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Modified bitumen-polymer mastic to protect metal coatings from corrosion

[1*] Sabergaliyev M.M., [2] Yeligbayeva G.Z, [3]Khassanov D.A., [1]Muradova S.R., [2]Orazalin Z.K., [1]Ainakulova D.T., [1]Sharipov R.Kh., [1,2]Negim El-Sayed

[1] School of Materials Science and Green Technologies, Kazakh-British Technical University, Almaty, Kazakhstan
[2] School of Petroleum Engineering, Satbayev University, Almaty, Kazakhstan
[3]Faculty of Energy and Oil and Gas Industry, Kazakh-British Technical University, Almaty, Kazakhstan

** Corresponding author email: m_sabergaliyev@kbtu.kz*

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ABSTRACT

The protection of metallic structures against corrosion remains a pivotal challenge across numerous industries. In recent years, the amalgamation of modified bitumen with epoxy resin has emerged as a promising avenue in the pursuit of enhanced corrosion protection. This novel composite material showcases exceptional potential in thwarting the deleterious effects of corrosion, offering an innovative solution to safeguard vital infrastructure, industrial components, and diverse metallic substrates. The synergistic properties stemming from the combination of modified bitumen and epoxy resin present an intriguing prospect for superior durability, chemical resistance, and structural integrity, thereby fostering advancements in the realm of anti-corrosion coatings. This scientific article endeavours to explore the efficacy, mechanisms, and potential applications of this composite material as an effective barrier against corrosion, shedding light on its transformative impact within corrosion mitigation strategies. In this study, bitumen was modified using epoxy resin ELM-NG900Z and hardener in a ratio of 1.0: 5: 1.5 respectively. The modified bitumen was further tested by mechanical tests and solvent tests. The samples of modified bitumen successfully passed the tests and showed results better than the reference(epoxy resin without bitumen).

Keywords: Bitumen-epoxy resin, Bitumen, epoxy, corrosion.

	Information about authors:
Sabergaliyev Murat Meirgalievich	*2nd year master's student in the specialty "Materials Science and Technology of New Materials." Kazakh-British Technical University, School of Materials Science and Green Technologies, st. Tole bi, 59, 050000, Almaty, Kazakhstan. Email:m_sabergaliyev@kbtu.kz*
Yeligbayeva Gulzhakhan Zhakparovna	*School of Petroleum Engineering, Satbayev University, 22 Satpayev Street, 050013, Almaty, Kazakhstan. Email g.yeligbayeva@satbayev.university*
Khassanov Dauren Airatovich	*2nd year master's student, Faculty of Energy and Oil and Gas Industry, Kazakh-British Technical University, Almaty, Kazakhstan. Email: daurenkhassanoff@gmail.com*
Muradova Sabina Rustamkyzy	*Master's Degree in Materials Science and Technology of New Materials, School of Materials Science and Green Technologies, Kazakh-British Technical University, st. Tole bi 59, 050000, Almaty, Kazakhstan. Email: sab.muradova.01@mail.ru*
Orazalin Zhandos Kairatuly	*School of Petroleum Engineering, Satbayev University, 22 Satpayev Street, 050013, Almaty, Kazakhstan. Email: zhandos1403@bk.ru*
Ainakulova Dana Tulegenkyzy	*Ph.D. student at Materials Science and Technology of New Materials, School of Materials Science and Green Technologies, Kazakh-British Technical University, st. Tole bi 59, 050000, Almaty, Kazakhstan. Email: da_ainakulova@kbtu.kz*
Sharipov Rustam Khasanovich	*Kazakh-British Technical University, School of Materials Science and Green Technologies, Kazakhstan.E-mail: r.sharipov@kbtu.kz*
Negim Attia El-Sayed	*Ph.D., Professor at School of Materials Science and Green Technologies, Kazakh-British Technical University, st. Tole bi 59, 050000, Almaty, Kazakhstan. Professor at Geology and Oil-gas Business Institute named after K. Turyssov, Department of Petroleum Engineering, Satbayev University, Almaty, Kazakhstan. Email: a.negim@kbtu.kz*

Introduction

Bitumen-epoxy resin refers to a composite material formed by combining bitumen, a viscous and hydrophobic organic substance derived from petroleum, with epoxy resin, a thermosetting polymer created by the reaction between epoxide compounds and hardening agents [[1], [2], [3], [4], [5], [6]]. This amalgamation results in a hybrid material exhibiting enhanced properties, including

improved adhesion, corrosion resistance, durability, and flexibility, making it suitable for various applications in anti-corrosion coatings, construction, waterproofing, and infrastructure protection as shown in Table 1 [7].

