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Research

Performance Evaluation of Fiber and Silica fume on Pervious Concrete Pavements Containing Waste Recycled Concrete Aggregate

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ABSTRACT

Pervious concrete as a paving material rehabilitate on a new interest due to its efficiency to permit water to drainage over itself to flow groundwater and reducing storm water runoff. The employment of Recycled Coarse Aggregates (RCA) from site of construction and destruction wastes to product green concrete as a sustainable solve with varied environmental interests. Three different series (A, B, and C) of pervious concrete were used in this work, every series consisting of four mixtures, The (series A) mixtures with RCA replacement were 25%, 50%, 75% and 100% by weight of Natural Coarse Aggregate (NA), and (series B) mixtures using the same replacement ratios of RCA in addition of (silica fume SF) of 2.5%, 5%, 10%, and 12% by weight of cement to strengthen the cement past of pervious concrete. Finally, the (series C) mixtures were included the similar ratios of RCA and SF in addition to glass fibers of volume fraction 0.05%, 0.1%, 0.15%, and 0.2%. The properties of RCA pervious concrete investigated from density, hydraulic conductivity coefficient, porosity, and strength indices were compressive, flexural, and splitting tensile strengths. The test results shows that the use of RCA slightly affect hydraulic conductivity and nugatory effect on compressive, tensile, and flexural strengths where the use of silica fume and glass fibres more strong effect on the hydraulic conductivity and positive effect on pervious concrete flexural, splitting tensile strengths.

Keywords: Pervious concrete pavements; Recycled concrete aggregates; Silica fume; Glass fibers; Hydraulic conductivity

INTRODUCTION

Each year for several reasons amounts of site and demolition wastes created the removal of these wastes is a hard environmental and public problem. Therefore, construction recycling and wastes of demolition for use as aggregates to manufacture new concrete can minimize the trouble of storage of waste and keep natural aggregate needed of resources [1]. Most classic Pavements surfaces prevent water from go to the subsoil under them. These impervious surfaces excess runoff, leads to flooding, pervious concrete pavement is the only means to gain environmental utilities. By blockade rainwater and permitting it to flow into the ground, also is tactical in reloading groundwater, reducing storm water runoff and considered a special type of porous concrete. Porous concrete can be classified into two types: one in which the voids is present in the aggregate component of the mixture RCA, and one in which porosity is introduced in the no aggregate component of the mixture previous concrete [2]. Pervious concrete also indicated to as absorbent concrete or permeable concrete is an unusual concrete has linked pores ranging in size from 2 to 8 mm and void contents from 18% to 35%. The cement paste envelope layer of pervious concrete is very thin. Thus, the strength of pervious concrete depends primarily on the strength of thin binder paste that its compressive strength is relatively low ranging from 2.8 to 28.0 MPa. Pervious concrete owns a bulk unit weight in extent between 1600 kg/m^3 and 2000 kg/m^3, and flexural strength generally ranges between about 1 MPa and 3.8 MPa [3]. It is different from normal concrete in a way that it includes very less or no amount of fine aggregate with comparatively rise porosity and

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high water permeability. Pervious concrete is used for a number of civil engineering and architectural applications such as in park areas, areas with light traffic, pedestrian walkways and tennis courts [4]. The interconnected voids of pervious concrete allow water to pass through and thus it can be used to reduce storm water runoff rate and in other employments like water purification, acoustic sucking the pervious concrete pavement be able to intake the vehicle noise, which to become quiet and comfortable environment. In rainy days, the pervious concrete pavement has no plash on the surface and does not luminosity at night. This improves the rest and safety of drivers [5]. As hydraulic structures but head for to reduce compressive strength too much less than normal concrete due to its high porosity and lack of fine aggregates, several studies have been carried out on mechanical properties of pervious concrete using Recycled Concrete Aggregate (RCA) by 0, 10, 20, 30, 50, and 100% were changed with coarse natural aggregates, results indicate that up to 50% substitution of course aggregate can be used in pervious concrete without compromising strength and hydraulic conductivity significantly . Mechanical properties of pervious concrete decreases and permeability increases with the increase in percentage of recycled aggregates [7]. The changes in mix composition with fiber, w/c ratio of 0.33, and supplementary cementitious additives like silica fume ash can easily are used in order to increase the mechanical properties of pervious concrete [8].

