TRENCHLESS REPAIRING OF UNDERGROUND PIPES USING RTM & DIELECTROMETRY

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Abstract

The excavation technology that conventionally used in repairing and replacing worn-out underground pipes induces traffic congestion and large amount of waste. To overcome the problems of conventional excavation technology, various trenchless (or excavation free) repair-reinforcement technologies have been developed and tried. But trenchless technologies so far developed have some drawbacks such as high cost and inconvenience of operation.

In this study, to overcome the problems of conventional trenchless technologies a repairing-reinforcing process for underground pipes with glass fiber fabric polymer composites using RTM (Resin Transfer Molding) has been developed. The developed process requires shorter operation time and lower cost with smaller and simpler operating equipments than the conventional trenchless technologies.

From the investigation, it has been found that the developed repair technology with appropriate process parameters and on-line cure monitoring has many advantages over conventional methods.

Keywords: Trenchless; Underground; RTM; Rehabilitation; Repairing; Void Removal; Dielectrometry

Introduction

Underground pipes already constructed, such as water-supply pipes, sewer pipes, gas pipes, and etc., have been undergone several problems such as aging, reduced strength, partially cracked, broken or corroded status before their expected life span due to the rough designs that do not consider the effects of load increase subjected by ground, dynamic relation between pipes and ground, careless management, and aging of pipe material due to acidification of soil [1].

When these problems have arisen, the excavation technology has been used mainly, which allows replacing the existing pipes with new pipes through the excavation of earth in a large area around the target pipes. In order to compensate the irrationalities of the conventional excavation technology and to insure the high durability and safe construction environment, various trenchless (excavation free or no-dig) repairing-reinforcing technologies have been proposed and tried. Among the trenchless technologies so far developed, the reverse lining process which uses the unwoven fabric tubes impregnated with polyester resin and the spirally winding process which uses thermoplastic resin such as PVC or PE are most representative [1].

But these trenchless technologies have many disadvantages such as high construction cost, inconvenience of operation and limited application to circular conduits. In order to overcome such problems of conventional trenchless rehabilitation technologies and develop a new process which is adequate to the situation of high traffic road, a study on repairing and reinforcing underground pipes with glass fiber fabric and unsaturated polyester resin by RTM (Resin Transfer Molding), a sort of composites manufacturing processes, has been investigated.

Since RTM has the capability to fabricate large and complex commercial products at low production cost [2], it may be plausible to apply the RTM process to repair and reinforce very large underground pipes.

There are many researches that are related to the trenchless rehabilitation technologies [3-6]. However, the RTM process to repair and reinforce underground pipes has not been hardly attempted until now.

Therefore, in this study, the method for repairing and reinforcing process of retired or damaged underground pipes by RTM has been attempted using fiber reinforced composite materials, the reliable repairing-reinforcing process of underground pipes is suggested and experimentally investigated through the various experiments and analyses.

Repairing-reinforcing Process of Underground Pipes Using RTM

Development of the Process

The reinforcing preform cut to near net-shape is placed at the inner cavity of the mold, and the mold is closed and clamped in the RTM process. Then the resin is injected into the mold through a resin inlet and transferred into the preform. When the injected resin spouts from the air vent of the mold, the flow of resin is stopped and the curing reaction is initiated. After curing of resin, the formed structure is demolded from the mold and the whole process is finished [7].

The developed repairing and reinforcing process of retired underground pipes based such a general RTM process is shown in Fig. 1 composed of 4 steps.

<Step 1>

As shown in Figure 1(a), the interior of a target underground pipe is cleaned and deposits and protrusions are removed at this time. Then the mobile robot conveys a rope from one manhole to the other one. The repairing and reinforcing reinforcement that is composed of glass fiber preform and two covering plastic films, is connected to one end of the rope as shown in Figure 1(b) and pulled using a winding machine. The shape and manufacturing method of composite reinforcements are shown in

