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Research paper

Investigation of the physical and mechanical properties and durability of pervious concrete: a review

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Abstract: In recent years, the application of pervious concrete (PC) in urban areas has expanded mainly due to its high potential for controlling and guiding surface waters and floods. However, its poor mechanical properties compared to conventional concrete hinder its widespread application and limit it to parking lots, sidewalks, and local streets. Therefore, identifying the parameters effective on PC's physical and mechanical properties and durability could help resolve its weaknesses and enhance its performance. This review article investigated and discussed the PC's performance properties and weaknesses and explore the solutions available for improving these properties. Based on a review of the literature, the solutions included the PC's mix design basic property variations and the incorporation of various additives. The common mixture utilized in most studies contained a water-to-cement ratio of 0.25:0.35, resulting in compressive strength of 7–27 MPa, porosity of 15–35%, and permeability of 0.2–1.22 mm/s.

Keywords: pervious concrete, mechanical properties, durability, strength, porosity, permeability

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1. Introduction

The application of pervious concrete (PC) as a layer of pavement dates back to the 1970s in mild regions of the United States, while some evidence indicates that it has been utilized since the 1800s [1]. As described by the American Concrete Institute (ACI), PC is a "near-zero slump, open-graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water with void contents ranging from 15% to 35% and compressive strengths of 2.8 to 28 MPa" [2]. However, in recent years, more strength has been obtained for PC with the incorporation of various additives.

Owing to its structure, PC has been used as drainage in the streets and transferred precipitation run-offs to drainage systems. This decreased the surface run-offs, the risk of flooding and, ultimately, the need for flood and run-off control facilities. Moreover, water penetration into the ground raised the level of underground water [3]. The other properties of PC include car tire-induced soundwave absorption and pavement-tire friction increment that motivate its application in European countries [4]. Superior performance against the freeze-thaw cycle compared to traditional concretes [5] and the capability to treat water before entering the underground water and polluting it [6] are the other characteristics of PC. However, the prime weakness of this concrete is its weaker mechanical properties compared to traditional concretes, hampering its wide application [7] and restricting its usage to low-traffic areas, parking lots, sidewalks, and local streets [8]. Furthermore, the low amount of fine aggregates in this concrete forms a rough mixture that can complicate the concrete curing process [9]. Also, owing to the advantages of pervious concrete, researchers have attempted to enhance its mechanical and physical properties and extend its applications in the field.

Herein, we reviewed different aspects of PC properties, including its porosity, permeability, compressive strength, tensile strength, flexural strength, fracture toughness, elastic modulus, resistance to the freeze-thaw cycle, resistance to dynamic loads, and fatigue. Studies published from 1988 to 2021 were reviewed. The primary keyword was pervious concrete, and the other keywords were mechanical properties (compressive strength, flexural strength, split tensile strength, resistance), porosity, permeability and mixture design. To investigate each characteristic of PC, were evaluated and discussed the effects of concrete components, e.g., coarse and fine aggregate type and size, aggregate grading, W/C ratio, the aggregate-to-cement ratio, and compaction on these properties and their interactions. Finally, the main results of this review are presented in Conclusion.

2. Mix design

Due to the highly pervious structure of PC, the methods of preparation, manufacture, and mix design of traditional concrete are not suitable for it, and many studies have attempted to propose a special mix design for PC (Table 1). An optimum mix design yields the best results in terms of concrete performance criteria. The evaluations show that the major performance criteria for PC quality include porosity, permeability, and compressive strength, while other important parameters such as flexural strength, durability against freezing and thawing, impact, and dynamic loads are less frequently considered and, therefore, have a lower priority. Meanwhile, impact and dynamic are the main forces on roads and airports, and it is essential to evaluate the properties of porous concrete against dynamic loads and impact.

