*Civil Engineering Infrastructures Journal, 52(1): 137 – 154, June 2019*
*Print ISSN: 2322-2093; Online ISSN: 2423-6691*
*DOI: 10.22059/ceij.2019.255225.1476*

# Analysis of the Modifying Effect of Styrene Butadiene Rubber Latex Copolymer on Strength and Permeability Properties of Structural Light Aggregate Concrete

**Rezaei, S.[1*] and Abedzadeh, K.[2]**

[1] Assistant Professor, Faculty of Civil Engineering, Pooyesh Institute of Higher Education, Qom, Iran.
[2] M.Sc., Faculty of Civil Engineering, Pooyesh Institute of Higher Education, Qom, Iran.

Received: 03 Apr. 2018; Revised: 24 Mar. 2019; Accepted: 09 Apr. 2019

**ABSTRACT:** Polymers not only possess repairing functions concerning the concrete structures, but also due to their properties are used in making different types of polymer cements and improving the matrix structure of cement materials, enhancing the viscosity, mechanical, and stability power of concretes. Today, there is limited knowledge on the use of SBR in structural light aggregate concrete. In the present research, light expanded clay aggregate was used to produce light weight concrete weighing 1740 to 1780 kg/M$^3$. Unlike the previously conducted studies in which the desirable properties of concrete were achieved by increasing the compressive strength, in the current study we have used C25 light concrete without any cement supplements. SBR latex copolymer was incorporated in concrete directly (additive) and indirectly (light aggregates coating) each based on a combinational performance of 28 and 60 days. The results revealed that based on the used cement matrix, the optimal performance of the latex in the direct method was enhanced by increasing the bending and tensile strength rather than the compressive strength. The indirect presence of latex not only imposed a new limit in ITZ, but also had no interfering role in modifying the chemical mechanism of cement hydration. Thus, the behavior of this concrete did not show any enhancement in the mechanical properties as it did in the case of direct implication of latex. The study also showed that the presence of latex in both methods led to reduced permeability of the concrete. This research also looked into the impact of cement matrix capability, latex consumption rate, curing age and method and the effect of copolymer ratio on improving the light weight concrete stability and mechanical properties.

**Keywords**: Combinational Curing, Mechanical Strength, Permeability, SBR Latex Copolymer, Structural Lightweight Aggregate Concrete.

## INTRODUCTION

The idea of producing a light concrete to achieve three functions of efficiency, strength, and durability by using cement adhesives has been under attention since the middle of the 20$^{th}$ century after production of artificial light aggregates (Mindess et al., 1981). These kinds of aggregates play important role in improving the inner processing of concrete (Ferrara et al., 2015), increasing the concrete strength against fire

* Corresponding author E-mail: rezaei@pooyesh.ac.ir

etc. (Sayadi et al., 2016). Thus, a concrete with less density and ITZ and more elasticity was produced (Chandra Berntsson, 2003) and used in most of structures such as the buildings and for repairing the concrete docks (Nair et al., 2016). However, despite the desirable advantages of light concrete, the big remaining challenge is the difference between the light weight concrete density and strength. This difference is due to the presence of porous light aggregates which while decreasing the concrete density increases the materials segregation risk, cement standard, and also the ratio of water to cement. Different opinions have been stated to deal with this issue (Bogas et al., 2015a; Shafigh et al., 2014; Bogas et al., 2015b; Real and Bogas, 2017).

Research concluded that adding 10 percent steel fiber not only slightly affects the compressive strength and modulus of elasticity of concrete, but also increases its tensile strength and toughness (Mo et al., 2017a). Researchers used different types of silica SCM like Nano silica and showed that they not only to decreased the amount of used cement and shrinkage resulted from drying, but also improved the hydration, mechanical, and stability performance of light concrete (Mo et al., 2017b; Bogas et al., 2014; Zhang et al., 2018). Therefore, researchers have attempted to improve the weak points of concrete and as a result, have introduced a new type of green concrete by changing the mix design and making use of light aggregates, fiber, and SCM (Mo et al., 2015; Nováková and Mikulica, 2016; Ardakani and Yazdani, 2014; Miller and Tehrani, 2017; Martínez-García et al., 2017; Shafigh et al., 2013; Mo et al., 2016; Vargas et al., 2017). Although concrete is a durable substance, it comprises a network of pores that cause moisture and harmful materials to penetrate into concrete especially the light concrete (Muhammad et al., 2015). Therefore, the strategy of using tiny polymer particles with latex solution began in 1960s to improve the durability of concrete, reduce the costs of keeping and repairing, and increase the lifetime of concrete structures (Ohama, 1995). Today, in addition to these purposes, polymers are also used to produce and improve the cement (Assaad, 2018). Due to the difference in the polymer chains, most of the polymer latexes used to modify cement are classified into two types. The first type is without any active group in polymer chains which includes only physical modification mechanisms such as Butyl benzene latex. In the second kind, polymer latexes are with active groups that include physical and chemical modifying mechanisms. This group can react with hydration products to create a 3-D network (Wang et al., 2016). Like SBR latex, carboxylic is also made from connection of two chains of flexible and hard Styrene (Ramli and Tabassi, 2012). In investigating different polymers, it was noticed that presence of SBR latex considerably changed the structure and distribution of cement paste pores, which in turn, led to better impermeability, strength, and viscosity, and the compressive strength. Polymer films play a role in cement hydration reactions (ACI Committee 548.1, 2009; Pascal et al., 2004; Silva and Monteiro, 2006; Wang et al., 2005).

Eren et al. (2017) reported that the ball bearing performance of SBR latex polymers not only increases the applicability, but also, increases the amount of entering unwanted airstream and reduces the density of the resulted concrete. However, it is still resistant against permeation of liquids and $CO_2$ gas in the long run. The researchers studied the effect of SBR latex on the structure and durability of the light self-compacting concrete with C40, concluded that SBR latex improved the static stability, increased tensile strength, and increased the binding between the light concrete and the old concrete bed. Studies have been conducted concerning the effect of SBR latex and its different recycles on the production and modification of the structure of high-strength, self-compacting, recycled, etc. concrete types, in different conditions (Doğan and Bideci, 2016; Said et al., 2016; Issa and Assaad, 2017; Ramli et al., 2013; Assad and Issa, 2017; Assad and Daou, 2017). However, these studies are few and thus, there are still remained questions on the effects of age, curing method, presence of latex, basic mechanisms of SBR copolymer film, and its role in improving light concrete with expanded clay light aggregates.

In this article, SBR latex copolymer was used in the light concrete with 0, 2.5, 5.0, and 7.5 percentages of consumed cement in the direct state (LM) and coating of light aggregates in one and two layers in the indirect state (CL). The samples were processed under three 28-day combination methods and one 60-day method. Then, the tensile, pressure, bending, and short-time strength tests were performed on them to examine the effects of the additives. The results of the tests revealed that simultaneous effects such as the W/C reduction, connection band strength, physical strength increase, and durability of light aggregate concrete did not happen as SBR latex was used in CL concrete (unlike LM concrete) because the effect of SBR latex in LM concrete is seen after passage of time and attaining a certain degree of cement hydration process in the desirable conditions which. This in turn, implies the role of SBR copolymer in the chemical process of cement hydration in LM concrete in contrast to CL concrete. This issue is the topic of another study that will be published in near future.

## MATERIALS AND METHODS

### Light Aggregate and Fine-grained Aggregates

The extracted clay of Leca Company with the trade name of Leca500 was used as the light aggregate with non-compacted mass specific weight and grain weight of 528 and 823 kg/m$^3$, respectively with grain size ranging from 2 to 10 mm and also half-an-hour water absorption of 11.8%. The used clay was from Saveh mine that, as seen in Table 1, has a fineness modulus of 3.3 and half-an-hour water absorption of 8.4% that changes into a fineness modulus of 3.1 when combined with Leca fine-grained aggregates and clay (Figure 1).