Rizvi et al. [9] studied the effects of different percentages of RCA content on void ratio, compressive strength, and permeability in pervious concrete. Increasing RCA content led to a decrease in compressive strength, an increase in permeability, and an increase in void ratio. Decreases in compressive strength were attributed to RCA being weaker than conventional 36 aggregates. Increases in permeability and void ratio were due to RCA being more angular than the virgin aggregate. This study showed pervious concrete with 15% RCA had compressive strength, permeability, and void content similar to that of the control mix. The authors recommended further research should be conducted to determine the effects of using different sources of RCA in pervious concrete.

MATERIALS

Portland cement type 1 conforming to ASTM C 150 [10]. Superplasticizer (SP) Type F [11] is used because of low water-cementitious ratios specified for pervious concrete. Recycled Concrete Aggregate (RCA) was the material used in this work according to ACI 555-01[12] was collected from a demolition site. The appearances are shown in Figure 1. RCA was crushed and sieved to obtain 4.75-9.50 mm particles for use as recycled coarse aggregates. Natural limestone Aggregate (NA), and RCA meets requirements specified by ASTM C33 [13]. Their properties are shown in Table 1. The low density, high water absorption and high Los Angeles abrasion loss of the recycled aggregate were due to the high porosity of adhered cement mortar on the recycled aggregate as indicated by previous researchers [14]. Silica Fume (SF) with 93.3% SiO^2 content, 25000 m^2/kg surface area, and 2.2 specific gravity was used in this study to boost pervious concrete properties, the chemical analysis of SF is shown in Table 1. Glass fiber with 2.63 (gr/cm^3) Specific gravity, 12 mm length and 0.1 mm diameter used as added material to concrete.

Table 1: The physical properties of NA and RCA.

Properties	NA	RCA	Specification
Dry- density (Kg/m^3)	1435	1350	ASTM C29 [15]
Fineness of modulus	5.88	5.98	ASTM 136 [16]
Specific gravity	2.69	2.57	ASTMC127 [17]
Absorption (%)	0.45	4.57	ASTM C127 [18]
Abrasion loss Angeles (%)	28.3	44.2	ASTM C127 [19]

Table 2: The chemical composition of Portland cement and silica fume.

Material	Chemical composition					
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	SO_3
Cement	22.6	5.6	62.7	1.7	4.3	2.5
Silica fumes	93.3	0.73	0.85	1.21	0.49	1.02

(a) RCA (b) Glass fibers

Figure 1: RCA and Glass fibers.

METHODOLOGY AND MIX PROPORTION

Hydraulic conductivity and porosity

The significant key characteristics of pervious concrete are its hydraulic conductivity. It was measured using the constant head method in accordance to ASTM D-2434-68 [19]. Figure 2 shows the device used to define the pervious concrete permeation used to inspect the permeation of cylindrical samples of (100 × 200) mm. To keep from the leakage of water between model and test device, the cylindrical sample was covered with a rubber tube and tightened by circular clamps. Water was permitted into the specimen to obtain a steady-state flow. The hydraulic conductivity of pervious concrete was computed by using Eq. (1)

Hydraulic Conductivity Coefficient, (cm/s), k=Ql/Hat (1)

Where Q is quantity of water (mm^3), L is length of pervious concrete specimen (150 mm), H is water head (200 mm), A is the cross-sectional area of sample, and, t is time taken for the water head to flow through the specimen (s).

