

# The Use of Seashell by-Products in Pervious Concrete Pavers

Dang Hanh Nguyen, Nassim Sebaibi, Mohamed Boutouil, Lydia Leleyter, Fabienne Baraud

**Abstract**—Pervious concrete is a green alternative to conventional pavements with minimal fine aggregate and a high void content. Pervious concrete allows water to infiltrate through the pavement, thereby reducing the runoff and the requirement for stormwater management systems.

Seashell By-Products (SBP) are produced in an important quantity in France and are considered as waste. This work investigated to use SBP in pervious concrete and produce an even more environmentally friendly product, Pervious Concrete Pavers.

The research methodology involved substituting the coarse aggregate in the pervious concrete mix design with 20%, 40% and 60% SBP. The testing showed that pervious concrete containing less than 40% SBP had strengths, permeability and void content which are comparable to the pervious concrete containing with only natural aggregate. The samples that contained 40% SBP or higher had a significant loss in strength and an increase in permeability and a void content from the control mix pervious concrete. On the basis of the results in this research, it was found that the natural aggregate can be substituted by SBP without affecting the delicate balance of a pervious concrete mix. Additional, it is recommended that the optimum replacement percentage for SBP in pervious concrete is 40 % direct replacement of natural coarse aggregate while maintaining the structural performance and drainage capabilities of the pervious concrete.

**Keywords**—Seashell by-products, pervious concrete pavers, permeability and mechanical strength.

## I. INTRODUCTION

**P**ERVIOUS concrete is one of the most important emerging technologies for sustainable facilities and infrastructure. American Concrete Institute (ACI) Committee 522 describes pervious concrete as a "near zero-slump, open-graded material consisting of hydraulic cement, coarse aggregate, little or no fine aggregate, admixtures, and water" [1]. Applications of pervious concrete include residential alleys, roads, driveways, sidewalks and pathways, parking lots, pavement, and edge drains. It is considered as a green building material, can be easy to install and produced from readily available materials.

Dang Hanh Nguyen is Ph.D at Ecole Supérieure d'Ingénieurs des Travaux de Construction de Caen, 14000 Caen, France, (phone: +33 2 31 46 23 00; fax: +33 2 31 43 89 74; e-mail: doctorant.dn@esitc-caen.fr).

Nassim Sebaibi is Researcher at Ecole Supérieure d'Ingénieurs des Travaux de Construction de Caen, 14000 Caen, France, (phone: +33 2 31 46 23 00; fax: +33 2 31 43 89 74; e-mail: ec.ecomateriaux@esitc-caen.fr).

Mohamed Boutouil is Director of Laboratory of Ecole Supérieure d'Ingénieurs des Travaux de Construction de Caen, 14000 Caen, France, (phone: +33 2 31 46 23 06; fax: +33 2 31 43 89 74; e-mail: dir.recherche@esitc-caen.fr).

Lydia Leleyter and Fabienne Baraud are Chemist-researchers at Normandie Univ, France, UCBN UR ABTE EA 4651, QALEA; F-14032 Caen, France. (phone: +33 2 31 56 72 18; fax: +33 2 31 56 73 03; e-mail: lydia.reinert@unicaen.fr, fabienne.baraud@unicaen.fr).

Some important environmental benefits of pervious concrete include the potential reduction of urban heat island effects, recharge of ground water, reduction of storm water runoff potential, and reduction of irrigation water use in urban landscapes by permitting rainfall water to infiltrate and be stored in the soil in areas where adjacent vegetation is growing [1]-[4]. Since its various environmental benefits, pervious concrete is increasingly used in all over the world and in France also.

Currently, according to the French Union of Aggregate Producers [5], 379 million tons of aggregates were consumed in France in 2009, *i.e.* 6 tons per inhabitant. Aggregate costs constituted as one of the greatest costs of highway construction, comprising between 20 and 30% of the cost of materials and supplies, or 10 to 15% of total construction costs (excluding engineering and right-of-way acquisition) [6]. However, most of the aggregates are used natural aggregates from quarries, river and sea dredging. While natural aggregate sources are vast, they are also finite; many high-quality, conveniently located natural aggregate sources are being depleted rapidly. In addition, environmental regulations, land use policies and urban/suburban construction and expansion are further limiting access to many natural aggregate resources. Natural aggregate costs can be expected to rise with scarcity of supply and increasing haul distances. In France, natural aggregate sources are limited and other sources need to be evaluated for use, such as recycled aggregates, slag aggregates, and recently seashells.

