NIPPON STEEL & SUMITOMO METAL TECHNICAL REPORT No. 107 FEBRUARY 2015

UDC 669 . 14 - 472 . 3

Technical Report

Development of Deformed Small-diameter Pipes by On-line Depression Forming Method in Hot Pipe-forming Process

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Abstract

Nippon Steel & Sumitomo Metal Corporation has developed an on-line method for forming depressions of desired shapes on pipe surfaces during hot pipe forming/rolling and produced small-diameter pipes with surface depressions formed by the developed method since 2006. When used for soil improvement, tunnel reinforcement and the like, these pipe products, excellent in bonding to cement materials, are effective at reducing the costs and period of construction work as well as enhancing the reliability of the structure. This paper outlines the method of depression forming, the kinds of pipe products with surface depressions, and introduces the features and properties of dimpled pipes, which were newly developed aiming at improving the bonding strength with cement materials and structural performance.

1. Introduction

A wide variety of construction methods using small-diameter steel pipes have been developed for civil construction work in restricted spaces or with tight time allowance, such as soil improvement or foundation work for residences and low-height buildings, piling work at restricted locations in urban areas, and tunneling work. Nippon Steel & Sumitomo Metal Corporation has developed a method for forming depressions of desired shapes on the surfaces of steel pipes during hot pipe forming/rolling processes, and they commercialized deformed small-diameter pipes having good bonding with such cement-based materials as soil cement and grout. Of such products, grooved pipes having circumferential grooves at prescribed intervals have been in the market since 2006. Owing to good adhesion of the grooves to cement-based materials, this product has earned many supply records as the cores for columnar soil improvement and for auxiliary work for tunnel construction. This paper outlines the method of forming depressions in pipe-forming lines that enabled the manufacture of deformed small-diameter steel pipes, the characteristics of dimpled pipes launched to the market in 2012, and the results of tests on the product performance.

2. On-line Depression Forming Method

Steel pipes are classified according to the forming method [1] into (1) welded pipes made by bending steel plates or strips into tubular shape and joining the edges by welding or forging, and (2) seamless pipes made by rolling hot ingots or billets of round or square section into tubular shape without joint (seam). The method of producing the former is classified according to the processing temperature into hot and cold forming processes.

The on-line depression forming process of Nippon Steel & Sumitomo Metal takes advantage of the hot pipe forming processes such as butt welding by forging and seamless pipe rolling. The processes in which the depressions are formed on the pipe surface are the continuous forming and forge-welding process for butt-welded pipes (hereinafter the continuous pipe forming process) and the Mannesmann rolling process for seamless pipes. The on-line depression forming method is explained below using the continuous forming process by way of example. **Figure 1** schematically illustrates the forming and forge-welding section of a continuous pipe forming line. By this process, material strips are welded into a long strip for continuous forming by rolls, heated to around 1300°C through a tunnel furnace, formed into tubular shape, forge-welded at the seam,

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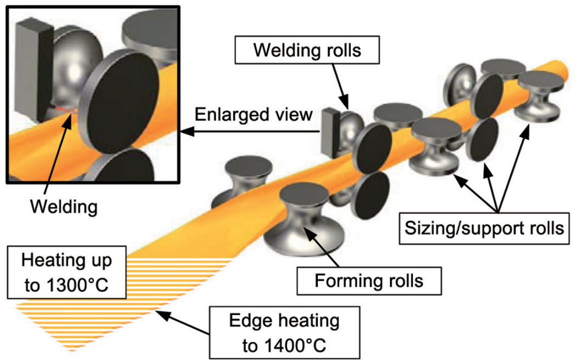

Fig. 1 Schematic illustration of continuous pipe forming process

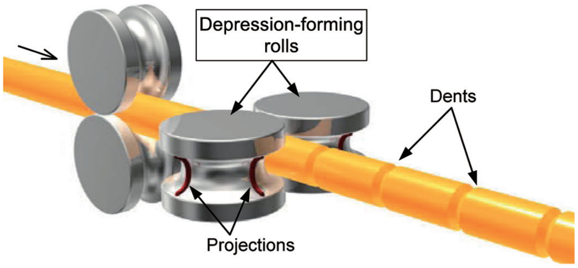

Fig. 2 Schematic illustration of depression forming on pipe surface

reduced in diameter, cut to prescribed length, and then cooled to room temperature on a cooling bed.

