Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2024, № 1 (117) https://doi.org/10.33108/visnyk_tntu2025.01
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 667.64:678.026

METHOD FOR IMPROVING THE EFFICIENCY OF OPERATION AND REPAIR OF WATER TRANSPORT USING THE NEWEST EPOXY PLASTICS

Andrii Buketov[1]; Kostiantyn Klevtsov[1]; Oleg Totosko[2]; Vitaliy Sotsenko[1]; Oleksandr Akimov[1]; Roman Negrutsa[1]; Danyl Zhytnyk[1]; Iryna Kulish[3]; Bohdan Krushelnytskyi[2]

[1]*Kherson State Maritime Academy, Kherson, Ukraine*
[2]*Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine*
[3]*Kherson National Technical University, Kherson, Ukraine*

Abstract. *Today, in order to improve the efficiency of operation and repair of water transport vehicles, it is important to apply a method that involves the use of the latest reactoplastics that can operate at high temperatures. Here, it is important to activate epoxy compositions by introducing active additives such as microdispersed filler into the oligomer. This allows for a simultaneous increase in the mechanical properties of the materials. In addition, the cohesive strength is crucial for the thermal properties of epoxy composites, which is especially important for the water transport vehicles operating in different time zones. Therefore, research in this area is relevant today. In this paper, the optimal content of synthesised and physically active dispersed filler in an epoxy oligomer was determined by the criteria of thermophysical properties, such as heat resistance and coefficient of thermal expansion of polymer composites. Epoxy resin was used as the basis for the formation of polymer compounds. The compositions were crosslinked with PEPA hardener. A titanium aluminium powder was used as a filler. It was determined that in order to form materials with improved performance characteristics, it is necessary to add a charge powder to the epoxy resin at a content of 0.5 % per 100 % of epoxy resin. Obtaining such a composite can significantly increase the heat resistance, glass transition temperature and reduce the CTE of protective coatings. This was considered to be caused by the influence of the microdispersed additive on the microheterogeneous structure of the developed materials. On the other hand, it is the structure that determines the cohesive strength of materials and is the basis for further adjustment of their thermal and physical characteristics. As a result, the degree of gelation of the materials increases, which implies an improvement in the thermal properties of the developed materials to increase the efficiency of operation and repair of water transport vehicles.*

Key words: *transport, polymer, filler, properties, method, operation, repair.*

https://doi.org/10.33108/visnyk_tntu2025.01.098 *Received 11.11.2024*

1. INTRODUCTION

The studies [1–6] prove that the selection of components and technological conditions of their formation are the main factors in regulating the characteristics of composites for the restoration of vessels. The properties of the matrix and microdispersed additives are essential for the characteristics, including thermal and physical ones, of the transport industry. These two components then form the molecular and supramolecular structure of composites.

Taking into account the operating conditions of modern commercial vessels, it is necessary to improve their mechanical properties under the influence of a thermal field. Due to the fact that it is under the influence of temperature that microdestruction processes occur in the structure of polymeric composite materials (PCM). The latter is the cause of the onset

 Corresponding author: Andrii Buketov; e-mail: buketov@tntu.edu.ua

of fractures in protective coatings, which subsequently leads to macrofractures and, as a result, to the failure of technological equipment.

Taking into account the operating conditions of modern commercial vessels, it is necessary to improve their mechanical properties under the influence of a thermal field. Due to the fact that it is under the influence of temperature that microdestruction processes occur in the structure of PCM. The latter is the cause of the onset of fractures in protective coatings, which subsequently leads to macrofractures and, as a result, to the failure of technological equipment.

Analysis of the papers [7–9] shows a wide range of approaches to the predictive control of the properties, even at temperatures, of PCM. This is important for thermoplastics used in the transport industry.

It is a priori that the introduction of components into a polymer implies strengthening their structure at the supramolecular level. This ensures the creation of supramolecular inclusions at the interface between the filler and the polymer. In turn, this is a prerequisite for improving the cohesive characteristics of PCMs only when they are filled with physically active microdispersed additives [10–15].