Regarding the seashells, in Europe, France has an important fishing and shellfish farming industry that produces nearly 200 000 tons of shells from shellfish breeding and nearly 50 000 tons of shellfish per year from fishing [7]. These activities generate thousands of tons of seashell by-products (empty shells) to be discharged, as they are considered as waste. For the moment, some attempts has been made in France to recycle them as soil conditioner or animals food but none of these attempts gave satisfaction in terms of viable and added value recycling.

Using SBP in pervious concrete has multiple advantages to the environment namely, reducing the amount of SBP being put into landfills, reducing dumping at landfill sites, reducing gravel mining and reducing hauling of natural aggregate and therefore reducing emissions. Additionally, the ecological benefits of pervious concrete can be taken a step further by incorporating SBP into the mix design.

While pervious concrete have been used and incorporating SBP in conventional concrete have been studied previously, the use of SBP in pervious concrete is just beginning to be

explored. Incorporating SBP in pervious concrete is still a relatively new idea, and the feasibility of SBP in pervious concrete is still under investigation.

It is likely SBP will not be able to replace natural aggregate completely unless the minimum compressive strength and hydraulic conductivity criteria are met. SBP contain not only the flat particles, but also high organic matter and chloride content. Resulting in lower density packing compared to natural aggregate and lower compressive strength. In this paper, the effects of SBP on density, porosity, mechanical strength, and hydraulic conductivity of pervious concrete pavers are evaluated.

## II. SPECIMEN PREPARATION AND TESTING

### A. Materials

#### 1. Cement and Aggregate

The cement used in this study is an Ordinary Portland Cement (OPC) CEM I 52.5 R.

The alluvial quartz sand with a grain size 0/4 mm was used. The sand presents a specific gravity of  $2620 \text{ kg.m}^{-3}$ , an absorption coefficient of 0.50 % and a fineness modulus of 2.81.

To ensure the infiltration capacity of pervious concrete, the selection of aggregate monogranular (single-sized aggregates) is critical to achieve the interconnection of the porous system [1], [2], [8]. The monogranular angular aggregate fraction 2/6.3mm was employed with a specified gravity of  $2716 \text{ kg.m}^{-3}$  and water absorption of 0.48%. The size distribution of gravel and sand is given on Fig. 1.

#### 2. Seashell by-Products

The Seashell By-Products (SBP) that was used for this research was comprised of queen scallop that were successively crushed and sieved to obtain the fraction 2/4mm (Fig. 2). It is noted that there is no cleaning step to remove the impurities, accordingly, the organic matter and chloride ions content are very high (Table I). The particle size distribution of crushed queen scallop is given also in Fig. 1.

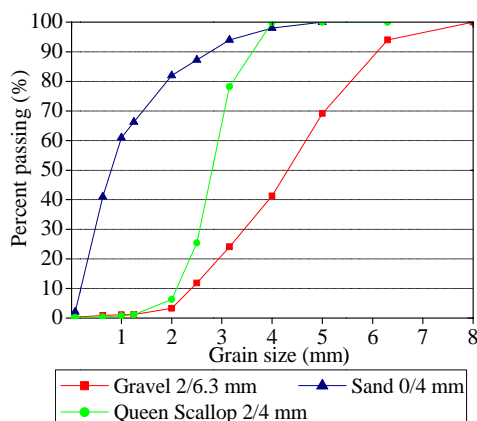


Fig. 1 Grain size distribution of natural aggregate and crushed queen scallop shell



