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Review

Physical and Hydraulic Properties of Porous Concrete

Carlos Sánchez-Mendieta [1,*], Juan Jose Galán [2] and Isabel Martinez-Lage [2]

[1] Campus Universitario, Universidad Técnica de Machala, Machala 070150, Ecuador
[2] ETSI Caminos, Canales y Puertos, Campus de Elviña s/n, University of A Coruña, 15071 La Coruña, Spain; jgalan@udc.es (J.J.G.); isabel.martinez@udc.es (I.M.-L.)
* Correspondence: csanchez@utmachala.edu.ec

Abstract: The work presented includes a review of the state of art of porous concrete. Its purpose is to evaluate the potential use of porous concrete in constructions where the level of surface runoff justifies it. A review of the literature presented here has been necessary where parameters of special consideration have been defined in the dosage of permeable mixtures. The study includes the definition of porous concrete in terms of its main components: cement, coarse aggregate, water, additives, and sand, in little or no quantity, to cause the generation of an effective content of interconnected voids that allow rapid storm drainage. Given the reports of variables of high incidence in the mechanical behavior of porous concrete (resistance/permeability relationship), an investigation is warranted to synthesize the effects of the variables in the preparation of the mixture: water–cement ratio, granulometry, and morphology of the aggregates, compaction pressure, and curing techniques, among others. Likewise, the protocols for the characterization of porous concrete and additional aspects relevant to support the experimental phase are exposed, constituting a reference or anchor point for developing technologies associated with the manufacture of this material and the possibilities of its implementation in constructions.

Keywords: porous concrete; mixing and admixture design; the proportion of aggregates–cement and water–cement

Citation: Sánchez-Mendieta, C.; Galán, J.J.; Martinez-Lage, I. Physical and Hydraulic Properties of Porous Concrete. *Sustainability* **2021**, *13*, 10562. https://doi.org/10.3390/su131910562

Academic Editor: Castorina Silva Vieira

Received: 19 August 2021
Accepted: 13 September 2021
Published: 23 September 2021

1. Introduction

Porous concrete is a mixture of cement, water, and coarse aggregate of a single size that, when combined, produces a porous structural material [1]. The main feature is its high permeability given the high content of voids, resulting in its light nature and less strength compared to traditional or waterproof concrete [2]. It is a binary mixture of coarse aggregates of a single size with an optimal amount of cement to coat and bond the aggregates; porosity varies in the range of 10% to 25%. The ratio of water to cement is in a range from 0.28 to 0.45, and the proportion of aggregates to cement has varied in a range from of 3 to 6; in addition, the volume of aggregates in porous concrete is approximately 50% to 65%. This porosity makes porous concrete very useful from an environmental point of view. Several studies affirm that porous concrete is a material that contributes to sustainability and it is, in addition, economically profitable [3].

Porous concrete has many advantages that improve the city's environment: rainwater can seep into the ground quickly so that groundwater resources can be renewed on time. Permeable concrete pavement can absorb vehicle noise, creating a quiet and comfortable environment. On rainy days, the porous concrete pavement has no reflection on the surface and does not shine at night; this improves the comfort and safety of drivers. Porous concrete pavement materials have holes that can accumulate heat, eliminating the phenomenon called hot islands in cities [1,4]. In addition, permeable pavements, due to their porosity and permeability, positively influence the hydrology of the area [2,5].

Volder et al. [6] pointed out that conventional concrete has caused changes in the hydrological aspect and the surroundings' thermal environment. The waterproof nature of these systems increases the amount of stormwater runoff [1,7].

The use of impervious pavements in flat urban development areas brings considerable problems in the evacuation of rainwater and runoff conditions downstream, increasing the risk of causing flooding in the lower sectors of urbanized areas [8,9].

The urban runoff of rainwater is a means of transport for many contaminants of anthropogenic sources [10]. There are many strategies available to treat these contaminants. One of the technologies for this purpose is permeable pavements to minimize the amount of runoff generated by waterproof surfaces within an urban basin. An analysis of the permeable pavement effluent demonstrated significant improvements in the quality of rainwater [11].

The design procedures were analyzed to size permeable concrete rainwater systems according to their protection standards against freeze and defrosting [12]. This design procedure offers a consistent basis for transforming these standard parameters based on inconsistent designs for permeable concrete storm systems.

Several authors have investigated the properties of porous concrete with fine aggregates and fly ash compared to ordinary road materials. The results indicate that fine aggregate can improve porous concrete's compressive strength and durability [13]. Other investigations applied the nanoparticle produced from the black rice husk ash, obtaining, as a result, a significant increase in the compression force and porosity [14]. In addition, porous concrete mixed with anti-pollution additives, vinyl fiber, and alumina cement also increased compressive strength and durability [15].

The importance of the bibliographic review determines the influential variables that porous concrete has. It is required to obtain values that relate to the variables to design porous concrete. The bibliographic analysis and the referencing of researchers and their results will serve to aid the design and elaboration of porous concrete with quarry aggregates located in the province of El Oro in Ecuador.

2. Aims and Scope

This study aims to investigate the characteristics of porous concrete through a literature review of published scientific documents regarding the physical and hydraulic properties, and the variables that influence the size and shape of aggregates, the water–cement ratio, and the aggregate content. The cement within different results was obtained by various mixtures and proportions, and by analyzing the effects on mechanical properties such as compressive strength, flexural strength, tensile strength, porosity, and permeability.

3. Aggregates and Mix Proportions Designs

According to their shape, the aggregates may be classified into two primary groups: angular and boulders. The former has well-defined edges arising from the intersection of quasi-plane faces, while the latter has rounded edges. The characteristics of the aggregate's shape and size, and their distribution in the mix play an essential role in the permeability, durability, and mechanical aspects of porous concrete [16].

Regarding the composition, Korat et al. [17] suggested that dolomitic-type aggregates provide greater compressive strength at higher porosity levels than similar mixtures made with limestone aggregates.

To obtain enough voids in the material, the porous concrete is usually formed by aggregate sizes in the range of 4.5–20 mm. However, several studies have used fine aggregates smaller than 2.5 mm in size with the primary objective of increasing strength properties. Tables 1 and 2 show the different designs of mixture proportions obtained from the study of the bibliography in this field.

Table 1. Proportions used to produce the mixture of porous concrete.

