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Properties of recycled aggregate pervious concrete modified with Styrene Butadiene Rubber Latex

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Abstract. Pervious concrete is a type of concrete mixture that is usually used in pavement with a high range of interconnected voids between large aggregate particles. Herein, an experimental study was conducted in order to figure out the effect of replacing (5%, 10% and 15%) of cement weight by the styrene-butadiene rubber latex (SBRL), in addition to the impact of replacing (0%, 25%, 50%, 75% and 100%) of natural coarse aggregates by recycled ones on the mechanical properties of the pervious concrete. The focused parameters in this experimental study were divided into two parts, permeability indices (density, voids ratio and water permeability) and strength indices (compressive, splitting and flexural tensile strengths and concrete potential to degradation). Additionally, since the water permeability is the most important property in the pervious concrete, relations between water permeability and the other mentioned properties were deduced. Generally, it is noticed that the addition of SBRL positively affects the mechanical properties of the pervious concrete. However, there is a slight decrease in permeability indices. It is observed that the addition of 10% of SBRL to the pervious concrete with 75% recycled aggregate increased the 28 days compressive, splitting tensile and flexural tensile strength by 70.8%, 49.4% and 29.7%, respectively. In addition, the results showed a reduction in the hardened voids content, water permeability and potential to degradation by 13.3%, 11% and 31.7%, respectively.

1. Introduction

Pervious concrete, also called permeable or porous concrete, is a type of concrete mixture with a broad range of interconnected voids between large aggregate particles. These interconnected voids can be achieved by minimizing or eliminating the fine aggregates from the mixture, as well as minimizing the cement paste and water/cement ratio as possible [1–4]. The main property that distinguishes this type of concrete is the high water and air permeability. This high permeability leads to many advantages such as: (a) fast and easy recharge of the water ground level, (b) reduction of the noises from the cars' wheels friction with the roads, (c) elimination of the hot island phenomena in cities [2, 5, 6]. However, this increase in the permeability and porosity leads to a significant reduction in the mechanical strength [6, 7].

Generally, recycling wastes became a matter of concern since it conserves the raw materials for the future generations. However, using the recycled materials in new products consequently affects the products' properties. Regarding pervious concrete, it was found that the use of the recycled coarse aggregates negatively affects the mechanical properties, meanwhile increasing the permeability and porosity [6, 8, 9]. Nonetheless, some researchers found that replacing up to 30% of the raw coarse aggregates with the recycled aggregate produces a negligible effect on the mechanical properties [10–13]. Some researchers even claimed that the percentage that has a non-pronounced impact on the mechanical properties is up to 60% [6, 14, 15]. Meanwhile, there is a research work showing sensitivity of the mechanical properties of pervious concrete to the recycled aggregate percentage [16].

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Many research works have been done to study and overcome the decay in the mechanical properties occurring either due to high porosity or the addition of the recycled aggregates. It was found that reducing the size of the coarse aggregate, decreasing the water-cement ratio or increasing the cement-to-aggregate ratio subsequently enhance the strength properties of the pervious concrete [1, 15, 17]. Additionally, using pozzolans (silica fume, fly ash, metakaolin, blast furnace slag) in the concrete mix showed remarkable enhancement in the mechanical properties with an acceptable decrease in the pervious concrete porosity and permeability [6, 18, 19]. However, all the mentioned solutions consequently lead to a reduction in the workability of the pervious concrete, where it intrinsically has zero slump. This reduction of the workability will lead to technical problems during the casting [20].

However, one of the best solution to overcome this decay in the mechanical properties, without affecting the workability [21–23], is the addition of styrene-butadiene rubber latex (SBRL). Its addition showed impressive results densifying the microstructure of the cement paste as well as helping in bridging the micro-cracks in the cement paste with a polymer film [24, 25]. It was found that the best dose of the solid latex is up to 10% of the cement weight [4, 15, 24], and even up to 15% in some cases [25]. However, another study noted that when the polymer-cement ratio is above 10%, the mechanical properties are not highly dependent on the apparent bulk density, and the flexural and compressive strength of the mortars are not improved further with more polymer [24].

Here in this research work, an experimental investigation was conducted to observe the impact of replacing 5%, 10% and 15% of cement weight by SBRL on the properties of pervious concrete with different levels of recycled coarse aggregates (0%, 25%, 50%, 75% and 100%). The aim of this research is to observe the permeability indices (density, voids ratio and water permeability) and strength indices (compressive, splitting and flexural tensile strengths and concrete potential to degradation) of this type of concrete. Also, deducing formulas for the water permeability and the other observed properties.

2. Materials and Methods

2.1. Experimental program

Table (1) shows 1m^3 concrete components of different 20 mixtures, which were designed according to ACI-522R-10 with a 20% designed porosity. The control mixes are those that are without SBRL. Mixes (6, 11 and 16), (7, 12 and 17), (8, 13 and 18), (9, 14 and 19) and (10, 15 and 20) are compared with 1, 2, 3, 4 and 5, respectively. Due to the high absorption of the recycled aggregate, a proper amount of water that is equal to the first 10 min water absorption of the recycled aggregate during the mixing is added to the water content [9]. Furthermore, the rolling ball test is conducted to make sure that the required workability is achieved [26, 27]. The details of the required specimens for each experiment for each mixture are shown in Table (2).

Table 1. Concrete mixes' components.