Fig. 2 Crushed Queen Scallop 2/4mm

TABLE I  
PHYSICAL AND CHEMICAL PROPERTIES OF THE CRUSHED QUEEN SCALLOP AND NATURAL AGGREGATES

Characteristics	SBP 2/4 mm	Aggregates	
		Gravel 2/6.3 mm	Sand 0/4 mm
Specific gravity ( $\text{kg.m}^{-3}$ )	2497	2716	2620
Water absorption (%)	2.91	0.52	0.50
Chloride ion content (%)	0.074	0	0
Organic matter content (%)	1.74	0	0

#### B. Mix Composition and Specimen Preparation

This research looked at substituting the natural aggregate with SBP in different percentages in order to determine the optimum percentage of SBP that can be added in to pervious concrete pavers. SBP was directly substituted for the natural coarse aggregate at 20%, 40% and 60% by mass. The mix proportions of the control pervious concrete pavers and the pervious concrete pavers based on the seashell by-product are summarized in Table II. For these mixtures, cement, water, sand and  $w/c$  ratio are kept constant while the gravel content varies with the incorporation of the crushed queen scallop 2/4 mm.

A total of 15 cubes  $15 \times 15 \times 15 \text{ cm}$  were cast for each mixture (see Table II) and the fresh concrete tests were done in order to evaluate the affects of the addition of the SBP into the pervious concrete mix. The cast cubic were demoulded 24 hours after casting, at which point they were set to cure in moist conditions for 28 days.

#### C. Test Procedures

##### 1. Compressive Test

The compressive strength is measured on cubic  $15 \times 15 \times 15 \text{ cm}$  specimens in accordance with the European Standard EN 12390 [9]. Samples were tested for compressive strength at 28 days of age. These tests were performed using a constant rate loading of  $0.06 \text{ MP.s}^{-1}$ . The reported result is an average of three to five tests.

##### 2. Splitting Test

According to the European Standard EN 1338 [10], the splitting tests were performed on cubic specimens  $15 \times 15 \times 15 \text{ cm}$ . These tests were performed at an imposed load rate of  $0.05 \text{ MPa.s}^{-1}$  (Fig. 3).

TABLE II  
COMPOSITION OF DIFFERENT MIXES PROPOSED

ID	Sample Type	Cement (kg/m <sup>3</sup> )	Water <sup>1</sup> (kg/m <sup>3</sup> )	Gravel 2/6,3mm (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	Queen Scallop 2/4 mm (kg/m <sup>3</sup> )	Theoretical specify density (kg/m <sup>3</sup> )	Rate <sup>2</sup> shell	Theoretical initial porosity (%)
PCP1-0	Control, Type 1	300.9	111.3	1574.3	110.2	0	2096.9	0	28.23
PCP1-20 <sup>3</sup>	20%SBP, Type 1	300.9	111.3	1259.6	110.2	314.9	2096.9	20	27.21
PCP1-40	40%SBP, Type 1	300.9	111.3	944.7	110.2	629.8	2096.9	40	26.20
PCP1-60	60%SBP, Type 1	300.9	111.3	629.8	110.2	944.7	2096.9	60	25.18
PCP2-0	Control, Type 2	363.1	134.4	1574.3	110.2	0	2182.2	0	26.25
PCP2-20	20%SBP, Type 2	363.1	134.4	1259.6	110.2	314.9	2182.2	20	25.23
PCP2-40	40%SBP, Type 2	363.1	134.4	944.7	110.2	629.8	2182.2	40	24.22
PCP2-60	60%SBP, Type 2	363.1	134.4	629.8	110.2	944.7	2182.2	60	23.20

<sup>1</sup>Efficient water

<sup>2</sup>Weight percentage of shell on the weight of the aggregate in the Control Pervious Concrete Pavers

<sup>3</sup>PCPx-y: Pervious Concrete Pavers in which y% by weight of gravel was replaced by the seashell by-product, based on the pervious concrete pavers type x



Fig. 3 Splitting tensile test

### 3. Measurement of Porosity and Density

The air void content of pervious concrete has been measured, using 'the experimental procedure' recommended by French Association of Civil Engineering [11]. The value obtained by this method is water-accessible porosity. Then, the dry-bulk density of concrete can be calculated.

