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Swelling Properties of Water-Swelling Materials Exposed to Organic Water Pollution

S. Inazumi[1], M. Kobayashi[2], T. Wakatsuki[2] and K. Shishido[3]

1. Department of Urban Management, Kyoto University, Kyoto 6158540, Japan

2. Nihon Chemical Paints Co., Ltd., Kanagawa 2521111, Japan

3. Tomec Corporation, Tokyo 1050012, Japan

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Abstract: A water-swelling material is one of the rubbery impermeable materials which mixed synthetic resin elastomers as a base material, high absorbency polymers, filler and solvents. In this study, swelling characteristics of the water-swelling material on the water polluted with COD and BOD, as an impermeable material at coastal landfill sites, are examined by laboratory swelling ratio test. Furthermore, the factor in which it influences the swelling pressure of water-swelling material is clarified by measuring the swelling pressure. As the results, the COD nor the BOD concentrations in the soaked water influence the swelling ratio of the water-swelling material. When the thicknesses of water-swelling material are 2 mm and 3 mm, the maximum swelling pressure of 0.5 MPa or more that corresponds to hydraulic pressure by depth of 50 m is possessed.

Key words: Coastal landfill site, swelling pressure, swelling ratio, water-swelling material.

1. Introduction

Water-swelling material is a fluid sealant obtained by blending high absorbency polymer, a filler and a solvent by using a synthetic resin elastomer as the base material. In the field of civil engineering, water-swelling materials are widely used as water cut-off treatment material for increasing water cut-off properties at the joint section of steel sheet piles or steel pipe sheet piles (Fig. 1) [1-3]. Further, the water-swelling material coated or pasted to the joint section swells on contact with ground water, blocks the water passage gaps and allows water cut-off at the joint section.

The water extracted from a dried film of water-swelling material fulfills the "Food Sanitation Law Standards" and is not harmful to the environment. At present, the composition of frequently used water-swelling materials (hereafter referred to as "current water-swelling material") is such that when it is soaked in plain water or sea water for 24 hours, it swells up to 15-30 times and 5-7 times, respectively,

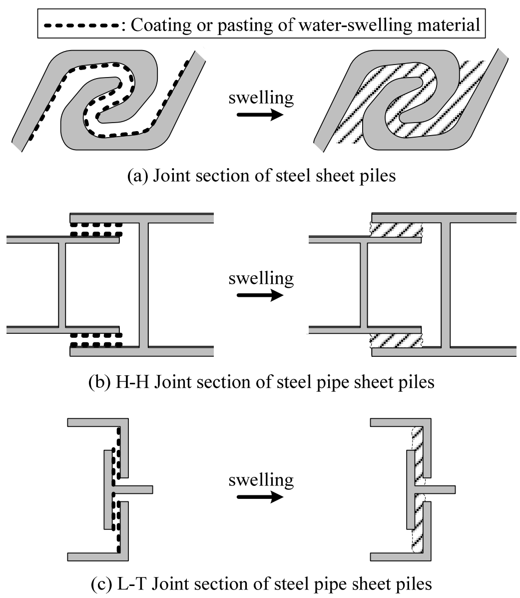


Fig. 1 Water cut-off treatment on joint section of steel sheet piles or steel pipe sheet using water swelling materials.

Corresponding author: S. Inazumi, assistant professor, Ph.D., research fields: geotechnical engineering, geo-environmental engineering, global environmental study. E-mail: inazumi.shinya.3c@kyoto-u.ac.jp.

in terms of weight ratio. Thus, the current water-swelling material has extremely high swelling ability in plain water, nevertheless, the swelling percentage in sea water is 1/6-1/3 of that in plain water. Further, there is a tendency for the strength of the swelling material film (strength of water-swelling material after swelling) to be lower in plain water due to the effect of the water temperature [4]. Because of this type of swelling and the strength properties, water-swelling material has, thus far, been used mainly as temporary water cut-off material. Here, the improvement in the swelling properties of the water-swelling material and the strength of the swelling material are not restricted only to increases in the water cut-off at the joint section of the steel pipe sheet piles or steel sheet piles, but they may be contributing to several other applications of water-swelling material.