Table 1. Some Mix Designs for Pervious Concrete

Ref.	Cement (Kg)	Coarse agg. (Kg/m^3)		Fine agg. (Kg)	W/C ratio	Compressive strength (MPa)	Void ratio (%)	Permeability (mm/s)
		9.5 mm	6.35 mm					
Torres et al. (2020) [10]	320	1525	–	2020	0.30 0.28 0.26 0.24 0.22 0.20	13.20 14.80 14.00 12.30 10.00 7.80	–	–
Ong et al. (2016) [11]	290 246 246 290	1095	–	–	0.33	15.75 15.24 12.81 14.10	25.0 22.7 25.6 23.2	0.24 0.26 0.44 0.25
Zhang et al. (2012) [12]	186 189 191 194	1168 1181 1195 1210	–	117 236 358 484	0.28	–	35.0 30.0 25.0 20.0	–
Park and Ride VT (2008) [13]	317 285 253 221	1402	–	–	0.35	11.03 10.76 9.45 9.03	35.2 34.8 35.1 35.4	1.36 1.17 1.22 1.18
Kevern et al. (2008) [14]	263 263 257	1166 1089 1163	–	59 59 61	0.27	16.13 15.10 18.90	27.0 32.6 22.0	0.96 1.01 0.49
Pindado et al. (1999) [15]	350 275 279 280	1427 1506 – –	– – 1352 1534	101 106 89 77	0.31 0.29 0.23 0.34	26.80 20.60 23.20 13.90	–	–

A major point in PC mix design for application in road pavement and maintanence is its sufficient permeability to prevent the possible filling of layer porosity due to various factors such as contaminants. On the other hand, to enhance permeability, the porosity of concrete should be increased, which could diminish the compressive strength. This can be compensated by incorporating various additives in the mix design to prevent compressive strength reduction and eliminate the destructive effects of contaminants.

3. Porosity and permeability

The ASTM C1754 test procedure yields PC's porosity based on the difference between the mass of dry (M_d) and underwater specimen (M_w), according to Eq. (3.1) [16].

$$P = 100 \cdot \left[1 \frac{(M_d - M_w)}{\rho_w^V} \right] \tag{3.1}$$

where ρ_w is the density of water, and V denotes the volume of the PC specimen. This test is popular because it is quick and straightforward and does not need sophisticated instruments.

The review of the literature shows that the amount of air in porous concrete pores depends on several factors, e.g., aggregates, water-to-cement (W/C) ratio, and each implementation phase's compaction level [17]. When the aggregates are mixed, the aggregate size ratio (the ratio of the larger to smaller aggregate diameter) should not be too high; if it is too high, most of the smaller aggregates would fill the remaining pores between larger aggregates, thereby reducing porosity and permeability (the most important properties of PC) because the water passage rate directly depends on the number of pores in the concrete. Due to this strong and direct relationship between permeability and porosity, porosity assessment has the highest priority in most studies [18].

In one of the most comprehensive studies, Cosic et al. (2015) examined the effect of aggregates on PC and found that the gradation and size of coarse aggregates, W/C ratio, and the compaction level affect the pore size. They also stated that same-sized coarse aggregates are usually used to make PCs; with this approach, the pores can easily reach >15%, which would result in an acceptable and permeable mix design [18]. Sonebi et al. (2013) [19] and Singh et al. (2020) [20] also mentioned that PC's porosity significantly depends on the aggregate materials' size.

It is also reported [21] that the minimum content of concrete pores should be 15% to ensure water permeability in PC, and the absence or reduction of permeability prevents sufficient connection and integrity between pores to accomplish a quick penetration.

ACI (2006) [22] recommends that the falling head method developed by Neithalath et al. (2006) [23] should be applied to determine PC's water permeability. This method measures the time taken by the water level to fall from the initial to the final water head; water permeability is then calculated by Darcy's first law. According to Neithalath et al. [23], even though permeability can normally be determined by Darcy's first law, there is no definitive relationship between porosity and permeability. Rather, the distribution of pores significantly impacts permeability and porosity, as depicted in Figure 1.

