EFFECT OF POLYMER/CEMENT RATIO AND CURING REGIME ON POLYMER MODIFIED MORTAR PROPERTIES

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ABSTRACT

Cement is the most consumed building material in the world. However, cement manufacture is responsible for 5–7% of the world CO_2 emissions. In this paper, cement was partially replaced by styrene-butadiene rubber (SBR) polymeric latex in order to reduce cement consumption. Besides, effects of SBR addition on the strength and physical properties of plain mortar exposed to three different curing regimes are presented. Three different curing regimes were applied to the 40 × 40 × 160 mm prismatic mortar specimens: (I): Specimens were cured in water until the test age (CW), (II): after demoulding, specimens were immersed in water for 2 days and kept in ambient temperature until the time of the test (2DWA) and (III) involved 2 days of water curing followed by 1 day in an oven at 50°C and subsequentely placing in ambient temperature until the test time (2W1OA). Results showed that combining 2 days of water curing followed by ambient temperature curing (2DWA) along with 3% SBR polymer content showed good performance in terms of compressive strength, water absorption and void content. Moreover, a good performance in terms of flexural strength was observed by combining 2W1OA curing regime with 2% SBR content. However, the detrimental effect of water curing regime (CW) in terms of compressive and flexural strength was also observed with the increase of SBR ratio.

KEYWORDS

SBR, CO_2 emissions, curing regime, strength

1. INTRODUCTION

Portland cement has been used as a binder in concrete production for a long time. However, with the production of ordinary Portland cement, 5% of the natural resources used in this production are consumed and this production constitutes 5–7% of total global CO_2 emissions, resulting in many environmental problems [1,2]. The amount of CO_2 released during cement production will decrease as cement consumption decreases due to the partial use of polymer instead of cement. Thus, environmental pollution arising from cement production will be prevented and greenhouse gas emissions reduced.

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Polymer based admixtures such as latexes, redispersible polymer powders, water-soluble polymers, liquid resins and monomers have been widely used in engineering construction to overcome the brittleness and durability deficiencies of mortar and concrete [3–6]. Due to application easiness, latexes are commonly used among these admixtures [4]. Latexes are widely used to improve adhesion and bond properties of cementitious-based repair materials to various substrates [7,8]. Depending on the type of monomers and polymers used in the manufacture of polymeric latex, several latex types such as acrylic ester homopolymers (PAE), styrene-butadiene copolymers (SBR), styrene-acrylic (SA), vinyl acetate copolymers (VAC) and vinyl acetate hopolymers (PVAC) have been used [9–12]. Among these latexes, SBR and acrylic latex (SA and PA) are the most frequently used recently [5,13,14]. Latexes such as styrene-butadiene rubber (SBR) are produced by emulsion polymerization and consist of very small (0.05–5μm in diameter) polymer particles dispersed and stabilized in water by surfactants [3]. The incorporation of polymeric latexes in cementitious-based materials such as concrete or mortar results in polymer-modified mortar or concrete and this type of concrete or mortar are widely used in civil engineering applications including deck coverings, floors and pavements, precast products and repair due to their excellent strength, durability and weather resistance [15,16]. Generally, noticeable improvement in transport properties [17], adhesion, flexural and tensile strengths with increased polymer/cement ratio is observed in polymer-modified mortar and concrete, whereas in compressive strength, a limited increase is observed when compared to normal mortar and concrete [7,18]. Doğan and Bideci [19] conducted an extensive experimental study to investigate the effect of SBR latex on high strength concrete's fresh and hardened properties. They reported that the addition of SBR latex improved the workability but decreased the unit weight of the fresh concrete. It was also determined that the SBR addition significantly decreased the water absorption ratio (40–49% decrease in water absorption for polymer-modified high strength concrete at 1–8% polymer/cement ratio); the maximum value of compressive strength was obtained from samples with 1%SBR addition whereas the maximum value of splitting tensile strength was obtained from samples with 8%SBR addition. Many researchers have noticed the durability benefits of SBR latex addition due to enhanced impermeability properties such as low chloride ion penetration and carbonation depths, water absorption and sorptivity as well as better acid, sulphate, abrasion and freezing/thawing resistances compared to unmodified concrete [20–26].

In ordinary concrete or mortar, after mixing, the placing and finishing process generally has a long curing period under 100% relative humidity to enhance the cement hydration which is essential to strength development, microstructure development and to control the early volume change [27,28]. On the other hand, polymer-modified concrete or mortar needs a few days of moist curing to ensure polymer film network formation. The formed polymer film surrounds the cement paste and retains the water inside the matrix for continued cement hydration [3,29]. The curing regime widely affects the short and long-term properties of unmodified concrete and mortar as well as polymer modified mortar and concrete. In the study conducted by Ramli and Tabassi [30], they reported that the addition of 15% of polymer latex improved the impermeability of ordinary cement mortar by about 4–5 times over that of the unmodified mortar. Besides, the cyclic water and air curing regime was found to be benefic to polymer modified mortar, unlike for the control cement mortar in which the prolonged water curing was the most benefic.

Although strength and physical properties of mortar and concrete modified by polymer were investigated by many researchers, there is a lack of knowledge about the optimum polymer/

cement ratio and the appropriate curing regime of mortar incorporating SBR latex. The present study aims to evaluate the influence of SBR-based latex, not only as an additive to reduce the mixing water but also as a Portland cement substitute, on fresh and hardened properties of polymer-modified mortar mixtures and also to assess the combining effect of polymer/cement ratio (P/C) and curing regime on the strength and physical properties of PMM.