This paper shows the swelling ratio characteristics for polluted water while assuming that the water-swelling material is applied as the water cut-off treatment material for the joint sections of steel pipe sheet piles and steel sheet piles in coastal landfill sites. Moreover, by experimentally measuring the swelling pressure of the water-swelling material as the water cut-off treatment material, it is possible to understand the reasons that affect the swelling pressure. Previous research has clarified the swelling characteristics of water-swelling material for polluted water using mainly heavy metals or organic solvents [4].

2. Background of Water-Swelling Material

2.1 Hydraulic Properties

Representative examples of the application of water-swelling material includes vertical water cut-off wall (barrier) built from steel sheet pile or steel pipe sheet pile in costal landfill sites. The vertical water cut-off property of steel sheet piles or steel pipe sheet piles is manifested by the swelling effect of water-swelling material previously coated or pasted at the joint sections before setting up (Fig. 1) [1-3]. While employing the water-swelling material for water cut-off treatment of joint sections, it may be used in the form of a sheet pasted inside the joint section (swelling-type sheet) or it may be used as a coated sealant. Depending upon the situation, it is possible to select the appropriate form of the material. Further, it is possible to prevent peeling off by synthesizing a swelling-type paint that adheres strongly to the steel. On the other hand, the hydraulic conductivity (water permeability factor) of swelling-type material itself and that of the steel or paint are not different and both are of the order of 1×10^{-9} cm/s [3].

Recently, the "H-jointed steel pipe sheet piles with an H-H joint", which is one of the newly developed methods for high water cut-off, is being tried for application of water-swelling material for water cut-off treatment of the joints section. In a series of research projects, one can see a number of reports regarding the performance of water cut-off steel pipe sheet piles making use of an H-H joint, using water-swelling material for adhesion [3, 5]. For example in plain water or artificial sea water (3% saline solution), low hydraulic conductivity of the order of 1×10^{-8} cm/s has been clearly confirmed. Peeling off or the ability of water cut-off of the water-swelling material at the field has been studied and good results have been reported in general.

2.2 Swelling and Strength Properties

Experimental studies were carried out in the case of the composition of water-swelling material, its swelling and swelling material strength [4]. Further long-term performance of water-swelling material used for water cut-off treatment of H-jointed steel pipe sheet piles with an H-H joint was discussed from the point of the variation of the swelling film strength and pressure resistance with elapsed time.

The obtained findings were as follows:

(1) In case of water-swelling material blended with high absorbency polymer with higher etherification

value (DS value), the swelling ratio is very high in artificial sea water. Especially, by reforming the DS value of the high absorbency polymer to 0.9 M/C6, swelling ratio that is 2 times the value of that of the currently used water-swelling material (with a DS value of the high absorbency polymer = 0.6 M/C6) can be obtained in an artificial sea water environment.

(2) An increase in the water temperature of plain water influences the increase in the swelling ratio of the water-swelling material. On the other hand, the temperature of sea water does not influence the swelling ratio of the water-swelling material. Further, water-swelling material shows a tendency of lowering the swelling ratio in strongly acidic or strongly alkaline areas, but the influence of pH on the swelling ratio of the water-swelling material is less in the area of pH 4-12.

(3) The quantity of synthetic resin elastomer, which is a component of the water-swelling material, contributes to the improvement of the swelling film strength of the water-swelling material. Especially water-swelling material blended with a higher quantity of synthetic resin elastomer B can increase the swelling film strength to about 2 times and 1.5 times that of the currently used water-swelling material in plain water and artificial sea water, respectively.

(4) The swelling film strength of water-swelling material is higher when exposed to a sea water environment as compared to that exposed to a plain water environment. Further, with elapsed time, the swelling film strength shows a tendency to stabilize. Moreover, the swelling film strength showing some stability has sufficient pressure resistance at coastal landfill sites.

3. Swelling Ratio Test

3.1 Outline

This section describes the independently assembled swelling ratio test implemented to evaluate the swelling ratio characteristics of water-swelling material in the organically polluted water conditions. To reproduce the organically polluted water, the chemical oxygen demand (COD) and biological oxygen demand (BOD) were set as the indicators.

