International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

The Participation Ratios of Cement Matrix and Latex Network in Latex Cement Co-Matrix Strength

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Accepted 25 November 2013, Available online 01 December 2013, **Vol.3, No.5 (December 2013)**

Abstract

This investigation aims to present a new approach to study the effect of using polymer latex on the performance of latex cement co-matrix strength. This study was carried out to investigate the effect of latex addition with styrene butadiene rubber as chemical base on cement matrix participation ratio in strength of modified cement paste. Degree of hydration, and compressive strength were measured to evaluate the effect of latex addition on cement participation ratio in latex modified co-matrix strength. According to the new approach, latex network has a great participation ratio in co-matrix strength. The second stage in this study shows an attempt to evaluate the latex participation ratio in mortar and concrete strength with different latex chemical bases. The new approach considers the latex with chemical base of acrylic ester, and polyvinyl acetate has similar effect of styrene butadiene rubber. Effect of latex particles size on latex network strength was studied using the new approach. The test results indicated that the latex participation ratio in co-matrix strength is influenced by type of cement matrix, type of curing, latex type, latex solid/water ratio, strength type and age. For modified concrete, when the SBR solid/water ratio increases the latex participation ratios in flexural and pull out bond strength increases. Generally, the latex participation ratio in co-matrix strength decreases as latex particle size increases.

Keywords: *Polymer latex, co-matrix strength, hydration degree, participation ratio.*

1. Introduction

Polymers are being increasingly used in civil engineering applications modifiers, especially for the purpose of improving service performance of both concrete and mortar (AC1 Committee, 2008; Mehta P.K, 2006). In fact, among the different presentations of polymeric substances, polymer latexes are the most widely used (AC1 Committee, 2003). However, inclusion of polymers particularly elastomeric latexes towards improving physical, mechanical and durability properties of normal concrete and mortar may cause undue loss of integrity (Bala Muhammad et al, 2011)

The microstructure of mortar and concrete is of considerable importance since it governs their mechanical properties, cement hydration and durability (AC1 Committee, 2008; Mehta P.K., 2006; AC1 Committee, 2003). In addition, chloride permeability is recognized as a critical intrinsic property affecting the durability of reinforced concrete (Denise A. Silva et al, 2006; Ohama Y., 1995). The use of polymer as a modifier in new structures seems to be a promising strategy in improving microstructure and enhancing the durability of cement mortar and concrete (Fowler D.W, 1999; AC1 Committee, 1998; Ohama Y., 1987). As one of the popular polymers suitable for admixing into fresh mortar and concrete, styrene butadiene rubber (SBR) latex has been widely used for a long time (Pascal S., A. et al, 2004; Schulze J., 1999). The molecular structure of SBR comprises both the flexible butadiene chains and the rigid styrene chains. The combination of those chains offers the SBR-modified mortar and concrete many desirable characteristics ices such as good mechanical properties, water tightness and abrasion resistance (Zhengxian Yang et al, 2009).

On the traditional (unmodified) mortar or concrete, the cement beside other constitutes have the full responsibility on mechanical properties of mortar and concrete. On the other hand, in modified mortar and concrete, latex shares cement and other constitutes on the responsibility of mechanical properties. In the presence of latex, cement does not share on the mechanical properties of modified mortar and concrete by its full capacity.

Many conclusions can be explained by the traditional phenomena such as, the effect of water cement ratio and cement content on the mechanical properties of mortar and concrete. On the contrary, some of test results in this research work cannot be explained easily by the traditional theories such as irregularly of latex modified mortar and concrete compressive strength relation with water cement

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Table 1 Chemical compositions physical and mechanical properties of used cement

Chemical Compositions	Value	Description of test	Value
Loss on ignition at 950 c	2.60 %	Percentage of retaining on sieve no.170 (%)	6.5
Insoluble residue in acid	1.80 %	Compressive strength of cement mortar	
Silicon oxide	22.10 %	- 3 days, (MPa)	18.5
Aluminum oxide	4.30 %	- 7 days, (MPa)	28.6
Ferric oxides	1.60 %	Initial setting time (min.)	175
Calcium oxide	59.10 %	Final setting time (min.)	285
Magnesium oxide	4.42 %	Soundness (mm)	1
Sulfur trioxide	2.40 %		

Table 2 Physical properties of different types of latex

Type	Commercial name	Production Company	Chemical base	Color	Specific gravity	Solids%	Solids particle N.M.S (µm*)
SBR-1	Adebond 65	CMB	Styrene butadiene rubber	Milky white	1.01	45.5	29.7
SBR-2	Sika latex	Sika	Styrene butadiene rubber	Milky white	1.02	35.0	18.2
SBR-3	Techbond SBR	MCC	Styrene butadiene rubber	Milky white	1.03	50.5	72.7
SBR-4	Sikabond latex	Sika	Styrene butadiene rubber	Milky white	1.01	17.0	255.8
SBR-5	Kim latex	Prokim	Styrene butadiene rubber	Milky white	1.02	38.0	153.2
ACR	Sika top 77	Sika	Acrylic	Milky white	1.01	37.0	125.8
PVA	Techbond PVA	MCC	Polyvinyl acetate	Milky white	1.01	38.0	79.7

ratio and cement content. In addition, the effect of polymer solid content and solid chemical base show an irregular trend with the co-matrix mechanical properties.

To interpret these previous phenomena, another expression can be used. This expression is called "Participation Ratio" of cement mixture and latex network in the latex cement co-matrix strength. This is due to the deposition of latex particles on the surfaces of unhydrated cement particles causing a decrease on each of cement matrix hydration degree (polymeric effect) durability (AC1 Committee, 2008; Mehta P.K., 2006; AC1 Committee, 2003). The share of cement on strength of latex cement co-matrix is called cement participation ratio. This phenomenon is described as; during the withdrawal of water in the latex cement co-matrix by hydration process, the latex particles started to deposit on the cement particles surfaces preventing the increase of cement hydration degree (Mehta P.K., 2006; AC1 Committee, 2003; Ohama Y., 1995]. This deposition leads to decrease cement hydration degree as latex solid content increases. This polymeric effect was confirmed by many previous researches (Akihama et al, 1973; Loukili A. et al, 1999; Termkhajornkit Pi. et al, 2012; Ru Wang Ru. et al, 2006; Ray I. et al, 1996). These researches showed that degradation of cement hydration degree due to latex addition, that were resulted a decrease on cement matrix strength (Bertil Pe., 1996; Darquennes A. et al, 2013; Boumiz, A. et al, 1996; Lam L. et al, 2000). Also, there is a linear relationship between strength of modified cement paste and degree of hydration. Bases on the previous phenomenon, one can conclude that the increase of latex cement co-matrix is the sum of cement and latex participation in strength. This study focuses on the participation ratios of cement mixture and latex network in the strength of latex cement co- matrix.

2. Experimental Program

The experimental program of this research divides into two phases; hydration degree and compressive strength of cement paste. The second phase is the mechanical properties of mortar and concrete.

2.1 Materials

Three types of latex chemical base were used; styrene butadiene (SBR), acrylic ester (ACR), and polyvinyl acetate (PVA). Different five particle sizes of styrene butadiene as a chemical base from different commercial companies were considered. The SBR particle size ranges from 18.2 to 255.8 µm. Table 1 and Fig. 1 presents the physical properties and grading of used latex. Type I cement according to ASTM C150 was used in this study. Chemical compositions, physical and mechanical properties of cement are given in Table 2. Natural sand with 2.8 fineness modulus and pink lime stone with nominal maximum size of 9.5 mm were used.

