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Quality Control Factors of CIPP Construction Management for Water Main Rehabilitation

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ABSTRACT: Cured-In-Place Pipe (CIPP) technology is worldwide conducted to various pipeline rehabilitations. CIPP entire projects combine the expertise of material chemistry, pipeline techniques, and civil construction in water main rehabilitations. Due to the requirements of high technique level, insufficient training for construction, the restriction of technical transfers, and the inadequacy of equipments resulted from limitations of application authorization, some failure projects occurred in the past years. The problems were, for example, collapse of cured tube, inversion hydrostatic pressure decline, and excessive longitudinal folks etc. Once the lining inversion and solidification operations were mistaken, the cost of reconstruction and the overdue risk of contract period must be assumed. Therefore, material preparation and on-site construction quality management are essential issues. In view of this, this paper proposed the framework of quality control factors on CIPP construction management, to establish the relationships between those key factors by the superposition effect, and three main operations including resin impregnation process, on-site inversion process and curing process. The quality control factors were discussed by means of the case studies of practical projects with 152m MJP DN1000 mm and 94m CIP DN800 mm water mains of CIPP rehabilitations in urban area of Taipei. The quality control factors of water main CIPP in this paper will provide to help the civil engineers of contractors, supervisory units and owners to establish overall quality concept of CIPP for reducing the risk of project failures.

Key words：CIPP, inversion hydrostatic pressure, curing temperature

1. INTRODUCTION

Since the initiative of Cured-In-Place Pipe (CIPP) method in 1971, the technology has been becoming mature. CIPP technology for rehabilitating existing damaged pipelines in many countries has been regarded as a trend. Its materials, equipments and technologies are still innovating and improving to meet the requirements of various pipelines and environmental conditions. However, the CIPP technology involves integrated applications of material chemistry, pipeline techniques and civil engineering expertise, which is a high level of technical requirements. Due to the restrictions of technologies transfer from patent scope, insufficient training and inexperience of construction workers, some CIPP projects failed. Based on the chemical reaction of the resin, once the construction operation is started, it is prevent to stop in the process. Any equipment mismatch or operation deviation will lead to the interrupt and delay, which could cause major risks and economic losses. Successful CIPP projects must be strictly managed and controlled key factors during the whole procedure of CIPP. Therefore, the purpose of this study was to analyze the impact effects and their relationships between the key quality factors for each stage and establish an overall quality management framework for water inversion thermal CIPP construction to ensure the success of pipeline rehabilitations.

2. LITERATURE REVIEW

CIPP system design generally has a life span of 50 years and long-life cycle characteristics. When the urban large-scale pipeline network is updated, it is necessary to evaluate the cost-effectiveness of the repair, rehabilitation and replacement strategies to facilitate investment decisions (Selvakumar, Ariamalar, 2015) (Bruaset Stian,2018). Extensive research investigated that implement inspection tests on CIPP rehabilitated pipelines after practically being used for 10 to 25 years. Verification results showed good performance retained and met the long-life cycle durability expectations. The backtracking test evaluation of quality assurance and quality control adopted various parameters, including specific gravity, thickness, bending test, elongation test and visual inspection (Allouche, E., 2014) (Alzraiee, Hani, 2015) (S. Alam, 2018). At the same time, the push-on joints of DIP also can significantly improve seismic performance after being renewed by the CIPP method (Zhong, Zilan, 2018). In fact, some studies have conducted research on the quality management of the CIPP construction process earlier. Nassar, R. (2002) delineated that ASTM D2992 uses the least squares regression method to determine the inversion time can cause serious errors, so experimentally accelerated time until buckling of cured-in-place plastic liners. Based on this experiment, the maximum likelihood approach of CIPP was determined. Jaganathan, A. (2007) depicted that the longitudinal folds in a CIPP liner causes stress concentration as a function of the fold's geometry and level of applied lateral pressure, and the maximum allowable size of CIPP liners was obtained by numerical evaluation under the resistance of the lateral pressure to flexible felt. To sum up, the CIPP long life cycle characteristics are based on the current successful construction quality management.