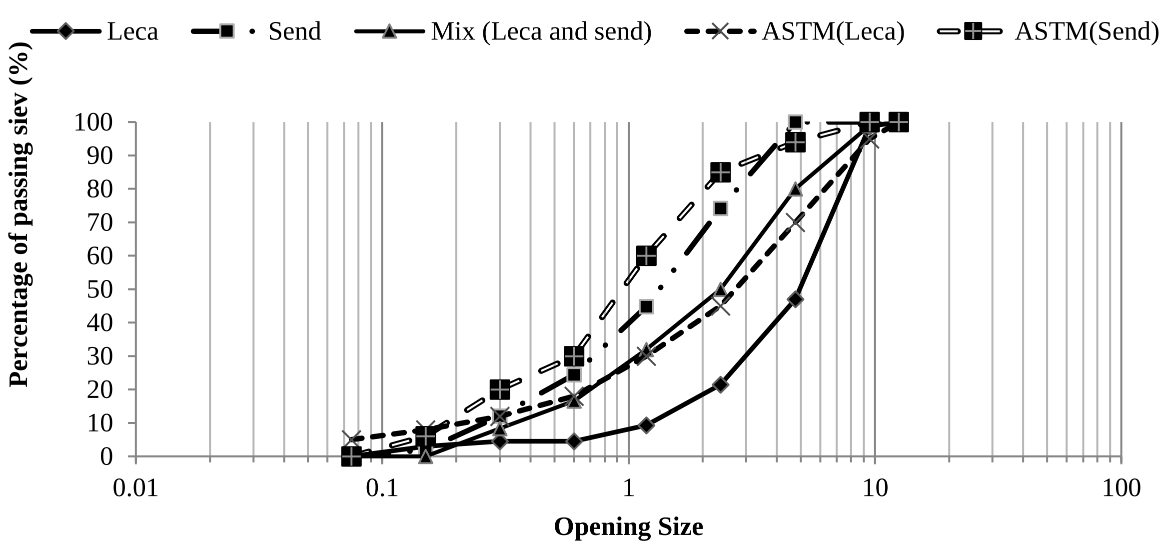



**Fig. 1.** Leca and sand grading curve

**Table 1.** Comparison of standard grading with existing material grading

| Percentage passing | | | | |
|---|---|---|---|---|
| Send | | Leca | | Sieve size (mm) |
| Used | ASTM | Used | ASTM | |
| - | 100 | - | 95-100 | 12.5 |
| - | - | 98.74 | - | 9.5 |
| 100 | 95-100 | 46.98 | 50-80 | 4.75 |
| 74.21 | 80-100 | 21.46 | - | 2.36 |
| 44.85 | 50-85 | 9.34 | - | 1.18 |
| 24.46 | 25-60 | - | - | 0.6 |
| 12.1 | 5-30 | 4.54 | 5-20 | 0.3 |
| 1.89 | 0-10 | 3.03 | 2-15 | 0.15 |
| - | - | - | 0-10 | 0.075 |

## LUBRICATING AND CEMENT MATERIALS

The Portland cement (type 2) of Ghazvin-Abiek factory with ASTM C150 standard and special weight of 3100 kg/m$^3$ was used as the main band to achieve the intended viscosity. Furthermore, to attain the intended efficiency, a super-lubricating poly carboxylic-based substance with a specific weight of 1.2 gr/cm$^3$ and PH between 6 and 7 was utilized.

### SBR Latex Copolymer

SBR Latex Copolymer was used as the polymer modifier with the trade name of NL05C (product of Paya Resin company in Isfahan) with the properties shown in Table 2.

### Mix Design and Curing

#### *Mix Design and Used Materials*

Table 3 represents the mix design of the structural light aggregate concrete (base) of SLAC with C25 concrete class based on the strength capacity method (ACI Committee 211.2, 2004). The concrete mix design contains a fixed amount of SBR latex for both methods; however, the ratio of water to cement changes in the direct presence of SBR latex. The method of mixing in the direct presence of SBR latex (LM): first, Leca along with half of the required sand and all used cement are input to the mixer and dry mixed for one minute. Then, the remained sand with half of water and SBR latex polymer are added to the mixture. Then, if needed, the remaining water and SBR latex polymer and extra water are gradually added to the mixture (in two to four minutes) on the basis of materials absorption power. Finally, all the content is mixed for one minute. The mixing method in the indirect presence of SBR latex (CL): is similar to the above-mentioned method. However, instead of SBR latex, a super-lubricating (to maintain the concrete workability) and instead of common light aggregate, coated light aggregate is used.

#### *Preparation Procedure*

To produce the CL concrete, coated light aggregate is needed. To create a polymer membrane in the aggregates, first, the remaining aggregates were segregated with a 4.75 sift and were then poured into a container including SBR latex. After complete soaking of aggregates, the material was taken out of the container and was spread on a clean surface for 48 hours to dry in environment temperature. The second layer underwent the same stages. Preparing and making the sample was done based on standard ASTM C192.

#### *Curing Method and Experiments*

Twenty-eight curing combinations in three ways and sixty one curing combinations in one way were conducted as follows:

1. Wet curing was done for 7 days (7w) at 23 $^0$C temperature, that after exiting from the receptacle, the curing method continued in dry state at the environment temperature for 21 days (21D). This method is abbreviated as 7W21D.
2. Curing with 14W14D method.
3. Curing with 21W7D method.
4. Curing with 28W32D method.

To comprehend the behavior of concrete with SBR latex, some experiments were done based on Table 4. It should, however, be mentioned that for each concrete mixture with similar properties the average results of three samples were used.

## RESULTS AND DISCUSSION

### Permeability and Specific Weight of Light Aggregates

As shown in Figure 2, the light aggregates coated with SBR latex had a specific weight of almost 2% higher compared with the ordinary ones. This increase stemmed from permeation of SBR latex polymer particles into the aggregates pores. This permeation, in turn, was the result of small diameter of polymer particles and suitable solids to liquid ratio in SBR suspension. This permeation changed the open pores into the closed ones and reduced water absorption of usual aggregates from 11.8% to 4.8% in the two-layer state.

### Performance and Specific Weight of the New Concrete

According to Figure 3, the direct presence of SBR latex in the new concrete (LM) causes remarkable reduction in the density and water to cement ratio, also increases the slimy state of concrete without using any lubricants as surfactants of latex suspension not only increases the spread of SBR latex among cement particles, but also causes more spread of cement particles and also unwanted air stream in concrete. This response is in accordance with others' research (Lewis and Lewis, 1990). However, except for reduction of lubricating factor, performance, and specific weight of CL concrete it is similar to SLAC concrete.

**Table 2.** SBR Latex Technical Specs

| Plasticizer | Emulsifier | Viscosity | PH | Appearance (%) | Property |
|---|---|---|---|---|---|
| 0 | A/N | 300-800 | 7-9 | 49-50 | white liquid |

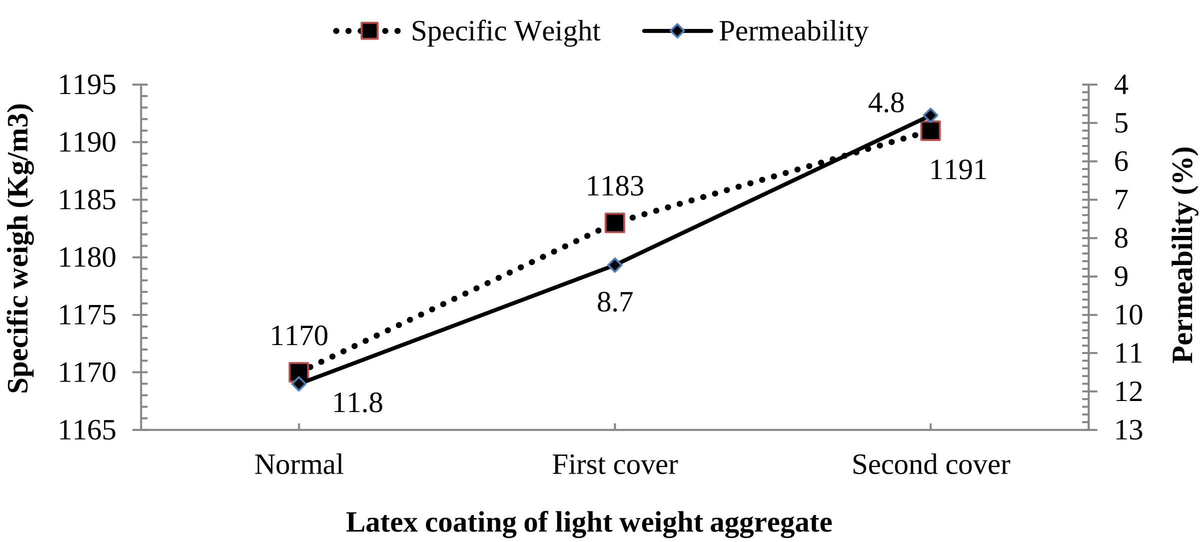



**Fig. 2.** Latex coating effects on the permeability and density of lightweight aggregate

**Table 3.** Concrete mix design

| Mix design | Latex coating (layer ) | Latex SBR (%) | Cement (Kg/m$^3$) | W/C | Plasticizer (%) | Send (Kg/m$^3$) | Leca (Kg/m3) | Slump (cm) | Density (Kg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|
| SLAC | 0 | 0 | 410 | 40 | 2 | 890 | 300 | 7 | 1775 |
| LM2.5 | 0 | 2.50 | 410 | 39 | 0 | 890 | 300 | 8 | 1775 |
| LM5.0 | 0 | 5.00 | 410 | 38 | 0 | 890 | 300 | 11 | 1765 |
| LM7.5 | 0 | 7.50 | 410 | 36 | 0 | 890 | 300 | 14 | 1742 |
| CL1 | 1 | 0 | 410 | 40 | 1.5 | 890 | 300 | 7 | 1777 |
| CL2 | 2 | 0 | 410 | 40 | 1.5 | 890 | 300 | 7 | 1777 |