2.2 Mix proportions and test procedure

For first phase, the latex with styrene butadiene rubber (SBR-1) as a chemical base was used in cement paste mixtures (P). The effect of latex addition on cement hydration degree was studied in cement paste. The water cement ratio was kept constant as 0.35. Different concentrations of latex ranged from 0.0 to 50.0% by

Table 3 Mix Proportions, hydration degree, and compressive strength test results of cement paste with SBR-1 latex (P)

Mix No.	Cement (kg)	w/c	Latex solid/water ratio	Water (kg)	Latex wt. (kg)	Degree of Hydration (α)			Compressive Strength (F_{cu}) (MPa)		
						7 Days	28 Days		7 Days	28 Days	
						Dry Curing	Dry Curing	Wet Curing	Dry Curing	Dry Curing	Wet Curing
P1	1472.6	0.35	0.00	515.4	0.0	65.00	68.7	74.9	32.0	38.0	46.0
P2	1455.3	0.35	0.02	509.4	10.2	64.20	66.9	70.2	29.4	34.0	33.0
P3	1430.0	0.35	0.05	500.5	25.0	63.20	65	66.8	24.0	30.0	28.0
P4	1405.7	0.35	0.08	492.0	39.4	62.50	63.7	65.4	27.0	33.6	32.0
P5	1389.9	0.35	0.10	486.5	48.6	61.70	63.2	65	30.0	44.0	35.5
P6	1351.9	0.35	0.15	473.2	71.0	60.40	62.7	64.5	32.2	52.0	40.0
P7	1316.0	0.35	0.20	460.6	92.1	56.40	62.1	64.1	30.0	57.6	44.0
P8	1249.5	0.35	0.30	437.3	131.2	52.30	61.6	63.7	27.0	49.6	43.0
P9	1189.5	0.35	0.40	416.3	166.5	46.50	61	63.5	24.2	46.8	41.0
P10	1134.9	0.35	0.50	397.2	198.6	43.50	60.5	63.1	23.0	43.0	40.0

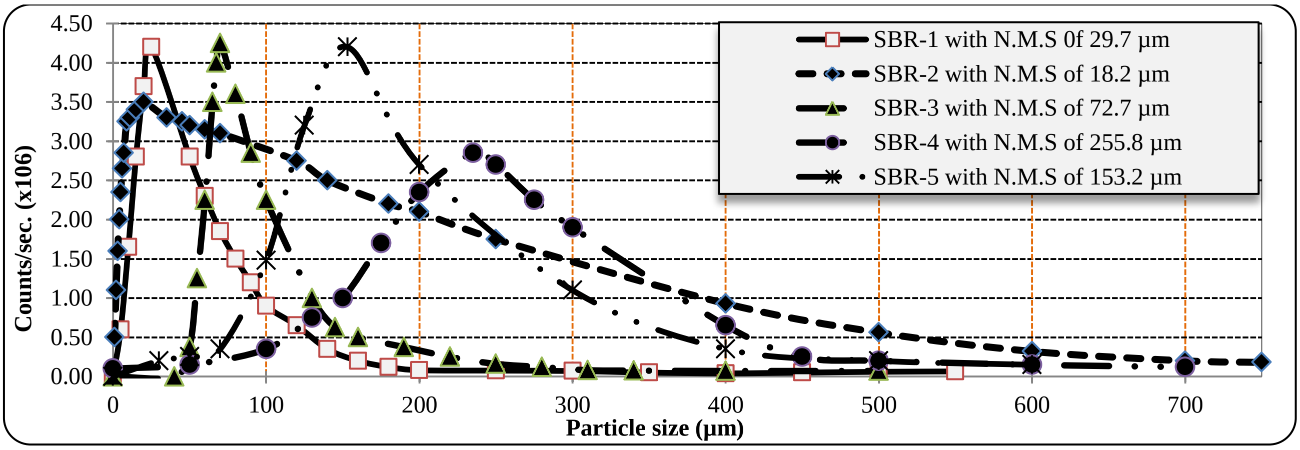

Fig. 1 Grading curve of different types of SBR with nominal maximum particle size (N.M.S) of 18.2, 29.7, 72.7, 153.2 and 255.8 µm.

Table 4 Mix Proportions and compressive strength test results for mortar (M)

Mix No.	Cement (kg)	w/c	Latex type	Sand (kg)	Water (kg)	Latex wt. (kg)	Latex solid/water ratio	Flow (%)	F_{cu} 28 days (MPa)
M1	596	0.28	---	1609	166.9	0.0	0	10	27.3
M2	590	0.28	SBR-1	1593	165.2	9.9	0.06	20	25.0
M3	584	0.28	SBR-1	1577	163.5	19.6	0.12	45	28.5
M4	582	0.28	SBR-1	1571	162.9	21.2	0.13	55	34.3
M5	581	0.28	SBR-1	1569	162.7	22.8	0.14	40	44.2
M6	581	0.28	SBR-1	1569	162.5	26.0	0.16	50	44.6
M7	578	0.28	SBR-1	1561	161.8	29.1	0.18	47	48.1
M8	566	0.28	SBR-1	1528	158.4	39.6	0.25	58	49.2
M9	568	0.28	SBR-1	1534	159.0	42.9	0.27	55	42.6
M10	566	0.28	SBR-1	1528	158.4	50.7	0.32	80	41.0
M11	562	0.28	SBR-1	1517	157.4	56.7	0.36	120	37.7
M12	581	0.28	SBR-1	1569	162.6	24.4	0.15	47	48.1
M13	581	0.28	SBR-2	1569	162.6	24.4	0.15	63	39.6
M14	581	0.28	SBR-3	1569	162.6	24.4	0.15	44	49.2
M15	581	0.28	SBR-4	1569	162.6	24.4	0.15	52	19.9
M16	581	0.28	SBR-5	1569	162.6	24.4	0.15	60	43.2
M17	580	0.28	ACR	1569	162.4	26.0	0.16	15	28.1
M18	566	0.28	ACR	1528	158.4	50.7	0.32	30	24.9
M19	582	0.28	PVA	1569	162.4	26.0	0.16	45	31.4
M20	569	0.28	PVA	1528	158.4	50.7	0.32	65	29.6

Table 5 Mix Proportions, slump, flexural, and bond strength test results for concrete (C)

Mix No.	Cement (kg/m^3)	Latex type	w/c	C.A (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Latex wt. (kg/m^3)	Latex solid/water ratio	Slump (mm)	Flexure 28 days (MPa)	Bond 28 days (MPa)
C1	450	---	0.40	978	652	180	0	0.00	20	5.0	7.5
C2	450	SBR-1	0.40	968	645	180	9	0.05	70	5.3	8.2
C3	450	SBR-1	0.40	959	639	180	18	0.10	100	6.3	8.8
C4	450	SBR-1	0.40	953	635	180	27	0.15	120	7.2	9.4
C5	450	SBR-1	0.40	948	632	180	36	0.20	130	7.8	9.8
C6	450	SBR-1	0.40	939	626	180	45	0.25	150	8.3	10.2
C7	450	SBR-1	0.40	927	618	180	54	0.30	180	8.7	8.5
C8	450	SBR-1	0.40	918	612	180	63	0.35	190	9.5	8.0
C9	450	ACR	0.40	953	635	180	27	0.15	40	6.4	5.7
C10	450	ACR	0.40	939	626	180	45	0.25	60	6.6	7.4
C11	450	PVA	0.40	953	635	180	27	0.15	50	5.6	7.6
C12	450	PVA	0.40	939	626	180	45	0.25	80	6.6	8.5

weight of water content were used. All cement paste specimens were subjected to dry and wet curing methods. In wet curing, the specimens were put in water after 48 hours of casting until testing date while the dried specimens were left in air until testing date. The degree of hydration of cement-modified paste was calculated using the thermo-gravimetric analysis test results (TGA). The determination of degree of hydration depends on the magnitude of the drop in the TGA curve between two distinct data points. The degree of hydration (α) can be calculated from TGA curves using Eq.1 (Abd_Elhakam A. et al, 2012) as follows:

$$\alpha = W_{n(t)} / M_c * W_{n(\infty)} \qquad \text{Eq. 1}$$

where, $W_{n(t)}$ is defined as mass loss recorded between 145 and 1000 C°, $W_{n(\infty)}$ is the ratio of non- evaporable water corresponding to full hydration, M_c is the initial unhydrous cement mass of sample in gram.

