Strength Characteristics and Effectiveness of Scotchkote® 2400 Liner Used for Utility Pipeline Rehabilitation

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June 10, 2020

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Abstract. The article considers the problem of rehabilitation of utility pipelines of public water supply systems. The article analyzes the results of the experiments for determining the strength characteristics of Scotchkote® 2400 protective corrosion resistant coating of pipes, that were carried out in the laboratory of the Water Supply and Sanitation Department of the Moscow State University of Civil Engineering with Instron 3345 electromechanical tensile testing machine. The effectiveness of Scotchkote® 2400 liner relative to restoring and improving the strength and hydraulic characteristics of wom water pipelines. The author comes to the conclusion that Scotchkote® 2400 liner is a substantial alternative to cement-sand and other internal coatings, since in many respects it surpasses them owing to the ability of colmatage sealing of large diameter holes; high wear resistance; smooth surface; ability to endure high hydraulic pressures. The coating does not overlap service connections and only slightly reduces the diameter of the restored pipelines. Based on the conducted research the characteristics of Scotchkote® 2400 liner spraying technology are presented compared to the basic methods of trenchless pipeline reconstruction.

Mathematical processing of the results of experimental studies of the physical and mechanical characteristics of Scotchkote® 2400 liner is given. As a result of the studies, the calculated values of the protective coating thicknesses for partially worn and worn out pipelines have been obtained and recommended.

Key words. Protective coating, pipeline, corrosion, technology, strength, calculation.

1 Introduction

In recent decades a promising direction, known as trenchless technologies, has been effectively developing in the field of construction, repair and rehabilitation of public water supply and sewer systems. [1.2].

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This trend is a weighty alternative to the open method of construction, repair and reconstruction of all types of underground pipelines since it surpasses it in almost all respects (cost-effectiveness, operational efficiency, environmental friendliness etc.) [3,4].
Scotchkote® 2400 liner is a new effective inside protective coating for pipeline rehabilitation. The coating is a fast-curing bicomponent polyurea-based polymer material applied to the inner surface of a pipeline using special centrifugal spraying equipment. The coating can be applied in water pipes transporting drinking or process water. Pipe material-steel, gray cast iron, ductile iron, PVC and asbestos-cement. Scotchkote® 2400 liner provides for renewing and improving the strength and hydraulic characteristics of obsolete pipelines while maintaining the properties of transported water; it ensures the required level of pipeline integrity, reduction of the failure rate, mitigation of the negative impact of repair works on the environment and reduction of energy costs while pumping water.

Table 1 presents the key physical characteristics of the cured Scotchkote® 2400 liner.

Table 1. Key physical characteristics of the cured Scotchkote® 2400 liner

Physical characteristics	Value
Volatile organic compounds (Mixed)	0 g/l
Presence of Bisphenol *A*	No
Tensile strength	39 MPa
Extension elongation	5%
Bending strength	58 *MPa*
Bending modulus	3620 *MPa*
Short-term hydraulic burst pressure	1.41 *MPa*
Hardness	87 D/by Shore
Impact strength, with a liner thickness of 1.7 *mm*	17 Joules
Impact strength, with a liner thickness of 6 *mm*	33 Joules
Abrasion resistance	Weight loss 193 *mg* per 1000 cycles
Glass transition temperature	96°*C*
Moisture absorption	1.31 % (21days)

In accordance with the required design values of the coating thickness and bury depth of the pipeline, Scotchkote® 2400 protective coating meets the requirements of ASTM F 1216-09 for material properties at the end of 50 years of operation [6]. [7].
Scotchkote® 2400 technology is used to form either an anticorrosion barrier or a thick-layered corrosion-resistant system for the renewal of the inner surface of a water distribution pipeline and restoration of its strength characteristics (structural integrity) while providing for [7]:
- maintaining the quality of transported water by applying a protective coating layer that meets the established sanitary and epidemiological requirements of the Russian Federal Service for Supervision of Consumer Rights Protection and Human Welfare (RF Rospotrebnadzor) on the inner surface of the old pipeline;
- maintaining (improving) the hydraulic characteristics of the pipeline by reducing the specific resistance and roughness coefficient of the inner surface of the rehabilitated pipeline while applying the liner.

Scotchkote® 2400 application types:
-structural;
-barrier corrosion-preventive.

In case of the structural application the resulted coating has the following characteristics:

- up to 50 years tensile strength at the maximum allowable operating pressure of the pipe subject to repair;
- the capacity to withstand dynamic loads and other short-term impact associated with loads of internal working pressure, load of soil, groundwater, as well as partial vacuum caused by sudden emptying of the pipeline. Table 2 presents the comparative characteristics of Scotchkote® 2400 spraying technology and those of the main trenchless methods of pipeline rehabilitation.