Ebrahim et al. investigated the effects of aggregate size, W/C ratio, cement percentage, and aggregate volume on PC's permeability, and presented the final equation to determine

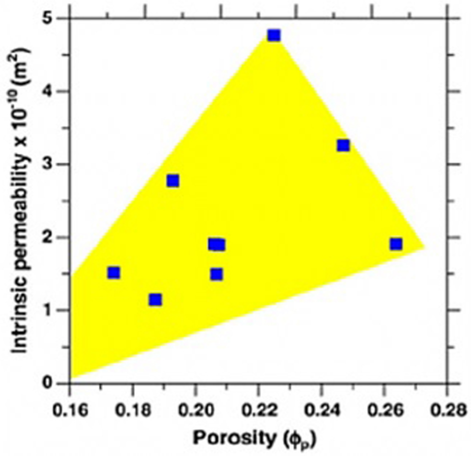

Fig. 1. Relationship between porosity and permeability [23]

permeability (Eq. (3.2)).

$$K = 0.01140.0014C + 0.0222\left(\frac{w}{c}\right) - 0.0019W + 0.0002A1 + 0.0003A2 + 0.0004A3 - 0.171W \tag{3.2}$$

where K is permeability (m/s); C is the cement content (kg/m^3); W is the water content (kg/m^3); $A1$ is the 4.5mm aggregate content (kg/m^3); $A2$ is the 9.5 mm aggregate content (kg/m^3); and $A3$ is the 19.5 mm aggregate content (kg/m^3). Based on the results, K ranged from 0.0028 to 0.015 m/s [24].

The PC structure to achieve a compound, including the necessary strength and permeability, was studied by Panimayam et al. (2017) [25] by using crushed gravel. They concluded that the W/C ratio should be 0.28–0.4 to achieve proper permeability and preserve the acceptable strength of PC.

Furthermore, Yahia et al. (2014) [26] explored the impacts of aggregate size and grading on PC's porosity and permeability. They assessed three aggregate sizes (2.5–10, 5–14, and 10–20 mm) and made all the samples with a W/C ratio of 0.3. Various PC mixtures were prepared using different ratios of paste volume (PV) to the inter-particle void (IPV). Based on the experiments, increasing the PV/IPV ratio reduced porosity and permeability. Moreover, 30% and 60% PV/IPV ratios were the optimum range to strike a proper balance between PC's mechanical properties and permeability.

Kovac and Sicakova (2018) [27] investigated various mixtures of water, cement, and aggregate to determine water penetration speed in PC. Based on the findings, PC can drain and remove water from the surface. Furthermore, compressive strength and permeability change by varying the W/C ratio from 0.25 to 0.35. In this experiment, hydraulic conductivity ranged from 7.5 to 10.2 mm/s.

According to most studies reviewed in this section, the minimum content of concrete pores should be 15% to ensure water permeability in PC.

4. Mechanical properties

4.1. Compressive strength

Measuring the 28-day compressive strength based on ASTM C39 is the most popular method for concrete quality examination, accomplished through cylindrically shaped samples. Compressive strength is significantly affected by the raw materials' mixture proportions, compaction level, and pore content. Soleyman et al. (2006) [28] reported a linear relationship between pores and compressive strength. On the other hand, Wang et al. (2008) [29] reported that this relationship is exponential, but this view was not confirmed in other articles. The ACI522R-10 standard proved that this relationship is inverse linear, such that strength increases by reducing the number of pores if concrete permeability is maintained [30].

Schaefer et al. (2006) [31] examined the linear relationship between PC strength and the number of pores (Figure 2 and Equation (4.1)) and found that less porosity leads to higher compressive strength.

$$\text{Compressive strength (MPa)} = 4762.1 - 97.16 \times [\text{void ratio } (\%)] \tag{4.1}$$

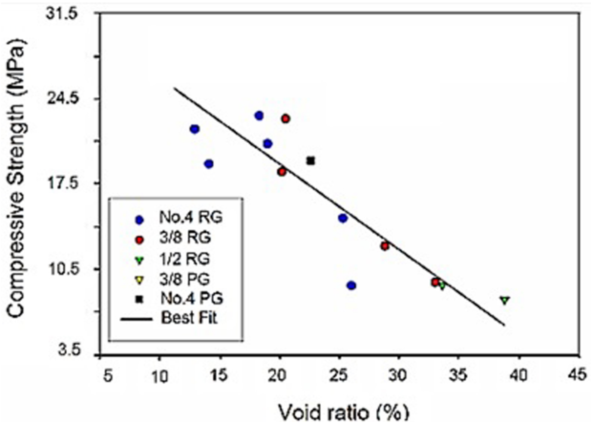

Fig. 2. Relationship between compressive strength and void content [31]