Mix Proportion			Materials and Mixing Designs				
W/C *	Voids [%]	A/C **	Water [kg/m^3]	Cement [kg/m^3]	Fine Aggregate ≤2.5 mm [kg/m^3]	Coarse Aggregate 4.5 a 20 mm [kg/m^3]	Reference
0.37	23	4.0	154	413		1651	[18]
0.38	26	4.5	143	376		1682	
0.39	26	5.0	136	348		1740	
0.42	28	6.0	125	300		1800	
0.30	16	4.5	105	345		1542	[19]
0.30	26	5.6	87	287		1620	
0.28	20	10.1	50	180		1820	[20]
0.27	20	6.5	70	260		1700	
0.26	20	5.2	80	310		1620	
0.27	20	4.8	90	330		1580	
0.28	20	4.3	100	360		1550	
0.26	20	4.0	100	380		1510	
0.24	20	4.7	80	340		1600	
0.30	20	4.8	100	330		1570	
0.30	20	4.7	100	330		1560	
0.35		4.5	112	320		1441	[21]
0.35		4.5	116	330		1487	
0.35		4.5	123	353		1587	
0.33		5.0	103	312		1559	[22]
0.33		5.0	104	314		1568	
0.33		5.0	103	312		1558	
0.33		5.0	101	305		1524	
0.33		5.0	102	309		1546	
0.33		5.0	102	309		1544	
0.39	40	4.0	161	415		1658	[16]
0.42	44	4.0	164	391		1563	
0.27	27	5.1	85	320		1620	[23]
0.27	22	6.9	70	260		1800	
0.30	20	5.5	89	300		1640	

* Water–cement ratio (W/C); ** Aggregate–cement ratio (A/C).

Table 2. Proportions used to produce the mixture of porous concrete.

Mix Proportion			Materials and Mixing Design				
W/C *	Voids [%]	A/C **	Water [kg·m^{-3}]	Cement [kg·m^{-3}]	Fine Aggregate ≤2.5 mm [kg·m^{-3}]	Coarse Aggregate 4.5 a 20 mm [kg·m^{-3}]	Reference
0.30		4.3	110	367		1560	[7]
0.30		6.5	73	242		1560	
0.33		3.3	145	440		1450	[24]
0.33		3.4	143	432		1472	
0.33		3.6	137	416		1500	
0.32		3.7	131	410		1532	
0.32		4.0	126	394		1570	
0.32		4.1	125	390		1591	
0.30		4.3	113	378		1611	
0.30		4.5	110	366		1637	
0.30		4.8	104	345		1654	
0.28		5.1	92	330		1668	
0.28		5.2	91	325		1690	
0.28		5.3	90	320		1702	

Table 2. *Cont.*

Mix Proportion			Materials and Mixing Design				
W/C *	Voids [%]	A/C **	Water [kg·m^{-3}]	Cement [kg·m^{-3}]	Fine Aggregate ≤2.5 mm [kg·m^{-3}]	Coarse Aggregate 4.5 a 20 mm [kg·m^{-3}]	Reference
0.35		8.0	70	200		1600	[3]
0.40		8.0	80	200		1600	
0.35		7.2	88	250		1800	
0.35		6.0	88	250		1500	
0.23	10	4.0	88	392	247	1563	[25]
0.22	15	4.8	73	328	207	1563	
0.23	20	5.9	60	264	166	1563	
0.22	25	7.8	45	201	126	1563	
0.23	30	11.4	31	137	86	1563	
0.25	10	4.1	95	379	239	1563	
0.25	15	4.9	79	318	200	1563	
0.25	20	6.1	64	256	161	1563	
0.25	25	8.0	48	195	123	1563	
0.25	30	11.8	33	133	84	1563	
0.30	10	4.4	107	357	225	1563	
0.30	15	5.2	90	299	188	1563	
0.30	20	6.5	73	241	152	1563	
0.30	25	8.5	55	183	115	1563	
0.30	30	12.5	38	125	79	1563	
0.30		6.5	90	300		1957	[26]
0.30		6.7	90	300		2013	
0.30		6.9	90	300		2070	

* Water–cement ratio (W/C); ** Aggregate–cement ratio (A/C).

As in Table 1, some researchers defined the type of mixture and proportions in their experiments to meet the appropriate strength [27]. This was compared with three types of porosities 0.19, 0.22, and 0.27 defined for four different aggregate sizes 2.36, 4.75, 9.50, and 12.70 mm.

On the other hand, Jain et al. [16] used three types and three sizes of aggregates to study the size of the aggregate (12.5 mm, 10 mm, and 6.3 mm), with a ratio of 0.30 to 0.45 water–cement ratio (W/C) maintaining an aggregate–cement ratio (A/C) of 4:1. In the results obtained, for all aggregate sizes, the permeability of the mixtures prepared with the aggregate of a lower value of angularity number showed lower permeability but greater compressive strength.

Another type of mixture was developed by Bhutta et al. [23] with: (1) a conventional porous concrete graded by separation without fines; the aggregate size was from 2.5 mm to 20 mm, with a W/C ratio of 0.27 and 0.30, and A/C mixing ratios of 5:1 and 7:1; (2) high-performance porous concrete with a W/C ratio of 0.30 and 0.35 and a 5:1 A/C mixing ratio with two types of additives. Porous concrete exhibited good workability and cohesion without segregation or bleed and developed high strength compared to conventional porous concrete.

Anne et al. [28] investigated the feasibility of reducing the volume of fine aggregate in the cement concrete mix and adding extra course aggregate. For this purpose, river sand as a fine aggregate, Portland pozzolana cement, and the coarse aggregates of 20 mm and 10 mm grain size were used as materials for their research. The study replaced the sand in a percentage of 25%, 50%, 75%, and 100% in its mixes. Both 10 mm and 20 mm aggregates were used separately.

In the observations obtained, they show that the compressive strength of porous concrete is lower than ordinary concrete; 90% of the required compressive strength is reached in 7 days, and they conclude that the construction of porous concrete is technically variable and feasible.

4. Properties

4.1. Physical and Mechanical Properties

The strength and structural performance of porous concrete is more variable than traditional concrete and depends mainly on the porosity [19]. The pore matrix allows water to flow through the material, reducing its strength. Haselbach and Freeman [29] reported that porosity not only varies with the change in the water–cement and aggregate–cement ratio but also varies with thickness because higher porosity can result in lower strengths, and the distribution of vertical porosity can decrease the tensile strength in its lower part; therefore, this should be considered in the design of porous concrete [30]. In this sense, Tennis et al. [31] report a range of values between 20 and 40 MPa for compressive strength in the case of conventional concrete, while for porous concrete, these values decrease to values of 4 and 30 MPa. In tensile strength, the decrease is not so pronounced: conventional concrete has a range of values between 2 and 6 MPa, and for porous concrete, the content is between 1–5 MPa [30].