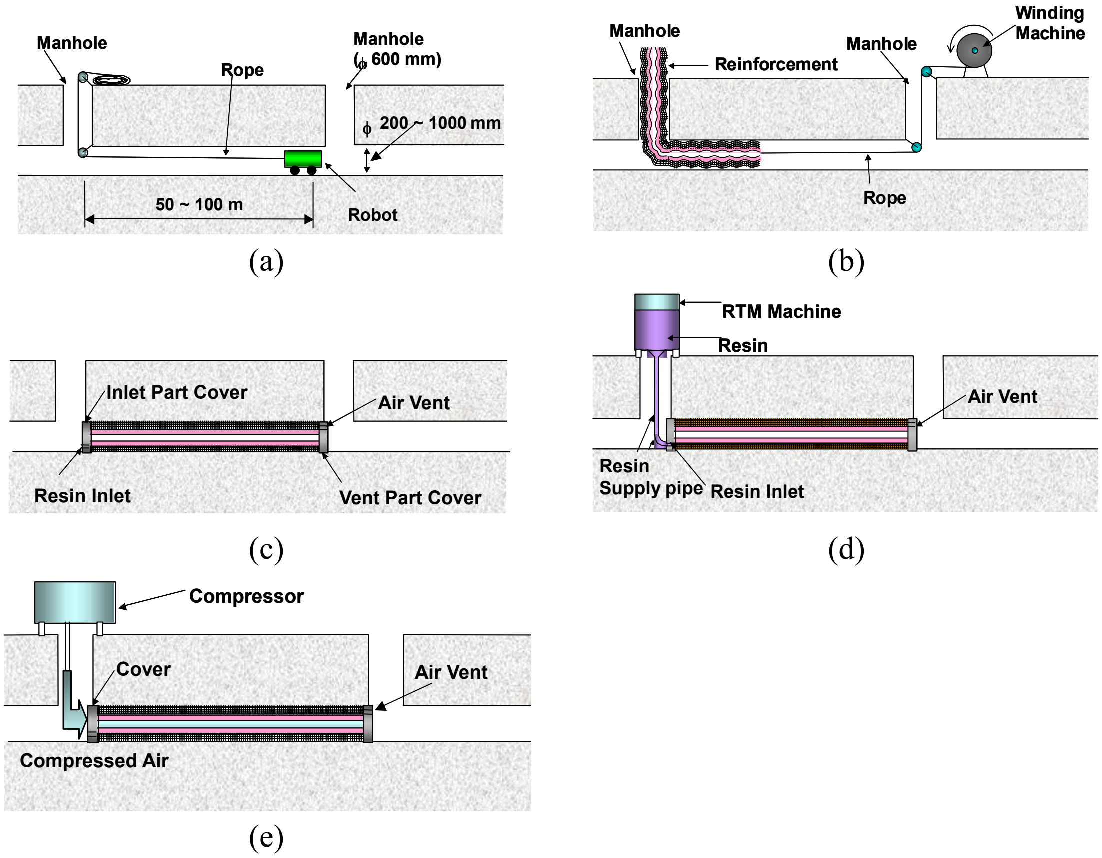


Figure 1. Repairing-reinforcing Processes of Underground Pipes with RTM: (a) Removing Deposits and Protrusions in the Pipe; (b) the Reinforcement Is Connected to a Rope and Pulled; (c) Closing Two Covers at the both Ends of Reinforcement; (d) Resin Injection; (e) Resin Wetting and Curing.

Figure 2.

<Step 2>

Both the ends of the reinforcement placed in the target pipe are closed as shown in Figure 1(c) using two covers that are composed of a steel ring and an acryl disk as shown in Figure 3 in which the assembling method of the cover is also depicted. In this method, the cover and the reinforcement were clamped with a band clamp that is tightly fitted into the groove of the steel ring. The groove on the circumferential face of the steel ring plays a role of a load supporter as well as resin sealant. After sealing the reinforcement in the tube, the compressed air from the air inlet of inlet part cover