Mixture proportions, hydration degree and compressive strength of cement paste with SBR-1 latex are presented in Table 3.

For all mortar mixtures (M) in the second phase, the ratio between cement and sand was kept constant of 1.0: 2.7 by weight. The water cement ratio was kept constant as 0.28. The used concentration of latex solids ranged from 0.0 to 36.0% by weight of water content were used. Three types of latex chemical base were used; styrene butadiene rubber, acrylic ester, and polyvinyl acetate. All mortar specimens were subjected to dry curing. Table 4 shows the mixture proportions, flow percent and compressive strength of cement mortar. To study the effect of particle size of SBR on modified mortar compressive strength, the latex solid/water ratio was kept constant as 0.15 and water cement ratio was 0.28.

For concrete mixtures (C), the ratio between coarse aggregates and sand was kept constant of 1.5: 1.0 by weight and cement content of 450 kg/m^3 was used. A constant water cement ratio was considered as 0.40. The used concentration of SBR-1 latex solids ranged from 0.0 to 35.0% by weight of water content was taken. All concrete specimens were subjected to dry curing.

Flow table test and slump test were performed according to ASTM C 1362 and ASTM C 143, respectively. The compressive strength test of cement paste and mortar according to EN 196 was carried out using cubes with cross section area of 50 cm^2. The ages of testing were 7 and 28 days for cement paste and 28 days for mortar. Three point loading test according to ASTM C293 was considered to determine the 28-day flexural strength of concrete using beams of 100x100x500 mm. 28-day pull out bond strength according to ASTM C234 was measured using a steel bar of 16 mm diameter embedded with length of 200 mm in the center of a concrete cylinder of 150 mm. This test was used only for comparison. Each result for different tests represents the average of three specimens. Table 5 shows the mixture proportions, slump values, flexural, and bond strength of concrete.

3. Test results and discussion

3.1 Phase (I): Cement paste results

3.1.1 Cement degree of hydration

Fig. 2 shows the effect of SBR solid/water ratio (weight of latex solid /weight of total water of concrete including the internal water of latex) on 7 or 28-day cement degree of hydration for cement paste subjected to dry and wet curing with water cement ratio of 0.35. From this figure, generally the increase of SBR solid/water ratio up to 0.10 leads to a noticeable reduction in 28-day cement degree of hydration. For SBR solid/water ratio greater than 0.10 the 28-day cement degree of hydration decreases slightly as SBR solid/water ratio increases. The 7-day cement degree of hydration is less than that of 28-day degree of hydration. Also for high values of latex (SBR) solid/water ratio, more reduction in degree of hydration is obviously observed.

The wet curing method improves the cement hydration degree of both conventional cement paste and modified

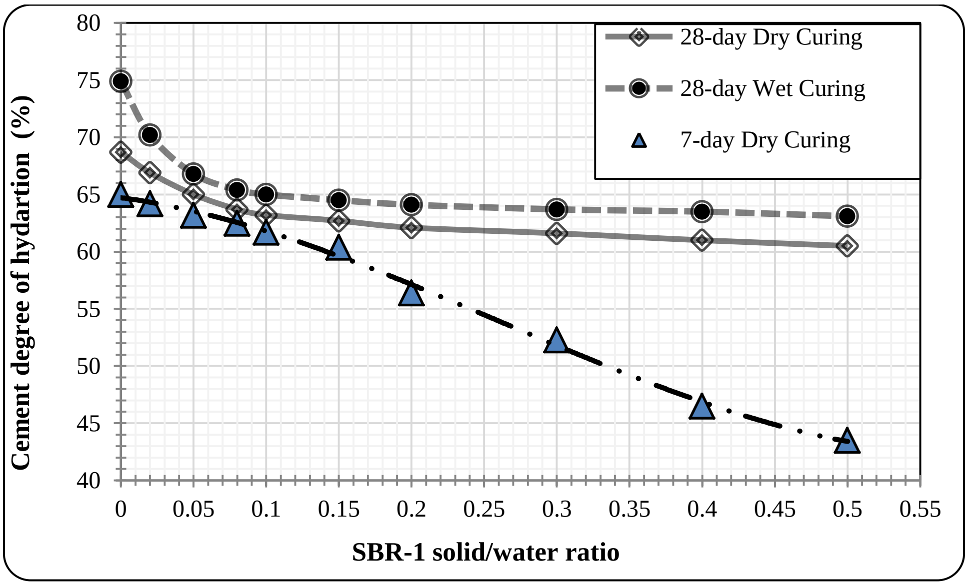

Fig. 2 Relation between 28 days cement hydration degree and SBR solid/water ratio for cement paste with water cement ratio of 0.35

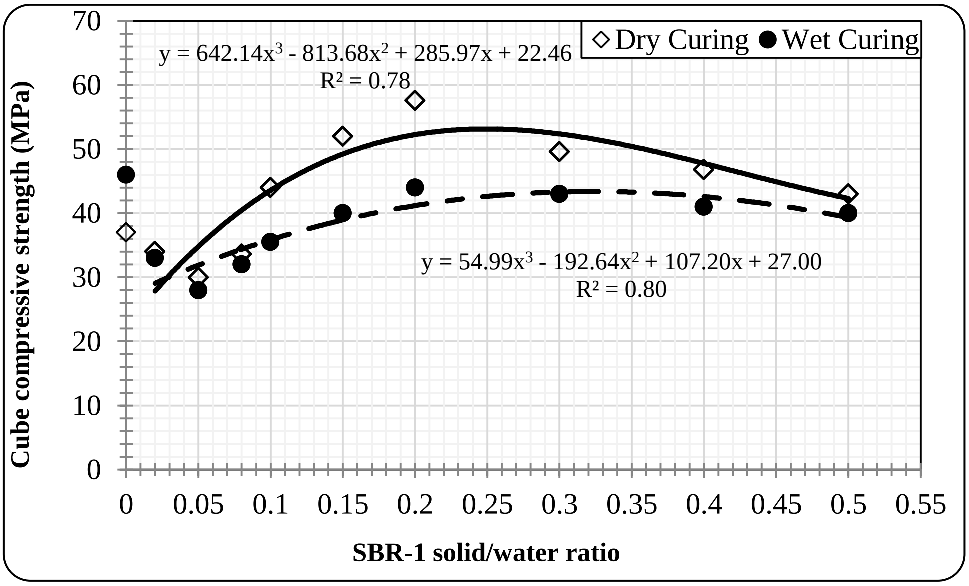

Fig. 3 Relation between 28-day compressive strength and SBR solid/water ratio for cement paste with water cement ratio of 0.35

cement paste. For example, the cement hydration degree for wet cured unmodified cement paste increases by 10% compared with dry cured cement paste. Wet curing enhances cement paste to increase its cement hydration degree after latex hydrolysis phenomenon that happens to latex film after immersing under water for 28 days.

