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Study on the Contact Angle, Adhesion Strength, and Antibacterial Activity of Polymer/Cement Composites for Waterproof Coating

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Abstract

In the present work, polymeric composites were prepared for coating floors and swimming pools in dark colors. This was achieved through the use of a polymer coating solution added to fine cement with weight percentage (wt%) values of 5, 10, 15, 20, and 25 to obtain dark-colored (gray) composites. Mortar samples were prepared using the adhesion test. The contact angle and adhesion strength were studied for the prepared samples concerning the effect of changing the weight ratio of additive cement on water absorption. Also, the antibacterial activity was tested for the prepared coatings. The results showed that the contact angle increases with increasing the weight ratios of additive cement, which indicates that the prepared coating is not hydrophilic and water-impermeable. Besides, the adhesion was shown to increase with increasing the weight ratio of cement. According to the antibacterial activity analysis, it was found that the highest efficacy for killing Staphylococcus areus was observed at cement ratios of 5 and 15 wt%, whereas no activity was observed against Escherichia coli.

Keywords: polymer coating, waterproof, contact angle, adhesion strength, antibacterial activity.

دراسة زاويه التماس, متانه الالتصاقية والفعالية الضد بكتيرية لطلاء بوليمر–سمنت للاستخدام كعازل للماء

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الخلاصة

تم تحضير متراكبات بوليمرية لغرض طلاء الارضيات والمسابح وبالون الغامق من بوليمر الطلاء مضاف اليها الاسمنت للحصول على طلاء غامق اللون(كالرصاصي) بتركيزات وزنية مختلفة من الاسمنت (25,20,15,10,5,0%). وتم تحضير عينات من الاسمنت لغرض فحص الالتصاقية. دُرست زاوية التماس والالتصاقية للعينات المحضرة ذات النسب الوزنية المختلفة، حيث تم دراسة تأثير تغير النسب الوزنية على قابلية الامتصاص للماء من قبل الطلاء المحضر ومقدار الالتصاقية. واجري فحص الفعالية البكتيرية للطلاء المحضر . أظهرت النتائج بأن زاوية التماس تزداد بزيادة النسب الوزنية للاسمنت وقيم الاسمنت كانت عاليه مما يدل على ان الطلاء المحضر غير محب للماء ولايسمح بنفاذية الماء من خلاله أما فحص الالتصاقية فان مقدار الالتصاقية يزداد بزيادة النسب الوزنية للاسمنت. كما تم اجراء فحص الفعالية البكتيرية ووجد ان الفعالية البكتيرية من قبل عينات الاسمنت لها فعالية مؤثرة على قتل البكتريا خاصة النسبة 5 و15% لنوع بكتريا S.areus في حين لم تبدي اي فعالية ضد البكتيريا من نوع E.coli.

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1- Introduction

Coating systems must be compatible with the surfaces to which they are applied. The incompatible coating could be failing merely following application or after a much longer time. Failures occurring just after application are due to solvent incompatibility or wetting problems [1].

Cement-based components have been used for many decades, and with the increasing advancement of human activities, such materials were modified to develop their applications in modern life [2]. The major work of cement is to act as a hydraulic binder which raises the chain between fragmented grains and thereby can enable their use in various fields [2].

It is well-known that a composite is composed of two or more specific types of materials, which can include metals, ceramics, and polymers. The goal of using composites is to achieve a combination of properties that are not exhibited by only a specific material. Composites are generally explained as the combination of a matrix and an additive, with at least one characteristic that is different from those of the specific components [3]. Within this context, waterproofing materials can be divided into two categories, flexible and rigid. Flexible waterproofing materials such as coils and coatings have the features of flexibility and good durability, but they are poor at adhesion and out of use in the case of wet base surfaces [4]. Rigid cementitious waterproofing materials are widely used because of their superior performance over the flexible waterproofing materials such as acrylic coatings. Notably, rigid cementitious waterproof materials, such as cementitious polymers, are the surface sealing waterproofing agents that work only on the surface [4]. Moisture diffusion in composite materials is thought to eventuate due to three different mechanisms. The first involves the diffusion of water molecules inside the micro gaps between polymer chains. While the second involves capillary transport into the gaps and flaws at the interfaces between the particle and the matrix. Whereas the third proposed mechanism involves the transport of micro-cracks in the matrix arising from the particles [5]. Previous laboratory results demonstrated that the chemical compound coat may certainly lower the shrinking of the concrete area; the thicker the coat, the lower shrinking rate at initial stages is. It was found by a previous study that the compound coating increases the mortar's initial age toughness of the solid space[6]. The study tested the capillary water absorption, impermeability, and cracking of cement mortars modified with three polymers and found that cracking is correlated with waterproof performance. The results showed that, with the increase in polymer content, especially as the polymer/cement ratio increases from 0 % to 5 wt%, the reduction in the capillary water absorption and the penetration depth of water into mortars is becoming more significant [7].

