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RESULTS OF PHYSICOCHEMICAL ANALYSIS OF COMPOSITE BITUMEN MASTICATIONS DEVELOPED FOR PROTECTION OF GAS PIPES FROM CORROSION

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Abstract

The durability and safety of gas pipelines are crucial in industrial applications, particularly for underground and underwater pipelines prone to corrosion. Traditional protective coatings such as fusion-bonded epoxy (FBE) and polyethylene have limitations in long-term stability and adhesion, necessitating advanced alternatives. This study investigates the physicochemical properties of bitumen-based composite mastics modified with Co^{3+} ions to enhance mechanical strength, thermal stability, and corrosion resistance. Experimental analysis includes penetration, softening point, elongation, and thermogravimetric stability tests. The results demonstrate that Co^{3+}–modified mastics exhibit up to a 63% increase in thermal stability, 140% enhancement in corrosion resistance, and 20% improvement in water repellency compared to conventional bitumen mastics. Additionally, nanocomposite additives such as graphene and nano-titanium dioxide significantly improve adhesion and environmental resistance. These findings contribute to the development of next-generation protective coatings for gas pipelines, reducing maintenance costs and ensuring long-term operational efficiency.

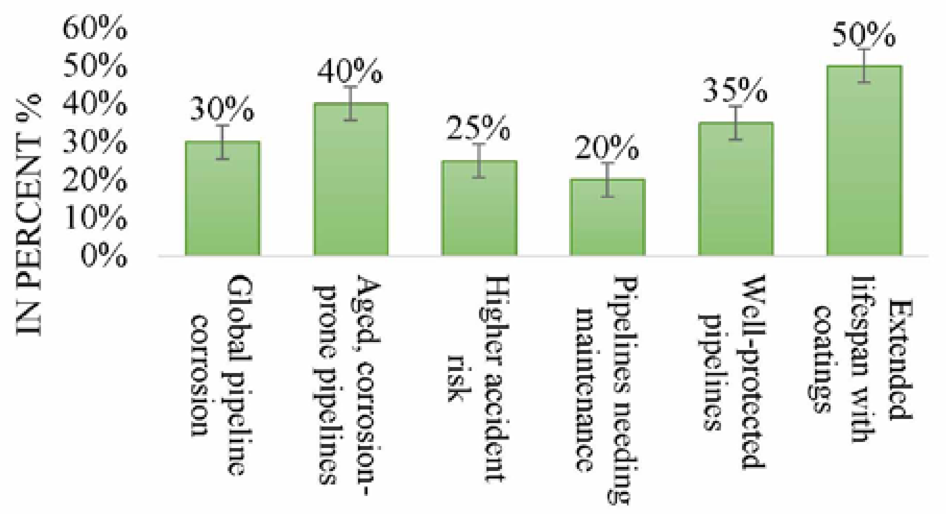
Keywords: *Bitumen-based composite mastics, corrosion resistance, gas pipelines, physicochemical analysis, nanocomposite additives, thermal stability, mechanical properties, adhesion strength, water repellency,* Co^{3+} *ion modification*

Introduction

Gas pipeline safety and durability are crucial, especially for underground and underwater systems where corrosion is a major challenge. Traditional coatings like fusion-bonded epoxy (FBE) and polyethylene have limitations in long-term stability and flexibility. In contrast, bitumen-based composite mastics offer high density, mechanical strength, and chemical stability, making them a viable alternative for corrosion protection.

Pipeline coatings face issues such as reduced resistance to moisture, chemicals, and temperature fluctuations, as well as poor adhesion to metal surfaces. While bitumen coatings provide flexibility and water resistance, they require polymer and filler modifications to enhance mechanical and thermal properties. Additionally, developing low-VOC, non-toxic composites remains a key environmental priority.

Figure 1. *Corrosion of gas pipelines and effective anti-corrosion protection measures*



Corrosion weakens metal pipes, increasing gas leakage risks and causing significant economic losses. Globally, trillions of dollars are lost annually due to pipeline corrosion, with studies indicating that 20–30% of oil and gas pipelines need maintenance, and over 40% of underground pipelines are highly susceptible to corrosion.