**Table 4.** Test list

| Group | Test name | Reference | Template size |
|---|---|---|---|
| Materials | Density and absorption of coarse aggregate | ASTM C127-88 | * |
| Not hard concrete | Slump of hydraulic-cement concrete | ASTM-C143 | * |
| | Density (unit weight) | ASTM-C138 | * |
| Hardened concrete | Compressive strength | ASTM C39 | Cylinder 150*300 mm |
| | Tensile strength | ASTM C496-04 | Cylinder 150*300 mm |
| | Flexural strength | ASTM C78 | Beam mold 100*100*500 mm |
| | Determination of water absorption | BS 1881 | Cube mold 100*100*100 mm |

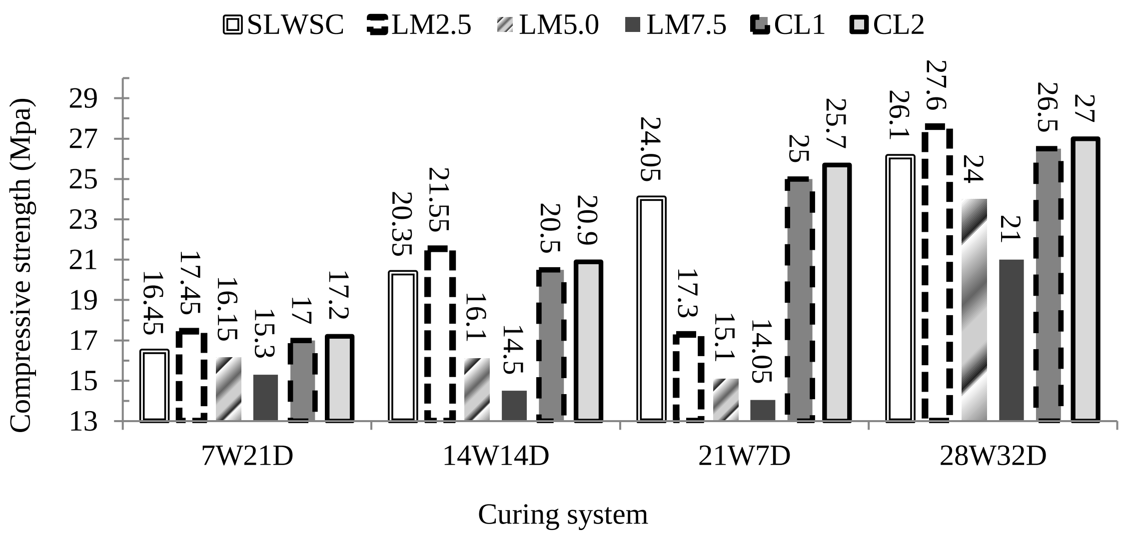



**Fig. 3.** Latex SBR effect and type of curing on concrete compressive strength

## Pressure Strength

In SLAC concrete, the formation of C-S-H gel of Portland cement type 2, which is a retarder, continues until water exists in the hydration process. Thus, supplying strength and confrontation against shrinkage of light aggregate concrete is highly dependent on the age of humidity and saturation degree of light aggregates. As Table 5 shows, there is 46% and 59% increase in 21W7D and 28W32D methods compared to that in 7W21D one is noticeable because continuous external moisture and light aggregates effect on internal curing prevent concrete shrinkage during dry curing. Examining the inner surface of broken samples showed that internal curing leads to penetration of hydration products into the light aggregate pores and increases the aggregates strength capacity against rupture path crossing and decreases the thickness of ITZ layer (Vargas et al., 2017). If 7W21D method is considered to be close to workshop internal curing, it is found that by decrease in the age of wet curing and by application of retarders (to slow down the setting) in cement, the compressive strength of SLAC concrete decreases by almost 66%. In the SBR latex contained concrete, (Table 3), the optimal compressive strength of LM concrete has been achieved and concrete is capable of reaching a specific degree of completing the cement hydration process in the damp conditions and then to form and strengthen the SBR latex polymer film in the dry state.

According to Figure 4, LM2.5 in the 7W21D and 28W32D methods, by maintaining the proportionality between dry and wet curing ages, could reach strength amounts of 17.45 and 27.6 MPa. This increase is, however, only 6% compared to SLAC concrete. By increase in the polymer film thickness from 5% to 7.5% or by increase in in the 21W7D method, the compressive strength would start to fall. According to figure 5, the maximum increase of strength for CL1 and CL2 concrete types in the 21W7D method is 4% and 7%, respectively, in comparison to SLAC concrete. Therefore, CL concrete types are too close to SLAC concrete in terms of hydrophilic and avoiding dry curing features. However, the best compressive strength in LM2.5 concrete was achieved at the age of 60 days. Thus, the participation ratio of latex and coated light aggregates in modifying the compressive strength is less than that of cement in both states, as attaining higher compressive strength is affected by completion of the cement hydration process and the polymer film has no significant role and ability to modify the compressive strength.

### Tensile Strength

Eq. (1) was used to calculate the tensile strength.

$$f_{ct} = {}^{2P}/_{DL\pi} \quad (1)$$

in which $P$: represents pressure strength at time of rupture in Newton, and $D$ and $L$: denote the cylinder diameter and length (mm) respectively.

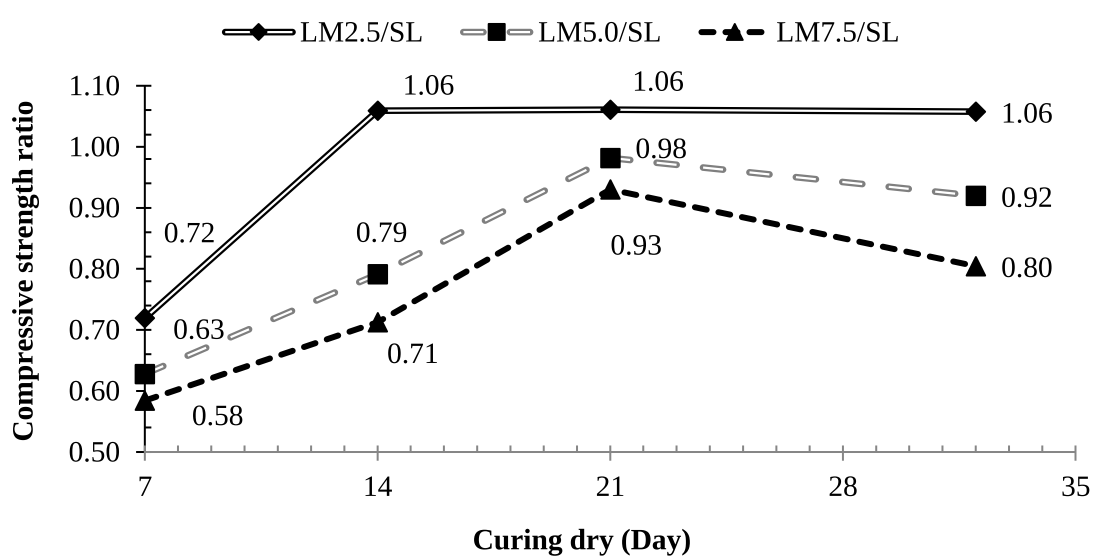



**Fig. 4.** Effect of SBR latex presence and age of dry curing in compressive strength variations relative to SLAC concrete

Presence of polymer film in the cement matrix was the factor that prevented the possibility of early failure in the tensile strength test (Mo et al., 2016; Valcuende and Parra, 2009) as polymer film created a viscosity power and a bridge between cracks and thus transferred the tensions in these areas. Figure 6 represents the effects of applying SBR shown in percentage, kind of latex presence, and the type of curing method in the mechanical property of concrete. As the Figure 6 shows, the least tensile strength for SLAC concrete belongs to the 7W21D method due to different causes such as increase of moisture gradient around the ITZ layer, development of tensile stress from drying at outer surfaces, increase of inner tensile stress between the dry surface and the inner humid surfaces of concrete, etc. these causes weaken the cement matrix. These conditions at the same time that facilitate the passing of rupture path from inside or around the light aggregates caused the early failure of concrete as well.

