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CHARACTERIZING POROUS CONCRETE MIXTURES FOR RIGID PAVEMENT

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Abstract

In highway engineering, the high porosity of Porous Concrete (PC) facilitates additional functions like noise reduction and urban ambient temperature minimizing, further, to hydroplaning control. The internal composited structure of PC plays the vital role in its mechanical behavior. However, increasing the concrete mixture's porosity can adversely affect the mixture's mechanical properties such as compressive and flexural strength, elasticity, and creep strains. This paper aims to demonstrate an experimental attempt to characterize the mechanical properties of porous concrete pavement (PCP) using local limestone aggregate. The attempt suggested a multistage process to optimize the best mixtures through five stages using different variables, namely: nominal maximum aggregate size (NMAS), w/c ratio, aggregate/paste ratio, superplasticizer dosage, and reactive powder dosage. Firstly, sample preparation was included paste preparation by mixing 75% of the specified mixing water (with SP if applicable) with OPC and SF (if applicable). In comparison, the remain 25% was used to wet the aggregate before continuing mixing. The prepared samples' mechanical and volumetric properties were determined to achieve this optimization process through compressive strength, flexural strength, porosity, coefficient of permeability, and density. The experimental results illustrated a wide range of variation in volumetric and mechanical properties of the produced mixes according to selected variables. The optimization is very significant to gain a PC mixture with an accepted property. Traditional PC mixture comparatively exhibited compressive strength of less than 15 MPa, and flexural strength of less than 3 MPa, while high performance PC mixture exhibited over 30 MPa compressive strength, 5 MPa flexural strength, 1.16 mm/s coefficient of permeability (for the mixture associated with 12.5 NMAS, 80% agg/paste ratio, 0.27 w/b, 0.7% (of binder weight) plasticizer, and 30% (of binder weight) silica fume). However, local limestone aggregate can offer PC mixture suitable for highway pavement when aggregate/cement, additives, and admixture are adequately optimized.

Keywords: Cement paste, Concrete pavement, Flexural strength, Interface zone, Stone on stone contact.

1. Introduction

Porous, pervious or popcorn concrete (PC) is concrete with high porosity and continual voids. It characterizes entirely different properties from conventional concrete, whereas its mechanical and volumetric properties differ seriously from traditional concrete properties. High porosity is facilitated specific functional properties that make PC very suitable in several architectural and civil engineering applications. For example, permeable concrete surface pavement, base course pavement, vegetation or living organism concrete bed, noise absorbing elements, thermal insulated elements, etc. Porous concrete pavement (PCP) application was initially applied in the USA and England from the 1970s [1]. PCP is offered distinct properties from traditional concrete pavement, especially in flood control and water purification [2], improving skid resistance in both wet and dry conditions [3], reducing noise or absorbing tyre sounds [4], and reducing the effect of urban heat island [5]. Moreover, PC offers less shrinkage and thermal expansion; therefore, fewer joints are needed, consequently reducing dowel deteriorations [6, 7].

Although PCP exhibits fascinating functional properties, its mechanical properties (such as compressive strength, flexural strength, abrasion resistance, etc.) show worse performance. The main cause of this drawback is the high pore percentage and the pores' continuous connection, which is in fact what distinguish the PC for its functional properties, as mentioned previously. Therefore, extensive researches have been conducted to upgrade mechanical properties with conserving the functional properties [8-17]. These attempts have been focused on strengthening the PC's open grade skeleton by using high quality aggregates to sustain high stone on stone contact performance and high-performance mortar to grip the aggregates efficiently [1, 18-23]. Other attempt use no traditional concrete constitutes to develop PC concrete by Recycle aggregate[24] furnace sludge aggregates [25]Fly ashes [26-29] polymers [30] geopolymer[31] superplasticizers [32] and nano-silica[33].

Surveying the previous attempts sustains that the acceptable PC concrete with sufficient volumetric and mechanical properties can be achieved by optimize the fundamental design indices [34, 35]. Fundamental design indices include nominal maximum aggregate size (NMAS), w/c ratio, aggregate/paste ratio, superplasticizer dosage, and reactive powder dosage. Air void and permeability are the main volumetric properties. Although some previous study indicated that 40% of air void is reachable [35], the interconnected voids are hardly exceeded 30% [36], other researchers stated that interconnected void represents about 82% of total voids [37]. However, extra compaction, fine materials, and additives have reduced air voids as low as 10% [35]. Permeability has accordingly ranged from 0.3-47.7 mm/sec due to PC mixture contents characteristics, e.g., increase aggregate size increase permeability [38], or incorporating silica fume homogenizes PC matrix and increases permeability[39].

It is worth mentioning that high air voids is significantly affected mechanical properties, while low pores size improves mechanical properties[40]. The mechanical properties are highly influenced by compaction methods, curing time and methods, testing methods, materials characteristics, and mix design [41-43]. Yeih and Chang suggested compressive strength at 28 days for structural concrete must be over 21 MPa, while for particular uses in airport runways have to exceed 35 MPa [25]. However, experiments proved that traditional PC compressive strength explored as low as 7 MPa [43], while under controlled design and quality materials and additives over 50 MPa was reachable [42]. Similarly, for other mechanical properties, e.g., flexural strength for traditional PC mixture recorded as low as 2 MPa [44], while specific additives improved it tile 4.4 MPa [35, 45].

As a summary, the literature review indicated that PC is special concrete highly affected by the used materials and application process. The global design method to specify design indices is not available yet [25, 35]. Furthermore, the mechanical and volumetric properties are conflicted with each other's. Therefore, this study attempts to characterise the PC properties using local limestone aggregate with a range of design indices to understand these indices' effect on finalising an acceptable PC mixture suitable for local pavement applications. This study suggests a multistage design method to achieve the planned aim. This characterization helps describe a mix design method introduced for pavement applications of roads and airports.