By the developed on-line depression forming method, rolls having protrusions on the pipe-contacting surfaces are provided in a manufacturing line for butt-welded or seamless pipes so that the protrusions are printed onto the pipe surface as depressions (**Fig. 2**). Similar methods are used for producing ribbed plates and deformed bars for concrete reinforcement: grooves are cut into the surfaces of the rolling rolls so that they are filled with steel material during rolling to form protrusions on the product surface.[2] In the case of hollow pipes, however, there is a problem: the steel material does not fill the roll grooves, and no protruded patterns are formed on the product surface. In developing the present method, instead of forming protrusions on the product surface, it was decided to form depressions, which had been confirmed to be equally effective for envisaged purposes.

Hollow section products of different sectional shapes have been produced from steel pipes through cold roll-forming methods by employing presses or multiple roll stands,[1, 3] but they are basically of the same sectional shape in the longitudinal direction. The developed method, in contrast, is characterized by forming steel pipes into products of intermittently different sectional shapes in the longitudinal direction, and being able to form continuous or non-continuous sectional shape as desired. In addition, because of the on-line forming in hot, large sectional change can be introduced using a small number of roll stands economically at high efficiency, which leads to a reduced inventory of forming rolls.

3. Products Manufactured through Depression Forming Process

The on-line depression forming process has made it possible to offer new pipe and tube products of unique features without requiring secondary fabrication. **Figure 3** shows examples of grooved, oblique grooved, and dimpled pipes from top to bottom.

Grooved pipes (top) have grooves at regular intervals along the pipe length. It is possible to form the grooves obliquely (middle) and change the groove shape and their interval. When such a pipe is set in a cement material, the grooves are filled with the surrounding material and the pipe is very firmly bonded to it. Grooved pipes already count a lot of supply references as the cores for columnar soil improvement work for residential buildings (**Fig. 4**). When they are used for the foot piling of tunnels,[4] the construction costs and work period can be reduced because of the stronger adhesion and consequent shorter piling lengths compared with ordinary pipes (**Fig. 5**[5]).

In dimpled pipes (on the bottom of Fig. 3), in contrast, the depressions are shallower and smaller than those of grooved pipes and are arranged regularly in the circumferential and longitudinal directions; thus, dimpled pipes are a kind of product distinctly different

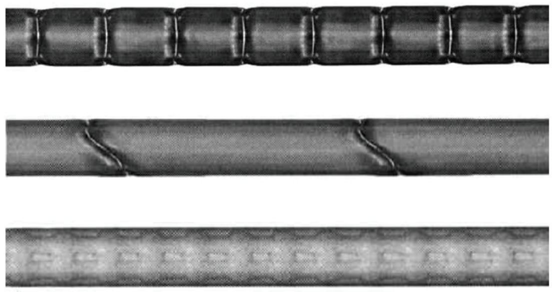

Fig. 3 Types of deformed pipes
Grooved pipe (top), oblique-grooved pipe (middle), dimpled pipe (bottom)

Fig. 4 Example of ground improvement work using grooved pipes

Fig. 5 Oblique-grooved pipes (left), and foot piling work for tunnel[5]

from grooved pipes.

As has been explained, it is possible by the developed method of on-line depression forming to change the size, depth, and arrangement of the depressions as desired, and, by so doing, offer different kinds of pipe products to meet different user requirements.

4. Dimpled Pipes

4.1 Diversified requirements and dimple specifications

Grooved pipes were developed originally for use as the cores for columnar soil improvement for small buildings, and in appreciation of the strong bonding with the surrounding cement material without having to weld protrusions, their application to varieties of structures were studied; the foot piling for tunnels mentioned above is one such example. On the other hand, from those studies, there arose the need for higher structural strength.[6, 7]

Since these surface-deformed products had depressions as shape irregularity, or defects, as manufactured, it was feared that the depressions might adversely affect the structural resistivity of the pipes. In other words, the pipes may buckle under loads with depression serving as the starting point. In fact, although the depressions significantly improve the bonding between the pipe and the cement material around it, there is the possibility that they deteriorate the pipe's structural strength.