According to Figure 7, the optimal ratio of the tensile strength to the compressive strength ranges from 11% to 12% for LM2.5 concrete, 9% to 11% for CL2 concrete, and 8% to 10% for SLAC concrete.

**Table 5.** Results of strength and permeability tests of concretes with and without SBR Latex

| Curing system | P/C | Latex coating (layer) | Symbol | Compressive strength (Mpa) | Relative compressive strength | Tensile strength (Mpa) | Relative tensile strength | Flexural strength (Mpa) | Relative flexural strength | Permeability (%) | Relative permeability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7W21D | 0 | 0 | SLAC | 16.45 | 1.00 | 1.38 | 1.00 | 1.95 | 1.00 | 5.2 | 1.00 |
| | 2.5 | * | LM2.5 | 17.45 | 1.06 | 1.91 | 1.38 | 2.62 | 1.34 | 4.09 | 0.79 |
| | 5 | * | LM5.0 | 16.15 | 0.98 | 1.8 | 1.30 | 2.43 | 1.25 | 3.52 | 0.68 |
| | 7.5 | * | LM7.5 | 15.3 | 0.93 | 1.4 | 1.01 | 1.7 | 0.87 | 4.26 | 0.82 |
| | * | 1 | CL1 | 17 | 1.03 | 1.57 | 1.14 | 1.95 | 1.00 | 4.2 | 0.81 |
| | * | 2 | CL2 | 17.2 | 1.05 | 1.4 | 1.01 | 2 | 1.03 | 4.08 | 0.78 |
| 14W14D | 0 | 0 | SLAC | 20.35 | 1.00 | 1.93 | 1.00 | 2.6 | 1.00 | 4.68 | 1.00 |
| | 2.5 | * | LM2.5 | 21.55 | 1.06 | 2.5 | 1.30 | 3.2 | 1.23 | 3.33 | 0.71 |
| | 5 | * | LM5.0 | 16.1 | 0.79 | 1.64 | 0.85 | 2.4 | 0.92 | 3.1 | 0.66 |
| | 7.5 | * | LM7.5 | 14.5 | 0.71 | 1.4 | 0.73 | 1.5 | 0.58 | 4.49 | 0.96 |
| | * | 1 | CL1 | 20.5 | 1.01 | 2 | 1.04 | 2.6 | 1.00 | 3.84 | 0.82 |
| | * | 2 | CL2 | 20.9 | 1.03 | 2 | 1.04 | 2.7 | 1.04 | 3.77 | 0.81 |
| 21W7D | 0 | 0 | SLAC | 24.05 | 1.00 | 2.16 | 1.00 | 3.29 | 1.00 | 4.38 | 1.00 |
| | 2.5 | * | LM2.5 | 17.3 | 0.72 | 1.89 | 0.88 | 2.4 | 0.73 | 3.73 | 0.85 |
| | 5 | * | LM5.0 | 15.1 | 0.63 | 1.46 | 0.68 | 2 | 0.61 | 3.9 | 0.89 |
| | 7.5 | * | LM7.5 | 14.05 | 0.58 | 1.22 | 0.56 | 1.4 | 0.43 | 4.64 | 1.06 |
| | * | 1 | CL1 | 25 | 1.04 | 2.2 | 1.02 | 3.4 | 1.03 | 3.59 | 0.82 |
| | * | 2 | CL2 | 25.3 | 1.05 | 2.29 | 1.06 | 3.45 | 1.05 | 3.41 | 0.78 |
| 28W32D | 0 | 0 | SLAC | 26.1 | 1.00 | 2.66 | 1.00 | 3.45 | 1.00 | 4 | 1.00 |
| | 2.5 | * | LM2.5 | 27.6 | 1.06 | 3.48 | 1.31 | 4.35 | 1.26 | 2.84 | 0.71 |
| | 5 | * | LM5.0 | 24 | 0.92 | 2.95 | 1.11 | 3.49 | 1.01 | 2.8 | 0.70 |
| | 7.5 | * | LM7.5 | 21 | 0.80 | 2.1 | 0.79 | 2.4 | 0.70 | 4 | 1.00 |
| | * | 1 | CL1 | 26.5 | 1.02 | 2.85 | 1.07 | 3.55 | 1.03 | 3.5 | 0.88 |
| | * | 2 | CL2 | 27 | 1.03 | 3 | 1.13 | 3.5 | 1.01 | 3.4 | 0.85 |

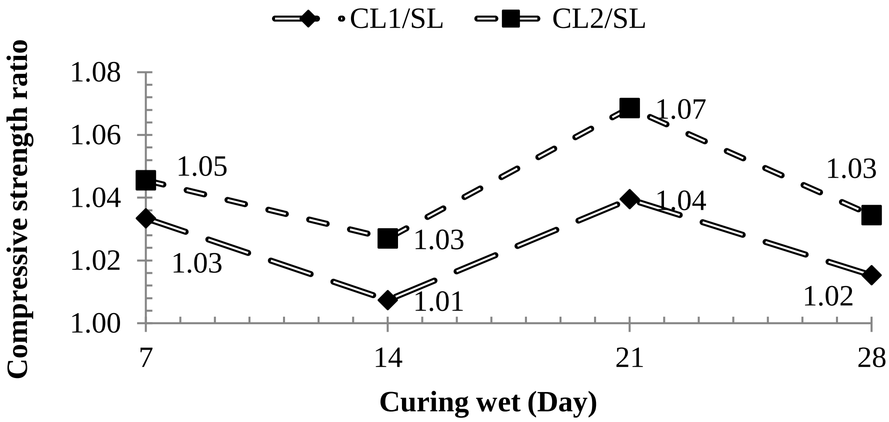



**Fig. 5.** The effect of indirect SBR latex presence and wet curing age on compressive strength variations relative to SLAC