Table 2. Comparative characteristics of Scotchkote® 2400 spraying technology

Comparative characteristics of the liner	**Application of protective polymer liner**	**Application of cement-sand coating (CSC)**	**Pulling flexible U-liner**	**Application of Scotchkote® liner**
Time of the pipeline commissioning	3-5 hours	3-5 days	5-11 hours	1.5 hour
Need in additional materials (water, steam) and energy for coating hardening	Yes	No	Yes	No
Need in reinstalling side connections	Yes	No	Yes	No
Ability to cover through defects (holes, cracks)	Yes	No	Yes	Yes, less than 5 *mm*, at larger dimensions cement grouting and/or installation of mechanical couplings, bandages, packers is used
Ability to ensure the integrity of the pipeline	Yes	No	Yes	Yes
Versatility of applying the original product for pipelines of different diameter	No	Yes	No	Yes

To put into practice the advanced Scotchkote® 2400 protective technology in Russia, studies shall be carried out on the specific features of its application for the protection of well-worn water transportation pipelines in Russian cities and settlements.
While choosing the thickness of the protective coating layer for the section of a pressure water pipeline, strength calculation of the "pipeline + coating" design must be made taking into account the degree of wear and tear; hypothetically, by this the condition "worn-out" and "partially worn" pipeline section is meant. Partially worn pipe - a pipe capable of

withstanding independently all loads (internal or external) throughout the entire life of the applied coating. In this case, the pipe may have displaced joints, cracks, and traces of corrosion. Moreover, the pipe under repair must withstand all soil loads and temporary loads during the presumable remaining life of the pipeline. The coating in this case must withstand the hydrostatic pressure caused by leaks, as well as the internal pressure in the places of pores bridging.

A worn-out pipe is a pipe that cannot independently withstand all loads (internal or external) during the entire service life of the applied coating. The key parameter for evaluating the effective coating thickness is the bending stress around the hole created by the internal pressure affecting the pipe surface.

In case of a partially worn pipeline Formula 1 can be used to determine the thickness of the protective coating layer:

$$t = \frac{D_O}{\left(\frac{5{,}33}{P_i}\left(\frac{D_O}{D_h}\right)^2 \frac{S_L}{N}\right)^{\frac{1}{2}} + 1} \quad (1)$$

where t - thickness of the protective coating layer taking into account the bending strength at the predicted pipeline service life in the range of 20 - 50 years, *mm*;

S_L – long-term bending strength, MPa;

D_0 – pipe diameter (ranging from 100 to 610), *mm*;

D_h – diameter of a through-hole in the pipe, *mm*;

P_i – pressure in the pipe (ranging from 0.4 to1.2), *MPa*;

N – design safety factor (for N values = 1-2).

The calculation results are compared with the coating thickness for partially worn gravity pipelines and an option is selected with a larger coating thickness. For a worn-out pipeline Formula 2 is used to determine the thickness of the protective coating layer:

$$t = \frac{D}{\left(\frac{2S_{tL}}{P_i N}\right) + 1} \quad (2)$$

where t - thickness of the protective coating layer, taking into account the tensile strength at the predicted service life of the pipeline in the range of 20 - 50 years, *mm*;

S_{tL} – long-term tensile strength, *MPa*;

D – pipe diameter (*ranging from* 100 to 610*), mm;*

P_i – *pressure in the pipe (ranging from* 0.4 to 1.2*), MPa*;

N – design safety factor (for N values = 1-2).

The calculated values of Scotchkote® 2400 liner thicknesses for partially worn and worn-out pipes are presented in Tables 3 and 4.

Table 3. Calculated values of the thickness of Scotchkote® 2400 liner in a partially worn pipeline

Operating lifetime – 50 years						
Factor of safety: $K_{зап.}$= 2.0						
Soil depth above the pipeline: 1 – 3.4* *m*						
Through-hole diameter in a pipe: 80 *mm*						
Pressure in the pipeline, *MPa*	0.4	0.6	0.8	1.0	1.2	- 0.1 vacuum

Diameter, *mm*	Minimum required coating thickness, *mm*					
100	2.0	2.9	4.1	5.0	5,9	1.2
200	3.8	5.5	6.7	8.1	8,25**(1.8)	2.5
300	4.8	6.5	8.1	8.25**(1.6)	8,25**(1.3)	3.4
410	5.1	7.0	8.25**(1.8)	8.25**(1.4)	8,25**(1.1)	3.9
510	5.3	7.4	8.25**(1.8)	8.25**(1.4)	8,25**(1.1)	4.2
610	5.6	7.6	8.25**(1.8)	8.25**(1.4)	8,25**(1.0)	4.4

Notes:
** With the depths of the pipeline above the specified range of values, reliable operation of the coating for an estimated period of 50 years cannot be ensured.*
*** For these values of Scotchkote® 2400 liner thickness the safety factor is: 1.0 < $K_{зап.}$ <2.0. The actual value of the safety factor for the given working conditions of the pipe structure is indicated in parentheses*

Table 4. Calculated values of Scotchkote® 2400 liner thickness for worn-out pipelines

