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Curing effect on mortar properties produced with styrene-butadiene rubber

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Abstract. This paper presents an experimentally investigation pertinent to the mechanical properties of rubberized mortar (RM) with styrene-butadiene rubber (SBR). The SBR were used with constant water-to-cement ratio of 0.485 and two different volume proportion of SBR particles were utilized as aggregates. One types of SBR particles with fineness modulus of 4.951 were utilized 0%, 10%, and 20% of aggregate volume. Effectiveness of SBR replacement ratio, curing and aging effect on the compressive strength, flexural strengths as well as load-displacement. Compressive and flexural strength of concrete were investigated at the end of 28-days and 56-days age. Obtained results demonstrated that utilization of SBR reduced the flexural strength of SBR mortar at the earlier curing age while SBR increased. Moreover, mechanical properties of mortar mentioned above were significantly affected by the water cure timing with an increasing proportion of the replacement level of SBR.

Keywords: fineness modulus; styrene-butadiene rubber; mechanical properties; rubberized mortar

1. Introduction

All engineering facilities are located on the idea of minimum cost, maximum serviceability and durability. Environmental friendly solutions draw attention to fulfill minimum cost to protect natural resources and to reuse waste material in civil engineering facilities. For this purpose, many alternative waste materials are evaluated in a study (Cemalgil and Onat 2016). Silica fume, fly ash and rubber can be listed for alternative external material can be used for mortar (Benli *et al*. 2017, Karataş *et al*. 2017, Turk *et al*. 2017). Rubber is one of the most abundant material obtained from discarded tire. The purpose of using rubber in construction industry is to obtain high toughness. Rubber contributes resistance against dynamic loading (Onat and Celik 2017). The accumulation of discarded tires allows potentially outbreak fire and result in health hazards (William and Weaver 1987, Resources Conservation Consultants 1987). In recent years, there has been a huge increase in the tires being scrapped by the rapid increase in production in the automobile industry. More than one billion tires are discarded every year on the world. This waste tire amount constitutes approximately 21% of a mixture of asphalt tile and Portland cement concrete (PCC) in a mixture among civil engineering applications (USEPA 2011). Most tires that are thrown is buried in landfill sites. Rubber is used maximum 25 % amount in a daily used commercial goods as a fuel or as a raw material for the manufacturing industry. The burial of scrap tires in the storage areas is unnecessary and costly. Because most of the storage lands are prohibited for the disposal of whole tires is bulky and tends to come to the surface over the time. The shredding process requires special equipment for per tire and cost is about $1. Adding more tires to decrease the disposal costs to prevent customers, several storage areas are required. The cost of storing is about $2 for per tire (Compressed Air Magazine 1988). Using disposal scrap tire rubber as aggregate in Portland cement concrete is a possible solution. However, using this scrap tires as in chip format is another solution to conduct an experimental study is another possible use. Selected mechanical properties of rubber mortar contains rubber particles as aggregate into the size of the pieces like in concrete and the percentage of the tires were determined by the grinding method.

Potential use of rubber-modified cement mortar has been reported by Xue and Cao (2017). Contemporary use of grout, floor and wall surfaces is widely applied for engineering purpose as decoration. Traditional water permeability of mortar and bonding property is weak. Wet surface before the mortar application cause hardness due to the rate of evaporation. Because, the rate of evaporation is faster than the rate of internal bleeding. This situation cause shrinkage and then stress distribution in the mortar. Once propagated internal stress excessed tensile strength, shrinkage cracking will be occurred. In addition, after exposing surface cracks of the mortar to low humidity, this situation may occur in the air during the long duration, the cracks gradually get deeper and expand. Deeper and propagated cracks seriously weaken the reinforced concrete structure. In the 1970s, cracking resistance of mortar is tried to be improved by polymer mortar. Due to high costs, unexpected behavior and poor durability reasons, using polymer mortar is given up. There are many methods to increase the toughness of cement and concrete as the addition of rubber particles in the concrete between them.

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Due to increasing attention of many scientists, using rubber or latex in concrete became the subject of research in the last years.

Tire steel reinforces rubber elastomer. Rubber products, natural rubber and combination of these listed products with high strength material contributes exceptional durability against fatigue, tension and cutting. Metallic rubber has excellent adhesion and low hysteresis codes and helps to maintain the integrity for a long time. Recycling tire uses some of these unique features. Recycling of scrap tires is an alternative due to some promising options to produce steam and electricity with incineration of tires (Fedford *et al*. 1996, Siddique and Naik 2004). Scrap tires, artificial reefs, as recommended earlier by other researchers, has been successfully used in cement kilns (Fattuhi and Clarck 1996). Mahdi *et al*. (2005) used scrap tires underground and buried infrastructure systems for scrap tires protective lining. Utilizing the tire due to high adhesion properties and durability is common in a number of applications. Other successful uses of scrap tires can be listed like acidic hot asphalt, recycled pavement, sub-floor insulation, lightweight fill material, drainage material, construction material fills and sets in the path of fluid includes the use under highway pavement. Asphalt concrete contains tyre rubber particles are one of the major studies have been reported in the literature (Fedford *et al*. 1996, Zanzotto *et al*. 1999, Pierce and Blackwell 2003).

Benazzouz *et al*. (2003) implemented an experimental study with rubber particles mixing between 15% to 35%. Then it was reported that since temperature of this mixture rises to a certain degree, bending strength and the compressive strength is decreased. Sangson *et al*. (2011) mixed rubber obtained from waste tires used with aggregate particles. It was emphasized that this mix has dropped slightly elastic modulus and compressive strength of the concrete. Meanwhile, increasing curvature ductility around 90% was reported in the same study. Adding certain amounts of rubber particles in cement-based materials improves toughness, impact resistance, sound and thermal insulation properties (Turatsinze *et al*. 2007). Whereas there are opposite studies claims that adding rubber to concrete decreases engineering properties (Huang *et al*. 2013, Turatsinze *et al*. 2005, Akkaya *et al*. 2007) like bending strength, compressive strength, resilient resistance and impact resistance. Benazzouk *et al*. (2003) propounded that the 28-day compressive strength of cement–rubber composites, produced with 1-4 mm size rubber aggregate, decreases engineering properties considerably, when the rubber aggregates amount increases. Furthermore, it is reported in the same paper that the compressive strength loss trend is slightly influenced by aggregate size. However, for a given amount of rubber, finer aggregates lead to obtain lower losses in compressive strength than coarse aggregates. Losses reach up to 85% of the compressive strength and reach up to 50% of the tensile strength. These losses depend mostly on the percentage of rubber. Turki *et al*. (2009) showed that the thickness values of layer between rubber aggregates and cement matrix changes with an increasing trend against the increasing content of rubber aggregate distribution. This result shows that the global porosity might be affected by the void space observed between matrix and rubber aggregates. Due to the increasing of rubber aggregates substitution influenced the adherence of cement paste and the mechanical behavior of specimens. All strength loss causes due to rubber creates weak bonding with cement paste. As a result of the increasing ratio of SBR replacement cause the mechanical strength loss for the same water cure and testing age time (Goldstein 1965, Toutanji 1996, Eldin and Senouci 1989). Khatib and Bayomy (1999) investigated the mechanical properties of rubberized Portland cement concrete. According to their study the flexural strength tended to decrease with the increasing rubber content in a similar manner to that measured in the compressive strength. Their experimental study showed that the initial rate of strength reduction was steeper than that of the compressive strength.