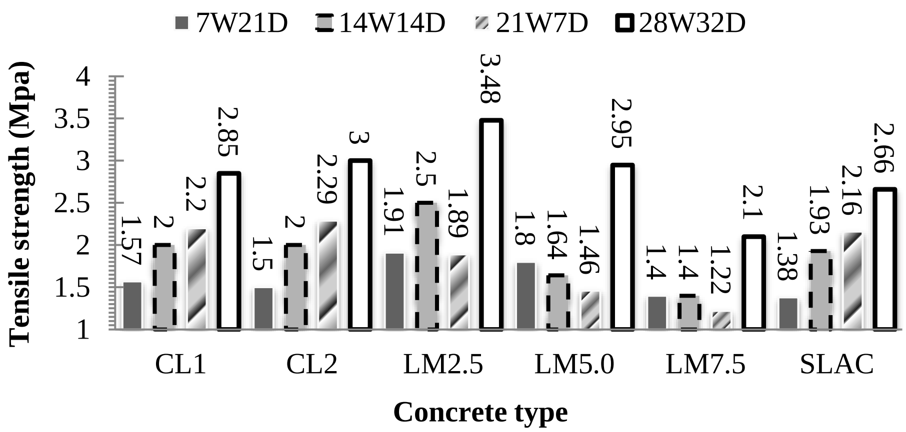



**Fig. 6.** Latex SBR effect and type of curing on concrete tensile strength

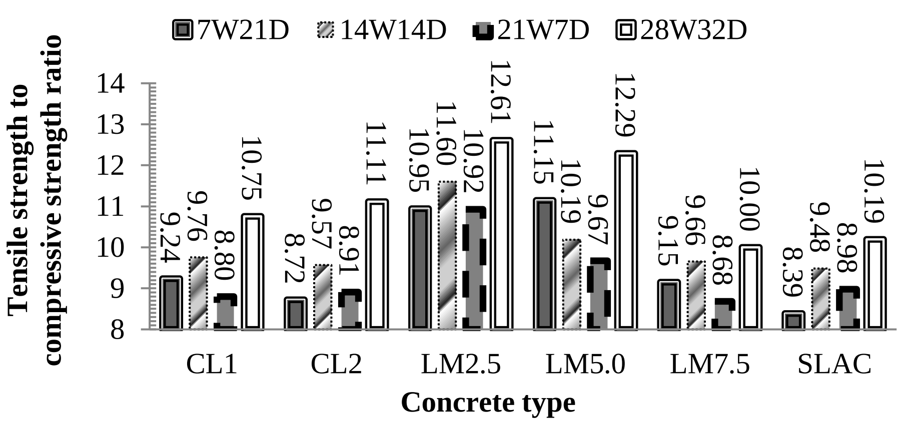
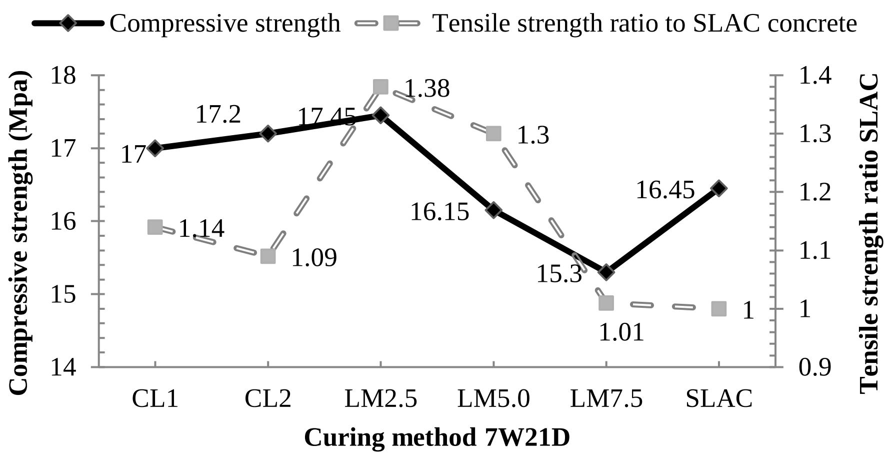


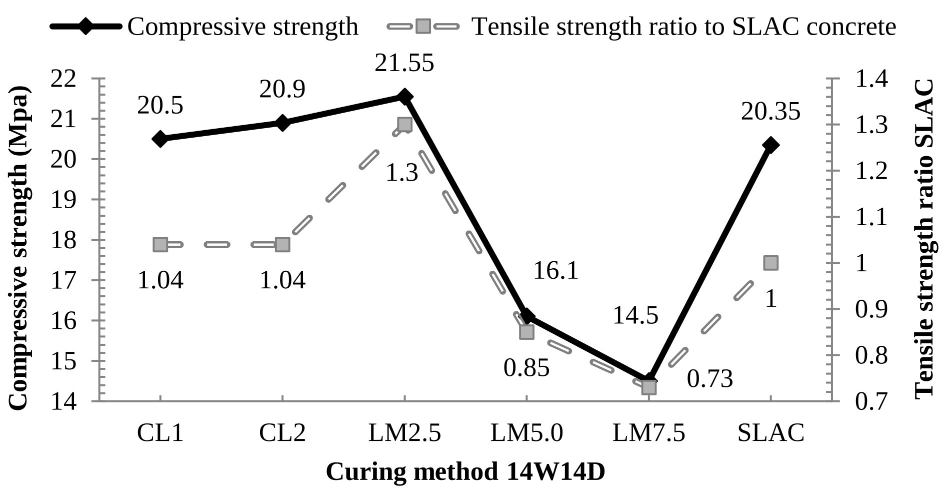

**Fig. 7.** Latex SBR effect and type of curing on concrete Tensile strength to compressive strength

In examining Figures 8a to 8d, it is found that the growth steps of tensile strength were higher than those of the compressive strength. More accurately, the tensile strength of

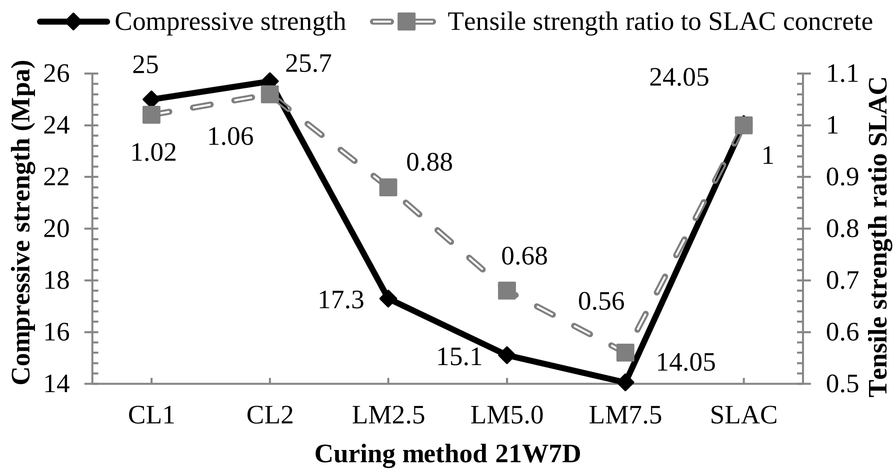
LM2.5 concrete in the 7W21D method has increased by 38% (from 1.38 to 1.91 MPa) compared to that of SLAC concrete; while the compressive strength in the same method has enhanced only by 6%. With increase of the SBR latex use by 5% and decrease of the compressive strength in all the methods, according to Figures 8b and 8c still an 11% to 30% growth is seen for the tensile strength except for the 21W7D and 14W14D methods. As seen in Figure 8d, as latex use increases by 7.5%, while resulting in a high compressive strength, the tensile strength continues its decreasing trend even with increase in the curing age up to 60 days. Thus, as the thickness of polymer film increases, it becomes necessary to lengthen the dry curing and increase the cement matrix via SCMs. However, based on Figure 8c, the 2% to 14% growth path of the tensile strength in CL concrete type is very close to its compressive strength growth conditions, as the impact of moisture in strengthening of cement matrix is like that in SLAC concrete and no track and sign of hydration process retard can be seen anymore. The noticeable lack of success of CL concrete in improving the tensile strength in comparison to LM concrete should be attributed to lack of polymer film and also the weak connection of light aggregates with cement paste in the border area.



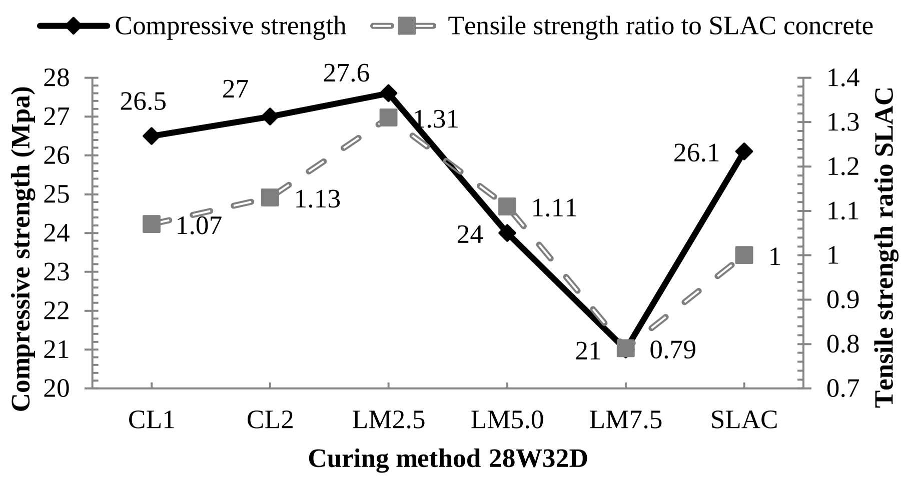

(a)




(b)




(c)




(d)

**Fig. 8.** Tensile strength variations in concrete relative to SLAC concrete and comparison with compressive strength in any curing method (8a to 8d)

**Bending Strength**

Assuming loading of one third of the span and also given the failure of samples due to bending in the middle one third of the span, Eq. (2) was used.

$$f_r = {}^{PL}/_{(bd.d)} \text{ (MPa)} \tag{2}$$

in which $P$: denotes the exerted force in Newton, $L$: denotes the beam span (mm), $b$: is the average width (mm), and $d$: is the average height (mm).