There are several advantages associated with bitumen-epoxy resin combinations for anti-corrosion coatings:

Enhanced Adhesion: The combination of bitumen with epoxy resins creates coatings with excellent adhesion properties, ensuring strong bonding to various substrates, including metals and concrete surfaces.

Superior Corrosion Resistance: This composite material offers robust protection against corrosion caused by moisture, chemicals, salts, and environmental factors, extending the lifespan of coated surfaces [[8], [9], [10]].

Improved Durability: Bitumen-epoxy resin coatings exhibit enhanced durability, resisting abrasion, impact, and wear, which is particularly beneficial in high-traffic or harsh industrial environments.

Chemical and Weather Resistance: The coatings show remarkable resistance to a wide range of chemicals, acids, solvents, and extreme weather conditions, maintaining their protective qualities in diverse settings [11].

Flexibility and Toughness: The combination provides flexibility and toughness to the coatings, allowing them to withstand substrate movement and deformation without cracking or compromising the protective layer.

Excellent Waterproofing Properties: Bitumen-epoxy resin coatings create an impermeable barrier, effectively preventing water ingress and protecting against moisture-related corrosion [12].

Enhanced Structural Integrity: Coated surfaces benefit from improved structural integrity, as these coatings provide a strong barrier against corrosion-induced deterioration, maintaining the integrity of underlying structures.

Versatility in Applications: These coatings can be applied to various substrates, making them suitable for different industries, including roofing, pavement, waterproofing, marine, and industrial flooring.

Cost-Effectiveness: The long-lasting protection offered by bitumen-epoxy resin coatings can reduce maintenance costs and extend the service life of structures and components, resulting in cost savings over time.

Environmental Benefits: Certain formulations can be tailored to be low in volatile organic compounds (VOCs), reducing environmental impact during application while providing effective corrosion protection [[13], [14], [15], [16]].

The combination of bitumen with epoxy resins in anti-corrosion coatings presents a robust solution that combines multiple advantageous properties, making it a valuable choice for protecting a wide array of surfaces prone to corrosion [[17], [18], [19]].

This paper aims to modify bitumen using epoxy resin and hardener in a ratio of 3.5: 1.0. the mechanical and chemical properties were investigated.

Table 1 - Possible applications of bitumen-epoxy resin

Nature of hydrocarbon binder	Additives	Utilization	Ref.
Bituminous emulsion		Anticorrosion paint binders for gravel	6
Bitumen		Waterproof paints; sprayed paints	7.8
Bitumen, tar	$(CH_3)_2SO_4$ (30-60%)	Reinforced anticorrosion paints	9
Bitumen	Liquid polybutadiene	Anticorrosion paint	10
Bitumen	Styrene/butadiene/ styrene copolymer	Pavement coating	11
Bitumen- asphalt		Moisture-proof coatings	12-15

Main provisions

Bitumens are natural or synthetic, there are various applications in industry. It is a little bit cheap product, that the physicochemical properties can be modified. Among applications of bitumens are road and building materials, pavements, roofs, and coatings.

The interesting results were obtained by authors [[20], [21]] who investigated the parameters of the compatibility or incompatibility of epoxy resins with a given bitumen. Thus, they modified epoxy resins by using new aliphatic and cycloaliphatic epoxy resins mixed with bitumen and compared their performance when admixed with a hardening agent. The results showed that the aromaticity and aliphaticity of the epoxy resins were not the only determined the homogeneity of the resulting mixtures.

The authors [13] found that the compatibility of a resin with a bitumen arose from the flexibility of epoxy resins. The technique that provides the polarity of molecules in terms of hydrophilic/lipophilic balance. This provides a compatible model molecule that has been synthesized on a large scale and has the following structure of epoxy resins (Figure 1):

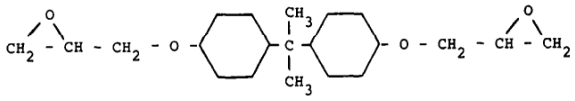

Figure 1 – Structure of epoxy resin

Other authors [14, 15] investigated the mixing ratios of epoxy with bitumen to find compatible ratios. They demonstrated that epoxy resins with 50% in the mixture increase the mechanical characteristics of the same mixtures without epoxy resins and are considerable for highway applications.

