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Performance Evaluation of Resin As a Coating Agent

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ABSTRACT

The durability of engineering structures is greatly influenced by adverse and hostile environment. However, this area has received less attention and, even worse, the literature pertaining to the effect of high temperature coupled with environmental/ atmospheric conditions on water absorption and compressive strength is very scarce. With this background, this research aims at evaluating the performance of polyester resin on mortar as a coating material in the local environment. Cubical specimens were fabricated and compressive strength and water absorption tests conducted as performance indicators. The tests were conducted in two different exposure conditions; dipped/ immersed in water and ambient environment. Results were compared with controlled specimens. The test results revealed that the increase in the number of resin layers (from zero to three) significantly reduced water absorption for the two different exposure conditions. The application of resin layers significantly enhanced compressive strength. Furthermore, a first-order multiple linear regression model was developed for water absorption as a function of the number of layers, exposure duration and conditions. Univariate GLM analysis of variance and two-level factorial design were carried out to validate the response of various parameters on water absorption and compressive strength, respectively.

KEYWORDS: Resin, Coating agent, Environment, Strength, Water absorption.

INTRODUCTION

The durability of engineering structures is greatly influenced by adverse and hostile environment. Engineering structures often experience rapid deterioration when exposed to adverse environmental conditions which lead to pre-mature failure. This pre-mature failure endangers the investment cost of construction and motivates researchers across the globe to look into alternative scientific techniques for increasing structural performance. Various advanced techniques and materials have been investigated, such as liquid membrane, polyethylene sheets, bitumen coating, bentonite, fly ash and silica fume, just to mention a few. The performance and efficiency of such materials as additives remained an active area of research in recent years. The motive was to find any material which can be efficient on one hand (be able to sustain extreme and adverse atmospheric conditions) and cost-efficient on the other.

With the paradigm shift in the practical application of various additives, polyester resin has gained global attention for its vast applications and adaptability. Polyester resin (called resin from hereon) remained the subject of various studies, focusing on improving engineering properties of concrete/ mortar. Resin is used in concrete known as resin-concrete. Resin-concrete is a composite material that is well known for its wide applications, such as easy adaptability, maintenance and

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repair of structures. Resin possesses some mechanical properties which increase its viability, such as easiness, fast setting time and water resilience with limited shrinkage (El-Hawary and Abdel-Fattah, 2000). Another type of resin is epoxy resin, which is also commonly used in building and road construction. Epoxy resins are characterized by adhesives and cementing properties. The practical applications of epoxy resin include low shrinkage, improved compressive strength, high setting time and resistance to chemical exposure (Lim et al., 2009; Ahari et al., 2015). However, this research focuses on the use of polyester resin and the evaluation of its performance.

Similar to resin-concrete, resin is also used as an additive to fiber-reinforced polymer (FRP) concrete composed of glass and carbon to investigate compressive strength. This study concluded that the use of resin in combination with carbon yields positive results even under high temperatures (Jung et al., 2015). Resin was used as a soil-cement agent and increased shear strength and stiffness of soil (Estabragh et al., 2010). In another study, polymer concrete (PC) also used resin as one of the constituents which help in increasing the setting time, improving strength and protecting from corrosive atmosphere. These properties increased its viability and potential to replace cement concrete in many areas, such as bridges, buildings, motorways, renovation, sanitation and structural elements (Garas and Vipulanandan, 2003). Resin was used by Anagnostopoulos (2007) to foresee its possible effect on water ingress in sub-structures as foundations.