3.1.1 Compressive strength

Table 3 shows the cube compressive strength test result of cement paste at different ages. The effect of SBR solid/water ratio on 28-day cube compressive strength for dry and wet curing with 0.35 water cement ratio is presented in Fig. 3. This figure shows that, generally the cube compressive strength increases as SBR solid/water ratio increases up to certain point and then compressive strength decreases with the increase of latex solid/water ratio. The optimum SBR solid/water ratio ranges 0.20 to 0.30 for cement paste.

As expected, wet curing improves the compressive strength of conventional cement paste. In contrary, the wet curing has a negative effect on compressive strength of modified cement paste. For example, the compressive strength for modified cement paste with wet curing decreases by 20 % compared with that of dry cured specimen at 0.25 solid/water ratio. Wet curing leads cement paste to decrease its compressive strength after latex hydrolysis phenomenon that happens to latex film after immersing under water for 28 days (AC1 Committee, 2008).

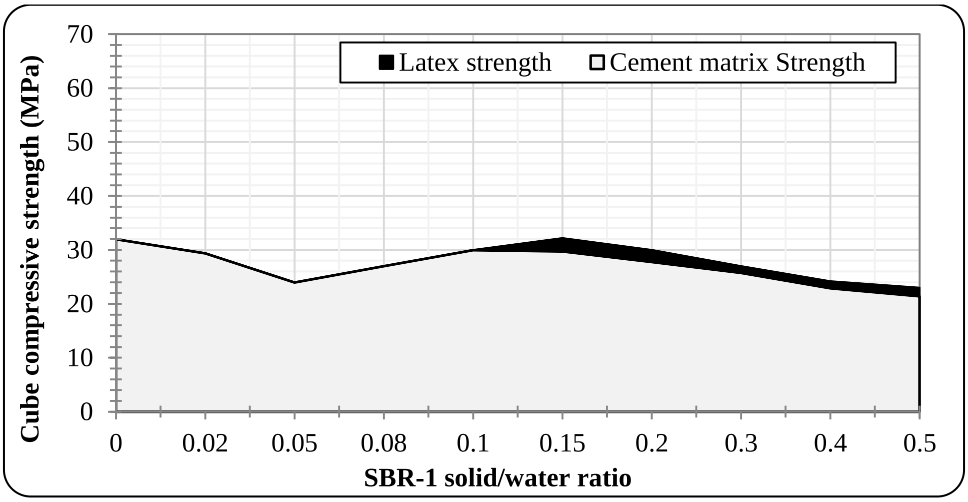

Fig. 4 Effect of SBR latex solid/water ratios on latex network and cement matrix compressive strength at 7days for cement paste co-matrix subjected to dry curing

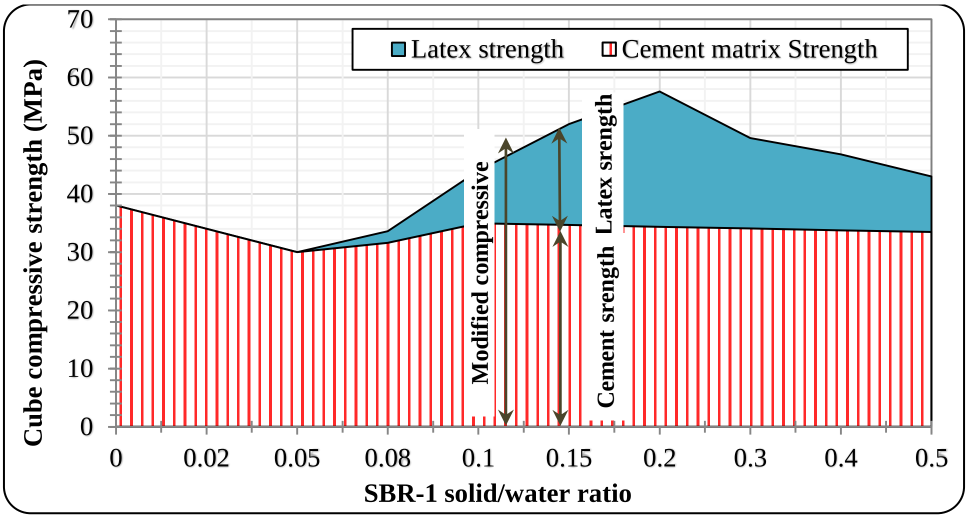

Fig. 5 Effect of SBR latex solid/water ratios on latex network and cement matrix compressive strength at 28 days for cement paste co-matrix subjected to dry curing

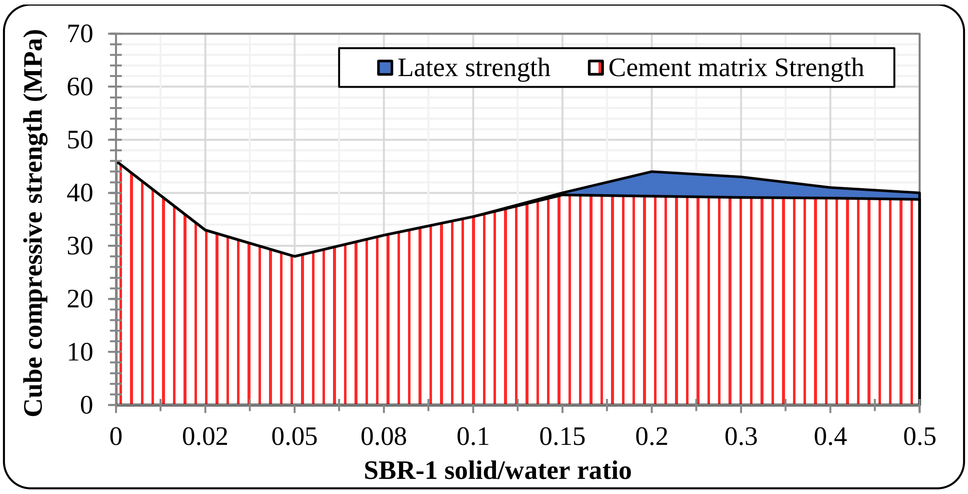

Fig. 6 Effect of SBR latex solid/water ratios on latex network and cement matrix compressive strength at 28 days for cement paste co-matrix subjected to wet curing

3.1.2 Latex cement co-matrix participation ratios

The participation ratios of latex network and cement mixture in co-matrix strength differs in the compressive, flexural, and bond strength of co-matrix. The high tensile and adhesion strength of latex increases the latex network participation ratio in co-matrix flexural and bond strength, while co-matrix compressive strength has a low latex network participation ratio due to the latex low compressive strength.