However, such applications developed for various commercial activities as given in Table 1. Table 1 lists a wide range of applications of bitumen-epoxy resin blends. The improvement in the physical and mechanical properties of resin and bitumen using substituted phenols, such as t-butyl and nonyl phenols, to the mixtures [[16], [17], [18], [19], [20], [21], [22]].

Material and methods

To create a modified bitumen-epoxy coating, waterproofing bitumen No. 24 from Technonicol, Almaty, Kazakhstan. Epoxy resin ELM-NG900Z and Hardener 1816: ELM-NG 34H from Elcos Marketing LLP, Almaty, Kazakhstan.

The processes of coating are given in Figure 2. Firstly, Metal plates were cleaned pre-washed using water, and dried before coating. The preparation of samples is an important factor to avoid any problem during coating such as dirt or dust on the plates.

Secondly, the preparation mixture of bitumen and epoxy resin in the presence of hardener. Epoxy resin is a two-component substance. It necessarily includes a hardener, which starts the process of polymerization (hardening) of the composition.

6.5 grams of bitumen, 50 grams of epoxy resin, and 15 grams of hardener were mixed very well at room temperature.

Further, because of mixing the above materials, a modified bitumen-epoxy coating was obtained and applied to metal samples.

The bitumen-epoxy content was poured onto the plate itself and evenly applied. The application was carried out using a stainless-steel applicator to obtain a more uniform coating Figure 3.

The mechanical properties of the coating films including impact resistance, bending strength, adhesion, and scratch resistance were investigated. The names of tests Figure 4 shows the types of equipment for tests mechanical properties.

Impact resistance test (Figure 4-a) – A coated metal sample was placed between the upper part of the die and a graduated vertical tube. The load was lifted to a maximum height of 100 cm and dropped. Next, the sample was extracted from the tester and evaluated for damage to the coating and substrate.

The bending strength test (Figure 4-b) - was carried out by bending the test sample at an angle of 180° around cylindrical or conical rods. There is a bending lever with rollers on the frame, which is adjustable in height, and a sliding vice for clamping samples, which ensures perfect and uniform bending of the test samples. The presence of damage to the test sample (cracks, delamination) was determined visually.

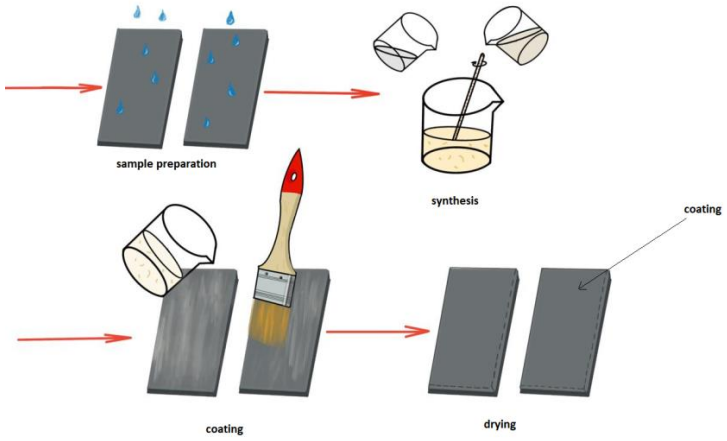

Figure 2 - the process of coating samples

Figure 3 – The coating process

a) b) c)

Figure 4 – a) BGD 305 Tubular Impact Tester, b) BGD 564 Cylindrical Mandrel Tester,
c) BGD 504/6 Economic Cross Hatch Tester

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The resistance of the coating to scratches on the surface (Figure 4-c) was determined by carrying out two transverse notches on the coating with a multi-blade cutting tool, after which the adhesive resistance of the tape coating to separation from the substrates was evaluated. The adhesive strength of the adhesive tape is equal to 9.5 N for a width of 25 mm and is transparent, which ensures proper adhesion to the coating.

