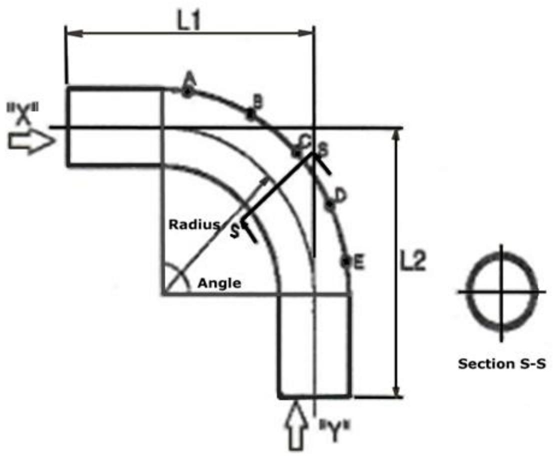

Fig. 6 Check point of bent pipe

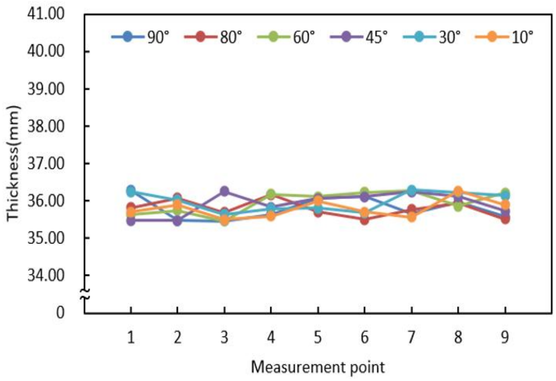

Fig. 7 Extrados thickness of pipe(Before)

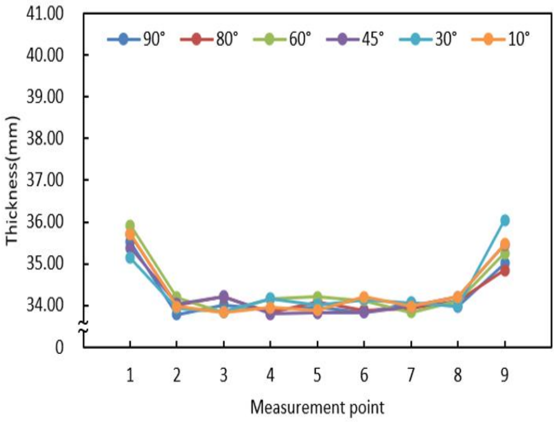

Fig. 8 Extrados thickness of pipe(After)

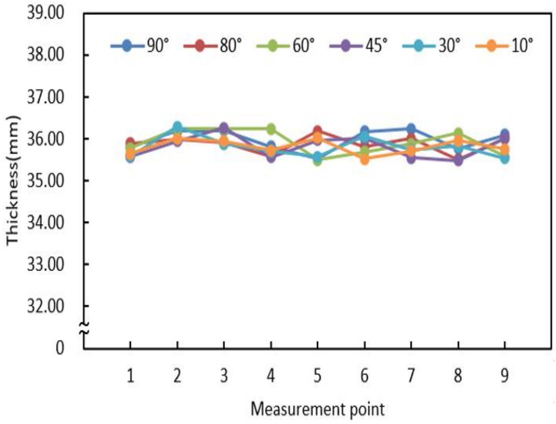

Fig. 11 Top thickness of pipe(Before)

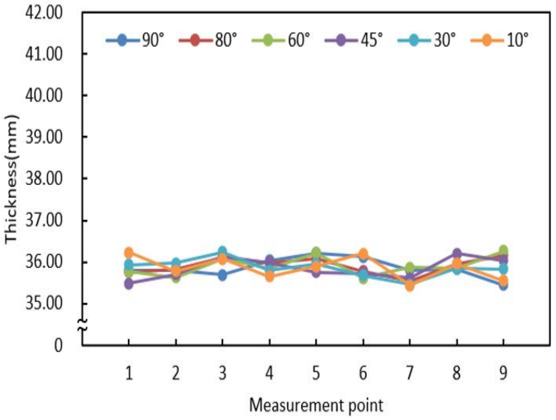

Fig. 9 Intrados thickness of pipe(Before)

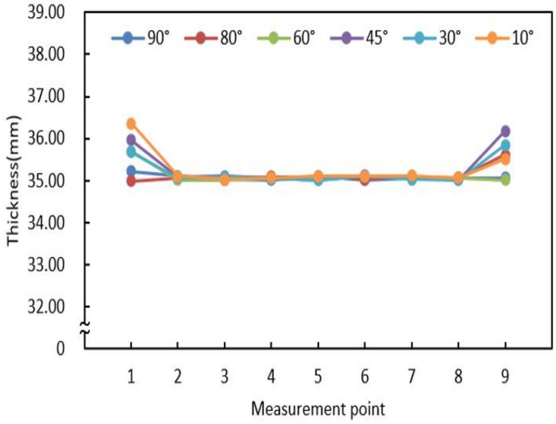

Fig. 12 Top thickness of pipe(After)