The participation ratio of latex network at a certain age will be calculated using the following assumption; latex effect on strength consists of two parts. The first is the increase of strength from unmodified cement paste to latex modified paste. The second part tends to the dilation effect of latex on hydration degree of cement. Based on the degree of hydration, compressive strength test results and the assumption of linear relationship between strength of cement modified paste and degree of hydration (Darquennes A. et al, 2013), the effect of latex at modified cement paste strength can be calculated as given in Eq. 2.

$$f_{Latex} = f_{cm} - f_{co}\frac{\alpha_m}{\alpha_o} \qquad \text{Eq.2}$$

where:

f_{Latex} : Latex network strength
f_{cm} : modified cement paste strength
f_{co} : unmodified cement paste strength
α_m : modified cement paste degree of hydration
α_o : unmodified cement paste degree of hydration
$f_{co}\frac{\alpha_m}{\alpha_o}$: cement matrix strength

For instance,
f_{cm} at 28 days for modified cement paste 0.2 SBR solid/water ratio subjected to dry curing = 57.6 MPa
f_{co} at 28 days for unmodified cement paste subjected to dry curing = 38.0 MPa
α_m at 28 days for modified cement paste with 0.2 SBR solid/water ratio subjected to dry curing = 62.1%
α_0 at 28 days for unmodified cement paste subjected to dry curing = 68.7%
f_{Latex} = 57.6 - 38*(62.1/68.7) = 23.25 MPa

Figs. 4, 5 and 6 show the participation of cement matrix and latex network in compressive strength at 7, and 28 days of modified cement paste, respectively. It can be noticed that, for low latex dosages measured as latex (SBR) solid/water ratio up to 0.10, the latex participation ratio in 7-day compressive strength of latex modified cement paste is negligible, while for latex solid/water ratio more than 0.10, the latex participation ratio in 7-day compressive strength is 6.7 % in average. The most compressive strength of modified cement paste is resulted from cement matrix strength.

For modified cement paste with low solid/water ratio (0 to 0.05) subjected to dry curing, the 28-day compressive strength is only due to the cement matrix strength while the latex network strength increases as SBR solid/water ratio increases up to 20% and then latex network compressive strength decreases for higher values of solid/water ratio due to high reduction in cement degree of hydration. At SBR latex solid/water ratio of 0.10, 0.15 and 0.20, the latex network strength is 20.5%, 33.4% and 40.0 % of 28-day modified cement paste compressive strength, respectively, while this strength at 0.40 and 0.50 SBR solid/water ratio is 27.9% and 22.0%. Also, it is clear that the cement matrix strength is almost constant (34 MPa) for modified cement paste with high SBR solid/water (0.10 to 0.50).

The negative effect on latex participation in co-matrix compressive for modified cement paste subjected to wet curing is obviously observed in Fig. 6. From this figure, the latex participation ratio in compressive strength of modified mortar subjected to wet curing is insignificant due to the hydrolysis of latex network in the water (Ohama Y., 1995). In addition, the cement participation ratio in co-matrix strength increases slightly in the water curing due to the slight increase of cement hydration degree. The latex modified paste shows a high stability in wet storage conditions at optimum latex solid/water ratio from 0.20 to 0.30 (Mehta P.K., 2006).

3.2 Phase (II): Predicting the latex network participation in mortar and concrete strength

3.2.1 Predicting the cement degree of hydration

In this study, the application of the concept of latex participation in phase of cement mortar and concrete needs the degree of hydration at w/c of 0.28 and 0.40 for mortar and concrete, respectively. These values are calculated based on test results of hydration degree at 0.35 w/c ratio. The presence of silica in mortar and concrete makes the measuring of cement hydration degree using TGA test is very difficult and not accurate. TGA test depends on the weight loss of sample due to increase of temperature. These measurements differ completely in case of mortar and concrete due to decomposition of silica at the same degree with calcium hydroxide in cement (Ray I. et al, 1996).

Based on the test results of previous researches, there is a linear relation between cement degree of hydration and water cement ratio (Bertil Pe., 1996; Darquennes A. et al, 2013; Boumiz, A. et al, 1996; Lam L. et al, 2000). According to TGA test results on cement paste with 0.35 as water cement ratio, linear regression method can extrapolate the relation between cement degree of hydration and latex solid/water ratio at 0.28 and 0.40 water/cement ratio as shown in Fig. 7. This trend was checked by one experimental test result at 0.25 solid/water ratio for each w/c ratio.

3.2.2 Latex network participation in mortar and concrete strength

The effect of SBR solid/water ratio on 28-day cube compressive strength for dry cured cement mortar with 0.28 of water cement ratio is presented in Fig. 8. This figure shows that, generally the cube compressive strength increases as SBR solid/water ratio increases up to a certain point and then compressive strength decreases with the

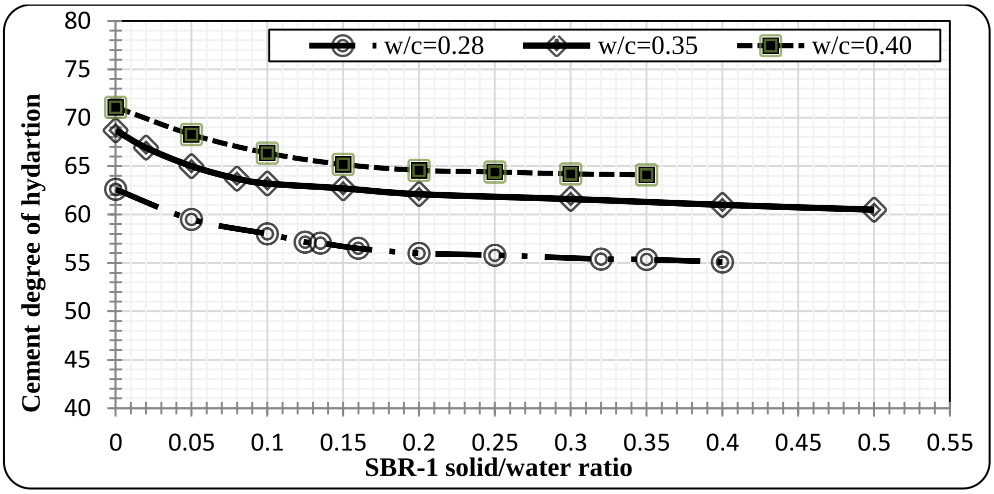

Fig. 7 Relation between 28-day cement degree of hydration and SBR solid/water ratio with water cement ratio of 0.28, 0.35, and 0.40

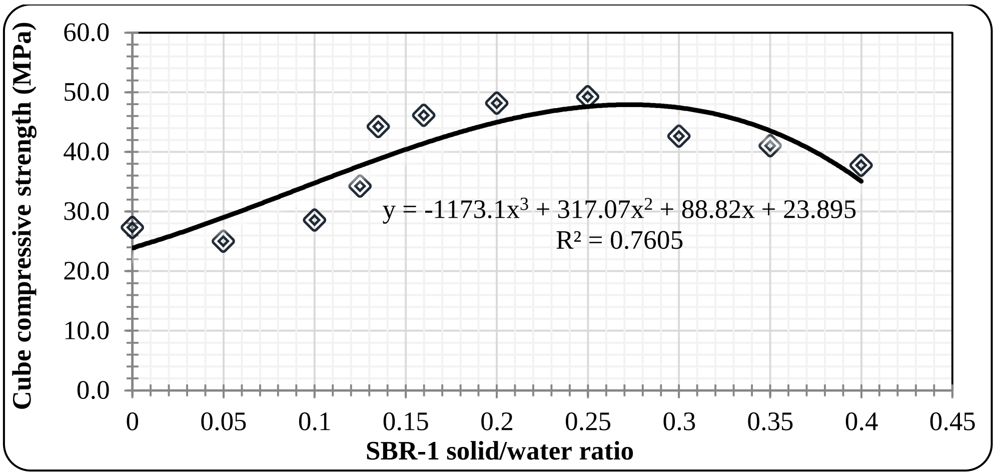

Fig. 8 Relation between 28-day compressive strength and SBR solid/water ratio for cement mortar with water cement ratio of 0.28