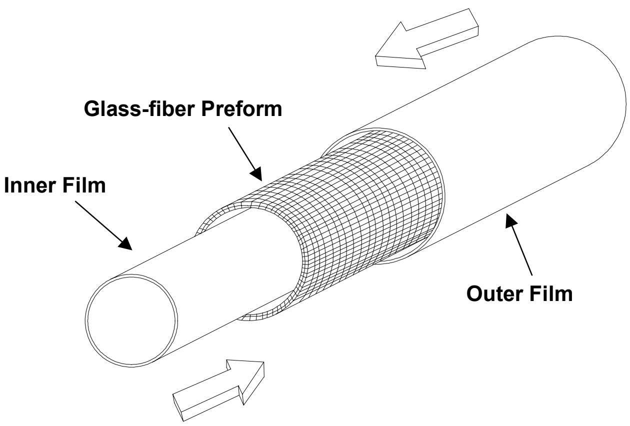


Figure 2. Preparation of the Reinforcement.

is supplied to expand the inner film of the reinforcement, which makes the outer film and glass fiber preform contact closely to the internal surface of the pipe to be repaired or reinforced, and removes wrinkles and twists in the reinforcement that might occur during inserting operation.

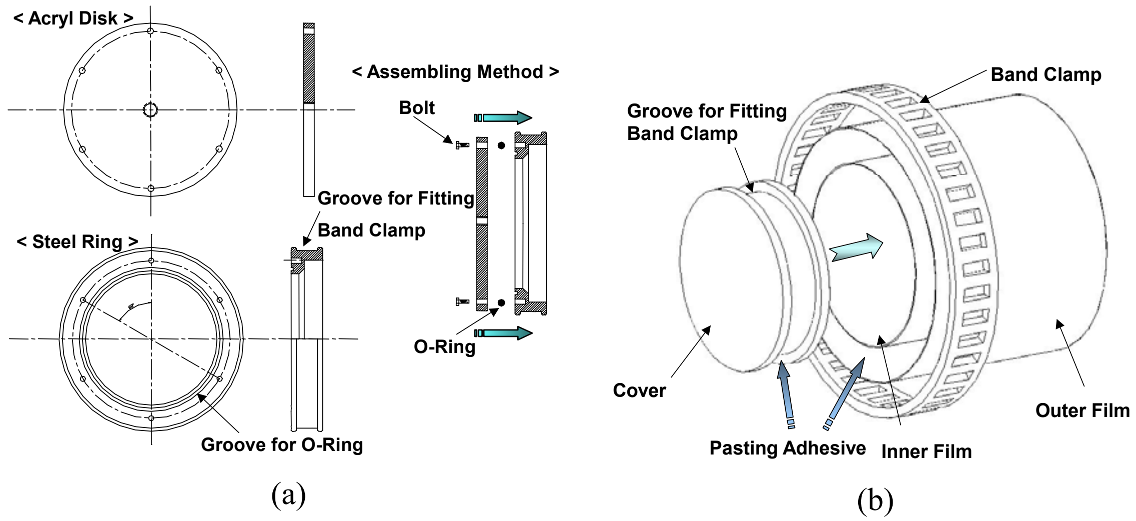


Figure 3. Cover Design and Assembling Method: (a) Detailed Design of the Cover (Steel Ring + Acryl Disk) and Its Assembling Method; (b) Clamping Method of Covers and Positions for Pasting Adhesive.

<Step 3>

After the pressure in the cavity is removed to help the resin flow easily, the thermosetting unsaturated polyester resin is injected into the glass fiber preform with a RTM machine through the resin inlet of the inlet part cover as shown in Figure 1(d). Since the unsaturated polyester resin is composed of a monomer with low viscosity [8], it is easy to feed the resin into the preform under low pressure.

<Step 4>

After injecting a predetermined amount of resin, the RTM machine is separated from the resin inlet. Then the compressed air is fed into the cavity to make the injected resin wet uniformly the glass fiber preform as well as contact closely the reinforcement to the internal surface of the pipe as shown in Figure 1(e). The air and volatiles produced during cure of polyester in the preform were evacuated through the air vent of the vent part cover by applying a vacuum to the air vent. After the resin in the fiber preform is completely cured, the covers at both ends of the pipe are removed to complete the process.