Another study introduced several properties of polymer emulsions-modified cement mortar, where water absorption was found to be decreased, whereas high values of mechanical properties (flexural, compressive, and adhesion strength) were recorded [8].

Epoxy resin coatings are a common way to finish industrial floors. Obtaining coating strength at the level declared by the manufacturer requires preparation of the cement substrate through mechanical treatment. A previous paper presented the results of tests aimed at improving the adhesion between a concrete foundation and an epoxy resin coating modified with waste glass powder. The addition of glass powder was found to improve the adhesion between the epoxy resin coating and the concrete substrate. The highest average peel strength of 3.07 MPa was obtained for one of the tested samples [9].

This work aims to improve water impermeability and adhesion strength of a flexible polymer coating used in the floors and swimming pools by the addition of different weight ratios of cement.

2. Experimental details

2.1 Materials

The polymer solution coating was of A.G.C.C. product manufacture, whereas the cement brand was the ordinary Portland fine cement, also manufactured by A.G.C.C., U.A.E., as shown in Figure- 1. The surface morphology of the cement powder particles was observed using atomic force microscopy (AFM), as shown in Figure- 2, which revealed an average diameter for cement particles of ~64.25 nm.

Figure1-Materials used in the present work; polymer solution (right-hand side) and cement (left-hand side).