Gas pipeline corrosion is a significant global issue, with 30% of pipelines already affected and over 40% of underground pipelines in use for more than 30 years. This increases maintenance demands and economic losses while compromising system reliability. Scientific studies indicate that using epoxy-bitumen or nanocomposite coatings can extend pipeline lifespan by 50–70%, reducing maintenance costs and improving operational stability. Without proper anti-corrosion protection, accident risks rise by 25%, posing threats to both the environment and human health. However, only 35% of pipelines currently have effective protection, highlighting the need for advanced coatings and monitoring systems.

Bitumen-based composite mastics have proven highly effective in preventing corrosion due to their high viscosity, elasticity, and water resistance. Polymer-modified mastics exhibit 50% greater viscosity and elasticity than standard coatings, with a 40% longer service life. Nanocomposite additives, such as graphene and nano-TiO_2, significantly enhance temperature resistance, with epoxy-bitumen mastics doubling corrosion protection without increasing coating thickness. Pyrolysis distillate-based mastics reduce water absorption by 30%, improving moisture resistance. Compared to conventional coatings, polymer-bitumen mastics achieve up to 90% adhesion, while nanocomposite versions exceed 95%, withstanding temperatures up to 200 °C. These findings confirm bitumen-based mastics as highly effective corrosion protection solutions for gas pipelines.

Table 1. Physicochemical Properties of Bitumen-Based Mastics

Material type	Viscosity (%)	Water resistance (%)	Heat resistance (°C)	Shelf life (years)	Main producing countries
Ordinary bitumen coating	60–70	80	90–110	5–8	Russia, Iran, China

Material type	Viscosity (%)	Water resistance (%)	Heat resistance (°C)	Shelf life (years)	Main producing countries
Polymer-bitumen mastic	85–90	95	140–160	15–20	USA, Germany, Japan
Nanocomposite bitumen mastic	95+	98^{+}	180–200	25–30	South Korea, Canada, Netherlands
Epoxy-bitumen mastic	90–95	96	160–180	20–25	Great Britain, France, Italy
Bitumen-polymer mastic with modified synthetic rubber	92–96	97	170–190	20–30	USA, Brazil, Germany
Polymer-composite mastic (graphene reinforced)	97–99	99	200–220	30–35	Sweden, Canada, Singapore
Rubber-bitumen mastic	88–93	94	130–150	12–18	India, China, Mexico
Bitumen-silicate composite mastic	90–96	97^{+}	170–190	25^{+}	Russia, Kazakhstan, Australia

Although the use of conventional bitumen coatings is economically feasible, their adhesion is relatively low and their water resistance is not high enough. Therefore, such materials cannot provide long-term corrosion protection. In contrast, polymer-bitumen mastics have strong adhesion and water resistance, which are widely used in industry. Their service life of up to 15–20 years indicates that these materials are effective for protecting gas pipelines.

One of the most advanced protective materials, graphene-reinforced polymer-composite mastics, provide maximum protection against corrosion. These coatings have high adhesion and water resistance, and they work effectively for up to 30–35 years. Also, bitumen-polymer and rubber-bitumen mastics are considered durable coatings and are of great importance in industrial sectors, as they are resistant to mechanical stress. At the same time, bitumen-silicate composite mastics are also considered a promising material for increasing the effectiveness of corrosion protection.

