EFFECT OF STYRENE-BUTADIENE COPOLYMER (SBR) LATEX ON MECHANICAL AND TRANSPORT PROPERTIES OF PORTLAND CEMENT MORTAR

Daniel Hatungimana,[1] Şemsi Yazici,[2] Şevket Orhan,[2] Ali Mardani-Aghabaglou[3]*

ABSTRACT

Portland cement is extensively used as a binder in concrete production. However, with Portland cement production, 5% of the natural resources used in this production are consumed, constituting 5–7% of the total CO_2 emission. In order to mitigate the environmental problems associated with cement production, styrene-butadiene rubber latex was used as cement replacement up to 20%. In this study, compressive strength, flexural strength, unit weight, water absorption, open porosity, water sorptivity and the chloride ion permeability of Portland cement mortar mixtures modified by styrene-butadiene rubber (SBR) polymeric latex were investigated. For this purpose, the sand/cement ratio and the water/cement ratio were kept constant as 3/1 and 0.5, respectively. In addition to the control mixture containing no polymer, 1, 2, 3, 5, 10 and 20 wt.% of cement was replaced with SBR. In this way, seven mortar mixtures were prepared. Mixed curing (wet cure and dry cure) method was applied to the mortar specimens. Results showed that up to a 5% replacement level, it is possible to improve the mechanical properties of cement mortars with SBR latex addition. However, at a 10% and 20% replacement level, SBR had a significant detrimental effect on the mechanical properties of polymer modified mortars. However, the transport properties decreased with the incorporation rate of SBR latex and the detrimental effect of SBR replacement was more pronounced in 20% SBR mortar mixtures.

KEYWORDS

mechanical properties, transport properties, SBR latex

1. INTRODUCTION

Cement is extensively used to produce concrete in today's construction industry. Calcium carbonate and aluminum silicate based materials and also some additions from industrial waste are

1. Department of Civil Engineering, Eng. Sciences Faculty, University of Burundi, 2700 Bujumbura, Burundi
2. Department of Civil Engineering, Eng. Faculty, Ege University, Bornova-İzmir, Turkey
3. Department of Civil Engineering, Eng. Faculty, Bursa Uludağ University, Nilüfer-Bursa, Turkey
* Corresponding author. Tel.: +90 224 294 27 93; Fax: +90 224294 19 03. E-mail address: ali.mardani16@gmail.com (A. Mardani-Aghabaglou).

used as raw materials for cement production [1]. In addition, the cement production process requires the raw materials to be heated in the rotary kiln at around 1450°C to produce clinker which is ground with about 5% gypsum to make cement. However, the world cement industry consumes a huge amount of natural resources and energy and may no longer be considered as a sustainable industry [1,2]. Moreover, cement production is responsible for 5% of CO_2 emissions through the combustion of fossil fuel through the heating of limestone in order to obtain clinker [1–5]. In order to mitigate the environmental concerns associated with the construction industry, sustainable approaches are suggested by various researchers. The general tendency is to reduce the cement consumption through the use of mineral additions such as silica fume, fly ash, rice husk ash, slag, metakaolin [6–9] and also through the production of concrete without cement such as geopolymer [10–12]. In the present study, styrene-butadiene rubber (SBR) polymeric latex is used at different replacement ratios of cement in order to improve some mechanical and transport properties of Portland cement mortar.

Cement based mortar and concrete possess the lower flexural strength, ductility, higher permeability, lower adhesion to substrate concrete than concrete and mortar modified by polymer additives [13,14]. Generally, polymer latexes are utilized to increase the tensile and flexural strengths and also to improve the durability properties [15–17]. Diab et al.[18] reported that polymer latexes affect the physical, mechanical and durability properties of Portland cement pastes, mortars and concretes and the magnitude of this effect depends on the latex type and latex concentration in the designed mixture. This occurs because in polymer modified mortar or concrete two complementary phenomena are observed. First, the hydration of Portland cement takes place and develops cementing properties. Second, the air drying enables polymer film formation to yield a monolithic matrix phase with a network structure in which the hydrated cement phase and polymer phase interpenetrate into each other [19,20]. Latexes, re-dispersible polymer powders, water soluble polymers, liquid resins and monomers are some of polymer generally used as cement additives [14,21]. Among these polymer additives, latex emulsions such as styrene-butadiene rubber (SBR) and acrylics are used in the vast majority of polymer modified applications due to their high performance, stability, bond adhesion and flexibility [14, 22–24].

In this study, the effect of SBR latex replacement ratio by weight of Portland cement on the mechanical and transport properties of the polymer-modified mortars was investigated.

2. EXPERIMENTAL STUDY

2.1 Materials

In this study, an ordinary Portland cement CEM I 42.5R type cement conforming to EN 197-1 [25] standard with a specific gravity of 3.15 and Blaine surface area of 3677 cm^2/g was used for all mixtures. Crushed limestone aggregate was 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 [26]. The chemical composition and some mechanical properties of Portland cement are given in Table 1. SBR latex was used at various replacement ratios (1, 2, 3, 5, 10 and 20 wt. % of cement), and its effect on the mechanical and transport properties of mortar at hardened state was investigated. The physical and chemical properties of styrene-butadiene rubber (SBR) latex are given in Table 2.

TABLE 1. Some physical, chemical and mechanical properties of cement.