### 4. Water Permeability Test

Hydraulic conductivity testing was performed by using a permeameter developed by Nguyen et al. shown in Fig. 4 [8]. The specimens were wrapped with thin layer mortar and then they were enclosed in a mold. The space between the specimen and the mold is filled using the plaster to prevent any flow along the sides of the specimen that would affect the measured results. The specimens were secured in the apparatus, and water was added under pressure to the downstream pipe in order to expel any air that may have been present in the specimen.

The falling head method was used to measure the water permeability with an initial water level  $h_1 = 255\text{mm}$  and final height  $h_2 = 75\text{mm}$ . Then, the permeability coefficient is calculated using Darcy's First Law [12]. Tests were performed a minimum of three times per sample to ensure accuracy of reported results. Permeability testing was done on the same samples that were tested for void content.

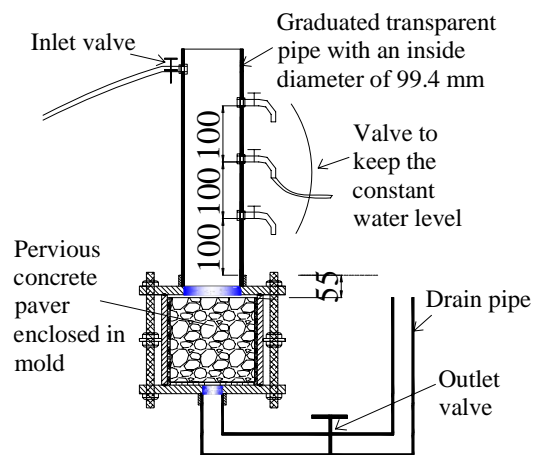


Fig. 4 Device for measuring the permeability coefficient of the pervious concrete pavers

### 5. Abrasion and Slip Resistance

Measurement tests of abrasion and slip resistance are performed according to standard NF EN 1338 [10]. The abrasion resistance is measured by the disc wheel wide and slip resistance was performed using the wet pendulum test. The reading on the scale of wet pendulum test apparatus is the British pendulum number (BPN).

### 6. Freeze-Thaw Durability

Profile cycle freeze / thaw to determine the sustainability freeze / thaw is defined in standard NF EN 1338 [10] but the liquid used for the test is drinking water instead of brine. However, a sample of pervious concrete is considered the off state due to freeze / thaw when the mass loss is about 15% [13] or test was completed when 300 cycles of freezing-thawing was reached.

## III. RESULTS AND DISCUSSION

### A. Fresh Concrete

During batching, the slump tests were done on each mixture. Fresh pervious concrete is characterized as having a very low slump, even zero slumps (Fig. 5). The fresh concretes are very stiff since there is less water and cement

paste which enables the voids in the concrete to remain open. This type of concrete is also referred to as zero slump concrete. By contrast, this characteristic makes it suitable for products prefabrication as pavers.



Fig. 5 Consistency of fresh concrete

TABLE III  
FRESH CONCRETE

Mix	Bach type	Slump (mm)	Real specify density (kg.m <sup>-3</sup> )
PCP1-0	Control, type 1	0	1948.16
PCP1-20	20% SBP, type 1	0	1949.87
PCP1-40	40% SBP, type 1	0	1898.24
PCP1-60	60% SBP, type 1	0	1826.07
PCP2-0	Control, type 2	0	2038.81
PCP2-20	20% SBP, type 2	0	2045.09
PCP2-40	40% SBP, type 2	0	1972.11
PCP2-60	60% SBP, type 2	0	1908.27

The unit weight of pervious concrete mixtures ranged from 1820kg/m<sup>3</sup> to 2050kg/m<sup>3</sup>. The unit weight in both SBP concrete and Control concrete increased with increasing volume fraction of the binder. The unit weight of SBP concrete was normally less than the control concrete and decreased with the quantity of SBP in the mix. The decrease in unit weight may be because SBP density is less than natural aggregate. This may be attributed by light packing of SBP particles.