Selection of the Resin and Film

Since the matrix of composite material prevents the fiber buckling, protects fibers and enhances the compressive strength of composite materials under compressive loads [9], the selection of suitable matrix is important, especially for the underground pipe structures under compressive loads. Typical resins for RTM are epoxy and polyester resin, and have various viscosities and material properties. Among several available resins for RTM, epoxy resin has best mechanical properties, however, its price is somewhat expensive and mainly used in the aerospace field. Therefore, in this work, the unsaturated polyester resin with low viscosity was selected because it is about five times cheaper than epoxy resin. The resin used in this work is orthophthalic type unsaturated polyester PC670 (Aekyung Chemical, Daejeon, Korea) that is semitransparent and violet. It has a low viscosity before cure (0.2 Pa·sec) with the possibility of filler addition to reduce cost and strengthen toughness.

The films should have sufficient tensile properties, durability and the chemical stability with the contact of unsaturated polyester because styrene that is monomer used for hardening of polyester may react with the film material. To select a suitable material for the inner and outer films of reinforcement, the static tensile tests and chemical stability tests with the unsaturated polyester resin were performed. Several film materials such as PVC (Poly-Vinyl-Chloride), PE (Polyethylene), PU (Polyurethane), and tarpaulin films that are composed of polyester fabric and PVC resin were tested [10]. For the tarpaulin films, Pro-Top, Pro-Sol, and Aqua-Tex (LG chemical, Seoul, Korea) were tested. The specimens were prepared with and without soaking into the unsaturated polyester resin (PC670) for 12 hours. Since the Pro-Sol film had superior tensile properties and chemical stability with styrene monomer in unsaturated polyester resin compared to other materials as shown in Table 1, it was selected for the film materials.

Table 1. Tensile Properties of Various Film Materials

Material		PVC	PU	PE	Aqua-Tex	Pro-Top	Pro-Sol
Strength (MPa)	A	12.0	28.4	12.4	78.8	38.4	94.5
	B	7.2	12.2	12.4	63.2	36.4	80.3
Failure Strain	A	2.7	3.1	4.8	0.33	0.29	0.30
	B	3.3	6.1	4.8	0.30	0.28	0.35
Required Thickness (mm)	A	2.1	0.9	2.0	0.32	0.65	0.26
	B	3.5	2.0	2.0	0.4	0.69	0.31
Available Thickness (mm)	A, B	0.1 ~ 1.0	0.1 ~ 0.5	0.1 ~ 0.17	0.45 ~ 1.0	0.35 ~ 0.6	0.55 ~ 1.0

A : Without Soaking into the Unsaturated Polyester Resin (PC670)

B : With Soaking into the Unsaturated Polyester Resin (PC670) for 12 Hours

Permeability Measurement and Selection of the Glass Fiber Mat

The resin wetting is the core process of RTM because the quality of product is dependent on the degree of wetting [11]. The resin wetting is related to the resin flow through porous media of reinforcement, and the average velocity $\overline{U}$ of resin is usually defined from Darcy's law [12] as follows:

$$\overline{U} = -\frac{K}{\mu}\nabla P \tag{1}$$

Where, K is the permeability of fiber preform, μ the viscosity of resin, and ∇P the pressure gradient.

From Equation (1), it is known that the average velocity of resin is affected by permeability of fiber preform, viscosity of resin, and pressure gradient. In order to increase the wettability of resin, the average velocity of resin through porous media has to be increased, which is closely related to the productivity. In this work, E-glass fiber mats with relatively low price were used to lower the material cost and the permeabilities of various fiber mats shown in Table 2 were measured through the permeability measuring experiment. Preform materials of the reinforcement were selected based on the test result. In order to compensate the defect of unidirectional mats, which cannot assure longitudinal strength, and that of continuous mats, which have too low fiber volume fraction, the stacked mats of [unidirectional mat 1 ply/continuous mats 2 plies/unidirectional mat 1 ply]$_T$ stacking sequence had been employed and tested. Finally the stacked mats of highest permeability and satin woven mats of good workability were selected for preform materials separately.