In consideration of this and in order to respond to user requirements for high tensile strength, together with high compressive resistivity, Nippon Steel & Sumitomo Metal studied the optimum shape of depressions that would not adversely affect the structural strength of the pipe proper but make the most of it, and as a result, worked out the dimple shape shown in **Fig. 6**.[8, 9] The dimple shape thus obtained is rectangular, 3 to 4 mm in width, 20 mm in length, and 2.3 mm in average depth, approximately. In the case of pipes 76.3 mm in outer diameter, for example, eight dimples are arranged circumferentially at longitudinal intervals of 25 mm; the number of dimples changes according to the pipe diameter and application conditions.

4.2 Structural performance of dimpled pipes

What was feared most about the structural performance of dimpled pipes was the deterioration of buckling resistance due to the depressions. Since buckling resistance is expected to decrease as the number of dimples increases, the structural performance was tested using specimens of dimpled pipes 76.3 mm in outer diameter having eight dimples in the circumferential direction at intervals of 25 mm in the longitudinal direction.

Figure 7 shows the results of short pipe compression test to examine the effects of the dimples over the local buckling behavior of pipes; the results of dimpled pipes are compared with those of smooth pipes without dimples. Here, the ordinate represents applied compressive stress made nondimensional through division by the yield strength of the material, and the abscissa axial displacement made nondimensional through division by the specimen length. With the specimens 3.2 mm in wall thickness, after hitting a maximum, the strength fell markedly because of the comparatively thin wall. In contrast, such a significant strength decrease did not occur with the specimens 4.5 mm in wall thickness, evidencing sufficient resistance to deformation. **Figure 8** shows how a specimen of wall thickness of 3.2 mm failed under the maximum load. Dimpled pipes of any wall thickness demonstrated compressive strength exceeding the yield strength of the steel, although the load–displacement relationship was considerably different from that of the smooth pipe given in Fig. 7 as a reference. These results indicate that the decrease in compressive strength due to the dimples is negligibly small.

Figure 9 shows the results of four-point bending test of dimpled pipes 76.3 mm in outer diameter and 4.7 mm in wall thickness, which were substantially the same as those for the specimens of the compression test. As evident from the load–displacement curves,