In this aspect, it is interesting to use active dispersions that will interact with the macrochains of the matrix at the molecular level. In this context, it is also worth conducting studies to assess the impact of active microparticles of titanium aluminium charge (TAC) on the thermal properties of the developed composites. The latter are intended to be used as protective coatings for sea and river transport.

2. EXPERIMENTAL METHODS

The objective of the research is to develop new epoxies to improve the efficiency of operation and repair of the water transport vehicles. The epoxy resin ED-20 (ISO 18280:2010) was used as the basis for obtaining new materials. The PCM was crosslinked using PEPA hardener (TU 6-05-241-202-78). Synthesised particles of titanium aluminium charge (TAC) were used as a microdispersed powder. The composition of the powder particles is as follows: Ti (75 %) + Al3Ti (15 %) + Ti3AlC2 (10 %). The particle size is dcep = 10±2 μm. The heat resistance of composites was studied in accordance with ISO 75-2.

The coefficient of thermal expansion (CTE) of the materials was also determined. When calculating the CTE, at the initial stage, a curve was constructed to determine the elongation of the samples under temperature loading and during the reduction of the thermal field effect. Based on these dependences, the shrinkage of the PCMs and their relative deformation were calculated. As a result, the TCLR was calculated at different temperature ranges, which made it possible to state the behaviour of materials under critical temperature conditions. It should be noted that the deformation properties of cementitious materials were analysed in relation to changes in the parameters of the samples under the influence of a thermal field (ISO 11359-2).

3. RESULTS AND DISCUSSION

Initially, the heat resistance *(T*) and glass transition temperature (T_c) of PCM were studied by introducing a different amount of filler into the epoxy resin. It was determined that the absolute value of the heat resistance of the unfilled composite in the form of a matrix was 340 K (Fig. 1).

It has been proved (Fig. 1) that filling with an additive in a small amount (0.05%) leads to an increase in the heat resistance of PCM. With this filling, a PCM was obtained with a heat resistance index of 351 K. The difference compared to the unfilled material is 11 K. The maximum value of the studied characteristic among the entire range of materials under consideration was obtained for the material filled with particles of the TAC additive with a content of 0.5%. Such a composite has the heat resistance value of 359 K. Subsequently, an increase in the amount of microdispersed filler in the composites provides a decrease in absolute values compared to the maximum. In particular, the material filled with an additive in the amount of 2% has an indicator of the studied characteristic of 348 K.

The results of such tests are interpreted as the activation of physical and chemical processes during the structure formation of materials in the presence of a dispersed filler. When it is present in the compositions in a small amount, interfacial interaction is activated. This involves the creation of new chemical bonds between the surface of the additive and the macromolecules of the epoxy resin. As a result, a three-dimensional structure of new chemical bonds is created, which complement the number of similar bonds between the epoxy macromolecules.

Next, when the filler is added at a critical content, the number of interfacial bonds is maximised. As a result, the cohesive strength and, as a result, the heat resistance significantly increase.

When the additive is over the critical content, the following occurs. The filler is not sufficiently wetted. Consequently, the number of interfacial bonds decreases, which leads to a reduction in the heat resistance of the developed materials.