2. Materials and testing

2.1. Materials

Ordinary Portland cement (OPC) was selected in the investigation; it supplied from Karbala Cement Plant. The supplied OPC is confirmed to the requirement of the I.Q.S. No.5 [46]. Crushed limestone aggregate was supplied from Karbala quarries. The aggregate washed and sieved to prepare three single size gradations, namely, 19-12.5, 12.5-4.74, and 4.75-2.36 mm, which defined according to Nominal Maximum Aggregate Size, (NMAS), 19, 12.5, and 4.75, respectively. Table 1 lists the characterization of the three aggregate gradations. Tap water was used for both mixture preparation and curing of all the PC specimens. Silica Fume (SF) was selected as a main additive recommended by previous studies to gain high-performance PC. Table 2 demonstrates the physical and chemical properties of the used SF, which was checked to confirm ASTM C1240. Finally, superplasticizer (SP) confirms the requirement of ASTM C494-type G was supplied to reduce w/c ratio and enhance the binding interface. Table 3 shows SP properties. Figure 1 shows the used materials in this study work.

Fig. 1. Used materials.

Table 1. Used aggregate properties.

NMAS, mm	Gradation, mm	Loss unit weight, kg/m^3	Bulk specific gravity	Apparent specific gravity	Water absorption, %	Void content, %
19	19-12.5	1411	2.684	2.723	0.44	38
12.5	12.5-4.75	1379	2.683	2.728	0.53	42
4.75	4.74-2.36	1362	2.688	2.739	0.62	40

Table 2. Chemical and physical properties of used silica fume.

Chemical properties		
Composition property	**SF**	**ASTM C1240 limitations**
SiO_2	91.65	≥85
Al_2O_3	0.03	-
Fe_2O_3	0.02	-
CaO	1.12	-
MgO	0.02	-
K_2O	0.13	-
Na_2O	0.21	-
SO_3	0.22	-
Loss on ignition, max. %	2.76	< 6
Moisture content, max. %	0.58	< 3
Physical properties		
Percent retained on sieve No.325 (45µm), max.	6	< 10
Accelerated P.A.I with P.C at 7 days	115.6	> 105
Specific particles surface area, min, m2/g	22	> 15
Specific gravity	2.251	> 2.2
Blaine fineness (m^2/kg)	21200	15000-30000

Table 3. Superplasticizer technical properties.

Property	Technical properties	Approval/standards
Description and base	Aqueous solution of modified polycarboxylate, water-reducing, high range, and retarder	ASTM C494-type G
Density	1.069 kg/Lt	
Appearance	heavy liquid, brownish colour	
PH	7.3	

2.2. Mix design

Generally, the previous concrete mixture comprises OPC, water, and coarse aggregates with or without, additives and/or superplasticizer. Therefore, to gain the high performance of these constitutes, optimizing the percent of each constitute has to be investigated individually. Moreover, the NMAS could be vital in determining the volumetric and mechanical properties of the PC; design variables can be considered as well. However, a multistage process was suggested, as can be seen in Fig. 2, to target the high-performance PC using mentioned variables in mix design, as follows:

- Investigating the best NMAS that facilitate the required porosity with higher compressive strength
- Identifying the optimum w/c ratio for the PC mixture of selected NMAS from stage one.
- Optimizing aggregate/paste ratio that conserves porosity and introduces higher compressive strength
- Identifying best admixture dosage that upgrades compressive strength with higher porosity.
- Optimizing reactive powder dosage with various W/B content within specific workability index.

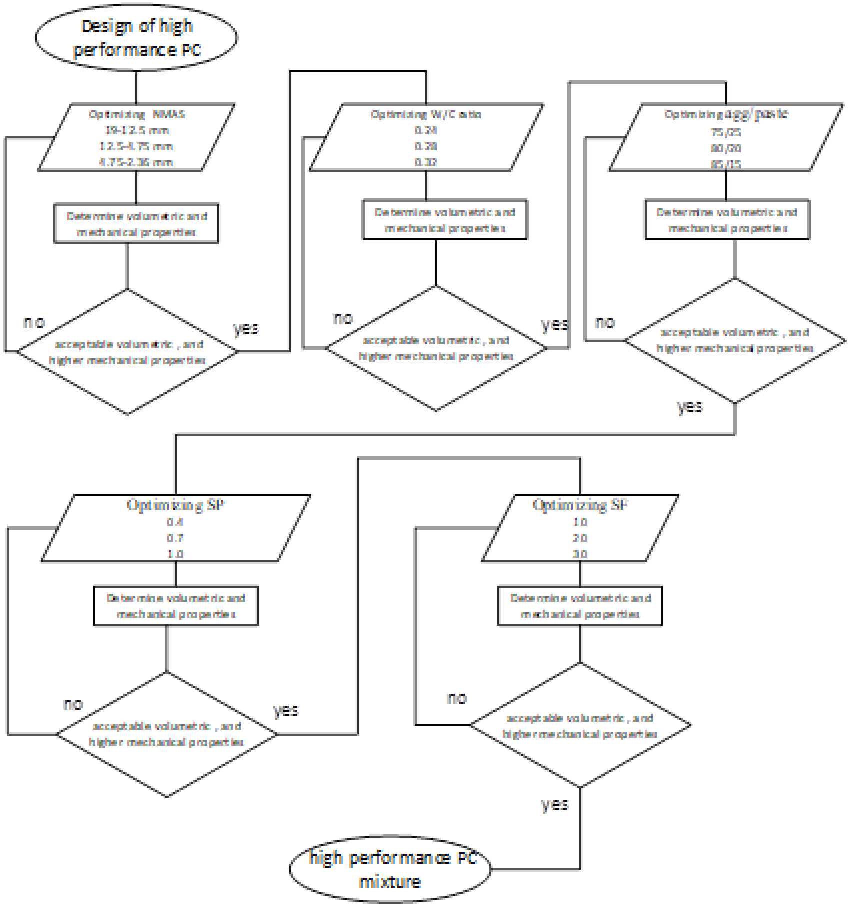

Fig. 2. Experimental program.