Table 2. Permeabilities of the Various E-glass Fiber Mats

Type of Mat	Volume Fraction (%)	K_{xx} (m^2)	K_{yy} (m^2)
Unidirectional	56.1	3.4519❹$10^{-9}$	2.9736❹$10^{-9}$
	67.3	4.6362❹$10^{-10}$	3.2806❹$10^{-10}$
Continuous Strand	12.1	1.7216❹$10^{-9}$	1.7049❹$10^{-9}$
	18.0	9.4450❹$10^{-10}$	9.3605❹$10^{-10}$
Stacked Mat [UD/CSM/CSM/UD]$_T$	34.5	3.6287❹$10^{-9}$	3.5347❹$10^{-9}$
Satin Woven	45.5	7.1261❹$10^{-11}$	5.8841❹$10^{-11}$
	50.0	4.4695❹$10^{-11}$	3.2401❹$10^{-11}$
	54.5	2.5488❹$10^{-11}$	1.8955❹$10^{-11}$
Plain Woven	45.5	6.3931❹$10^{-11}$	5.3651❹$10^{-11}$
	50.0	4.2934❹$10^{-11}$	3.2552❹$10^{-11}$
	54.5	2.1315❹$10^{-11}$	1.8154❹$10^{-11}$

Resin wetting experiments

Resin Wetting Experiments and Void Removal Method

In order to check the degree of resin wetting and void removal, the resin wetting experiment was performed in the transparent acryl pipe of 180 mm (the smallest inside diameter of the target conduit of this study) diameter with 1 m length and 5 mm thickness. For the wetting experiments, satin woven mats and stacked mats were covered with transparent PVC films of 1 mm thickness to observe the flow of resin although the Pro-Sol tarpaulin film was used in the real operation. In the manner shown in Figure 2, two reinforcements were manufactured using satin woven mats, stacked mats, and PVC films respectively.

After placing the reinforcement in an acryl pipe, the thermosetting adhesive, DP460 of 3M was pasted on the surface of the two covers, followed by fastening with the band clamps as shown in Figure 3(b). The circumferential surfaces of the steel rings were abraded with the sand paper of 80 meshes to increase the adhesion strength [13]. In this resin wetting experiments, the silicon oil of same viscosity of the unsaturated polyester resin (PC670), was used because the tensile strength of the PVC films decreased when contacted with the unsaturated polyester resin. The silicon oil was mixed with small amount of ink for the flow observation. From the test, it was found that the resin wetting could be completed with relatively low air pressure below 100 kPa. However, the air-entrapped area was generated at the middle upper region of the reinforced pipe due to the side effect of both ends, which was induced by the difference of permeability. Since the fiber preform could not be filled completely both the ends of flexible mold, which made the fully opened channels whose permeability was much higher than that of the fiber preform, it was easier for resin to flow through those channels than through the fiber preform. So it made the air within the preform entrapped at the middle upper region as shown in Figure 4.

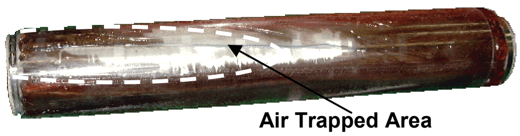
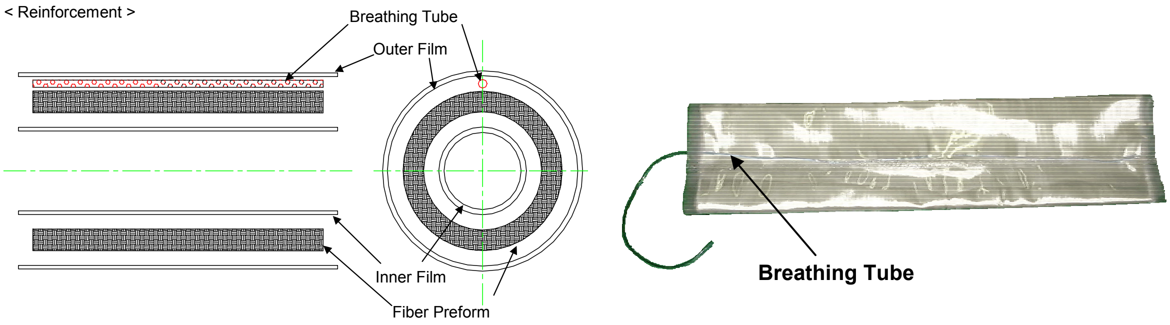


Figure 4. Formation of the Air-entrapped Area.