Chemical properties		Mechanical and physical properties			
Oxide	**(%)**	**Properties**			**Cement**
SiO_2	19.52	Compressive strength (MPa)		2 day	24.5
Al_2O_3	5.39			7 day	37.2
Fe_2O_3	2.48			28 day	47.4
CaO	62.5	Fineness		Specific gravity	3.15
MgO	1.09		Blaine Specific Surface (cm^2/g)		3677
Na_2O	0.27		Residual of 0.090 mm sieve (%)		1.1
K_2O	0.8		Residual of 0.032 mm sieve (%)		23.4
SO_3	3.41				
LOI	1.42				
Insoluble Residue	0.63				

TABLE 2. Physical and chemical properties of SBR.

Physical and chemical properties	
Physical state	Liquid
Color	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
Vapor pressure	Like water

2.2 Cost comparison

In order to make comparison between modified mortars and plain mortar, the costs of cement and styrene-butadiene rubber latex were collected from several Turkish companies (Table 3). The costs of other ingredients were not taken into account because the amount of those ingredients did not change.

TABLE 3. Unit cost of cement and SBR.

Raw material	Unit cost ($/tonne)
CEM I 42.5R	53
SBR	1250

By using the costs given above, the plain mortar (0%SBR) cost 0.024$ whilst the mortar modified with 20% of SBR (20%SBR) cost 0.134$. By comparing these costs, it is possible to conclude that the mortar with SBR is more expensive than the plain mortar.

2.3 Test procedures

SBR latex has been used in the preparation of latex-modified mortars. The mix proportioning was done according to guidelines given in EN 196-1 [27] 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 six different dosages (1%, 2%, 3%, 5%, 10% and 20% by weight of cement respectively). The water/cement (W/C) ratio was kept constant as 0.50. For 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. Seven mortar mixtures were designed as shown in Table 4.

The following procedure has been used to prepare mortar mixtures: first, cement and sand were mixed for 2 min. Second, mixing water and SBR latex emulsion were added to the dry mix and the mixing procedure was continued up to 5 min to reach homogenous mixing. A flow table was used to determine the flow spread values in accordance with the ASTM C230 standard. Specimens were prepared by filling the 40 x 40 x 160 mm prismatic molds with mortar and vibrated using a vibrating machine. The filled molds were kept in curing room for 24 h. Fresh densities were also determined. Theoretical air contents have been determined by taking the difference between the theoretical density and the measured fresh density values. After 24 h, the specimens were removed from the molds. The demolded specimens were cured in 20°C water for 2 days and then cured in air conditions until the testing day. Standard bending and compression tests of polymer modified mortars were performed on 40 x 40 x 160 mm specimens according to EN 196-1 [27] at the ages of 7 and 28 days. Dry unit weight, water absorption, void content and water sorptivity tests were determined at 28 days in accordance with ASTM C 642-13 [28] and ASTM C 1585 [29] standards, respectively. The rapid chloride permeability test (RCPT)

TABLE 4. Mortar mixture design.

Material (g)	0%SBR	1%SBR	2%SBR	3%SBR	5%SBR	10%SBR	20%SBR
Aggregate	1350	1350	1350	1350	1350	1350	1350
Cement	450.0	447.9	445.8	443.7	439.4	428.9	407.7
SBR	0	4.5	9	13.5	22.5	45	90
Water	225	225	225	225	225	225	225

was carried out on specimens with 100 mm in diameter and 50 mm thick in accordance with the ASTM C 1202 [30] standard.

3. TEST RESULTS AND DISCUSSION

3.1 Effect of latex modification on fresh density and air content

The effects of SBR latex on the fresh densities and calculated air content values of latex modified cement mortars are presented in Figure 1. As seen from Figure 1, SBR latex addition decreased the fresh densities and as a result of this decrease, air contents of the cement mortars increased. The air entraining effect of SBR latex is not very distinctive at low dosages; however, at high dosage, the calculated air content values of 13% and 18% were calculated at 10% and 20% of SBR latex addition.

3.2 Effects of latex modification on mechanical properties

The 7 and 28-days flexural and compressive strength test results of latex modified cement mortars were plotted in Figure 2 and Figure 3, respectively. The 7-days flexural strength slightly decreased as the SBR content increased. It can be seen that the longer the curing age the higher the compressive and flexural strength. This may be explained by the fact that the long curing is helpful for the polymer film formation and the cement hydration. By analyzing the 28 days of flexural strength of produced samples, it is observed that the maximum value was obtained from the sample containing 3%SBR (10.4MPa) and the minimum value was obtained from the sample containing 20%SBR (7.5MPa). An increase of the 28days flexural strength was observed as the SBR dosage increased up to 3% and decreased slightly with the increase of SBR dosage. Compared to 0%SBR (control) sample, flexural strength of samples containing 1%SBR, 2%SBR, 3%SBR and 5%SBR were determined to be increased by 9–32% for samples of 28

FIGURE 1. Fresh unit weight and calculated air contents of cement mortars.