ASTM C1754 [20], was followed to calculate the density and the porosity of pervious concrete, porosity of pervious concrete; It is a ratio of the volume of voids, to all volume of cement paste and aggregate cylinders, (method A) at 28 days of age was used, by taking the difference in weights of an oven-dried (100 mm × 200 mm) cylindrical specimens, the test was performed at three samples for each mix design.

Figure 2: Constructed a device for a hydraulic conductivity test.

Concrete testing

Pervious concrete samples set in general, according to ASTM C192-02 [21]. For each mix, three (150 mm) standard cubic steel molds used for casting specimens and for Compression strength in (28) days in agreement with ASTM C39-98 [22], the splitting tensile strength used three molds of (100 200) mm cylindrical concrete samples measured conformity to the ASTM C 496M-04 two (100 × 100 × 400 mm) prisms for flexural strength at (28) day, correspond with ASTM C78-02 [23,24]. Moreover, in order to calculate the hydraulic conductivity coefficient and porosity, three (100 × 200) mm cylindrical specimens casts. The samples cast in three layers by Rodding 25 times by applying a vibration for (10) seconds. After mixing, the specimens disposed of the molds and maintained in the water until they will arrive the test age of (28) days when they are ready to do the experimental tests.

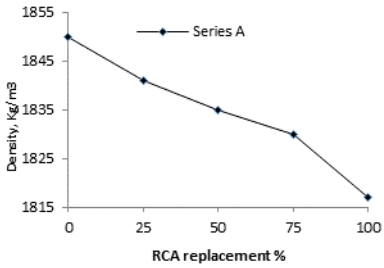

Figure 3: Density for series A.

Table 3: Mix proportions for all mixes.

Mix Design	Cement Content Kg/m^3	Water (Kg/m^3)	Coarse (Kgm^3) Aggregates NA	RCA	Glass Fiber%	Silica Fume%	S.P.% of Cement
NC-0	370	98	1400	0	0	0	0
Series A							
RC25%-(R1)	370	98	1050	350	0	0	1.83
RC50%-(R2)	370	98	700	700	0	0	2.34
RC75%-(R3)	370	98	350	1050	0	0	2.6
RC100% -(R4)	370	98	0	1400	0	0	2.9
Series B							
RC25%-S 2.5%-(RS1)	360.75	98	1050	350	0	2.5	2.76
RC50%-S 5%-(RS2)	351.5	98	700	700	0	5	3.14
RC75%-S10%-(RS3)	333	98	350	1050	0	10	3.37
RC100%-S12%-(RS4)	325.6	98	0	1400	0	12	3.52
Series C							

RC25-GL0.5%- S 2.5% (RGS1)	360.75	98	1050	350	0.5	2.5	3.32
RC50-GL0.1%-S 5% (RGS2)	351.5	98	700	700	0.1	5	3.65
RC75-GL0.15%-S10%-(RGS3)	333	98	350	1050	0.15	10	3.85
RC100 -GL0.2%-S12% (RGS4)	325.6	98	0	1400	0.2	12	4.23

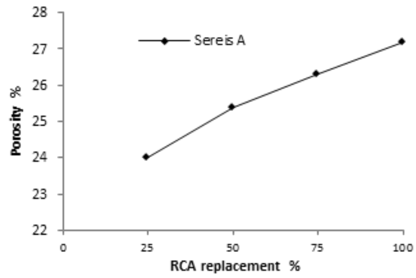

Figure 4: Porosity for series A.

Mix proportions

The pervious concrete proportioning mixture with RCA is different compared to normal concrete. The density of RCA is usually lower and higher more absorbent of water compared to natural aggregate due to the cement paste has a high attraction to water [24]. This absorption capacity of the cement paste is one of the most significant differences in properties and which distinguishes RCA from natural aggregate, execution of concrete with RCA depends on the water-cement (w/c) ratio of the genuine concrete and the w/c ratio of the recently created concrete, it's designed to allow the discharge of water through its surface. The first stride in proportion the mixture is to define the aggregate void ratio, correspondence with ASTM C29 [14], the aggregate specific gravity. The void content of aggregate that will be used in a previous concrete mixture variable and depend on the grading. The reference mixture is made by ACI 211.3-02 [25], and the target void content range of the pervious concrete mixture should be specified The control pervious concrete (NC) consisted of (370 kg) of Portland cement, 98 kg of water, and (1450 kg) of NA for 1 m^3 of concrete with three series A, B, and C, each series consist of four mixes.

