

Effect of polymer additives on mechanical properties of high-strength mortar for marine structures

Ảnh hưởng của phụ gia polymer đến một số tính chất cơ học của vữa cường độ cao cho công trình biển

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ABSTRACT

This study evaluates the effect of polymer additives on the mechanical properties of high-strength modified mortar (HPMM), with the aim of using it as a protective layer for reinforced concrete in a marine environment. The research utilized a redispersible polymer powder (RDP) at contents ranging from 1% to 10% and a latex emulsion at a content of 5% by mass of cement, in mortar with a water-to-cement (w/c) ratio of 0.2. The conducted experiments included evaluating the flowability, compressive strength, flexural strength, and corrosion resistance in a saltwater environment (Cl⁻ ions, 3.5% NaCl solution). The results showed that as the RDP content increased from 1% to 10%, the flowability was in the range of 11.0 to 16.0 cm, while the compressive strength varied from 74.67 MPa to 81.78 MPa and the flexural strength ranged from 17.68 MPa to 19.99 MPa, showing no clear trend. The bulk density gradually changed from 2066 kg/m³ to 2238 kg/m³. The HPMM with RDP produced higher compressive and flexural strengths than that with latex. Notably, the polymer-modified mortar layer demonstrated superior protective capabilities, significantly reducing rebar corrosion. The study proposes that polymer-modified mortar is an effective and economical solution for protecting concrete marine structures, contributing to extending the service life of Vietnam's coastal infrastructure.

Keywords: Corrosion protection, high-strength modified mortar, marine structures, mechanical properties, polymer additives.

TÓM TẮT

Nghiên cứu này đánh giá ảnh hưởng của phụ gia polymer đến một số đặc trưng cơ học của vữa biến tính cường độ cao (HPMM), nhằm ứng dụng làm lớp bảo vệ cho bê tông cốt thép trong môi trường biển. Sử dụng polymer dạng khô tái phân tán (Redispersible Polymer Powder - RDP) với hàm lượng từ 1% đến 10% so với khối lượng xi măng và dạng latex với hàm lượng 5% trong vữa có tỷ lệ nước/xi măng (N/X) = 0.2. Các thí nghiệm được thực hiện bao gồm đánh giá độ chảy xè, cường độ nén, cường độ uốn và khả năng chống ăn mòn trong môi trường nước mặn (ion Cl⁻, dung dịch 3.5% NaCl). Kết quả cho thấy, khi tăng hàm lượng RDP từ 1% đến 10%, độ chảy xè của vữa dao động từ 11.0 đến 16.0 cm, trong khi cường độ nén dao động từ 74.67 MPa đến 81.78 MPa và cường độ uốn từ 17.68 MPa đến 19.99 MPa, không có xu hướng biến thiên rõ rệt. Vữa cường độ cao sử dụng RDP đạt cường độ chịu nén và uốn cao hơn hẳn so với sử dụng Latex. Khối lượng thể tích dao động từ 2066 kg/m³ đến 2238 kg/m³. Đặc biệt, lớp vữa biến tính với polymer thể hiện khả năng bảo vệ vượt trội, giảm đáng kể ăn mòn cốt thép nhờ cơ chế lấp đầy mao quản và hình thành màng liên tục, giảm hệ số thấm. Nghiên cứu đề xuất vữa biến tính polymer là giải pháp hiệu quả, kinh tế cho bảo vệ bê tông công trình biển, góp phần nâng cao tuổi thọ hạ tầng ven biển Việt Nam.

Từ khóa: Chống ăn mòn, kết cấu công trình biển, phụ gia polymer, tính chất cơ học, vữa biến tính cường độ cao.

1. INTRODUCTION

With the current development of the economy and the advancement of science and technology, the development and

exploitation of marine resources have become a focus of attention. Bridges and seaports have become a crucial part of driving infrastructure development. However, reinforced concrete

structures frequently operate in an aggressive environment. The corrosion of concrete and steel reinforcement leads to cracking and the destruction of the structure, causing premature damage to the concrete and failing to ensure the service life of the structure. The actual service life and durability of reinforced concrete structures in a marine environment are often lower due to the negative effects of harmful agents from the sea (chloride ions, sulfates, etc.), as well as a lack of regular and timely maintenance measures.