COD is one of the indicators of the degree of pollution in lakes and marshes, ocean areas and industrial waste water by showing the amount of oxygen consumed in oxidation of water agents. The COD density that is an environment standard (living environment items) for preserving the living environment should be 1-8 mg/L or lesser in case of lakes and marshes and 2-8 mg/L or less in case of ocean areas. On the other hand, BOD is one of the indicators of the degree of pollution in rivers as it is the amount of water oxygen consumed in the process that is analyzed by taking the water organic compound as micro-organisms. The water grade quality (pattern) is set based on points like river water utilization or preservation of the natural environment as the environmental standards (living environment items) for preservation of the living environment and the standard values for BOD density is set for every pattern. For example, the river section with the best water quality is taken as pattern AA and the BOD density is 1 mg/L or less. One the other hand, the river section with the worst water quality is taken as pattern E and the BOD density is 10 mg/L or less.

In the swelling ratio test, plain water and artificial sea water (3% saline solution) were taken as the base, and the swelling ratios for water-swelling materials dipped in the adjusted aqueous solutions were measured for different levels of density of COD and BOD.

The swelling ratio test procedures are as shown below.

(1) A definite quantity of water-swelling material was dried, it was converted into a 2 mm thick sheet and a test piece sized 2 cm × 2 cm was prepared.

(2) The initial weight of the test piece was measured and it was soaked in a water tank having various qualities of water at various temperatures. After soaking for 48 hours, it was taken out and the

weight was measured.

(3) Swelling ratio (= weight after soaking/initial weight) was calculated.

(4) The swelling ratio has been calculated by weight due to difficult in measuring volume of the water-swelling material after swelling. The swelling ratio by volume almost equaled 70% of it by weight, as a result of a preliminary test on swelling ratio of water-swelling material.

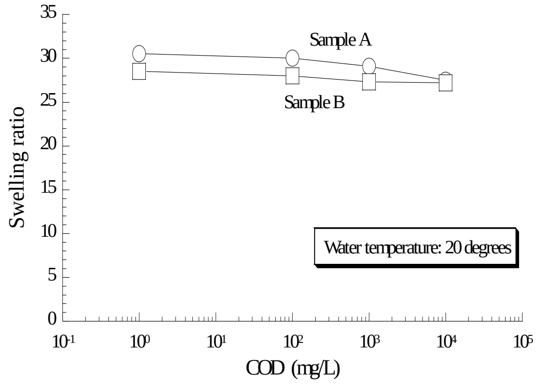
Each COD density of the solution was prepared by adjusting the quantity of hydrogen peroxide added to the solution. The simple colorimetric evaluation measurement method (alkaline potassium permanganate oxidation method) was used for COD density. Each BOD density of the solution was prepared by acquiring river water, adding glucose (dextrose) to it, and being maintained for a few days while bubbling with air cultivating the micro-organisms. The BOD investigation was the same as for COD and the simple measurement method (acid indigo carmine colorimetric) for colorimetric evaluation was used.

Sheet form water-swelling material provided for testing was a composite and there were two types, namely, Sample A (DS-0.6/M/C6) and Sample B (DS-0.9M/C6) where the DS value of high absorbency polymer, which is the composite, was different. Adulteration of the high absorbency polymer DS value contributed greatly to the increase in the swelling ratio of water-swelling material in artificial sea water.

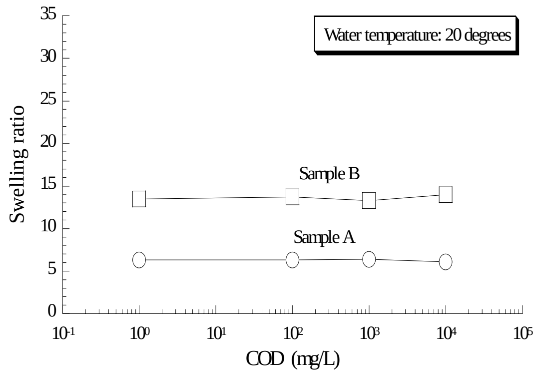
3.2 Evaluation of Swelling Ratio

Fig. 2 shows the COD density and swelling ratio of water-swelling material in plain water and artificial sea water (3% saline solution). From this we can understand that there is a tendency for a slight decrease in the swelling ratio in both Sample A and Sample B following an increase in COD density.