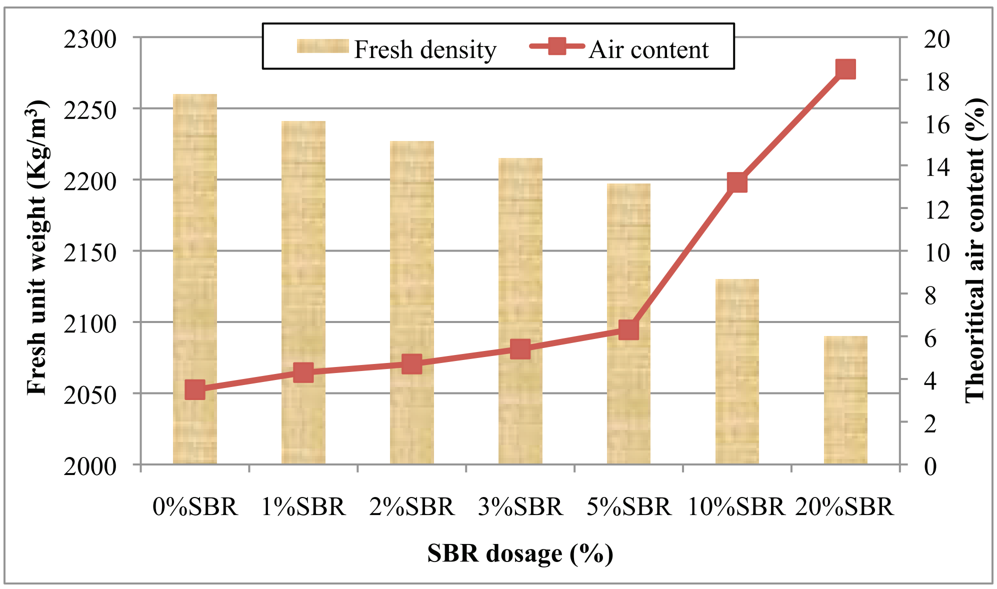


Figure 1. Fresh unit weight and calculated air contents of cement mortars.

days. On the other hand, the flexural strength of samples containing 10%SBR and 20%SBR were determined to be decreased by 5–9% for samples of 28 days. This decrease was attributed to the air entrainment effect of the used latex emulsion as seen from Figure 1.

The same trend was also observed for the compressive strength where the maximum value was obtained in 28 days from the sample containing 3%SBR (75.9MPa) and the minimum value was obtained from the sample containing 20%SBR (29.1MPa). Compared with control samples, the compressive strength of samples containing 1%SBR, 2%SBR, 3%SBR and 5%SBR were determined to be increased by 8–17% for samples of 28 days. However, the compressive

FIGURE 2. 7 and 28-day flexural strength of SBR modified mortars.

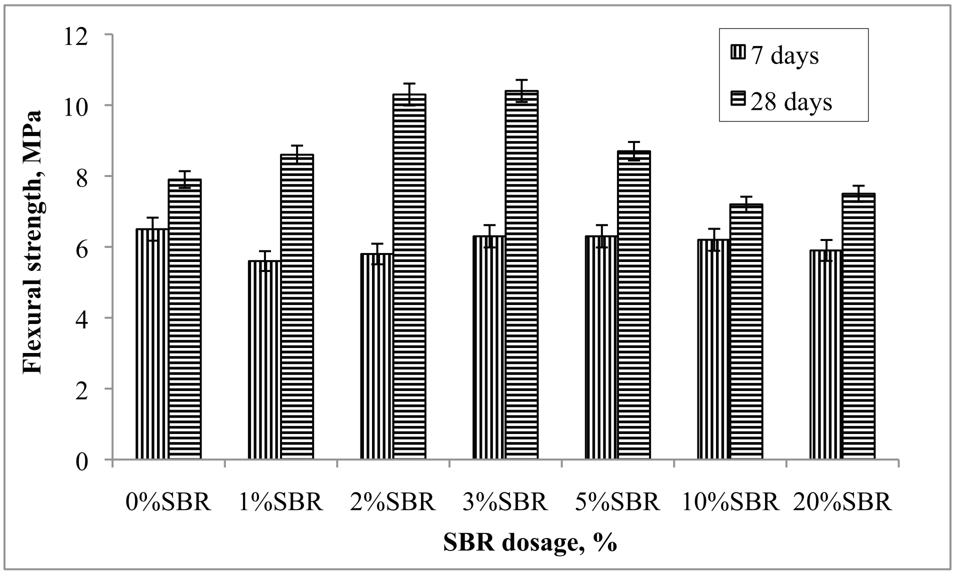


FIGURE 3. 7 and 28 days compressive strength of SBR modified mortars.

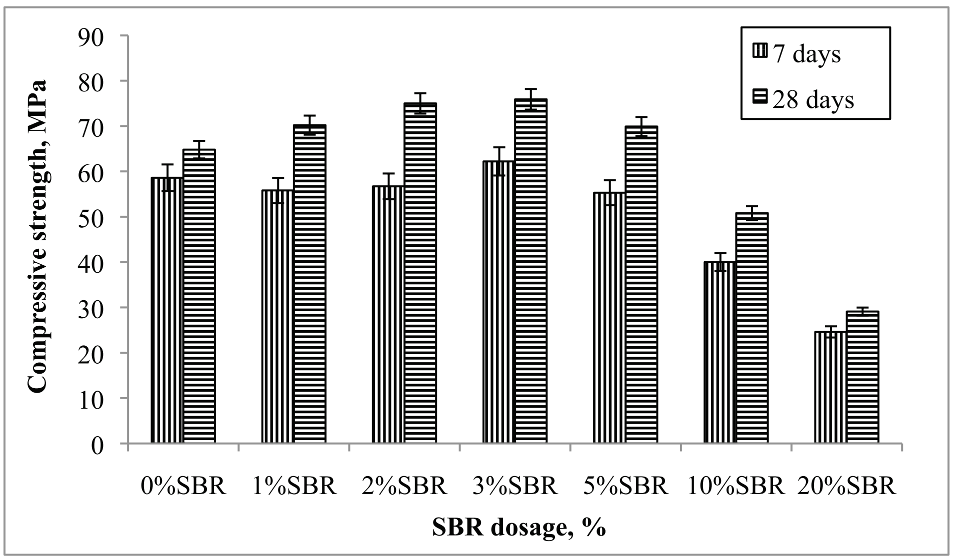


TABLE 5. Mean difference between the compressive strength and flexural strength of mortar. Data include the 95% confidence limit (CL) and the t and P values from paired comparison test.