According to Zhang et al. [1], the design service life for coastal reinforced concrete structures is typically 50 years. However, the actual service life of many structures has been significantly reduced in recent years due to harsh operating environments, severe structural corrosion, frequent extreme weather events, and overloading. Traditional concrete, the primary construction material for marine structures, fails to meet the special operational demands of complex marine environments due to its low compressive and tensile strength, poor crack resistance, and insufficient durability [2-8].

According to recent study [9], the addition of polymer materials to cement mortar enhances corrosion resistance, improves durability, and reduces the permeability of the mortar, making it a favorable and economical option for certain applications. Latex polymers, redispersible dry polymers, and water-soluble polymers are different types of polymers used to produce polymer-modified mortar. In addition to improving workability, polymers also increase the mortar's adhesion, toughness, flexural or tensile strength, and chemical resistance. High-strength polymer-modified mortar requires less water than traditional concrete, which helps reduce excess water in the concrete, creating a denser structure and increasing its strength.

Most of the polymer-modified mortars available on the Vietnamese market are primarily supplied for general construction projects, with very few types specifically designed for marine environments that must withstand harsh and complex conditions.

This study aims to solve a current challenging problem by researching and fabricating high-strength modified mortar using polymer additives to serve as a protective layer for concrete in

marine structures. The research examines the effects of Redispersible Polymer Powder (RDP) (1-10% by cement weight) and polymer emulsion (latex) (5% by cement weight).

The influence of each type of additive on flowability, compressive strength, flexural strength, and corrosion resistance was investigated. The findings from this research will provide valuable insights for developing optimal high-strength mortar mixes, which will facilitate their application as a protective layer for marine structures.

2. MATERIALS AND EXPERIMENTAL PROGRAM

Table 1 summarizes the compositions of the High-Performance Modified Mortar (HPMM) samples, which contain varying amounts of Redispersible Polymer Powder (RDP) and Latex emulsion. The letters R and L in the sample names respectively denote HPMM containing RDP and latex emulsion, respectively. The numbers that follow indicate their respective content. For example, R1 signifies high-strength mortar containing 1% RDP by mass of cement. The composition of HPMM was designated adopted from previous studies [10-14].

2.1. Materials

Figure 1 shows the main materials used for the high-strength mortar. PCB40 cement (Hoang Thach) and silica fume (SF90) were used as binders in the high-strength mortar mixture and were sieved to remove any clumps formed during storage. Quartz sand with an average diameter of 0.3 to 0.7 mm was used as the fine aggregate. A superplasticizer was used to reduce the water content and increase the flowability of the HPMM, with the water-to-cement (W/C) ratio controlled at 0.2. Polymer additives, in the form of a RDP and a latex emulsion, were used to improve the mechanical properties and enhance the durability of the high-strength mortar. The polymer additives used are readily available on the Vietnamese market, which helps to optimize the product cost.

Table 1 summarizes the mix design of the HPMM, which was designed based on high-strength concrete in accordance with TCVN 10306-2014 [15].