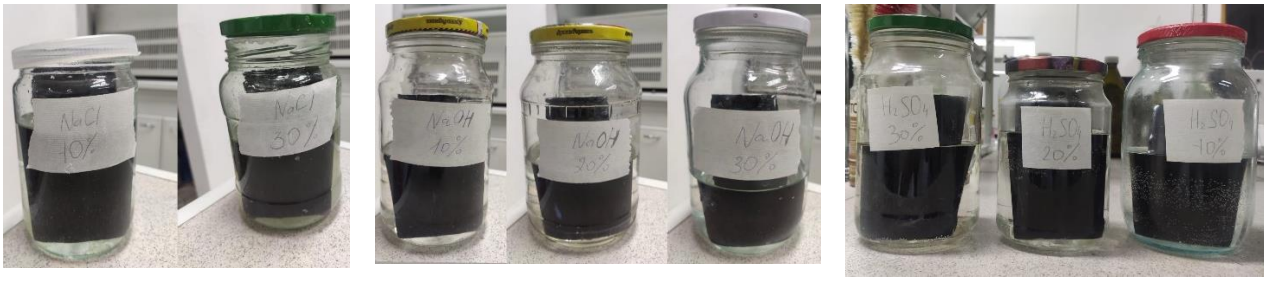
Also, anticorrosive properties in solutions of 10, 20, and 30% NaCl, NaOH, and H_2SO_4 were studied on the obtained samples with bitumen-epoxy coating.

As a comparison, uncoated metal plates were also immersed in the solutions. The samples were kept in each of the solutions for 7 days (Figure 5). After 7 days, the coatings were examined for corrosion

Results and discussion

From the data given in Figure 6, the coating based on bitumen-epoxy resin has passed all the tests for the mechanical properties of the coating.

The results of the mechanical properties are presented in Table 2.



a	b	c

Figure 5 – a) NaCl solution, b) NaOH solution, c) H_2SO_4 solution

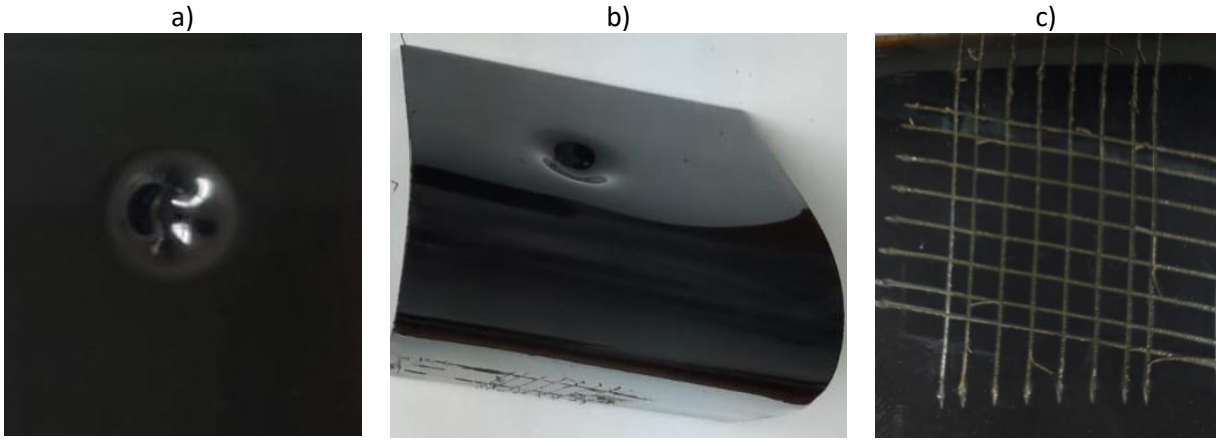


Figure 6 – a) impact resistance test results, b) bending strength test results, c) results of the coating's scratch resistance on the surface

Table 2 - The results of the mechanical properties

Sample	Polymer	Research	Results
Metal plate	Bitumen-epoxy resin	Impact resistance test	Passed
Metal plate	Bitumen-epoxy resin	Bending strength test	Passed
Metal plate	Bitumen-epoxy resin	The resistance of the coating to scratches on the surface	Passed