Research has shown that the main factors that affect the permeable resistance include the porosity of concrete, the water–cement ratio material, the characteristic of the paste, and the size and volume content of coarse aggregates [19]. Huang et al. determined a balance between polymer-modified porous concrete's permeability and resistance properties [21].

The mechanical properties of porous concrete can be improved by suitable mixing ratios [31]. Yang et al. suggested that silica fume and superplasticizer could substantially enhance the strength of porous concrete [4]. The objective of this method was to reduce the size of the pores in the cement paste binder. Before incorporating the mixture of silica fume and superplasticizer, the diameter of the pores was approximately between 5 and 50 µm. Once this mixture was incorporated, the diameter of the pores of the cement paste binder were reduced by about 0.1 and 0.2 µm. The fine particles of the mixture were introduced into the pores of the cement paste increasing its density. Likewise, this also reduces the thickness of the transition zone between the aggregate and the binder. Thus, the strength of the binder cement paste is enhanced [4].

Superplasticizers reduce the water content in a concrete mix. The mechanism used by these additives can be of the electrostatic or steric type. In the first case, superplasticizers are high surface activity surfactants between water and cement. The cement particles adsorb the superplasticizer molecules preventing flocculation. In this way, a dispersion of cement particles in aqueous solution is obtained. When the superplasticizer molecules are long and dense, they create a high volume adsorption layer that prevents the cement particles from coming together. A physical force appears to be originated when two polymers try to occupy the same space. In this case the electrostatic effect is minimal. This mechanism is called steric hindrance. Either of these two mechanisms induces a greater contact surface between cement and water, causing better hydration and, by causing a more effective dispersion, a more complete hydration is promoted that leads to obtaining a more resistant porous concrete.

Table 3 shows the measurement of physical and mechanical properties of all porous concrete mixtures such as density, 28-day compressive strength, and flexural and tensile strength reported by several authors. The compressive strength of porous concrete usually is less than 10 MPa due to the high porosity. According to the data collected, the compressive strengths range from 3.53 to 46.70 MPa for mixtures proportioned from a coarse aggregate with a size between 4.5 and 20 mm and a fine aggregate <2.5 mm.

To evaluate the quality and performance of concrete, its compressive strength must be taken into consideration. Figure 1 describes the relationship between compressive strength and W/C. Chen et al. recorded high strength (46.70 MPa at 28 days) by modifying the mixture by adding to the cement mixture using silica fume, superplasticizer, and polymer modification. The aggregate size was from retention in a 4.75 mm sieve and a 9.5 mm sieve, and the mixing ratio was 4:1 with an amount of 1450 kg·m^{-3} of concrete, and tested on specimens of size 150 × 150 × 150 mm. Figure 2 shows the relationship between compressive strength and A/C.

Table 3. Mechanical and physical properties of pervious concrete.

Mix Proportion		Mechanical and Physical Properties				References
W/C	A/C	Density [kg·m^{-3}]	Compressive Strength [MPa]	Flexural Strength [MPa]	Tensile Strength [MPa]	
0.37	4.0	1710	15.54	2.96	1.76	[12]
0.38	4.5	1652	13.45	2.58	1.64	
0.39	5.0	1652	12.32	2.56	1.61	
0.42	6.0	1640	11.14	2.12	1.61	
0.35	5.0		6.75	1.17		[21]
0.39	4.0		12.18			[16]
0.42	4.0		11.47			
0.27	7.0		11.89	2.75		[23]
0.30	5.0		13.86	3.27		
0.28	5.1		37.60	4.70		[24]
0.30	4.3		40.50	5.10		
0.32	3.7		42.70	5.40		
0.33	3.3		46.70	6.10		
0.30	4.3		13.50	3.07		[7]
0.30	6.5		13.90	3.00		
0.35	8.0	1716	3.53		0.47	[3]
0.40	8.0	1753	3.92		0.79	
0.35	7.2	1809	4.76		0.66	
0.35	6.0	1805	6.95		1.32	
0.23	4.0		36.40			[25]
0.25	4.1		31.60			
0.30	4.4		31.80			
0.30	7.0		20.00	3.54	1.60	[26]
0.31	4.0		34.50			[32]

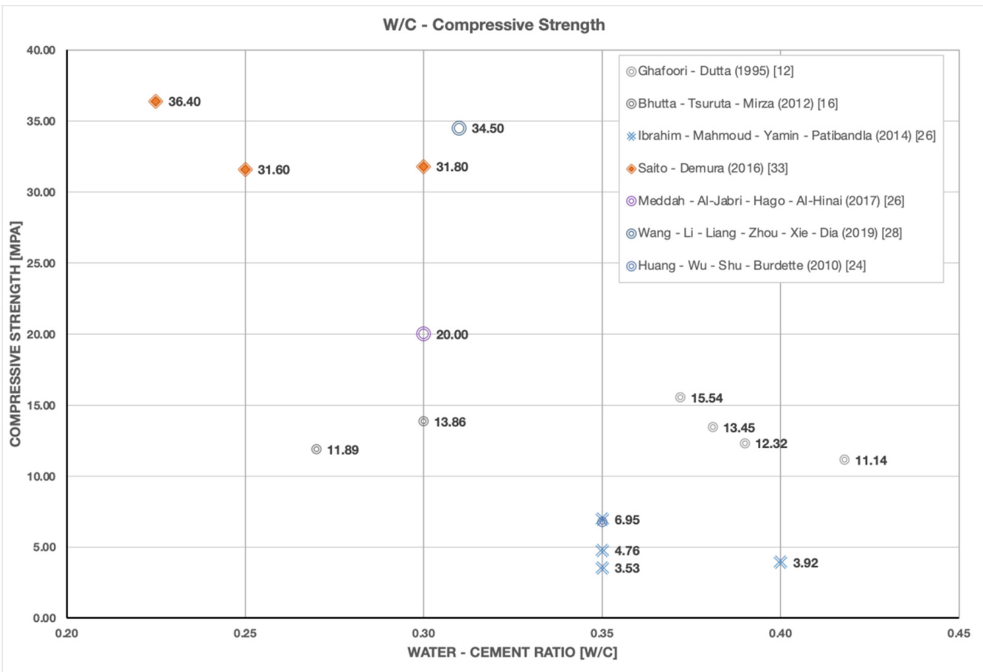


Figure 1. Relationship between water–cement and the compressive strength.