2. EXPERIMENTAL STUDY

2.1 Materials

In this study, an ordinary Portland cement CEM I 42.5R type cement conforming to EN 197-1 [31] standard with a specific gravity of 3.15 and Blaine surface area of 3677 cm^2/g was used as the main binder for all PMM mixtures. Crushed limestone aggregate were used as fine aggregate. The specific gravity of crushed limestone aggregate was determined to be 2.66 in the saturated surface dry state, and its water absorption capacity was determined as 0.93%. The specific gravity and water absorption of limestone aggregate was performed according to ASTM C 128-15 [32]. The fineness modulus of used sand was 2.41. Styrene-butadiene rubber (SBR) polymeric latex emulsion was used to enhance the mechanical and physical properties of mortar at fresh and hardened states. The physical and chemical properties of SBR latex are given in Table 1. Polycarboxylic ether-based high range water reducing (HRWR) admixture with a specific gravity range of 1.069–1.109 was used. This admixture conforms to ASTM C 494 [33] Type F and can be used up to 1.5% of cement mass.

2.2 Test procedures

The mix proportioning was done according to guidelines given in EN 196-1 [34] standard and cement/fine aggregate ratio (by weight) was kept constant as 1/3 for all mixtures. SBR latex emulsion was added to cement mortar mixtures at four different dosages (1%, 2%, 3% and 5% by weight of cement respectively). Five polymer modified mortar mix proportions were designed as shown in Table 2. The water/cement (W/C) ratio was kept constant as 0.50. For

TABLE 1. Physical and chemical properties of SBR used in this study.

Physical and chemical properties	
Physical state	Liquid
Colour	White (Milk-like)
Polymer type	Styrene–Butadiene
Solid content (% by weight)	47.0±1
pH value	8.5–9.5
Viscosity of emulsion (mPa.s) (Brookfield RV 1/10 at 20°C)	<300
Density	1.02
Initial boiling point (C)	Like water
Emulsifier type	Anionic/non-ionic
Vapour pressure	Like water

TABLE 2. SBR-modified mortar mixture design.

Type of mix	Cement (kg/m³)	SBR* (kg/m³)	Sand (kg/m³)	Water (kg/m³)	SP** (kg/m³)	Slump (mm)
SBR0	532	0	1597	266	0	175
SBR1	525	5.3	1597	262	4.12	170
SBR2	518	10.56	1597	258	4.93	180
SBR3	510	15.78	1597	255	5.38	180
SBR5	497	26.16	1597	248	5.81	175

*Styrene-butadiene rubber **Superplasticiser

that reason, the solid content of latex emulsion was taken into account in order to calculate the mixing water content of each polymer modified mortar. Polymer modified mortar mixtures including control mixture (0SBR) have been prepared with the help of a laboratory type mortar mixer. Superplasticiser (SP) admixture has been used to have the flow value of the SBR-modified mortar similar to that of the reference mortar (170 ± 10 mm). The flow value was determined according to ASTM C1437-15 [35].

The following procedure has been used to prepare mortar mixtures: first, cement and sand were dry mixed for 1 minute. Second, two thirds of mixing water and SBR latex emulsion were added to the dry mix and the mixing was continued for another minute. Third, the remaining water and SP are then added and the mixing procedure was continued up to 5 minutes to reach homegenous mixing. After the mixing process, $40 \times 40 \times 160$ mm^3 prismatic specimens were prepared by filling the mould with mortar and vibrated using a vibrating machine. The $40 \times 40 \times 160$ mm^3 sized prismatic specimens were kept in moulds at ambient temperature for hardening before being removed from the moulds. Three different curing regimes were applied to the demoulded specimens: (I): Specimens were cured in water until the test age (CW), (II): after demoulding, specimens were immersed in water for 2 days and kept in ambient temperature until the time of the test (2DWA) and (III) involved 2 days of water curing followed by 1 day in an oven at 50°C and subsequentely placing in ambient temperature until the test time (2W1OA). Standard bending and compression tests of SBR-modified mortars were performed on $40 \times 40 \times 160$ mm^3 specimens according to EN 196-1 [34]. The tests were conduceted at the age of 28 days. Density, porosity accessible to water and water absorption ratio tests of the specimens were applied on $40 \times 40 \times 160$ mm^3 prismatic specimens in accordance with TS EN 12390-7 [36] and ASTM C 642-13 [37] standards, respectively at the age of 28 days.

The following equations ([1] and [2]) were used for the calculations of the water absorption ratio and porosity accessible to water:

$$\text{Water absorption } (\%) = \frac{M_{air} - M_{dry}}{M_{dry}} 100 \qquad [1]$$

$$\text{Porosity accessible to water } (\%) = \frac{M_{air} - M_{dry}}{M_{air} - M_{water}} 100 \qquad [2]$$

Where M_{air}, M_{dry} and M_{water} are the mass of saturated sample weighed in air, the mass of oven dried sample and the mass of saturated sample weighed in water, respectively.