According to the above stages, Table 4 presents the basic mix proportion suggested for this study. All these proportions were based on previous studies; i.e., a range for each variable was nominated from a set of prior attempts to characterize the PC performance; for more details, see the mix proportion references [6-31].

Table 4. Mix design stages and mix proportions.

Mix No.	stage	Agg. size	Agg./paste	W/B	SP	SF
1	Stage 1: identifying optimum NMAS	19.0-12.5	80/20	0.24	0	0
2		12.5-4.75	80/20	0.24	0	0
3		4.75-2.63	80/20	0.24	0	0
4	Stage 2: identifying optimum w/c	12.5-4.75	80/20	0.28	0	0
5		12.5-4.75	80/20	0.32	0	0
6	Stage 3: identifying optimum agg/paste	12.5-4.75	85/15	0.28	0	0
7		12.5-4.75	75/25	0.28	0	0
8	Stage 4: identifying optimum plasticizer dosage	12.5-4.75	80/20	0.25	0.4	0
9		12.5-4.75	80/20	0.23	0.7	0
10		12.5-4.75	80/20	0.20	1.0	0
11	Stage 5: identifying optimum reactive powder dosage	12.5-4.75	80/20	0.24	0.7	10
12		12.5-4.75	80/20	0.25	0.7	20
13		12.5-4.75	80/20	0.27	0.7	30

2.3. Sample preparation and curing

75% of the specified mixing water (with SP if applicable) was firstly used to prepare a paste, while the remain 25% are used to wet the aggregate before mixing, OPC and SF (if applicable) was blended in a dry state before gradually added to the water with continuing mixing operation, as can be seen in Fig. 3. Then, a mechanical mixer was utilized to mix the PC mixtures. The well-homogenized PC mixture was cast in cylindrical specimens with 100 mm in diameter and 200 mm high in consecutive layers 50 mm each using standard rodding for compaction. It is worth mentioning that the curing of PC is highly affected by the curing process. It was found that direct tightly covering of mold face by plastic membrane is essential to conserve the water required for curing (hydrate water, gel water, and pores saturation water) in the early stage. After two days in a standard moisture curing chamber, the specimens were demoulded and cured in temperature control traditional curing units until the days of testing. For each testing indices, at least three samples were prepared.

(a). binder is added to 75% of the water to prepare paste

(b). 25% of the water is used to wet the aggregate

Fig. 3. paste and aggregate preparation.

2.4. Test methods

The successful design method has to facilitate the measurement of the performance by effective indices on one side. On the other side, it has to be well-known and straightforward as everywhere as possible. Therefore, the following tests were suggested to characterizing PC for pavement application:

2.4.1. Volumetric properties tests

Three indices can describe the PC volumetric properties: effective air voids (porosity), density, and permeability. Air voids content determination is started by knowing the bulk volume of the compacted concrete; as the PC has high interconnected air voids, submerged weight measurement to obtain the bulk volume is not applicable. Also, measuring the specimen geometrical dimension does not reflect the surface texture. Therefore, the vacuum sealing method according to ASTM D 7063, which commonly used for asphalt mixtures, was used to determine the effective air voids (porosity) for the PC specimens in this study. Simultaneously, the same method can be used to determine the density of the PC, as an additional volumetric property. Permeability is the crucial index of PC, as the PCP layer is mainly designed to perform drainage. Fulling head method was used in this study to determine the permeability measurement, the measurement device, suggested by previous studies [47-49], was built and successfully used to identify permeability of PC. Figure 4(a) shows the permeability measurement devise.

2.4.2. Mechanical properties tests

Compressive strength test is usually nominated as a main mechanical properties' representative; the test was conducted at the age of 28 days, following the requirements of the ASTM C39 procedure. Cylindrical specimens with 100mm diameter and 200mm height were subjected to the test protocol, as shown in Fig. 4(b), where at least three specimens' readings were averaged to represent a single index of compressive strength. The other important test for PCP is the flexural strength test to explore the loose of support characteristics; the test was conducted according to ASTM C 293 requirements, at least three prism specimens of 100×100×500 mm was tested, as can be seen in Fig. 4(c). The readings were averaged for each flexural strength single index.

(a) (b) (c)

Fig. 4. Test methods.
(a) Permeability test, (b) Compressive strength test, (c) Flexural strength test.

3. Results and Discussion

The result has been stated according to the design mix stages to identify the characteristics of each stage variable on the development in *PC* indexes, i.e., Volumetric (porosity, density, and permeability) and mechanical (Compressive strength and flexural strength).