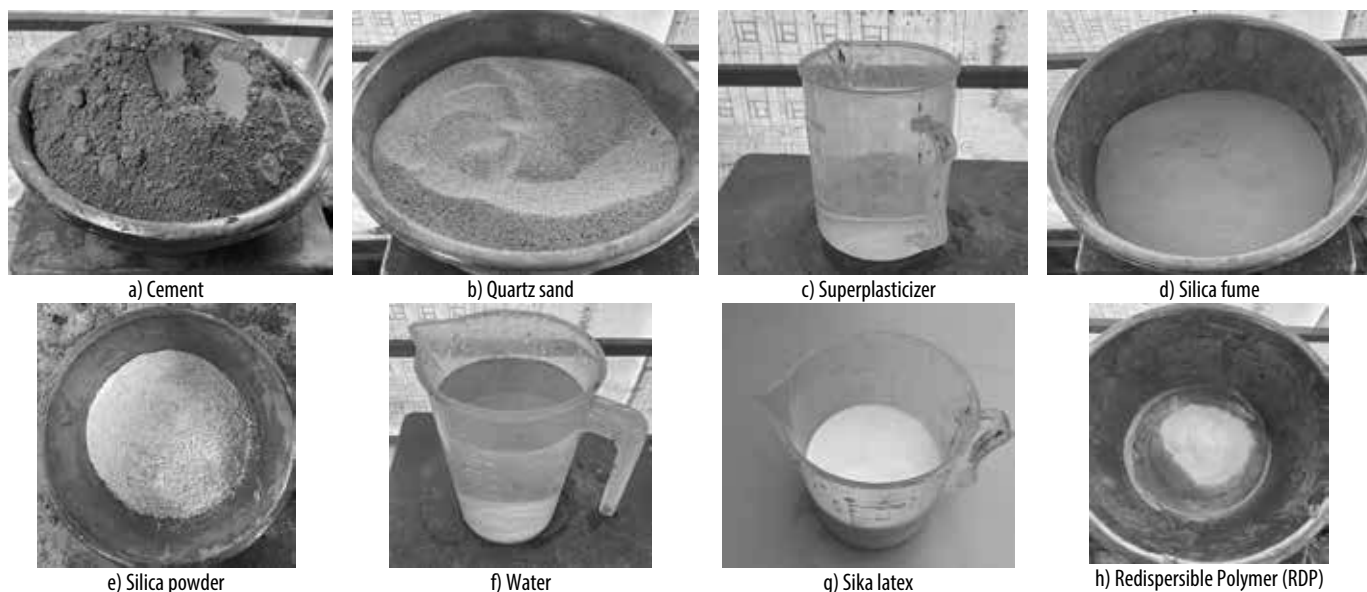


Figure 1. Images of the materials

Table 1. HPMM mix design composition by cement mass ratio

Components	L5	R1	R5	R10
Cement	1	1	1	1
Quartz sand	1	1	1	1
Water	0.2	0.2	0.2	0.2
Superplasticizer	0.04	0.04	0.04	0.04
Silica fume	0.25	0.25	0.25	0.25
RDP (%)	-	1	5	10
Latex (%)	5	-	-	-

2.2. Preparation of Materials

The research team used a 30L mixer to prepare the HPMM samples containing RDP and Latex emulsion. First, cement, silica fume, silica powder, quartz sand, and Redispersible Polymer Powder were mixed for 5 minutes. Then, the superplasticizer and water were gradually added and mixed for another 3 minutes. Next, the Latex emulsion was manually added to the mixture and mixed for an additional 2 minutes. The team then performed a flow test on the fresh mortar mixture. The flow spread was determined using a mini cone with a 50 mm diameter. The procedure was as follows: first, the mortar was placed into the cone and gently tamped until it was full. The cone was then slowly lifted, allowing the mortar to spread on a flat surface until the flow stopped. Finally, the dimensions of the two-way spread were measured with a ruler (as shown in Figure 2a) to calculate the average flow value.

The mixture was then poured into compression molds (50x50x50 mm³) and flexural molds (40x40x160 mm³). All specimens were compacted to remove air bubbles from the surface. They were then arranged in a dry, ventilated area and stored at room temperature for 2 days. After demolding, the samples were labeled and placed in a thermal curing machine for 3 days in hot water (60°C).

To prepare specimens for evaluating corrosion protection, steel reinforcing bar with 16 mm in diameter was embedded in the center of cylinder concrete specimens with diameter of 100 mm and high of 200 mm. The HPMM with 5% RDP was used to generate a cover of specimen with sizes of 150 mm and 200 mm.

2.3. Experimental Setup

The flowability test was conducted in accordance with the Vietnamese standard TCVN 9204:2012 [16]. The resulting flow value was calculated as the average of two orthogonal measurements. Figure 6 illustrates the flow measurement.

Compressive strength and flexural strength were determined using an ADVANTEST 9 system (Controls - Italy) with a 3000 kN load capacity according to the Vietnamese standard TCVN 3121:2022 [17]. The loading rate was precisely controlled at 0.5 MPa/s. The workability of the fresh mix was tested using a mini cone with a diameter of 50 mm and a height of 100 mm. Additionally, the density of HPMM was calculated from the weight of 50x50x50 mm³ samples. The corrosion resistance test of HPMM was performed following the NT Build 356 [18-21]. This evaluation was carried out by immersing standard concrete samples coated with high-strength mortar in water, followed by an assessment of the waterproofing capability of the mortar coating. The experiment was conducted based on the Vietnamese standard TCVN 13599:2022 for polymer-modified mortars [22].