In series A the NA was replaced with RCA at the levels of 0%, 25%, 50%, 75%, and100% by weight of coarse aggregate for (R1, R2, R3, and R4), but series B the silica fume replacement with cement at (2.5%, 5%, 10%, and 12%) for the same percentages of the RCA were replaced with NA. Series C was containing glass fibers at (0.5%, 0.1%, 0.15%, and 0.2%) with the same present of RCA and silica fume, Table 3 gives the summary of pervious concrete mix proportions, for all mixtures the aggregates were used in saturated surface dry casings S.S.D. Specific surface area of S.F is greater than the cement, therefore the concrete performance is reduced fundamentally and more water is needed to fix it, because the concrete Performance should not be changed; the amount of superplasticizer is increased.

RESULTS AND DISCUSSION

Effect of RCA replacement level (series A)

Density and porosity: The effect of employing recycled concrete aggregate as a coarse aggregate replacement on density is declared in Figure 3, it is obvious that the use of recycled concrete aggregate slightly decreases density in general, the use of recycled concrete aggregate decreases the density of pervious concrete. This manner may be due to the higher voids ratio of recycled aggregate. For example, in (series A), the reduction in hardened density of pervious concrete at 100% recycled aggregate replacement level is 1.8% compared with that of control mix. From the test results, the reduction in concrete density as a result of the increasing of recycled concrete aggregate is 0.5%, 0.8%, 1.1% for 25%, 50%, 75% recycled concrete aggregate replacement level, respectively. The density values of pervious concrete correspond with the submitted values by ACI 522 [3], which summed up in Table 4.

Figure 4 shows the effectiveness of recycled aggregate replacement level on porosity. From this figure, the utilizing of RCA increases the porosity which demonstrates the reduction in pervious concrete density like the results of using recycled aggregate concrete. The increase in concrete porosity ratio for (R1, R2, R3, and R4) mixtures are 4.3%, 10.4%, 14.3%, and 18.3 for 25%, 50%, 75%, and 100% replacement level compared with that of control mix. The increase of porosity because of the lower workability of pervious concrete with RCA due to more angular shape of recycled aggregate compared with that of natural aggregate [5]. The results of porosity agree with those suggested by ACI 522R [3].

Hydraulic conductivity: Figure 5 debates the effect of RCA replacement grades on pervious concrete. From the test results, the rising of recycled aggregate content increases hydraulic conductivity the slightly increase percentage in pervious concrete water permeability made with (series A) is 0.5%, 9.1%, 10.9%, and 13.6% for 25%, 50%, 75%, and 100% recycled concrete aggregate replacement levels, respectively. In addition, it is renowned that the achieved values of

Hydraulic Conductivity are remaining in the ideal ranges given in Table 4.

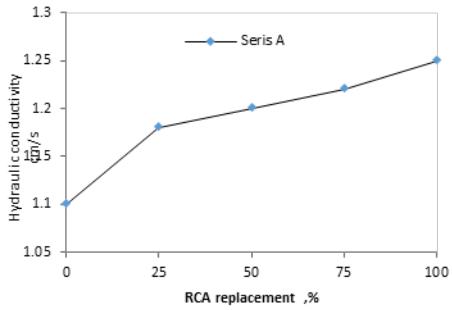

Figure 5: Hydraulic conductivity coefficient for series A with RCA replacement.