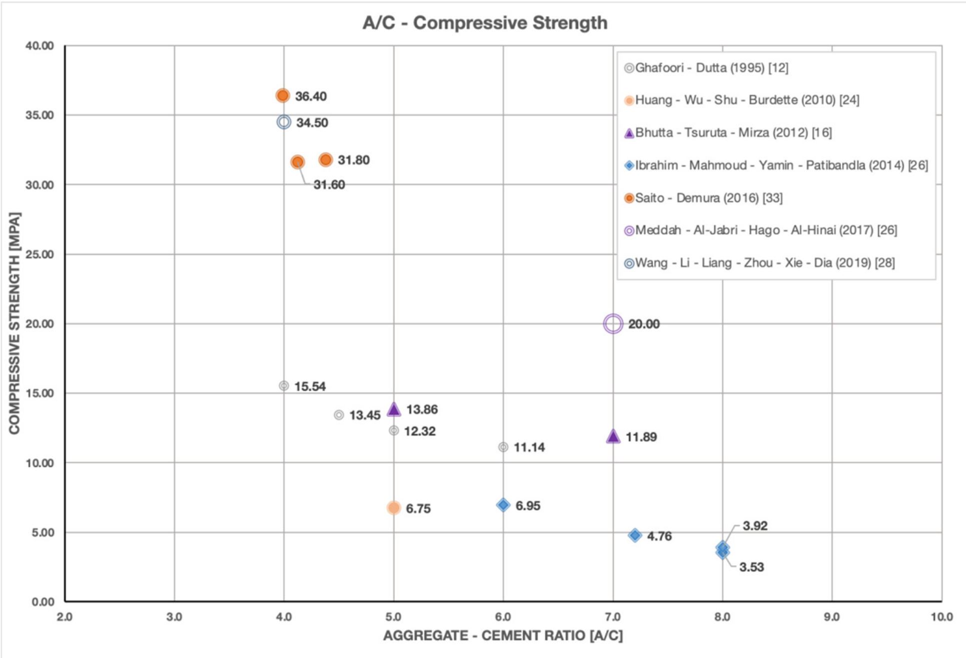


Figure 2. Relationship between aggregate–cement ratio and the compressive strength.

Figures 2 and 3 show that the highest compressive strength achieved is between 0.30 and 0.35 W/C ratio and from 3:1 to 5:1 of A/C. The density of porous concrete is in the range 1640–1809 kg·m^{-3}; the difference in viscosity is attributed to the different cement content and the dry weights for the different mixtures.

The properties relevant to permeable concrete include compression, flexing, and fatigue forces. The results of studies indicate that the proportions of resistance are the mixing variables function and are more sensitive to the ratio of aggregate to cement instead of the water to cement ratio.

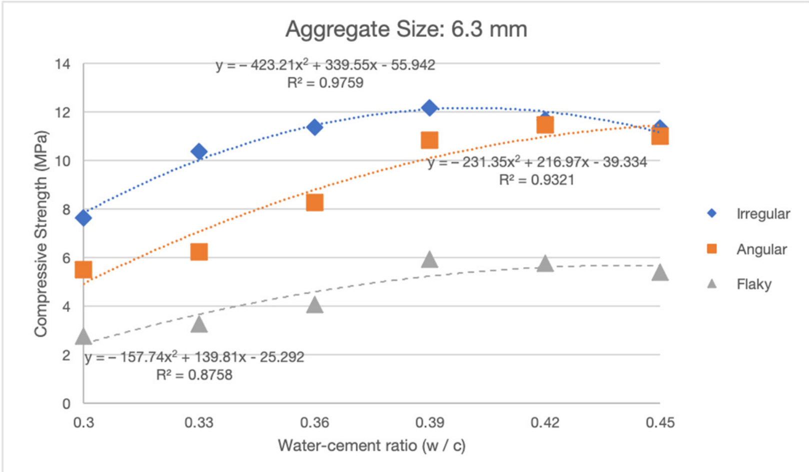
In addition, compressive strength depends on the size, shape, and gradation of the aggregate. Crouch et al. [19] reported that a uniformly graduated aggregate would result in greater compressive strength as well as a greater proportion of voids. A uniformly graduated aggregate is also beneficial as it also indicates that smaller aggregates will produce greater compressive strength than larger aggregates and will result in similar porosities [19].

The relationship between W/C and the compressive strength for various aggregate sizes and angularity demonstrates that the compressive strength of porous concrete mixtures varies inversely with the range of angularity of the aggregate used. Figure 3a–c reflects the above in accordance with the results of Jain et al. [16].

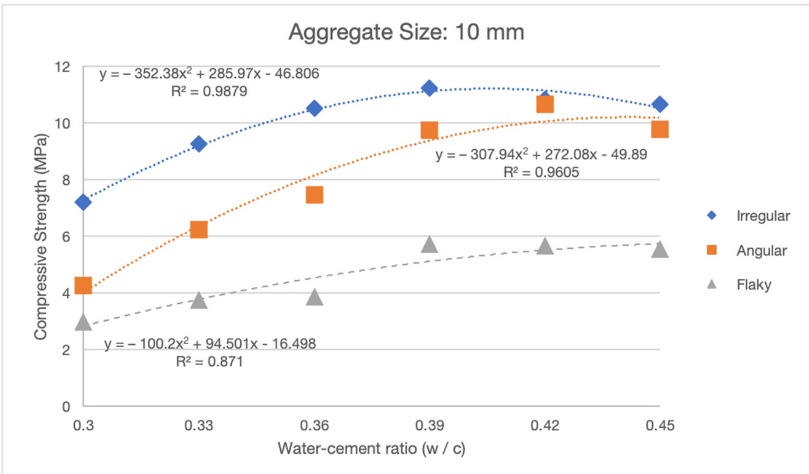
According to Jain et al. [16], mixtures prepared using irregular aggregates showed greater strength, followed by mixtures prepared using angular aggregates and aggregates in the form of scales for a given aggregate size and W/C ratio. The figures also demonstrate this for all types of aggregate and all aggregate sizes; the compressive strength of concrete mixes increases with the increase in the W/C ratio to a particular value. The compressive strength tends to be reduced.

For the curing of porous concrete samples, the same criteria were performed for a simple concrete sample. As described by the researchers in all of the trials, the cylinders were submerged in water. Others were executed in curing rooms controlled with heating or cooling devices to ensure that the resistance results were as reliable.

Figures 4 and 5 show the relationship between compression and flexural strengths for all porous concrete mixtures. The results demonstrate a significant trend: as compression resistance increased the bending strength increased with the use of one or two sizes added in all mixtures. On the other hand, (Figure 5), it can be seen that the trend line for relationships indicates that compression resistance is between 15 and 20 MPa with trials elaborated with cylindrical specimens.