The American Concrete Institute (ACI) specifies that the unit weight of concrete should be within 80kg/m<sup>3</sup> of a specified density [1]. The specified densities were that of the control mixes, which were 1948.16 and 2038.81kg/m<sup>3</sup> respectively as can be seen from Table III. Table III also shows that the mix containing 20% SBP and 40% SBP were within the 80kg/m<sup>3</sup> of the specified density. However, the mixes containing 60% SBP had densities that were significantly lower than 80kg/m<sup>3</sup> of the specified density, and therefore did not meet ACI specification.

## B. Mechanical Properties

### 1. Compressive Strength

The compressive strength for all the eight mixture is shown on the Fig. 5. Based on the values which found in this study, the pervious concrete pavers incorporating SBP present comparable or smaller compressive strength values. Results

were within the typical range of about 3.5MPa to 28MPa (500 to 4,000 psi) for compressive strength [1], [2].

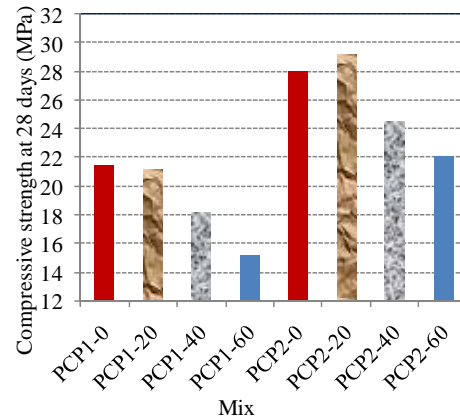


Fig. 6 Compressive strength of pavers 15x15x15cm at 28 days

As the SBP content increased the compressive strength of the samples decreased. There was a significant drop in strengths from the control mixes for the 40% SBP and 60% SBP samples. The 60% SBP samples had the lowest average strength of 15.21MPa and 22.11MPa on 28 days.

The SPCP have a lower compressive strength than CPCP (see Fig. 6). Three hypotheses may explain this result:

- The SBP is fragile than the natural aggregate. In fact, the resistance to fragmentation of natural aggregate obtained through the Los Angeles test [14] is 11 which compared with 15 in case of SBP.
- The substitution of aggregate with SBP can increase with the total porosity. In fact, the natural gravel has a round shape that allows an optimum packing degree of mixture. By contrast, the SBP has the flat shape, once incorporated, they play a role as a wall, will prevent the approach of natural aggregates and disturb the granular arrangement, thus reduce the compactness (Fig. 7). For confirming this observation, compactness test of particle fractions on the shaking table has been used to determine the packing of mixture of SBP and natural aggregate. Referring to the Fig. 6, packing degree decreased with increased percentage of SBP in the mixture.
- The SBP are flats, the flakiness index of natural aggregates 4/6.3mm is 20.1 instead of 98.4 for the case of SBP 4/6.3mm. These values were determined through the European standard EN 933-03 [15]. Hence the surface area of SBP is greater than that of natural aggregate. As a consequence, with the same amount of cement paste, the coating of cement paste around the grains of the natural gravel and SBP for SBP concrete is more slight, probably the gravel are not fully covered. One incorrect paste thickness causes a weak bond of the matrix. Therefore, the strength was smaller. In fact, it was observed that the majority of failures intensively took place in the interface between cement paste and SBP, the SBP surface is as clean as initial state before incorporation into the concrete.

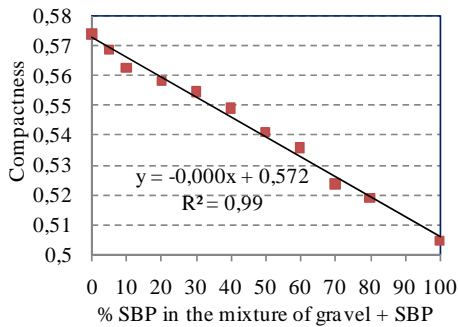


Fig. 7 Variation of the compactness of the mixture depending on the percentage of SBP

Throughout the compressive strength testing it can be seen that the PCP2-20 samples increased a significant amount of strength when compared to the control mix. This was likely due to the decrease of the void content of these samples. Despite the compactness of mixtures decreases slightly by adding 20% of SBP, this does not take into account the presence of cement and water. Perhaps, the presence of these elements will improve the compactness of the mixture at 20% SBP.