In order to remove the air-entrapped area, a porous breathing polyurethane tube was inserted into the upper position of reinforcement as shown in Figure 5(a). The breathing tube was found to be very effective to expel the air entrapped and was easily removed by pulling out one end of the tube before curing. Also it was found that the vacuum application to the air vent enhanced the efficiency of void removal. The polyurethane tube whose outside diameter of 6 mm with 1mm thickness was used for the air breathing experiment after making several small holes through its length. The tube was fixed on the glass fiber preform by stitching as shown in Figure 5(b). From the experiment, it was found that the air-entrapped area that had been formed in the previous experiment was not formed when the breathing method was used.

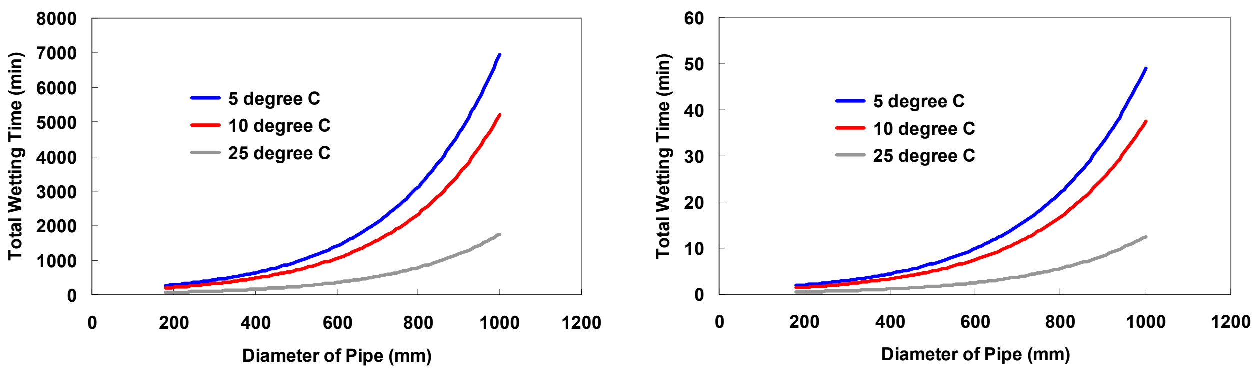


(a) (b)

Figure 5. Void Removal Method Using the Porous Breathing Tube: (a) Schematic Diagram; (b) Photograph of the Reinforcement Applying This Method.

Resin Flow and Wetting Analysis

The resin flow during RTM process is closely related to the viscous flow through the porous media defined by Darcy's law of Equation (1). Using this simple Darcy's law and fluid dynamic relations, the resin flow analysis and predictions of wetting time had been investigated with respect to the temperature, types of fiber preform, and diameters of conduits on the assumption that vacuum and air pressure of 30 kPa is applied to the reinforcement. Analytical results are shown in Figure 6. From these resin flow and wetting analysis, it was possible to predict the problems that might occur at the real operations and to determine the important process variables.



(a) (b)

Figure 6. Resin Flow Analysis and Predictions of Wetting Time w.r.t. the Temperature and Diameter of Pipes: (a) Satin Woven Preform; (b) Stacked Preform.

Repairing-reinforcing experiments of underground pipes

RTM Process Monitoring with Dielectrometry

Since the resin flow status cannot be observed due to the Pro-Sol films that are not transparent and the actual repairing-reinforcing is performed underground, it is necessary to on-line monitor the wetting and curing status of resin during the process. For this end, dielectrometry and dielectric sensors were employed to monitor the resin status in this work. When an alternating electric field is connected to the dielectric sensor that are embedded in the composite material, the dipoles and ions within the resin, which is a dielectric material, are aligned following an applied alternating electric field. The mobility of dipoles and ions has close relations with the cure state and the viscosity of resin within the composite material. The principle of dielectrometry is to monitor the cure state by measuring the dissipation factor, which is the amount of energy loss expended in aligning its dipoles and moving its ions in accordance with the direction of an alternating field [14]. Since the value of the dissipation factor changes when the dielectric sensor contacts the resin, it is possible to on-line monitor the resin wetting as well as the cure status by measuring the dissipation factor continuously. Therefore, in this work the monitoring of resin wetting and curing during the repairing-reinforcing process were performed by using a commercial dielectrometric cure monitoring system CM102 (LACOMTECH, KAIST, Daejeon, Korea). Figure 7 shows the dielectric sensor embedded in the glass fiber preform by stitching with the line of sensor to be connected to the dielectrometer LACOMCURE as well as the breathing tube.