Results	Mean	95% Confidence limit		t	P
		Low	High		
Compressive strength	62.24	46.64	77.84		
Flexural strength	8.66	7.48	9.84		
Difference				2.447	0.0001

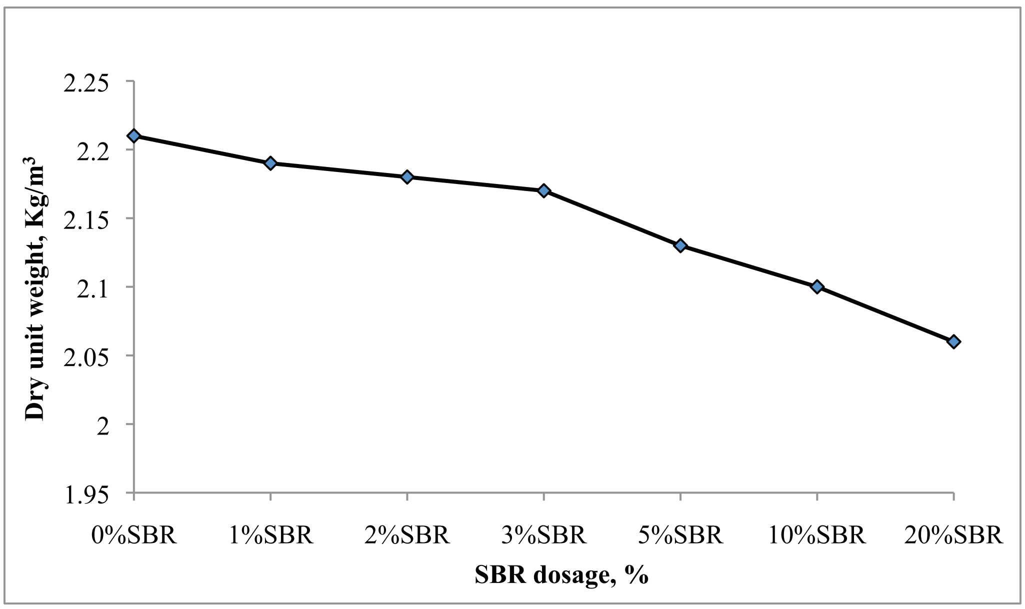
strength of samples containing 10%SBR and 20%SBR were determined to be decreased by 31–58% for samples of 28 days. The same results were also observed by Marceau et al.[21] who stated that the decrease of the mechanical strength was related to the increase of porosity due to the air entraining effect of the polymer latex emulsion.

The paired comparison test was used to know if there is any difference between the compressive strength and flexural strength of mortar modified by SBR latex. The results presented in Table 5 show that there is a significant difference between the compressive strength and the flexural strength results of mortar modified by SBR latex.

3.2 Effects of latex modification on dry unit weight

Dry unit weight results of polymer modified mortars were plotted in Figure 4. As seen from Figure 3, the unit weight values decreased from 2210 to 2060 kg/m^3. Also, compared to the control mixture (0%SBR), the unit weight values of the SBR modified mortars decreased by 0.9%, 1.4%, 1.8%, 3.6%, 5% and 6.8% for samples with 1%SBR, 2%SBR, 3%SBR, 5%SBR,

FIGURE 4. Dry unit weight of SBR modified mortars.



10%SBR, and 20% SBR, respectively. As expected, a decrease of dry unit weight values was observed as the rate of polymer dosage increased due to the low specific weight of SBR compared to that of cement.

3.3 Effects of latex modification on water absorption and permeable voids

Water absorption and void contents values obtained in 28 days cured SBR modified mortars are plotted in Figure 5. Water absorption values decreased with increasing SBR latex dosage. The water absorption ratio of polymer modified mortar decreased by 5% for samples with 1% SBR, 11% for samples with 2% SBR, 25% for samples with 3% SBR, 30% for samples with 5% SBR, 36% for samples with 10%SBR, 28% for samples with 20%SBR. It is observed that SBR addition to mortar significantly decreased the water absorption ratio.

A decrease of voids with increasing SBR latex dosages was also observed. As seen from the Figure 4, SBR latex addition significantly decreased the voids of the mortar. This decrease varied between 15% and 46% as the rate of SBR dosage increased. The reduction in water absorption and permeable pores may be attributed firstly to the filling effect of SBR polymer particles due to the SBR polymer particles being smaller than the cement particles; consequently, they could fill the voids of the cement paste. Secondly, the formed polymer film that surrounds the aggregates and cement particles would also reduce the volume of the pores and modified the pore structure, by the way a reduction of water absorption values was observed [31–33].

3.4 Effects of SBR latex modification on water sorptivity

The results of water sorptivity tests for various mortar mixtures are presented in Figure 6. As seen from Figure 6, the water sorptivity decreased by 6–48% in the SBR latex modified mixtures as compared to 0%SBR mixtures at the 28-day age. The significant decrease of the water sorptivity could be owing to the coagulated polymer filling of the pores, lowering of permeable pores and bridging of the microcracks propagating inside the matrix [34]. Moreover, the relationship

FIGURE 5. Water absorption and void content of SBR modified mortars.