3.1. Effect of various aggregate size

As mentioned, three aggregate sizes were selected to identify their effect on PC performance. Figure 5 demonstrates the variation in porosity and permeability due to change in aggregate size. In general, aggregate size showed a substantial effect on the porosity and permeability; as NMAS increases, both indices increase dramatically, nonlinear formulas are governed the relationship. It was detected that the produced PC samples have porosity ranging from 19-33 %; this is an acceptable range for PCP (15-25%) [50]. Similarly, permeability ranging from 6-36 mm/s, this is acceptable as well (at least 1.16 mm/s) [51]. The bigger aggregate size facilitates higher air voids, and this explains the higher permeability. Beyond that, the density of the produced PC can be affected accordingly, as shown in Fig. 6. All the obtained volumetric properties results are confirmed to those gained by other studies [50, 52, 53]. Although superior volumetric properties are associated with higher NMAS, mechanical properties have to pass the desirable limits.

The Compressive strength and Flexural Strength of PC with a variation in aggregate size are disclosed in Fig. 7. It is noticed that both indices have identical relation patterns, where nonlinear formulas are gained. Surprisingly, the smaller NMAS PC mixture does not give the higher strength, as expected. This is due to the increase in stone on stone contact and higher surface areas of blend mixture with decrease NMAS, the obtained results disagree with some study [50], but agree with other [21]. Other factors like the mechanical properties of aggregate particles, and the paste characteristics are after the superiority of 12.5 mm NMAS mixture in mechanical properties. Whereas intermediate NMAS balancing the paste quantity and thickness, resulting in better performance. Therefore, this aggregate size was selected to investigate the rest stages of characterizing PC mixtures. It is worth mentioning that the mechanical properties like compressive strength do not reach the minimum required level, i.e., 21 MPa internationally/or 30 MPa locally for traditional rigid pavement, so, extra development is in high demand to produce more durable PCP.

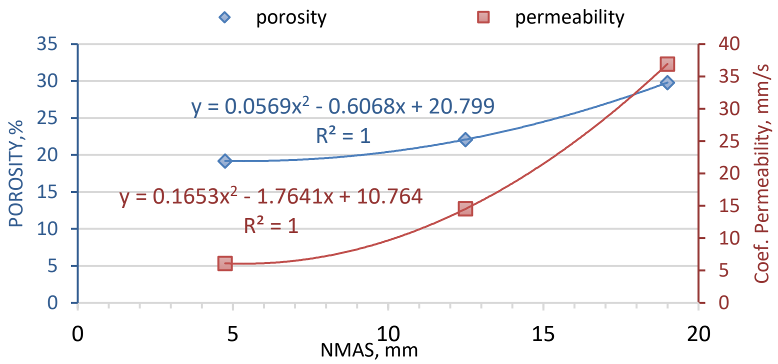

Fig. 5. Variation of porosity and permeability with agg. size.

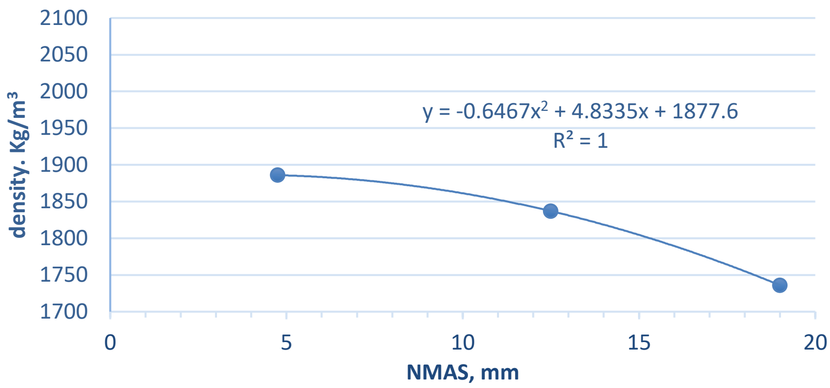

Fig. 6. Variation of density with agg. size.

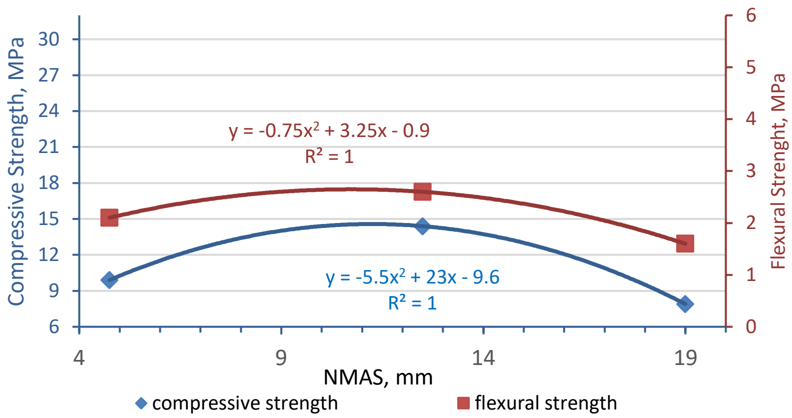

Fig. 7. Variation of compressive and flexural strengths with agg. size.

3.2. Effect of water/ cement ratio

Three w/c ratios were chosen to optimize the volumetric and mechanical properties of traditional PC mixtures. The rheology of the paste is highly affected by w/c ratio, moreover, this rheology affects all indices, as shown in Figs. 8-10. Increasing w/c reduces both porosity and permeability, with a significant effect on permeability than that for porosity, as shown in Fig. 8. This is due to the lubricant effect of extra water and flowable paste. Undesirably, the low viscosity of the paste results in segregation of the paste at the lower part of the sample and reduce the interconnected voids. Noticeably, still the gained results within the specified limitations. Moreover, the improvement in the rheology of the paste facilitate increases in density, as can be seen in Fig. 9.