Singh et al. (2020) [20] combined various aggregate sizes, W/C ratio, and a proper amount of supplementary cementitious materials to improve PC's mechanical performance. The mix with the highest compressive strength and void ratio ranging from 15% to 20% turned out to be optimum. Furthermore, a high-strength PC (i.e., a compressive strength of 32–45 MPa at 28 days of curing) was achieved even with a void ratio (%) of > 15%.

The relationship between porosity, W/C ratio, cement content, and compressive strength was presented by Nasiri et al. (2017) [32] (Eq. (4.2)):

$$f'_{c-28\text{day}} = 25.38 - 0.539 - 13.12\left(\frac{w}{c}\right) + 0.0045C \tag{4.2}$$

Here, $f'_{c-28\text{day}}$ is the compressive strength (MPa); P is porosity (%); W/C is the w ratio; and C is the cement content (kg/m^3). Based on the findings, the f'_{c-28} ranged from 0.9 to 23.7 MPa.

Gaedicke et al. (2013) [33] proposed that PC's compressive strength is impacted by different variations, including porosity ratio, the number of fine aggregates, additives, and the level of pavement compaction during implementation. Generally, a high porosity ratio leads to a lower compressive strength. Therefore, the applications of PC are limited to low-traffic roads, parking lots, and sidewalks. Its performance in cold weather also causes concern because it has an open structure that might be damaged by freezing and thawing.

Jimma and Rangarju (2014) [34] concluded that increasing the amount of cement paste promotes the PC mixture's overall strength. They confirmed that an enhanced cement paste level could easily be achieved by using fine aggregates. After utilizing fine aggregates, the specific surface area of the aggregates rises, and the cement paste covers a wider area of the aggregates; the amount of fine aggregates used in this concrete is limited and will not decrease its porosity and permeability for strength enhancement.

Ghafuri and Dutta (1995) [35] determined the effects of impact-compaction energies, consolidation techniques, mix proportions, curing types, and testing conditions on PC's compressive strength. They reported a strong relationship between compressive strength, mix proportions, and compaction energy.

Ibrahim et al. (2014) [24] investigated the effects of aggregate size, W/C ratio, cement percentage, and aggregate volume on PC's compressive strength using 24 samples. The highest compressive strength was achieved as 6.95 MPa and belonged to the sample with an aggregate size of 9.5 mm and a cement ratio of 250 kg/m^3.

The compressive strength is also related to PC's density; the higher the density, the higher the compressive strength [30]. The relationship between 28-day compressive strength and unit weight was investigated by Meininger (1988). With increasing unit weight, compressive strength also increased. Since there is a straight relationship between the unit weight of PC and the percentage of voids in the material, it is not surprising that the compressive strength is linearly proportional to unit weight but inversely proportional to the void ratio [36].

Sonebi and Bassuoni (2013) [19] explored the effects of various ranges of W/C ratio (0.28–0.4), cement content (350–415 kg/m^3), and coarse aggregate content (1200–1400 kg/m^3) on PC's compressive strength. Based on the results, the W/C ratio, cement content, coarse aggregate content, and their interactions were the key parameters, significantly affecting PC's compressive strength.

Based on the studies reviewed here, the compressive strength of PC can reach 45 MPa if porosity is limited to 15–20%.

4.2. Tensile strength

The tensile strength test is performed according to the ASTM C496M-04 standard. Maguesvaria and Narasimha (2013) [37] investigated the effect of fine and coarse aggregate quantities on PC's tensile strength. Four sizes of coarse aggregate (4.75–9 mm, 9–12.5 mm, 12.5–16 mm, and 16–19.5 mm), a w/c ratio of 0.34, and cement content of 400 kg/m^3 were used, and the aggregate cement ratio was maintained at 4.75:1. During the research, 50–100% (by weight) of coarse aggregates were replaced by fine aggregates. By raising the content of fine aggregates, the tensile strength increased; on the other hand, as the size of coarse aggregates decreased, tensile strength increased. The results showed that the specimens with all four selected aggregate sizes followed the same trend, and the increase in fine aggregate raised the tensile strength. The maximum tensile strength of PC reached 3.34 MPa in coarse aggregates sized 4.75–9 mm.