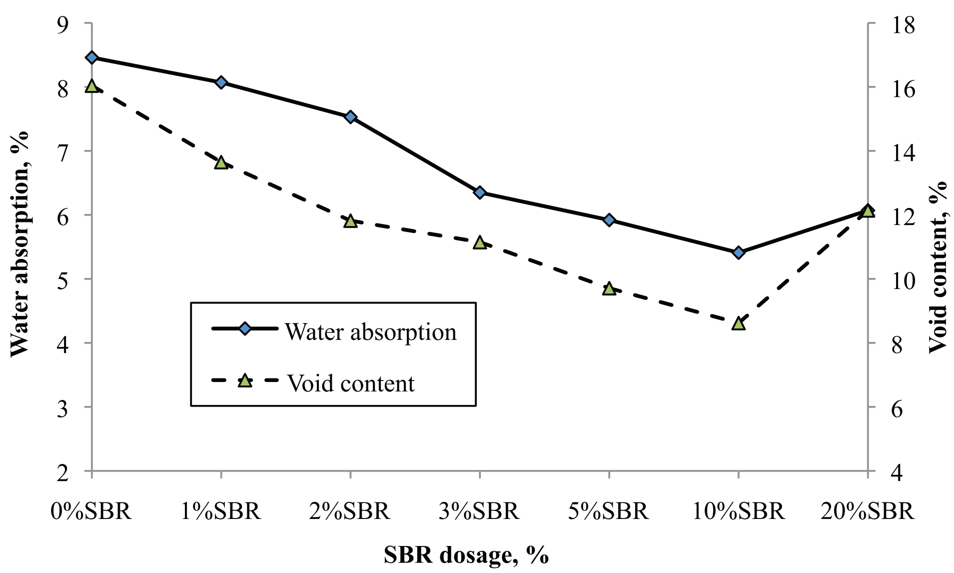
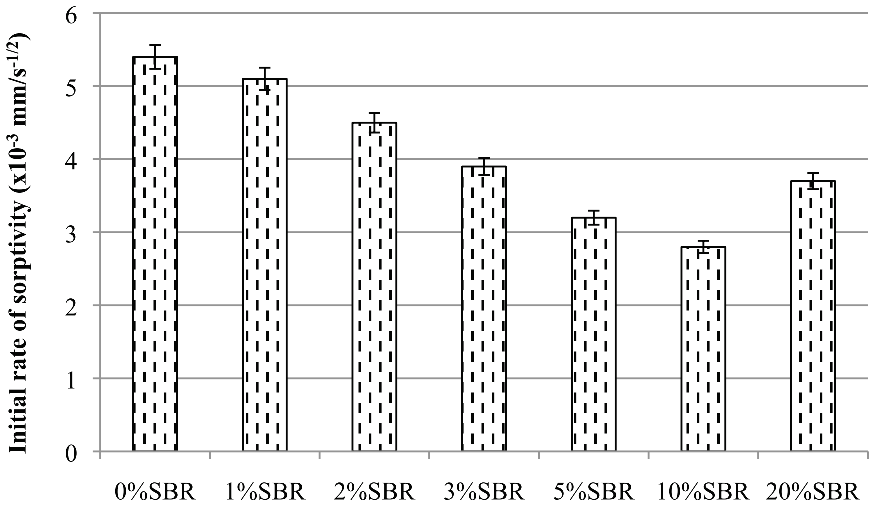


FIGURE 6. Effect of SBR latex on water sorptivity of Portland cement mortar.



between the water absorption and water sorptivity has been presented in Figure 7, which is a linear function form and with a coefficient of correlation of 0.89.

3.5 Effects of SBR latex modification on chloride ion ingress

The results of the rapid chloride permeability test (RCPT) are plotted in Figure 8. It was observed that rapid chloride permeability test values decreased by 10–50% in the SBR latex modified mixtures as compared to 0%SBR mixtures at the 28-day age. It can be also observed

FIGURE 7. Relationship between water absorption and water sorptivity.