Operating lifetime – 50 years						
Factor of safety: $K_{зап.}$=2.0						
Soil depth above the pipeline: 1 – 3.4* *m*						
Pressure in the pipeline, *MPa*	0.4	0.6	0.8	1.0	1.2	- 0.1 vacuum
Diameter, *mm*	Minimum required coating thickness, *mm*					
100	3.6	3.9	4.4	5.1	5.9	2.7
200	4.5	5.6	6.7	8.1	8.25**(1.8)	3.1
300	5.5	7.8	8.25**(1.7)	8.25**(1.4)	8.25**(1.2)	3.4
410	7.2	8.25**(1.6)	8.25**(1.2)	-	-	4.1
510	8.25**(1,8)	8.25**(1.4)	-	-	-	5.5
610	8.25**(1,5)	8.25**(1.1)	-	-	-	6.5

Notes
** With the bury depth of the pipeline above the specified range of values, reliable operation of the coating for an estimated period of 50 years cannot be ensured.*
*** For the given values of Scotchkote® 2400 liner thickness the safety factor is: 1.0 < $K_{зап.}$ <2.0. The actual value of the safety factor for the given working conditions of the pipe structure is indicated in parentheses*

2 Methods and experiments

Experimental studies of the physical and mechanical properties of Scotchkote® 2400 liner were conducted in Instron 3345 electromechanical tensile testing machine according to the current method described in GOST 25.601-80, Fig.1 [8].

Fig 1. Instron 3345 tensile machine

The following physical and mechanical characteristics of the liner were subjected to the experimental research: the maximum load applied to the liner sample (*F, N*), the maximum damage emerging in the sample (σ, MPa), the maximum extension of the sample (*x*, mm), and the maximum longitudinal deformation of the sample (ε, mm / mm), as well as the deformation diagram (characteristic curve of σ versus ε).

The physical and mechanical characteristics of Scotchkote® 2400 liner used as a coating material were obtained by the calculation and analytical methods, taking into account 50 years of its operation. They include: maximum tensile strength (σ_{50}, MPa); Young's modulus (modulus of elasticity E_{50}, *MPa*); density (ρ, kg/m^3); Poisson's ratio (v); shear modulus (G_{50}, MPa); modulus of volume elasticity (K_{50}, *MPa*).

3 Results

The mathematical processing of the results of studying the physical and mechanical characteristics of Scotchkote® 2400 liner was carried out by modeling Ansys finite element analysis in automated computer environment. This automated system provides for the accurate representation of the object of study on the basis of its geometric characteristics and

the physical and mechanical characteristics of the materials of the target [9].
The computer model of the pipe structure based on Scotchkote® 2400 allows exploring the strength capacity of this protective coating for 50 years of its use, taking into account partial or complete wear of the original pipeline and the effect of Scotchkote® 2400 liner with the accommodation of various loads and impacts.
Table 5 gives the initial data for modeling the strength capacity of a pipe structure based on of Scotchkote® 2400 liner when in use for 50 years.

Table 5. Initial data for modeling the strength capacity of a pipe structure based on Scotchkote® 2400 liner

Data name	Considered values
Outer diameter of coating, mm	100, 150, 200, 250, 300, 360, 410, 460, 510, 560, 610
Thickness of the coating layer, mm	≤8.25
Diameter of the through-hole in the pipe, mm	80
Length of the section with applied coating, mm	300
Water pressure in the pipe, *MPa*	0.4; 0.6; 0.8; 1.0; 1.2
Depth of the soil layer above the pipe, *m*	1 – 3.4
Groundwater layer depth, m	1 – 3.4
The influence of atmospheric pressure during vacuum generation in the pipeline, *MPa*	0.1

The following parameters were determined in order to evaluate the efficiency of Scotchkote® 2400 liner:
- maximum equivalent stress σ_e, *MPa*, determined by Formula (3):

$$\sigma_e = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]}\ , MPa, \qquad (3)$$

where σ_1, σ_2, σ_3 - primary stresses, *MPa*;
- reserve coefficient $K_{зап.}$ (the ratio of the maximum tensile strength of the coating material to the maximum equivalent stresses arising in it), determined by Formula (4):

$$K_{зап.} = \sigma_{разр.} / \sigma_{экв.} \qquad (4)$$

4 Conclusions

1.Scotchkote® 2400 liner is a considerable alternative to cement-sand and other internal coatings, as it is superior in many respects owing to the ability to seal large diameter holes, and to withstand high hydraulic pressures; owing to high wear resistance, and smooth surface. Scotchkote® 2400 coating does not block service laterals and only slightly reduces the diameter of the pipelines under repair.
2.The use of Scotchkote® 2400 technology ensures either an anti-corrosion barrier or a thick-layer corrosion-resistant system that restores the inner surface of the water pipe and its strength characteristics (structural integrity), and provides for:
- maintaining the quality of the transported water by applying on the inner surface of an old pipeline a protective coating layer that meets the sanitary-epidemiologic requirements set by RF Rospotrebnadzor;

- maintaining (improving) the hydraulic characteristics of the pipeline by reducing the specific resistance and roughness coefficient of the inner surface of the pipelines subject to rehabilitation, which ensures the energy saving effect while pumping water.

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