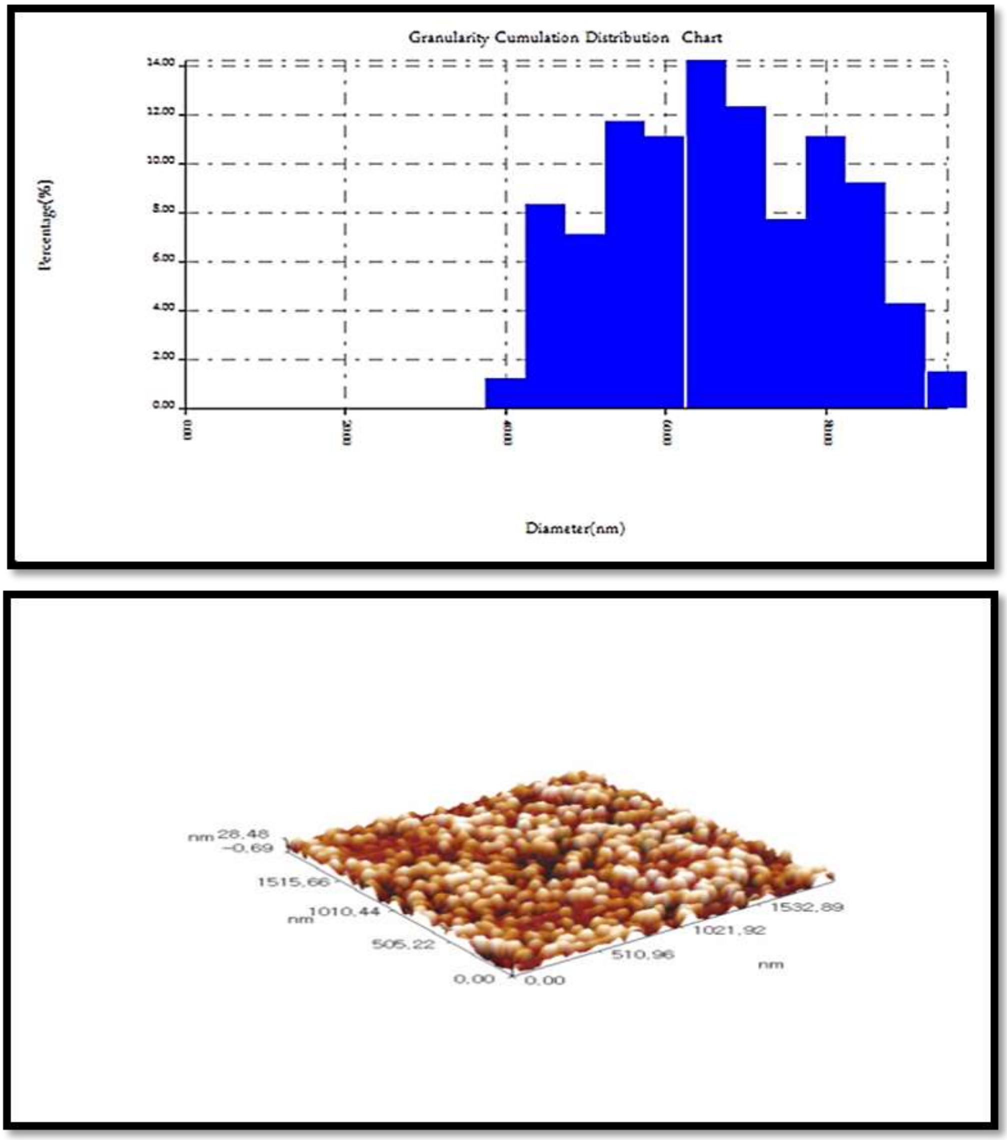

Figure 2-(a) Granularity normal distribution, and **(b)** 3D image for cement nanoparticles used in this work.

2.2 Preparation of samples polymer solution coating and polymer/cement

The solution of polymer was formed with a weight of 100 g using the casting method at room temperature. The solution was left at room temperature for 24 hours to dry. The polymer/cement mixture was prepared with different cement percentages (5, 10, 15, 20, and 25 wt%) being added to the polymer solution. Then the resulting solution was placed in a glass tube on a magnetic stirrer at room temperature for 1 hour. The prepared polymer/cement samples are shown in Figure-3.

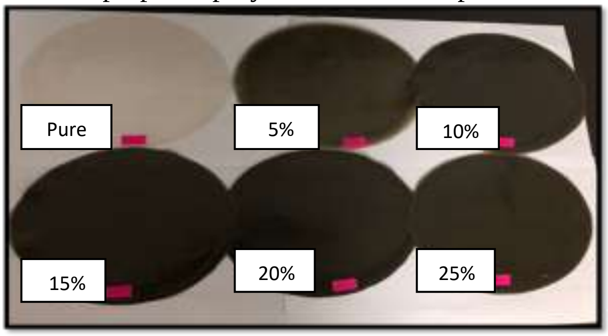

Figure 3-Samples of polymer solution/cement mixture.

2.3 Mortar substrate

The mortar substrate samples were prepared by using cement (Portland) forms with dimensions of 12×8×0.5 cm, with a maximum mixing time for cement and water of 5 min. The samples which were tested using the pull-off adhesion test are shown in Figure-4.

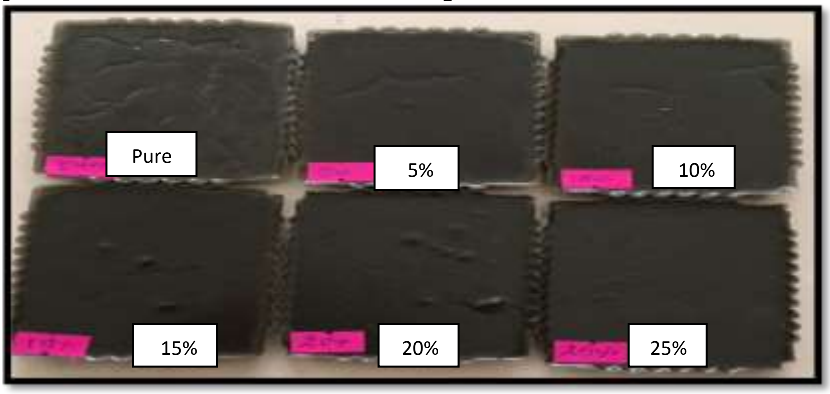

Figure 4-Samples (polymer solution/cement) tested by adhesion pull-off test.