3. TEST RESULTS AND DISCUSSION

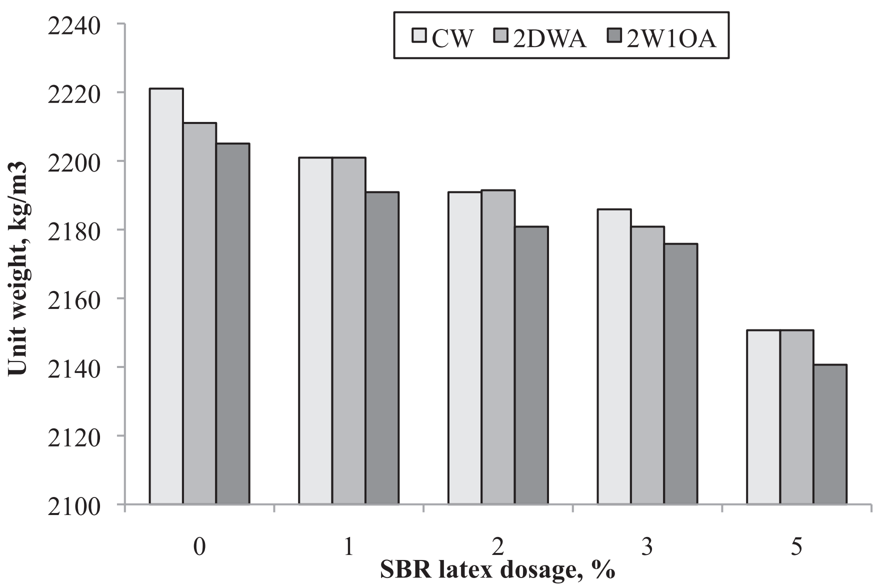
3.1 Unit weight

The 28-days unit weight results of SBR-latex modified cement mortars with increasing latex dosage under different curing conditions are plotted in Figure 1. Each presented result is the average of three tests on mortar samples. It can be observed that the unit weight results of produced mortar mixtures vary between 2151 kg/m^3 and 2221kg/m^3 for specimens continuously cured in water, 2151 kg/m^3 and 2211 kg/m^3 for specimens cured 2 days in water and kept in ambient temperature until the time of the test, 2141 kg/m^3 and 2205 kg/m^3 for specimens cured 2 days in water followed by 1 day in an oven at 50°C and subsequentely placed in ambient temperature until the test time. By comparing the unit weights of SBR-modified mortar samples with the reference mortar (SBR0), a decrease of 0.9%, 1.36%, 1.58%, 3.17% for samples cured in CW regime, 0.46%, 0.89%, 1.37%, 2.73% for samples cured in 2DWA condition and 0.64%, 1.10%, 1.32%, 2.92% for samples cured in 2W1OA regime with the increase of SBR amount. The decrease of the unit weights of SBR-modified mortars were attributed to the lower specific gravity of SBR-latex compared to that of cement. The curing condition did not remarkably affect the density of the SBR-modified mortars.

3.2 Flexural tensile strength

The results of the 28-days flexural tensile strength of reference and SBR-modified mortars as a function of polymer content and curing regime are presented in Figure 2. These results are the average of three tests on 40 × 40 × 160 mm^3 prismatic specimens. It can be stated that the flexural tensile strengths of all SBR-modified mortar increased with SBR dosage up to 3%SBR

FIGURE 1. Unit weight of SBR-modified mortars under different curing conditions.



and decreased slightly for specimens cured in 2DWA and 2W1OA conditions. A decrease of flexural tensile strength with the increase of SBR dosage was also observed for specimens kept permenently in water. This implies that the beneficial effect of SBR-latex on flexural strength is more pronounced for mixed curing than continously water curing. By analysing the flexural tensile strength results, it can be observed that for samples cured in CW condition, the maximum value was obtained from control (SBR0), sample (7.9 MPa) and the minimum value was obtained from SBR5 sample (6.1 MPa). For samples cured in 2DWA and 2W1OA conditions, the maximum values were obtained from SBR3 samples (9.5 MPa) and SBR2 samples (9.8 MPa) while the minimum values were obtained from SBR0 samples (7.4 MPa) and SBR0 samples (7.6 MPa), respectively. When compared with reference samples (SBR0), a decrease of 5%, 13%, 19% and 23% for SBR1, SBR2, SBR3 and SBR5 samples was observed, respectively, for samples cured in the CW condition. Unlike the CW regime, an increase of flexural tensile strength values with the increase of SBR dosage for samples cured in 2DWA and 2W1OA regimes was observed. The flexural tensile strengths of the SBR-modified mortar mixture SBR1, SBR2, SBR3 and SBR5 were increased by 16%, 23%, 28% and 18%, respectively, in comparison to the flexural tensile strength of unmodified mortar for samples cured in the 2DWA condition. For samples cured in the 2W1OA regime, the flexural tensile strengths of the SBR-modified mortar mixtures SBR1, SBR2, SBR3 and SBR5 were increased by 14%, 25%, 29% and 13%, respectively. The flexural tensile strength improvement of SBR-modified mortar may be attributed to possible interactions between the cement hydration products and the polymer particles or to film formation in the interface between the cement paste [38,39]. The increasing of flexural strength may be explained by the fact that the polymer addition leads

FIGURE 2. Flexural tensile strength of SBR-modified mortars under different curing regime.

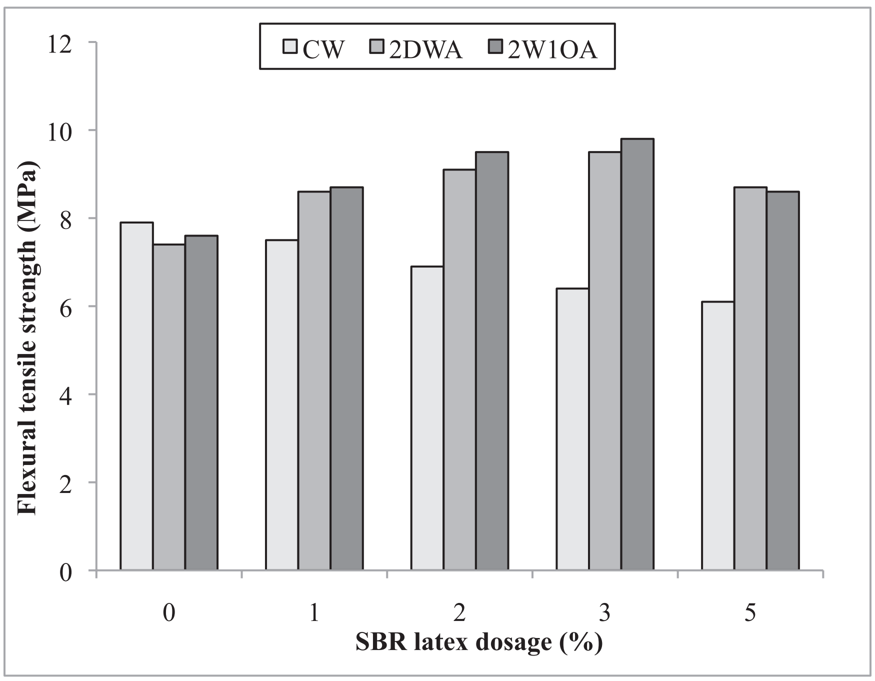


TABLE 3. Results of two-way ANOVA for flexural tensile strength.

