SOME EVALUATION AND RESEARCH RESULTS OF MECHANICAL PROPERTIES AND SEAWATER RESISTANCE OF EPOXY COATINGS ON POROUS MATERIALS

MỘT SỐ KẾT QUẢ NGHIÊN CỨU, ĐÁNH GIÁ CƠ TÍNH VÀ KHẢ NĂNG CHỊU NƯỚC BIỂN CỦA LỚP PHỦ EPOXY TRÊN NỀN VẬT LIỆU XỐP

Do Dinh Trung[1], Nguyen Manh Tuong[2], Nguyen Ngoc Linh[3], Nguyen Minh Viet[4,*]

DOI: https://doi.org/10.57001/huih5804.75

ABSTRACT

Due to outstanding properties of mechanical properties, resistance to chemicals, seawater etc., epoxy materials are used effectively in the fields of paints, glues, composites, bulk materials, etc., and in many other specialized sectors such as transportation, aerospace. Within the scope of this research, the efficiency of epoxy materials is evaluated in the marine environment with the main purpose of improving the resistance capacity of seawater intrusion and also increasing the mechanical properties of porous materials in quick assembly works in the sea and on islands. This research presents some research results on the effectiveness of epoxy coatings on expanded polystyrene foam, extruded polystyrene foam and polyurethane foam. The achieved results showed that, when coating foam panels with the quantity from 460g/m^2 to 570g/m^2 by epoxy resin, the level of seawater resistance reaches 97.7%, the compressive strength of the porous materials when coating epoxy reaches 1219.3kJ/m^2.

Keywords: *Epoxy resin YD-128; hardener polyethylene polyamine; EPS foam; XPS foam; PU foam.*

TÓM TẮT

Với những đặc tính nổi trội về cơ tính, khả năng kháng hóa chất, nước biển,… vật liệu epoxy được sử dụng hiệu quả trong lĩnh vực sơn, keo, composite, vật liệu khối,… trong nhiều lĩnh vực đặc chủng từ giao thông vận tải, hàng không vũ trụ,… Trong khuôn khổ bài báo này đã nghiên cứu, đánh giá hiệu quả của lớp vật liệu epoxy trong môi trường nước biển, với mục đích chính là cải thiện khả năng ngăn chặn môi trường nước biển xâm nhập, đồng thời tăng cơ tính cho vật liệu xốp trong các công trình lắp ghép nhanh vùng biển, trên các đảo. Bài báo trình bày một số kết quả nghiên cứu hiệu quả của lớp phủ epoxy đối với xốp polystyrene giãn nở, xốp polystyrene ép đùn và xốp polyurethane. Các kết quả xác định cho thấy, với các tấm xốp được phủ lớp nhựa epoxy với lượng 460g/m^2 đến 570g/m^2, mức độ ngăn chặn nước biển đạt đến 97,7%, độ bền nén của tấm vật liệu xốp được phủ lớp epoxy này đạt 1219,3kJ/m^2.

Từ khoá: *Nhựa epoxy YD-128; chất đóng rắn polyethylene polyamine; xốp EPS; xốp XPS; xốp PU.*

[1]Institute of tropical durability, Joint Vietnam-Russia Tropical Science and Technology Research Center
[2]Institue of Chemistry and Materials, Academy of Military Science and Technology
[3]Faculty of Pharmacy, Thanh Do University of Education
[4]Faculty of Chemical Technology, Hanoi University of Industry
[*]Email: minhviet@haui.edu.vn
Received: 15/9/2022
Revised: 25/10/2022
Accepted: 22/11/2022

1. INTRODUCTION

Vietnam is located in a humid tropical climate with a long coastline along the country and has many big and small islands [1]. In the context of serious damages caused by the impact of high temperatures, rising sea levels, and floods, we have come up with many solutions to overcome and adapt to the new situation, in which the construction of coastal houses from quick assembly works is considered as a solution with high adaptive efficiency [1, 2]. Porous materials used to create building blocks can be easily implemented on a large industrial scale with domestically available equipment. The quick assembly works clearly show the advantages of weather resistance, seawater resistance, effective temperature and sound insulation etc. [3, 4, 5], as well as the high flexibility when dismantling and moving, especially low initial investment costs.