3. CONSTRUCTION QUALITY MANAGEMENT FRAMEWORK

Since the water inversion thermal-curing CIPP technique involves the integrated application of material chemistry, pipeline techniques and civil engineering expertise, which requires a high technology level, if the worker training and experience of on-site construction are insufficient, it may probably result in poor quality or even fail to meet the commitments of the contract. The most important steps in on-site construction are inversion and heat-curing operations. Once the inversion operation is started, it must be continuously operated until the entire flexible tube has completed the compact procedure consist of resin impregnation, inversion and heat-curing. Any mistake in the process may lead to a failure of the whole project. Installation operating conditions are closely related to the material properties of resin and flexible felt, which must be mutually supported and adjusted. It is different from the traditional construction that follows regular construction standards. This paper introduced the key factors of the CIPP operating quality management based on practical field experience, and established the overall concept of construction quality management framework in the stages of process for meeting the requirements of contract, which is shown in Figure 1. The three most important processes were divided to resin impregnation, inversion and thermal curing. The key factors of resin impregnation were mainly resin type and its prescription, filling volume, and vacuum level. As for the inversion operations, the key factors were inversion hydrostatic head, inversion speed and inversion time. As for the thermal curing operations, the key factors were the curing temperature, required pressure and curing period. All key factors were oriented to meet the contractual functionality, safety, durability, and timeliness requirements.

The key factors of quality of the main construction operations, some were independent factors, and some were related to each other. This study proposed a pyramid model to illustrate the superposition effect of CIPP quality, as shown in Figure 2. On-site civil engineers and supervisors must realize the superposition effect of key factors of CIPP quality management, master the interrelated relationships between each other, and control the details of inversion and curing processes to ensure the construction quality.

Adopting water inversion thermal curing CIPP method, in order to ensure that materials, construction methods, workplace conditions and equipment adopted in the project meet the contract requirements, the parameters and restrictions of key quality control on three operations, resin impregnation, inversion and heat-curing, are shown in Table 1..