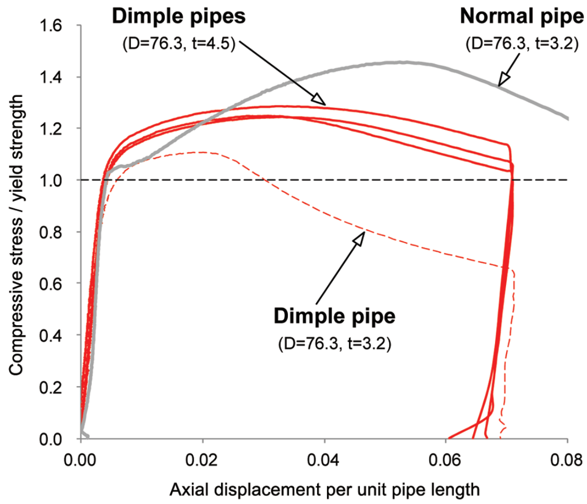

Fig. 7 Result of short pipe compression test

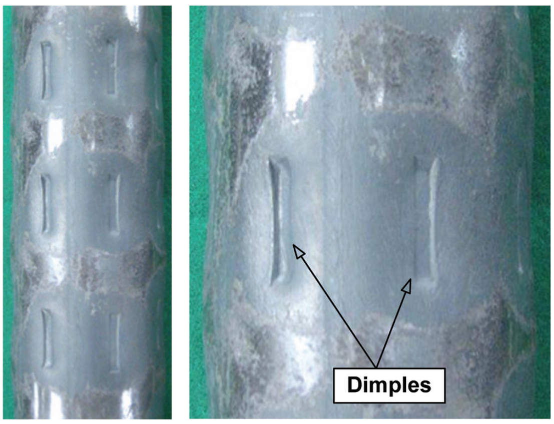

Fig. 6 Dimpled pipe

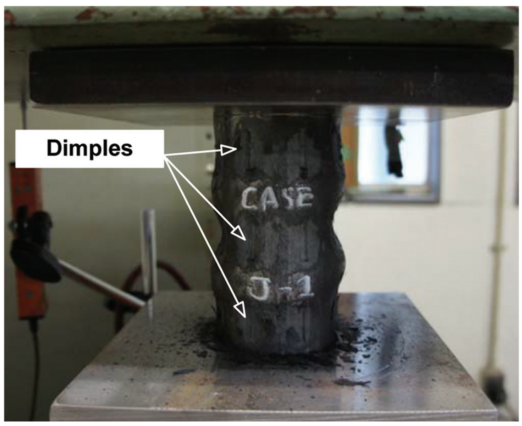

Fig. 8 Deformation under ultimate load

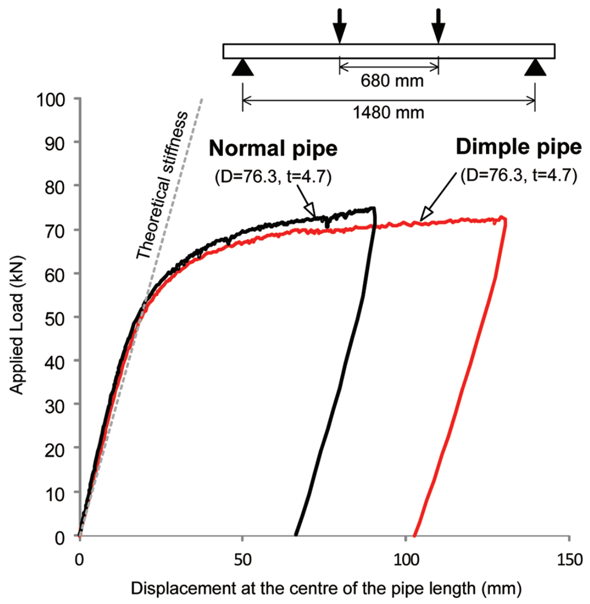

Fig. 9 Result of four-point bending test

dimpled pipes have sufficiently high bending resistance, if slightly poorer in terms of maximum load than ordinary pipes.

4.3 Cement adhesion onto dimpled pipes

The envisaged application of dimpled pipes is mainly ground reinforcement such as columnar soil improvement, foot piling for tunnels, and slope revetments. It has been common practice in this kind of construction work to weld protrusions onto the steel pipe surfaces to obtain good bonding with the cement material.[6, 7)]

It has been known that the strength and stiffness of soil depend strongly on the stress level and in testing the bonding strength of a steel pipe with a medium surrounding it using specimens of limited dimensions simulating real conditions, it is very important to take into consideration the conditions at the outer boundaries of the specimens.[10)] Because the bonding strength of a dimpled pipe with cement changes depending on the restriction by the earth around the pipe-cement unit; therefore, it was necessary in the test to consider the restricting force due to the stiffness of the soil surrounding the simulated piling.

In consideration of the above, the specimens for the test were prepared such that the steel pipe to test was placed at the center of a large-diameter pipe serving as a confining medium, and soil cement or mortar was cast inside the medium to surround the pipe to test. For foundation pilings[11)] and grounding anchors,[12)] several formulae have been proposed to calculate the stiffness of a soil portion due to the restriction imposed by surrounding earth. Thus, it is possible to evaluate the bonding performance required under different conditions by using the formulae and correlating soil stiffness with the rigid springiness of the piling due to the structural inner pressure imposed by the large-diameter pipe used as the confining medium. To evaluate the effects of the soil restriction, steel pipes, 216.3 mm in outer diameter and 5.8 mm in wall thickness, and polyvinyl chloride (PVC) pipes, 216.3 mm in outer diameter and 10.3 mm in wall thickness, were used as the confining medium to simulate strong and comparatively weak restricting force, respectively, on the pipe to test. Note that the diameter-thickness ratio (D/t) of the PVC pipes (weaker restricting force) is roughly 20, and they were expected to exert a restricting force equivalent to that of the kind of soil where reinforcement is required for tunneling work.[6, 7)]