Beginning curing by the 7W21d method and its enhancement by the 14W14D method, the LAC concrete bending strength, improves up to 60% to 80% in comparison to the 21W7D method. Hence, the wet curing age, as shown in Figure 9, is the main reason for attaining the bending strength of SLAC concrete. As Figure 10 reveals, the ratio of bending strength to compressive strength of SLAC concrete is within the range of 13-14%; and in the presence of 2.5-5% of SBR latex increases up to the range of 15-16%. According to Table 5, an optimal amount of SBR (2.5%) leads to 34, 23, and 26% increase in the bending strength of the 7W21D, 14W14D, and 28W32D methods, respectively. Increase of SBR latex from 2.5% to 5%, not only reduces the compressive strength in all ranges, but also leads to a 24% increase in the bending strength corresponding to the 7W21D method. However, a triple presence of SBR latex in concrete that is with increase in viscosity and decrease in density of new the concrete cannot be compared with the cement matrix capacity and optimal performance of concrete. As seen in Figure 10, there is 1-5% improvement in the bending strength of CL concrete compared to SLAC concrete (in terms of the ratio of bending strength to compressive strength).

This indicates the consistency among the aggregates and cement paste which is an important factor to achieve the tensile strength due to bending as the presence of polymer layer on the surface of light aggregates prevents locking between the aggregates and cement paste which, in turn, decreases the percentage of improving bending and tensile strength values (Figure 11). Generally, it might be stated that the concrete bending and shear strength values are largely a function of tensile strength.

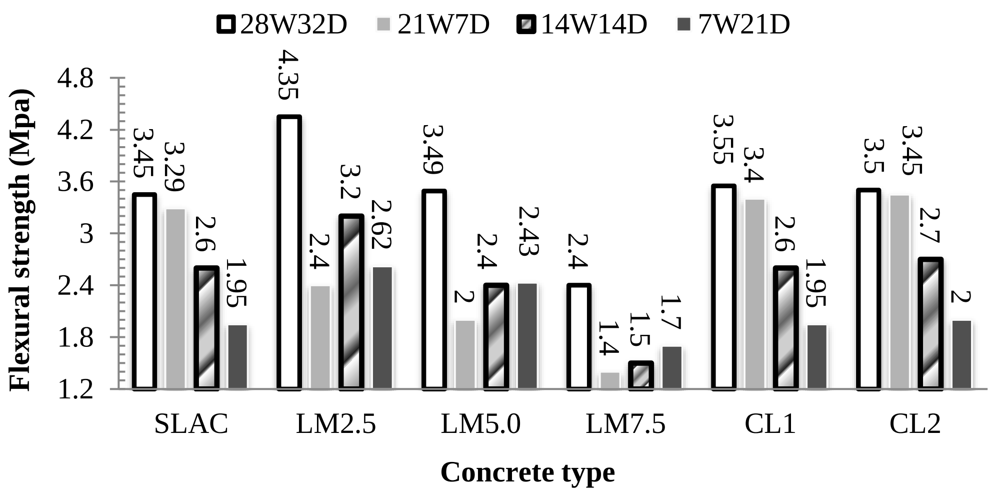



**Fig. 9.** Latex SBR effect and type of curing on concrete flexural strength

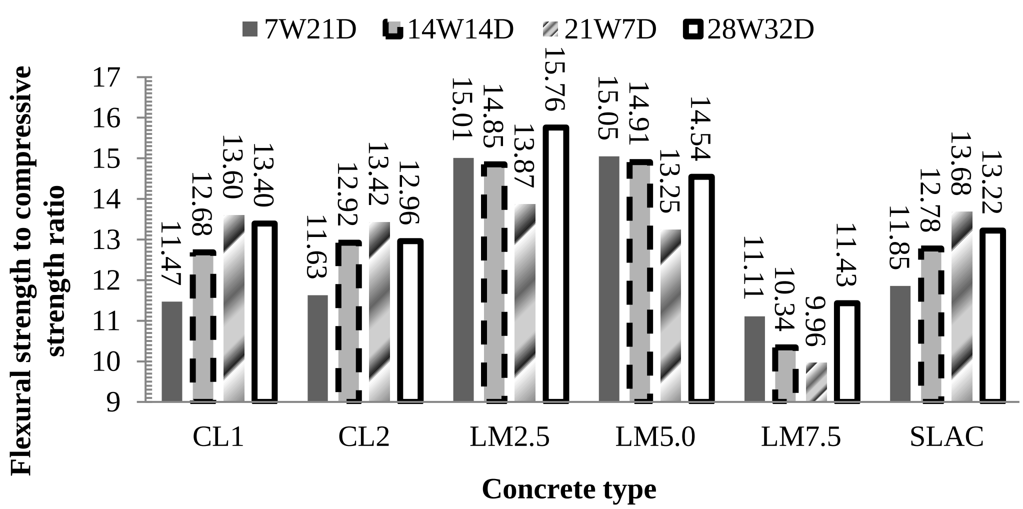



**Fig. 10.** Latex SBR effect and type of curing on concrete flexural strength to compressive strength ratio

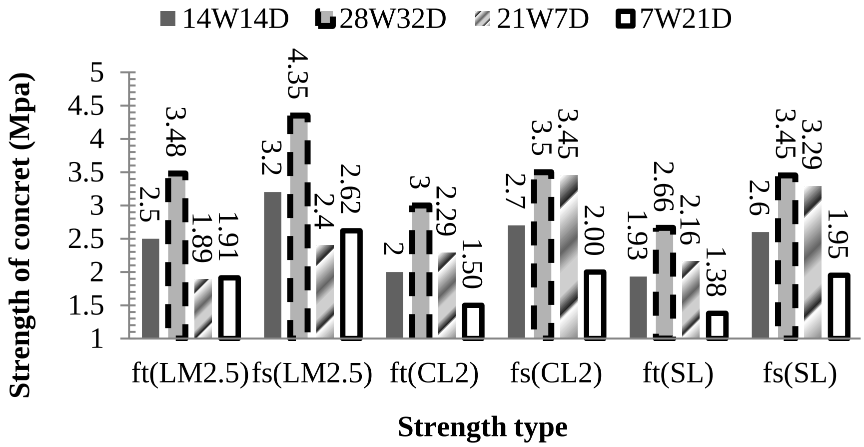



**Fig. 11.** Investigation of tensile and flexural strength of concrete SLAC, LM2.5, CL2

**Short-Term Permeability**

In this experiment, after the end of curing time, the samples were exposed to 110 ℃ temperature for 24 hours to be dried. After taking them out of the machine, their weights were specified and were soaked in water. After 30 minutes, they were taken out of water and after drying them with a cloth, their humid weights were measured. Relation 3 was used to determine the short-term (30 minutes) permeability:

$$A = \frac{m - m_0}{m_0} \times 100 \quad (3)$$

where *m*: is the water soaked sample weight in 30 minutes, and $m_0$: represents the dried sample in the machine before being soaked in water.

Figure 12 also reveals that increasing the wet curing age not only reduces the inactive silicate of cement, but also causes the permeation of C-S-H gel in the light aggregates and thus, improves the permeability. The concrete permeation decreases with enhancing of curing method from the 7W21D method to the 28W32D method. By using the coated light aggregates in CL1 concrete, its permeability improves compared to SLAC concrete, which is within the range of 79% and 88%. Although the viscosity and density of cement solution are more than those of the pure water. This permeability improvement of concrete by 73% due to the coated light aggregate permeability is proportional to the usual type. The main factor in permeability increase of light concrete is light aggregates and porosity. In CL2 concrete, the increase in permeability in CL1 concrete increased only by 3% which is not proportional with 59% permeability improvement of its light aggregates. Therefore, such issues as increase in the open pores compared to the closed ones, reduction in effective depth of light aggregate walls in the first polymer coated layer, etc. prevented the permeability reduction trend in CL2 concrete.

According to Figure 13, presence of different percentages of SBR latex (except for the 21W7D in LM7.5 concrete) leads to reduction of permeability in comparison to SLAC concrete.

Comparing variation in permeability percentage and the compressive strength of CL and LM concrete types utilizing each of the four curing methods in Figures 14a-14d, it is found that presence of latex not only causes a 6% improvement in the compressive strength, but also causes a 70-80% improvement in the permeability. However, in LM7.5 concrete, after release of cement particles from thick polymer film in the long run, the permeability in comparison to SLAC concrete still lies on the stability path. Thus, the direct presence of SBR latex in concrete plays its role in covering the surface pores of light aggregates, tiny pores of matrix, and also inactive silicates of cement hydration. As a result, as the dry curing age increases, the LM concrete types act more effectively compared to CL concrete types in terms of decreasing permeability.