Ghafuri and Dutta (1995) [35] studied the relationship between PC's splitting tensile and compressive strength according to Equation (4.3) where f_t' is the tensile strength (MPa) and f'c-28day denotes the compressive strength (MPa).

$$f_t' = 0.039\left(f_{c-28\,\text{day}}'\right)^{0.5} \tag{4.3}$$

Tensile strength ranges were 1.24–2.75 MPa at the compressive strength ranges of 8.56–30.88 MPa.

4.3. Flexural strength and fracture toughness

The flexural strength and fracture roughness of specimens with dimensions of 100 × 100 × 400 mm were examined using the four-point flexural strength test according to the ASTM C78 standard. According to the procedures, the load is applied at a rate of 50 mm/min using the UTM device, and the maximum load is recorded. Next, flexural strength is obtained according to the following equation:

$$R = \frac{PL}{B^2H} \tag{4.4}$$

where L represents the distance between the two lower supports, B denotes the width, and H is the height of the specimen. Fracture toughness, (K_{IC}), the stress intensity factor, is then calculated according to Equation (4.5):

$$K_{IC} = \frac{PL}{BH^{1.5}} \cdot \left[2.9\left(\frac{a}{H}\right)^{\frac{1}{2}} - 4.6\left(\frac{a}{H}\right)^{\frac{3}{2}} + 21.8\left(\frac{a}{H}\right)^{\frac{5}{2}} - 37.6\left(\frac{a}{H}\right)^{\frac{7}{2}} + 38.7\left(\frac{a}{H}\right)^{\frac{9}{2}}\right] \tag{4.5}$$

where L, B, and H respectively represent the specimen span, width, and height; a is the notch depth; and P is the maximum load.

Singh et al. (2020) [20] reported that high-strength PC (flexural strength of 3.9–5.29 MPa) could be achieved even with a void ratio of >15%. Furthermore, the flexural and compressive strengths of a PC mixture have a direct relationship with each other, and this relationship depends on multiple factors, including pore volumes, W/C ratio, and aggregate type and size [38].

Figure 3 displays the relationship between compressive strength and flexural strength at the same void ratio. Based on the literature, as the void ratio rises, compressive strength tends to decrease more rapidly than flexural strength.

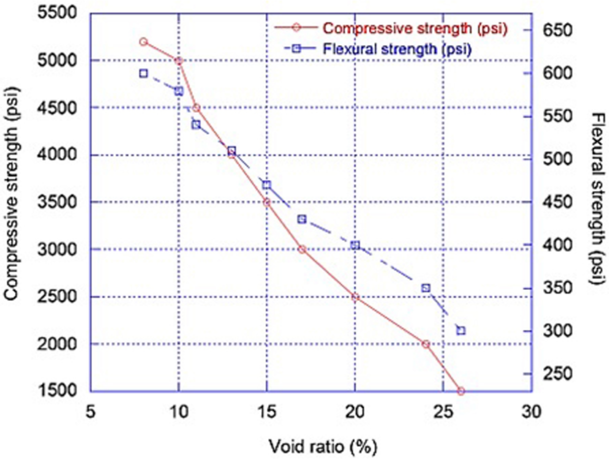

Fig. 3. Comparison of the effect of void ratio on compressive and flexural strength [36]

Nassiri and AlShareedah (2017) [32] determined the relationship between flexural strength and porosity, cement content, and W/C ratio by developed regression models. The flexural strength regression models (Eq. (4.6)) were developed using the results obtained from 18 samples.

$$M = 5.18 - 0.0731P - 3.621\left(\frac{W}{C}\right) \tag{4.6}$$

where: M is flexural strength (MPa), P is porosity (%), C and W respectively denote cement and water content (kg/m^3) [35]. Based on the literature, flexural strength ranged from 1.1 to 2.7, P from 15 to 38%, and W/C from 0.27 to 35%.