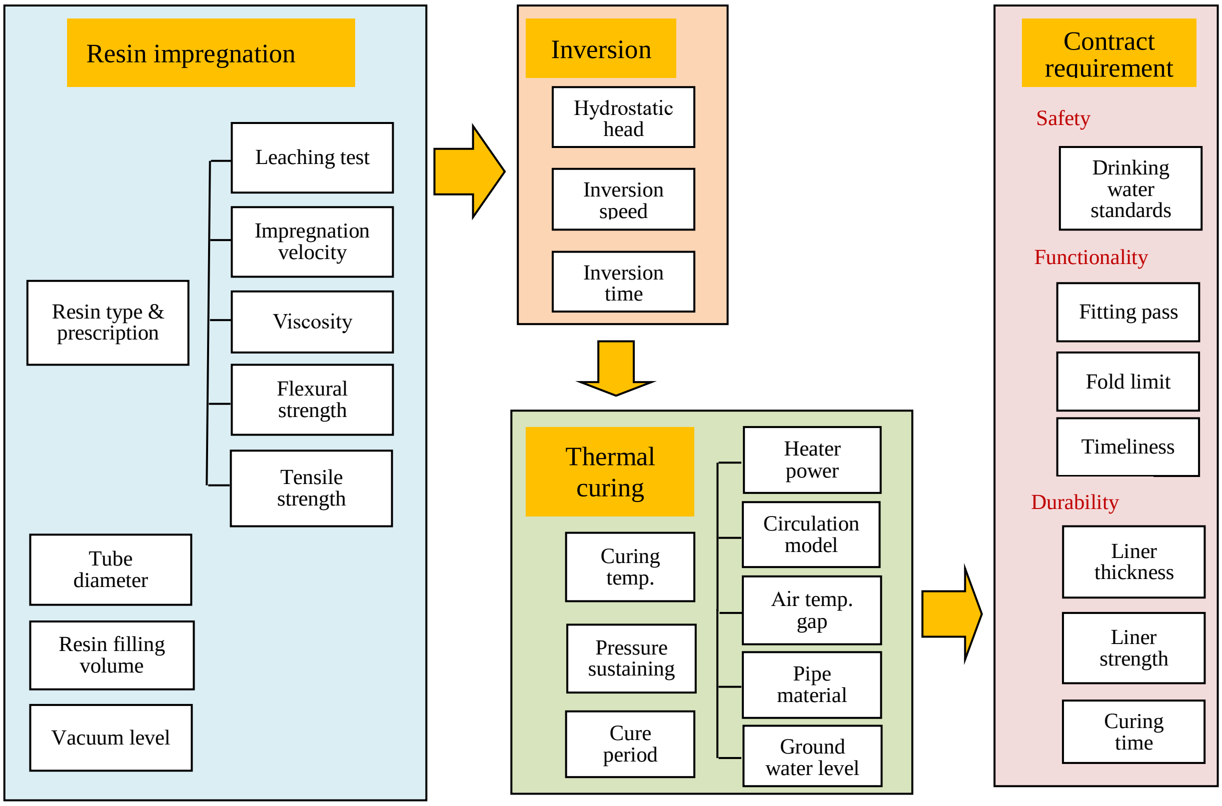

Figure 1. Quality Management Framework on Construction Processing Flow

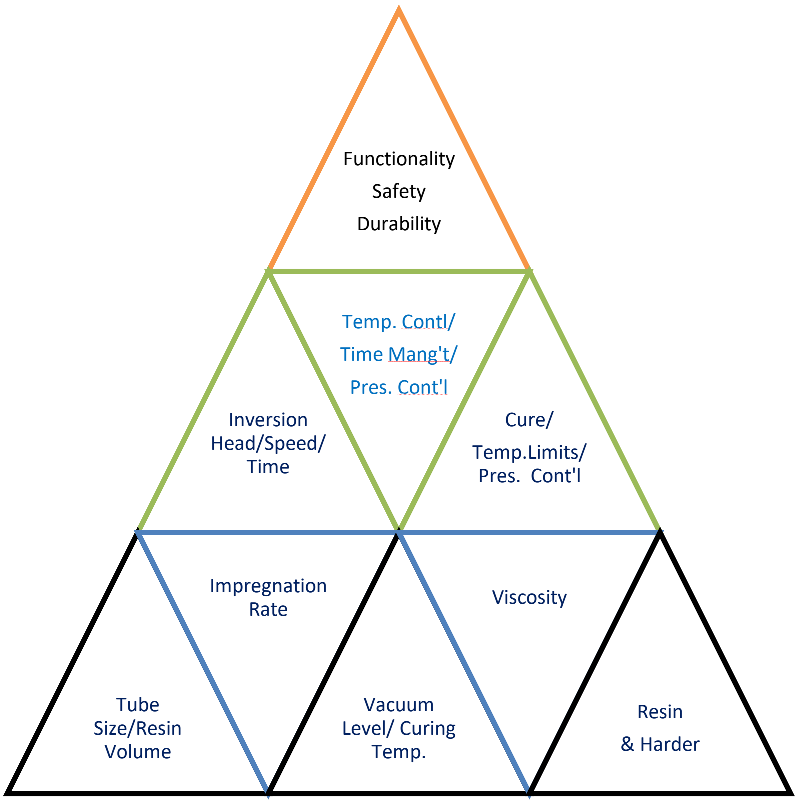

Figure 2. Pyramid model: the superposition effect of CIPP quality factors

Table 1. Major Control Factors of CIPP Technique Quality

Operation	Control Factors	Quality parameters	Operation required & Standards
Resin Impregnation Operation	Flexible felt size	● Length ● Axial folds criteria(diameter oversize)	● Sampling bare tube at terminal ● Elastic coefficient of the lining tube (Tensile strength)
	Prescription of resin & hardener	● Leaching test ● Compatibility tests (viscosity, permeability, impregnation rate, reaction rate) ● Flexural strength test ● Tensile strength test ● Gravity deformation rate of bare tube	● Drinking water quality standards ● Porosity of woven fabric and glass fiber layer ● Structural strength of bare tube
	Volume of resin filled	Thickness	Cost of resin and hardener
	Vacuum level	● Impregnation velocity ● Thickness of the cured tube ● Structural strength of cured tube	● Viscosity ● Structural strength of the cured tube
Inversion Operation	Inversion hydrostatic head	Inversion driving force	● Features of existing pipe (material ,diameter, length, fitting types and number) ● Limitation of operating space ● Viscosity of the resin mixture
	Inversion speed	● Design thickness ● Pass the bends ● Circumferential folds	● Tube feeding capability (forward) ● Control cable operations (brake) ● Allowable operating time for inversion
	Inversion time	● Strength of cured tube	● Resin & hardener features
Curing Operation	Curing temperature	● Curing time ● Temperature uniformity	● Heater power ● Heater and circulation system
		Material deformation of plastic layer(Water-contacted)	Upper limit of temperature
		Total curing Time	Lower limit of temperature
	Required pressure	Flexible tube tight against existing pipe wall	Inversion water head
	Curing time	Strength of the cured tube (Hardness test at terminal)	Texture of the existing pipeline, air Temperature, underground Water level, etc.