2.4 Contact angle

The contact angle was evaluated with water on square specimens of 1 cm edge. The amount of the sessile dip was controlled to be 5 ml. The contact angle was uniform within 45–60 s of the inclusion of the solvent dip, with an efficiency of +1 and -1.

2.5 Adhesion pull-off test

The compact standard PosiTest pull-off bond tester was applied to test the strength desired to pull a certain diameter of the covering away from its substrate, raising hydraulic power. Types of standard devices are ASTM D4541, D7234, and ISO 4624. The PosiTest calculates the adherence (pull-off strength) of the coating through determining the biggest pull-off strength that it can move before dissociating. Crashing spots, exhibited by fractured areas, results in a forward weakens face within the structure consisting of the dolly, adhesive, glazing sheets and the substrates.

2.6 Evaluation of antibacterial activity

In the calculated antibacterial activity of the specimens, we used the disc diffusion assay with Muller–Hinton agar. Specimen sheets were cut into disc patterns of 6 mm diameter. The discs were put on the bacterial culture and the inhibition zone in millimeters (mm) was measured. The films were observed versus *Escherichia coli* (*E. coli*) and *Staphylococcus aureus* (*S. aureus*) at room temperature (37°C) for 6 hours for pure polymer solution coating in addition to the polymer with different weight ratios of cement.

3- Results and Discussion

3.1 Contact angle

The wetting management of the polymer/cement nanocomposites regarding water has been evaluated. The hydrophobic nature of the composites was found to increase with the addition of fillers. To address this concern, polymer coating with cement nanocomposites in addition to nanofiller concentration with water were investigated. The obtained results (Figure-5) suggest the aversion of the nonionic surface towards a polar liquid of cement with nanofillers. The compound surface provides additional non-polar, *i.e.* hydrophobic surface, and therefore increases the contact angle. The deduced contact angle of the compound coating has values of 70, 76.5, 77.5, 87, 92.5, and 126.8° for the polymer composites with weight ratios of cement of 5, 10, 15, 20, and 25 wt%, respectively. The addition of cement resulted in a nanocomposite characterized by a non-wetting surface. It is thought that fillers and the organic tail of surface treatment relate well with the polymer chain and increase the homogeneity of the system. Thus, the intrinsic properties of nanofillers and theiir effective distribution might explain the non-wettable surface features of the nanocomposites [10].