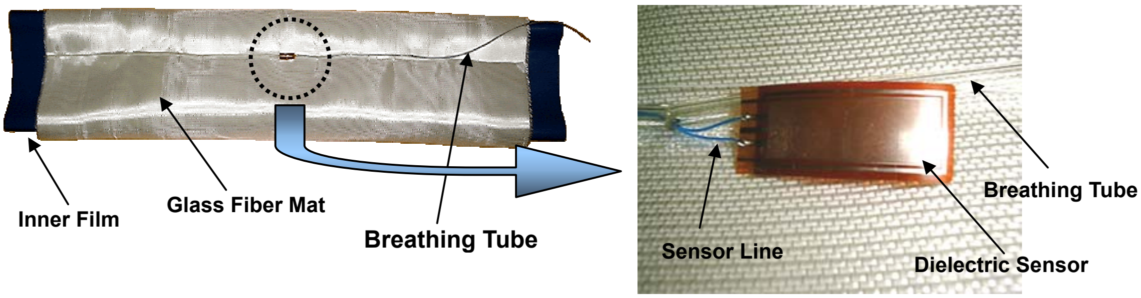


Figure 7. Reinforcement with a Breathing Tube and a Dielectric Sensor whose Dimension Is 9 mm × 250 mm × 168 μm.

Repairing-reinforcing Experiments

In order to verify the analysis results and to confirm the whole process, the repairing-reinforcing experiments were performed in the acryl pipe of 180 mm inside diameter using the reinforcement with the dielectric sensor and the breathing tube. In the manner shown in Figure 2, the reinforcement was fabricated using satin woven mats, and Pro-Sol tarpaulin films. After injecting the unsaturated polyester resin, PC670, the compressed air was applied to the cavity between the two covers and the inner film to wet the glass fiber preform covered by the inner and outer films, which worked as a flexible mold. The pressure of the air was varied from 40 kPa to 70 kPa while vacuum was applied to the air vent to remove voids within the preform. At this time, the ambient temperature was 32℃. The volume ratio of resin to catalyst (MEKPO; Methyl-Ethyl-Ketone-Peroxide) was 100 to 1.

When the resin mixed with voids spouted out through the breathing tube, the surplus resin within the reinforcement was removed gradually. When the surplus resin was completely removed, the flow of resin through the breathing tube was stopped. When the resin contacted the dielectric sensor during resin injection, the value of dissipation factor increased as shown in Figure 8, in which it took about 7.5 minutes to complete the wetting and about 3 hours to complete the curing at 60℃. The experimental wetting time (7.5 minutes) had an error of 6.7 % with the analytical result, 8 minutes, as shown in Figure 9(a).