4. MANAGEMENT OF QUALITY CONTROL FACTORS - CASE STUDY

4.1 Project Information

1. 2017 The Fuxing Project

   1971, DN1000 mm MJP pipeline, with a total length of 812m and a depth of 4.2m, layout 6 work pits and 5 inversion sectors. This paper took the construction data analysis of the third sector 152m to demonstrate quality management.

2. 2019 The Xinsheng Project

   1963,DN800 mm CIP pipeline, with a total length of 771m, layout 7 work pits and 6 inversion sectors. This paper took the construction data analysis of the second sector 94m to demonstrate quality management.

4.2 Quality Control Factors

4.2.1 Resin Impregnation Operations

1. Resin and its prescription

The reliability and stability of the quality of the resin is the key to the success of the CIPP method. Before on-site installing, leaching test for drinking water standards, flexural and tensile strength test of bare tube, and compatibility test between resin and flexible felt are necessarily performed in the factory. Compatibility tests include viscosity, permeability, impregnation velocity, and reaction rate. It is a necessary condition that leaching test is in accordance with drinking water quality standards, while selecting resin and hardener type. Then the prescription with resin and harder needs to be checked its viscosity, permeability, impregnation velocity and initial strength based on the construction conditions such as the time limit for transportation and inversion, the number and type of bends etc. The ratio of resin and harder adopts double variable adjustment matching. The porosity of the flexible felt is also a key parameter, because the viscosity of the mixture will affect the permeability and the impregnation rate, which will disturb the structural strength of the cured liner. The viscosity of the resin mixture is usually controlled at 3300~3800 cps. The purpose is not only to facilitate the vacuum extracted effect, but also avoid vertical flow which will result in uneven thickness of tube (upper thin and lower thick) after curing. During the process, the viscosity will rise gradually to 7800~9500cps with time. The resin prescription must provide enough inversion operation time. Generally, the water pipe is set for 72 hours (at 25 °C) and the sewage pipe is set for 48 hours.

The projects adopted Japan's high-solid epoxy resin which met the safety level of drinking water. The volatile organic compound (VOC) content is 0%. The resin can be cured in the water. The curing time at temperature (23 ℃) needs more than 24 hours and initial curing temperature is about 80 ℃ / 2 hours.

2. Tube size

The length of the flexible felt depends on the distance between two work pits, and the length of the bare tube is reserved. As for the diameter of the tube, it must be determined by measuring the diameter of the existing pipe. If the diameter of the tube is oversized, excessive axial folds will be generated during inversion. If it is less too much, the liner wall will expand due to the water pressure as inversion, and the thickness will become thinner. Or, the tube will fit to the host pipe wall incompletely, and may collapse at any time. Therefore, the tensile features of the lining tube, such as tensile strength and the modulus of tension elasticity should be taken into consideration. In addition, the inner diameter of the host pipe is often affected by the tolerance of the anti-corrosion or the cement mortar inner layer, thus the diameter of the flexible felt is usually reduced by 1% to cope with the situation. When the roundness is insufficient, the tube size can be reduced by 2-3% to avoid the axial folds.

3. Resin filling volume

The volume of resin needed is to fill the flexible felt completely and achieved a saturated impregnation condition. A 3-5% additional resin mixture can be added, which enables to fill out holes or gaps in the existing pipeline and enable the liner to attach pipe wall closely.

4. Vacuum level

Implement vacuum extraction to accelerate the process of the resin mixture filling the woven pores of the flexible felt in resin impregnation. During impregnation process, the increased viscosity of the mixture will slow down the impregnation progress, and even leave excess pores which reduce the structural strength of the cured tube in the future. Hence, the control of the vacuum level will affect the impregnation rate, uniformity of the lining resin and also the structural strength of cured liner.