However, if the COD density at 1 mg/L or less and at 10,000 mg/L is compared, there is the tendency for a 10% reduction in the swelling ratio in Sample A and a 5% reduction in Sample B. From this result, we can judge that the COD density has practically a minor impact on the swelling ratio of water-swelling material (Fig. 2(a)). Similarly, even in artificial sea water, the impact of the COD density on Sample A and Sample B is minor (Fig. 2(b)).



(a) Soak in plain water

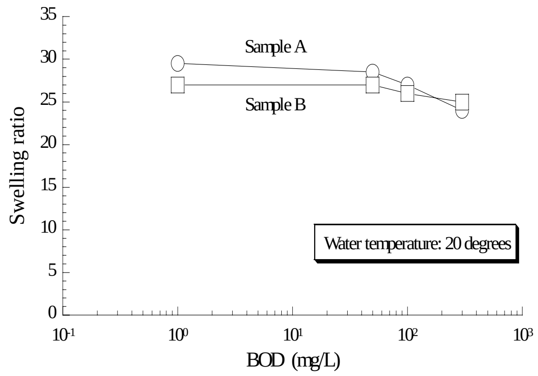


(b) Soak in artificial sea water (3% saline)

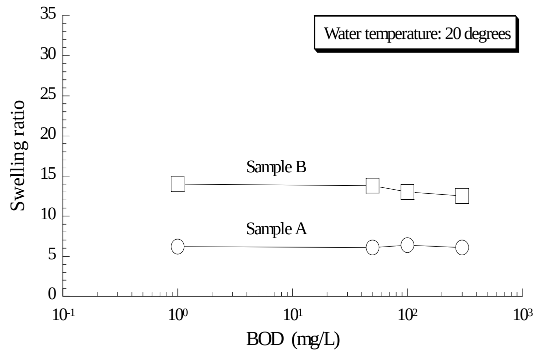
Fig. 2 Relationship between swelling ratio and COD concentration of soaking water for water-swelling material.

Fig. 3 shows the swelling ratio of water-swelling material and the BOD density in plain water and artificial sea water (3% saline solution). This shows the same as for the COD aqueous solution, while there is a minor impact on the swelling ratio of Sample A and Sample B in plain water and artificial sea water environments.

As mentioned above, in relation to the swelling in water-swelling material, the impact of COD and BOD in the exposed water is minor. However, the tendency for a decrease even if it is very little in the swelling ratio of water-swelling material with increase in COD



(a) Soak in plain water



(b) Soak in artificial sea water (3% saline)

Fig. 3 Relationship between swelling ratio and BOD concentration of soaking water for water-swelling material.

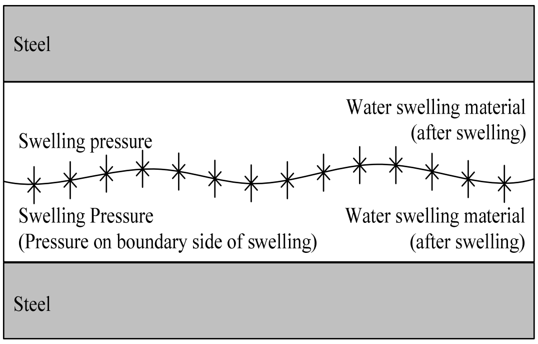


Fig. 4 Image of swelling pressure on swelling boundary.

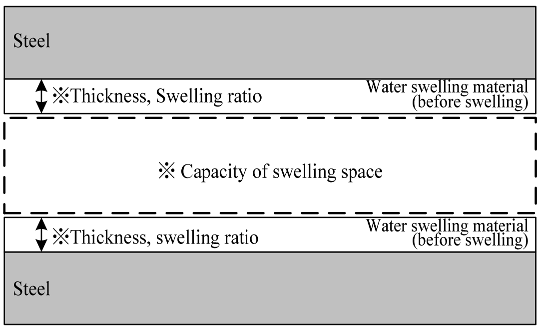


Fig. 5 Factor that influences swelling pressure of swelling still water material.