A wide variety of polymer types have been investigated for use of Polymer-modified cementitious mixtures (ACI 1997), but the majority types of used today are as follows: Styrene-butadiene copolymers, acrylic ester homopolymers and copolymers, particularly with styrene, vinyl acetate copolymers, vinyl acetate homopolymers (Çavdar *et al*. 2014). Copolymers of styrene and butadiene produced from a general-purpose synthetic rubber with Styrene-Butadiene Rubber (SBR). With over consumption of all other synthetic rubbers, which is called as SBR and possible to see in a daily use on automobile and truck tires in a large quantity.

In the current study, effectiveness of water cure effect and SBR amount on the mechanical properties of mortar was investigated through an experimental program. The mortar properties were determined in terms of compressive and load-displacement measured flexural strengths at the end of 28 and 56 days' age. The type of cure method is water curing and the changing parameter is curing time. The curing time applied for 3 days, 7 days and 28 days. Mortars were produced with a constant water/cement ratio and two different SBR contents were considered. One types of SBR particles with fineness modulus of 4.951 were mixed with 0%, 10% and 20% of aggregate by volume.

2. Experimental campaign

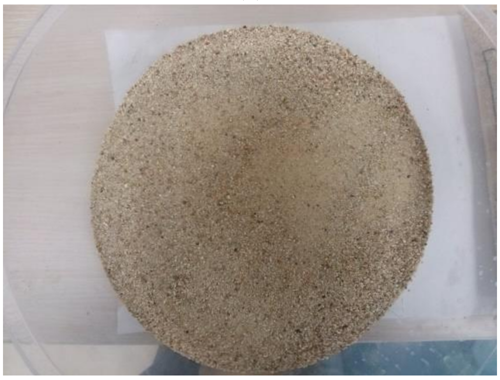
2.1 Materials

Table 1 Physical properties and chemical compositions of Portland cement and fly ash

Chemical analysis (%)	Portland cement
CaO	63.84
SiO_2	19.79
Al_2O_3	3.85
Fe_2O_3	4.15
MgO	3.22
SO_3	2.75
K_2O	-
Na_2O	-
Loss on ignition	0.87
Specific gravity	3.15
Fineness (cm^2/g)	3260*

*Blaine specific surface area, -=not measured items

(a)



(b)

Fig. 1 Photographic view of: (a) SBR particle (b) Standard RILEM Cembereau sand

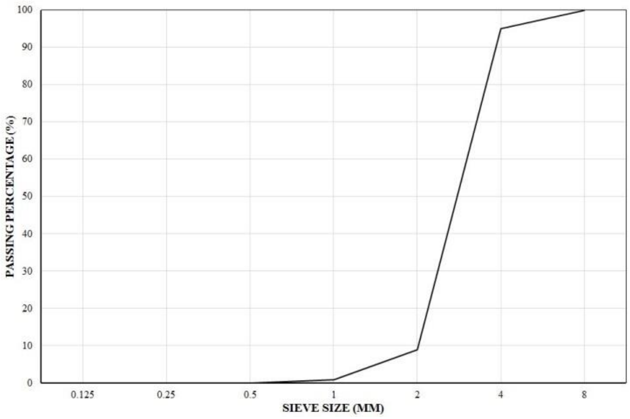


Fig. 2 SBR particles sieve analysis

Ordinary Portland cement (CEM I 42.5R) was used in mixture. Specific gravity of used cement was 3.15 g/cm3 and Blaine fineness was 3260 cm^2/g. Chemical composition of the cement is given in Table 1.

Standard RILEM Cembereau sand was used as fine aggregate (TSE 1989). Aggregates were saved in water along 24 hour and then Specific Gravity of the saturated surface dry (SSD) were measured according to ASTM C127 (ASTM 2002). Specific Gravity and Water Absorption were measured 2.263 and 0.61% respectively. SBR substituted with the RILEM Cembereau sand 10% and 20% by volume. SBR specific gravity is 1.013. SBR and RILEM sand used as shown in Fig. 1(a), 1(b).

Sieve analysis of SBR is plotted in Fig. 2.

Table 2 Mix proportions for 1 m^3 mortar (in kg/m^3)

Mix ID	Cement	Water	RILEM sand	Volume fraction of SBR* (%)	SBR*
RSM0R	520	252.2	1430.1	0	0
RSM10R	520	252.2	1287.1	10	55.23
RSM20R	520	252.2	1144.0	20	110.46

* SBR: styrene-butadiene rubber

Fig. 3 Slump flow test according to ASTM C1437 (ASTM 2001)

Eldin and Senouci (1994) reported the unit weight of the dry rodded rubber between 800 and 960 kg/m^3. In addition, reported specific gravities for different types of rubber used in the different investigations widely varied (0.65, 0.80 and l.06-1.09). Possible reasons for the variations in specific gravities could be the rubber quality and/or experimental errors (Ali *et al*. 2000, Rostami *et al*. 2000, Topçu 1995).

2.2 Mix proportions

To investigate the curing effect on mechanical and fracture properties of mortar produced with SBR and blended standard cement, a total of 3 mortar mixes were designed with constant water/cement ratio (*w/c*) of 0.485 and cement content of 520 kg/m^3. Mortars were produced with two different SBR aggregate replacement ratio of 10% and 20%. Furthermore, to assess the curing effect on the rubberized mortar, 3 different mix ratios and 3 different curing ages were considered. For this purpose, produced mortar specimens were saved in water bath at 22±2℃. Actual proportions for 1 m^3 concrete were tabulated in Table 2.