4.2.2 Inversion Operations

1. Inversion hydrostatic head

The inversion hydrostatic head represents the inversion potential energy. As for the setting of the maximum inversion potential energy, it will have to calculate the total driving force according to the length and diameter of the pipe, the type and amount of the pipe fittings, elevation differences of the path and the material parameters of the tube. The maximum inversion hydrostatic head has to being sufficient for fluent inversion process. In general, the total propulsion of the inversion water level is set between 4.5~6.5m. For the water level control during the inversion process, it must take account of the stress force of lining fiber provided by the flexible felt manufacturer, and convert it to the water level limitation according to the allowed pressure range. Appropriate inversion water head will enable the lining to be tight closely against the existing pipe wall. When water level is too high, the front end will be squeezed by the water pressure and expand, the tube wall will become thinner. If the inversion water level exceeds 1~3m (0.1~0.3kg/cm^2), the flexible felt could burst. Therefore, throughout the inversion processes, the pressure should be maintained between the minimum and maximum pressure until the inversion process is completed.

The inversion water level (hydrostatic head) was monitored and recorded by a high-temperature resistant submersible digital level transmitter in study cases. The maximum water head was set to 6.5m in standpipe for

152m MJP pipeline. The inversion water head changed with time as shown in Figure 3. It was controlled between 3.2~5.6m and the high water head was operated between 4.98~5.59m at inversion stage, which was below the upper limit 6.2m recommended by material supplier.

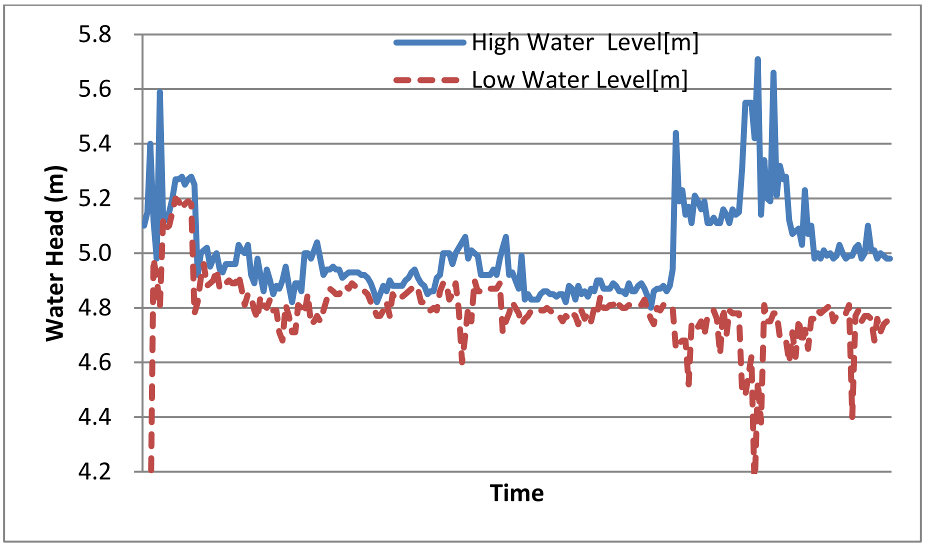

Figure 3. Control of Inversion Water Level of the Fuxing Project with Time

3. Inversion speed

The inversion speed is controlled by the hydrostatic head and the feeding speed of the liner as the forward pushing force, and the control cable acts as the brake application. The synergetic operations of the two forces generate a stable and uniform inversion speed. The inversion speed is generally set between 1.0 ~ 2.0 m/min. At this time, the reduction value of water level in the vertical inversion standpipe equals to the forward length of the tube. If inversion speed is too fast, it is easy to generate circumferential folds. Especially, the tube could be spiraled and increase the forward resistance at the initial stage. Therefore, the initial inversion speed is suggested to be controlled below 1.0 m/min to ensure smoothness.

Inversion speed control is reflected in the operating water head. Inversion of the initial head control must be controlled at a low water level to make the speed slow. Increase the head to rise up the inversion speed when the inversion tube is over half. The water level control during the inversion period of the Xinsheng project is shown in Figure 4. The first half of the water head was 2-3m, and the second half rose to a constant stable water level of 4.6m.