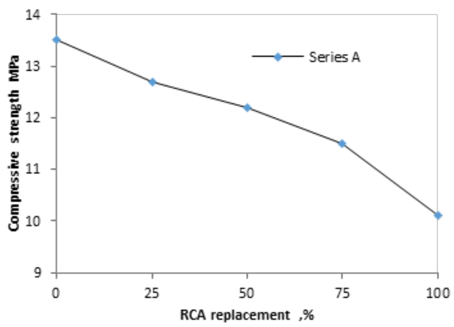

Figure 6: Compression strength with RCA replacement percent for series A at (28) day.

Compressive strength: The effect of RCA replacement levels on pervious concrete compressive strength is illustrative in Figure 6; it is obvious that the use of RCA has an important effect on compressive strength where the excess of RCA content reduces the resulting concrete compressive strength. This inefficient influence may be due to the higher porosity in concrete with RCA and due to the poor bonding between RCA and cement paste [26]. In addition, the bad transition zone properties between recycled aggregate and cement paste may cause this negative effect [27]. The reduction in 28 days concrete compressive strength is 6%, 10%, 14.8% and 25% for 25%, 50%, 75% and 100% recycled aggregate levels, respectively compared with that of control mix. Finally, it is important to mention that although the using of recycled aggregate adversely affected the compressive strength of pervious concrete the achieved results stay fulfil the proposed typical ranges by ACI 522 [3].

Flexural and splitting tensile strength: Figure 7 shows the effect of RCA replacement levels on pervious concrete flexural strength. From this Figure, the increase of replacement levels of the recycled aggregate reduces the pervious concrete flexural strength. The range of decrease in flexural strength as the results of using recycled aggregate from 25% to 100% replacement levels is 10.8% to 41%, respectively. This behavior is the same for splitting tensile strength as shown in Figure 7 and Table 4. The negative effect of using recycled aggregate may be assigned to the bad properties of transition zone in case of RCA. The transition zone greatly affects the concrete tensile strength [28].

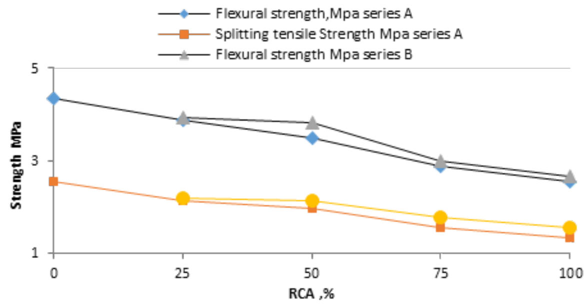

Figure 7: Flexural and splitting tensile strengths with RCA replacement percent for series A and B at (28) day.

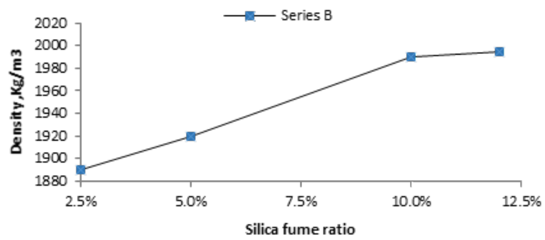

Figure 8: Porosity for series B with silica fume ratios.

Addition of silica Fume to RCA pervious concrete (Series B)

Density and porosity of pervious concrete: In Table 4, it can be seen that by incorporating SF with the same replacement level of RCA, for series A, and B, the increase of silica fume content to series B mixes increase density of pervious concrete as shown in Figure 8. As an example, the increase in pervious concrete density is 2.7%, 4.6%, 8.7%, and 9.7% for 2.5%, 5%, 10% and 12% silica fume content, respectively in comparison between series A and B mixes. The influence of using silica fume on porosity of pervious concrete is shown in Figure 9. From this figure, the increase in silica fume levels decreases the resulting voids ratios. From the test results, the decrease in hardened pervious concrete voids ratio in the range from 11.3% to 23.5% from 2.5% to 12% silica fume. This behavior may be due to the filling effect of silica fume in addition to the good ability of compaction in the presence of very fine silica fume [29].