Table 3 Slump flow values for mixes

MIX ID	Curing time (day)	Flow table diameter (cm)	
RSM0R	3 day curing	18.0	18.5
RSM0R	7 day curing	17.5	18.0
RSM0R	28 day curing	19.0	19.5
RSM10R	3 day curing	18.5	18.0
RSM10R	7 day curing	20.0	20.5
RSM10R	28 day curing	18.0	18.5
RSM20R	3 day curing	22.0	23.0
RSM20R	7 day curing	19.0	19.5
RSM20R	28 day curing	19.0	19.5

In mix ID, volume fraction of SBR aggregate is represented by *R*. For example, RSM0R indicates that the Rilem Sand Mortar (RSM) mixture is designed with SBR content of 0%.

2.3 Specimen production and curing

Power-driven revolving pan mixer with capacity of 5 liters was used to mix the mortars. SBR particles were used as fine aggregate for all mixtures. First, RILEM sand, SBR particles and cement were started to be mixed in the mixer with a speed of 140 r/min during 30 second. After the dry mixing completed, water added to mixer and mixed for along 30 second with a speed of 280 r/min. Finally, the mixer was stopped and quickly scrape down into the batch. Any mortar that may have collected on the side of the bowl then the mixing finish with a speed of 280 r/min during 60 second. Workability measurements were implemented with flow table test according to ASTM C1437 (ASTM 2001) as shown in Fig. 3.

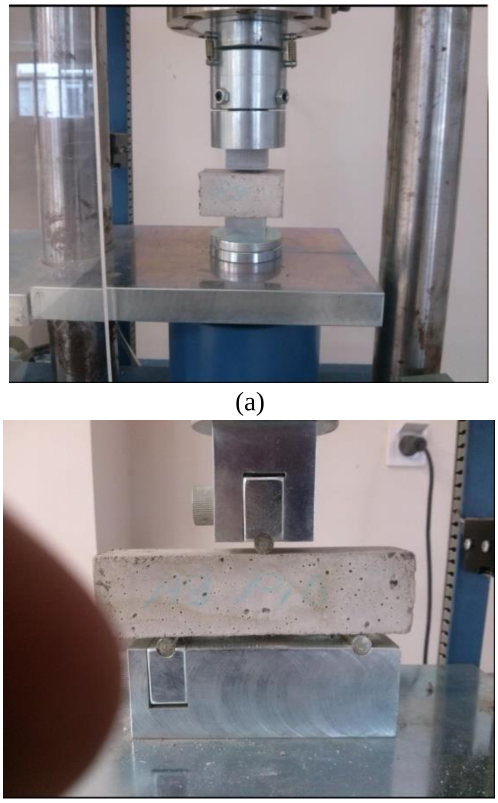
The measured slump values were 18±1 cm for control mixes, whereas slump values of SBR blended mortar with 10 and 20% replacement level were 19.5±1 cm and 21±2 cm respectively.

Fresh concrete was casted into steel molds in two layers and vibrated for a couple of seconds. The specimens were wrapped with plastic sheet and saved in the laboratory along 24 h at 20±2℃ and then they were demolded and cured in water according to curing time as given in Table 3.

2.4 Testing procedure

Compression test was conducted with respect to ASTM C109 (ASTM 2002) and ASTM C349 (ASTM, 2002). 40x40x160-mm prisms and 50x50x50 mm prismatic molds were used to determine flexural strength and compressive strength at the age of 28 and 56 days. Three specimens utilized for each testing. Firstly, prisms were tested to assess flexural strength after that broken 2 parts tested for compressive strength. Compressive strength test of broken prisms was implemented at 28 and 56-day ages. Only compressive strength test of cube specimen was performed at 56-day age as shown in Fig. 4.

Compressive strength test of cube specimens was carried on with a constant load rate of 1kN/s. Flexural strength test was performed according to ASTM C348-14



(a)

(b)

Fig. 4 (a) Compression test and ASTM C349 (ASTM 2002), (b) Flexural strength ASTM C348-14 (ASTM)

code (ASTM), and the flexural strength was obtained using the following equation

$$S_f = 0.0028 * P \tag{1}$$

where S_f and *P* are the flexural strength and maximum load, respectively. Units of S_f and *P* are MPa and N, respectively. Besides, for the compressive strength of broken prisms were implemented on the base of ASTM C349 (ASTM) and the compressive strength was obtained using the following equation

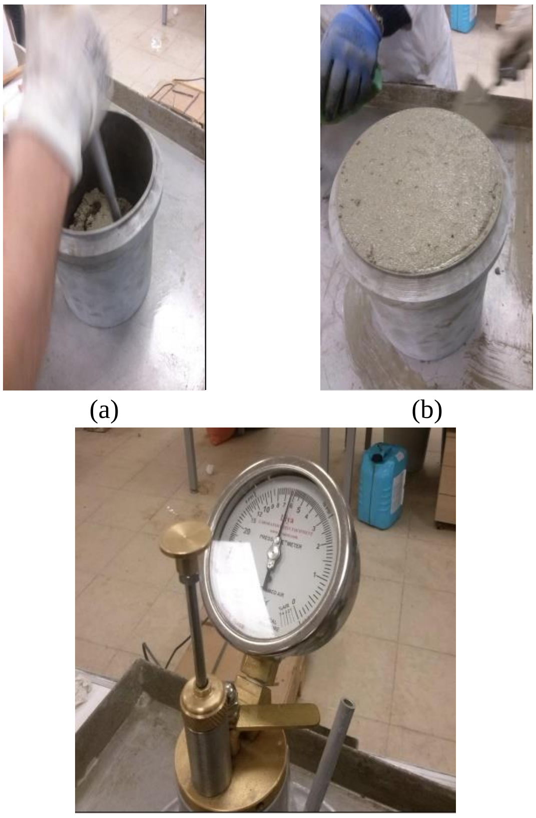
$$S_c = 0.00062 * P \tag{2}$$

where *Sc* and *P* are the compressive strength and maximum load, respectively. Units of *Sc* and *P* are MPa and N, respectively.

Load-displacement behavior of cube specimen was measured by a linear variable displacement transducer (LVDT). Load versus deflection curve was obtained for each specimen. Fracture energy is calculated by using the total area under the load versus deflection curve for the mortar.