(**a**)



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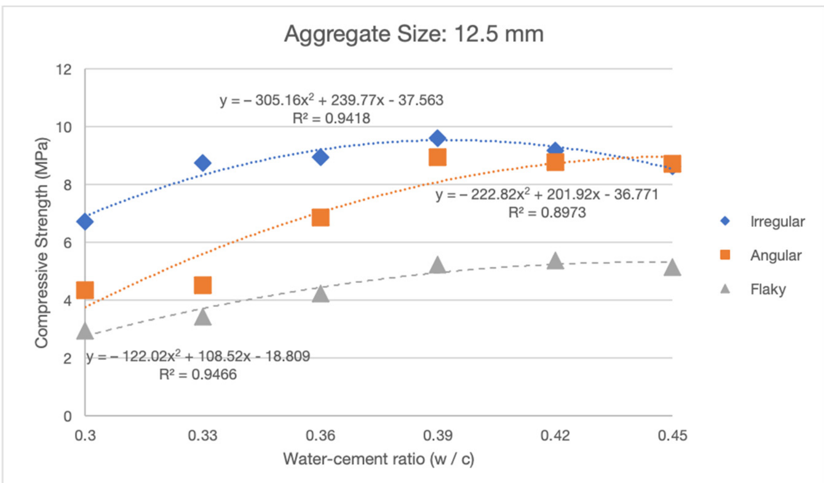

(**c**)

Figure 3. Relationship between the W/C and the compressive strength of porous concrete for a 6.3 mm (**a**), 10 mm (**b**), 12.5 mm (**c**) aggregate.

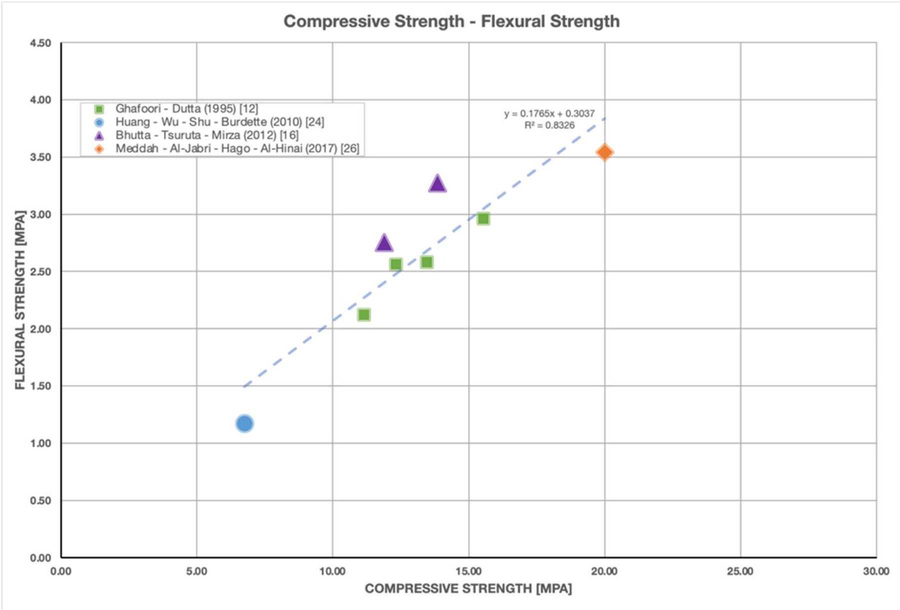

Figure 4. Relationship between compressive strength and flexural strength of porous concrete.

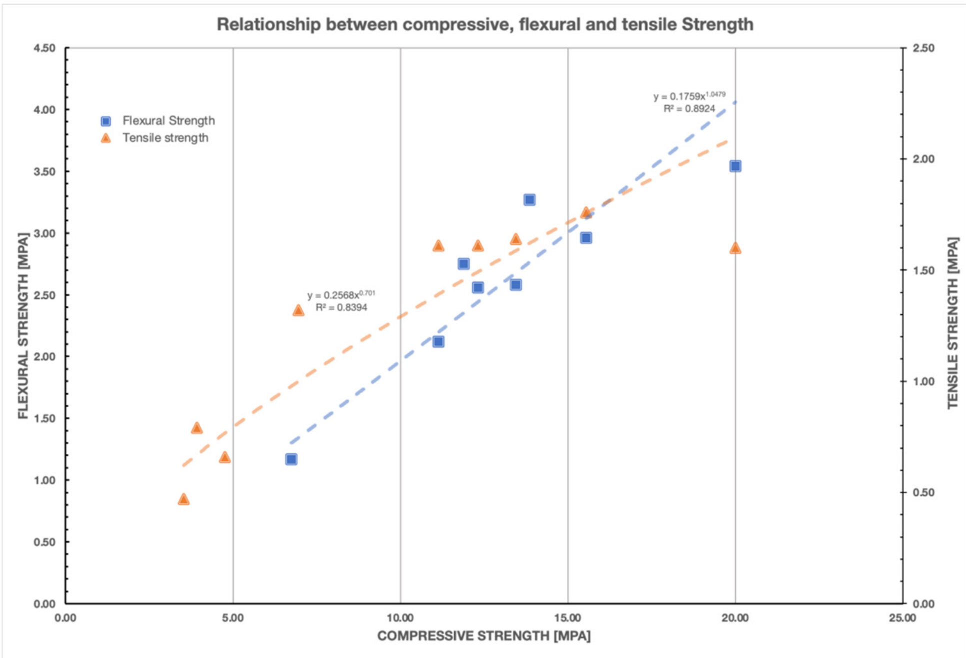

Figure 5. Relationship between compressive, tensile and flexural strength.

4.2. Hydraulic Properties

Porosity is the relationship between the volume of voids and the total volume of the sample. Ref. [29] recommended finding the total porosity of porous concrete using a water displacement method based on the Archimedes buoyancy principle. The dry mass, the submerged mass, and the total volume must be known to calculate the porosity using the displacement method; therefore, total porosity is directly related to the compressive strength due to the effectiveness of its void volume.

Regarding permeability, the results obtained by Yang et al. demonstrate that a cement proportion of only 150 kg·m^{-3} has high strength and a good permeability when the aggregate has a step percentage of 4.75 mm around 10% to 15%; with the increase in the maximum aggregate size, the strength of the porous concrete decreases and the permeability increases.