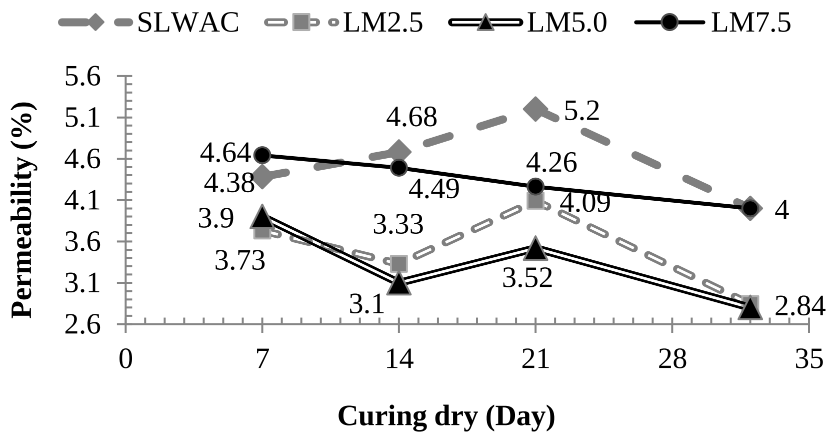
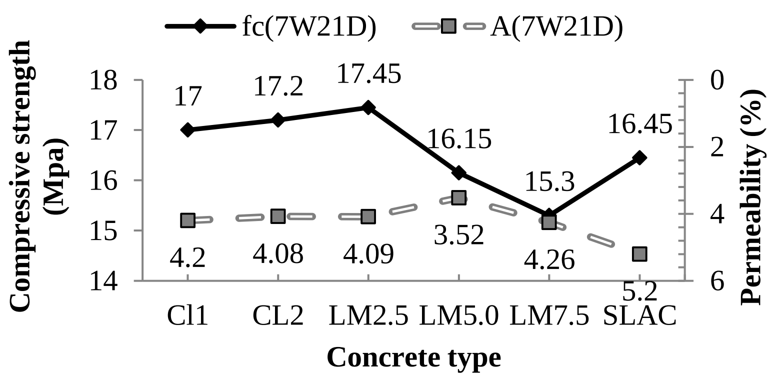
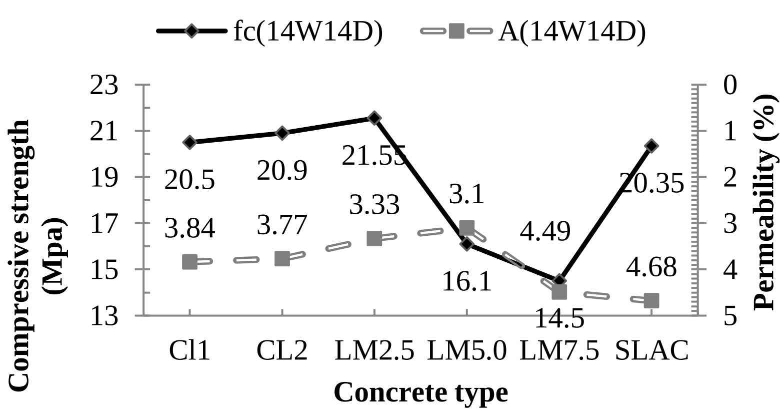


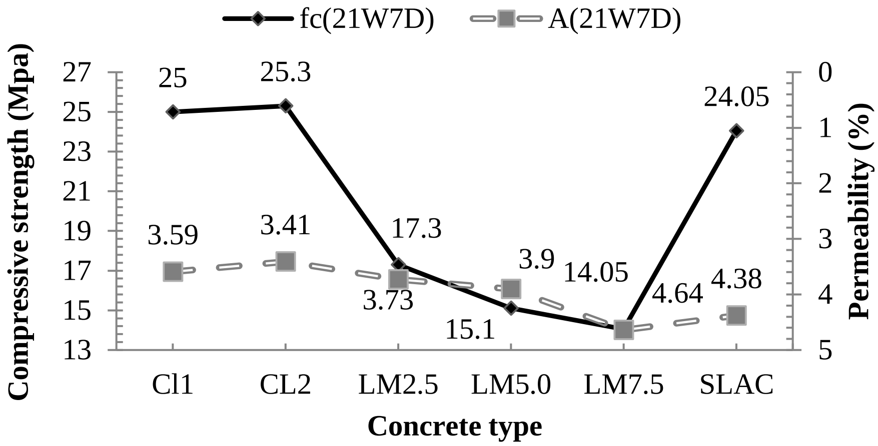

**Fig. 13.** Effect of latex direct SBR presence and age of dry curing in the rate of concrete permeability (SLAC, LM2.5, LM5.0, LM7.5)



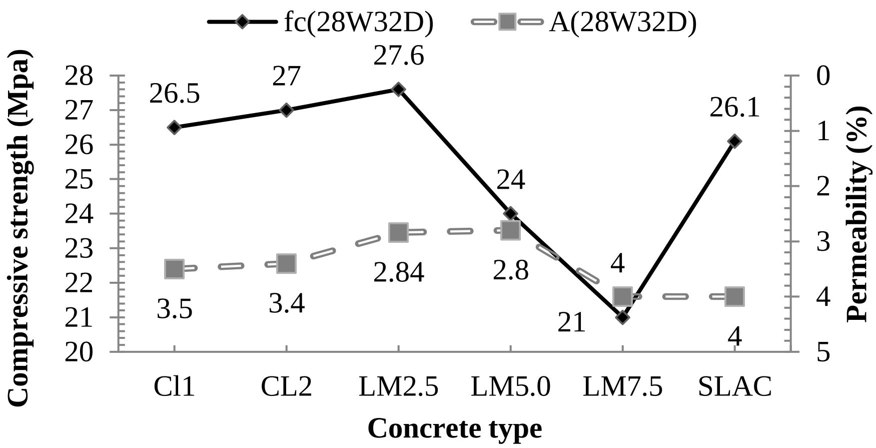

(a)




(b)




(c)




(d)

**Fig. 14.** Rate of change in permeability compared to compressive strength in each curing method (a to d)

## CONCLUSIONS

From the experiments it could be concluded that:

A) Coating light aggregates with SBR not only increases their specific weight by almost 2% percent, but also decreases the water absorption power of common aggregates from 11.8% to 8.7% and 4.8% in the one-layer and two-layer states.

B) The hydrophilic behavior of concrete with coated light aggregate is still similar to that of the ordinary concrete.

C) In CL concrete, simultaneous reduction in w/c, strengthening of connection band, increase of the physical strength and also durability of light aggregate concrete are not achieved with SBR latex use as those of LM concrete. The reason is that the SBR latex effect is achieved by passage of time and attaining a specific degree of cement hydration in the humid conditions and then formation and strengthening of the polymer film in dry conditions. This, in fact, indicates the role of polymer in the chemical process of cement hydration in LM concrete unlike CL concrete.

D) The tensile and bending tests showed an increase in the rupture path due to the aggregates as using the polymer membrane leads to creation of a new border area at the interface of cement matrix and aggregate surface. This, in turn, prevents permeation of cement paste into the pores and increases the light aggregates strength capacity. Thus, indirect presence of SBR latex cannot have constructive and positive effects on the cracks and pores as it does in the case of direct presence of the SBR latex state.

E) The ratio of polymer participation in the light aggregate concrete modification mechanism depends on factors such as the type of used cement, strength of the cement matrix, ratio of the solid particles to latex suspension liquid, type of the mix design, the method of latex presence in the mix design, age and curing method.

F) As the thickness of SBR latex hydrophobic layer in the cement and mineral materials increases, it becomes essential to increase the dry curing age and cement matrix strength just like increasing the cement strength using the silica additives to enhance the hydration process.

G) Direct use of SBR latex in concrete is more effective in increasing the tensile and strain strength values resulted from bending in comparison with increase in the compressive strength. Therefore, the optimal performance of SBR latex considering the related matrix capability is attained at 2.5% dosage which results into 7%, 23%, and 30% improvement in the compressive, bending, and tensile strength values along with 71% modification in the permeability rate at age of 60 days in SLAC concrete.