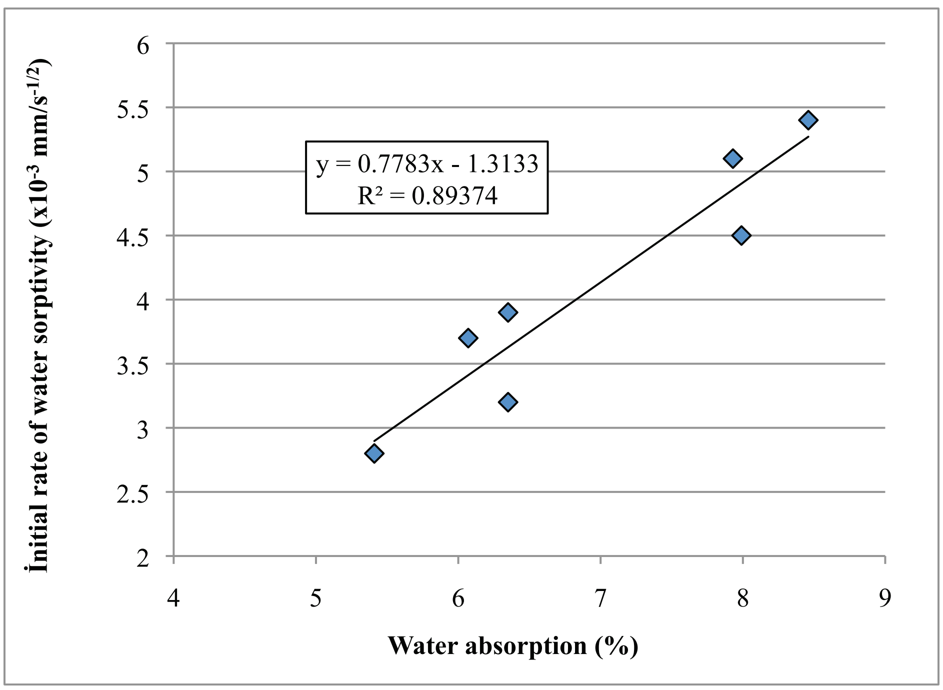
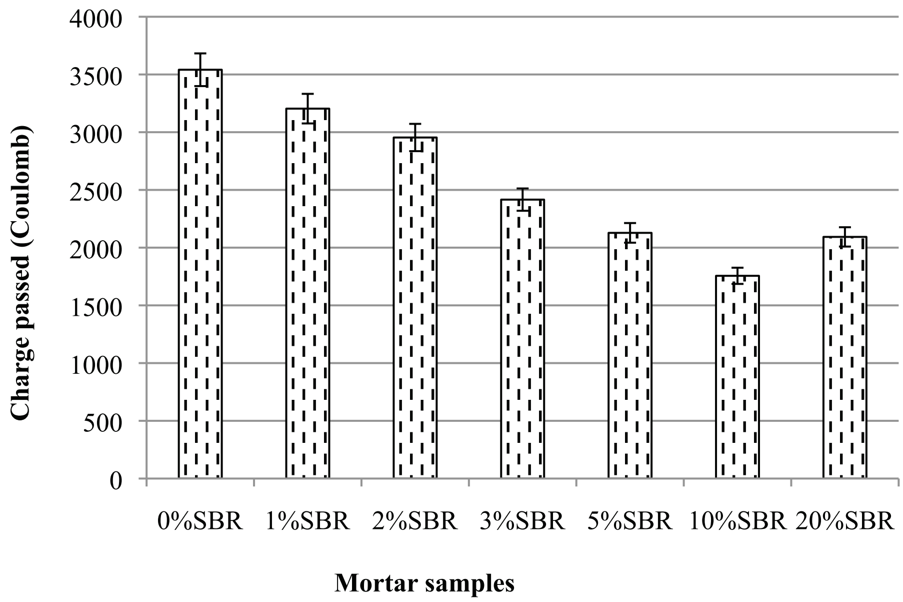


FIGURE 8. Effect of SBR latex on chloride ion permeability of Portland cement mortar.



that all mixtures exhibited moderate and low values at 28 days according to ASTM C 1202 [30]. The decrease in amount of chloride ion penetration value may be attributed to the dense ITZ and lesser open porosity of the SBR latex modified mortar mixtures compared to unmodified mortar mixtures [35–37]. Moreover, the relationship between chloride ion penetration,

FIGURE 9. Relationship between chloride ion permeability and water sorptivity.

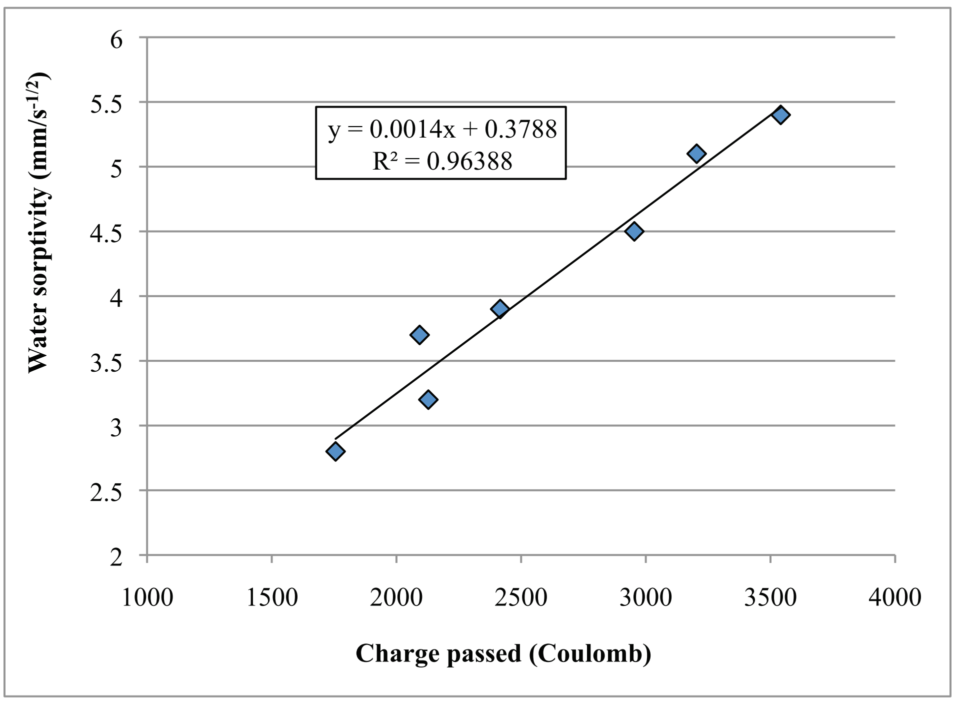
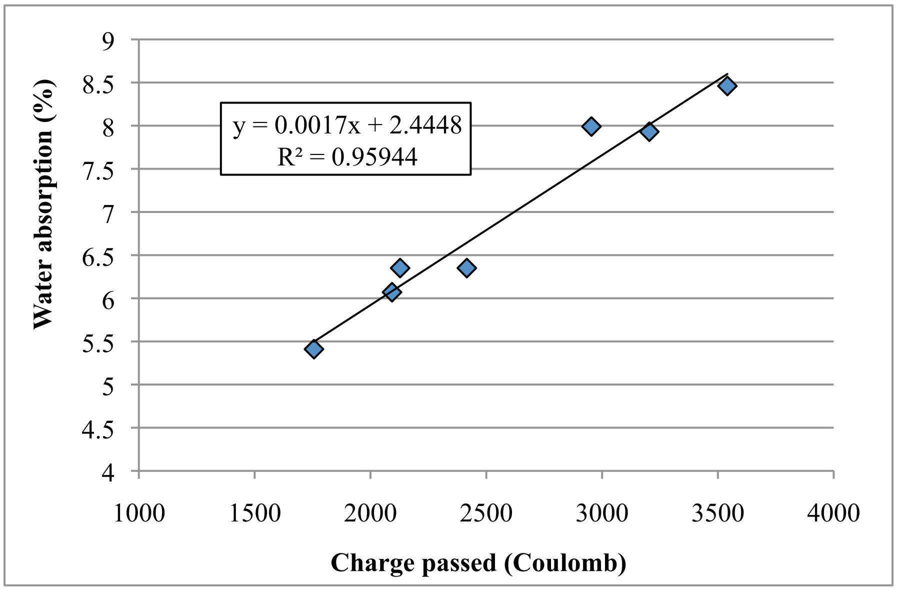