Source of Variation	Sum of square (SS)	Degree of freedom (DF)	Mean square (MS)	F	P-value	Fcrit
Sample	6.80	4	1.70	5.606	0.002	2.690
Columns	33.40	2	16.70	55.058	0.000	3.316
Interaction	16.69	8	2.09	6.879	0.000	2.266
Within	9.10	30	0.30			
Total	65.99	44				

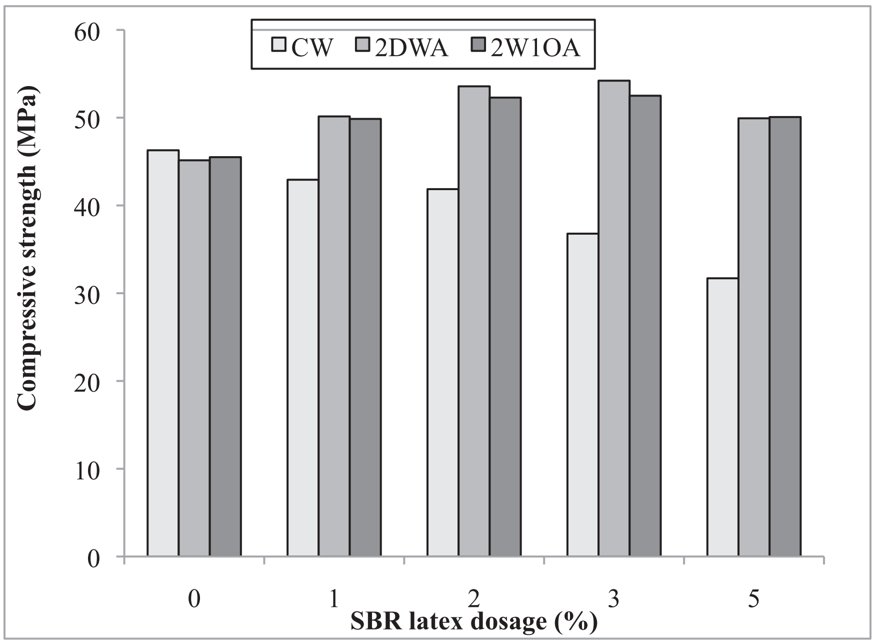
to the refinement of the specimens's interface transition zone (ITZ), thereby improving the bond strength between the aggregate and the matrix [40–42].

The results of ANOVA for flexural tensile strength are presented in Table 3. It can be seen from Table 1 that the effect of the factors "SBR replacement ratio" and "curing regime" on the flexural tensile strength of mortar showed statistical significance (p-value= 0.002< 0.05).

3.3 Compressive strength

The 28-days compressive strength results of SBR-modified mortars as a function of polymer content and curing regime are illustrated in Figure 3. Each presented value is the average of six tests on fragments recovered from the flexural tensile strength test. By analysing the 28-days compressive strength of produced SBR-modified mortar samples, it can be observed that the

FIGURE 3. Compressive strength of SBR-modified mortars under different curing regime.



maximum value was obtained from the reference (SBR0) sample (46.3 MPa) and the minimum value was obtained from SBR5 sample (31.7 MPa) for specimens cured in CW regime. For samples cured in 2DWA and 2W1OA conditions, the maximum values were obtained from SBR3 samples (54.2 MPa) and SBR3 samples (52.5 MPa), whereas the minimum values were obtained from SBR0 samples (45.1 MPa) and SBR0 samples (45.5 MPa), respectively. The compressive strengths of the SBR-modified mortar mixture SBR1, SBR2, SBR3 and SBR5 were reduced by 7%, 10%, 21% and 32%, respectively, in comparison to the strength of unmodified mortar (SBR0) for the samples cured in CW condition. The decrease of mechanical strength in wet curing was also reported by Jenni et al. [43] in their study dealing with the changes in microstuctures and physical properties of polymer modified mortars under wet and dry curing conditions.

Otherwise, for samples cured in the 2DWA condition, the compressive strengths of the SBR-modified mortar mixture SBR1, SBR2, SBR3 and SBR5 were increased by 11%, 19%, 20% and 11%, respectively, in comparison to the strength of unmodified mortar (SBR0). For samples cured in the 2W1OA regime, the compressive strength also increased by 9.6%, 14.9%, 15.4% and 10%, respectively. As a result, the best contribution to compressive strength was obtained from samples containing 3% SBR and cured in 2DWA regime.

The two-way ANOVA findings on the effect of the factors "SBR replacement ratio" and "curing regime" on the compressive strength of mortar given in Table 4 showed statistical significance (p-value = 0.00 < 0.05).

3.4 Correlation between compressive strength and flexural tensile strength

The mean values, standard deviation and 95% confidence intervals of compressive strength and flexural tensile strength are given in Table 5.