In general, if the density of the mixture or aggregate increases, the strength also increases while the permeability decreases. In addition, the test results showed the beneficial effect of fine particles in the development of porous concrete strength [33]. The porosity, as the main parameter to estimate the efficiency of the porous concrete, is influenced more by the type and size of the aggregate in the properties of the porous concrete [17]. Table 4 illustrates the results of the researchers on the qualities observed for each mix proportioning design.

Table 4. Hydraulic properties of pervious concrete.

Mix Proportion		Hydraulic Properties				
W/C	A/C	Density [kg·m^{-3}]	Compressive Strength [MPa]	Permeability [mm/s]	Porosity [%]	References
0.37	4.0	1710	15.54		20.77	[18]
0.38	4.5	1652	13.45		25.83	
0.39	5.0	1652	12.32		25.45	
0.42	6.0	1640	11.14		27.06	
0.35	5.0		6.75	17.44	29.70	[21]
0.39	4.0		12.18	0.03		[16]
0.42	4.0		11.47	0.41		
0.27	7.0		11.89	23.13		[23]
0.30	5.0		13.86	4.94		
0.28	5.1		37.60		23.20	[24]
0.30	4.3		40.50		20.10	
0.32	3.7		42.70		18.40	
0.33	3.3		46.70		15.20	
0.30	4.3		13.50	8.00	23.50	[7]
0.30	6.5		13.90	22.80	23.40	
0.35	8.0	1716	3.53	15.60	35.00	[3]
0.40	8.0	1753	3.92	21.40	35.00	
0.35	7.2	1809	4.76	16.30	35.00	
0.35	6.0	1805	6.95	15.00	30.00	
0.23	4.0		36.40			[25]
0.25	4.1		31.60			
0.30	4.4		31.80			
0.30	7.0		20.00	15.00	27.00	[26]
0.31	4.0		25.70	7.10	23.30	[32]

Figure 6 shows the aggregate–cement ratio (A/C) effect on the porosity for all porous concrete mixtures. The results indicate a satisfactory trend as the porosity increases with an increase in the A/C ratio, producing an effect as the porosity decreases with an increase in density. The data in Figure 7 were collected from the investigations carried out by Ibrahim et al. [3] and Ghafoori et al. [12].

Figure 8 shows the effect of porosity on compressive strength; in general, compressive strength decreased (from 46.70 MPa to 3.92 MPa) with an increase in porosity from 15% to 35%.

Figure 9 illustrates the effect of porosity on the permeability coefficient. Although there is a noticeable dispersion in the graphed data, water permeability generally increases as porosity increases. The highest permeability is around 21.40 mm/s when the porosity is 35%. The authors believe that this type of dispersion is due to the total porosity being measured, and a better relationship is expected if an "effective" porosity is used.

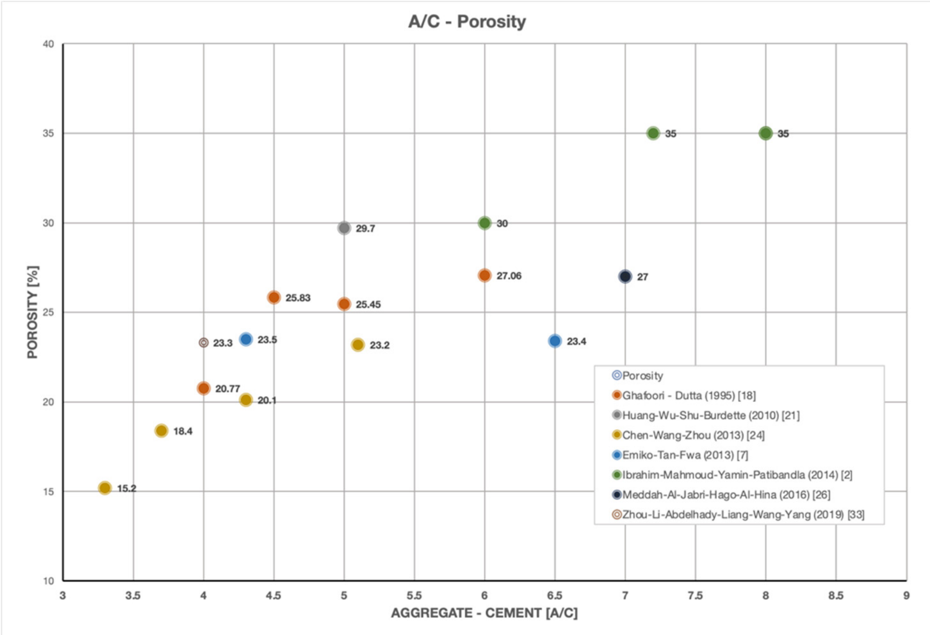

Figure 6. Relationship between A/C and Porosity.

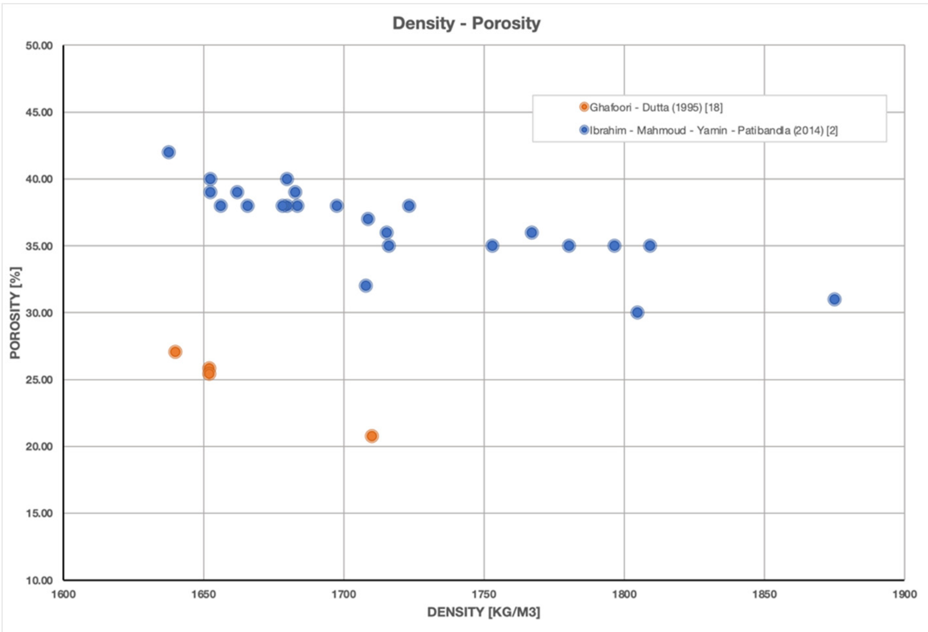

Figure 7. Results obtained by Ibrahim and Ghafoori–Dutta relating the density and porosity of a porous concrete.