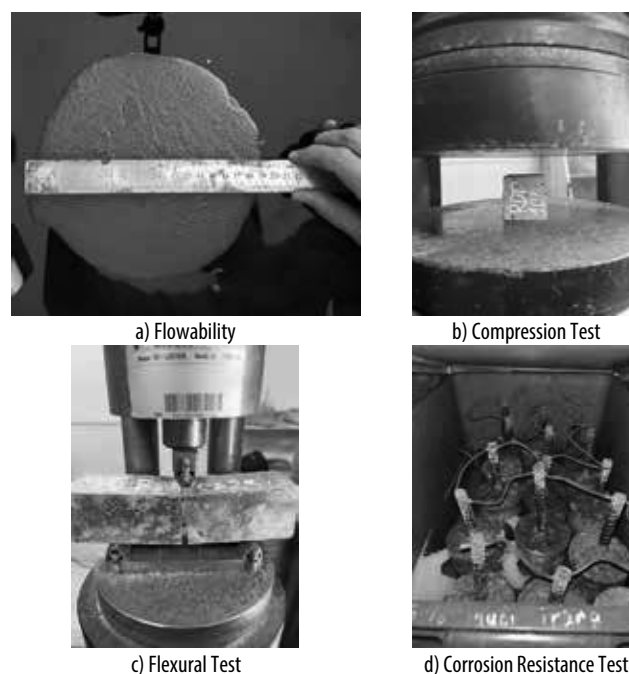


Figure 2. Test setups

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties of HPMM Containing Redispersible Polymer Powder and Latex Emulsion

Table 2 summarizes the values for flow spread, bulk density, compressive strength, and flexural strength for different types of HPMMs containing varying amounts of RDP and Latex emulsion. Figure 3 and Figure 4 show images of HPMM samples with different RDP and Latex emulsion contents under compressive and flexural loads, respectively. Figure 5 illustrates a cross-section of the HPMM containing RDP and Latex emulsion after testing. Figure 6 compares the mechanical properties of HPMM with different RDP contents. Figure 7 compares the mechanical properties of HPMM containing RDP and Latex emulsion.

The change in compressive and flexural strength when the RDP content varies is not clearly defined. Specifically, sample R1 (with 1% RDP content) had a compressive strength of 79.18 MPa and a flexural strength of 17.68 MPa. When the RDP content was increased to 5% in sample R5, the compressive strength decreased to 74.67 MPa, while the flexural strength increased to 19.99 MPa. When the RDP content was further increased to 10%, the compressive strength was 81.78 MPa, and the flexural strength was 18.99 MPa. Thus, increasing the RDP content has no clear effect on the compressive and flexural strengths of the HPMM.

The flow spread was 14.5 cm, 16 cm, and 11 cm for samples R1, R5, and R10, respectively. As the RDP content increased from 1% to 5%, the flow spread increased, but when it was increased from 5% to 10%, the flow spread decreased. This indicates that the effect of increasing RDP content on flow spread is not straightforward. The bulk density of the HPMM samples ranged from 2066 to 2238 kg/m³.

As can be seen in Fig. 7, the HPMM with RDP produced higher compressive and flexural strengths than that with latex. It would be owing to the water in latex solution increased the total amount of water in the matrix composition and consequently increased the pores in the microstructure of the HPMM, as can be seen in Fig. 5.