Chandrappa and Biligiri (2017) [39] developed a model to predict PC flexural behavior. Various beam specimens were prepared and tested. Flexural strength and stiffness were found to be in the range of 1.5–3.2 MPa and 8,000–15,000 MPa, respectively. The predictive models based on the basic properties were calculated according to Eq. (4.7), where M represents flexural strength (MPa), P is porosity (%), and W denotes the weighted aggregate size (mm).

$$M = 6.016 - 0.089P - 0.171W \tag{4.7}$$

Brake et al. (2016) [40] studied low-strength/low-unit weight and high-strength/high-unit weight PC mixes using notched three-point bend specimens to ascertain the strength and fracture size effects via beam depths ranging from 100 to 200 mm. Flexural strength depended on the size and could be predicted using Bazant's size effect law by a unit weight-dependent tensile strength parameter and a characteristic crack length. The tensile strength and initial and total fracture energy, however, were not found to be size-dependent.

4.4. Elastic modulus

The elastic modulus has rarely been determined for PC because there is no particular standard for conducting an experiment and the loading rate; moreover, due to the high porosity, two samples with the same mixture design and porosity may demonstrate different elastic modulus values only due to a different pervious structure. Still, Vancura and Khazanovich (2010) showed that the elastic modulus for a PC could vary from 14000 to 20000 MPa [41].

Zhong and Wille (2015) [42] presented a regression model to relate the elastic modulus to compressive strength according to Eq. (4.8), where E is the elastic modulus (MPa) and f_c' is the compressive strength (MPa).

$$E = 4880\sqrt{f'_{c-28\text{ day}}} + 2800 \tag{4.8}$$

Ridengaoqier and Hatanaka [43] investigated the elastic modulus of PC. Based on the results, the elastic modulus varied from 10000 MPa to 50000 MPa.

Alam and Haselbach [44] calculated the modulus of elasticity of PC at three performance zones at the stress levels of 2.2 and 2.8 MPa, i.e., lower, average, and upper. Based on the findings, the modulus of elasticity in the lower performance zone was 15% more than the others. The literature [43, 44] indicates that the elastic modulus in PC significantly depends on the aggregate types, the cement and aggregate ratio, porosity, and W/C ratio.

5. Durability

PC's freeze-thaw resistance is evaluated according to the ASTM C666 standard. The samples' resistance to rapid repeated cycles of freezing and thawing in the laboratory is determined by two methods of Rapid Freezing and Thawing in Water and Rapid Freezing in Air and Thawing in Water [17].

Tennis et al. (2004) [45] mentioned three conditions causing freeze-thaw damage and reducing PC's durability. First, if PC is clogged, clogging impacts the movement of water in PC. The second cause is a reduction in the average daily temperature below the freezing point for a long time in specific regions. Third, when the groundwater table reaches within 0.9 m of the top of the concrete, PC can become saturated. Freezing and thawing damage happens quickly if the large voids of PC become saturated [46].

Zaldo (2006) [47] mentioned the primary factors affecting PC's durability, namely mix design, placement, and proper maintenance. Zaldo pointed that PC's freezing and thawing damage depends on the level of saturation. Therefore, annual cleaning in severe conditions should be performed to prevent this type of damage. How freely water is allowed to flow through PC plays a significant role in freezing and thawing problems. Consequently, maintaining a clean infiltration system mitigates the severity of these damages.

During freeze/thaw cycles, debonding occurs between the aggregates and the cement paste. Sand and latex as admixture and compaction energy are parameters that promote freeze-thaw durability. The degree of saturation of the paste layer coating the coarse aggregate particles also impacts PC's durability.