Various materials and techniques have been used to improve water absorption and compressive strength. A study used paper sludge ash for hydrophobic concrete as water-repelling admixture and determined that replacing Portland cement to 12% by paper sludge ash resulted in a reduction of water ingress, conductivity and sorptivity without any negative effect on mechanical properties of concrete, like hydration, strength and density (Wong et al., 2015). Tegguer (2012) developed a new hydrostatic weighing approach for determining water absorption of aggregates used in various concrete mixes. Experimental test results revealed that good correlation exists between hydrostatic weighing approach and current method per NF EN 1097-6. Chahal et al. (2012) investigated the effect of bacteria in addition with silica fume on properties of concrete, like water absorption and compressive strength. The findings of this study showed that adding bacteria into concrete led to increased compressive strength, as well as to reduction in porosity and permeability. In a parallel study, Siddique (2013) used coal bottom ash in self-compacting concrete (SCC) to determine compressive strength, water absorption, sorptivity, abrasion resistance and permeability of concrete. The results indicated that addition of bottom ash increased abrasion resistance, water absorption and sorptivity of SCC mixes up to a certain level and started decreasing with further addition of ash (Siddique, 2013).

In an experimental study, strength and slump loss of concrete was investigated. It was found out that limestone aggregate can absorb about 3/4 of absorption capacity while being mixed in concrete. However, in concrete, loss of slump was found to be the same for both dry and wet aggregates (Alhozaimy, 2009). Castro et al. (2011) carried out a research study on water absorption of concrete with the main focus on the effect of sample conditioning and summarized that water absorption is largely influenced by sample preparation. Effect of porosity and water absorption on concrete at high temperatures was investigated and results showed that porous and coarser pore size distribution has a noticeable effect on water absorption rate when samples are exposed to higher temperatures (Mendes et al., 2012). De Schutter and Audenaert (2004) evaluated the effect of carbonation and chloride migration on water absorption and reported that water absorption is not a robust parameter to capture the durability of concrete/ mortar. However, disagreement has been found and researchers have reported that water absorption is a reliable parameter for measuring durability of structures (Wirquin et al., 2000).

The available literature suggested that numerous additives and materials are available to improve compressive strength and water absorption. However, these materials are either costly or not feasible for adverse environments, such as humidity, corrosiveness and high temperature (Hall, 1989; Wirquin et al., 2000; Safiuddin et al., 2011; Mohan and Sumathi, 2015; Dhinakaran and Gangava, 2016; Naganathan and Mustapha, 2015). The overall literature is very scarce and an advanced material is needed to fill this gap. Therefore, this research aims to determine the efficacy of resin as a coating agent to improve compressive strength and water absorption without loss of generality.

Research Aims, Objectives and Scope

The main aim of this study is to understand the mechanical properties of resin when applied as a coating agent. This study focuses on the performance evaluation of resin as a coating agent in terms of water absorption and compressive strength when exposed to local ambient environmental conditions for the period up to 75 days. The performance was evaluated by comparing compressive strength and water absorption of resin-coated mortar with controlled condition specimens. One set of specimens were kept in water from one day up to 75 days at room temperature in the laboratory. However, the other set of specimens were exposed to the ambient environment for the same period, where maximum temperature of 50°C was recorded during the study period with rainfall as well. The scope of this study is limited to polyester resin with hardener and cobalt. Ordinary Portland cement (OPC) was used to prepare to mortar of ratio 1:6 and water to cement (W/C) ratio was kept constant at 0.5.

EXPERIMENTAL PLAN

This study uses a two-phase experimental plan to determine the effect/ performance of resin on mortar. The methodology adopted in this study can be seen in Figure 1. The first phase explains the preliminary testing of resin to get the desired pot life, while the second phase of the study is dedicated to performance testing, such as water absorption and compressive strength.