Moreover, the correlation between compressive strength and flexural tensile strength was investigated and the relationships between the compressive strength and the flexural tensile strength of the SBR-modified mortar cured under different conditions as well as their 95% confidence intervals are plotted in Figures 4–7. It can be seen from Figure 4 that there is a high correlation between the results of SBR-modified mortars subjected to different curing regimes. It is worth noting that the second order polynomial relationship was found as the best fit curve. The correlation coefficients (R^2) obtained in the CW, 2DWA and 2W1OA series are 0.861, 0.993 and 0.976, respectively. The highest correlation coefficient (i.e. 0.993) is obtained in the 2DWA series.

TABLE 4. Results of two-way ANOVA for compressive strength.

Source of Variation	Sum of square (SS)	Degree of freedom (DF)	Mean square (MS)	F	P-value	Fcrit
Sample	141.07	4	35.27	24.97	0.00	2.69
Columns	1099.05	2	549.52	389.00	0.00	3.32
Interaction	508.99	8	63.62	45.04	0.00	2.27
Within	42.38	30	1.41			
Total	1791.49	44				

TABLE 5. Mean values, standard deviations and 95% confidence interval of compressive and flexural tensile strengths.

Mortar	Mean	Standard deviation	95% Confidence interval		Curing regime
			Lower limit	Upper limit	
Compressive strength (MPa)					
SBR0	46.3	0.691	44.6	48.0	CW
SBR1	42.9	1.675	38.8	47.1	
SBR2	41.9	1.695	37.7	46.1	
SBR3	36.8	0.721	35.0	38.6	
SBR5	31.7	0.626	30.2	33.3	
SBR0	45.1	1.300	41.9	48.3	2DWA
SBR1	50.1	0.886	47.9	52.3	
SBR2	53.6	0.950	51.3	56.0	
SBR3	54.2	0.707	52.5	56.0	
SBR5	49.9	1.258	46.8	53.0	
SBR0	45.5	1.039	42.9	48.0	2D1OA
SBR1	49.9	1.077	47.2	52.5	
SBR2	52.3	1.785	47.8	56.7	
SBR3	52.5	1.488	48.8	56.2	
SBR5	51.1	1.010	48.6	53.6	
Flexural tensile strength (MPa)					
SBR0	7.86	0.410	6.84	8.88	CW
SBR1	7.48	0.351	6.61	8.36	
SBR2	6.91	0.872	4.74	9.07	
SBR3	6.37	0.246	5.76	6.98	
SBR5	6.09	0.651	4.47	7.70	
SBR0	7.41	0.760	5.52	9.29	2DWA
SBR1	8.58	0.387	7.62	9.54	
SBR2	9.34	0.617	7.80	10.87	
SBR3	9.47	0.592	8.00	10.94	
SBR5	8.68	0.365	7.77	9.59	
SBR0	7.61	0.656	5.98	9.24	2D1OA
SBR1	8.68	0.586	7.22	10.14	
SBR2	9.48	0.436	8.40	10.57	
SBR3	9.80	0.202	9.30	10.31	
SBR5	8.59	0.645	6.99	10.20	

FIGURE 4. Relationship between flexural tensile strength and compressive strength of SBR-modified mortar mixture.

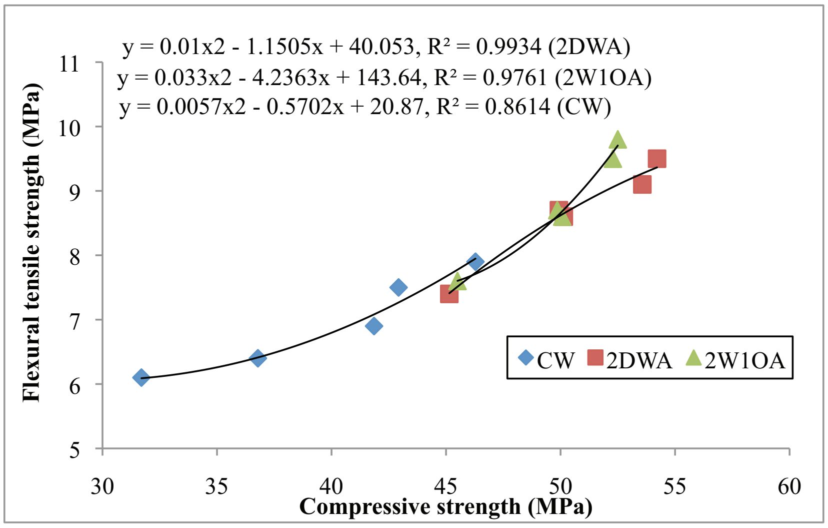
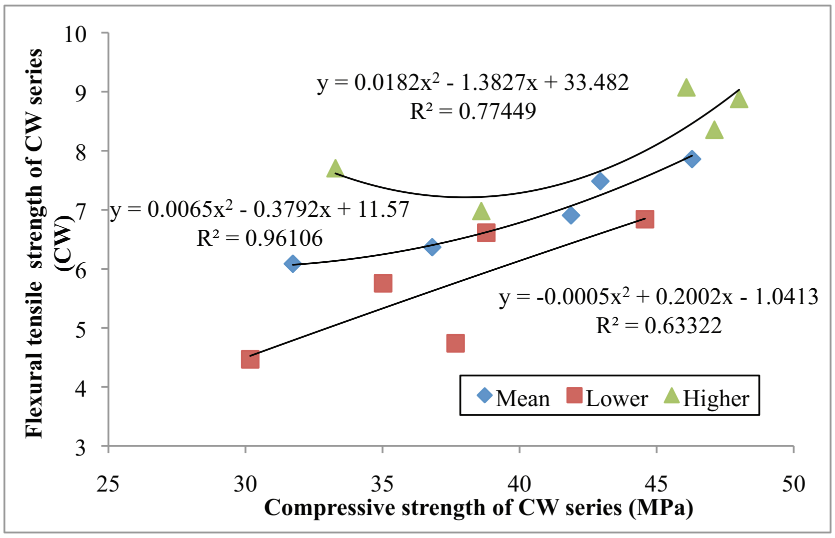


FIGURE 5. 95% confidence intervals of relationship between flexural tensile strength and compressive strength of CW series.