H) Adequate strength and permeability were achieved at age of 28 days in SLAC, LM, and CL concrete in the methods of 21W7D, 14W14D, and 21W7D, respectively. Hence, using SBR latex could be suitable for reducing the negative effects of defective curing of at site concrete.

I) Presence of SBR latex in both methods improved the permeability of light concrete. This reduction in permeability might be due to the hydrophobic effects of polymer film or its role in covering the pores.

J) Using two-layered coated light aggregate had not any remarkable effect on the reduction of light concrete permeability (like CL1 whose permeability improvement was 79-88% in comparison with SLAC concrete, while this index for CL2 concrete is only 3% in comparison with CL1 concrete). Therefore, such factors as increased number of open pores changed into the closed ones, reduction of effective depth of light aggregate pore walls in the first layer of polymer coating, etc. caused that the permeability reduction not continue with increase in the number of coated layers in CL2 concrete.

## REFERENCES


ACI Committee 548.1. (2009). *Guide for the use of polymers in concrete*, American Concrete Institute, Detroit.

ACI Committee 211.2. (2004). *Standard practice for selecting proportion for structural lightweight concrete*, American Concrete Institute, Detroit.

Ardakani, A. and Yazdani, M. (2014). “The relation between particle density and static elastic moduli of lightweight expanded clay aggregates”, *Applied Clay Science*, 93, 28-34.

Assaad, J.J. (2018). “Development and use of polymer-modified cement for adhesive and repair applications”, *Construction and Building Materials*, 163, 139-148.

Assaad, J. and Daou, Y. (2017). “Behavior of structural polymer-modified concrete containing recycled aggregates”, *Journal of Adhesion Science and Technology*, 31(8), 874-896.

Assaad, J.J. and Issa, C.A. (2017). “Mixture optimisation of polymer-modified lightweight SCC”, *Magazine of Concrete Research*, 69(14), 745-756.

Bogas, J.A., Nogueira, R. and Almeida, N.G. (2014). “Influence of mineral additions and different compositional parameters on the shrinkage of structural expanded clay lightweight concrete”, *Materials and Design*, (1980-2015), 56, 1039-1048.

Bogas, J.A., Gomes, M.G. and Real, S. (2015a). “Capillary absorption of structural lightweight aggregate concrete”, *Materials and Structures*, 48(9), 2869-2883.

Bogas, J.A., de Brito, J. and Figueiredo, J.M. (2015b). “Mechanical characterization of concrete produced with recycled lightweight expanded clay aggregate concrete", *Journal of Cleaner Production*, 89, 187-195.

Doğan, M. and Bideci, A. (2016). "Effect of Styrene Butadiene Copolymer (SBR) admixture on high strength concrete", *Construction and Building Materials*, 112, 378-385.

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

Ferrara, L., Cortesi, L. and Ligabue, O. (2015). "Internal curing of concrete with presaturated LWA: A preliminary investigation", *Special Publication*, 305, 12-1.

Issa, C. A. and Assaad, J.J. (2017). "Stability and bond properties of polymer-modified self-consolidating concrete for repair applications", *Materials and Structures*, 50(1), 28.

Lewis, W.J. and Lewis, G. (1990). "The influence of polymer latex modifiers on the properties of concrete", *Composites*, 21(6), 487-494.

Martínez-García, C., González-Fonteboa, B., Martínez-Abella, F. and Carro-López, D. (2017). "Performance of mussel shell as aggregate in plain concrete", *Construction and Building Materials*, 139, 570-583.

Miller, N.M. and Tehrani, F.M. (2017). "Mechanical properties of rubberized lightweight aggregate concrete", *Construction and Building Materials*, 147, 264-271.

Mindess, S., Young, J.F. and Darwin, D. (1981). *Concrete*, Prentice-Hall. Englewood Cliffs, NJ, 481 P.

Mo, K.H., Alengaram, U.J., Visintin, P., Goh, S.H. and Jumaat, M.Z. (2015). "Influence of lightweight aggregate on the bond properties of concrete with various strength grades", *Construction and Building Materials*, 84, 377-386.

Mo, K.H., Alengaram, U.J. and Jumaat, M.Z. (2016). "Bond properties of lightweight concrete, A review", *Construction and Building Materials*, 112, 478-496.

Mo, K.H., Goh, S.H., Alengaram, U.J., Visintin, P. and Jumaat, M.Z. (2017a). "Mechanical, toughness, bond and durability-related properties of lightweight concrete reinforced with steel fibres", *Materials and Structures*, 50(1), 46.

Mo, K.H., Ling, T.C., Alengaram, U.J., Yap, S.P. and Yuen, C.W. (2017b). "Overview of supplementary cementitious materials usage in lightweight aggregate concrete", *Construction and Building Materials*, 139, 403-418.

Muhammad, N.Z., Keyvanfar, A., Majid, M.Z.A., Shafaghat, A. and Mirza, J. (2015). "Waterproof performance of concrete: A critical review on implemented approaches", *Construction and Building Materials*, 101, 80-90.

Nair, H., Ozyildirim, C. and Sprinkel, M. (2016). "Use of lightweight concrete for reducing cracks in bridge decks (No. FHWA/VTRC 16-R14)", Virginia Transportation Research Council.

Nováková, I. and Mikulica, K. (2016). "Properties of concrete with partial replacement of natural aggregate by recycled concrete aggregates from precast production", *Procedia Engineering*, 151, 360-367.

Ohama, Y. (1995). *Handbook of polymer-modified concrete and mortars: Properties and process technology*, William Andrew.

Pascal, S., Alliche, A. and Pilvin, P. (2004). "Mechanical behaviour of polymer modified mortars", *Materials Science and Engineering: A*, 380(1-2), 1-8.

Ramli, M. and Tabassi, A.A. (2012). "Effects of polymer modification on the permeability of cement mortars under different curing conditions: A correlational study that includes pore distributions, water absorption and compressive strength", *Construction and Building Materials*, 28(1), 561-570.

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

Real, S. and Bogas, J.A. (2017). "Oxygen permeability of structural lightweight aggregate concrete", *Construction and Building Materials*, 137, 21-34.

Said, A.M., Quiroz, O.I., Hatchett, D.W. and ElGawady, M. (2016). "Latex-modified concrete overlays using waste paint", *Construction and Building Materials*, 123, 191-197.

Chandra Berntsson, L. (2003). Lightweight aggregate concrete science, technology and applications.

Sayadi, A.A., Tapia, J.V., Neitzert, T. R. and Clifton, G.C. (2016). "Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete", *Construction and Building Materials*, 112, 716-724.

Shafigh, P., Ghafari, H., Mahmud, H.B. and Jumaat, M.Z. (2014). "A comparison study of the mechanical properties and drying shrinkage of oil palm shell and expanded clay lightweight aggregate concretes", *Materials and Design*, 60, 320-327.

Shafigh, P., Jumaat, M.Z., Mahmud, H.B. and Alengaram, U.J. (2013). "Oil palm shell lightweight concrete containing high volume ground granulated blast furnace slag", *Construction and Building Materials*, 40, 231-238.

Silva, D.A. and Monteiro, P.J. (2006). "The influence of polymers on the hydration of Portland cement phases analyzed by soft X-ray transmission microscopy", *Cement and Concrete Research*, 36(8), 1501-1507.

Valcuende, M. and Parra, C. (2009). "Bond behaviour of reinforcement in self-compacting concretes", *Construction and Building Materials*, 23(1), 162-170.

Vargas, P., Restrepo-Baena, O. and Tobón, J.I. (2017). "Microstructural analysis of Interfacial Transition Zone (ITZ) and its impact on the compressive strength of lightweight concretes", *Construction and Building Materials*, 137, 381-389.

Wang, M., Wang, R., Yao, H., Farhan, S., Zheng, S., Wang, Z. and Jiang, H. (2016). "Research on the mechanism of polymer latex modified cement", *Construction and Building Materials*, 111, 710-718.

Wang, R., Wang, P.M. and Li, X.G. (2005). "Physical and mechanical properties of styrene-butadiene rubber emulsion modified cement mortars", *Cement and Concrete Research*, 35(5), 900-906.

Zhang, P., Xie, N., Cheng, X., Feng, L., Hou, P. and Wu, Y. (2018). "Low dosage nano-silica modification on lightweight aggregate concrete", *Nanomaterials and Nanotechnology*, 8, 1847980418761283.