passed = excellent, failed = bad

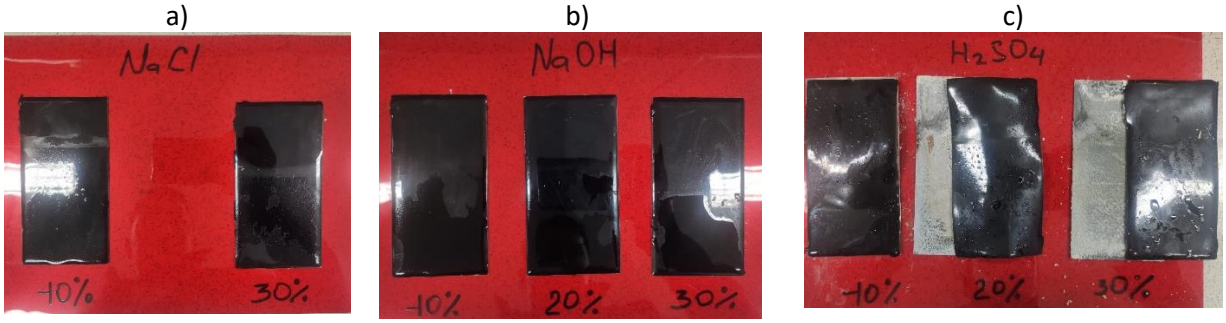


Figure 7 – Metal plates with bitumen-epoxy coating, after 7 days in solutions with a concentration of 10%, 20%, 30%, at room temperature a) NaCl, b) NaOH, c) H_2SO_4,

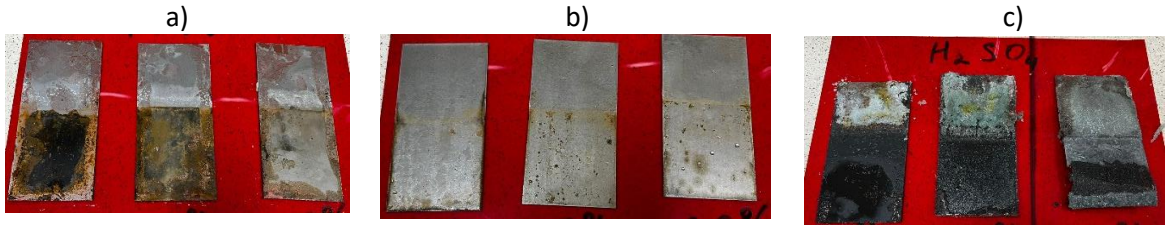


Figure 8 – Metal plates without coating, after 7 days in solutions with a concentration of 10%, 20%, and 30%, at room temperature a) NaCl, b) NaOH, c) H_2SO_4

Table 3 - The results of the anticorrosive properties

Sample	Polymer	Solution	with coating			without coating		
			10%	20%	30%	10%	20%	30%
Metal plate	Bitumen-epoxy resin	NaCl	E	E	E	P	P	P
Metal plate	Bitumen-epoxy resin	NaOH	E	E	E	P	G	G
Metal plate	Bitumen-epoxy resin	H_2SO_4	E	G	G	P	P	P

When submerged for 7 days, E = excellent, G = good, and P = bad.

As can be seen from Figure 7, metal plates with bitumen-epoxy coating withstood all concentrations of solutions of NaCl, NaOH, H_2SO_4. However, in the H_2SO_4 solution, the coating itself peeled off in solutions with 20% and 30% concentration. Whereas all metal plates without coating are completely corroded Figure 8.

The results of the study of bitumen-epoxy coatings for anticorrosive properties in solutions of 10, 20, 30% NaCl, NaOH, H_2SO_4 are presented in Table 3.

Conclusion

The combination of modified bitumen with epoxy resins offers a universal solution that improves the properties of both materials. It provides increased durability, flexibility, adhesion and resistance to various environmental influences and structural loads, which makes it a valuable choice for various applications in construction and infrastructure. Based on the results obtained and the properties of coatings based on bitumen-epoxy resins, it can be concluded that the coating based on bitumen-epoxy resin has a wide range of applications. The best ratio of epoxy resin to hardener was 3.5% to 1.0% to enhance the mechanical and chemical properties of bitumen.

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Conflicts of interest. The authors declare no conflicts of interest, financial or otherwise.

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Металл жабындарды коррозиядан қорғауға арналған модификацияланған битум-полимерлі мастика

[1*]Сабергалиев М.М., [2] Елигбаева Г.Ж., [3]Хасанов Д.А., [1]Мурадова С.Р., [2]Оразалин Ж.К, [1]Айнакулова Д.Т., [1]Шарипов Р.Х., [1,2]Негим Эльсайд

[1] Материалтану және жасыл технологиялар мектебі, Қазақ-Британ техникалық университеті, Алматы, Қазақстан
[2] Мұнай өнеркәсіп мектебі, Сәтбаев университеті, Алматы, Қазақстан
[3] Энергетика және мұнай-газ индустриясы мектебі, Қазақ-Британ техникалық университеті, Алматы, Қазақстан