Their porosity and permeability usually denote permeable concrete's properties. According to the results of the researchers, the relationship between the porosity and permeability of porous concrete mixtures differs for different aggregate sizes in different proportions of water–cement and different percentages of fine aggregates. As the primary function of porous concrete is to infiltrate water in the soil, permeability and porosity exhibit an essential role in the design of the mixture. The mixture of porous concrete includes the strength, as well as the permeability and porosity of the mix. The variation in the permeability with the porosity of the mixture is shown in Figure 10. There is an exponential relationship between the permeability and the porosity of the porous mixture; it is perceived that the general tendency of permeability is to increase with the increasing level of porosity, and that the compressive strength of porous concrete continues to decrease exponentially with increasing porosity. Considering both the compressive strength and the permeability of the mixture, an optimal range of porosity can be selected where the porosity value will be between 10 and 30%. The compressive strength will then be between 15 to 20 MPa, and the permeability will be between 8 to 10 mm/s.

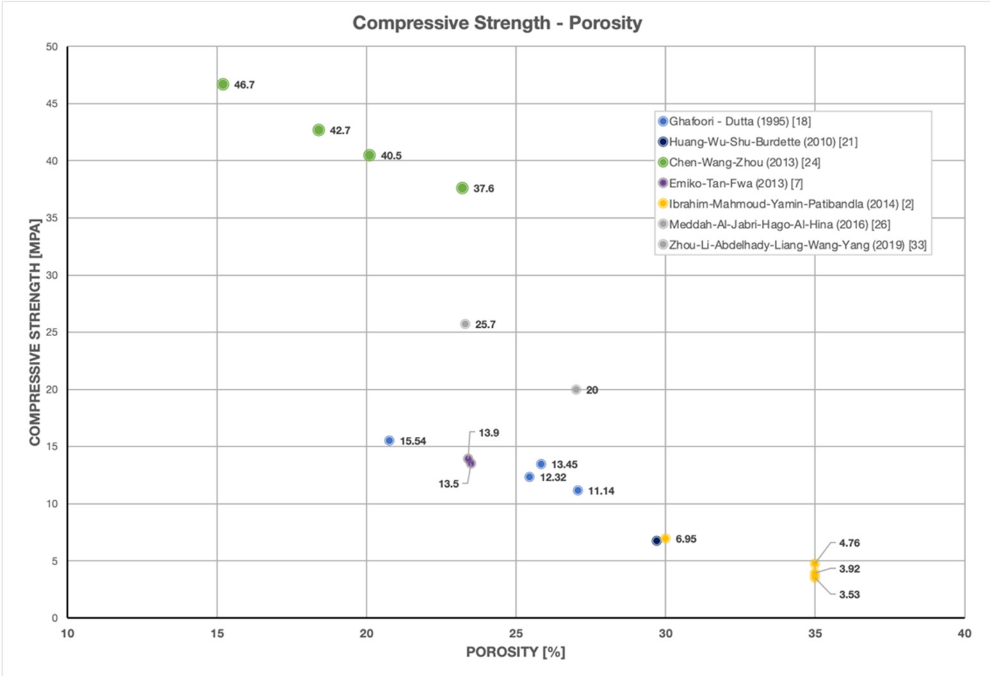

Figure 8. Relationship between porosity and compressive strength.

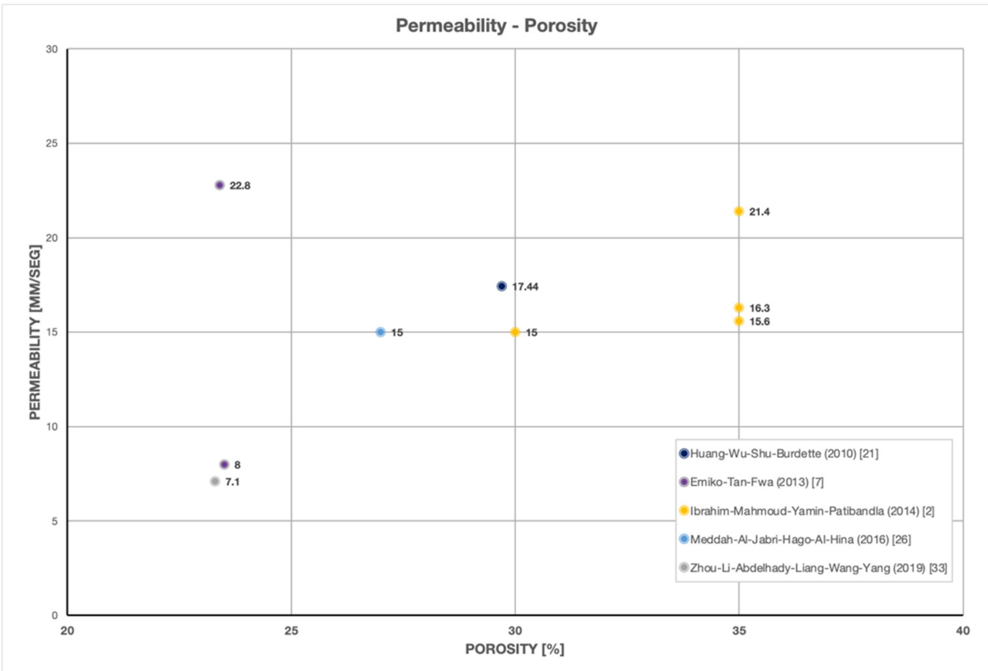

Figure 9. Relationship between porosity and permeability.