Air content of freshly mixed mortar was conducted with respect to ASTM C231 (ASTM, 2002) and application of this test is also used for fresh density measurement (Fig. 5).

Results of air content measurement are 6, 5.33, and 5 for 0%, 10%, and 20% replacement level of SBR aggregates, respectively. After mortar was placed into the container of air meter as shown in Fig. 5(b), its weight is measured by using a balance and then the density equation was used for



(a) (b)

(c)

Fig. 5 (a) Mortar were placed, (b) Density measurement, (c) Air content measurement

Table 4 Density and air content of mix.

MIX ID	Fresh density (kg/m3)	Air content (%)
RSM0R	2.178	6.0
RSM0R	2.183	6.0
RSM0R	2.184	6.0
RSM10R	2.152	5.5
RSM10R	2.109	5.0
RSM10R	2.117	5.5
RSM20R	2.053	5.5
RSM20R	2.049	4.5
RSM20R	2.082	5.0

freshly mixed mortar. According to results of fresh density of mortars are 2.182, 2.126, and 2.061 for 0%, 10%, and 20% replacement level of SBR aggregates, respectively. The results of mix design were summarized in Table 4 for density and air content.

3. Results and discussion

A brief presentation of the test results on the base of compressive strength, flexural strength, and fracture energy produced with two different ratios of SBR aggregate volume fractions are given in Table 5. The data presented in Table 5 were used for graphical presentation of the test results for evaluation and discussion under related sub-sections.

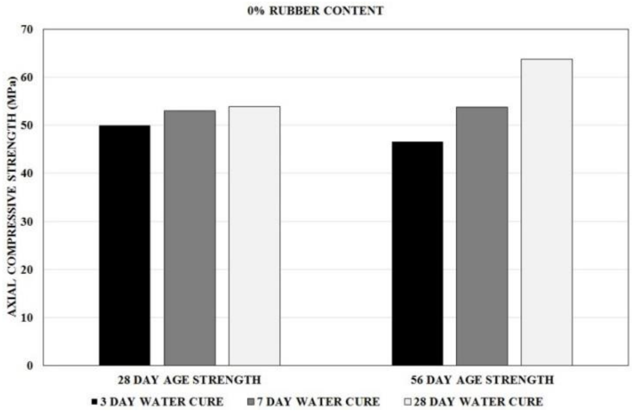


Fig. 6 Control mix compressive strength change with the curing time

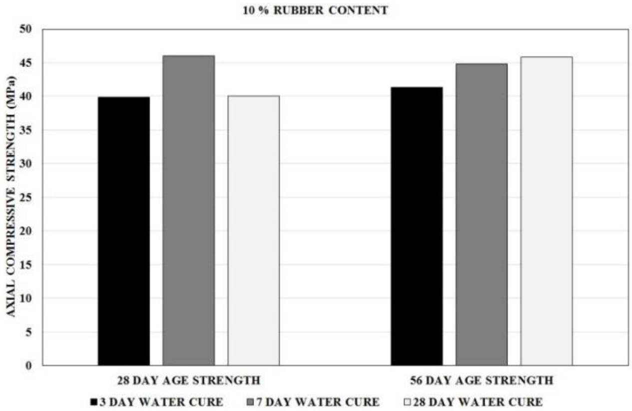


Fig. 7 10% SBR replacement effect on compressive strength change with the curing time

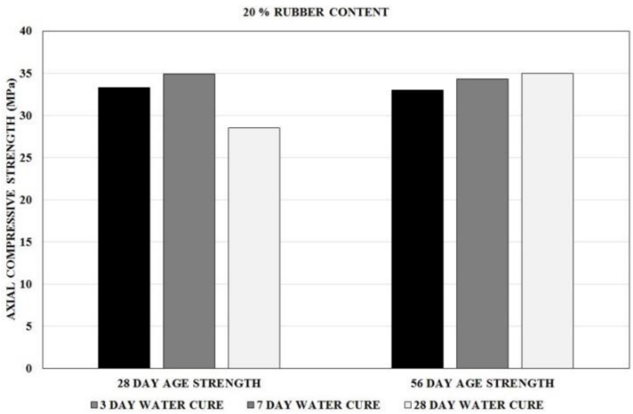


Fig. 8 20% SBR replacement effect on compressive strength change with the curing time

3.1 Compressive strength

Compressive strength test results obtained from broken prisms samples are demonstrated in Table 5 and the change in compressive strength of mortar containing 0%, 10%, and 20% SBR replacement are shown in Figs. 6, 7, and 8, respectively.

Compressive strength was measured 49.91 MPa and it provides the minimum condition according to TS EN 197-1 (2012). Besides, it is clearly seen from the results the

Table 5 Mechanical properties of concretes

		…..28 days prisms..….		…...56 days prisms.….		…..56 days……
SBR volume fraction (V_{SBR}), %	Water cure time (day)	Compressive strength (S_c), MPa	Flexural strength (S_f), MPa	Compressive strength (S_c), MPa	Flexural strength (S_f), MPa	Toughness
0	3	49.91	7.854	46.66	5.9	0.487
	7	52.979	6.958	53.81	7.48	0.493
	28	53.899	6.692	63.81	7.83	0.608
10	3	39.866	6.963	41.36	6.48	0.339
	7	46.035	5.915	44.85	6.79	0.315
	28	40.052	4.242	45.83	7.63	0.295
20	3	33.273	5.255	32.96	6.73	0.286
	7	34.906	5.362	34.29	4.63	0.255
	28	28.489	3.388	34.99	5.5	0.24