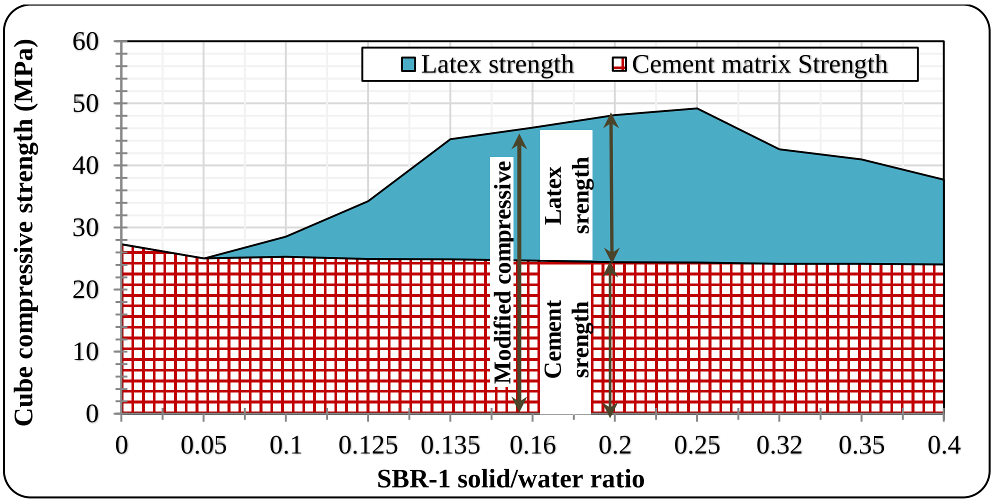

Fig. 9 Effect of SBR latex solid/water ratios on latex network and cement matrix compressive strength at 28 days for cement mortar co-matrix subjected to dry curing

increase of solid/water ratio. The optimum SBR solid/water ratio is about 0.25 for cement mortar.

Fig. 9 shows the participation of cement matrix and latex network at 28 days compressive strength of modified mortar. It can be noticed that, the latex participation in compressive strength of latex modified mortar is similar with the results of modified cement paste. At low solid/water ratio (0 to 0.05), weak latex network does not participate in compressive strength. The latex network strength increases as SBR solid/water ratio increases up to 0.25 and then latex network compressive strength decreases as the solid/water ratio increases. The use of SBR solid/water ratio more than 0.05 does not affect the matrix compressive strength and is clearly constant (24 MPa). At SBR solid/water ratio of 0.10, 0.16 and 0.25, the latex network strength is 11.2%, 46.6% and 50.6% of modified cement mortar compressive strength, respectively, while this strength for 0.32 and 0.40 SBR solid/water ratio is 41.0% and 36.0%, respectively.

This increase of latex network strength in mortar co-matrix is according to the presence of sand, which combines with latex to form the silica latex cross linking relation (Ohama Y., 1987). Ohama describes this phenomenon as; the free calcium ions which formed by cement hydration combines with water, silica aggregate surfaces, and latex carboxylate group to form a cross linking bond between the cement mixture, latex network, and silica aggregate in latex cement co-matrix (Ohama Y., 1987).

Figs. 10, and 11 shows the participation ratios of cement matrix and latex network in flexural and pull-out bond strengths of latex modified concrete, respectively. It can be noticed that, for modified concrete when the SBR solid/water ratio increases the latex participation ratios in flexural and pull out bond strength increases. The increase in latex participation in flexural and bond strength compared with its participation in compressive strength for cement paste or mortar is due to the high tensile and adhesion strength of latex, while the low compressive strength of latex leads to a low contribution of latex network on co-matrix compressive strength. Also from these figures, the flexural and pull out bond strength of cement matrix is almost constant at different used of SBR solid/water ratios. it is about 4.6 MPa for flexural strength and 6.8 MPa for pull out bond strength, while the latex participation ratio in flexural strength at SBR solid/water ratio of 0.10, 0.25 and 0.35 is 26%, 44.9% and 52.5%, respectively. Also the latex participation ratio in bond strength at SBR solid/ water ratio of 0.10 and 0.25 is 20.6% and 33.4%, respectively.

In general, latex modified mortar and concrete show a considerable increase in the compressive, flexural, and bond strengths as compared with unmodified mortar and concrete (Mehta P.K., 2006). This is interpreted in terms of the contribution ratios of high tensile and adhesion strength by the latex network itself and the overall improvement in cement matrix properties. The addition of latex has a double effect on the co-matrix strength. The first effect is the presence of latex membranes in pore structure of co-matrix to increase its general performance (Ohama Y., 1987). The second effect of latex addition is the reducing of water content to get the same workability (AC1 Committee, 2008). This effect is due to the presence of the super plasticizing agents on latex surfactants.

3.2.3 Effect of latex type on Latex network participation in mortar and concrete strength

It can be noticed that, the latex solid chemical base is a significant effect on modified mortar and concrete strength. Figs. 12, 13, and 14 show the participation ratios of different latex chemical bases at the same solid percentage in co-matrix compressive, flexural, and pull-out bond strength. It can be noticed from these figures that, SBR latex has the highest participation ratio in co-matrix strength compared with those of ACR and PVA. The improvement of SBR participation ratio in compressive, flexural, and bond strength may be due to its high tensile and adhesion strength (Ohama Y., 1995).

This variation of latex influence at different chemical bases in co-matrix strength is due to the difference of latex chain length and latex tensile strength (AC1 Committee, 2008; Jae-Ho Kim et al, 1998; Lavelle J. A., 1987). So SBR modified concrete generally has the highest value of flexural strength compared with latex modified concrete with ACR and PVA due to its high tensile strength (Jae-Ho Kim et al, 1998).

Lavelle concluded the relation between the compressive, flexural strengths and the unit weight of latex modified mortar and concrete (Lavelle J. A., 1987). Therefore, the high compressive and flexural strength of SBR cement co-matrix is corresponding to the high performance of SBR on co-matrix unit weight, while the light unit weight of ACR and PVA modified mortar produced a low compressive and flexural strength (Mehta P.K., 2006; Ohama Y., 1995).

3.2.4 Particle size effect on latex participation in mortar strength

The size of dispersed polymer particles of latexes affects the strength of latex cement co-matrix (Mehta P.K., 2006). Fig. 15 shows the effect of SBR particle size on the co-matrix strength. It can be noticed that, for SBR latex, the compressive strength increases as latex particle size increases up to 75 μm while for particle size more than 100 μm the compressive strength decreases as latex particle size increases. For example, 28 days compressive strength of mortar with SBR particle size of 72.7 μm is higher than that of particle size of 29.7 μm and 255.8 μm by 12.8% and 185.8%, respectively.