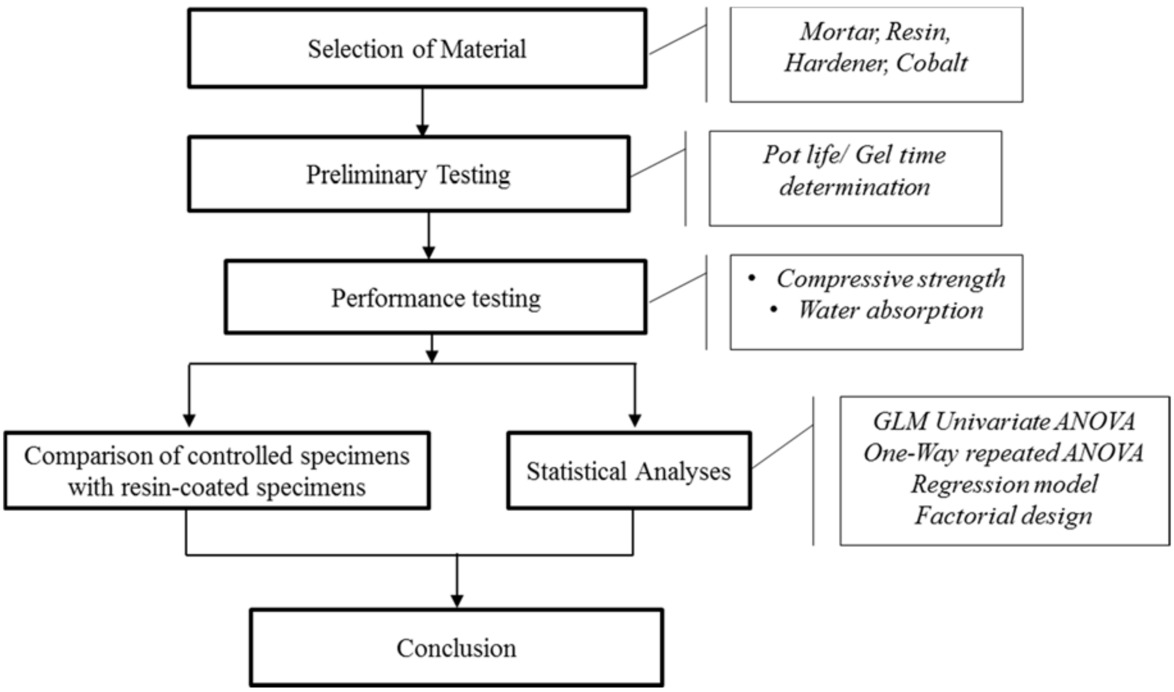

Figure (1): Experimental design of the study

Raw Material

Polyester resin used for this research is a viscous material having glass fiber profile, which is most widely used in composite industry due to its good balance of mechanical, electrical and chemical properties. The polyester resin belongs to the general-purpose resin group having relatively low cost. This type of resin is commonly known as PET (polyethylene terephthalic) and some properties of the polyester resin are described in Table 1.

Table 1. Properties of polyester resin

Property	Value	ASTM Standard
Tensile strength (MPa)	71	D 638
Tensile Modulus (GPa)	3.31	D 638
Elongation, %	2.9	D 638
Flexural Strength (MPa)	122	D 790
Flexural Modulus (GPa)	3.49	D 790
Compressive Strength (MPa)	113	D 695
Viscosity (Pa.s)	1.8	D 4603
Density (kg/m^3)	1975	

The hardening process was initiated by adding cobalt to the resin, which is one of the constituents. Cobalt is the liquid material used for the hardening purpose. The resin to cobalt ratio was kept constant at 1:0.1 by weight (obtained from the preliminary testing program). West system 209 extra slow hardener was used in this study to impart the properties of gel time and plasticity. In order to achieve the desired gel/ pot life of ½ – ¾ hour and final setting time of 24 – 36 hours, the hardener's quantity was adjusted and results are presented in the next sub-section.

For the preparation of mortar, fine aggregate (sand) passing #16 sieve was used in addition with OPC (CEM-I 43.5) by keeping cement to sand (C/S) ratio at 1:6. Note that W/C ratio was kept constant at 0.5.

Preliminary Testing

In the first phase, optimization was carried out by maximizing pot life and solidification and minimizing the hardener quantity. A gel time of 30 minutes and solidification time of 36 hours were selected. The initial time of 30 minutes proved to be sufficient to apply the resin layers on the specimens. Table 2 shows the results obtained from preliminary testing .The proportion selected for this study was 1:0.01, which gave an initial pot/ gel life of 30 minutes, that was required for resin application before solidification.