Thanks to the advantage of light weight (specific gravity is in the range of 16kg/m^3 to 50kg/m^3), types of foams such as expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PU), glass wool panel, mineral wool panel, etc., have been manufactured by many companies and firms, their panels can be used in the construction of assembly works. However, the use of these porous blocks is limited due to its short lifespan, especially at the wall foundation, which absorbs a lot of salt due to frequent contact with seawater. Epoxy based materials have superior properties compared to other resins such as good adhesion on the surface of different materials, strong impact resistance, salt resistance (the E-glass/epoxy retained 94% of its strength after 7.5 years of immersion in seawater) [6], chemical resistance etc. [7, 8, 9]. This type of materials has been applied as a coating on the surface of different types of foam to solve the disadvantages of some types of foam to improve the durability and increase the lifespan of all types of foam. This is a scientific and effective solution in practice.

2. MATERIALS AND METHODS

2.1. Materials

XPS, EPS and PU foam (Vietnam), ethanol 99.6% (Vietnam), epoxy resin YD-128 (Korea), hardener polyethylene polyamine (PEPA) (China), acetone (China), solution NaCl 3.5%, laboratory analytical balance PR224/E (Ohaus, USA), heating oven UN110 (Memmert, Germany), templates, electronic calipers, rulers, and cutting machines.

2.2. Fabrication of epoxy materials

The epoxy resin YD-128 and hardener PEPA are prepared according to the weight rate as specified in Table 1 [10]. Stir well to make a homogeneous mixture solution (epoxy resin sample), the mixture cures at the room temperature for 24 hours.

Table 1. Component of epoxy resin samples

Component	Sample				
	M1	M2	M3	M4	M5
Epoxy resin YD-128	50	60	70	80	90
Hardener PEPA	10	10	10	10	10

An epoxy resin YD-128 is poured into a mold (cleaned and non-stick mold) according to the standards for the determination of tensile, bending and impact strength.

2.3. Fabrication of samples

PU, EPS, XPS foam panels are cut, measured and weighed.

Weight rate of epoxy resin and curing agent; the quantity of epoxy material coated on the surface of the foam panel is calculated previously.

A bristle brush is used to coat epoxy on the surface of foam panels EPS [11] (PU or XPS), making sure to cover the entire foam surface evenly and tightly. The surface of specimen panel is dried after 24h at the room temperature. The coating is stabilized for at least 7 days. It is required to determine the criteria of compressive strength, salt water absorption rate.

2.4. Test methods

The salt water absorbance is determined according to TCVN 178:1986 [12].

The tensile strength is determined according to ASTM D638 [13], on the Instron 5582-100kN device (USA), and at a tensile rate of 5 mm/min.

The bending strength is determined according to ASTM D790-10 [14], on the Instron 5582-100kN device (USA).

The impact strength (grooved) is determined according to ISO 180:1993 [15], on the Tinius Olsen device (USA).

The compressive strength is determined according to ISO 604:2002 [16], on the Z010TH ProLine/Zwick device.

The gel content is determined as follows:

Crush the epoxy material, pack it into a filter paper and place in the Soxhlet extraction system. Acetone solvent is used to extract the residual epoxy resin and PEPA curing agent that are still residual in the epoxy material specimen after the curing reaction.

The gel content (G, %) is determined according to the following formula (1):

$$G = \frac{(g_2 - g_0)}{(g_1 - g_0)} . 100\% \quad (1)$$

In which:

g_0 - mass of dry filter paper, (g);

g_1 - total mass of dry filter paper and study sample before extraction, (g);

g_2 - total mass of dry filter paper and study sample after extraction, (g);

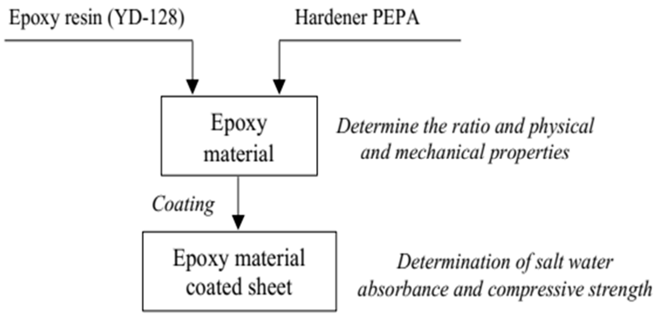

Figure 1. Testing procedure

3. RESULTS AND DISCUSSION

3.1. Evaluation of epoxy resin-based fabrication materials

3.1.1. Surveys of epoxy resin curing degree

During the curing process of epoxy resin, the accurate amount of hardener used is very important because it determines the physical and mechanical properties of the material after curing.

The gel content represents the curing ability of the material after fabrication, from which the appropriate rate of components is selected to assure that the fabricated material can achieve the highest physical and mechanical properties.

The gel content is determined according to formula (1), and the results are presented in Figure 2.

