Technical Report

Steel Pipe Products and Mechanical Connections for Improving the Productivity and Quality of Auxiliary Methods in Mountain Tunnel Construction

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Abstract

In mountain tunnel construction, various auxiliary methods are applied for improving the instability of ground conditions. Nippon Steel Corporation has contributed to improving the productivity and quality of mountain tunnel construction by developing pipe products—lightweight pipes with high strength, dimpled pipes for high bond strength. In addition, thread connections for new pipe products have been developed. This paper introduces details of the pipe products and thread connections for the auxiliary method in mountain tunnel construction.

1. Introduction

The New Austrian Tunneling Method (NATM) is often used to construct tunnels in mountainous areas and some urban areas in Japan. In the NATM, which was introduced into Japan in the 1970s, after natural ground has been excavated, a tunnel is constructed while the stability of the excavated bevel (working face) is secured by characteristic timbering, such as shotcrete and lock bolts. If the stability of the working face cannot be secured by timbering alone, an auxiliary method may sometimes be additionally applied. Nippon Steel Corporation has been contributing to improving the productivity and quality of mountain tunnel construction methods by providing steel pipes, which are used as reinforcement members in auxiliary methods in mountain tunnel construction, as well as the technologies to use such pipes. This paper introduces part of Nippon Steel's technical development of steel pipes for auxiliary methods in mountain tunnel construction.

2. Development of High-tension Steel Pipes for Forepiling

In forepiling methods, reinforcement members are driven into the crown face of a tunnel diagonally from above as shown in **Fig. 1**. Then a urethane-based or cement-based chemical is charged to the natural ground via the reinforcement members to secure the stability of the natural ground, including the working face, which will be excavated immediately after that.[1] As reinforcement members, carbon steel pipes for general structural purposes (STK400) with the diameter of approximately 100 mm specified in JIS G 3444 are often used. Among steel pipe forepiling methods, in the All Ground Fasten (AGF) method, a drill carriage for excavation is used to drive reinforcement members into natural ground and four or so of approximately 3-m long steel pipes are connected in many cases. In this step, operators load reinforcement members onto the drill carriage by human power. The weight of a pipe is close to the upper weight

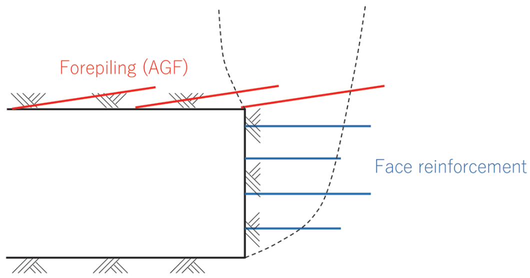

Fig. 1 Schematic drawings of forepiling method and face reinforcement method

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limit that can be moved by human power and thereby the workload is high. Nippon Steel cooperated with Obayashi Corporation and Kameyama Co., Ltd. to develop thin, lightweight, high-tension steel pipes for this construction method as well as tread connections for joining such steel pipes, aiming to improve the quality and productivity of the construction method.

2.1 Details of the high-tension steel pipes

Figure 2 shows photographs of STK400, which is used for the conventional AGF method, and the developed steel pipe for comparison. **Table 1** lists the comparison of the cross-sectional and structural performance. The developed high-tension steel pipes are cold-finished electric resistance welded pipes manufactured from hot-rolled steel plates; the outer diameter is 114.3 mm and the wall thickness is 3.5 mm while the wall thickness of the conventional steel pipe is 6.0 mm (the outer diameter is the same). This thickness decrease reduced the weight from 48.0 kg to 28.7 kg (approximately 40%) per pipe with a length of 3.0 m, which is often used in forepiling construction methods. The minimum yield strength of the high-tension steel pipe was set to 600 MPa and the minimum ultimate tensile strength was set to 730 MPa. As a result of this, both the tensile strength and bending moment of the pipe body that are theoretically calculated from the minimum yield and ultimate tensile strength exceed those of the conventional steel pipe. Thus, we succeeded in developing the steel pipes that can reduce the workload and that have excellent structural performance as reinforcement members.