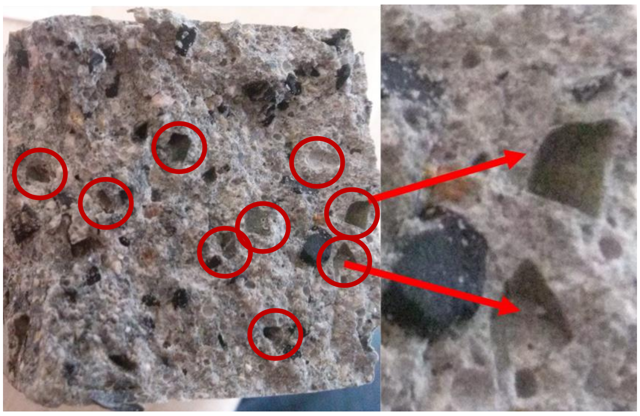


Fig. 9 Bond loss between the SBR particles and cement paste

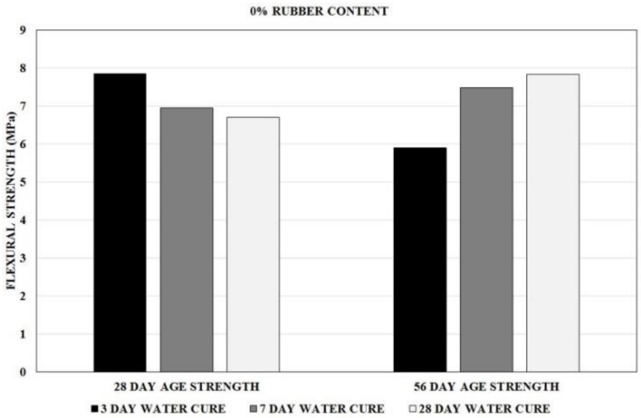


Fig. 10 Control mix flexural strength change with the curing time

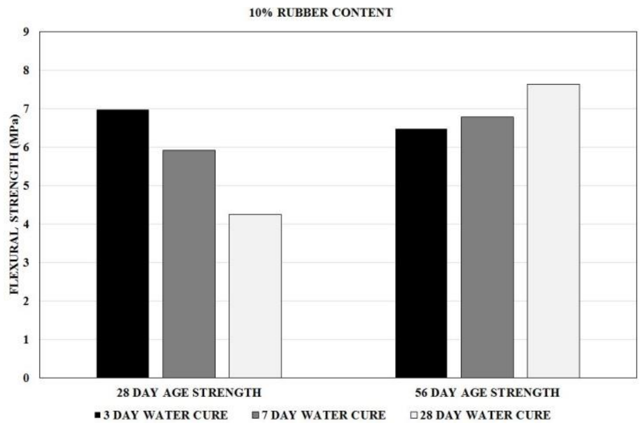


Fig. 11 10% SBR replacement effect on flexural strength change with the curing time

compressive strength of almost 28 MPa can be achieved in SBR blended mortar. However, achieved compressive strength for non-load bearing concrete wall units at the age of 28-days should be minimum 3.50 MPa according to ASTM C 129 (ASTM 2014). For all replacement level of SBR mortars fulfills this criterion.

There is no extreme change in compressive strength of 10% and 20% replacement level of SBR for each one of the 3 and 7-day water cure results at 28 and 56 day-age tests (Figs. 7 and 8). Moreover, when the curing time increase, the strength loss of samples is also increase (Figs. 6, 7, and 8). The curing time of 3 and 7 days increased the compressive strength of SBR mortar mix. Whereas, 28-day water curing reduced the compressive strength of SBR mortars at the 28-day tests. However, the 56-day test showed that increasing water curing time enhanced compressive strength of SBR mortars (Figs. 7 and 8). Water curing time is more effective on SBR mortars at the 56-day age test. Whereas, the water curing time effect is vague in 28-day age tests (Figs. 7 and 8). 56-day age test of SBR mortars showed that the compressive strength enhancement rises up linearly with the time of water curing (Figs. 7 and 8). Figs. 7 and 8 demonstrate that the 7-day water curing is the best curing time to obtain the optimum performance while compared with the 3 and 7-days water curing at the test age of 28 days.

3.2 Flexural strength

Flexural strength of prismatic specimens was tabulated in Table 5. Material orientation can be seen in Fig. 9 after Flexural Strength test.

Flexural strength of the SBR mortar range between 3.388 MPa to 6.963 MPa and 4.63 MPa to 7.63 MPa for SBR mortars at the test age of 28 and 56 days, respectively (Figs. 10, 11 and 12). Measured compressive strength test result of 49.91 MPa provides the minimum condition according to TS EN 197-1 (TS 2012).

Increasing the amount of SBR aggregate content resulted in decrease in the flexural strength as reported in the

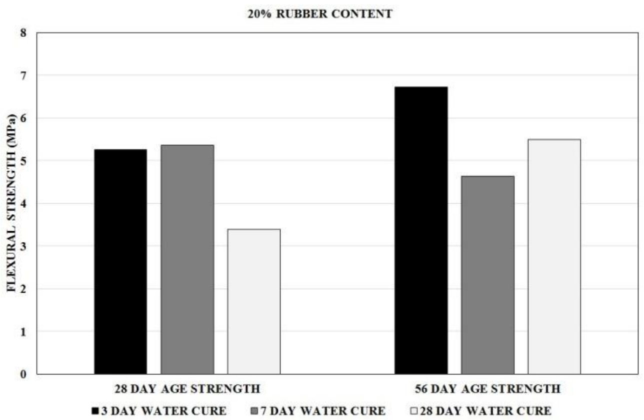
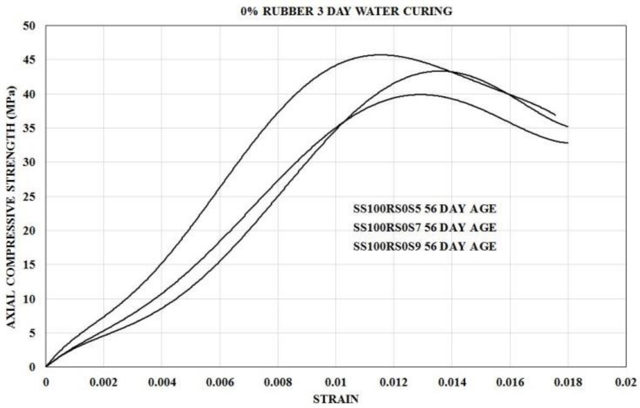


Fig. 12 20% SBR replacement effect on flexural strength change with the curing time