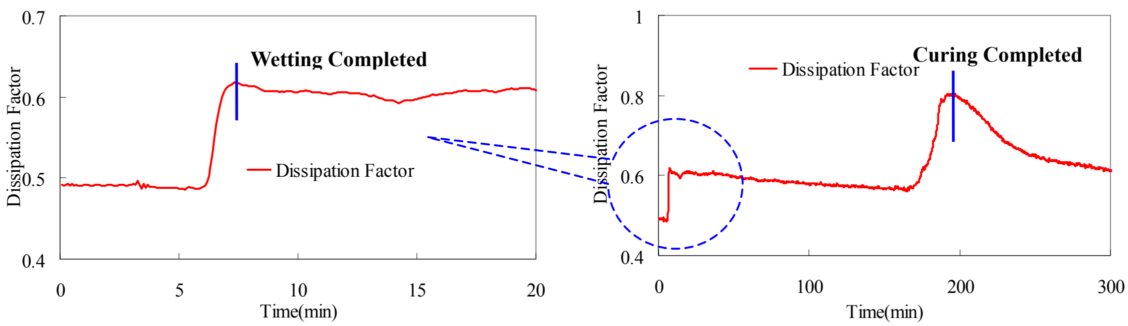
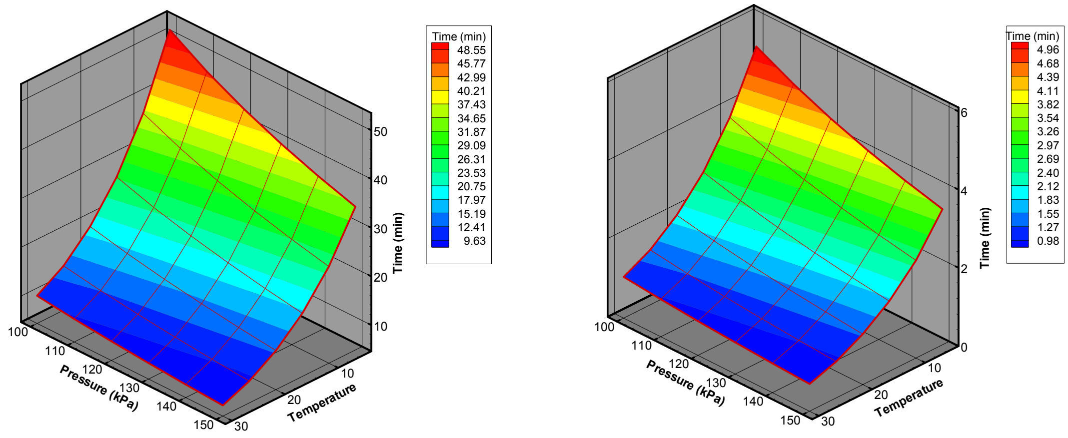


Figure 8. Dissipation Factor of Unsaturated Polyester during the Repairing Process Measured by Dielectrometry.

In case of repairing the pipe of larger diameter at lower ambient temperature with the preform of satin woven mats, it took so much time to wet the preform entirely as shown in the analysis result of Figure 6. Since the ambient temperatures of underground conduits are almost uniform all year round, between 10 and 18℃, and the viscosities of PC670 are between 0.7 and 1.0 Pa&sec at this temperature range, it is hard to meet the required process time with the preform of satin woven mats. To solve these problems, the repairing-reinforcing experiments were performed in the acryl pipe of 300 mm inside diameter using the preform of stacked mats, which has the highest permeability. After injecting the predetermined amount of resin, vacuum and air pressure of 10 kPa was applied to the reinforcement while the ambient temperature was 10℃, and it took about 4.5 minutes to wet the preform completely. The experimental wetting time (4.5 minutes) had an error of 6.7 % with the analytical result, 4.8 minutes, as shown in Figure 9(b).

After curing, the fiber volume fractions of the reinforcements were calculated from the amount of injected resin and that of expelled resin. From these calculations, it was found that the fiber volume fractions were between 25 % and 40 %, which depending on vacuum applying time and applied air pressure, and that the unsaturated polyester resin was wetted to the glass fiber preform uniformly.



(a) (b)

Figure 9. Resin Flow Analysis of the Reinforcing Experiment: (a) Satin Woven Preform; (b) Stacked Preform.

Compression Test of Reinforcement

The compressive strengths of the reinforcement made of glass fiber polyester after the acryl pipe was removed were measured through the compression test based on ASTM C 497M [15]. The load capability of the reinforcement with 1.6 mm thickness which was made of satin woven preform and polyester was 6.9 kN/m. Considering that the typical compressive strength of reinforced spun concrete pipe with the same diameter of the acryl pipe in this study and thickness of 27 mm is 25.6 kN/m, the reinforcement increased the compressive strength of the pipe about 27 %, let alone the repairing advantage.

Conclusion

In this study, a new Resin Transfer Molding (RTM) process for repairing-reinforcing of retired or damaged underground pipes using fiber reinforced composite materials has been developed. For the reliable repairing-reinforcing process of underground pipes using RTM, the glass fiber reinforcement was covered with tarpaulin films that worked as a flexible mold and protection skin and a porous breathing tube was used to remove air-entrapped area in the reinforcement. The resin wetting and curing status were monitored with commercial dielectrometry equipment. From the compression tests of the reinforcement made by the developed method, it was found that the compressive load capability of the reinforced pipe had increased about 27 % let alone the repairing advantage.

Acknowledgements

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