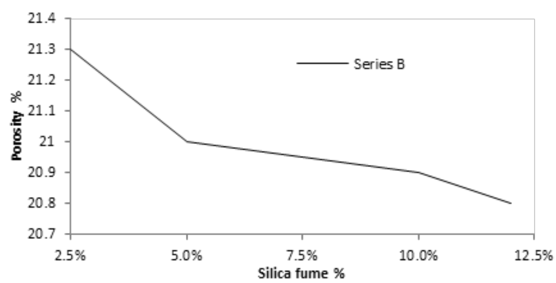

Figure 9: Porosity for series B with silica fume ratios.

Table 4: Results of all mixtures.

Mix Design	Bulk density Kg/m^3	Hydraulic Conductivity cm/s	Porosity (%)	Comp. Strength 28-day MPa	Flexural Strength 28-day MPa	Tensile Strength 28-day MPa
NC-0	1850	1.1	23	13.5	4.34	2.56
Series A						
RC25%-(R1)	1841	1.18	24	12.7	3.87	2.12
RC50%-(R2)	1835	1.2	25.4	12.2	3.5	1.98
RC75%-(R3)	1830	1.22	26.3	11.5	2.87	1.54
RC100%-(R4)	1817	1.25	27.2	10.1	2.56	1.33
Series B						
RC25%-S 2.5%-(RS1)	1890	1.12	21.3	14.87	3.93	2.18
RC50%-S 5%-(RS2)	1920	1.08	21	16.21	3.43	2.14
RC75%-S10%-(RS3)	1990	0.97	20.9	17.35	2.98	1.78
RC100%-S12%-(RS4)	1995	0.95	20.8	17.51	2.66	1.54
Series C						
RC25-GL0.5%- S 2.5% (RGS1)	1887	0.9	21	14.99	4.76	3.32
RC50-GL0.1%-S 5% (RGS2)	1916	0.89	21.9	14.32	7.54	4.23
RC75-GL0.15%-S10%-RGS3)	1986	0.88	22.8	13.61	8.54	5.43
RC100 -GL0.2%-S12% (RGS4)	1990	0.82	24	9.54	8.56	4.98

Hydraulic conductivity coefficient: The silica fumes influence of series B on Hydraulic Conductivity is shown in Figure 10. From the test results for concrete with the same replacement of recycled aggregate, the increase of the silica fume decreases pervious concrete hydraulic conductivity coefficient.

These results may be due to the improving of pervious concrete density as the result of adding silica fume. The decrease in pervious concrete porosity is 5.1%, 10%, 20.5%, and 19.2% for RS1, RS2, RS3, and RS4 mixtures of 2.5%, 5%, 10% and 12% silica fume, respectively compared with series A.

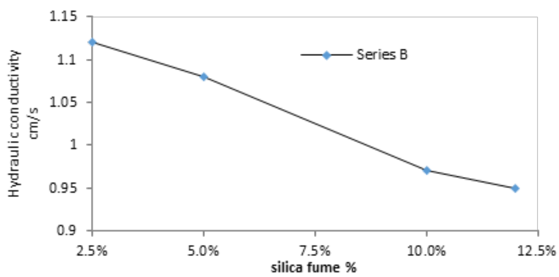

Figure 10: Hydraulic conductivity coefficient for series B with SF ratios.

Compressive strength of pervious concrete: From this Figures 11 and 12, it can be found by comparing the series A and B the influence of silica fume on pervious concrete compressive strength, the use of silica fume enhances pervious concrete compressive strength. This increase on 28 days compressive strength for pervious concrete with the Similar RCA replacement ratios and is 17.1%, 32.9%, 50.9% and 73.4% for 2.5%, 5%, 10%, and 12% silica fume, respectively. This enhancement may be attributed to the improvement of cement matrix because of filling effect and Pozzolanic reaction of silica fume [30].