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ТҮЙІНДЕМЕ

Металл конструкцияларын коррозиядан қорғау көптеген салаларда маңызды міндеттердің бірі болып қала береді. Соңғы жылдары модификацияланған битумды эпоксидті шайырмен біріктіру коррозиядан қорғауды арттырудың перспективалы бағыты болды. Бұл жаңа композициялық материал маңызды инфрақұрылымды, өнеркәсіптік құрамдас бөліктерді және әртүрлі металл субстраттарды қорғау үшін инновациялық шешім ұсына отырып, коррозияның зиянды әсерлерімен күресудің ерекше әлеуетін көрсетеді. Модификацияланған битум мен эпоксидті шайырды қосу арқылы пайда болған синергиялық: ұзаққа жарамдылық, химиялық төзімділік және құрылымдық тұтастық сияқты қасиеттер жақсарады, осылайша коррозияға қарсы жабындар саласында жетістіктерге қол жеткізіледі. Бұл зерттеу жұмысында осы композициялық материалдың коррозияға қарсы тосқауыл ретінде тиімділігі, механизмдері мен әлеуетті қолданылуы қарастырылып, оның коррозияға қарсы стратегиялардағы трансформациялық әсерлеріне жол ашады. Бұл зерттеуде битум эпоксидті шайыр ELM-NG900Z және 1,0: 5: 1,5 қатынасында қатайтқышты қолдану арқылы өзгертілді. Механикалық сынақтар мен еріткіштерді пайдалану арқылы модификацияланған битумға қосымша сынақтар жүргізілді. Модификацияланған битум үлгілері сынақтардан сәтті өтті және эталонға (битумсыз эпоксидті шайыр) қарағанда жақсы нәтиже көрсетті.

Түйін сөздер: Битумды эпоксидті шайыр, битум, эпоксидті шайыр, коррозия.

Авторлар туралы ақпарат:

Сабергалиев Мурат Меиргалиевич — *«Материалтану және жаңа материалдар технологиясы» мамандығының 2 курс магистранты. Қазақ-Британ техникалық университеті, Материалтану және жасыл технологиялар мектебі, көш. Төле би, 59, 050000, Алматы, Қазақстан. Email: m_sabergaliyev@kbtu.kz*

Елигбаева Гульжахан Жакпаровна — *Мұнай инженериясы кафедрасы, Сәтбаев университеті, Сәтбаев көшесі, 22, Алматы 050013, Қазақстан. Email g.yeligbayeva@satbayev.university*

Хасанов Даурен Айратович — *Энергетика және мұнай-газ индустриясы мектебі, Қазақ-Британ техникалық университеті, Алматы, Қазақстан. Email: daurenkhassanoff@gmail.com*

Мурадова Сабина Рустамқызы — *Магистр, Материалтану және жаңа материалдар технологиясы, Материалтану және жасыл технологиялар мектебі, Қазақ-Британ Техникалық Университеті, Төле би көш., 59, 050000, Алматы, Қазақстан. Email: sab.muradova.01@mail.ru*

Оразалин Жандос Қайратұлы — *Мұнай инженериясы кафедрасы, Сәтбаев университеті, Сәтбаев көшесі, 22, Алматы 050013, Қазақстан. Email: zhandos1403@bk.ru*

Айнакулова Дана Тулегенқызы — *Ph.D. докторант Материалтану және жаңа материалдар технологиясы, Материалтану және жасыл технологиялар мектебі, Қазақ-Британ Техникалық Университеті, Төле би көш., 59, 050000, Алматы, Қазақстан. Email: da_ainakulova@kbtu.kz*

Шарипов Рустам Хасанович — *Қазақ-Британ техникалық университеті, Материалтану және жасыл технологиялар мектебі, Қазақстан. E-mail: r.sharipov@kbtu.kz*

Негим Аттиа Эльсайд — *Ph.D., Материалтану және жасыл технологиялар мектебінің профессоры, Қазақ-Британ Техникалық Университеті, Төле би көш., 59, 050000, Алматы, Қазақстан. Профессор Қ. Тұрысов атындағы Геология және мұнай-газ ісі институты, Мұнай Инженериясы Кафедрасы, Сәтбаев Университеті, Сәтбаев көш. 22а, 050013, Алматы, Қазақстан. Email: a.negim@kbtu.kz*

Модифицированная битумно-полимерная мастика для защиты металлических покрытий от коррозии

[1*]Сабергалиев М.М., [2] Елигбаева Г.Ж., [3]Хасанов Д.А., [1]Мурадова С.Р., [2]Оразалин Ж.К, [1]Айнакулова Д.Т., [1]Шарипов Р.Х., [1,2]Негим Эльсайд