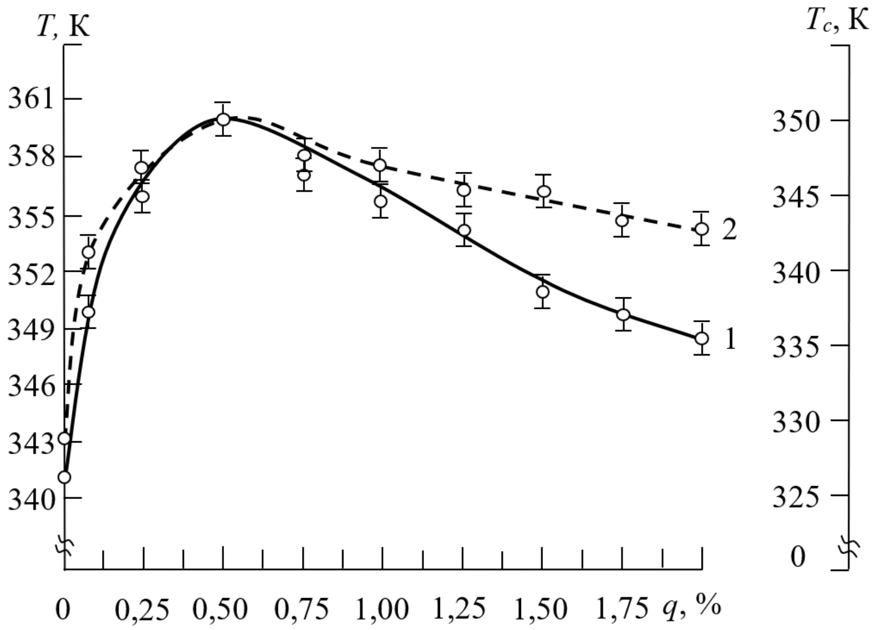


Figure 1. Dependence of heat resistance (T) and glass transition temperature (Tc) of composites on the amount of TAC microadditive

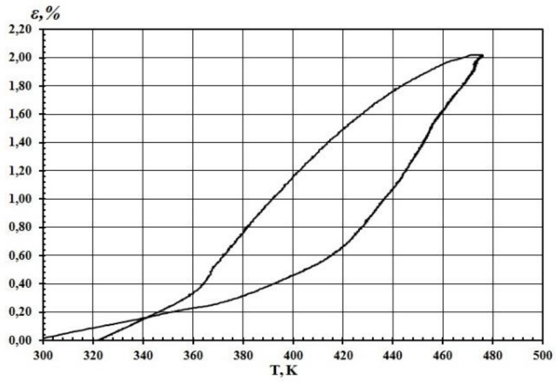
Simultaneously, the test results were analysed to determine the dependence of the glass transition temperature (Tc) of PCM on the amount of microdispersed filler introduced into the polymer. It was proved (Fig. 1) that the glass transition temperature of the material based on unfilled epoxy resin is 326 K. The addition 0.05% of dispersed particles to the resin increases this indicator to 342 K.

It was found that the maximum value of this property of all the materials studied was obtained for the composite filled with 0.5% TAC particles. This filling produced a material with a glass transition temperature of 345 K.

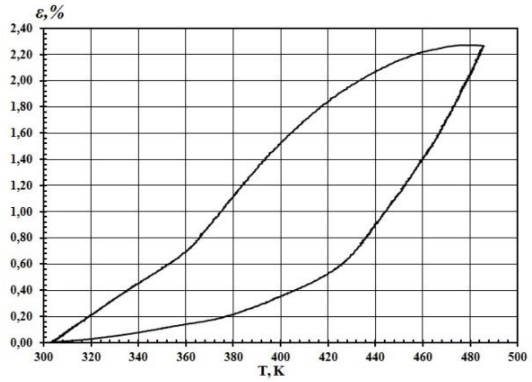
Similarly to the dynamics of heat resistance as a function of TAC concentration, it has been proved that filling the matrix with additive particles beyond critical values implies obtaining a material with deteriorated thermal properties. In particular, Fig. 1 shows that for the material filled with 2% TAC, the glass transition temperature has an absolute value of 342 K.

Based on the above, it can be concluded that the dynamics of thermal properties in the complex depends on the amount of the additive introduced. In other words, it can be argued that the optimal amount of the TAC filler has been identified from the perspective of the studies of the thermophysical properties of PCM. It was determined that the filling of epoxy resin with TAC dispersed particles at a content of 0.5% provides an increase in heat resistance from 340 K (for epoxy matrix) to 359 K, and the glass transition temperature of PCM increases from 326 K to 345 K.