Test Program

In the second phase, cubes of 50×50×50 mm (L×B×H) were fabricated for performance testing. The performance was evaluated using water absorption (ASTM, 2013) and compressive strength test (ASTM, 2002). The cast specimens were demoulded and immersed in lime-saturated water for curing purpose at a room temperature of 23 ± 2 °C to achieve 28-day strength. Later, the specimens were coated with resin layers from zero to three, where zero layers referred to controlled condition specimens (with no resin layer). Moreover, the specimens were placed to different conditions; 1) Exposure to ambient environment 2) Exposure to water. The specimens placed in the ambient environment are presented in Figure 2, which indicated controlled specimen placed on the right. However, a single layer of resin specimens is on the left. The exposure duration was one day up to 75 days and testing was carried out after an interval of 15 days.

Table 2. Preliminary testing results (Ali et al., 2015b)

S. No.	Proportion (%)	Quantity (mL)		Gel/ Pot life (minutes)
		Resin	Hardener	
01	1:1	05	05	Nil*
02	1: 0.5	10	05	Nil*
03	1: 0.4	03	1.2	Nil*
04	1: 0.3	08	2.4	Nil*
05	1: 0.1	09	0.9	25
06	1: 0.08	08	0.64	26
07	1: 0.05	10	0.5	27
08	1: 0.03	09	0.27	28
09	1: 0.02	10	0.2	28
10	1: 0.01	10	0.1	30

** The resin at these ratios did not harden or form gel or precipitate.*

Figure (2): Specimen placed in ambient environment (left: single layer of resin, right: controlled)

RESULTS

Water Absorption

Water absorption test was conducted as per ASTM Standard (ASTM, 2013). All the fabricated specimens were completely immersed into water and tested after every (15) days up to (75) days. Triplicate specimens were tested for each layer of resin coating. Equation (1) was used to obtain water absorption in percentage.

$$W_a = \frac{W_w - W_d}{W_d} \times 100 \qquad (1)$$

In the above equation:

W_a = Percentage of water absorption.

W_w =Weight of wet specimen (grams).

W_d = Weight of dry specimens (grams).

Figures 3 and 4 show the results obtained from laboratory and calculated using Eq. (1). During the testing period (up to 75 days), the maximum temperature observed to which the specimens were exposed in ambient temperature was as high as 50°C. Note that specimens were exposed to different climatic changes, such as high/ low temperature, rain, dust and wind. The decrease in water absorption (%) is clearly evident from the laboratory results, which suggests the efficacy of resin coating. The increase in number of resin layers tends to significantly decrease water absorption even after exposure up to 75 days (Figure 3). The results of one-day exposure to ambient environment showed that water absorption dropped down to 0.96% from 2.9% on average, when three layers of resin were applied. The continuous exposure to environment deteriorates the resin coating, albeit, resin showed outstanding performance in decreasing water absorption when three layers of resin were applied.