3.5 Water absorption and porosity accessible to water

The water absorption ratio and porosity accessible to water results of SBR-modified mortar samples after 28 days'curing under CW, 2DWA and 2W1OA curing conditions are plotted in Fig. 5 and Fig. 6 For samples cured in the 2DWA condition, the water absorption ratio of mortar samples decreased by 8% for SBR1 samples, 13% for SBR2 samples, 17% for SBR3 samples and 24% for SBR5 samples. The same trend was also observed for samples cured in the 2W1OA condition where the water absorption ratio of mortar samples decreased by 8%, 10%, 12% and 14% for SBR1, SBR2, SBR3 and SBR5 samples, respectively. The water absorption

FIGURE 6. 95% confidence intervals of relationship between flexural tensile strength and compressive strength of 2DWA series.

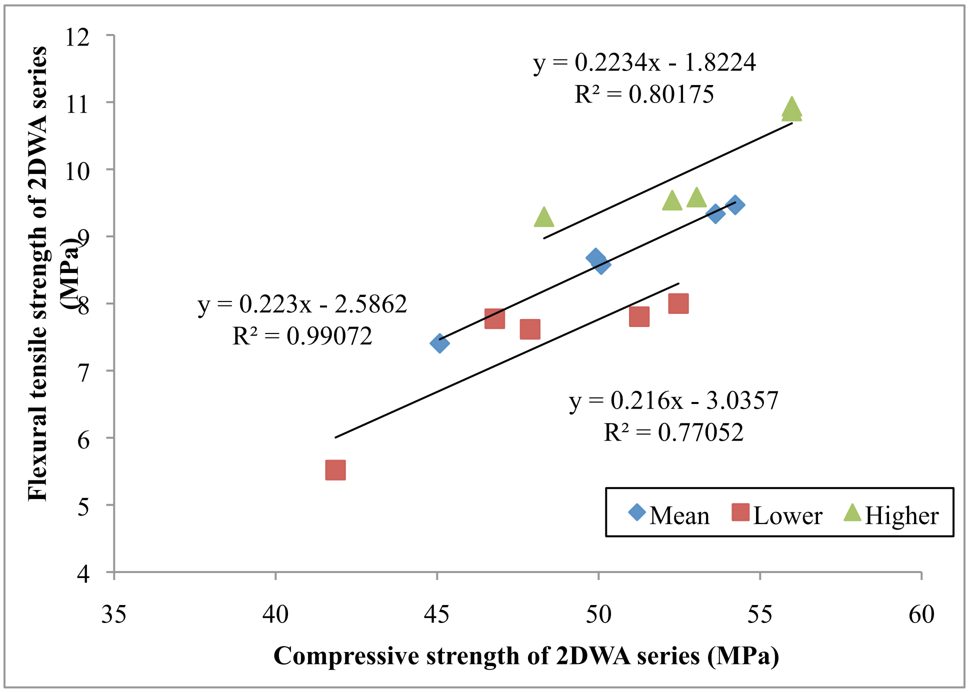
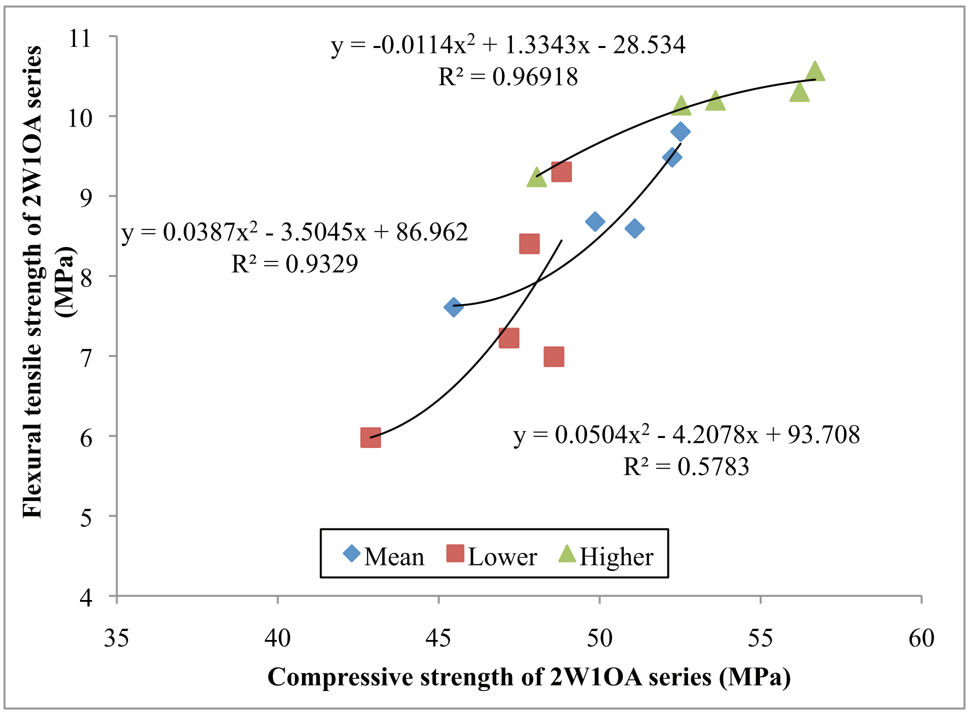


FIGURE 7. 95% confidence intervals of relationship between flexural tensile strength and compressive strength of 2W1OA series.