The dimpled pipes that underwent the bonding test were the same as those for the compression and bending tests: pipes 76.3 mm in outer diameter with eight dimples in the circumferential direction at intervals of 25 mm in the longitudinal direction. For comparison purposes, specimens were prepared using smooth steel pipes of the same outer diameter and D51 deformed bars under JIS G 3112. The bonding strength was tested, as seen in **Fig. 10**, by the downward push-out test method wherein downward load was applied to the object pipe from the top end while the mold pipe (confining medium) and the filling material was supported at the bottom. Since cement materials of different strengths may be chosen in real construction work depending on the type and the work method of the structure, soil cement having compressive strength of 2 to 5 MPa and mortar of compressive strength of roughly 20 and 36 MPa were used as the filling material around the object pipes.

First, **Fig. 11** shows the result of the bonding test under the strong restricting force imposed by the confining medium of the steel pipe and grout having compressive strength of 36 MPa. It is clear from the graph that the bonding strength of the normal pipe without depressions was extremely low: after hitting a peak load, the pipe/soil joint failed by sliding. The D51 deformed bar exhibited a bonding strength higher than that of the dimpled pipe, but the

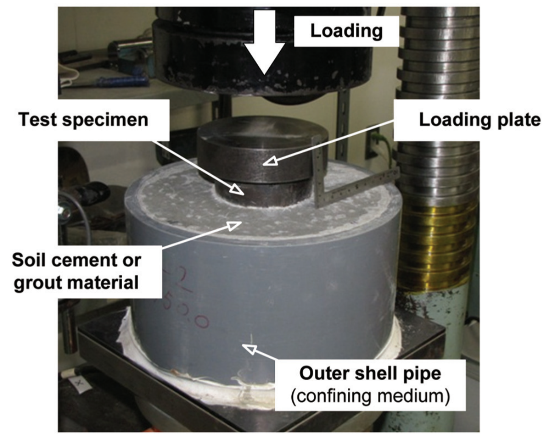

Fig. 10 Bonding test under downward loading

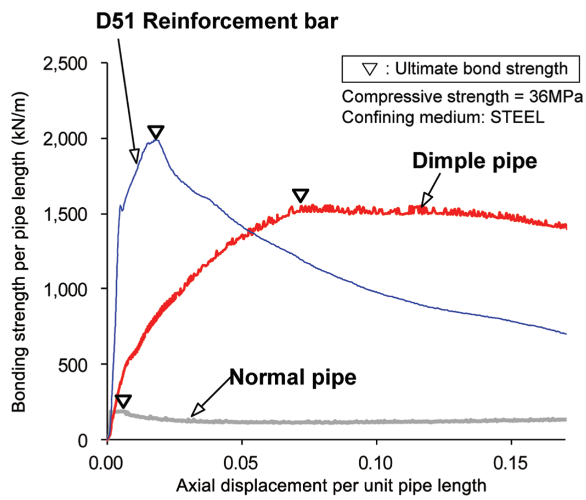

Fig. 11 Load-displacement curves in bonding test

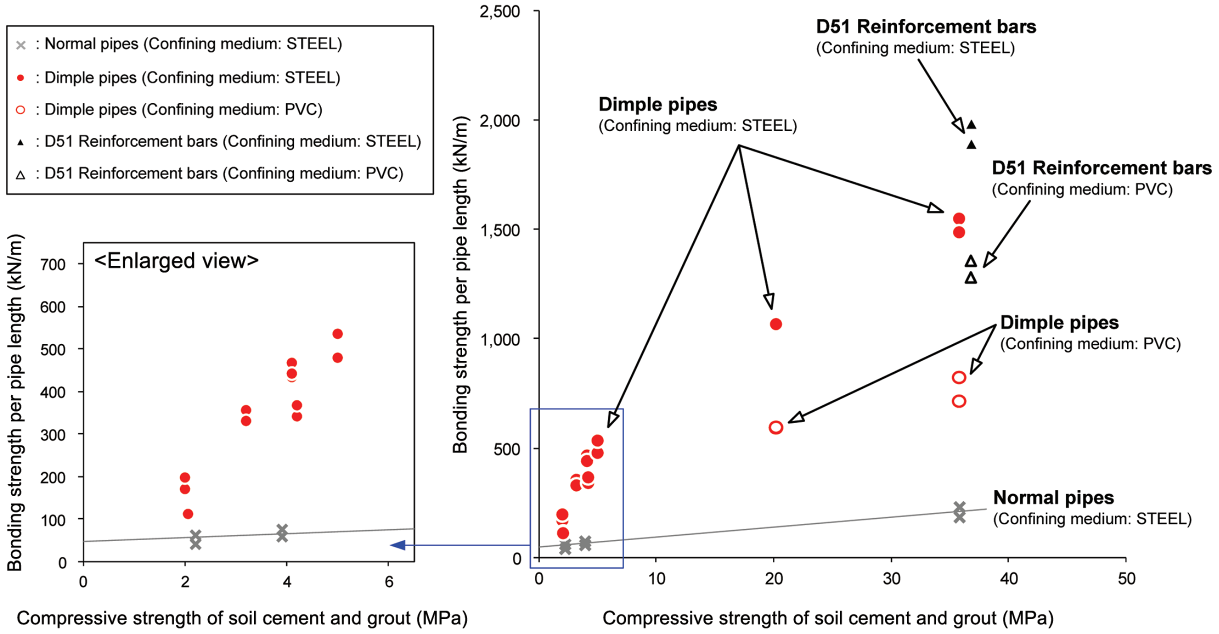

Fig. 12 Relationship between compressive strength of cement material and bonding strength of pipes

strength fell markedly after the peak load; the mode of failure was similar to brittle fracture. In contrast, although the peak load of the dimpled pipe was lower than that of the deformed bar, the bonding strength little fell thereafter, staying very steadily at a high level.