Based on Figure 2, the results showed that samples M1, M2, M4 and M5 have lower gel content. Sample M3 has the highest gel content (G = 98.19%). It can be explained that, in the fabricated material samples, there is also an excessive amount of epoxy resin (for samples M4 and M5) or excess PEPA (for samples M1 and M2) that does not participate in the crosslinking reaction so that it is extracted by acetone solvent from the material sample, causing the total sample mass after extraction decreases significantly; as a result, the gel content (G) reaches a low value. For the material sample M3, the gel content reaches a higher value, which means that the rate of epoxy resin/PEPA = 7/1, this makes the curing mixture more thoroughly, and this rate is used to fabricate the material samples for further studies and surveys.

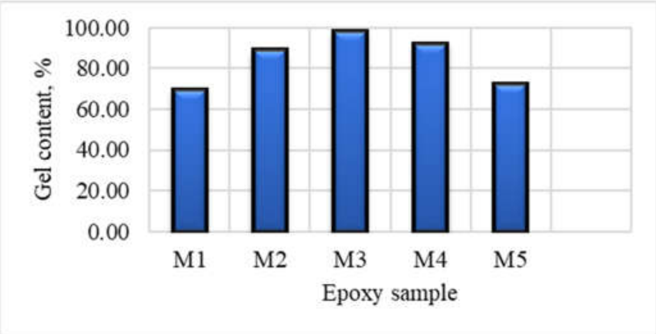

Figure 2. Gel content of epoxy material specimens

3.1.2. Evaluation of the mechanical strength of epoxy materials

Epoxy resin-based paints, coatings and composite materials using curing agents PEPA are widely applied because of their outstanding advantages such as high strength, minor shrinkage, effective chemical resistance, and especially, this material is available on the domestic market, so it is completely active for the manufacture of these materials.

Based on the survey as mentioned above, it is possible to choose an appropriate rate of epoxy resin/PEPA = 7/1. Some mechanical properties of epoxy material samples such as tensile strength, bending strength and impact strength are summarized in Table 2.

Table 2. Physical and mechanical properties of epoxy material samples

Mechanical properties	Value
Tensile strength, MPa	45.3
Bending strength, MPa	132.5
Impact strength, kJ/m^2	4.6

The strength values of epoxy materials as described in Table 2 meet the requirements for the purpose of strengthening the mechanical properties of other materials to improve the use efficiency in practice.

3.2. Surveys of the properties of epoxy-coated foam panels

The epoxy material layer is used as a coating on the surface of PU, EPS and XPS foam panels with the quantity listed in Table 3.

Table 3. Quantity of epoxy coating

Type of foam panel	Epoxy resin quantity, g/m^2
EPS	458.1
XPS	487.1
PU	570.2

3.2.1. Seawater absorption of the material

The epoxy-coated porous material panels are immersed in seawater (NaCl 3.5%) for 48 hours. The results for determination of seawater absorption of foam panels are summarized in Table 4.

Table 4. Seawater absorption of epoxy-coated foam panels

Material sample	Seawater absorption, g/m^2	
	Non-coating epoxy	*Coating epoxy*
EPS	34.176	1.157
XPS	37.022	1.021
PU	36.835	0.861

Based on Table 4, the results showed that the epoxy-coated PU material samples have the highest seawater resistance capacity (the lowest seawater absorption is 0.861g/m^2), the epoxy-coated XPS and EPS foam samples have the lower seawater resistance capacity (the seawater absorbance values are of 1.021g/m^2 and 1.157g/m^2, respectively). This can be explained as follows: the surface structure of PU foam has small and uniform pores. In addition, there is polar hydroxyl group in the chemical structure of epoxy resin, so it is easy to bond and compatible with PU foam, thereby creating a dense mass of materials and increasing the water penetration prevention capacity.

The results of Table 4 also expressed that the seawater absorption of foam panels is greatly improved when coated with epoxy, these values are very low compared to the samples of porous materials not coated with epoxy.

Figure 3. Testing for determination of seawater absorption

3.2.2. Compressive strength of fabricated materials

For porous materials, compressive properties are important mechanical properties to evaluate the structural stability of pores under the impact of external forces. For porous material panels coated with epoxy material, this epoxy resin layer will greatly determine the mechanical properties of the fabricated materials.

The results for determination of the compressive strength of material samples are summarized in Table 5.

Table 5. Compressive strength of epoxy-coated porous samples

Material samples	Compressive strength, kJ/m^2
EPS	714.9
XPS	563.1
PU	1219.3

Based on the results of Table 5, it showed that the epoxy-coated PU material samples achieve the highest compressive strength. This is explained as follows: 1) PU foam panel has higher compressive strength than EPS and XPS foam panels; 2) The quantity of epoxy coating on the surface of PU panels (570.2g/m^2) is the highest compared to the quantity of epoxy coating on the EPS and XPS foam panels, this provides high mechanical properties for the PU foam panels.