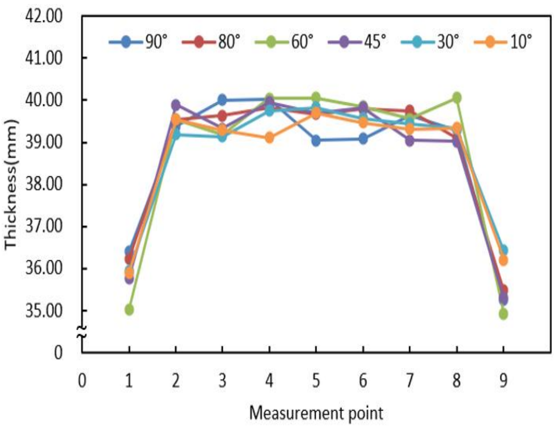

Fig. 10 Intrados thickness of pipe(After)

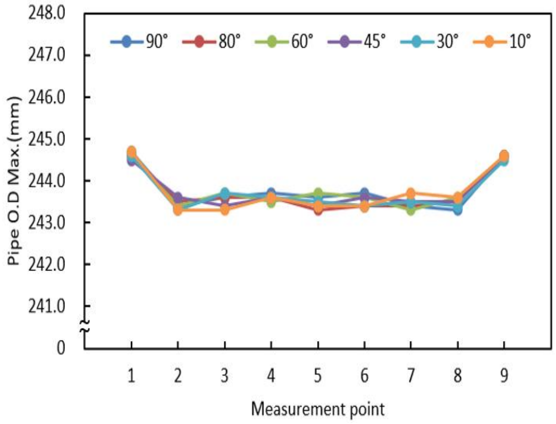

Fig. 13 Pipe O.D Max.

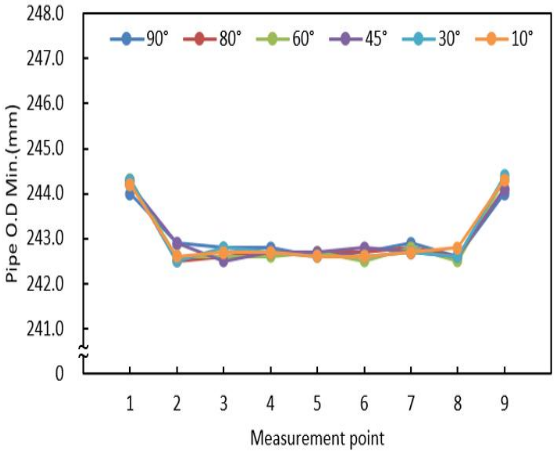

Fig. 14 Pipe O.D Min.

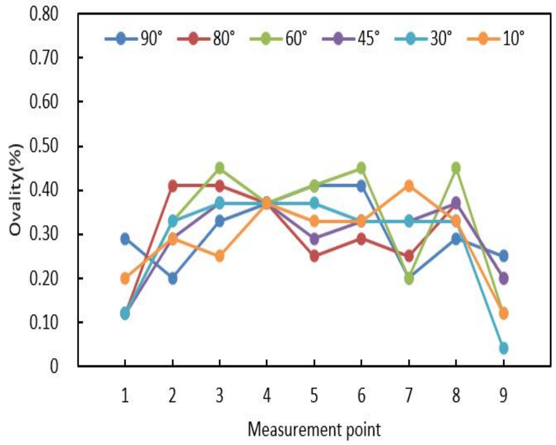

Fig. 15 Ovality

inside of the pipe showed the largest change, whereas the thickness at the top of the pipe showed the least change.

The changes in pipe ovality while the API 5L X65 QS PSL2 OD 245mm diameter pipe was subjected to high-frequency bending at 90°, 80°, 60°, 45°, 30°, and 10° are shown in Figs. 13 to 15.

The test results show that 60° bending case had the highest average ovality of 0.32%, whereas 10° and 30° bending cases had the lowest average ovality of 0.29%.

5. Conclusion

The conclusions of this study are as follows:

1. The average thickness reduction of the outer thickness of the API 5L X65 QS PSL2 OD 245 mm diameter pipe was found to be in the range of 1.44 – 1.62 mm, which is a 4.32% reduction from the overall average thickness.
2. The average increase in the inner thickness of the API 5L X65 QS PSL2 OD 245 mm diameter pipe was found to be in the range of 2.79 – 2.88 mm, i.e., an increase of 7.87% from the overall average thickness.
3. The average decrease in the upper-side thickness of the API 5L X65 QS PSL2 OD 245 mm diameter pipe was found to be in the range of 0.53 – 0.90 mm, i.e., a reduction of 1.91% from the overall average thickness.
4. The test shows that the ovality at each point of the API 5L X65 QS PSL2 OD 245 mm diameter pipe was in the range of 0.29 – 0.32%, and the overall average ovality was 0.30%.

In this study, it was observed that the pipe with high-frequency bending maintained roundness better than the pipe with general bending. However, the thickness change that occurs during bending must be considered while designing the pipe layout. The results of this study can be used as a reference for the optimal design of high-frequency bending of pipes for shipbuilding and offshore plants.

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