ratios of samples cured in CW regime decreased by 5%, 7%, 15% and 16% for SBR1, SBR2, SBR3 and SBR5 samples, respectively. For samples cured in the 2DWA condition, porosity accessible to water of mortar samples decreased by 13% for SBR1 samples, 20% for SBR2 samples, 22% for SBR3 samples and 26% for SBR5 samples. For samples cured in the 2W1OA condition, porosity accessible to water of mortar samples decreased by 15%, 25%, 28% and 30% for SBR1, SBR2, SBR3 and SBR5 samples. Porosity accessible to water of samples cured in the CW regime also decreased by 1%, 4%, 6% and 12% for SBR1, SBR2, SBR3 and SBR5 samples, respectively. The reduction in water absorption and porosity may be attributed firstly to the filling effect of SBR polymer particles due to the fact that SBR polymer particles were smaller than the cement particles; thus, they could fill the micropores and voids occurred in Portland cement system during cement hydration process [44]. Secondly, the formed polymer film that surrounds the aggregates and cement particles would enhance the ITZ microstructure by bridging the open pores and cracks and also slowing their progress [44].

3.6 Correlation between porosity accessible to water and water absorption ratio

The correlation between porosity accessible to water and water absorption was investigated and the relationships between the porosity accessible to water and water absorption of the SBR-modified mortar cured under different conditions are also presented in Fig. 7. It can be seen from Fig. 7 that there is a high correlation between the results of SBR-modified mortars subjected to different curing regimes. The second order polynomial relationship was found as the best fit curve. The correlation coefficients (R^2) obtained in CW, 2DWA and 2W1OA series are 0.861, 0.985 and 0.956, respectively. The highest correlation coefficient (i.e. 0.985) is obtained in 2DWA series.

The two-way ANOVA results on the effect of "SBR replacement ratio" and "curing regime" on the water absorption and porosity accessible to water of mortar presented in Table 6 and Table 7 showed statistical significance (p-value = 0.00 < 0.05). Moreover, the mean values, standard deviation and 95% confidence intervals of water absorption and porosity accessible to water are presented in Table 8.

FIGURE 8. Water absorption of SBR-modified mortars under different curing regime.

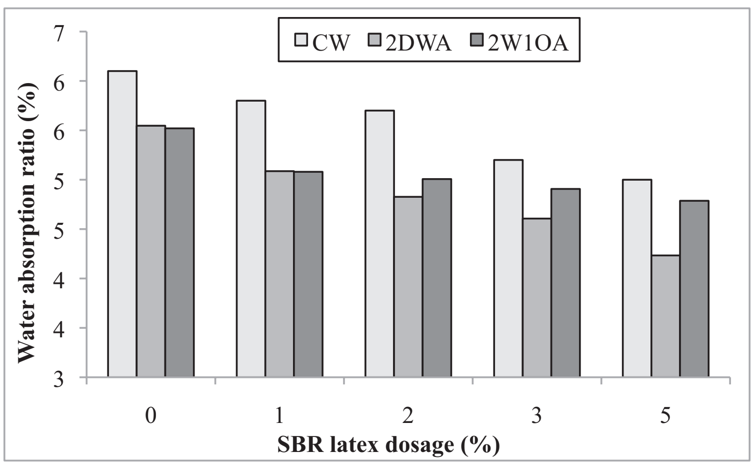


FIGURE 9. Porosity accessible to water of SBR-modified mortars under different curing regime.

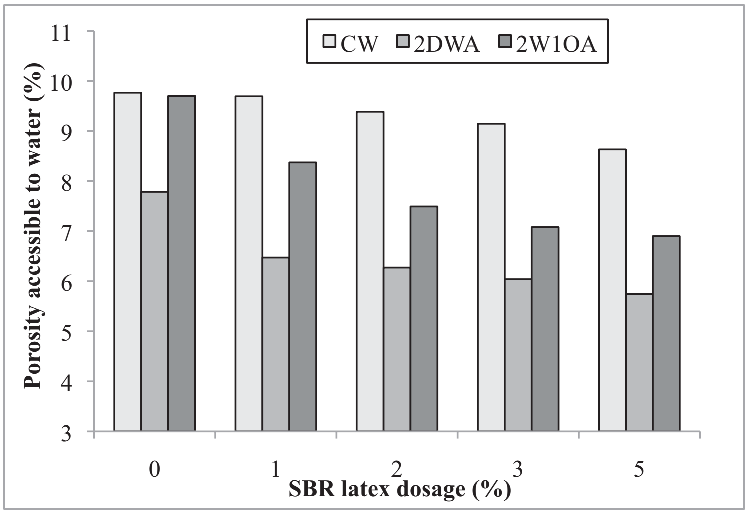


FIGURE 10. Relationship between porosity accessible to water and water absorption of SBR-modified mortar mixtures.

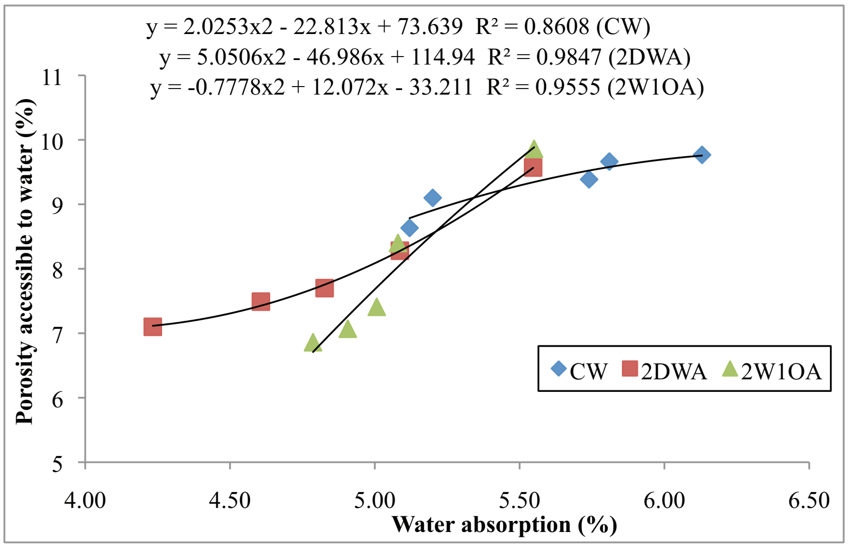


TABLE 6. Results of two-way ANOVA for water absorption.