2.2 Development of special thread connections

In the AGF construction method, steel pipes are constructed while often coupled by fastening thread connections through human power. However, the developed steel pipes are thin and thereby if the conventional thread connections are applied without being processed, sufficient structural performance cannot be secured. To resolve this issue, we developed special thread connections. When element pipes are thin and thread connections are used, couplers are used to connect the pipes and connections or the diameter at the element pipe ends is widened or reduced by processing to secure structural performance in many cases. Nippon Steel succeeded in securing structural performance equal to or higher than that of the conventional steel pipe base material listed in Table 1 only by directly processing male and female threads on element pipes thanks to our original connection design (**Fig. 3**). The structural performance was sufficiently verified by freely using bending and tensile tests and structure analysis as shown in **Fig. 4**. Figure 4 shows the results of the thread connection bending test as an example. Six thread connections with the same specifications were subjected to the bending test. The test results show that the maximum bending moment exceeds the targeted 12.3 kN m (yield bending moment of the conventional steel pipe body) stably.

2.3 Construction records, etc.

The developed high-tension steel pipes were tested at actual tunnel construction sites and then put into practical use. Their actual application has been completed at multiple actual sites.[2] **Figure 5**[2] is a photo showing the test construction. Application of the high-tension steel pipes produced the following two advantages mainly.

(1) Reduction of loads on operators

As shown in Fig. 2, the weight of a single steel pipe was reduced by 40%. Operators working at actual sites reported that loads on them were reduced.[2]

(2) Reduction of cycle time

The reduction of the steel pipe weight has made it possible to

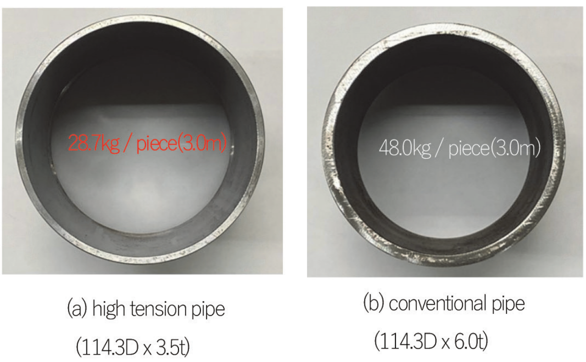

Fig. 2 Comparison between cross sections of conventional and high-tension pipes

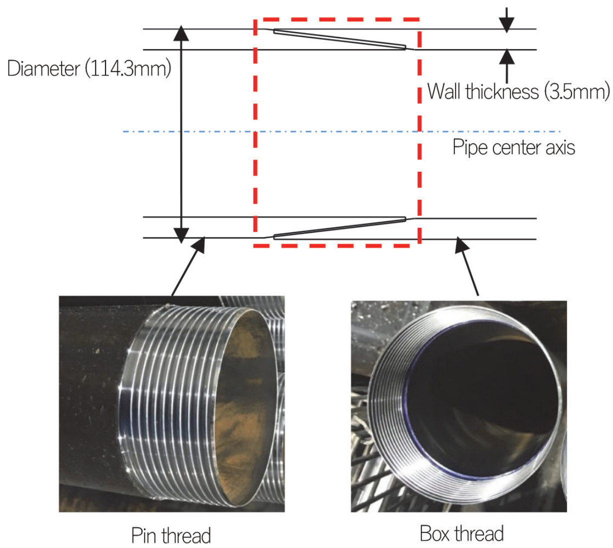

Fig. 3 Schematic drawings and pictures of thread connection for high-tension pipe

Table 1 Comparison between structural performance of conventional and high-tension pipes

Pipe	Diameter	Thickness	Weight	Specified minimum strength		Strength of pipe body	
				Yield	Tensile	Tensile strength	Yield bending moment
	mm	mm	kg/m	MPa	MPa	kN	kN m
Conventional	114.3	6.0	16.0	235	400	480	12.3
High-tension	114.3	3.5	9.56	600	730	731	19.6

load members onto construction machinery while boring the ground, which reduces the cycle time of construction. As an actual construction record, it was reported that the use of high-tension steel pipes reduced the cycle time by approximately 10% (150 minutes to 135 minutes per member (12.5 m)).[2)]