Mix number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Styrene butadiene rubber later (cement replacement ratio by weight)	0%					5%						10%					15%			
Coarse aggregate replacement %	0%	25%	50%	75%	100%	0%	25%	50%	75%	100%	0%	25%	50%	75%	100%	0%	25%	50%	75%	100%
Water content (L/m^3)	105	107	110	112	115	105	107	110	112	115	105	107	110	112	115	105	107	110	112	115
Water/binder ratio	0.3																			
Coarse aggregate content (kg/m^3)	1430																			
Coarse aggregate nominal size (mm)	9.5																			
Fine aggregate content (kg/m^3)	72																			
Cement content (kg/m^3)	350																			

Table 2. Quantity and dimensions of the specimens for each experiment for each mixture.

Experiment	Num. of specimens	Shape and dimensions
Fresh density and voids content	3	Cylinder, D = 20 cm, H = 20 cm
Hardened density and voids content	3	Cylinder, D = 7.5 cm, H = 15 cm
Water permeability test (falling head method)	3	50×50cm^2 slab with a 10 cm thickness
Compressive strength	3	Cylinder, D = 15 cm, H = 30 cm
Splitting tensile strength	3	Cylinder, D = 7.5 cm, H = 15 cm
Flexural tensile strength	3	15×15cm^2 beam with a 45 cm span
Degradation and potential resistance	9	Cylinder, D = 10 cm, H = 10 cm

2.2. Concrete components

In this research, all the used components in casting the pervious concrete passed the acceptance criteria experiments. Portland cement is categorized as Type I 42.5 N according to ASTM C150 [28], and its properties are presented in Table (3). The natural coarse aggregate is crushed pink limestone with a single size of 9.5 mm, specific gravity of 2.63 and water absorption of 1.4%.

The recycled coarse aggregate was extracted from debris of a 40~50 year old building using a drilling and Los Angeles machine, and then sieved. According to the visual inspection, no visible cracks appeared on the recycled aggregates, and the old mortar covered about 30~40% of the recycled aggregates surface area. The building was in a dry environment during the operation period. The recycled coarse aggregate is also crushed pink limestone with a single size of 9.5 mm, specific gravity of 2.4 and water absorption of 7.1%.

The Natural fine aggregate is siliceous sand with specific gravity of 2.69 and fineness modulus of 2.65.

The styrene butadiene rubber latex is a thick white material in a liquid state with specific gravity of 1.0, low viscosity, 54% liquid content and a P.H. value of 11.0.

Table 3. Properties of the used Portland cement.

Item	Percentage
Calcium oxide (CaO)	63%
Silicon dioxide (SiO_2)	21.3%
Aluminum oxide (Al_2O_3)	6.2%
Iron oxide (Fe_2O_3)	3.9%
Magnesium oxide (MgO)	2.5%
Sulfur trioxide (SO_3)	1.7%
Potassium oxide (K_2O)	0.7%
Sodium oxide (Na_2O)	0.5%
Loss on ignition (LOI)	2.5%

2.3. Methods of testing

2.3.1. Fresh concrete density and voids content

Samples of well-consolidated fresh concrete are placed in the standard measure, then the fresh concrete density and voids content were calculated according to ASTM C1688 [29], as follows:

$$D_f = \frac{M_c - M_m}{V_m}, \quad (1)$$

where D_f represents density of fresh pervious concrete, M_m represents mass of the measure, M_c represents mass of measure filled with pervious concrete and V_m represents volume of the measure;

$$T = \frac{M_s}{V_s}, \quad (2)$$

where T represents the theoretical density, M_s represents the total mass of the pervious concrete components (cement, water, aggregate and SBRL) and V_s is the absolute volume of the concrete components (the sum of mass of each component divided by its specific gravity);

$$V_f = \frac{T - D_f}{T} \times 100, \tag{3}$$

where the V_f represents the voids ration of the fresh state of the pervious concrete.

2.3.2. Hardened concrete density and voids content

The hardened density and voids content were obtained by recording the mass of dried and submerged specimens, then the hardened concrete density and voids content were calculated according to ASTM C1754 [30] as follows:

$$D_h = \frac{K_d \times A}{d^2 \times L}, \tag{4}$$

where D_h represents the density of the concrete, K_d represents a conversion factor that is worth 1273240 in SI units, A represents the dry mass of the specimen and d represents the specimen diameter, and L represents the specimen length;

$$V_h = 1 - \frac{K \times (A - B)}{\rho_w \times {D_h}^2 \times L}, \tag{5}$$

where V_h represents the voids content of the hardened concrete, B is the submerged mass of the specimen and ρ_w is the water density and the rest of the variables are the same as in Eq. (4).

According to ACI 522R, the upper limit is 2000 kg/m^3 and the lower limit is 1600 kg/m^3 with voids ratio ranging from 15% to 35%.

2.3.3. Water permeability test (falling head method)

The water permeability is described as the infiltration rate. A 30 cm diameter watertight infiltration ring is placed and fixed on the surface of the concrete as shown in Fig. 1. Then, the consumed time to infiltrate a known mass through the infiltration ring is measured. Afterwards, the infiltrate rate can be calculated according to ASTM C1781 [31] as follows:

$$IR = \frac{K_p \times M}{d^2 \times t}, \tag{6}$$

where IR represents the infiltration rate, M represents the mass of infiltrated water, d represents the inside diameter of the infiltration ring, t is the time required for the designated mass of water to infiltrate through the concrete, and K_p represents a correction factor which is equal to 4 583 666 000 in SI units.

According to ACI 522R, the upper limit is 1.2 cm/s and the lower limit is 0.2 cm/s.