Kevern et al. (2008) [48] mentioned that replacing coarse aggregates with 7% sand and using fibers and latex significantly enhance PC's freeze-thaw resistance. Moreover, Taheri et al. (2021) [49] studied various parameters affecting the freeze-thaw durability of PC, namely W/C ratio, air entrainment, sand inclusion, and coarse aggregate size. It was reported that replacing 8% of coarse aggregates with sand and using a higher W/C improved the strength and freeze-thaw durability. On the other hand, the positive effect of air-entraining admixture (AEA) on freeze-thaw durability, manifested in previous studies, was not clearly observed in this study. In addition, varying the coarse aggregate size did not significantly affect the strength and freeze-thaw durability of PC.

6. The most popular dynamic tests of pervious concrete

Although there have been extensive efforts to incorporate PC in road pavement, most studies have focused on static tests and paid little attention to dynamic performance. However, the main forces on roads are impact and dynamic forces. PC has a moderate static strength compared to normal concrete due to the high percentage of intentional meso-size air pores, but its dynamic performance is distinctive. In what follows, three of the most common dynamic tests used to examine PC performance are reviewed.

Chandrappa et al. (2017) [50] reviewed the impact of different stress levels on PC's resistance against fatigue. The non-parametric and parametric methods revealed that the stress levels and stiffness are more important in affecting the fatigue life compared to the loading frequency in the range.

Jiao et al. (2020) [51] studied compressive fatigue under fatigue loads at four stress levels (S): 0.6, 0.7, 0.8, and 0.9 MPa, and at three loading frequencies of 10, 15, and 20 Hz. Based on the results, fatigue life was controlled by stress, while loading frequency showed no statistically significant impact on them. The fatigue failure of PC did not occur under a stress level of 0.6.

Bai et al. (2018) [52] studied the dynamic properties, including strength properties, deformation properties, impact toughness, and energy absorption of PCs by F 100-mm SHPB test improved by waveshaping technology. The PCs were sensitive to the strain rate. By elevating the strain rate, dynamic compression strength increased. The correlation between the peak strain, ultimate strain of lightweight PC, and strain rate could be expressed by a quadratic polynomial equation. Under the impact loading, the impact toughness of lightweight PCs increased with strain rate, and the amount of absorbed energy rose with the average incident energy change rate.

Jingwu et al. (2018) [53] investigated PC's dynamic behavior and energy evolution under impact loading in the laboratory. The dynamic compression and split tests were conducted by using SHPB equipment. The PC turned out to be sensitive to the strain rate. By increasing the strain rate, the dynamic strength rose, and the time to failure decreased linearly. Furthermore, by raising the strain rate, total damage energy was elevated, suggesting that more energy is required to produce irreversible damage as the loading rate increases. The results revealed that the impact toughness of PC could be increased from 0.15 to 0.55 when strain rate changed from 40 to 120 S^{-1}.

Ozbek et al. (2013) [54] investigated the relationship between the PC's impact strengths, mixture compositions, and production techniques using a drop weight impact test set-up while the measurements were taken via laser Doppler velocimetry. The results revealed that the aggregate properties and compactive effort were the major parameters affecting the dynamic performance.

7. Conclusion

The results of this review are summarized as follows:

- The PC mix design commonly used in the literature included a W/C ratio of 0.25–0.4 that mainly led to a compressive strength of about 7–45 MPa, an approximate porosity of 15–35%, and a permeability of 1.22–2 mm/s.
- PC parameters and major factors influencing them are as follows:
  - Mix design: coarse aggregate type and size, aggregate grading, fine aggregate content, porosity, W/C ratio, aggregate-to-cement ratio,
  - Mechanical properties: coarse aggregate type and size, aggregate grading, fine aggregate content, porosity, W/C ratio, aggregate-to-cement ratio, compaction, curing,
  - Physical properties: coarse aggregate size, aggregate grading, fine aggregate content, porosity, W/C ratio, aggregate-to-cement ratio,
  - Durability: coarse aggregate size, fine aggregate content, porosity, W/C ratio, compaction, curing.

  Among the factors influencing PC parameters, the main parameters are porosity and water-to-cement ratio which must be limited to 15% and 0.25–0.4, respectively, to achieve the best mechanical properties.
- The dynamic properties of PC have received less attention in the literature. Since impact and dynamic forces constitute a significant portion of the forces on roads and airports, these properties merit for consideration.

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