[1] Школа материаловедения и зеленых технологий, Казахстанско-Британский Технический Университет, г. Алматы, Казахстан
[2] Кафедра Нефтяной Инженерии, Сатбаев Университет, ул. Сатбаева 22а, 050013, г. Алматы, Казахстан
[3]Факультет Энергии и Нефтегазовой Индустрии, Казахстанско-Британский Технический Университет, г. Алматы, Казахстан

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Аннотация
Защита металлических конструкций от коррозии остается одной из важнейших задач во многих отраслях промышленности. В последние годы соединение модифицированного битума с эпоксидной смолой стало перспективным направлением в деле усиления защиты от коррозии. Этот новый композиционный материал демонстрирует исключительный потенциал в борьбе с пагубным воздействием коррозии, предлагая инновационное решение для защиты жизненно важных объектов инфраструктуры, промышленных компонентов и различных металлических подложек. Синергетические свойства, обусловленные сочетанием модифицированного битума и эпоксидной смолы, открывают захватывающие перспективы для повышения долговечности, химической стойкости и структурной целостности, способствуя тем самым прогрессу в области антикоррозионных покрытий. Данная научная статья посвящена изучению эффективности, механизмов и потенциальных возможностей применения этого композитного материала в качестве эффективного барьера против коррозии, проливая свет на его преобразующее воздействие в рамках стратегий борьбы с коррозией. В данном исследовании битум был модифицирован с использованием эпоксидной смолы ELM-NG900Z и отвердителя в соотношении 1,0:5:1,5 соответственно. Модифицированный битум был подвергнут дальнейшим испытаниям с помощью механических испытаний и испытаний с растворителем. Образцы модифицированного битума успешно прошли испытания и показали результаты лучше эталона (эпоксидная смола без битума).

Ключевые слова: Битумно-эпоксидная смола, битум, эпоксидная смола, коррозия.

Сабергалиев Мурат Меиргалиевич	***Информация об авторах:*** *Магистрант 2-го курса по специальности "Материаловедение и технология новых материалов". Казахско-Британский технический университет, Школа материаловедения и зеленых технологий, ул. Толе би, 59, 050000, Алматы, Казахстан. Email:m_sabergaliyev@kbtu.kz*
Елигбаева Гульжахан Жакпаровна	*Кафедра Нефтяной Инженерии, Сатбаев Университет, ул. Сатбаева 22а, 050013, г. Алматы, Казахстан. Email g.yeligbayeva@satbayev.university*
Хасанов Даурен Айратович	*Факультет Энергии и Нефтегазовой Индустрии, Казахстанско-Британский Технический Университет, г. Алматы, Казахстан. Email: daurenkhassanoff@gmail.com*
Мурадова Сабина Рустамқызы	*Магистр по специальности Материаловедения и Технологии Новых Материалов, Школа материаловедения и зеленых технологий, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, Алматы, Казахстан. Email: sab.muradova.01@mail.ru*
Оразалин Жандос Кайратулы	*Кафедра Нефтяной Инженерии, Сатбаев Университет, ул. Сатбаева 22а, 050013, г. Алматы, Казахстан. Email: zhandos1403@bk.ru*
Айнакулова Дана Тулегенқызы	*Ph.D. докторант Материаловедения и Технологии Новых Материалов, Школы материаловедения и зеленых технологий, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, Алматы, Казахстан. Email: da_ainakulova@kbtu.kz*
Шарипов Рустам Хасанович	*Казахско-Британский технический университет, Школа материаловедения и зеленых технологий, Казахстан.E-mail: r.sharipov@kbtu.kz*
Негим Аттиа Эльсайд	*Ph.D., Профессор Школы материаловедения и зеленых технологий, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, Алматы, Казахстан. Профессор Института геологии и нефтегазового дела им. К. Турысова, Кафедра Нефтяной Инженерии, Сатбаев Университет, ул. Сатбаева 22а, 050013, г. Алматы, Казахстан. Email: a.negim@kbtu.kz*

References

[1] Syrmanova K, Negim E, Kaldybekova J, Tuleuov A. M. Epoxylitane compositions modification with using thermoplastic polyurethane. Orient J Chem. 2016; 32(1):1-7.

[2] Apostolidis P, Liu X, Erkens SMJG, & Scarpas A. Evaluation of epoxy modification in bitumen. Construction and Building Materials. 2019; 208:361-368.