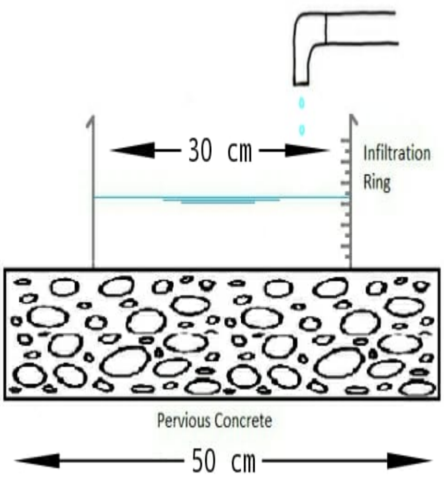

Figure 1. Water Permeability test (falling head method).

2.3.4. Compressive strength

The value of the uniaxial compressive stress that causes the failure of the material is determined, then the ultimate compressive strength can be calculated according to ASTM C 39 [32] as follows:

$$\sigma = \frac{P}{A}, \tag{7}$$

where σ represents the compressive strength, P represents the ultimate loading and A represents the cylinder area.

According to ACI 522R, the compressive strength should not be lower than 3 MPa.

2.3.5. Splitting Tensile strength

The compressing value that causes a compressed concrete cylinder on its side to crack is determined. The splitting tensile strength can be calculated according to ASTM C496 [33] as follows:

$$F_t = \frac{2 \times P}{\pi \times d \times L}, \tag{8}$$

where F_t represents the concrete tensile strength, P represents the maximum loading, d represents diameter of the cylinder and L represents the length of the cylinder.

According to ACI 522R, the splitting tensile strength should not be lower than 1 MPa.

2.3.6. Flexural tensile strength

A 15×15 cm^2 concrete beam with a 45 cm span is loaded at the one-third and two-thirds of its span till failure as shown in Fig. 2. The flexural tensile strength can be calculated according to ASTM C78 [34]. The flexural tensile strength is expressed as modulus of rapture and is calculated as follows:

$$R = \frac{P \times L}{b \times h^2}, \tag{9}$$

where R represents modulus of rapture, P represents maximum applied load, L represents the beam span length, b represents width of beam and h represents depth of beam.

According to ACI 522R, the flexural tensile strength should not be lower than 1 MPa.

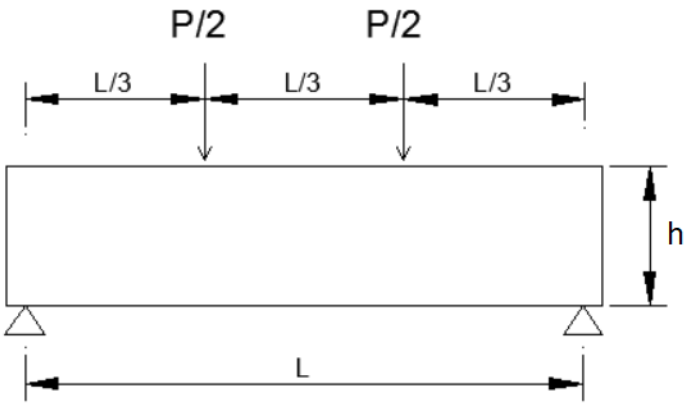

Figure 2. Flexural tensile strength test.

2.3.7. Degradation and potential resistance

The ability of the pervious concrete to resist the degradation occurred from the abrasion and impact is figured out through this test. A known mass of concrete cylinders with 10 cm diameter and 10 cm height are inserted three at a time in the Los Angeles machine without the steel balls, then the Los angles machine rotates 500 cycles. Afterward, the crushed samples are sieved, then the retained concrete on the (1-in.) sieve is weighted. The degradation and potential resistance can be calculated according to ASTM C1747 [35], as follows:

$$Deg = \frac{A - B}{A} \times 100\%, \tag{10}$$

where A is the weight of 3 cylinders and B is the weight of the pervious concrete that retained on sieve size (1-in.) after placing the 3 cylinders in Los Angeles device without balls and perform the test at a speed of 30.33 r/min.

According to ACI 522R, the upper limit is 95% while the lower limit is 19%.

3. Results and Discussion

3.1. Density

Fig. 3.1.1 and 3.1.2 present the relation between the density of the pervious concrete in (kg/cm^3), recycled aggregate proportion and SBRL replacement percentage, respectively. Generally, there is a decrease in the density by the increase in the proportion of the recycled aggregate since the aggregate itself possess more micro cracks because of the extraction process; the attached old mortar decreases the concrete density as well. There is a subsequent increase by the addition of the SBRL. It is noticed that at the fresh state the SBRL has almost a linear effect on the density: the addition of 5% SBRL to the pervious concrete – whether with recycled aggregate or not – increases the density by about 4~5% as shown in Fig. 3.4. Regarding the hardened pervious concrete density, it can be noticed that there is almost no difference between concrete with natural aggregate and 25% recycled aggregate, as shown in Fig. 3.1.2.

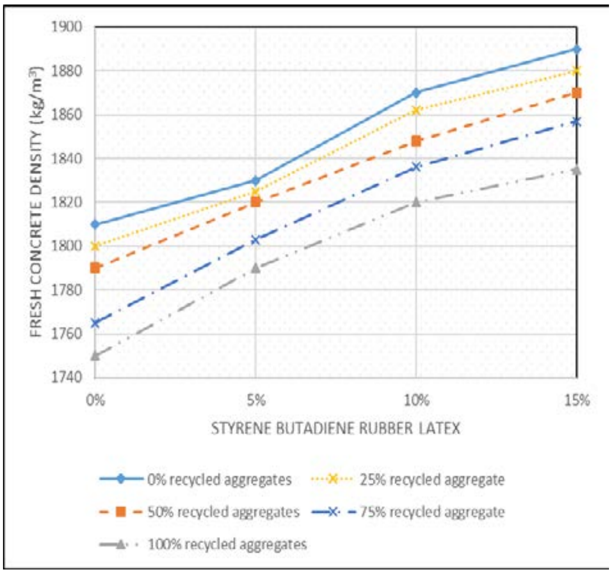

Figure 3.1.1. Density of the fresh pervious concrete.