2. Tensile Strength

Fig. 8 shows the tensile strength of the pervious concrete pavers according to the amount of SBP and binders. Similar to the compressive strength of the pavers, the same evolutionary trend in tensile strength was observed: more SBP in the mixture, the lower the tensile strength. As can be seen in the test result for compressive strength, the tensile strength tends to increase as the amount of binder increases, regardless of the amount of SBP in use. For pervious concrete in which cement is used as a binder, the tensile strength is significantly degraded compared with compressive strength because of the low binding force of cement.

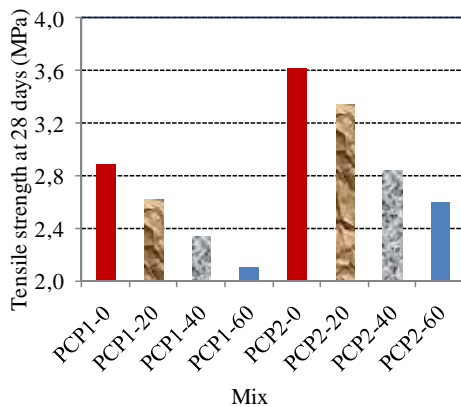


Fig. 8 Tensile strength at 28 days

C. Physical Properties

1. Dry Bulk Density

Fig. 9 displays density testing on pervious concrete samples by percent SBP. Average density values ranged from 1760 to

1985kg/m<sup>3</sup>. This range of values is comparable to density values reported in previous research on pervious concrete, which ranged from 1,710 to 2,009kg/m<sup>3</sup> [1], [2], [13].

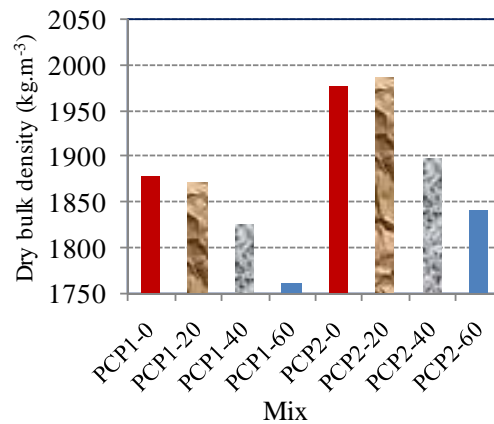


Fig. 9 Dry bulk density for all mixtures

Mix designs with 20% SBP replacement were found to have densities within the same general range; however, 40% and 60 % SBP replacement resulted in decreased density. Previous studies have seen a general trend of decreasing density as SBP increased [8]. The reduction in density for the SBP mixes could be caused by several factors. The manner in which the SBP are arranged in the samples could affect density results. One high flakiness index indicated that SBP was more flat, and this could result in a less compact sample when compared to traditional aggregate even under similar compaction effort. Additionally SBP is assumed to be less dense than natural aggregate due to the presence of important intragranular porosity. The decreased in density for the SBP mixes could be also due to the density difference between the SBP and natural aggregate.

2. Porosity Accessible to Water

Fig. 10 shows the average porosity of the porosity for each of the eight mixes. The porosity of pervious concrete pavers is between 24.2% and 34.3% with the highest void content being 34.3% for the PCP1-60 sample.

All the samples based on the control matrix of type 1 (PCP1) had porosities that were higher than the recommended range of 15% to 30%. Although it could be assumed that a higher void content is preferable, this is not the case in fact. A higher void content usually compromises the compressive strength and loads bearing capacity of the concrete. If the void content is close to or within the range suggested, then the compressive strength can be considered to not have been compromised.

The porosity of the samples increased as the percentage of SBP in the mix increased and this was likely due to the increase of packing degree of the mixes as in the case of density. The disk shape of the SBP causes the grain to form different bonds when compared to the relatively more rounded natural aggregate in the control mix. The increased porosity can also be due to the porosity of the SBP. The SBP was

significantly more porous than the natural aggregate which would affect the porosity measured.