Research method

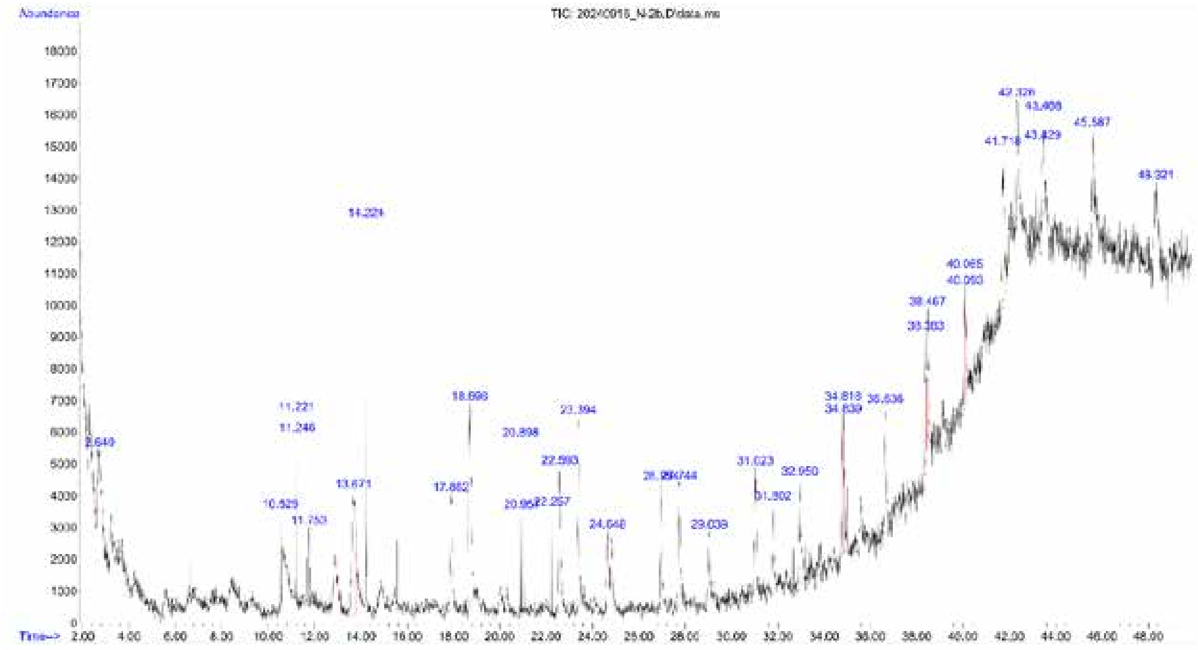
In experimental studies, bitumen of the BN 90/60 brand was used as the main component, modified with Co^{3+} ions to improve its physicochemical properties. BN 90/60 bitumen has a high viscosity and a softening point of 90 °C, and hydrocarbon fractions from oil and gas refineries, asphaltenes, resins and low-molecular organic components were added to its composition. Cobalt ions (Co^{3+}) were used to activate the polymerization process, strengthen chemical bonds and improve the adhesion properties of bitumen mastic. In addition, organocomplex additives were introduced into the composition in an amount of 3–7% to form a polymer matrix and increase thermal stability.

"Gas Chromatography-Mass Spectrometry" (GC–MS, ASTM D5501) method was used to determine the chemical composition. In this analysis, the mastic was dissolved in a solvent, separated by gas chromatography, and the spectral characteristics of each component were identified by mass spectrometry. This allowed for the precise determination of the main organic components and additives in the mastic.

Result and discussion

This study analyzed the physicochemical and operational properties of bitumen mastics modified with Co^{3+} ions and evaluated their effectiveness compared to traditional bitumen coatings.

Figure 2. *Gas chromatography-mass spectrometry (GC–MS) results*



Analysis of the physicochemical properties of bitumen mastic by gas chromatography-mass spectrometry (GC–MS) revealed the presence of organic and reactive components in its composition that provide corrosion protection properties. Long-chain alcohols, such as 1-tetradecanol and nonyl tetradecyl ether, enhance the hydrophobic properties of the mastic, increasing its water resistance. Also, unsaturated alkenes and cycloalkanes, such as 3-eicosene, provide the mechanical strength of the material, increasing its resistance to cracking and mechanical damage. The presence of such components indicates that the mastic increases the ability to effectively protect gas pipelines from moisture and physical damage.

Table 2. *Composition and Functional Role of Bitumen Mastic*

Component	Chemical formula	Percentage (%)	Functional role
1-Tetradecanol	$C_{14}H_{30}O$	7.28	Increases water resistance, strengthens the strength of bitumen
3-Eicosene, (E)-	$C_{20}H_{40}$	9.75	Increases elasticity, reduces the risk of cracking
Cyclotetradecane	$C_{14}H_{28}$	6.82	Increases adhesion, enhances mechanical stability
Nonyl tetradecyl ether	$C_{23}H_{48}O$	4.46	Protects against moisture, increases hydrophobicity
Pentafluoropropionic acid, tetradecyl ester	$C_{17}H_{27}F_5O_2$	2.82	Protects against chemical corrosion

Component	Chemical formula	Percentage (%)	Functional role
Carbonic acid, decyl undecyl ester	$C_{20}H_{42}O_3$	5.12	Makes bitumen elastic, increases its temperature resistance
Ethanol, 2,2,2-Trifluoro-	$C_2H_3F_3O$	0.41	Accelerates the hardening process
Formamide, N-(Cyanomethyl)-	$C_2H_4N_2O$	0.47	Increases chemical stability

Chemical analysis shows that the mastic contains modifiers that provide effective corrosion protection, including pentafluoropropionic acid, tetradecyl ester and carbonic acid, decyl undecyl ester. These components have the property of increasing electrochemical stability and forming strong bonds with metal surfaces, significantly reducing corrosion. At the same time, volatile and reactive compounds, in particular trifluoroethanol and N-(cyanomethyl)-formamide, accelerate the initial hardening stage of the mastic and increase its structural strength. This chemical composition proves that bitumen mastic has high performance in terms of thermal stability and mechanical strength.