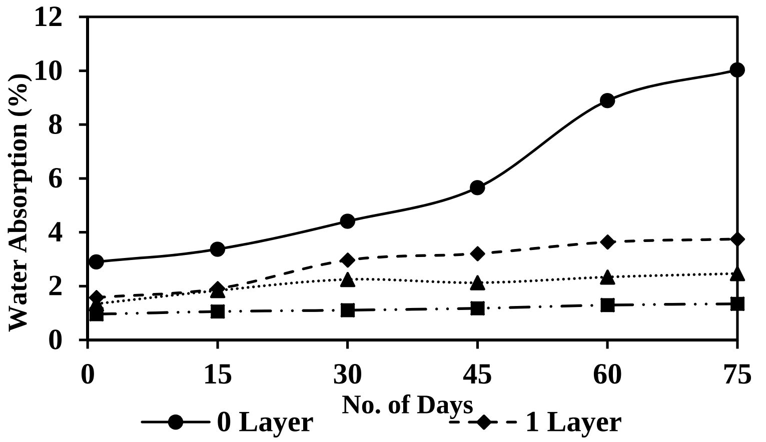

Figure (3): Average water absorption (%) - ambient environment

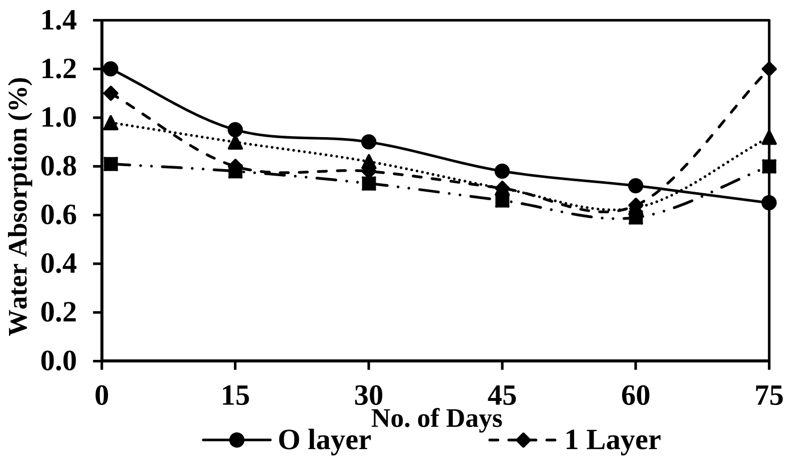

Figure (4): Average water absorption (%) - dipped in water

Another set of specimens were dipped/ immersed in water for the same duration of time and results indicated that water absorption decreases from 1.2% (controlled) to 0.8% (three resin layers). It can be inferred from Figure 4 that water absorption tends to decline for controlled specimens during the study period, which suggests that with continuous exposure to water, all air voids are filled and water absorption practically decreases. However, in the case of resin coating, water absorption is relatively low, decreasing up to 60 days and increasing afterwards. The reason of increase in water absorption after 60 days could be the diminishing of resin layers continuously exposed to water, leading to exposing the external surface of the specimen to water, causing water absorption to increase.

Compressive Strength Test

ASTM standard was used to determine compressive strength in the laboratory (ASTM, 2002). Figures 5 and 6 show the results of compressive strength, which imply that the performance of resin-coated mortar is significantly improved. Intuitively, compressive strength was found to be directly related to number of resin layers. The maximum and minimum compressive strengths recorded for the ambient environment (refer to Figure 5) were 17.41 MPa (3 resin layers) and 8.67 MPa (controlled), respectively. However, in the case of exposure to water (see Figure 6), 15.21 MPa (3 resin layers) and 7.10 MPa (controlled) were measured as maximum and minimum compressive strength, respectively.

Close inspection of compressive strength results reveals that the increase in the number of resin coating layers had a significant impact on compressive strength. On average, compressive strength for resin coated specimens is 69% higher than in controlled specimens for the same exposure, condition and duration. However, this increase is observed up to 60-day exposure, because compressive strength tends to decline when tested after 75 days. The initial increase in compressive strength can be referred or simulated to wax curing technique, in which wax is applied as a sealant to improve compressive strength. A similar effect was observed in resin coating, as resin layers limit water evaporation, which resulted in prolonged and continuous curing, thereby significantly improving strength. Conversely, continuous exposure disposed of resin layers, leading to a reduction in compressive strength for both exposure conditions and the reason could be diminishing of resin layers, which provided additional strength to mortar.