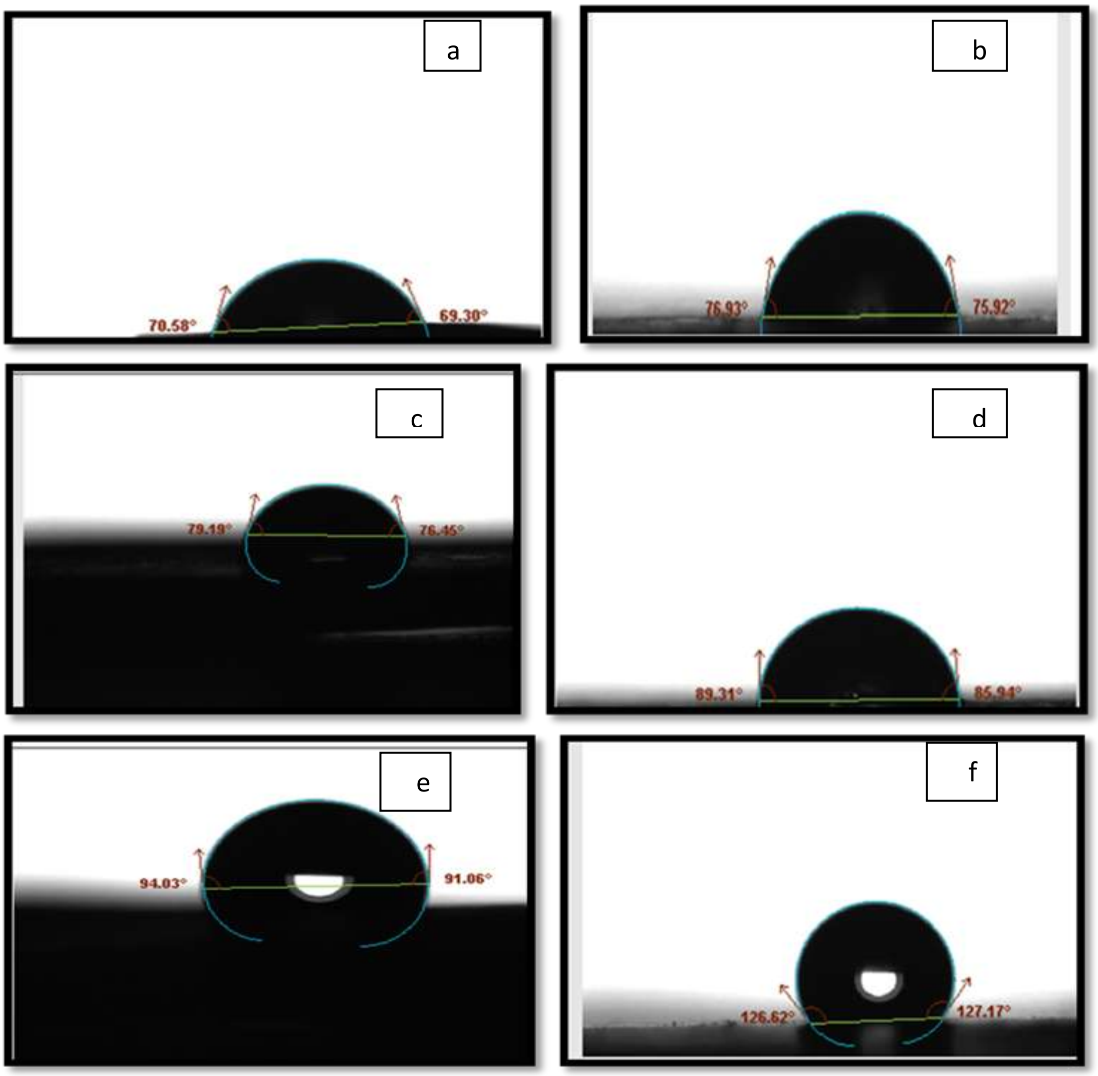

Figure 5-Contact angle for water with (a) polymer solution, (b) 5wt% cement, (c) 10wt% cement, (d) 15wt% cement (e) 20wt% cement, and (f) 25 wt% cement.

3.2 Adhesion pull off strength-

The adhesion between the coating and the substrate below depends on the mechanical properties, chemical structure, and physical characteristics of the coating and the formed interface. The adhesion strength is thought to be profoundly dependent on the chemistry and physics of the interface as well as the tensions inside the film and substrate [11]. Adherence bond strength contains either cohesive failing that relies on film properties or surface failure which is the failure at the interface between the film and substrate. Adhesion is the combination of the unit interactions (ionic, covalent, polar, and van der Waals) between two materials. It is often expressed either in terms of strain or work around the attachment [12]. Polymer solutions have good resistance to a number of chemicals and a higher thermal stability than polyimides. Fillers like cement are usually added to polymers to lower natural shrinking and increase the adhesive strength of the polymer coating composites [13].

Figure-6 displays the relationship between the strength adhesive pull-off and the weight ratio of the added cement. It can be observed that the values of pull-off strength for the polymer coating with cement was higher than that for the polymer coating alone. However, coatings resulted in a pull-off strength that is higher than 13.5 MPa (for the polymer coating), which well agrees with the results obtained by Szymanowski [14]. Polymer coating with cement showed an increased pull-off strength with increasing weight ratio of cement. It is believed that the incorporation of cement particles enables a chemical interaction and generates new chemical bonds that would not be activated with the polymer per se.