The inversion time took 1 hour 40 min for the Fuxing Project, and the average inversion speed was 1.52 m/min. The initial 50m inversion speed even was controlled down to 0.4m/min only. In the middle and rear parts, the inversion water level was stably controlled at 4.8~5.6 m.

In addition, it is worth mentioning that inversion operation pass through the bends. Water pressure pipeline is often installed by a set of fittings with four 45° bends, known as "boat-shaped groove", to pass obstacles underground. Under this situation, the control cable could be completely released, not only to provide more driving force, but also avoid the friction of cable damage the inner plastic layer.

2. Inversion time

After the resin is mixed with the hardener, a chemical reaction begins and starts curing gradually. During the impregnation and transportation process, low temperature storage is needed to retain the flexibility of the lining tube for the inversion process. The available inversion operating time of the water pipeline is usually set in 72 hours. However, if the inversion process encounters difficulties and the expected allowable time of the resin mixture is exceeded, the cured tube strength could be less than the design value, and even the inversion could stop before arriving the termination point, resulting in failure. Therefore, integral planning and equipment preparation for the prior process are very important.

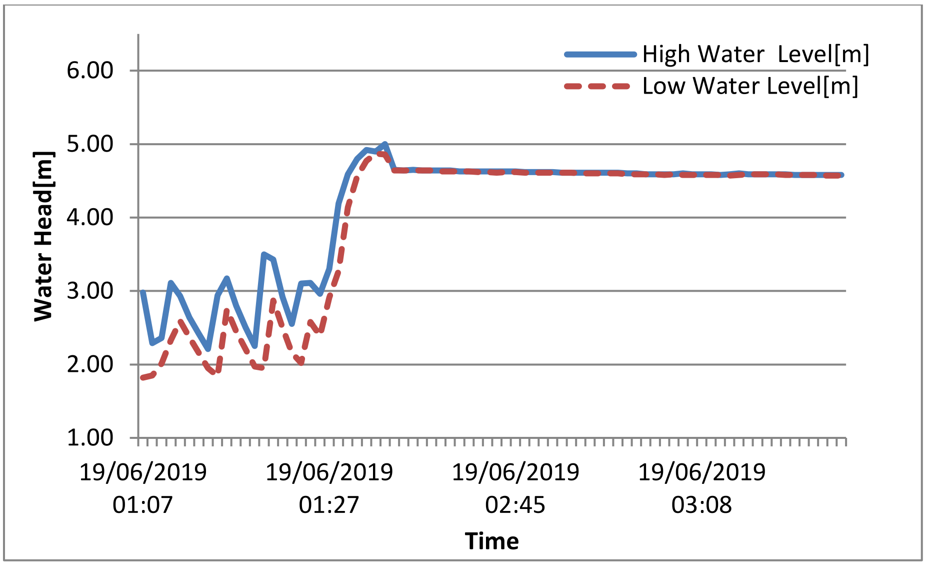

Figure 4. Control of Inversion Water Level of the Xinsheng Project

4.2.3 Thermal Cure Operations

1. Curing Temperature

The hot water supply pipe is brought to the end of the termination point following the inversion tube go forward, and the pumping pipe is set at the start point of the tube. Connect the pumping pipe with a heater to form a heating circuit, which enables the water temperature inside the tube to rise to the curing temperature. Although the ASTM F1216 specification should be less than 82.2 ° C for heat curing temperatures, the real significance is to match the material properties of resin and flexible felt, typically is between 80 and 90 °C. The temperature and heating time required for the curing process must be determined according to the resin characteristics, the liner material, the power efficiency of the heating system, and air temperature. Therefore, the temperature limits of various pipelines such as sewage, tap water, gas, and industrial pipes are different.