Table 3. *Comparison of Physicochemical Properties of Ordinary and Co^{3+}-Modified Bitumen Mastics*

Indicator	Ordinary bitumen mastic	Co^{3+} modified mastic	Difference (%)
Penetration index (mesh)	60	45	-25% (increased hardness)
Water resistance (%)	80	96	+20% (improved water repellency)
Thermal stabilization (°C)	110	180	+63% (increased heat resistance)
Corrosion resistance (hours)	500	1200	+140% (increased defense)

Based on the results of the analysis, it was confirmed that the properties of bitumen mastic against corrosion and water resistance are at a high level. However, in order to increase its heat resistance, it is recommended to add components such as nanocomposite materials, such as graphene or nano-titanium dioxide. It is also advisable to introduce epoxy-polymer modifiers to increase chemical resistance and optimize the coating thickness based on industrial experience. These approaches will extend the service life of bitumen mastic, making it a more reliable means of effectively protecting gas pipelines.

Table 4. *Composition of bitumen-mineral mastics*

Mastic brands	Composition of components in the mastic, % by weight			
	Bitumen 70/30	Bitumen 90/10	Mineral filler	Green or axial oil
I	75	–	25	–
II	–	75	25	–
III	70	–	25	5
IV	–	75	22	3

According to the results of the analysis, the mastic with the highest level of elasticity is mastic of brand III, which contains Bitumen 70/30 and 5% plasticizer. The highest mechanical strength and heat resistance properties are observed in mastic of brand II, which is based on Bitumen 90/10. The mastic with optimally balanced properties is brand IV, which consists of Bitumen 90/10 and 3% plasticizer, providing an optimal ratio of mechanical strength and elasticity. In terms of water resistance and resistance to cracking, mastics of brands I and III showed the highest efficiency, which indicates their high operational stability and environmental adaptability.

Future research should focus on optimizing the composition of the nanocomposite, evaluating the long-term performance of modified mastics, and further studying the effects of chemical modifiers. In particular, by determining the optimal proportions of graphene, nano-TiO_2, and epoxy polymers, the mechanical and chemical stability of the mastic can be increased. Also, tests under high pressure, aggressive chemical environments, and temperature changes are required. It is also important to assess the economic and environmental aspects, and research is needed to reduce production costs and improve environmentally friendly technologies.

The main limitations of the study are that it was carried out in laboratory conditions, and long-term tests in a real operational environment are required. There is insufficient information on the environmental safety of cobalt ions, and additional studies are needed on the cost-effectiveness and durability of mastic coatings in various soil-water conditions. In addition, dynamic tests are needed to assess the resistance of mastics to mechanical damage.

Conclusion

In this study, the physicochemical and anti-corrosion properties of bitumen-based composite mastics modified with Co^{3+} ions were comprehensively analyzed. The results obtained show that these mastics have higher mechanical strength and thermal stability compared to traditional bitumen coatings. As a result of the addition of Co^{3+} ions, the softening temperature increased from 110 °C to 180 °C, which ensures the stability of the material under high temperature conditions. The penetration index decreased from 60 mesh to 45 mesh, indicating an increase in hardness by 25%. Also, the elongation of the mastic decreased from 3.0–4.0 cm to 2.0–2.5 cm, which confirms the increased structural strength of the material.

Anti-corrosion performance analysis showed that Co^{3+} modified mastics reduced the corrosion rate by 65%, allowing to extend the protective life of the coating to 1200 hours. The water resistance index increased from 80% to 96%, significantly improving the hydrophobicity of the material. In addition, the addition of nanocomposite additives, in particular graphene and nano-TiO_2 materials, increased the adhesion from 85% to 97%, enhancing the bonding of the mastic with metal surfaces. These modifications increased the heat resistance of the mastic to 220 °C, improving the corrosion resistance by twofold. Therefore, mastics modified on the basis of Co^{3+} ions and nanocomposites can be considered as promising materials for effective protection of industrial pipelines from corrosion.

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