FIGURE 10. Relationship between chloride ion permeability and water absorption.



water absorption and water sorptivity are presented in Figures 9 and 10. As it can be observed, chloride ion permeability and water sorptivity are highly correlated (R^2 = 0.96). An increase in RCPT value of mortar mixtures was also correlated with the increasing in water absorption.

4. CONCLUSIONS

In this study, the mechanical and physical properties of SBR modified mortars have been investigated. Based on the results presented in this study, the following conclusions may be drawn:

- SBR additions were more effective at the curing period of 28 days for the mechanical properties. An increase of SBR dosage resulted in the decrease of compressive and flexural strengths. The decrease of the compressive strength up to 58% was reached at 20%SBR. The excessive amount of air entrainment as the amount of SBR polymer increased was the main cause of the decrease.
- The results also showed that by modifying cement mortar with 3%SBR polymer latex, the flexural strength is increased by 17%.
- A reduction of dry unit weight with increasing SBR polymer dosage was also observed.
- A decrease of water absorption and void content up to 36% and 46% respectively was observed. The decrease was due to the formation of monolithic film in cement matrix which surrounded the aggregate and resulted in modification of the pore structure.
- The water sorptivity decreased by 6–48% in the SBR latex modified mixtures as compared to reference (0%SBR) mixtures at a 28-day age.
- The rapid chloride permeability test values decreased by 10–50% in the SBR latex modified mixtures as compared to 0%SBR mixtures at a 28-day age.

REFERENCES

[1] Supino, S., Malandrino, O., Testa, M., Sica, D., Sustainability in the EU cement industry: the Italian and German experiences, *Journal of Cleaner Production*, 112 (2016) 430–442.

[2] Shanks, W., Dunant, C.F., Drewniok, M.P., Lupton, R.C., Serrenho, A., Allwood, J.M., How much cement can we do without? Lessons from cement material flowin the UK. Resources, *Conservation & Recycling*, 141 (2019) 441–454.

[3] Kajaste, R., Markku, H, Cement industry greenhouse gas emissions-management options and abatement cost, *Journal of Cleaner Production*, 112 (2016) 4041–4052.

[4] Mejia-Ballesteros, J.E., Savastano Jr., H., Fiorelli, J., Rojas, M.F., Effect of mineral additions on the microstructure and properties of blended cement matrices for fibre-cement applications, *Cement and Concrete Composites*, 98 (2019) 49–60.

[5] Schmidt, W., Alexander, M., John,V., Education for sustainable use of cement based materials, *Cement and Concrete Research*, 114 (2018) 103–114.

[6] Cheah, C.B., Tan, L.E., Ramli, M., The engineering properties and microstructure of sodium carbonate activated fly ash/slag blended mortars with silica fume, *Composites Part B*, 160 (2019) 558–572.

[7] Medina, C., Sáez del Bosque, I.F., Frías, M., Sánchez de Rojas,M.I., Design and characterization of ternary cements containing rice husk ash and fly ash, *Construction and Building Materials*, 187 (2018) 65–76.

[8] Hatungimana, D., Taşköprü, C., İçhedef, M., Saç, M.M., Yazıcı, Ş., Compressive strength, water absorption, water sorptivity and surface radon exhalation rate of silica fume and fly ash based mortar, *Journal of Building Engineering*, 23 (2019) 369–376.

[9] Mardani-Aghabaglou, A., Sezer, G.I., Ramyar, K., Comparison of fly ash, silica fume and metakaolin from mechanical properties and durability performance of mortar mixtures view point, *Construction and Building Materials*, 70 (2014) 17–25.

[10] Mabah, D.E.T., Tchakouté, H.K., Rüscher, C.H., Kamseu, E., Elimbi, A., Leonelli, C., Design of low cost semi-crystalline calcium silicate from biomass for the improvement of the mechanical and microstructural properties of metakaolin-based geopolymer cements, *Materials Chemistry and Physics*, 223 (2019) 98–108.