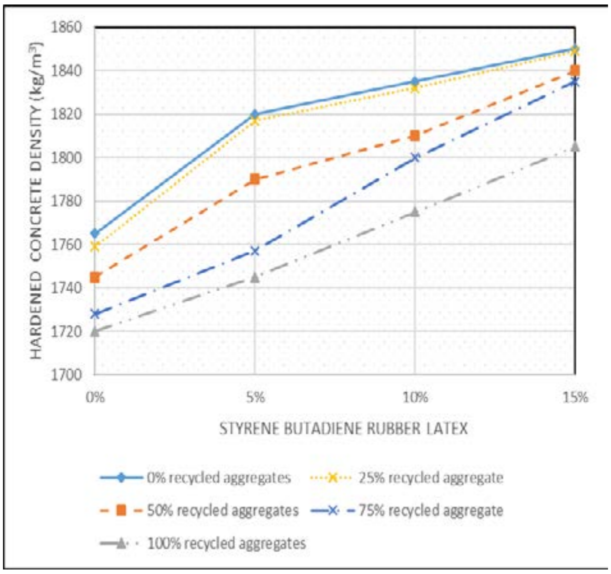

Figure 3.1.2. Density of the hardened pervious concrete.

3.2. Voids content

Figs. 3.2.1 and 3.2.2 show the relation between the voids content of the pervious concrete and recycled aggregate replacement proportion along with the SBRL for the fresh and hardened pervious concrete, respectively. In general, an increase in the voids content is accompanied by the increase of the proportion of the recycled aggregates, which contradicts (Zaetang, Y. et al.), where the authors noticed that the addition of the recyceld aggregate has no signifcant effect [14]. At the same time, there is a decrease in the voids content by the increase of the SBRL percentage. Same as for the density, there is no pronounced difference between the results of pervious concrete with natural aggregate and 25% recycled aggregate. It is observed that replacing 15% of cement weight by SBRL will result in voids ratio less than 15% except for pervious concrete with 100% recycled aggregate, wherein it is recommended in ACI 522R that the voids content should not be less than 15%.

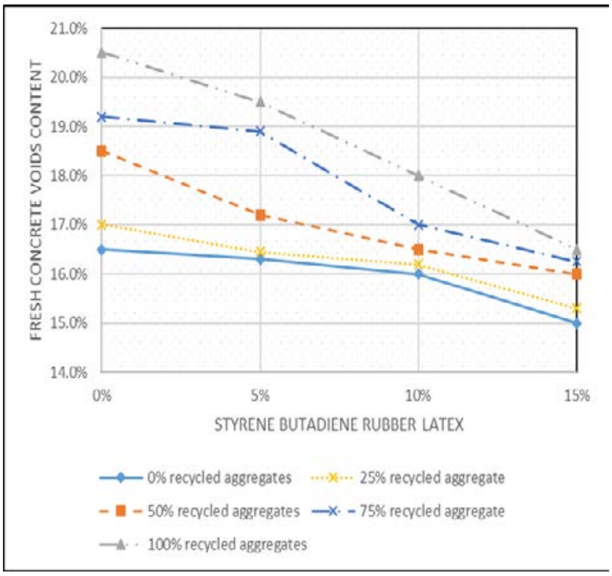

Figure 3.2.1. Voids content in the fresh pervious concrete.

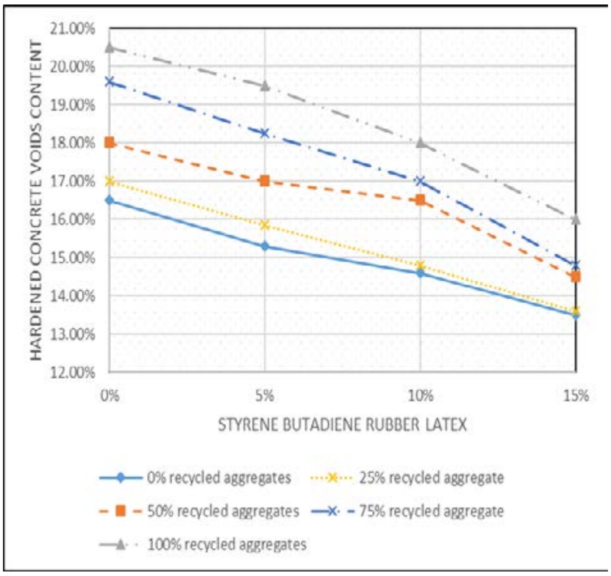

Figure 3.2.2. Voids content in the hardened pervious concrete.

3.3. Water permeability test (falling head method)

Fig. 3.3 shows the relation between the water permeability of the pervious concrete and recycled aggregate replacement proportion along with the SBRL for the fresh and hardened pervious concrete, respectively. It is observed that the SBRL has a negative impact on the water permeability. At the same time, increasing the recycled aggregate percentage in the mixture increases the water permeability. It is observed that the addition of 15% SBRL decreased the water permeability of the pervious concrete with (0%, 25%, 50%, 75% and 100% recycled aggregate) by (10.7%, 14.4%, 14.1%, 16.2% and 11.4%), respectively as shown in Fig. 3.4.