The mentioned paste's rheology variation slightly affects the compressive strength and flexural strength. Figure 10 demonstrates that 0.28 is the optimum value. Although, decrease the viscosity of the paste increase the segregated paste layer at the lower part of the sample, but higher w/c led to drain-down of the upper binder, which slightly weakening the PC sample. Noticeably, this phenomenon was recognized in the beam than the cylinder samples. This is explained by the noticeable concave pattern of the flexural curve than that of the compressive one. The results imply that the cement aggregate bonding force is affected slightly within moderate w/c ratio variation, namely, 0.24-0.32. The loss of bounding in the upper zone is supplemented by lower part, as confirmed by other studies [1, 21, 53]. However, within all the volumetric and mechanical properties 0.28 w/c ratio, the more appropriate performance, although mechanical properties, is still under the requirements. Where is further development to the mechanical properties with conserving the volumetric properties are in high demand.

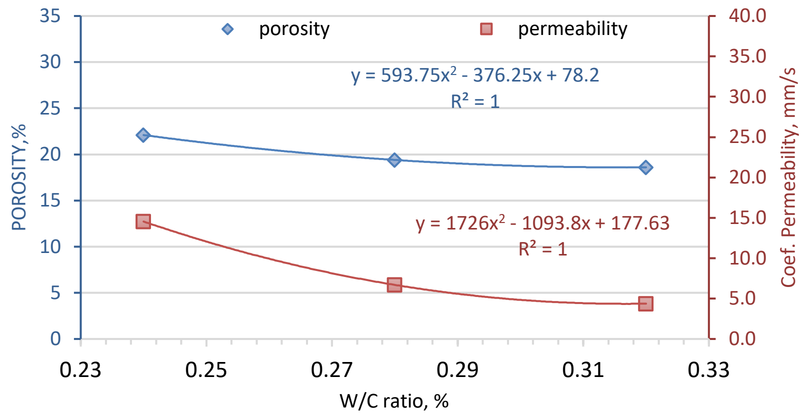

Fig. 8. Variation of porosity and permeability with various w/c ratio.

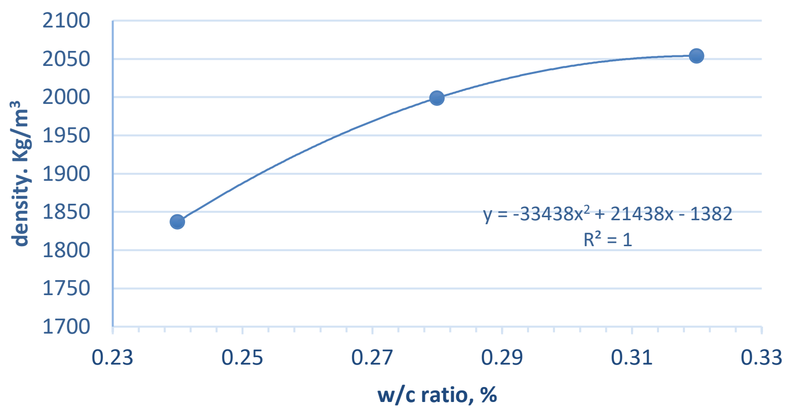

Fig. 9. Variation of density with various w/c ratio.

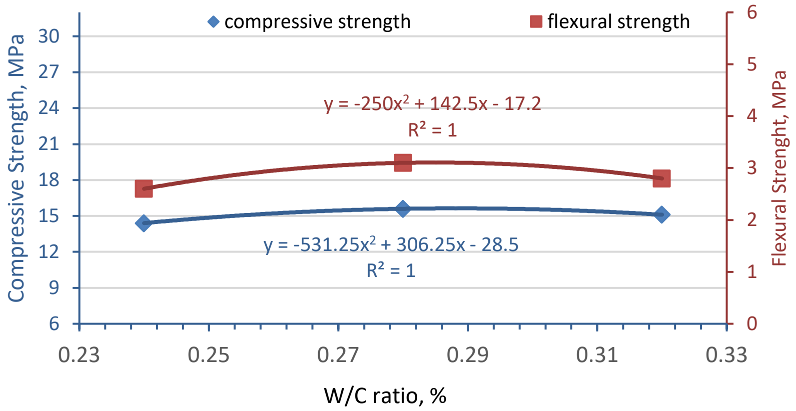

Fig. 10. Variation of compressive and flexural strengths with various w/c ratio

3.3. Effect of aggregate/paste ratio

As expected, increasing the agg./paste ratio provides higher porosity and permeability, as shown in Fig. 11. The influence of increasing the paste ratio affects the permeability more than porosity, as disclosed by the patterns and the equations that correlate agg/paste on one side and the porosity and permeability on the other side, i.e., convex and concave. As a rule, extra paste decreases the interconnection voids, even when they exist. This can also be approved by increasing the PC's density, as can be seen in Fig. 12. Two other important notes are recognized regarding this variable. Firstly, the nonlinear relations between agg/paste value and all volumetric indices imply this variable's sensitivity in determining the PC properties. Serious care should be taken in PC production regarding this variable. Secondly, the lower limit of porosity and permeability (15% and 1.16 mm/s, respectively) can achieve only when agg/paste ratio is over 78%. Within this study's variables ranges, unlike the aggregate size and w/c ratio, agg/paste variable verifies its sensitivity on volumetric properties of PC. Similarly, other studies gained the same conclusion [21, 54]

The high variation of volumetric properties due to variation in agg/paste ratio reflected extensively on mechanical properties of PC samples, as can be seen in Fig. 13. The range of this variable is approximately doubled both compressive and flexural strengths. The increment of paste increases the binding of aggregates togethers and the sufficient quantity of binder, strengthening both the cement microstructure and interfacial transition zone (ITZ). When the paste is skinny, especially the ITZ, it is very brittle and easy to break. It worth mentioned that a similar result had been confirmed by other studies [1, 21, 25]—unfortunately, the improvement in volumetric properties in contrast to the improvement in mechanical properties. Indeed, the functional properties of PC do not associate with high paste content. Alternatively, strengthen the cement micro-structure and ITZ have to be improved by other means. Finally, this stage confirmed the limitation of using agg/paste ratio of 80%. Although a bit low percent is allowed (i.e., 78%), the sharp limits could gain undesirable volumetric indices.