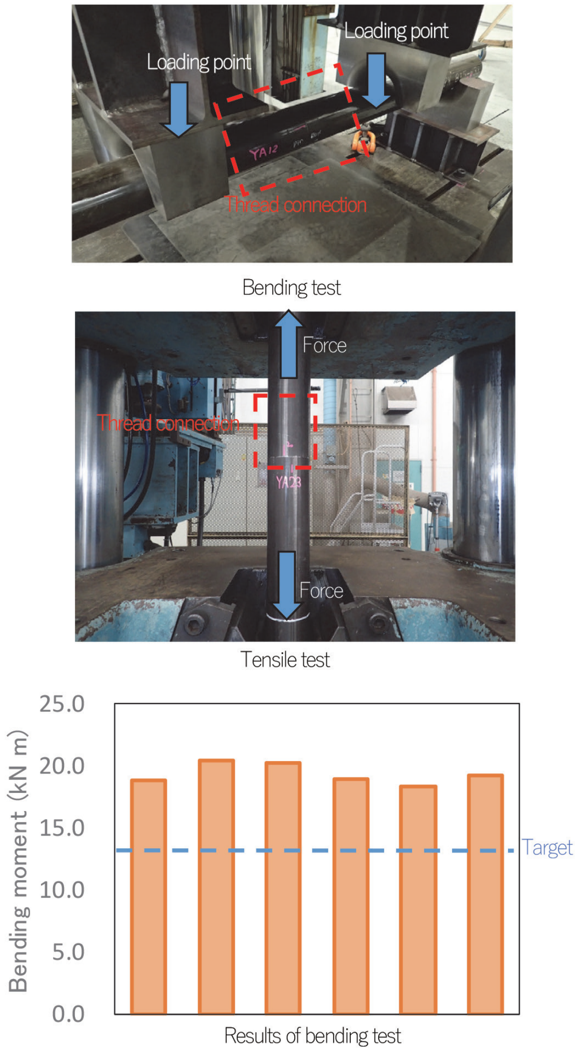

Fig. 4 Pictures of mechanical test of thread connection and the results of bending test

Fig. 5 Picture of AGF method with high-tension pipe[2)]

3. Development of NS-SUPERGRIP™ (Dimpled Steel Pipes) for Face Reinforcement Methods

When mountain tunnels are drilled, to secure the stability of the mirror planes, reinforcement bolts are placed into the mirror planes as an auxiliary method in some cases (Fig. 1). In a face reinforcement bolt construction method, extra-long face bolts 3.0 m to 5.0 m in length are placed into the natural ground as reinforcement bolts. Then, in many cases, a mortar- or resin-based chemical is also charged to fix the mirror planes loosened during the drilling to the natural ground. In this method, the placed bolts will eventually be drilled along with the natural ground and thereby easy-to-break bolts made from resin materials are sometimes used to make drilling easy. However, in recent years, to make it easy to separate the solidified chemical, reinforcement bolts, and earth/sand, etc. after drilling, slit-type steel pipes that are easily broken have been used as bolts in more and more cases.[1)]

Steel pipes to be used as face reinforcement bolts need to adhere to chemicals that were charged to secure the stability of the natural ground as their property and thereby if the adhesion of normal steel pipes is insufficient, they need to be supplementarily processed (boring holes and mounting ribs). Nippon Steel offers NS-SUPERGRIP™ (dimpled steel pipes) (herein after referred to as dimpled steel pipes) as face reinforcement bolts. The dimpled steel pipes have dents formed on the surfaces during the manufacturing to enhance the bonding property of the element pipes.

3.1 Details of dimpled steel pipes

Nippon Steel provides various types of dent-formed steel pipes. Such hot-finished electric resistance welded pipes are manufactured as follows: A hot-rolled steel plate is formed into a pipe shape and electric-welded; and then the plate passes between rollers with ribs provided, which forms dents on the surface of the steel pipe (**Fig. 6**[3)]). In addition to the dimpled steel pipe (**Fig. 7**[3)] (a)) introduced in this paper, various types of stepped steel pipes shown in Figs. 7(b)

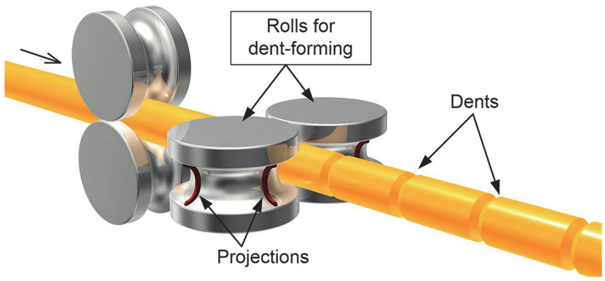

Fig. 6 Schematic drawing of dent forming process on pipe surface[3)]