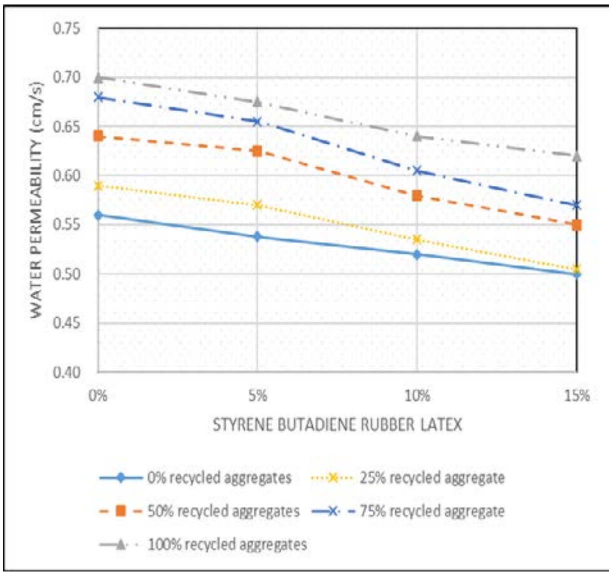

Figure 3.3. Water permeability of the hardened pervious concrete.

3.4. Summary of the effect of styrene butadiene rubber latex on the permeability parameters

Fig. 3.4 highlights the effect of SBRL on the permeability parameters of the recycled aggregate pervious concrete. The figure emphasizes that the addition of the SBRL increases the density while reducing the voids content and the water permeability. For example, replacing 10% of cement weight by SBRL increased the fresh and hardened concrete density by 3.2% and 3.7%, respectively, wherein decreased the hardened voids content and the water permeability by 8.3% and 9.4%, respectively for pervious concrete with 50% recycled aggregate.

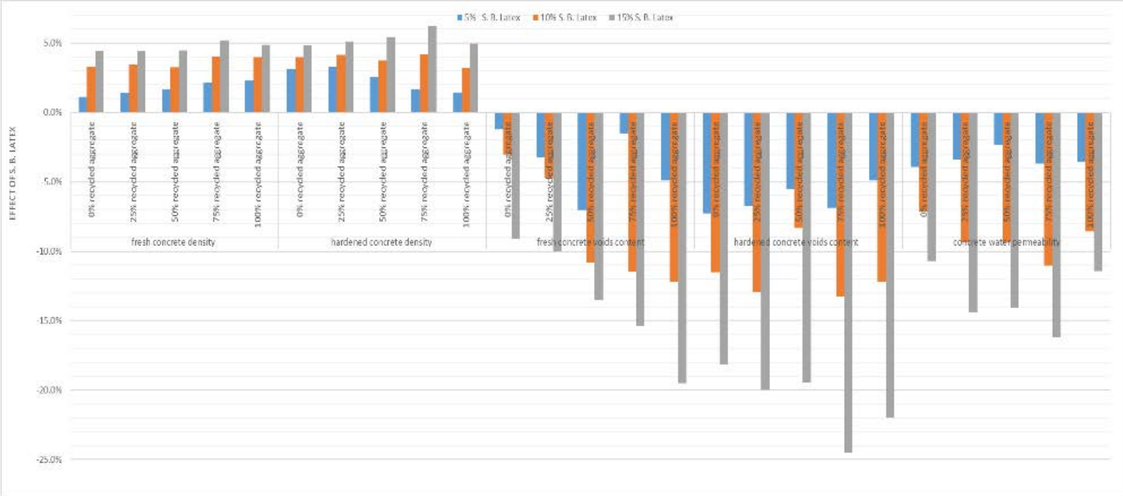

Figure 3.4. Effect of SBRL on the permeability parameters of the recycled aggregate pervious concrete.

3.5. Compressive strength

Fig. 3.5 presents a relation between the 28 days concrete compressive strength (MPa), recycled aggregate replacement percentage and SBRL. Generally, it is observed that by the increase of the dose of the SBRL there is a significant increase in the compressive strength of the pervious concrete. Additionally, it is noticed that when 15% of cement weight is replaced by the SBRL, the difference between the compressive strength of pervious concrete with 50% and 75% recycled aggregate vanishes. This is attributed to the SBRL related densification in the interfacial transition zone between the aggregate and the cement paste [24, 25]. Also, there is no significant deterioration or reduction in the compressive strength of the pervious concrete as a result of replacing 25% of the natural aggregate with recycled ones.

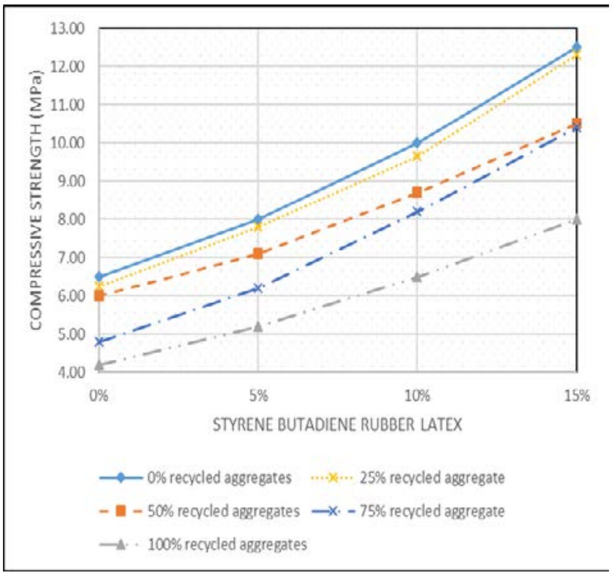

Figure 3.5. 28-day compressive strength of the pervious concrete.