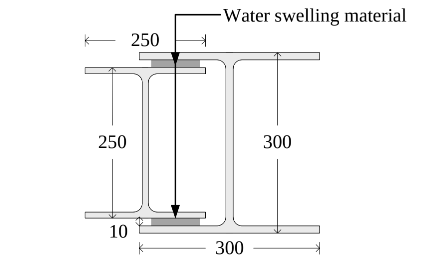
and BOD density (Fig. 2 and Fig. 3) as can be understood from below. The increase in the amount of oxygen in the exposed water and the amount of micro-organisms could be because of the insolubility of high absorbency polymer that is a water-swelling material composite. The insolubility of high absorbency polymer causes a reduction in the absorption volume of the water absorbed by high absorbency polymer, and that causes an impediment against swelling of water-swelling material.

4. Swelling Pressure Test

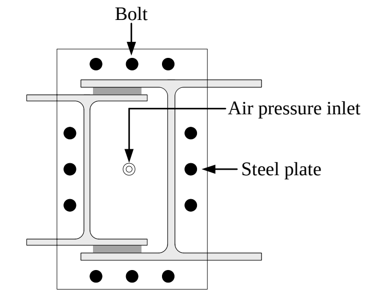
4.1 Outline

This section discusses a study of the swelling characteristics of coated and adhered water-swelling material (Fig. 1) in joint sections of steel pipe sheet piles and steel sheet piles from the viewpoint of swelling pressure as the objective and implementing the test for the swelling pressure of water-swelling material. Here, the water-swelling material swelling pressure refers to pressure in the swelling surface of the water-swelling material that swelled in the joint sections of steel pipe sheet piles and steel sheet piles (Fig. 4). It is thought that the water-swelling material swelling pressure depends on the amount of swelling of water-swelling material, swelling free space, and the adhesive conditions (Fig. 5). In the same swelling free space conditions increase in the swelling amount (ratio) of water-swelling material leads to an increase in the swelling pressure.

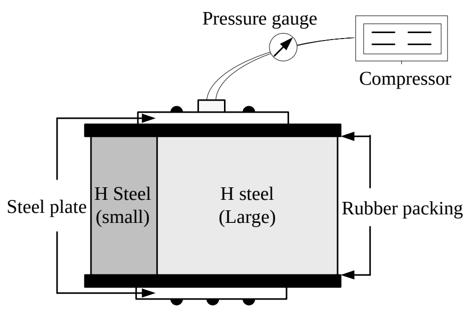
For testing the swelling pressure of water-swelling material, adhere specific thickness (1, 2, and 3 mm) of water-swelling materials to both of the H alloy flange (interval: 10 mm) clearance of different sizes. The water-swelling material adhesive conditions and the swelling free space in the general joint sections of steel pipe sheet piles and steel sheet piles are reproduced in the test for swelling pressure (Fig. 1) [1-3]. Fig. 6 is used to explain the swelling pressure testing device.



(a) Detail of test specimen



(b) Upper view of test apparatus



(c) Side view of test apparatus

Fig. 6 Outline of swelling pressure test for water swelling material.

The sample preparation method and the testing procedures are explained below.

(1) Apply water-swelling material of specified thickness to both surfaces of H alloy flange clearance (hereafter, referred to as "sample").

(2) Use the rubber seal and steel plate to clamp the upper and lower parts of the sample and fix using bolts such that there is no space between the rubber seal, steel plate, and sample.

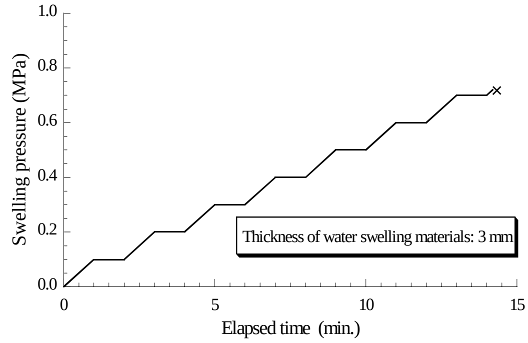
(3) Dip the sample created in (ii) in constant temperature (20 ℃) water bath filled with plain water for 3 days and the water-swelling material applied to the sample will swell completely.