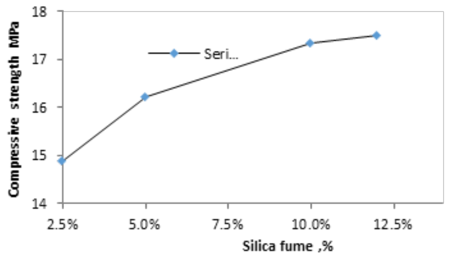

Figure 11: Compression strength with SF ratios for Series B at (28) day.

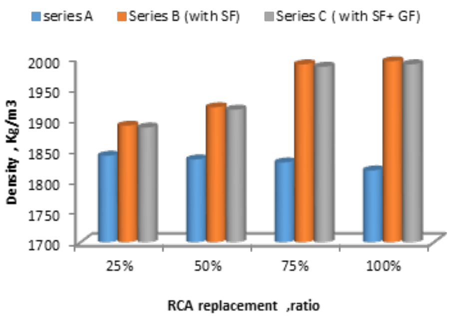

Figure 12: Density for all series with RCA replacement ratio.

Flexural and splitting tensile strength: Figure 7 shows the influence of silica fume on 28 days pervious concrete flexural and splitting tensile strength. From this figure, it is clear that the silica fume slightly improves pervious concrete flexural and splitting tensile strength. This improvement may be attributed to the enhancement of the cement matrix and transition zone because of using very fine silica fume [31]. For example for series B with recycled aggregate and silica fume, the increase in pervious concrete 28 days splitting tensile strength is 2.8%, 8.1%, 15.6%, and 15.7% for 2.5%, 5%, 10% and 12% silica fume compared with series A. This increase in splitting tensile strength enhances the tensile strength of pervious concrete mix with 100% recycled aggregate to the accepted limits given in Table 4.

Effect of glass fiber on the properties of RCA pervious concrete (series C)

Hardened density and Porosity: The experimental results of series C are shown in Figure 7. From the test results, the increase of glass fiber volume fraction decreases hardened pervious concrete density in the presence of silica fume compared to results of series B without glass fibers. These reductions are 0.1%, 0.21%, 0.2%, and 0.25% for hardened density of pervious concrete with 0.05%, 0.1%,0.15, and 0.2% glass fiber volume fraction, respectively compared with results of series C, these decreases in density of pervious concrete with glass fibers may be due to the lower density of glass fibers and the increase of voids ratio due to the presence of fiber [32].

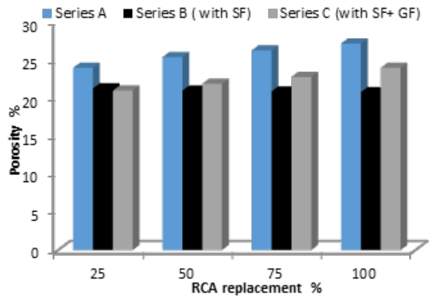

Figure 13: Porosity for all series with RCA.

The values of hardened density of pervious concrete match with the proposed values by ACI 522 [3]. The results of using glass fibers are presented in Figure 13 for the porosity of pervious concrete with SF at series C, it is clear that the increase of glass fibers levels slightly increases the resulting voids ratios. This is attributed to the absence of cohesion and bad dispersion of fibers [33]. From the test results, the increase in hardened pervious concrete porosity is 9% and 5.3% for 0.1% and 0.2% glass fiber volume fraction, respectively compared with series B. This slight increase in porosity decreases the density of pervious concrete with glass fibers.

Hydraulic conductivity coefficient: The influence of glass fibers volume fraction on Hydraulic Conductivity is given in Figure 9 and Figure 14. From the test results and in comperation between results of series B and C, the increase of glass fiber volume fraction increases pervious concrete hydraulic conductivity coefficient. These results may be due to the increase of the voids ratio of pervious concrete with the presence of glass fibers [34]. The increase in pervious concrete permeability is 2% and 8.7% for 0.1% and 0.2% glass fiber volume fraction, respectively compared with the control mix.