3.6. Tensile strength

Figs. 3.6.1 and 3.6.2 show the impact of the SBRL on the 28 days splitting and flexural tensile strength (MPa) of pervious concrete with different levels of recycled aggregates, respectively. Regarding the splitting tensile strength, it is noticed that the concrete mixtures with 75% and 100% recycled aggregate don't meet the ACI 522R specifications. Additionally, it is observed that the occurred deterioration from the introduction of the recycled aggregates to the concrete mix is reduced by the increase of the SBRL dose.

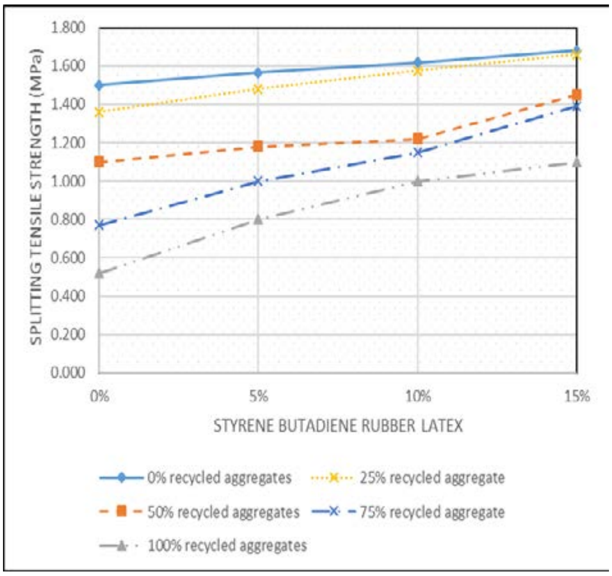

Figure 3.6.1. 28 days splitting tensile strength of the pervious concrete.

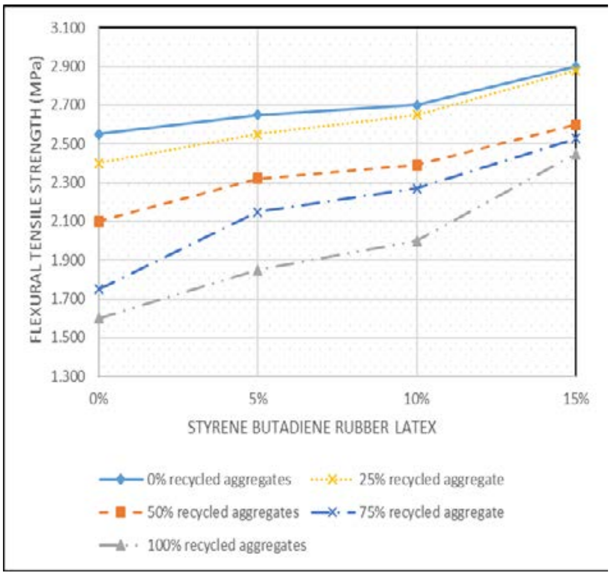

Figure 3.6.2. 28 days flexural tensile strength of the 28 days pervious concrete.

3.7. Degradation and potential resistance

Fig. 3.7 shows the effect of SBRL on the pervious concrete with different levels of recycled aggregates. The figure confirms that SBRL significantly enhances the abrasion resistance of the concrete. Additionally, Fig. 3.8 reveals that when 10% of cement weight is replaced by SBRL, the degradation potential is reduced by 31.7% for the concrete with 75% recycled aggregates.

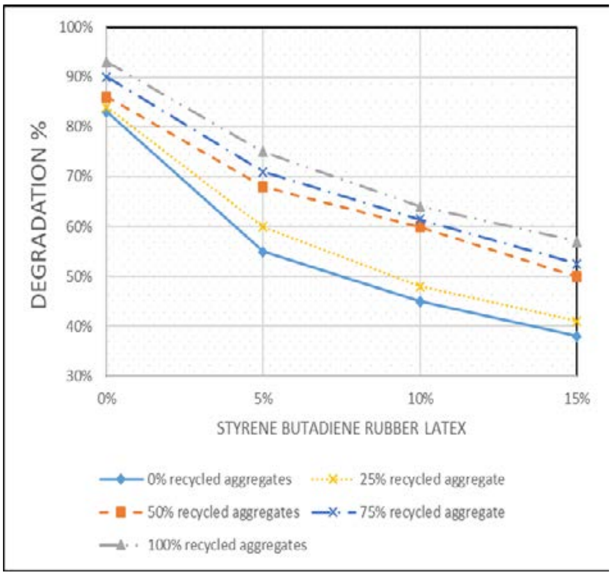

Figure 3.7. Degradation of the pervious recycled aggregate concrete.

3.8. Summary of the effect of styrene butadiene rubber latex on the strength parameters

Fig. 3.8 presents the effect of SBRL on the strength parameters of the pervious concrete with different levels of recycled aggregates. Generally, its noticed that the addition of the SBRL significantly enhances the mechanical properties even above the 10% dosage which agrees with (Shaker, F.A. et al.) [25] and disagrees with (Wang, Ru. Et al.) [24]. It was noticed that the addition of 15% of SBRL to a pervious concrete with 75% recycled aggregate increased the compressive strength, splitting tensile strength and flexural tensile strength by 116.7%, 80.5% and 40.6%, respectively.