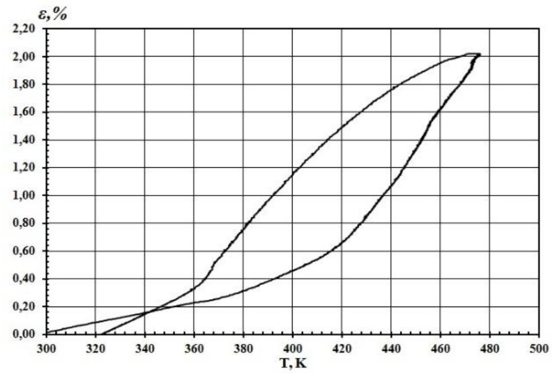
To verify the reliability of the results obtained, the coefficient of thermal expansion (CTE) of epoxy composites was additionally determined (Fig. 2). Initially, it was found that the CTE of the material based on unfilled epoxy resin in the temperature range of 304...324 K was 6.4 × 10-5 K-1 (Table 1). Filling the polymer with dispersed additives helps to reduce the CTE of PCM to (2.7...3.4) × 10-5 K-1. At the same time, the lowest CTR (2.8 × 10-5 K-1) was observed for the material filled with TAC particles within 0.5%.



a)



b)



c)

Figure 2. Dilatometric graphs of PCM with different amounts of TAC filler: a) 0.05 %; b) 0.5 %; c) 2 %

The test results in the temperature range of 304...424 K prove that the CTE of PCM relative to the original epoxy matrix decreases rather significantly (from 10.0 × 10-5 K-1 to (5.3...5.5) × 10-5 K-1). It should be noted that there is virtually no difference between the CTE values of materials with the additive (in different ranges) (the difference is 0.2 × 10-5 K-1). Thus, it can be stated that within the range of raised temperatures, the effect of the additive on improving the cohesive strength and, consequently, the thermal properties is not as important as at lower temperatures.

Finally, the change in the parameters of the samples under the influence of temperature in the range of 304...474 K was analysed. It was found (Table 1) that the values of the CTE of the epoxy matrix and the created composites do not actually differ. The values of all studied materials are in the range of (10.7...11.0) × 10^{-5} K^{-1}. It can be concluded that the volume of air inclusions in such materials significantly increases due to the breakage of physical bonds at such temperatures. In our opinion, the operation of new materials at this temperature range is not advisable.

Table 1

Coefficient of thermal expansion (CTE) of PCM at different temperature test limits

Content of TAC particles, *q*, %	Coefficient of thermal expansion, $\alpha \times 10^{-5}$, K^{-1}			
	Test temperature range, ΔT, K			
	304…324	304…374	304…424	304…474
–	6.4	6.9	10.0	11.0
0.05	3.4	3.5	5.4	10.9
0.5	2.7	3.4	5.3	10.7
2	3.4	3.9	5.5	10.8

Thus, it has been concluded that in the formation of composites for vessels operating at high temperatures, it is necessary to add TAC powder in the amount of 0.5 % to the epoxy oligomer as a microdispersed additive. Introduction of such a composite can significantly increase the heat resistance, glass transition temperature and reduce the CTE of protective coatings for water transport.

4. CONCLUSIONS

As a result of the conducted research, the following has been revealed.

1. It has been proved that in order to obtain epoxy composites with improved thermal and physical characteristics, it is necessary to introduce a microdispersed powder of titanium aluminium charge into the epoxy oligomer as a filler at a content of 0.5% per 100% of ED-20 epoxy resin. This composite provides an increase in heat resistance relative to the original epoxy matrix from 340 K to 359 K, and the glass transition temperature from 326 K to 345 K. It is substantiated that this is due to the activation of physical and chemical processes during the structure formation of materials in the presence of a dispersed filler. When the filler is used in the compositions at the optimum amount, the interfacial interaction is activated. This involves the creation of new chemical bonds between the surface of the additive and the macromolecules of the epoxy resin. As a result, a three-dimensional structure of new chemical bonds is formed, which complement the number of similar bonds between the epoxy macromolecules.

2. It has been determined that the materials with 0.5% TAC particles are characterised by the lowest thermal expansion coefficient among the predefined

temperature ranges of tests. The introduction of such a composite in the transport industry will help reduce the CTE compared to epoxy matrix by 1.8...2.3 times. At the same time, we note a decrease in the CTE:

- in the temperature range 304...324 K from 6.4×10^{-5} K^{-1} to 2.7×10^{-5} K^{-1};
- in the temperature range 304...374 K from 6.9×10^{-5} K^{-1} to 3.3×10^{-5} K^{-1};
- in the temperature range 304...424 K from 10.0×10^{-5} K^{-1} to 5.3×10^{-5} K^{-1}.