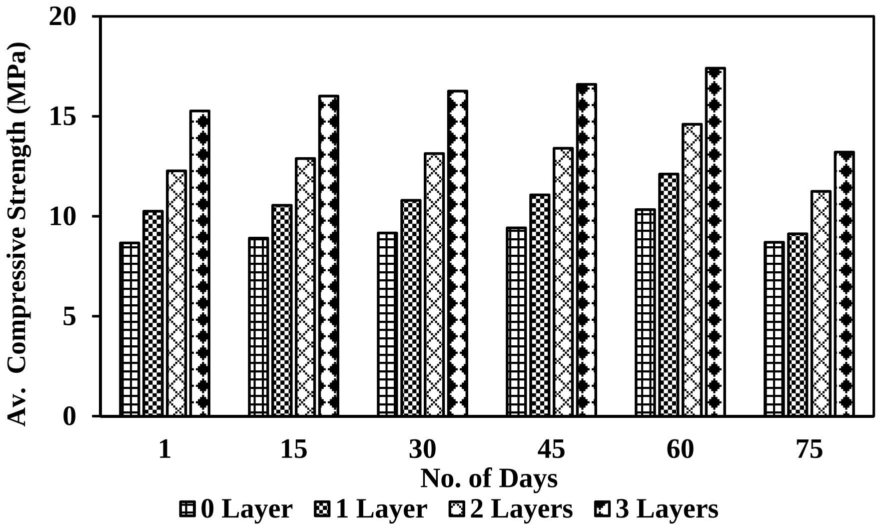

Figure (5): Average compressive strength (MPa) of mortar – ambient environment

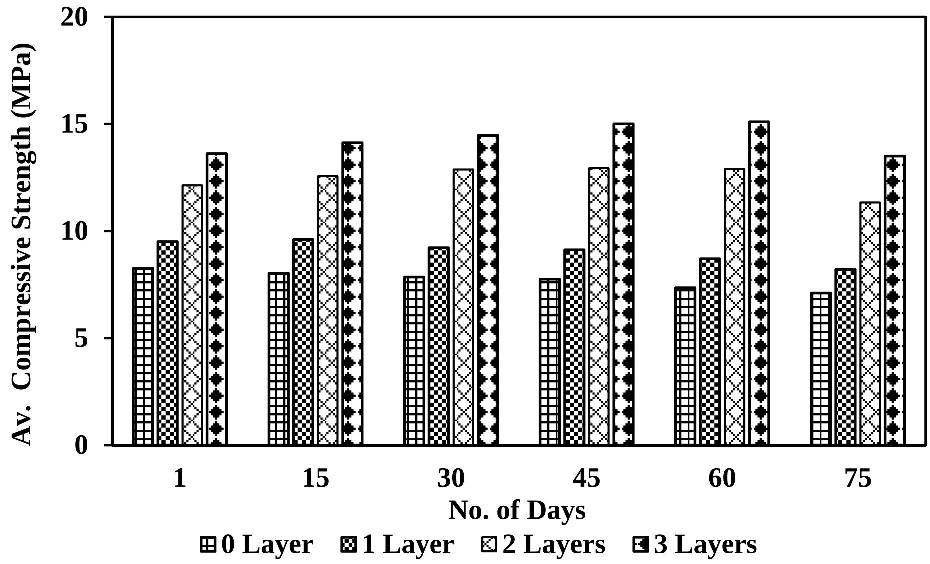

Figure (6): Average compressive strength (MPa) of mortar – dipped in water

Statistical Analysis

The laboratory test results were further employed to statistical analysis in order to confirm the efficacy of resin in improving water absorption and compressive strength.

Water Absorption

The laboratory test results reveal that resin is a useful material for reducing water ingress in mortar specimens even when exposed to two different conditions (environment and water) and yields more positive results when the number of layers is increased. One-way repeated analysis of variance (ANOVA) was conducted to confirm and validate the laboratory results of resin coating on water absorption. One-way ANOVA results suggested that three resin layers had the highest effect (F= 26.84, p-value < 0.001), followed by two layers (F= 20.52, p-value = 0.001), then by a single layer (F=16.44, p-value=0.002).

It can be concluded that the increase in resin layers (from 0 to 3) translated into 48 % and 97% reduction in water absorption on average for the two different exposure conditions (water and ambient environment), respectively. The effect of resin coating layers gradually decreases with the passage of time when exposed to water for a long duration and under different atmospheric conditions, like high and low temperatures, humidity and rainfall, which leads to an increase in water absorption after 75 days, as resin coating was deteriorating at a rapid pace. This aspect may need further investigation.