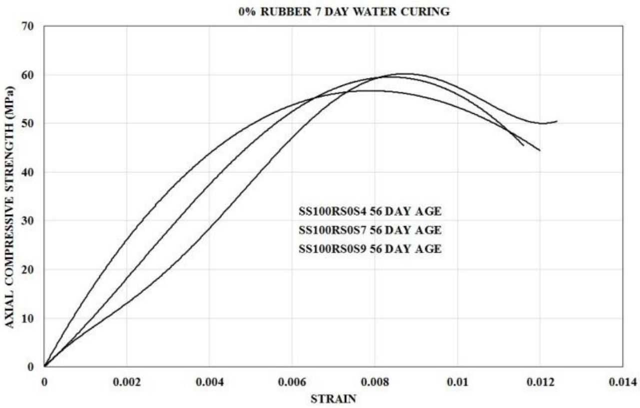
literature studies revealed by Khatib and Bayomy (1999). In this study, similar trend was observed for the 7 and 28-day water cured specimens as reported by Khatib and Bayomy (1999). On the opposite manner, the 3-day water curing caused reverse trend in the strength reduction rate. Increasing the SBR fraction from 0% (control mix) to 20% has resulted in decreasing of flexural strength. For instance, 20% SBR content and 28-day water curing caused the flexural strength to decrease up to 49.4%. Meanwhile, 10% SBR addition and 28-day water curing decreased the flexural strength up to 36.6%. The best results were obtained with the 3-day water curing and 56-day age test with 20% SBR replacement level. Under this condition, the flexural strength gain 14.15% strength. whereas the flexural strength loss increases up to 38.1% for other curing and test ages. Khatib and Bayomy (1999) presented that the strength loss can be observed up to 80% with substitution of 10% and 20% of SBR replacement level at the 7-days and 28-days ages. The reason of decreasing flexural strength with utilization of SBR is that reaching the bond capacity to a certain level between the SBR and the matrix. The loss of the interfacial bond between the SBR and the matrix caused loss and propagated failure as indicated in Fig. 9. It was also possible to observe that indents in the cement matrix at locations where tire particles were pulled out. These indents actually come to an important role due to enhancing the bond strength between the tire particles and the cement paste. Fig. 9 shows indents marks on the cement paste after tire rubber particle pull out of the cement matrix. These observations contradict with reported notes in the literature on the weak bond between tire rubber particles and the cement paste matrix (Reda-Taha *et al*., 2008).

3.3 Toughness

Toughness is an ability of energy absorption by which the materials or structures deform plastically and fracture against the exterior load. Material toughness is not only related to capacity, but also to deformability. Cube samples tested at the age of 56 days for axial compressive strength and strain. The loads applied until the loss of 20% of ultimate compressive strength. Their behavior capacity is calculated with the area which is stay under stress-strain



(a)



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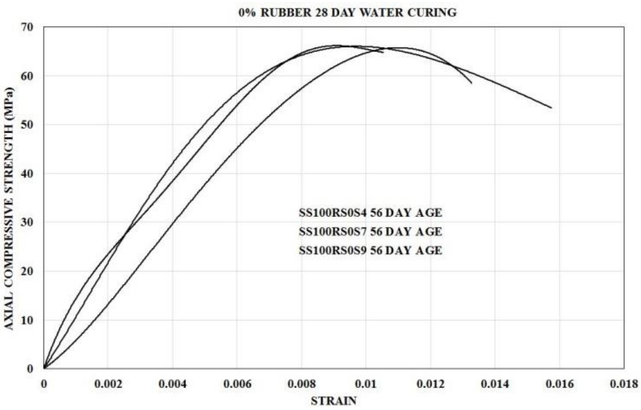


(c)

Fig. 13 Control mix compressive strength-strain graph a) 3-days water curing b) 7-days water curing c) 28-days water curing at the age of 56 days

curve. This area represents the samples toughness. Compressive stress and strain curves plotted for each replacement level plotted in Figs. 13, 14, and 15.

The toughness is calculated by the area of the average calculated by each of three curves. The results tabulated in Table 5. According to Table 5 control mix toughness increases with the rising water curing time. whereas the SBR mortar toughness decreases with the increasing water curing time. 10% SBR replacement level toughness loss is 30%, 36%, and 51.4% for the 3, 7 and 28-day water curing periods, respectively. Besides, toughness loss is 41%, 48%, and 60% for the 3, 7, and 28-day water curing periods with

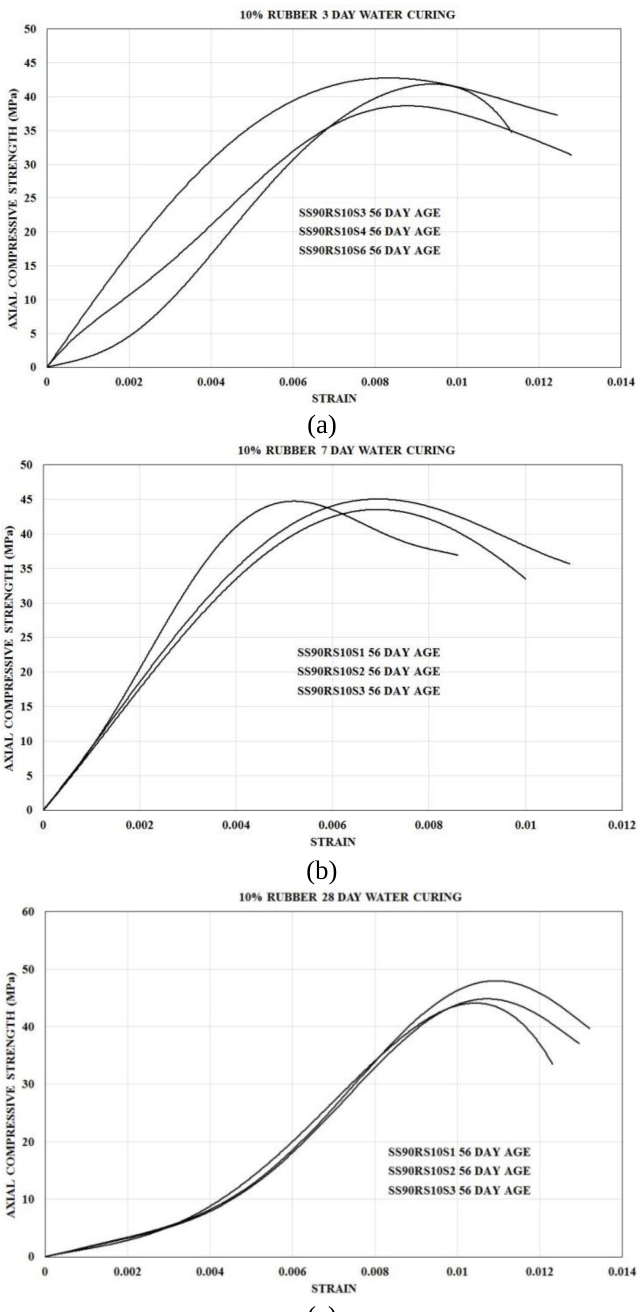


Fig. 14 10% SBR replacement effect on compressive strength-strain graph (a) 3-days water curing (b) 7-days water curing (c) 28-days water curing at the age of 56 days