[11] Asim, N., Alghoul, M., Mohammad, M., Amin, M.H., Akhtaruzzaman, M., Amin, N., Sopian, K., Emerging sustainable solutions for depollution, Geopolymers, *Construction and Building Materials*, 199 (2019) 540–548.

[12] Carreño-Gallardo, C., Tejeda-Ochoa, A., Perez-Ordoneza, O.I., Ledezma-Sillas, J.E., Lardizabal-Gutierrez, D., Prieto-Gomez, C., Valenzuela-Grado, J.A., Hernandez, F.C.R., Herrera-Ramirez, J.M., In the CO_2 emission remediation by means of alternative geopolymers as substitutes for cements, *Journal of Environmental Chemical Engineering*, 6 (2018) 4878–4884.

[13] Zhang, D., Ueda, T. and Furuuchi, H., Fracture and mechanisms of polymer cement mortar: Concrete interfaces, *Journal of Engineering Mechanics*, 139(2) (2013) 167–176.

[14] Eren, F., Gödek, E., Keskinateş, M., Tosun-Felekoğlu, K. and Felekoğlu, B., Effects of latex modification on fresh state consistency, short term strength and long term transport properties of cement mortars, *Construction and Building Materials*,133 (2017) 226–233.

[15] Lavelle, J.A., Acrylic latex modified Portland cement, *ACI Materials Journal*, 85(1) (1988) 41–48.

[16] Kim, J.H., Robertson, R.E., Naaman, A.E., Structure and properties of poly (vinyl alcohol)-modified mortar and concrete, *Cement and Concrete Research*, 29(3) (1988) 407–415.

[17] Yang, Z., Shi, X., Andrew, T., Creighton, A.T. and Peterson, M.M., Effect of styrene-butadiene rubber latex on the chloride permeability and microstructure of Portland cement mortar, *Construction and Building Materials*, 23(6) (2009) 2283–2290.

[18] Diab, A.M., Elyamany, E.H. and Ali, A.H., Experimental investigation of the effect of latex solid/water ratio on latex modified co-matrix mechanical properties, *Alexandria Engineering Journal*, 52 (2013) 83–98.

[19] Ohama, Y., *Polymer-modified mortar and concrete, concrete admixtures handbook*, New Jersey: Noyes Publication, 1984.

[20] Ramli, M., Tabassi, A.A., Hoe, K.W., Porosity, pore structure and water absorption of polymer-modified mortars: An experimental study under different curing conditions, *Composites: Part B*, 55 (2013) 221–233.

[21] Marceau, S., Lespinasse, F., Bellanger, J., Mallet, C. and Boinski, F., Microstructure and mechanical properties of polymer modified mortars, *European Journal of Environmental and Civil Engineering*, 16(5) (2012) 571–581.

[22] Wang, R., Li, X.G. and Wang, P.M., Influence of polymer on cement hydration in SBR-modified cement pastes, *Cement and Concrete Research*, 36 (2005) 1744–1751.
[23] Assaad, J. and Daou, Y., Behavior of structural polymer-modified concrete containing recycled aggregates, *Journal of Adhesion Science and Technology*, 31(8): 874–896, 2017.
[24] Durability of styrene butadiene latex modified concrete, *Cement and Concrete Research*, 27(5) (1997) 711–720.
[25] EN 197-1, Cement-Part1: Composition, specifications and conformity criteria for common cements, European Standard, Brussels, 2010.
[26] ASTM C 128-15, Standard Test Method for Density, Relative density (Specific gravity) and Absorption of Fine Aggregates, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, PA, USA, 2015.
[27] EN 196-1, Methods of testing cement-Part 1: Determination of strength, European Standard, Brussels, 2009.
[28] ASTM C 642-13, Standard test method for density, absorption and voids in hardened concrete, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, PA, USA, 2013.
[29] ASTM C1585-13, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, PA, USA, 2013.
[30] ASTM C 1202, Standard test method for electrical indication of concrete's ability to resist chloride ion penetration, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, PA, USA, 2005.
[31] Shaker, F.A., El-Dieb, A.S., Reda, M.M., 1997, Durability of styrene-butadiene latex modified concrete, *Cement and Concrete Research*, 27(5) (1997) 711–720.
[32] Benali, Y., Ghomari, F., Latex influence on the mechanical behavior and durability of cementitious materials, *Journal of Adhesion Science and Technology*, 31(3) (2017) 219–241.
[33] Doğan, M., Bideci, A., Effect of styrene-butadiene copolymer (SBR) admixture on high strength concrete, *Construction and Building Materials*, 112 (2016) 378–385.
[34] Ukrainczyk, N. and Rogina, A., Styrene-butadiene latex modified calcium aluminate cement mortar, *Cement & Concrete Composites* 41 (2013) 16–23.
[35] Yang, Z., Shi, X., Creighton, A.T. and Peterson, M.M., Effect of styrene-butadiene rubber latex on the chloride permeability and microstructure of Portland cement mortar, *Construction and Building Materials*, 23 (2009) 2283–2290.
[36] Shadmani, A., Tahmouresi, B., Saradar, A. and Mohseni, E., Durability and microstructure properties of SBR-modified concrete containing recycled asphalt pavement, *Construction and Building Materials*, 185 (2018) 380–390.
[37] Patel, J., Patil, H., Patil, Y. and Vesmawala, G., Strength and transport properties of concrete with styrene butadiene rubber latex modified lightweight aggregate, *Construction and Building Materials*, 195 (2019) 459–467.