4. CONCLUSION

Based on the rate (mass ratio) of epoxy resin/hardener PEPA = 7/1, epoxy materials achieve the highest curing efficiency, the material achieves the tensile strength of 45.3MPa, bending strength of 132.5MPa and impact strength of 4.6kJ/m^2.

The use of epoxy materials on the surface of EPS, XPS and PU foam panels helps reduce significantly the seawater absorption from 96.6% to 97.7%, its compressive strength reaches 563.1kJ/m^2 (for XPS panels), reaching values of 714.9kJ/m^2 (for EPS panels) and 1219.3kJ/m^2 (for PU panels). These epoxy-coated foam panels are suitable for quick-assembly works in coastal and island areas, meeting the requirements of durability, mobility, flexibility and timely adaptation in stormy conditions, floods and rising sea levels due to climate change.

ACKNOWLEDGMENTS

The authors sincerely thank the Ministry of Construction Project "Research and fabrication of panels based on nanocomposite materials, application of quick-assembly works for residents in coastal and island areas". We have received a great support in terms of contents and facilitated to conduct of this research.

REFERENCES

[1]. 14th National Assembly, Committee on Science, Technology and Environment, 2017. *Responding to climate change in Vietnam*. Youth Publishing House.

[2]. Dasgupta S., et al., 2009. *The impact of sea level rise on developing countries: a comparative analysis.* Climatic change, Vol. 93, pp.379-388.

[3]. Xi Meng, et al., 2015. *Thermal performance improvement of prefab houses by covering retro-reflective materials*. Procedia engineering, Vol. 121, pp.1001-1007.

[4]. Martin Haller, Lars Stehn, 2014. *Increasing the accuracy of a prefab building design process simulation using simulated annealing*. Procedia engineering, Vol. 85, pp.214-221.

[5]. Jun Wang, et al., 2013. *Ultrathin envelope thermal performance improvement of prefab house by integrating with phase change material*, Energy and buildings, Vol. 67, pp.210-216.

[6]. Abdel-Hamid Ismail Mourad, et al., 2019. *Long-term durability of thermoset composites in seawater environment*. Composites Part B: Engineering, Vol. 168, pp. 243-253.

[7]. Zeze Armande Loraine Phalé, et al., 2021. *Study on seawater corrosion resistance of epoxy resin-geopolymer composites coating.* Materials reports, Vol. 35 (Z1): pp.600-606.

[8]. Catherine A.Wood et al, 1997, *Determination of the effect of seawater on the interfacial strength of an interlayer E-glass/graphite/epoxy composite by in situ observation of transverse cracking in an environmental SEM*. Composites science and technology. Vol. 57 (8), pp.1033-1043.

[9]. E.P.Gellert, D.M. Turley, 1999. *Seawater immersion ageing of glass-fibre reinforced polymer laminates for marine applications*. Composites Part A: Applied Science and Manufacturing Vol. 30 (11), pp.1259-1265.

[10]. Ho Ngoc Minh et al, 2018. *Fabrication, characterization, and properties of epoxy resins cured by titanium and some amino compounds*. Vietnam Journal of Chemistry, Vol. 56 (3), pp. 401-406.

[11]. Ercan Aydoğmuş, 2022. *Synthesis and characterization of EPS reinforced modified castor oil-based epoxy biocomposite.* Journal of Building Engineering, Vol. 47, https://doi.org/10.1016/j.jobe.2021.103897.

[12]. TCVN 178:1986 *Refractory materials - Method for determination of water absorption volume mass.*

[13]. ASTM D638, *Standard test method for tensile properties of plastics*.

[14]. ASTM D790-10, *Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials*.

[15]. ISO 180:1993, *Plastics - Determination of Izod impact strength*.

[16]. ISO 604:2002, *Plastics - Determination of compressive properties.*

THÔNG TIN TÁC GIẢ

Đỗ Đình Trung[1], Nguyễn Mạnh Tường[2], Nguyễn Ngọc Linh[3], Nguyễn Minh Việt[4]

[1]Viện Độ bền Nhiệt đới, Trung tâm Nhiệt đới Việt - Nga

[2]Viện Hoá học - Vật liệu, Viện Khoa học - Công nghệ quân sự

[3]Khoa Dược, Trường Đại học Thành Đô

[4]Khoa Công nghệ Hoá, Trường Đại học Công nghiệp Hà Nội