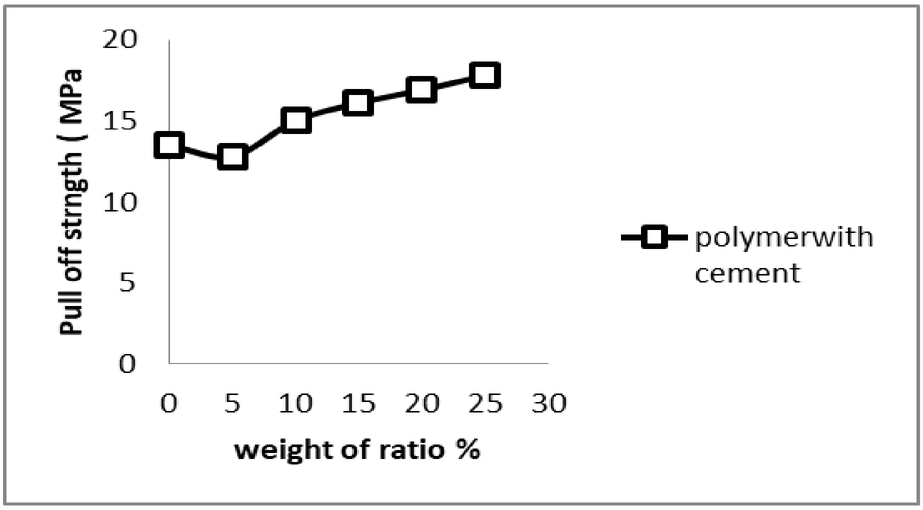

Figure 6- Pull off adhesion strength as a function of polymer coating and different weight ratio of cement .

3.3 Antibacterial activity

Agar dispersion evaluations exhibited that only *S. areus* was inhibited by cement weight ratios of 5 & 15 wt%, as presented in Figure- 7 and Table- 1. This process allows the calculation of the antimicrobial properties of various materials (please refer to Table- 1). The important factors such as the physicochemical properties of the materials should be taken into the account when calculating material components using the agar diffusion test [15]. A fascinating application of antimicrobial nanoparticles and incorporating metals and oxides was found in building materials (especially cement-based composites). However, apart from the known toxicity of nanomaterials, the cement-based composites have limitations associated with the blending and distribution of materials [16].

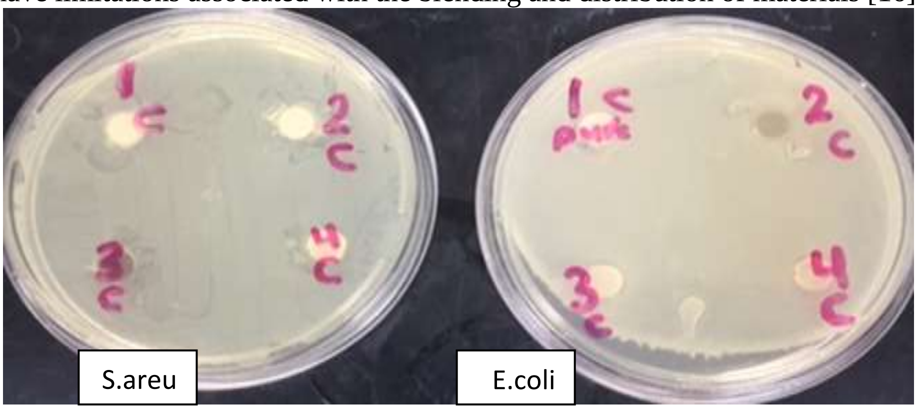

Figure 7- Inhibition zone of polymer coating and polymer with different ratio of cement

Table 1- Inhibition zone values of polymer coating and polymer with different ratio of cement

Samples no.	Samples	S.areus	E.coli
1C	Pure	8	-
2C	5% cement	13	-
3C	10% cement	-	-
4C	15% cement	14	-

5C	20% cement	-	-
6C	25% cement	-	-

4- Conclusions

The following conclusions can be drawn based on the above results.

The contact angle of polymer coating increases from 70° to 126° as the addition of cement increased from 0 to 25 wt%. The non-wetting surface of nanocomposite can be obtained for composites consisting of 25 wt% of cement.

2. Pull-off strength for the polymer coating with cement was greater than that for the polymer coating alone. Besides, the pull-off strength of polymer/cement coating was increased with increasing weight ratio of cement to up to 25 wt%.

3. The results of agar diffusion demonstrated that only *S. areus* species were inhibited by the cement with best results being obtained using cement ratio 15 wt %.

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