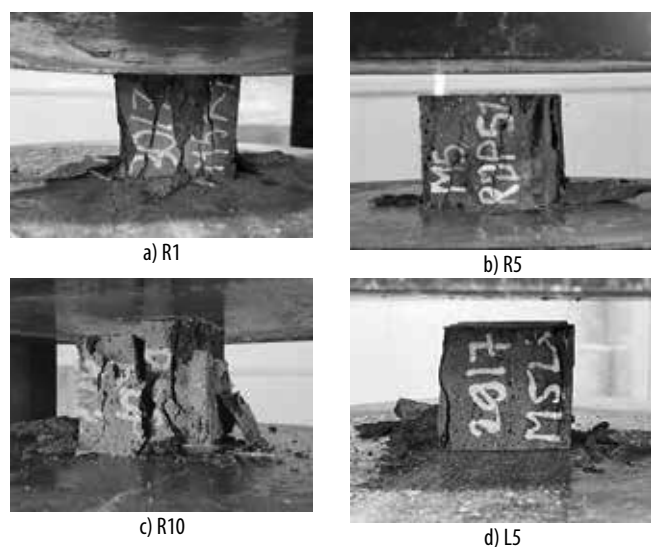


Figure 3. Image of HPMM failure under a compressive load

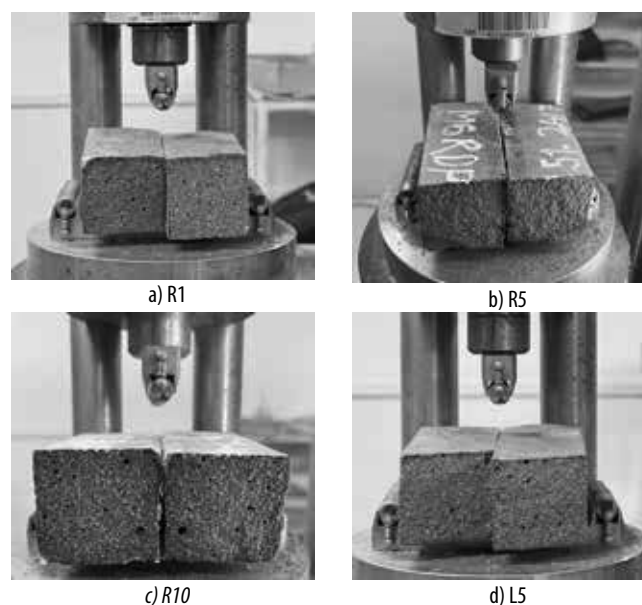


Figure 5. Cross-section of HPMM

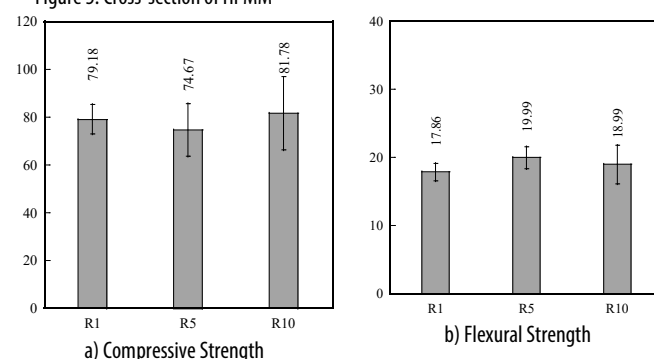


Figure 6. Effect of graphite on the mechanical properties of HPMM

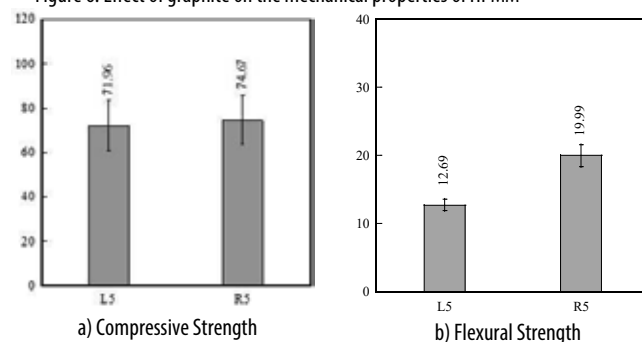


Figure 7. Effect of different polymer types on the mechanical properties of HPMM

Table 2. Mechanical properties of HPMM containing Redispersible Polymer Powder and Latex emulsion

Sample name		Bulk density (kg/m ³)	Flowability (cm)	Compressive strength (MPa)	Flexural strength (MPa)
R1	SP1	2253.6	14.5	79.48	16.88
	SP2	2227.36		73.02	17.4
	SP3	2234.8		85.04	19.31
	Average	2238.59		79.18	17.86
	STD	13.52		4.91	1.28
R5	SP1	2112	16	68.22	21.12
	SP2	2200		87.42	18.86
	SP3	2144		68.38	19.92

	Average	2152.00		74.67	19.99
	STD	44.54		11.04	1.60
R10	SP1	2250.88	11	85.55	16.74
	SP2	2182.88		64.86	22.18
	SP3	2172.72		94.94	18.05
	Average	2202.16		81.78	18.99
	STD	42.50		15.39	2.84
L5	SP1	2031.68	14.5	62.13	11.74
	SP2	2070.96		84.48	13.38
	SP3	2095.84		69.28	12.94
	Average	2066.16		71.96	12.69
	STD	32.3		9.31	0.85

STD: standard deviation.