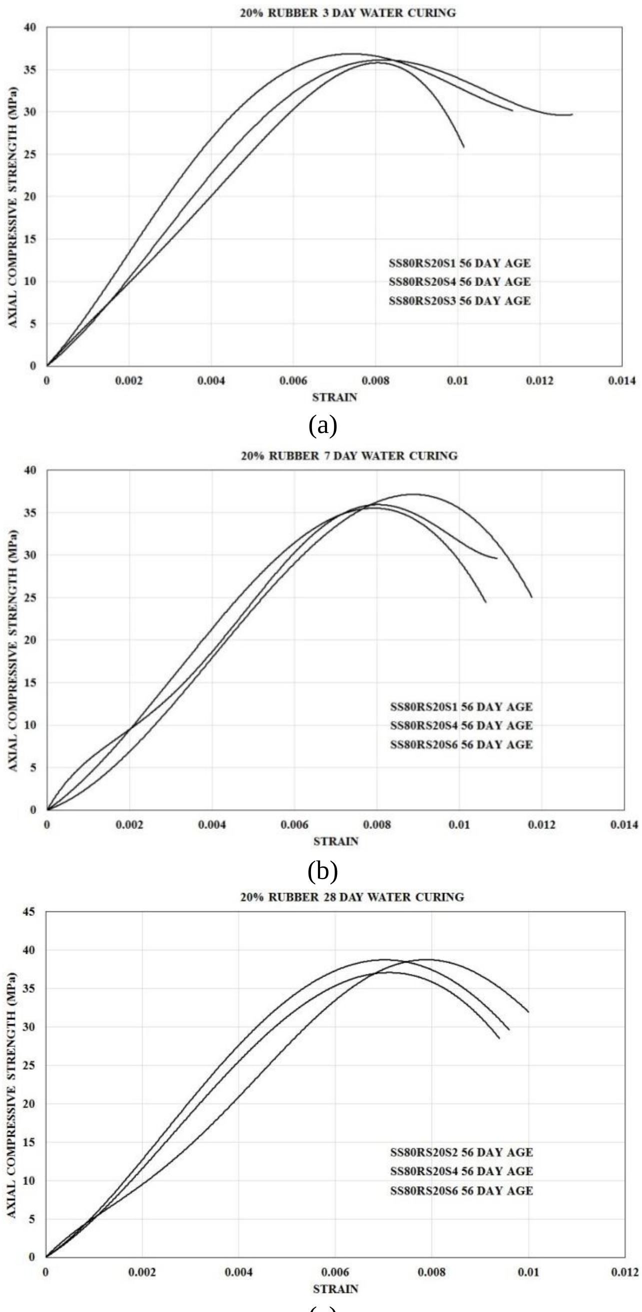
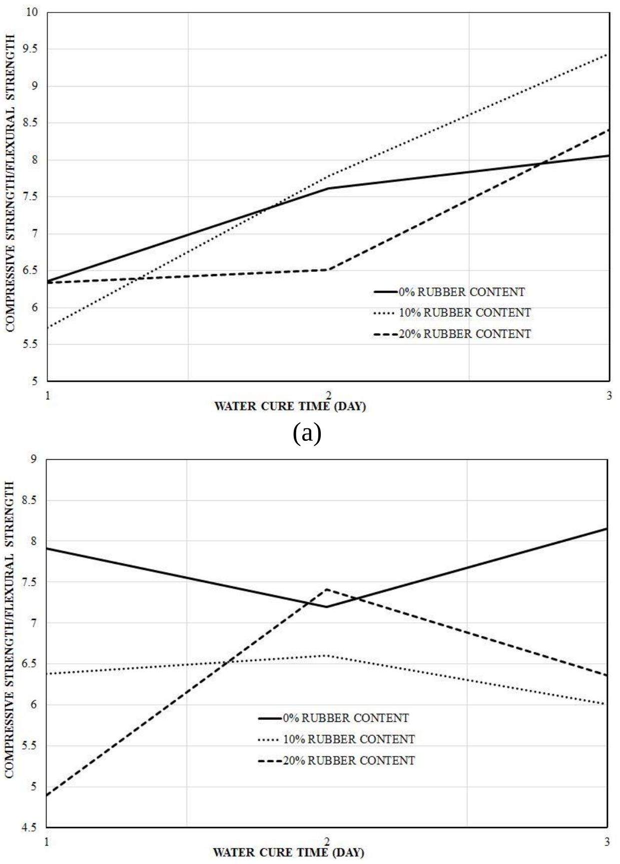


Fig. 15 20% SBR replacement effect on compressive strength-strain graph (a) 3-days water curing (b) 7-days water curing (c) 28-days water curing at the age of 56 days

20% SBR replacement level, respectively. According to the strength consequences of the tests, the ratio of compressive strength to flexural strength of the rubber particles, cement mortar can be calculated with an index to detect cracking of mortar and the smaller ratio of compressive strength to flexural strength which is better for mortar toughness as indicated by Xue and Cao (2017). Ratio of compressive strength to flexural strength is given in Fig. 16. 28-day age test showed great performance in terms of the compressive strength and flexural strength ratio. That ratio shows almost a linear increase with the rising curing time at the 28-day age test. On the contrary, the 56-day test age SBR mortar showed the best performance at the 7-day water curing.