Figure 12 shows the relationship between the uniaxial compressive strength of the cement material of the specimens and the maximum bonding strength obtained through the test; the larger graph on the right shows the entire test result, and the smaller graph on the left is an enlarged view of the part where the strength of the soil cement is plotted, and the bonding strength along the ordinate is the figure per unit length of the object pipe. It is clear from the graph that the bonding strength of the dimpled pipes is far greater than that of the smooth pipes. It is also clear that whereas the bonding strength of the ordinary pipes does not improve significantly as the strength of the filling material increases, that of the dimpled pipes increases to three to seven times, by simple comparison, that of the normal pipes with increasing strength of the filling material. This strength improvement effect is equal to or larger than that obtained through another test using pipes to which protrusions were welded at intervals of 25 cm (four protrusions in every 1 m length).[6, 7)]

The outer surfaces of the dimpled pipes were observed after the bonding strength test; **Fig. 13** shows two examples, one with soil cement of a compressive strength of 2 MPa, and the other with mortar of a compressive strength of 36 MPa. It is clear from the photos that the cement material filled the dimples, which presumably brought about the high bonding strength seen in Fig. 12.

Fig. 13 Outer surfaces of pipes after bonding test (left: soil-cement of 2 MPa; right: mortal of 36 MPa)

4.4 Performance of dimpled pipes (summary)

As explained above, it has been confirmed through tests that the steel pipes having surface dimples formed by the developed on-line depression forming method maintain substantially the same level of structural strength as that of normal pipes without dimples, and in addition, exert very high bonding strength with cement material cast around them, as the dimples, though comparatively small in size, are filled with it to exert strong bonding strength. Thus, compared with steel pipes with welded protrusions, dimpled pipes have the advantage of virtually the same bonding strength to cement material without having to incur the cost and time for the welding work. Although the outer diameter of the dimpled pipes used for the tests reported herein was 76.3 mm, and the arrangement of the dimples was not changed, the pipe diameter, wall thickness, and dimple arrangement can be selected optimally in accordance with the type and conditions of the structure for which the product is used.