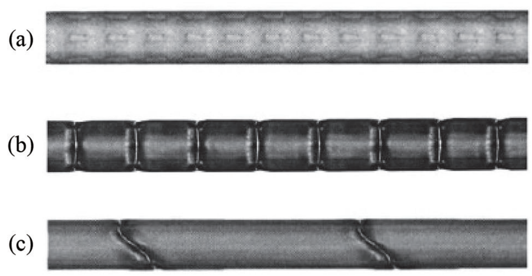

Fig. 7 Examples of dent-formed pipe[3)]
(a) Dimpled pipe, (b) Grooved pipe, (c) Oblique grooved pipe

and 7(c) are manufacturable. They have been applied to a foot pile construction method among auxiliary methods in mountain tunnel construction.[4] The strength of bonding with mortar was tested under the same test conditions using three types of materials: Normal smooth-surface steel pipe, dimpled steel pipe, and D51 reinforcement bar. **Fig. 8**[3] shows a photo during the test and results as an example showing the bonding strength of the dimpled steel pipe. The bonding strength of the dimpled steel pipe is approximately seven times higher than that of the normal steel pipe. When comparing to the reinforcement bar, although the maximum bonding strength of the dimpled steel pipe is lower than that of the bar, the decrease in the bonding strength after the peak is characteristically small.

Table 2 lists the example specifications of dimpled steel pipes provided for face reinforcement methods. The outer diameter is 76.3 mm, the wall thickness is 4.5 mm, the minimum yield strength of the material is 235 MPa, and the minimum ultimate tensile strength is 400 MPa. The secured material strength corresponds to that of carbon steel pipe STK400 for general structural purposes. The numbers of dents in the circumference and pipe axis directions and the intervals between them can be adjusted based on the necessary bonding strength.

Table 2 Specification of dimpled pipe for face reinforcement method

Pipe	Diameter	Thickness	Specified minimum strength	
			Yield	Tensile
	mm	mm	MPa	MPa
Dimpled pipe	76.3	4.5	235	400

3.2 Development of special thread connections

Multiple extra-long face reinforcement bolts are connected with mechanical connections (e.g., thread connections) for construction in many cases. However, screw threads cannot be formed on the dents on the surfaces of dimpled steel pipes. If threads are directly processed on steel pipes, the necessary structural performance may not be secured. To supplement this, we developed special thread connections (**Fig. 9**); female threads are processed at the dimpled steel pipe ends and a nipple that was produced by processing male threads at both ends of a short normal steel pipe (STK400) is used to connect the dimpled steel pipes with each other. The wall thickness of thread connections on dimpled steel pipes is thicker and the tensile strength necessary for face reinforcement members was secured thanks to the method. Figure 9 shows the results of a tensile test of thread connections. The tensile testing machine shown in Fig. 4 was used for the test. Three thread connections with the same specifications were subjected to the tensile test. The test has confirmed that the tensile strength stably exceeds 300 kN of the target strength (tensile strength of the steel pipe body).

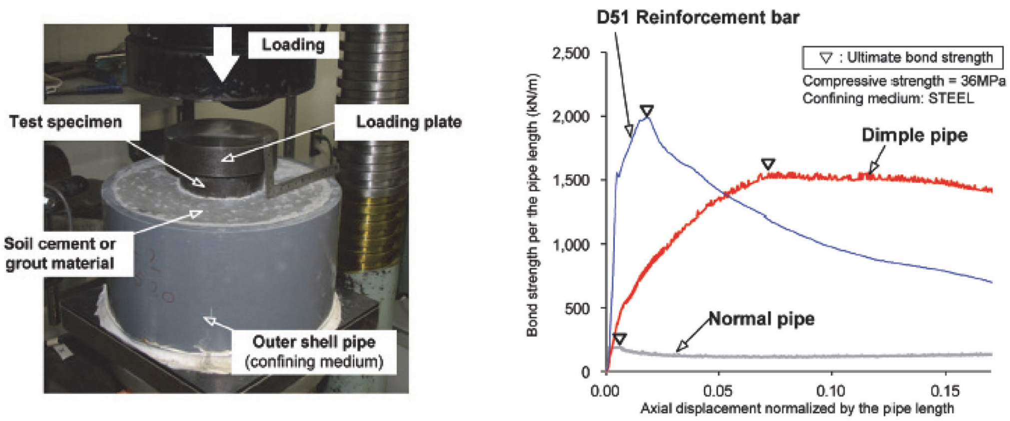

Fig. 8 Picture and results of bonding test[3]