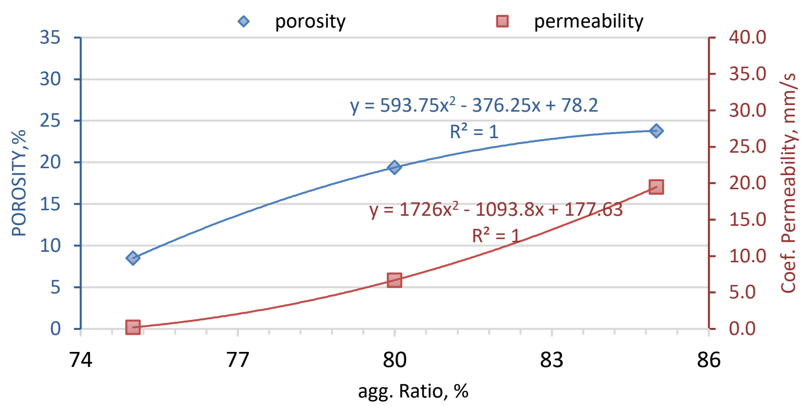

Fig. 11. Variation of porosity and permeability with various agg./paste ratio.

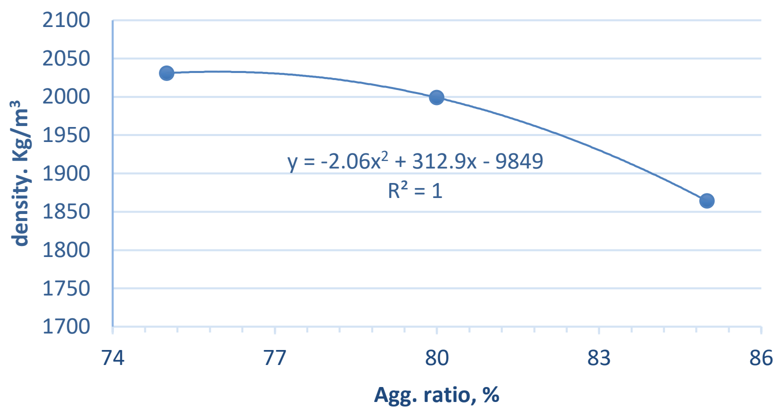

Fig. 12. Variation of density with various agg./paste ratio.

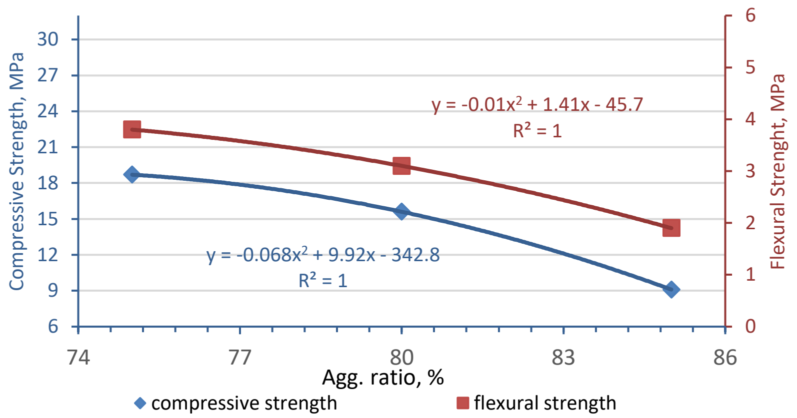

Fig. 13. Variation of compressive and flexural strengths with various agg./paste ratio.

3.4. Effect of superplasticizer

It is believed that the potential for higher performance is achievable with paste optimization. The paste has to be flowable to a specific state to cover all aggregates surface under the nominated compaction method without any segregation of paste. Also, it has sufficient thickness that enables continuous mass and continuously interconnected voids. Simultaneously, such paste has to associate high strength for cement microstructure and ITZ. For these reasons, adding SP can achieve these goals when the SP is optimized, as shown in Figs. 14-16. SP dosage is highly dependent on its type; in this study, the used type G is recommended up to 2% of OPC weight for traditional concrete, but for PC it has to be lower due to the absence of fine fractions. Thus, up to 1% was utilized as recommended by other studies [1, 50]. In general, SP has comparatively affected the permeability than porosity, as shown in Fig. 14, even in maximum dosage, the permeability being out of limitation. This due to the high flowability of the produced paste, which causes segregation of paste and blocks the voids. Nevertheless, such flowability facilitates lower binder thickness that reflects less density, although the packing of the mix constitutes is increased, as can be noticed in Fig. 15. However, 0.7 % dosage associated a reduction in w/c ratio from 0.28 to 0.23 with the same workability. Such dosage looks an optimum for improving the volumetric properties.