In order to facilitate temperature control, digital thermocouple meters were installed in the front, middle and end of the tube, so that temperature data of each point could be transmitted to the monitoring panel immediately, hence the water flow could be adjusted flexibly. The length of this construction section was 152m, the total water volume needed 123 m^3, and two 1500 KW hot water boilers were prepared. The thermosetting resin were accelerated the thermal curing reaction at 80~90 °C. The upper limit of the temperature management at the tube end was set at 90℃. The temperature of the tube head was lower, but still reached 82.7 ℃, so that the thermal curing reaction was fully completed and achieved the required design strength. In additional, the ceiling of the temperature limit was due to the mixed plasticized material of the water-contacted layer, covering the PE, PP or PE mixed with PP, and their heat resistance levels are below 90℃, 100℃ and 100℃, respectively. In this case, the water-contacted layer of flexible felt adopts PE, when the circulating thermal curing temperature was too high, it might damage the PE thin film layer of the inner liner, it might generate surface drums, melting deformation, and even peeling off. On the other hand, if the curing temperature was too low, the total curing time would be extended, thus affected the subsequent progress.

2. Required Pressure

It is crucial to maintain enough hydrostatic head in the standpipe for keeping flexible tube tight against the existing pipeline wall during whole cure period. According to ASTM F1216 specification, the pressure deviate more than 70 cm of water head from the required pressure, the installed tube shall be removed from the existing pipe. Therefore, the water level needs to set the lower limit and keep stable during the heating period and the cure period. The setting of allowable water head range should be based on the recommend of the flexible felt manufacturer.

3. Curing Time

The temperature and heating time required for curing must be determined according to the resin mixture characteristics, the power efficiency of the heater and circulation system, and the air temperature. As for the ambient temperature, low air temperature, high heat dissipation on metal material of the existing pipe, and high groundwater level are common considerations. Those factors will extend the entire cure time that may be disallowed because of the traffic jam condition in urban.

Due to the limit of out of water service and the permit for traffic impact from the authorities, the time management of the curing process was of paramount importance. The entire cure period must be completed within a restrict time limit. Figure 5 shows the temperature control of the heat curing temperature. The heating time was 27.6 hours, the curing time was 5 hours, the cooling time was 30.6 hours, and the total cure period took 63.2 hours. The heating temperature was increased from the initial average temperature of 29.2 °C to 82.5 °C, and maintained at 78-83 °C. The average temperature before cooling was 81.5 °C, and the temperature was 42.7 °C after completion of cooling. Therefore, the average heating rate was 1.93 °C / hour, and the average cooling rate was 1.27 ° C / hour.

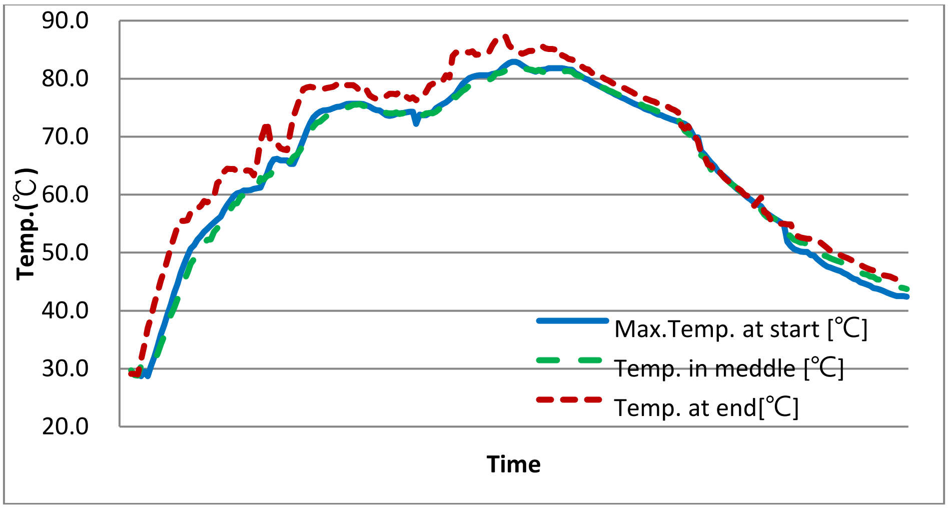

Figure 5. Thermal Curing Curve of the Fuxing Project

5. CONCLUSION

The quality management framework of CIPP projects consist of three operations, resin impregnation, tube inversion, and lining curing, which shall be managed as a whole in construction. The key operational factors of quality control are mutually influenced by each other and have a superposition effect. The features of tube materials are regarded as high relatively factors with operations of construction on-site. It is recommended that civil engineers manage CIPP projects in a full process perspective and comprehend the characteristics of resin and flexible felts in cases, which will reduce the risk of failures and ensure the expected lifespan.

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