Figure 14 shows an example of proven applications of dimpled pipes; pilings for solar panels. In appreciation of the enhanced structural strength as well as the excellent compatibility with cement material, dimpled pipes are expanding the use as piling/column members. The application of dimpled pipes is not limited to such proven applications as columnar soil improvement and the foot piling for tunnels; it is expected to cover things such as the micro-pilings for foundation reinforcement, soil nailing for slope revetments, and the reinforcement of a tunnel cutting face, as illustrated in **Fig. 15**.

5. Conclusions

Nippon Steel & Sumitomo Metal has developed a unique meth-

Fig. 14 Application Example: Pilings for solar panels

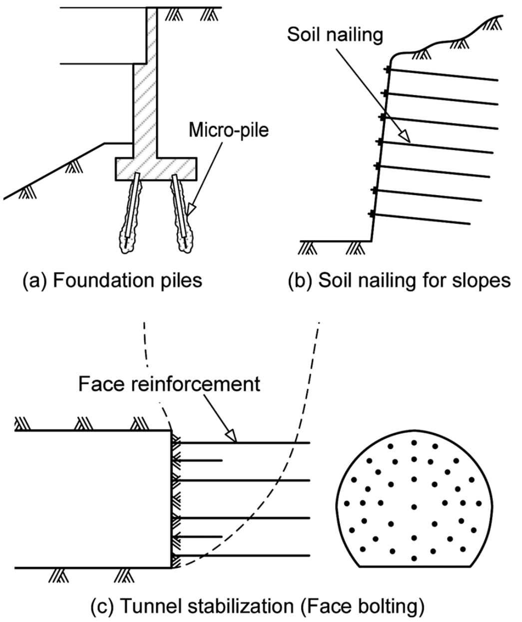

Fig. 15 Promising applications of small-diameter pipes with high bonding strength

od for forming depressions on pipe surfaces on line during hot pipe production processes, and taking advantage of the method, launched in the market new deformed pipe products having high bonding strength with cement materials. The shape of the depressions and their arrangement can be selected flexibly in accordance with the conditions of application. Such small-diameter pipes having excellent bonding strength with cement material as well as structural strength can be used effectively for construction work in restricted spaces or that with tight time allowance, such as soil improvement or foundation work for residences or low-height buildings, piling work at restricted spaces in urban areas, and tunneling work, opening possibilities of new structures and work methods.

References

1) Kirimoto, T.: Outline of Steel Pipe Products and Production Process Development. Proc. 171st and 172nd Nishiyama Memorial Seminar. 1999, Iron & Steel Institute of Japan
2) Matsumura, H. et al.: Tetsu-to-Hagané. 76 (8), 75 (1990)
3) Kiuchi, M. et al.: Proc. 77th Roll-forming Committee, Japan Society for Technology of Plasticity. 2008
4) Nikkei Construction. Dec. 11, 2009, p. 27
5) Home page of Obayashi Corporation http://www.obayashi.co.jp/press/news20091027
6) Takahashi, Y. et al.: J. of Tunnel Eng. 65, 123-128 (2010)
7) Kinashi, H. et al.: Tunnels and Underground. 504 (43), 645-654 (2012)
8) Taenaka, S. et al.: Proceedings of State of the Art of Pile Foundation and Pile Case Histories (PILE2013). Indonesia, 2013-6, G2-1
9) Taenaka, S. et al.: Proc. 48th Japan National Conference on Geotechnical Engineering. Toyama, 2013-7, Japan Geotechnical Society, No. 747, p. 1493-1494
10) Salgado, R. et al.: Journal of Geotechnical and Geoenvironmental Engineering. ASCE, 124 (9), 878-888 (1998)
11) Airey, D.W. et al.: Geotechnical Testing Journal. ASTM, 15 (4), 388-392 (1992)
12) Hyett, A.J.: International Journal of Rock Mechanics and Mining & Geomechanics Abstracts. 29 (5), 503-524 (1992)

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