Source of Variation	Sum of square (SS)	Degree of freedom (DF)	Mean square (MS)	F	P-value	Fcrit
Sample	5.717	4	1.429	14.793	0.000	2.690
Columns	4.307	2	2.154	22.292	0.000	3.316
Interaction	0.497	8	0.062	0.644	0.735	2.266
Within	2.898	30	0.097			
Total	13.420	44				

TABLE 7. Results of two-way ANOVA for porosity accessible to water.

Source of Variation	Sum of square (SS)	Degree of freedom (DF)	Mean square (MS)	F	P-value	Fcrit
Sample	26.911	4	6.728	24.108	0.000	2.690
Columns	17.968	2	8.984	32.192	0.000	3.316
Interaction	4.997	8	0.625	2.238	0.053	2.266
Within	8.372	30	0.279			
Total	58.248	44				

TABLE 8. Mean values, standard deviations and 95% confidence interval of water absorption and porosity accessible to water.

Mortar	Mean	Standard deviation	95% Confidence interval		Curing regime
			Lower limit	Upper limit	
Water absorption (%)					
SBR0	6.13	0.054	5.99	6.26	CW
SBR1	5.81	0.225	5.25	6.37	
SBR2	5.74	0.471	4.57	6.91	
SBR3	5.20	0.104	4.94	5.46	
SBR5	5.12	0.194	4.63	5.60	
SBR0	5.55	0.568	4.14	7.0	2DWA
SBR1	5.09	0.204	4.58	5.6	
SBR2	4.83	0.126	4.52	5.1	
SBR3	4.61	0.264	3.96	5.3	
SBR5	4.23	0.295	3.50	5.0	
SBR0	5.56	0.172	5.14	5.99	2D1OA
SBR1	5.08	0.463	3.93	6.23	
SBR2	5.01	0.539	3.68	6.35	
SBR3	4.91	0.183	4.46	5.37	
SBR5	4.79	0.142	4.44	5.14	
Open porosity (%)					
SBR0	9.77	0.244	9.16	10.37	CW
SBR1	9.66	0.453	8.54	10.79	
SBR2	9.39	0.458	8.25	10.53	
SBR3	9.10	0.704	7.35	10.85	
SBR5	8.63	0.780	6.69	10.57	
SBR0	9.57	0.910	7.31	11.83	2DWA
SBR1	8.28	0.512	7.01	9.55	
SBR2	7.70	0.435	6.61	8.78	
SBR3	7.49	0.469	6.32	8.65	
SBR5	7.10	0.495	5.87	8.33	
SBR0	9.86	0.277	9.17	10.55	2D1OA
SBR1	8.40	0.645	6.80	10.00	
SBR2	7.41	0.453	6.28	8.53	
SBR3	7.07	0.377	6.13	8.01	
SBR5	6.86	0.148	6.49	7.23	

4. CONCLUSIONS

In this study, the effects of SBR polymer/cement ratio on the strength and physical properties of polymer modified mortar mixtures exposed to three different curing regimes have been investigated. Based on the experimental results, the following conclusions can be drawn:

1. The unit weight of hardened mortar gradually decreased as the amount of SBR increased. At 5% of the replacement level, the unit weight decreased about 3.17%, 2.73% and 2.92% for samples cured in CW, 2DWA and 2W1OA regimes, respectively. As it can be observed, the curing regime did not remarkably affect the unit weight of the SBR-modified mortars.
2. Unlike the water curing (CW) regime, an increase of flexural tensile strength values with the increase of SBR dosage for samples cured in 2DWA and 2W1OA regimes was observed.
3. The flexural tensile strengths of the SBR-modified mortar mixtures SBR1, SBR2, SBR3 and SBR5 were increased by 16%, 39%, 41% and 18%, respectively, in comparison to the flexural tensile strength of unmodified mortar for samples cured in the 2DWA condition. For samples cured in the 2W1OA regime, the flexural tensile strengths of the SBR-modified mortar mixtures SBR1, SBR2, SBR3 and SBR5 were increased by 14%, 38%, 34% and 13%, respectively.
4. The compressive strengths of the SBR-modified mortar mixtures SBR1, SBR2, SBR3 and SBR5 were reduced by 7%, 10%, 21% and 36%, respectively, in comparison to the strength of unmodified mortar (SBR0) for the samples cured in the CW condition. However, at 3% of the replacement level, the compressive strength increased about 20% and 15% for samples cured in the 2DWA and 2W1OA regimes, respectively. As a result, the best contribution in compressive strength was obtained from samples containing 3% SBR and cured in 2DWA regime. However, prolonged water curing was not beneficial to the SBR-modified mortar mixtures.
5. The results also confirmed that water absorption and porosity accessible to water were improved by SBR addition for samples cured in 2DWA and 2W1OA regimes.
6. For samples cured in CW, 2DWA and 2W1OA conditions, porosity accessible to water of the mortar samples decreased up to 12%, 26% and 29 %, respectively.
7. For samples cured in CW, 2DWA and 2W1OA conditions, water absorption of mortar samples decreased up to 18%, 24% and 13%.
8. A good correlation was also observed between the porosity accessible to water and water absorption for both the SBR-modified and unmodified mortars, irrespective of their curing conditions.

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