The analysis of the results of studying the change in the parameters of composites under the influence of temperature in the range of 304...474 K proves that the values of the CTE of the epoxy matrix and the created composites do not significantly differ. The values of all studied materials are in the range of $(10.7...11.0) \times 10^{-5}$ K^{-1}. It can be concluded that the volume of air inclusions in such materials considerably increases due to the breakage of physical bonds at such temperatures. In our opinion, the operation of new materials at this temperature range is not advisable.

Further research is planned to determine the impact of filler content on the anti-corrosion properties of protective coatings for vehicle repair.

References

1. Dobrotvor I. G., Stukhlyak P. D., Mykytyshyn A. G., Stukhlyak D. P. (2021) Influence of Thickness and Dispersed Impurities on Residual Stresses in Epoxy Composite Coatings. Strength of Materials, 53 (2), pp. 283–290. https://doi.org/10.1007/s11223-021-00287-x
2. Dobrotvor I. H., Stukhlyak P. D., Buketov A. V. (2009) Investigation of the formation of external surface layers in epoxy composites. Materials Science, 45 (4), pp. 582–588. https://doi.org/10.1007/s11003-010-9217-0
3. Moroz K. M., Stukhlyak P. D. (2011) Influence of porosity in the epoxy matrix-polyvinyl alcohol-disperse filler system on the impact toughness. Materials Science, 46 (4), pp. 455–463. https://doi.org/10.1007/s11003-011-9312-x
4. Stukhlyak P. D. (1986) Antifriction and adhesive properties of coatings of thermosetting plastics modified with thermoplastic polymers. Soviet Journal of Friction and Wear (English translation of Trenie i Iznos). 7 (1), pp. 138–141.
5. Totosko O., Stukhlyak P., Mytnyk M. et al., (2022) Investigation of Corrosion Resistance of Two-Layer Protective Coatings. Challenges to National Defence in Contemporary Geopolitical Situation, 2022 (1), pp. 50–54. https://doi.org/10.47459/cndcgs.2022.6
6. Stukhlyak P. D., Bliznets M. M. (1989) On the influence of metal oxides on the wear resistance of modified epoxy resins. Soviet Journal of Friction and Wear (English translation of Trenie i Iznos). 10 (3), pp. 70–73.
7. Miroshnichenko D., Lebedev V., Riabchenko M. et al. (2023) Use of the Graphite to Obtain Composites for Absorbing Electromagnetic Radiation. Petroleum and Coal. 65 (3), pp. 718–723.
8. Sapronov O., Maruschak P., Sotsenko V., Buketova N., Bertem A., Sapronova A., Prentkovskis O. (2020) Development and Use of New Polymer Adhesives for the Restoration of Marine Equipment Units. Journal of Marine Science and Engineering. 8 (7), p. 527. https://doi.org/10.3390/jmse8070527
9. Sapronov O. O., Dyadyura K., Vorobiov P. O., Sharanov V. D., Karpash M. O, Bishchak R. T., Hrebenyk L. (2023) Corrosion-Resistant Epoxy Coatings Filled with Nanoparticles of Vegetable Origin to Protect Water Vehicles. Journal of Nano- and Electronic Physics, 15 (5), pp. 1–7. https://doi.org/10.21272/jnep.15(5).05025
10. Cho Soo Hyoun, R. Scott, V. Paul, (2009) Self-healing polymer coatings. Advanced Materials, 21 (6), pp. 645–649. https://doi.org/10.1002/adma.200802008
11. Shaffer E. O., McGarry F. J., (1996) Lan Hoang. Designing reliable polymer coatings. Polymer Engineering & Science, 36 (18), pp. 2375–2381. https://doi.org/10.1002/pen.10635
12. Momber A., Irmer M., Gluck N. Performance characteristics of protective coatings under low-temperature offshore conditions. Part 1: Experimental set-up and corrosion protection performance. Cold Reg. Sci. Technol, 127, 76–82 (2016a). https://doi.org/10.1016/j.coldregions.2016.03.013
13. Buketov A. V., Dyadyura K., Shulga Yu. M., Sotsenko V. V., Hrebenyk L., Pastukh O. A., Zhytnyk D. V. (2024) The Method of Increasing the Mechanical Characteristics of Sea Transport Vehicles due to Environmentally Friendly Nanomodification of Epoxy Composites. Journal of nano- and electronic physics, 16 (4), 04027 (10pp). https://doi.org/10.21272/jnep.16(4).04027
14. Buketov A. V., Shulga Yu. M., Fesenko I. P., Bezbakh O. M., Pastukh O. A. (2024) Increasing the Lifetime of Water Transportation Vehicles by Using Multifunctional Composites with a Polymer Matrix, Ultradisperse Diamond, and Discrete Fibrous Filler. Journal of Superhard Materials, 46 (1), pp. 40–54. https://doi.org/10.3103/S1063457624010027