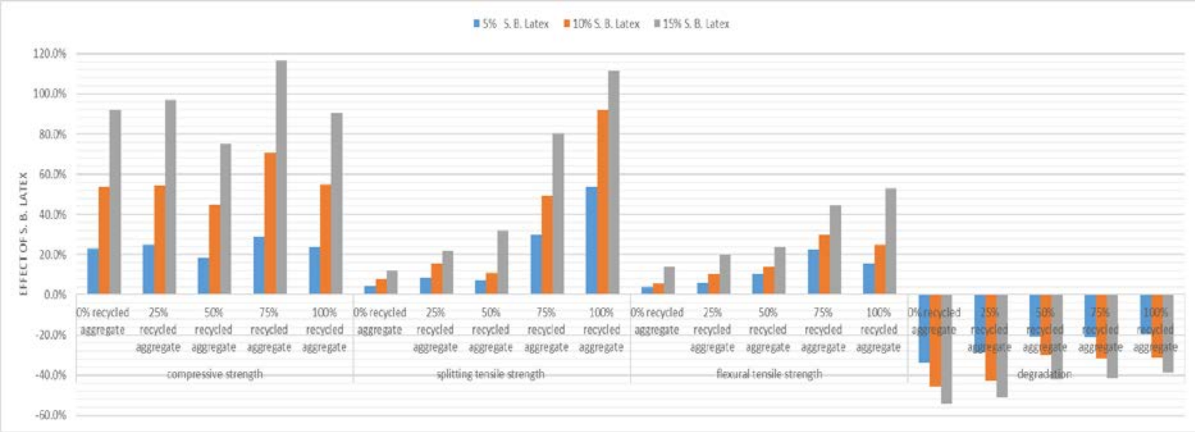

Figure 3.8. Effect of SBRL on the strength parameters of the recycled aggregate pervious concrete.

3.9. General relations between water permeability and other parameters

There are many works establishing relationships between porosity and other parameters [20, 26, 37, 40–41], while there were only a few attempts to find relations between permeability and other properties with a degree of fit (R^2) ranging from 0.53 to 0.91 [20, 36–39].

This section investigates a correlation between water permeability and other parameter, since it is the main parameter in pervious concrete.

It is observed from Fig. 3.9.1 that the increase of the concrete density (D) in (kg/m³), is accompanied by a consequent decrease in the water permeability (P) in (cm/s). The inferred formula has a very good degree of fit (R^2 = 0.9245) and is as follow:

$$D = -550.11P + 2127.9. \tag{11}$$

It is noticed from Fig. 3.9.2 that there is a direct polynomial relationship between the water permeability (P) in (cm/s) and the voids content (V), where the inferred formula has a very good degree of fit (R^2 = 0.9232) and is as follow:

$$V = 0.4476P^2 - 0.2151P + 0.1341. \tag{12}$$

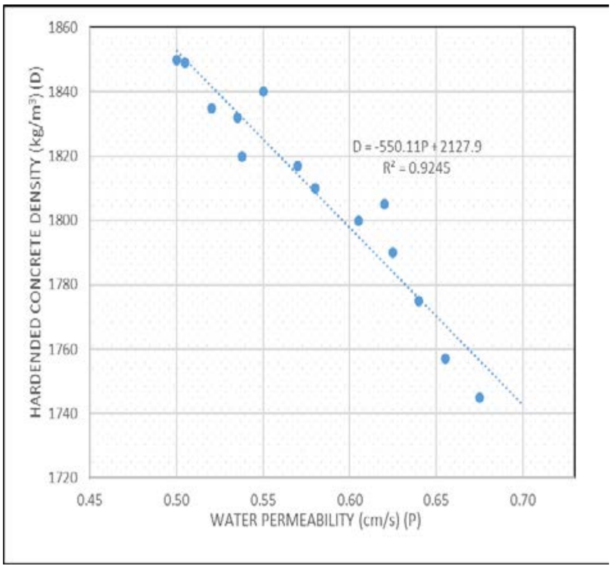

Figure 3.9.1. Correlation between water permeability and hardened concrete density.

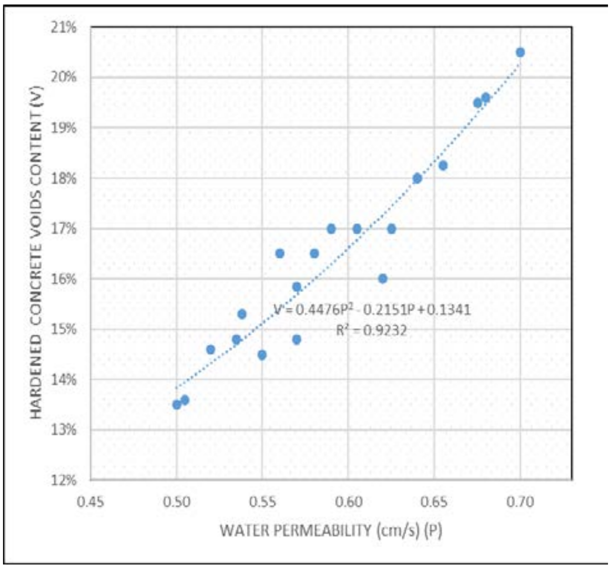

Figure 3.9.2. Correlation between water permeability and hardened concrete voids content.

It is observed from Fig. 3.9.3 that there is an indirect exponential relationship between the water permeability (P) in (cm/s) and the 28 days compressive strength (F_c) in (MPa), where the inferred formula has a good degree of fit (R^2 = 0.8024) and is as follow:

$$F_c = 111.32e^{-4526P}. \tag{13}$$

Fig. 3.9.4 presents the inferred relationship between the water permeability in (cm/s) and the 28 days tensile strength in (MPa), whether the splitting tensile strength (F_t) or the flexural tensile strength (F_b). It is observed that there is an indirect exponential relationship between the water permeability (P) and the 28 days tensile strength (F_c), where the inferred formula between the water permeability and the splitting strength has an excellent degree of fit (R^2 = 0.9684) and is as shown in Eq. (4). In addition, the inferred formula between the water permeability and the flexural tensile strength has an excellent degree of fit (R^2 = 0.9491) and is as shown in Eq. (5).