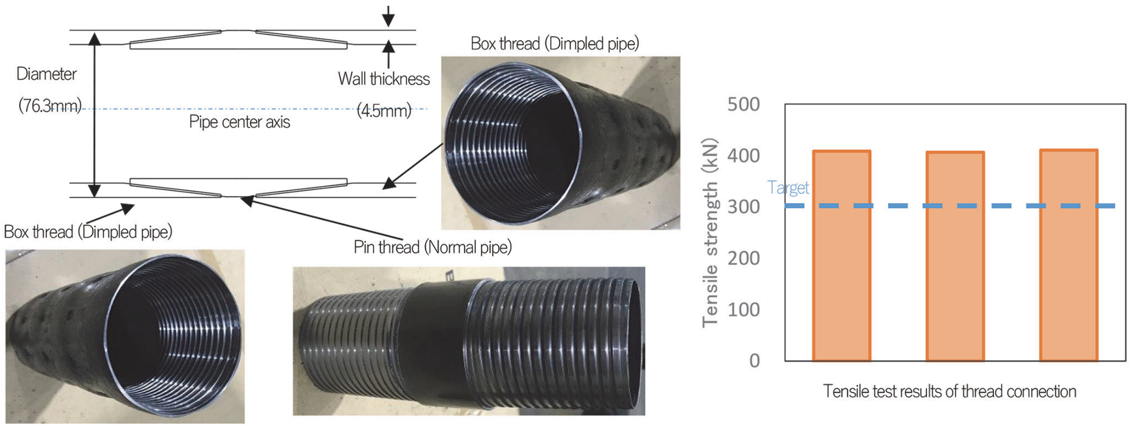

Fig. 9 Picture and tensile test results of nipple thread connection for dimpled pipe

3.3 Construction records, etc.

Before applying the developed dimpled steel pipes and connections to actual tunnel construction, a simulated construction test shown in **Fig. 10** was conducted in cooperation with Kameyama. A concrete block was regarded as natural ground and a drilling machine was used to penetrate a dimpled steel pipe member (steel pipes coupled with connections). The test has confirmed that there are no problems with the workability and other matters. Then on-site construction tests were carried out before commercialization. They have been adopted in multiple mountain tunnel construction sites.

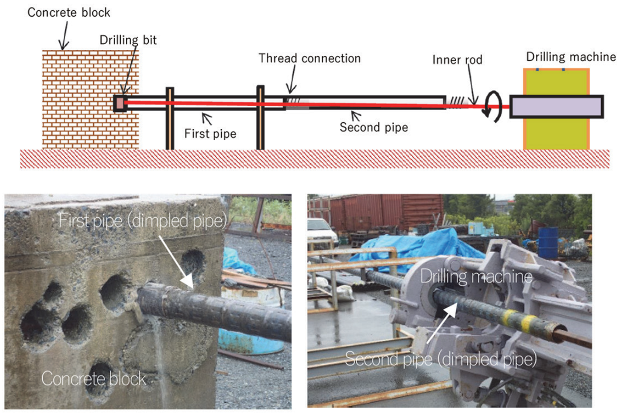

Fig. 10 Simulated construction test for dimpled pipe

4. Conclusion

Nippon Steel developed high-tension steel pipes, dimpled steel pipes, and thread connections for them as reinforcement members to be used in auxiliary methods in mountain tunnel construction, contributing to resolving issues. They were developed to reduce the loads on human operations as well as to secure the strength of bonding with grouting materials while satisfying the required structural performance. We will continue to satisfy customer needs by developing high-functionality products and peripheral technologies in various construction sectors where structural pipes are used, in addition to mountain tunnels, also in the future.

Acknowledgments

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References

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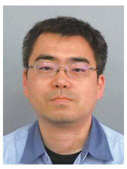

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