Laboratory test results were further assessed using SPSS statistical software package to determine the effectiveness and efficiency of resin coating on water absorption. A univariate GLM analysis of variance of measured water absorption is used to examine the effect of various layers and other parameters. ANOVA presented in Table 3 revealed that the effect of number of layers (as a whole) on water absorption is significant (F = 205, p-value < 0.001) at 95% confidence level, which refers to efficacy of resin in reducing water ingress to mortar specimens. Also, the exposure duration and conditions have a prominent effect on water absorption capacity of resin as illustrated by ANOVA in Table 3.

Table 3. Results of univariate GLM analysis of variance

Source	Type III Sum of Squares	df	Mean Square	*F*	Sig.
Corrected Model	887.65[a]	15	59.18	194.56	0.000
Intercept	934.22	1	934.22	3071.47	0.000
Layers	187.21	3	62.404	205.17	0.000
Exp. Duration	224.99	1	224.99	739.7	0.000
Exp. Conditions	261.71	1	261.71	860.43	0.000
Error	9.733	32	0.304		
Total	897.388				

[a]*R- squared = 0.923 (adjusted R-squared = 0.797).*

Table 4. Model estimation results

Variable	Coefficient	*t*-statistics	p-values
Constant	-3.84	-1.98	0.02
Layers	-2.52	-5.12	<0.001
Exposure Duration	0.63	5.44	<0.001
Exposure Conditions	4.15	6.10	<0.001
R^2	0.78		
Adjusted R^2	0.75		
Number of Observations	96		
MAPE	0.10		

Furthermore, the test results were employed to develop a first-order multiple regression model to express water absorption as a function of number of layers, exposure duration and conditions. The generalized form of the first-order multiple regression is presented in Equation 2 (Ali et al., 2016; Ali et al., 2015a).

$$y\,(i) = \beta_0 + \sum_{i=1}^{j} (\beta_i x_{i)} + \varepsilon_i \qquad (2)$$

where:

y (i) = water absorption (%).

β's = Model coefficients.

x_i = Independent variables considered in this study are number of layers (from 0 to 3), exposure duration (1 to 75 days) and exposure conditions are dipped/ immersed in water and exposed to ambient environment.

ε's = Error terms.

The summary of first-order multiple regression model is shown in Table 4. The coefficient of determination (R^2) of 0.78 suggested that about 78% of the variation in water absorption is being explained by a change in corresponding independent variables. The presented model shows that all variables; i.e., number of layers, exposure duration and exposure conditions have a significant impact on water absorption. The model also revealed that layers are negatively associated with water absorption (correlation coefficient (*r*) = -0.394). The predictive capability of the model was tested by calculating mean absolute percentage error (MAPE) which measures the relative error expressed in percentage. In order to validate the preciseness of the model, MAPE is used, which is described in Equation (3).

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}|\text{PE}_i| \quad (3)$$

where:

$PE_i = 100 \times (X_i - P_i) / X_i$ is the percentage error for observation *i* of actual X_i and predicted P_i.

X_i = Actual/ observed value, P_i = Predicted value.

The MAPE value indicates the underestimation or overestimation of the model. The predictive capability of the model is defined by the lower value of MAPE and *vice versa*. For the developed model, MAPE value is 0.10, which suggests that the model is reasonably good in predicting laboratory results. The model validation is shown in Figure 7. Closer values to line-of-equality (45º degree line) referred to high predictive capability.