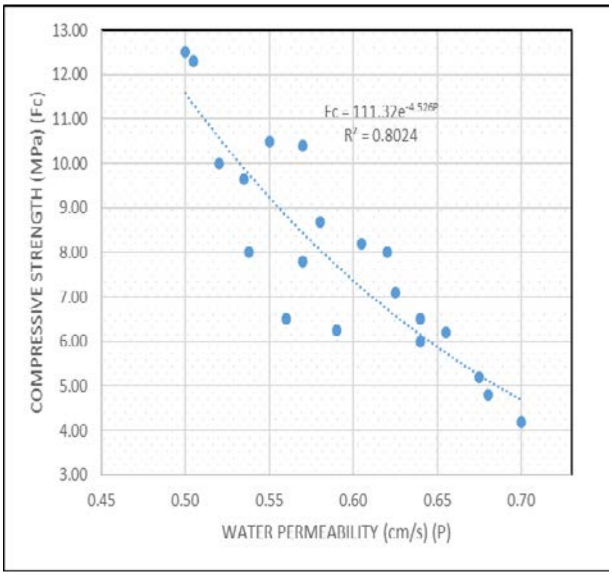

Figure 3.9.3. Correlation between water permeability and pervious concrete compressive strength.

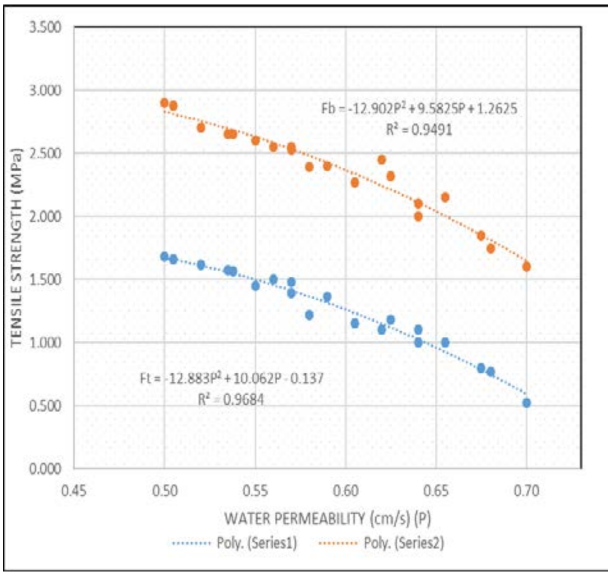

Figure 3.9.4. Correlation between water permeability and pervious concrete tensile strength.

$$F_t = -12.883P^2 + 10.062P - 0.137, \tag{14}$$

$$F_b = -12.902P^2 + 9.5825P + 1.2625, \tag{15}$$

$$Deg = 1.845P - 0.5046. \tag{16}$$

It is observed from Fig. 3.9.5 that there is a direct linear relationship between the water permeability (P) in (cm/s) and the pervious concrete degradation (Deg). The inferred formula has a very good degree of fit (R^2 = 0.8936), and is as follow:

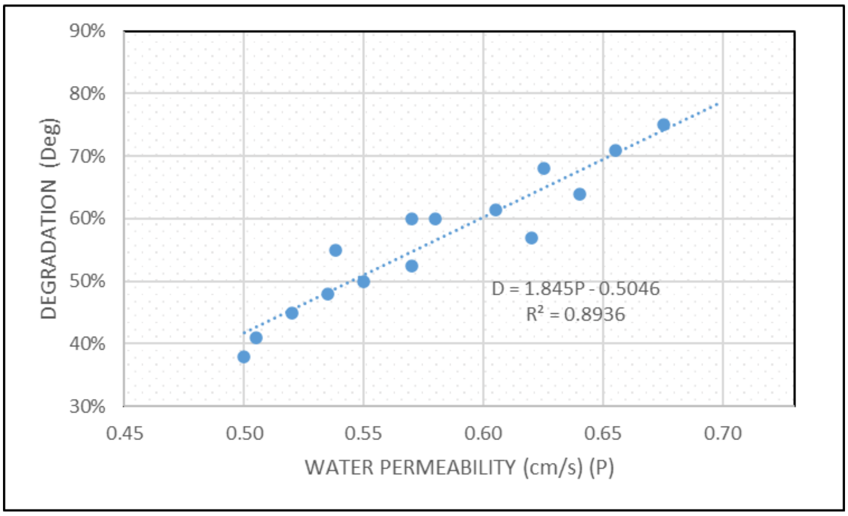

Figure 3.9.5. Correlation between water permeability and pervious concrete degradation.

4. Conclusion

This study focused on the impact of replacing (5%, 10% and 15%) of cement weight by styrene butadiene rubber latex in pervious concrete with different levels of recycled coarse aggregate (0%, 25%, 50%, 75% and 100%).

Thus, it was concluded that:

1. Replacing 25% natural aggregate by recycled aggregates produces next to no negative effect or deterioration in the mechanical properties. Moreover, the deterioration caused by replacing up to 50% of the natural coarse aggregate by the recycled ones is negligible, as the reduction in the mechanical properties is less than 15%.

2. In case of casting mixtures with 75% or more recycled aggregate, it is recommended to use a dose of 10% SBRL in order to meet ACI 522R specifications and to overcome the tensile strength deterioration.

3. High permeability is accompanied by reduced density, compressive strength and tensile strength, but improved voids content and degradation potential.

4. Although a 15% replacement the cement weight by SBRL is the best option, it was found that a 10% replacement is better both in terms of costs and compliance with ACI 522R specifications.

5. In case of using recycled aggregate, it is recommended to increase the mixing water by the amount of the first 10 min absorbed water by the recycled coarse aggregates.

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