3.2. Corrosion Resistance of High-Strength Modified Mortar with Different Redispersible Polymer Powder and Latex Emulsion Contents



a) Plain Concrete Sample



b) Sample of concrete coated with high-strength modified mortar



c) Plain concrete sample after the corrosion test in a corrosive environment



d) High-strength mortar-coated concrete sample after the corrosion test in a corrosive environment

Figure 8. HPMM sample testing as a protective layer

Figure 8 illustrates the effect of the high-strength mortar protective layer using polymer additives. Figure 8a shows a regular concrete sample at the beginning, without a protective layer. Figure 8b shows a regular concrete sample wrapped in a layer of high-strength mortar. After the corrosion resistance test, Figure 8c reveals that the steel reinforcement inside the regular concrete sample was noticeably corroded due to the effects of the saltwater environment. In contrast, Figure 8d shows that the sample with the high-strength mortar protective layer exhibited negligible corrosion of the steel reinforcement after the test. This demonstrates the superior corrosion resistance of the high-strength mortar protective layer, which is attributed to the polymer additives. Tran Viet Phuong Dong and Nguyen Ba Phu also indicated that the higher density of mortar produced better corrosion protection [23]. Nguyen Ngoc Tan [24] reported that higher-strength concrete increased the corrosion protection. Due to the polymer molecules disperse in the cement solution and filling the pores and capillaries when mixed into the high-strength mortar. After hardening, the polymer forms a continuous film network within the high-strength mortar, which helps reduce the size and number of capillaries. As a result, the path for penetrating water and ions is elongated and convoluted, thereby reducing the permeability coefficient. Nguyen Thi Diem Thuy et al. [25] reported that the polymer enhanced the permeability resistance owing to the generation of a polymer film. Polymers also have high ductility and elasticity, which increases the plastic deformation and reduces the shrinkage of the concrete. Less cracking means a reduction in the direct pathways for water and ion ingress.

4. CONCLUSION

The study investigated the effect of the content of Redispersible Polymer Powder (RDP) and Latex emulsion on the workability, compressive strength, flexural strength, and corrosion resistance of a high-strength polymer-modified mortar (HPMM) layer. The key findings from the investigation are as follows:

The experimental results show that varying the content of RDP in the range of 1-10% by mass of cement did not produce a clear trend for the mechanical strength of the HPMM. The compressive strength fluctuated between 74.67-81.78 MPa, while the flexural strength ranged from 17.86-19.99 MPa, reflecting a non-uniform variation among the samples. The flow spread of the mixture

increased as the RDP content rose from 1% to 5% but decreased significantly at 10%, indicating a non-linear effect of the polymer additive on the workability of the high-strength modified mortar. The bulk density of HPMM with polymers changed from 2066 to 2238 kg/m³. Based on these results, it can be concluded that, within the investigated range, RDP affects the structure and properties of HPMM through a complex mechanism. It has not yet formed a clear linear relationship with mechanical strength, but does show a tendency to decrease bulk density and alter workability.

The HPMM with RDP produced higher compressive and flexural strength than that with latex.

The experimental results show that the high-strength mortar layer with polymer additives acts as an effective protective layer for plain concrete in a corrosive saltwater environment.

While the plain concrete sample without the protective layer experienced significant rebar corrosion after a period, the sample with the polymer mortar coating showed almost no signs of noticeable corrosion.

Overall, the polymer-modified mortar not only maintains high strength but also enhances long-term durability, making it suitable for the requirements of Vietnamese marine structures.

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Author Contributions: Nguyen Sy Duc prepared the samples, conducted the experiments, and wrote the original draft. Dinh Ngoc Trung prepared the samples, conducted the experiments, and wrote the original draft. Le Huy Viet wrote the original draft and edited the manuscript. Ngo Xuan Hung wrote the original draft, edited the manuscript, and conceptualized and implemented the experiments.

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