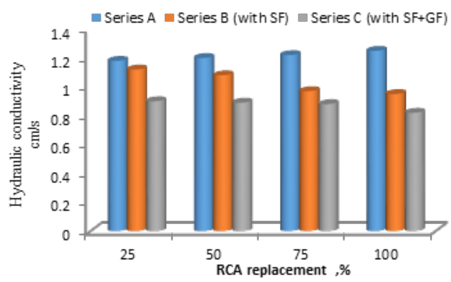

Figure 14: Hydraulic conductivity coefficient for all series with RCA.

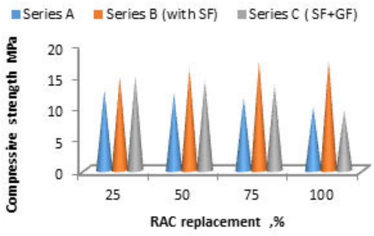

Figure 15: Compressive strength for all replacement ratios series with RCA.

Compressive strength: The influence of glass fibers at series C on compressive strength of pervious concrete is explained in Figure 10. From the figure 15, the use of glass fiber slightly decreases pervious concrete compressive strength the reduction in pervious concrete 28 days compressive strength is 1.6% and 3.2% for 1.5% and 3% glass fibers content . This behavior may be due to the lower modulus of elasticity of glass fibers [4].

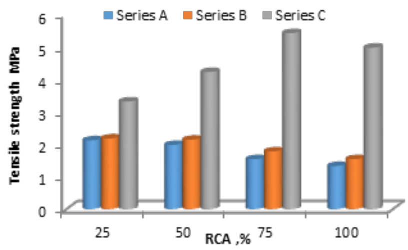

Figure 16: Tensile strength for all series with RCA.

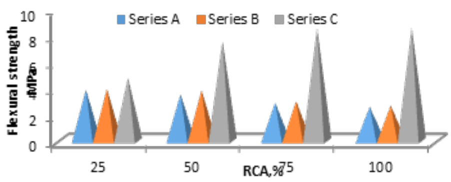

Figure 17: Flexural strength for all series with RCA.

Flexural and splitting tensile strength: Figures 11 explains the influence of glass fibers volume fraction on 28 days pervious concrete flexural and splitting tensile strength, it is clear that the glass fibers has improvement effect on pervious concrete flexural and splitting tensile strengths where the increase of glass fiber volume fraction enhances pervious concrete flexural and splitting tensile strength [Figure 16 and Figure 17]. For example, the increase in pervious concrete 28 days splitting tensile strength is 12.8% and 34.5% for 0.1% and 0.2% glass fiber volume fraction. The positive effect of glass fibers on pervious concrete tensile strength may be due to the bridging mechanism of glass fibers which arresting the failure propagation [35].

CONCLUSION

- The use of recycled concrete aggregate and glass fibers slightly affect the permeability indices where the use of silica fume yield more ingenuous effect on the hydraulic conductivity indices
- Utilizing recycled concrete aggregate has a significant negative effect on compressive strength but the achieved results are still in the proposed typical ranges by ACI 522R
- Tensile strength test results of pervious concrete indicate that the use of recycled aggregate has a significant negative effect where the use of 25% and 100% recycled aggregate generally produces splitting tensile strengths less that the recommended.
- Addition of silica fume significantly promotes strength indices of pervious concrete where it is recommended to use 5% silica fume in case of using recycled aggregate in pervious concrete production
- The use of glass fiber slightly decreases pervious concrete compressive strength, and has a positive effect on pervious concrete flexural, splitting tensile strength percentage. This improvement enhances the tensile strength of pervious concrete mix with 25% to 100% recycled aggregate to achieve the accepted limits

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