(4) Connect the air compressor to the air pressure filler hole opened in the middle of the steel plate.

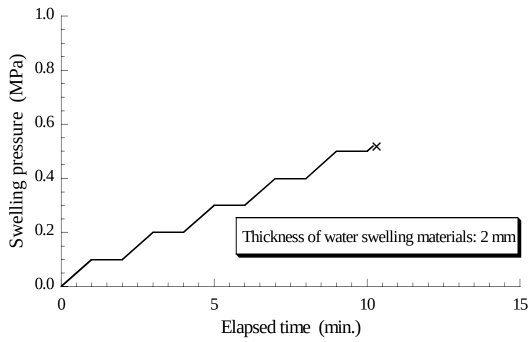
(5) Open the air compressor and send air pressure to the inside of the sample. Adjustments in the air pressure are made using the pressure gauge. The method of adjustment is to increase by 0.1 MPa every minute and add pressure till the air flows out. The air pressure at the point where the air flows out is defined as the swelling pressure.

4.2 Evaluation of Swelling Pressure

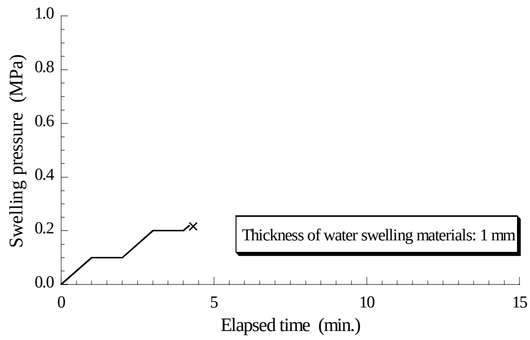
Fig. 7 shows the relationship between the adhesive



(a) Thickness of water swelling material bonded to both sides: 3 mm.



(b) Thickness of water swelling material bonded to both sides: 2 mm.



(c) Thickness of water swelling material bonded to both sides: 1 mm.

Fig. 7 Swelling pressure of swelling still water material.

thickness and the swelling pressure of the water-swelling material. According to the figure, the thinner the adhesive thickness of the water-swelling material, the lower is the swelling pressure, and if the adhesive thickness is 1 mm then the swelling pressure is 0.2 MPa. On the other hand, if the adhesive thickness of water-swelling material is 2 mm and 3 mm then the swelling pressure becomes 0.5 MPa or higher corresponding to water depth of 50 m.

The hydraulic conductivity of water-swelling material in testing conditions was the same as the corresponding swelling pressure test, was 1×10^{-9} cm/s, in the work water pressure below the swelling pressure. In other words, the hydraulic conductivity of water-swelling material adhered to both sides of H alloy flange clearance were the same as the hydraulic conductivity of the water-swelling material in the external work pressure below the swelling pressure (see 2.1). Therefore, when water-swelling material is applied as the water cut-off treatment material for joint sections of steel pipe sheet piles and steel sheet piles, we can confirm that there is a relationship between the swelling pressure and the swelling amount (ratio) of water-swelling material in relation to external exposure conditions (exposure level and work water pressure, etc.) and also in the current scenario it is necessary to decide the coating thickness and adhesive thickness of the water-swelling material.

5. Conclusions

In this paper, discussion was undertaken regarding the swelling ratio of water-swelling material dipped in polluted water while assuming that the water-swelling material is applied as the water cut-off treatment material of joint sections of steel pipe sheet piles and steel sheet piles. Moreover, by measuring the swelling pressure of water-swelling material used as water cut-off treatment material it is possible to clarify the reasons that affect the swelling pressure.

The achieved results are:

(1) The swelling ratio of water-swelling material is not affected by COD and BOD of the water where the water-swelling material is exposed in plain water and artificial sea water environments.

(2) The swelling pressure of water-swelling material is 0.2 MPa in an adhesive thickness of 1 mm. On the other hand, if the adhesive thickness of water-swelling material is 2 mm and 3 mm then the swelling pressure is 0.5 MPa or higher.

(3) The hydraulic conductivity of water-swelling material applied to both sides of the H alloy flange clearance is equal to the hydraulic conductivity of the actual water-swelling material depending on the external work pressure below the swelling pressure.

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