3.3 Strength reduction factor

Strength reduction factor is one of the most important index to determine loss of strength due to addition of external material like rubber content in the mixture. Moreover, this index also depends on the strength of Portland cement mortar mixtures. A characteristic power function regression analysis was conducted to determine the parameters of this function and to find reduction (Khatib and Bayomy, 2008). It is found that the best mathematical



(b)

Fig. 16 Compressive strength/ flexural strength ratio (a) 28-days age test (b) 56-days age test

function that resembles trend of the strength reduction curve as stated in the form in Eq. (3)

$$SRF = \mathrm{a} + \mathrm{b} * (1 - \mathrm{R})^m \quad (3)$$

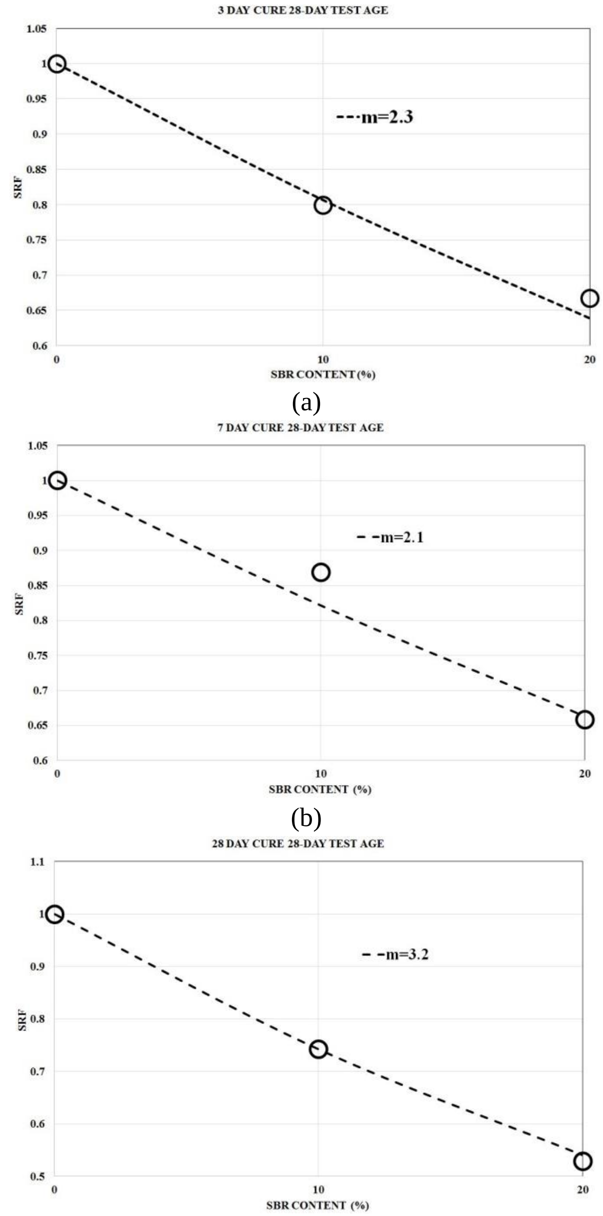
with the condition that

$$a = 1 - \mathrm{b} \quad (4)$$

where *SRF* is the strength reduction factor; *R* is the rubber content, volumetric ratio by total aggregate volume, *a*, *b*, and *m* are the function parameters (Khatib and Bayomy 2008). The exponent *m* reflects the degree of curvature of the curve down. Therefore, the strength with rubber content of the mixture indicates that it is sensitive. For example, in a mixture where *m*=2, *m* value compared to a mixture of 4 are less susceptible (Khatib and Bayomy 2008).

In the current study, the *m* values calculated for each curing time condition and results were plotted and presented in Figs. 16, 17 and 18.

At 28-days test age, *m* values are 3.3, 2.1, and 3.2 for 3-days, 7-days and 28-days water curing, respectively (Fig. 17). According to these results, the best sensitivity was observed at 7-days water curing and a test at the age of 28-days. On the other hand, for 56-days test age, *m* values are 1.75, 2.3, and 3.2 for 3-days, 7-days and 28-days water curing, respectively (Fig. 18). Once the comparison of the test age of 28-days and 56-days with SRF, it possible to see that the best compatibility can be obtained from 56-days



(c)

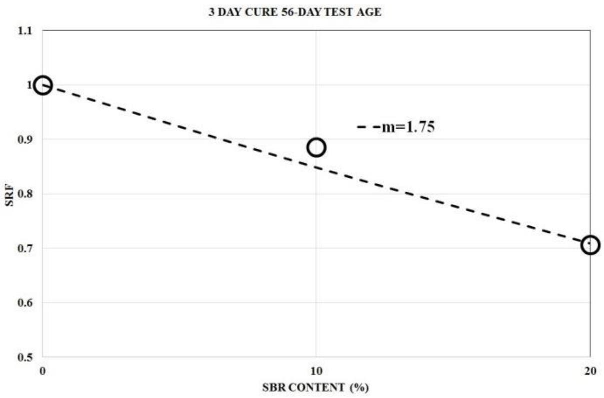
Fig. 17 Curves for proposed SRF characteristic function at 28-days test age (a) 3-days water cure (b) 7-days water cure (c) 28-days water cure

results (Fig. 16, 17 and 18). Besides, 3-days water curing results showed the best results according to Khatib and Bayomy's (2008) SRF definition for 56-day test age of SRF (Fig. 16, 17 and 18).

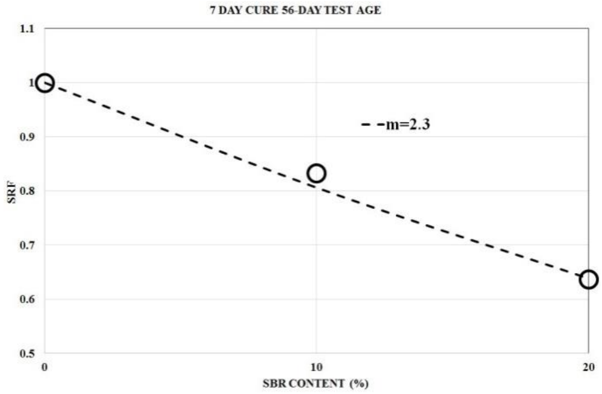
5. Conclusions

It is investigated in this study that the effects of water curing time and SBR content on mechanical properties of cement mortars. Based on the experimental study presented above the following conclusions can be listed below:

- Different water curing time of SBR mortar and SBR content has no contribution to flexural strength at 28-day age. On the contrary, the flexural strength loss observed with increasing water curing time. Only 3-days



(a)



(b)

(c)

Fig. 18 Curves for proposed SRF characteristic function at 56-days test age (a) 3-days water cure (b) 7-days water cure (c) 28-days water cure

water curing has a positive effect on flexural strength with increasing SBR content based on control mix 56-days results.

• For all water curing time, SBR replacement has a negative effect on compressive strength of mortar at 28-days and 56-days test age according to control mix values at the same age. All of the strength loss is shown almost an increasing trend with the increasing water curing time according to control mix values at same age.

• Toughness of SBR mortars shows a gradual decrease with increasing of water curing time. Therefore, increasing rubber content tends to higher increasing ratio with increasing curing time.

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