[3] Apostolidis P, Liu X, Kasbergen C, van de Ven MFC, Pipintakos G, & Scarpas A. Chemo-rheological study of hardening of epoxy modified bituminous binders with the finite element method. Transportation Research Record. 2018; 2672(28):190-199.

[4] Cong P, Tian Y, Liu N, & Xu P. Investigation of epoxy-resin-modified asphalt binder. Journal of Applied Polymer Science. 2016; 133(21).

[5] Zhou W, Xia Y, Tsai FC, Jiang T, Zhao H, & Wen J. Effects of compound curing agent on the thermo-mechanical properties and structure of epoxy asphalt. International Journal of Pavement Engineering. 2017; 18(10):928-936.

[6] Lu Q, & Bors J. Alternate uses of epoxy asphalt on bridge decks and roadways. Construction and Building Materials. 2015; 78:18-25.

[7] Sun Y, Zhang Y, Xu K, Xu W, Yu D, Zhu L, ... & Cheng R. Thermal, mechanical properties, and low-temperature performance of fibrous nanoclay-reinforced epoxy asphalt composites and their concretes. Journal of Applied Polymer Science. 2015; 132(12).

[8] Yin H, Jin H, Wang C, Sun Y, Yuan Z, Xie H, ... & Cheng R. Thermal, damping, and mechanical properties of thermosetting epoxy-modified asphalts. Journal of Thermal Analysis and Calorimetry. 2014; 115:1073-1080.

[9] Xiao Y, Van De Ven MFC, Molenaar AAA, Su Z, & Zandvoort F. Characteristics of two-component epoxy modified bitumen. Materials and structures. 2011; 44:611-622.

[10] Dauletov Y, Abdiyev K, Toktarbay Z, et al. Radical Polymerization and Kinetics of N, N-diallyl-N, N-dimethylammonium Chloride and Vinyl Ether of Monoethanolamine. Fibers Polym. 2018; 19:2023-2029. https://doi.org/10.1007/s12221-018-6947-3

[11] Fischer HR, & Cernescu A. Relation of chemical composition to asphalt microstructure–Details and properties of micro-structures in bitumen as seen by thermal and friction force microscopy and by scanning near-filed optical microscopy. Fuel. 2015; 153:628-633.

[12] Li H, & Li SQ. Research on asphalt oil corrosion mechanism. Highw. Eng. 2016; 41:229-231.

[13] Makhmetova A, Negim E-S, Ainakulova D, Yeligbayeva G, & Khatib J. An Overview of Epoxy Resins as coating to protect metals from corrosion. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2023; 328(1):20-32.

[14] Li Q, Li K, Zhao K, Sun G, & Luo S. Fuel oil corrosion resistance of asphalt mixtures. Construction and Building Materials. 2019; 220:10-20.

[15] Gao X, Pang L, Xu S, Lv Y, & Zou Y. The Effect of Silicone Resin on the Fuel Oil Corrosion Resistance of Asphalt Mixture. Sustainability. 2022; 14(21):14053.

[16] Jin FL, Li X, & Park SJ. Synthesis and application of epoxy resins: A review. Journal of industrial and engineering chemistry. 2015; 29:1-11.

[17] Xiang Q, & Xiao F. Applications of epoxy materials in pavement engineering. Construction and Building Materials. 2020; 235:117529.

[18] Cong P, Luo W, Xu P, & Zhang Y. Chemical, and physical properties of hot mixing epoxy asphalt binders. Construction and Building Materials. 2019; 198:1-9.

[19] Ainakulova D, Muradova S, Khaldun MAA, Bekbayeva L, Megat-Yusoff P, Mukatayeva Z, Ganjian E, & Negim E-S. Analytical Review of Conductive Coatings, Cathodic Protection, and Concrete. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2023; 329(2):92-102.

[20] Ignatenko VY, Kostyuk AV, Kostina JV, Bakhtin DS, Makarova VV, Antonov SV, & Ilyin SO. Heavy crude oil asphaltenes as a nanofiller for epoxy resin. Polymer Engineering & Science. 2020; 60(7);1530-1545.

[21] Syrmanova K, Negim E, Kaldybekova J, Suleimenova M, Baizhanova S. Study of modification process of the epoxylitane composites. Industrial Technology and Engineering. 2015; 3:75-83.

[22] Muradova S, Negim E-S, Makhmetova A, Ainakulova D, & Mohamad N. An Overview of the Current State and the Advantages of using acrylic resins as anticorrosive coatings. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2023; 327(4):90-98.