SP introduced comparatively moderate improvement for PC mechanical properties, as shown in Fig. 16. The compressive and flexural strength are high within the optimum 0.7 % SP dosage, where the porosity and permeability are upgraded. This improvement is back to reducing the w/c ratio in the first instant, improving the paste matrix (cement micro-structure), and enhancing ITZ. The last two result from creating interpenetrating matrices from the introduction of SP and those resulting from the hydration process, consequently more strength paste. Moreover, the increase of packing product an increase in stone-on-stone contact or contact area. Altogether help in PC mechanical properties' moderate improvement. It is worth mentioning that the relatively improvement in the mechanical properties of PC with maximum dosage reflects the segregation of the paste more than the enhancement in paste strength, as clear from volumetric indices. Thus, the sensitivity of paste consistency for obtaining a high-performance PC is proven again, as pointed in w/c optimization stage. Such sensitivity was highlighted by other researchers [29, 50, 52].

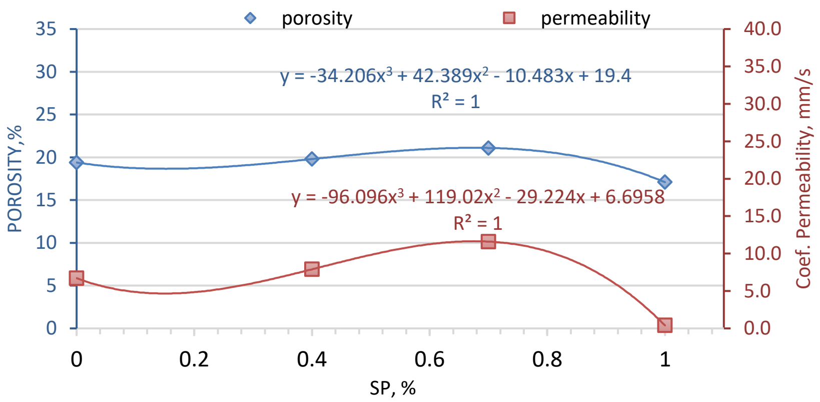

Fig. 14. Variation of porosity and permeability with various SP percentages.

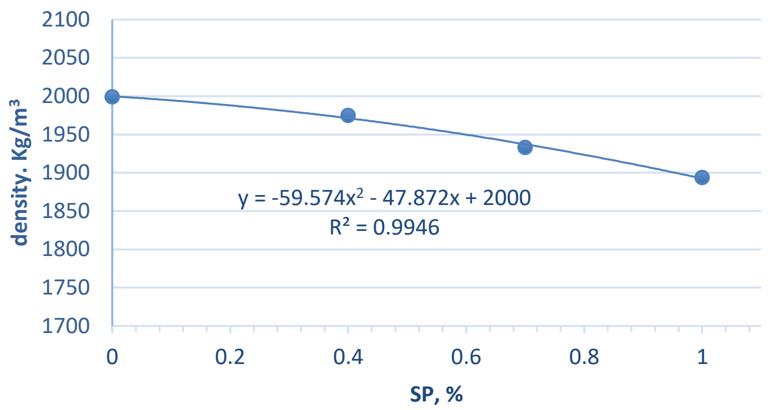

Fig. 15. Variation of density with various SP percentages.

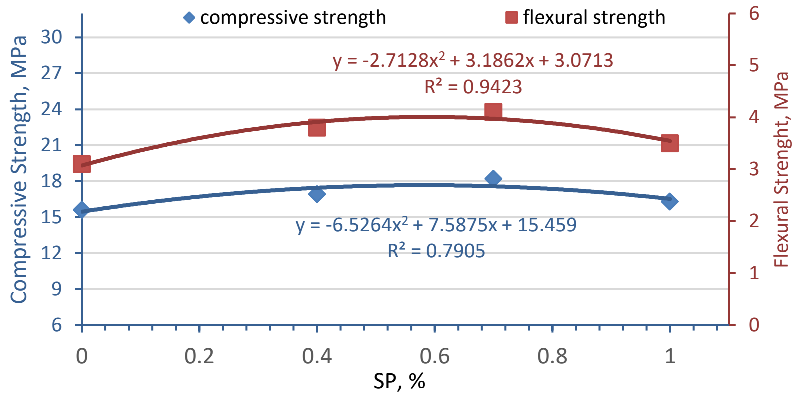

Fig. 16. Variation of compressive and flexural strengths with various SP percentages

3.5. Effect of reactive powder (SF)

Comprising SF within the paste constituents with optimizing W/B ((water/binder), as OPC is no longer represented the binder alone), showed significant results in conserving the gained volumetric performance with improving mechanical properties, as can be seen in Figs. 17-19. It is evident that the volumetric properties of PC were affected due to SF introduction; porosity and permeability exhibit a slight reduction but within the specification limits for all dosage of SF, as demonstrated in Fig. 17. Although the consistency of the paste is controlled (through slump test) using constant SP and increase the W/B as SF increase, the reduction in these indices is still recognized. This might be a result of an increase in the thickness of the paste that covers aggregate surfaces, as it becomes more stable at a fresh state when very fine particles introduce; this is based on the reduction in density, as can be seen in Fig. 18. The charges repelling and chemical reaction among paste constitutes; is also after such stability of the thick paste. Therefore, thicker paste minimizes the voids and voids interconnection.

It is believed that the bonding force of the cement microstructure matrix and ITZ had significantly improved by adding SF. The compressive strength is increased from about 45-101 %, and the flexural strength is increased from about 48-74%, when SF is added from 10-30%, respectively, as shown in Fig. 19. The proposed increase in paste thickness with properties of the paste itself is both after the improvement. More important for the high mechanical performance of paste is the type and quantity of the hydration products that appear due to SF, where the less is the micro matrices from the presence of SP. In all cases, the higher SF and the higher SP (constant to the binder content, not to the mix) facilitate high compressive and flexure strength to high levels. It is worth mentioning that at high SF dosage, the gain in compressive strength is higher than that for flexural strength, which might be to the test setup and brittleness increment of the cement micro-structure than the ITZ. Finally, introducing SF as approved by other studies [54, 55] is more significant than fiber, polymer or cohesive agents [1, 50, 53].