It can be concluded from Fig. 16 that, the latex participation ratio in co-matrix strength decreases as latex particle size more than 29.7 μm increases. Latex compressive strength participation ratios of particle size of 18.2 μm, 29.7 μm, 72.7 μm, 153.2 μm, and 255.8 μm are 14%, 42%, 37%, 32% and 9%, respectively. From these results, particle size of 29.7 μm gives the highest value of latex compressive strength participation ratio compared with those of used particle size of SBR. Ohama showed

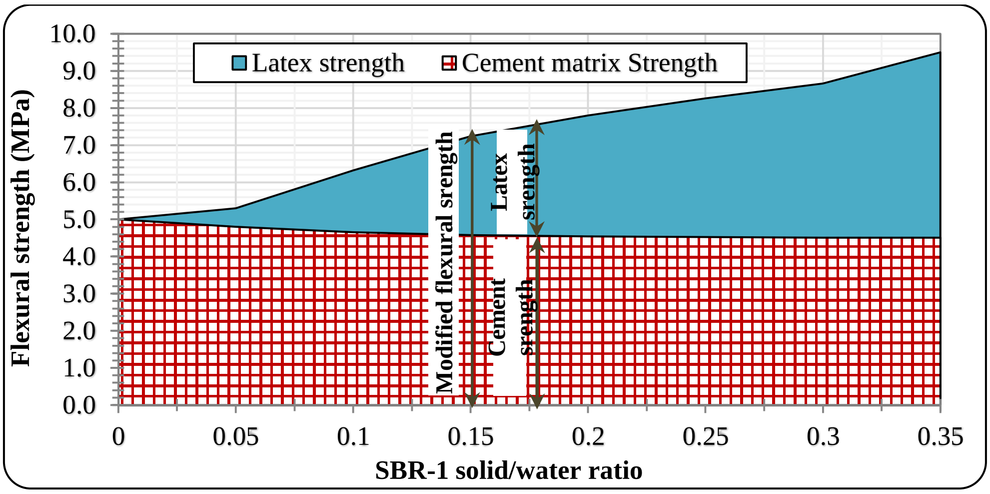

Fig. 10 Effect of SBR latex solid/water ratios on latex network and cement matrix flexural strength at 28 days for latex modified concrete subjected to dry curing

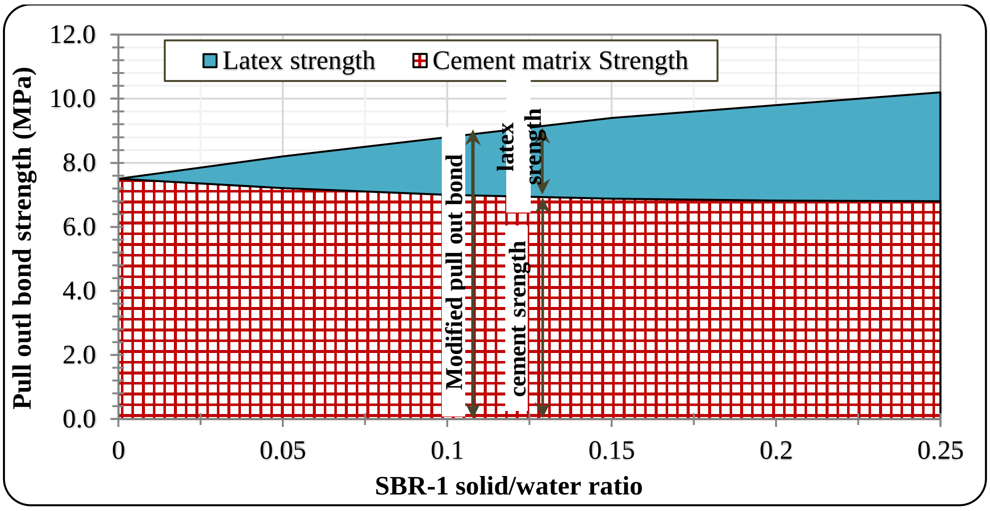

Fig. 11 Effect of SBR latex solid/water ratios on latex network and cement matrix pull out bond strength at 28 days for latex modified concrete subjected to dry curing

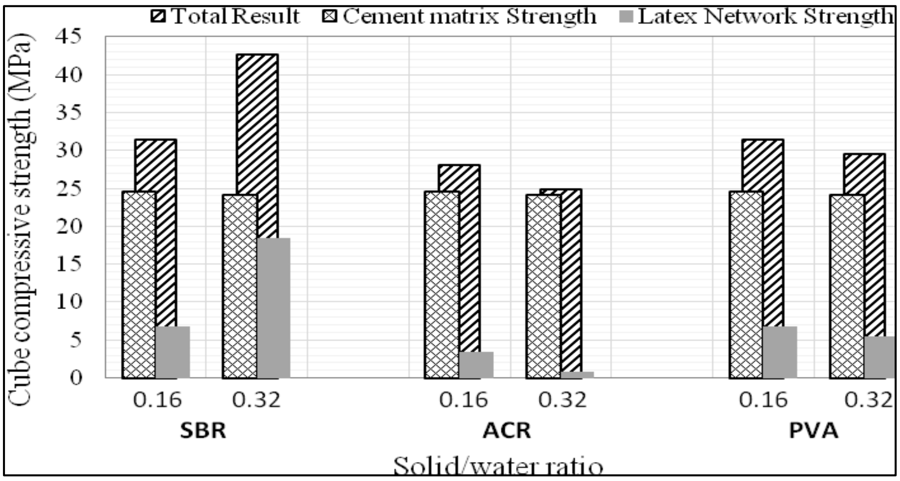

Fig. 12 Effect of latex chemical base on mortar compressive strength at 28 days with 0.16 and 0.32 latex solid/water ratio

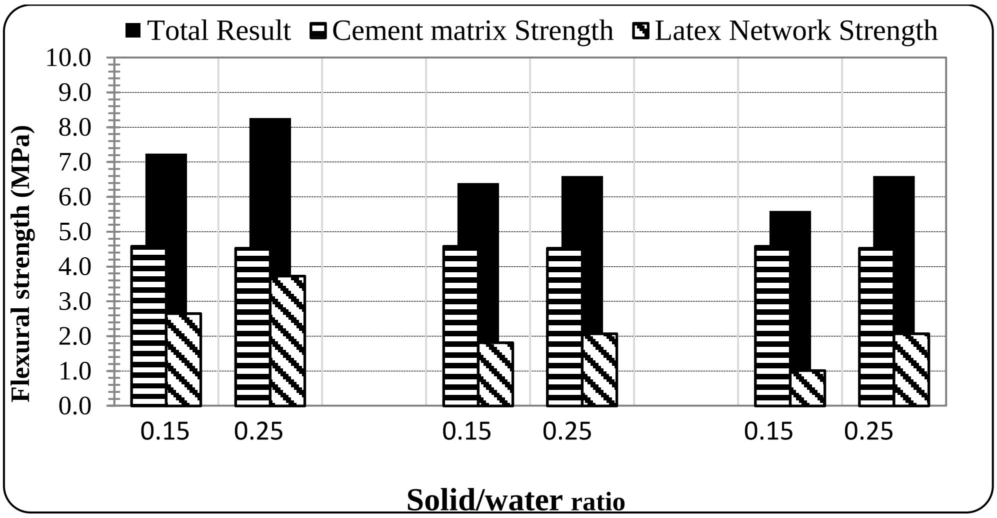

Fig. 13 Effect of latex chemical base on concrete flexure strength at 28 days with 0.15 and 0.25 latex solid/water ratio