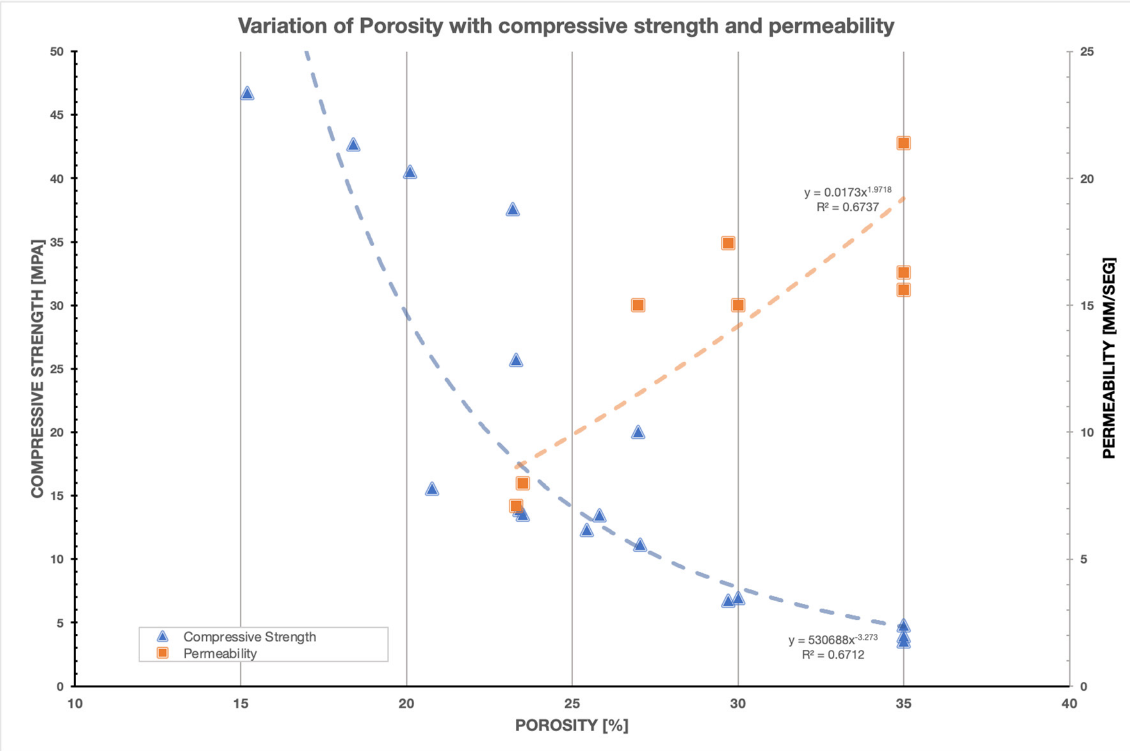

Figure 10. Estimated variation of porosity versus the results obtained for compressive strength and permeability.

4.3. Durability

One of the reasons for the elaboration of porous concrete is to reduce the environmental impacts of water and air and to increase the driver's safety [34]. However, its use is still limited since there are not enough studies that have reviewed the research on the mechanical properties and the durability of permeable concrete performed in several studies [35].

The research indicates that silicone smoke particles improve the mechanical properties and durability of porous concrete [4,36,37]. This was elaborated upon by the addition of silica smoke, superplastifying, and polymer to increase durability [24]. In addition, with a smaller-size aggregate, porous concrete with a much greater force is obtained [38]. The appropriate content of the rice husk could improve compression resistance and tensile strength. At the same time, not all Pozzolanic materials can be used as supplementary material to enhance porous concrete [39,40]. The latex, the polymer, and the fibers can efficiently improve the mechanical properties and the durability of mesh freezing [30–34], and the fibers can also reduce the loss of mass and the abrasion of the surface [41,42].

The design of the mixture to produce porous concrete with the most significant resistance and durability is related to the proportion of empty gaps designed [43]. This is mainly because porous concrete is a special concrete with the design and compaction of different mixtures that allow continuous gaps to be formed with relatively good compression resistance.

Physical characteristics of porous concrete play an important role in both its mechanical properties and its permeability. The aggregate form is defined as the angular or divided rock, which has well-defined edges formed at the intersection of the faces and the shape of rolled edge, which is partially molded at the edges by wear. The aggregates with irregular shapes between 6 and 13 mm obtain a compression resistance more significant than 9.5 to 12.5 MPa with a ratio of 0.39 to 0.41 in W/C.

Tables 5 and 6 are included as a summary, where the influence on the physical and hydraulic properties of the technological parameters is shown, both for the angular shape and for the irregular shape.

Table 5. Influence of technological parameters on physical and hydraulic properties (Angular Shape: Rock Party).

Aggregate Size [mm]	Mix Proportion W/C	A/C	Properties Compressive Strength [MPa]	Permeability [mm/h]
10–6.3	0.39	4.0	12.18	122
12.5–10	0.39	4.0	11.23	152
16–12.5	0.39	4.0	9.60	176

Table 6. Influence of technological parameters on physical and hydraulic properties (Irregular shape: Rolled edge).

Aggregate Size [mm]	Mix Proportion W/C	A/C	Properties Compressive Strength [MPa]	Permeability [mm/h]
10–6.3	0.39	4.0	11.47	1464
12.5–10	0.39	4.0	9.75	2314
16–12.5	0.39	4.0	8.95	2714

5. Conclusions

Usually, the compressive strength of porous concrete is less than 10 MPa due to its high porosity. However, the documentary review of several investigations on the physical and mechanical properties of porous concrete evidenced that with densities that vary between 1640–1809 kg·m^{-3}, that difference is attributed to the different cement content and the weights of the aggregates for the different mixtures. It is observed that the compressive strengths achieved by the researchers were 10 to 20 MPa for mixes between 0.30 to 0.35 W/C ratio and from 3:1 to 5:1 A/C ratio.

The compressive strength of porous concrete also depends on another variable and, to a large extent, on the particle size distribution of the aggregate; according to the documentary review, a uniformly graduated aggregate from 4.5 to 20 mm results in higher compressive strength, as well as a higher proportion of voids. In addition, some investigations have shown that it is beneficial to use fine aggregates <2.5 mm as they produce a higher compressive strength than aggregates with similar porosities.

According to the analysis developed in the present bibliographic review, the influential variables are porosity, permeability, and compression resistance. In some research cases, the effect of porosity on compressive strength is evident; in general, the compressive force decreases. Considering both the compression resistance and the permeability of the mixture, an optimum range of porosity can be selected where the value of the porosity will be between 20% and 25%; the compression resistance will be 10 to 20 MPa and permeability is from 8 to 10 mm/s.

In general, the strength and structural performance, depending on the results obtained by different mixtures and tested proportions of various investigations of porous concrete, depends mainly on the porosity, and the W/C and A/C ratio with a 4.5 size aggregate at 20 mm; another variable is the thickness. Thus, we can say that the greater the porosity, its compressive strength decreases by 60% and the distribution of the vertical porosity decreases the tensile strength in the lower part by 50% of conventional concrete. Both are variables that should be considered in the design of porous concrete.

Author Contributions: Conceptualization, C.S.-M., J.J.G. and I.M.-L.; methodology, J.J.G. and I.M.-L.; software, C.S.-M.; validation, C.S.-M., J.J.G. and I.M.-L. formal analysis, C.S.-M., J.J.G. and I.M.-L.; data curation, C.S.-M.; writing—original draft preparation, C.S.-M.; Writing—review and editing, C.S.-M.; supervision, J.J.G. and I.M.-L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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