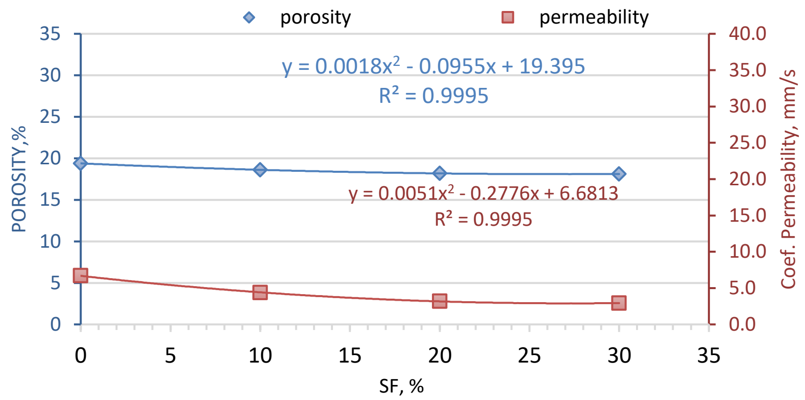

Fig. 17. Variation of porosity and permeability with various SF percentages.

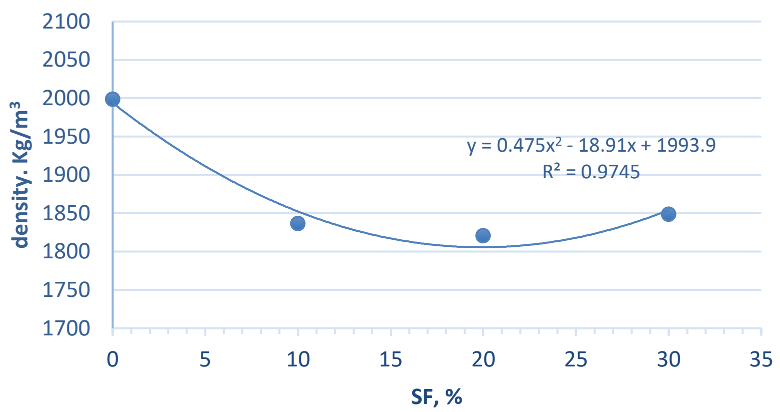

Fig. 18. Variation of density with various SF percentages

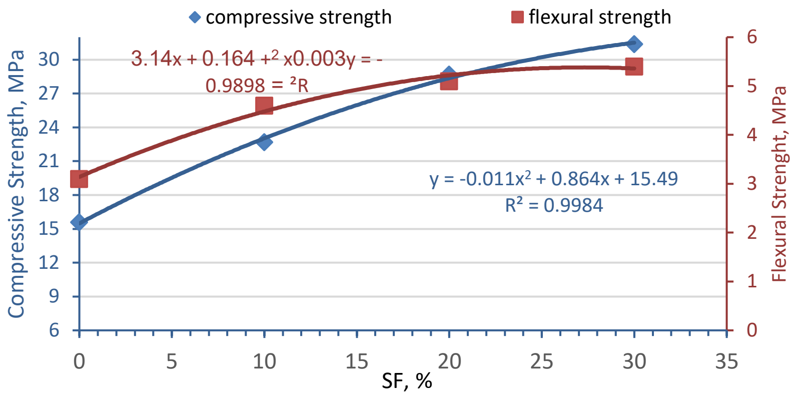

Fig. 19. Variation of compressive and flexural strengths with various SF percentages

4. Conclusions

The influence of different variables on the mechanical and volumetric properties for PC mixture was investigated. These variables included: aggregate size, agg/paste ratio, w/c ratio, SP dosage, and SF dosage. From the extensive experiment program results, the following can be concluded:

- Higher NMAS is facilitated better volumetric properties; at the same time, it is disclosed the inferiority of mechanical properties. Conversely, the lower NMAS, while the intermediate 12.5 mm NMAS is balancing between mechanical and volumetric properties of PC mixtures.
- Water/cement or water/binder ratio is a vital variable in PC mix design; minimal variation in such ratio is allowed to conserve the required high-performance PC mixture.
- Agg/paste ratio appears to be very sensitive in determining the volumetric and mechanical properties of PC mixtures. A ratio of 80% is a boundary of a high-performance PC.
- SP comprising to optimum value is exhibited a moderate role in enhancing mechanical properties with conserving the gained volumetric properties of PC mixture.
- Introducing SF is significant in the production of high-performance PC mixtures. Up to 30% of the OPC percentage with optimizing SP and W/B ratios is key element for mechanical and volumetric properties of PC mixtures.
- Almost always, nonlinear equations are governing the relations between PC mix design variable and performance indices. Such patterns explore the sensitivity of these variables in limiting the PC performance.

Based on obtained results, sufficient volumetric properties (e.g., high permeability) with comparative mechanical properties required for normal concrete for pavement applications encourage the development of high-performance PC for applications like highway pavement intersection area, car parking lots, bridge deck, etc. Its ability for the primary function, namely, vehicle load transition to subgrade, further to additional functions like hydroplaning control and high skid resistance, noise reduction and urban ambient temperature minimally highlighted a unique paving material. However, other research studies are required in different ways like curing protocol, sustainable materials incorporation, numerical analysis, etc. Still, the most important is moving the studies from lab scale to field scale investigations.

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