15. Rakha S. A., Ali N., Haleem Y. A. et al. (2014) Comparison of Mechanical Properties of Acid and UV Ozone Treated Nanodiamond Epoxy Nanocomposites. Journal of Materials Science & Technology, 30 (8), pp. 753–758. https://doi.org/10.1016/j.jmst.2013.12.011

УДК 667.64:678.026

МЕТОД ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ЕКСПЛУАТАЦІЇ Й РЕМОНТУ ЗАСОБІВ ВОДНОГО ТРАНСПОРТУ НОВІТНІМИ ЕПОКСИПЛАСТАМИ

Андрій Букетов[1]; Костянтин Клєвцов[1]; Олег Тотосько[2]; Віталій Соценко[1]; Олександр Акімов[1]; Роман Негруц[1]; Данило Житник[1]; Ірина Куліш[3]; Богдан Крушельницький[2]

[1]Херсонська державна морська академія, Херсон, Україна
[2]Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна
[3]Херсонський національний технічний університет, Херсон, Україна

Резюме. *Актуальним на сьогодні для підвищення ефективності експлуатації й ремонту засобів водного транспорту є застосування методу, який передбачає використання новітніх реактопластів, здатних працювати за підвищених температур. При цьому важливим є активація епоксидних композицій шляхом уведення в олігомер активних домішок у вигляді мікродисперсного наповнювача. Це дозволяє одночасно підвищити в комплексі механічні властивості матеріалів. При цьому когезійна міцність є визначальною для теплофізичних властивостей епоксидних композитів, що особливо актуально для засобів водного транспорту, які експлуатують у різних часових поясах. Тому робота в цьому напрямку на сьогодні є актуальною.*

У роботі визначено оптимальний вміст синтезованого й фізично активного дисперсного наповнювача в епоксидному олігомері за критеріями теплофізичних властивостей, таких, як теплостійкість і коефіцієнт теплового розширення полімерних композитів. За основу при формуванні полімерних компаундів взято епоксидну смолу. Зшито композиції твердником ПЕПА. Як наповнювач застосовано порошок у вигляді титано-алюмінієвої шихти.

Встановлено, що для формування матеріалів з підвищеними експлуатаційними характеристиками в епоксидну смолу необхідно добавляти порошок шихти за вмісту 0,5% на 100% епоксидної смоли. Отримання такого композиту дозволяє значно підвищити теплостійкість, температуру склування й зменшити КТР захисних покриттів. Вважали, що це зумовлено впливом мікродисперсної добавки на мікрогетерогенну структуру розроблених матеріалів. З іншого боку, саме структура визначає когезійну міцність матеріалів і є основою для подальшого регулювання їх теплофізичних характеристик. У результаті підвищується ступінь гелеоутворення матеріалів, що передбачає покращення теплофізичних властивостей розроблених матеріалів для підвищення ефективності експлуатації й ремонту засобів водного транспорту.

Ключові слова: *транспорт, полімер, наповнювач, властивості, спосіб, експлуатація, ремонт.*

https://doi.org/10.33108/visnyk_tntu2025.01.098 *Отримано 11.11.2024*