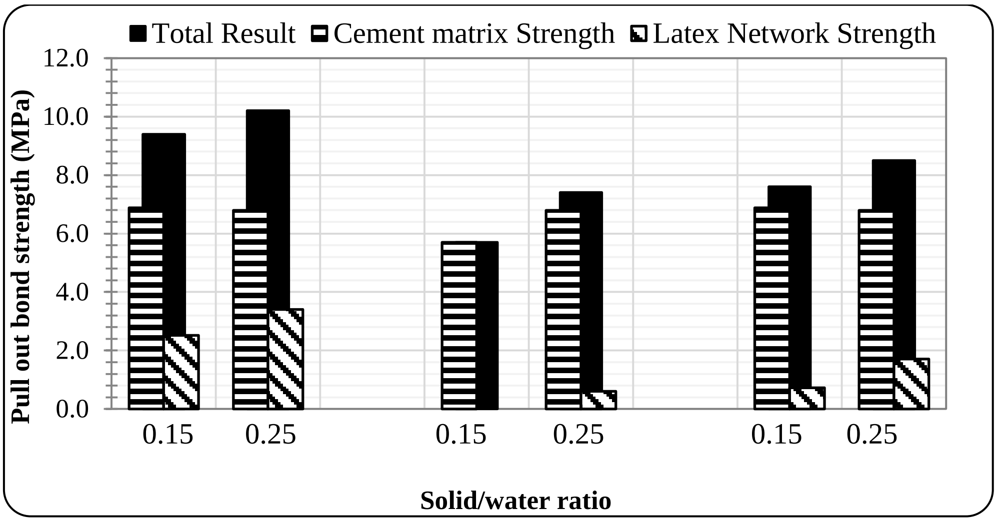

Fig. 14 Effect of latex chemical base on concrete steel bond strength at 28 days with 0.15 and 0.25 latex solid/water ratio

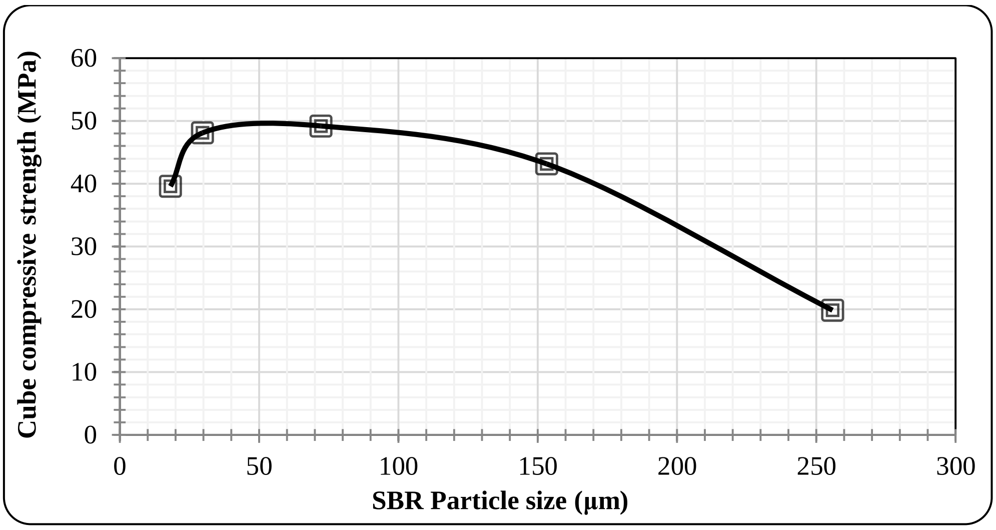

Fig. 15 Effect of SBR particle size on mortar compressive strength at 28 days with 0.15 latex solid/water ratio

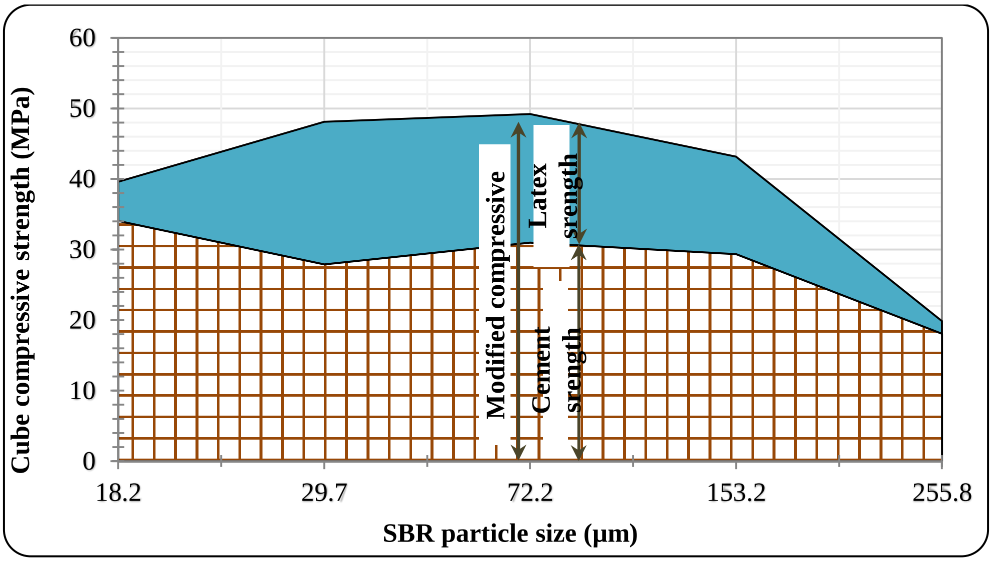

Fig. 16 Effect of particle size with 0.15 latex solid/water ratio on latex network

that there is a strong interaction between styrene acrylic ester latex particles and cement grains after mixing. Based on latex particle size, only a small part of latex particles are free dispersing in pore solution and more than 70% of them are absorbed by cement grains or the hydration products (Ohama Y., 1987). In addition, the contribution ratio of latex network on co-matrix strength tends mainly on the tensile strength of latex membrane which depends on latex particles coalescence degree. The latex with small particle size and good grading has a high effect on the increase of latex deflocculating degree, which tends to have high coalescence degree (Ohama Y., 1995; Loukili A. et al, 1999).

Conclusions

Based on the experimental test results which have been discussed in detail previously, the following conclusions can be drawn:

1. The strength of modified cement paste, mortar and concrete divides into latex network strength and matrix cement strength. These strengths depend upon unmodified cement paste degree of hydration and modified cement paste degree of hydration.
2. The cement degree of hydration decreases as latex solid/water ratio increases.
3. The wet curing enhances the degree of hydration of modified cement paste by 10%.
4. The latex participation ratio in co-matrix strength is influenced by type of cement matrix (cement paste, mortar or concrete), type of curing (dry, wet), latex type, latex solid/water ratio (dose), strength type (compressive, flexural or bond strength) and age.
5. For low SBR solid/water ratio up to 0.10, the latex participation ratio in 7-day compressive strength of latex modified cement paste is negligible, while for latex solid/water ratio more than 0.10, this ratio is 6.7 % in average.
6. Latex network strength for modified cement mortar subjected to dry curing at 28 days increases as SBR solid/water ratio increases up to 0.20 and then latex network compressive strength decreases for higher values of solid/water ratio. At SBR latex solid/water ratio of 0.10, 0.15 and 0.20, the latex participation ratio in 28-day compressive is 20.5%, 33.4% and 40.0 %, respectively,
7. The latex participation ratio in 28-day compressive strength of modified mortar is higher than that of modified cement paste. The latex participation ratio in 28-day compressive of modified mortar with SBR solid/water ratio of 0.16 and 0.25 is 46.6% and 50.6%., respectively.
8. For modified concrete, when the SBR solid/water ratio increases the latex participation ratios in flexural and pull out bond strength increases. The ratio in flexural strength at SBR solid/water ratio of 0.10, 0.25 and 0.35 is 26%, 44.9% and 52.5%, respectively. Also the latex participation ratio in bond strength at SBR solid/ water ratio of 0.10 and 0.25 is 20.6% and 33.4%, respectively.
9. The latex participation ratio in co-matrix strength decreases as latex particle size more than 29.7 µm increases. Latex compressive strength participation ratios of particle size of 18.2 µm, 29.7 µm, 72.7 µm, 153.2 µm, and 255.8 µm are 14%, 42%, 37%, 32%, 9%, respectively. The optimum particle size is 29.7 µm.

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