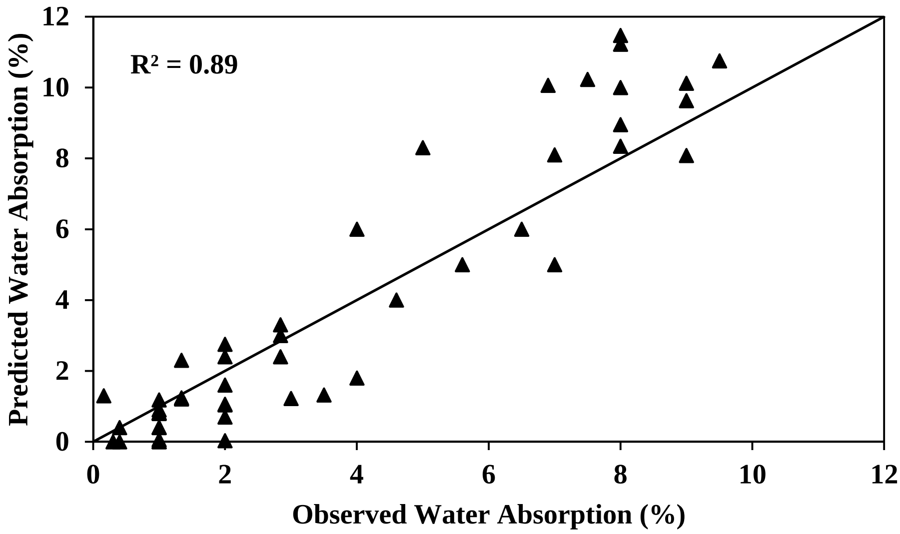

Figure (7): Comparison of actual *versus* predicted water absorption

Table 5. Factors for two-level factorial analysis

Factors	Abb.	Low Level	High Level
Layers	A	0	3
Exposure Duration	B	1	75
Exposure Conditions	C	Ambient (coded as 1)	Water (coded as 2)

Compressive Strength

Data obtained from compressive strength test were subjected to two-level factorial design of the experiment. Each factor considered in this experiment is specified by two levels; i.e., high and low. The factors, abbreviations and their levels considered for factorial design are presented in Table 5. It should be noted that exposure conditions are a categorical variable, which is coded into a numerical variable, so that the experiment can be performed. The main effect is the difference in the mean response between the low and high levels of a factor, while interaction effect is the mean difference between effects of one factor at the highest values of other factor; i.e., high and low level.

This experiment assumes 95% confidence level (significance level, $\alpha = 0.05$). The arithmetic sign (either positive or negative) associated with the effect shows the direct and indirect relation of factors with compressive strength, while the magnitude of effect shows the strength of effect (Table 6). The effect significance or otherwise can be assessed by *p*-value less than or greater than $\alpha = 0.05$, respectively. All the main effects are statistically significant at the given significance level, whereas two-way and three-way interactions were notified as insignificant by higher *p*-values.

Table 6. Main and interaction effects of compressive strength

One factor			Two Factors			Three factors		
Main Factors	**Effects**	**p-value**	**Interaction**	**Effects**	**p-value**	**Interaction**	**Effects**	**p-value**
A	6.29	0	A*B	-0.268	0.653	A*B*C	0.386	0.518
B	-4.31	0	A*C	0.323	0.43			
C	-0.89	0.005	B*C	-0.152	0.732			

CONCLUSIONS

This study utilizes polyester resin to investigate its efficacy in terms of water absorption and compressive strength. The laboratory results are promising and indicated a drastic decrease in water absorption when resin layers are applied. The developed model suggested that number of resin layers is inversely related to water absorption. The maximum decrease in water absorption was recorded as 0.8% for three layers of resin coating and exposure to ambient environment. The layers of resin coating started to diminish for the specimens exposed to water for 75 days. 60-day exposure was found to be the optimal exposure duration for three layers of resin coating. The resin-coated mortar also showed improved compressive strength up to 69% in contrast to controlled specimens for the same exposure conditions and duration. However, a decrease in compressive strength was observed when tested after 75 days. The test results evaluated using GLM univariate ANOVA advocated the significance of number of layers, exposure duration and conditions in terms of water absorption. Keeping this as a base, a first-order multiple regression model was developed to express water absorption as a function of number of layers, exposure duration and conditions. It is envisaged that the findings of this study would be useful for preserving structures from adverse environmental conditions and improving their performance. This study has lain the foundation for further research on the applicability of resin as a sealant in various infrastructures, like sewers, water tanks and many other water retaining structures and its effect on the curing process.

Acknowledgments

The authors of this research study gratefully acknowledge the contribution of laboratory technical staff for preparation of samples for testing. This research is completely a reflection of the authors' view for this scope and they are fully responsible for data accuracy,

facts and results presented. This article is merely an investigation report for use of polyester resin for checking its effect on performance properties and should not be established as a standard, specification or regulation.

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