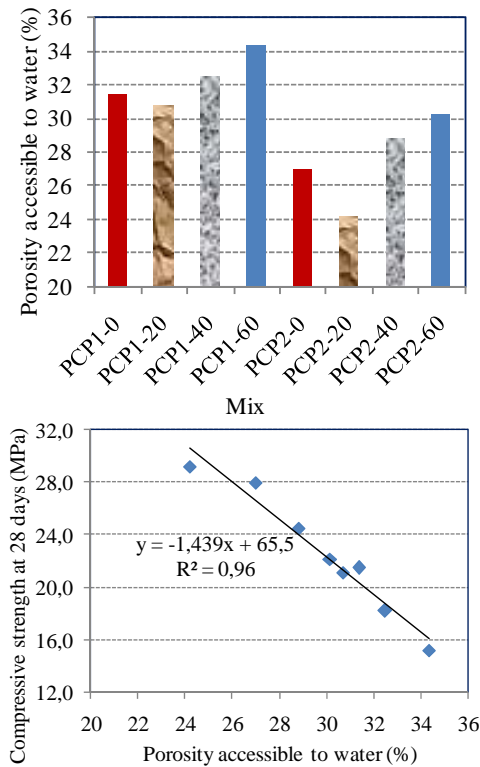


Fig. 10 Porosity accessible to water (a) and relationship between porosity and compressive strength (b)

The porosity of the samples increased as the percentage of SBP in the mix increased and this was likely due to the increase of packing degree of the mixes as in the case of density. The disk shape of the SBP causes the grain to form different bonds when compared to the relatively more rounded natural aggregate in the control mix. The increased porosity can also be due to the porosity of the SBP. The SBP was significantly more porous than the natural aggregate which would affect the porosity measured.

Fig. 10 (b) shows the relationship between compressive strength and porosity for pervious concrete pavers according to the amount of SBP and binders. Regardless of the amount of SBP and binder, porosity decreases as compressive strength increases. This shows that the compressive strength and porosity are opposing requirements, meaning that increased compressive strength requires a thicker layer of cement paste, whereas an increased porosity requires thinner layer of cement paste.

Linear relationship between strength and porosity showed a very high degree of correlation, (square of the correlation coefficient of 0.96).

#### D. Permeability to Water

Permeability coefficient of the pervious concrete is very important to ensure proper design and work for permeable

pavement, and rainwater should be fully permeated when it rains, regardless of how heavy the rainfall is. It is generally known that permeability coefficient increases and strength decreases as porosity increases.

Fig. 11 shows the average permeability of each of the mixes. Fig. 11 shows that the pervious concrete pavers with or without SBP had permeability values between 0.29mm/s to 3.37mm/s, which are high enough to be used as a drainage layer for pavement structures.

In addition, the permeability coefficient tended to decrease dramatically as the amount of binder increased. Like the result of the void ratio test, the permeability coefficient of pervious concrete pavers based on the control matrix of type 2 (PCP2) were lower than those of pervious concrete pavers based on the control matrix of type 1 (PCP1). Regardless of the amount of SBP and binder, they all exceeded the standard permeability coefficient of  $5.4 \cdot 10^{-2}$  mm/s for pervious concrete pavers [16] or 0.1mm/s (100m per day) for permeable asphalt mixture [17]. As it can be seen, these permeability rates are substantially greater than the rainfall rate that is categorized as a thunderstorm by Environment France which defines a severe thunderstorm as rainfall at a rate of 0.033mm/s (2cm in 10 minutes).

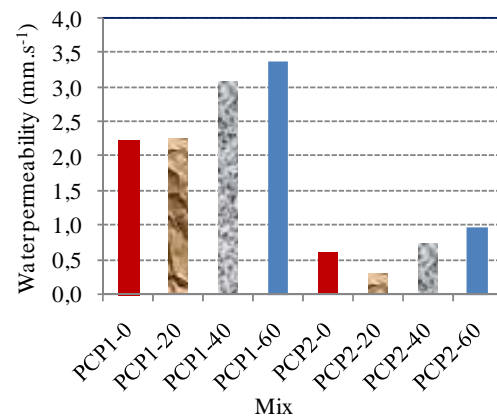


Fig. 11 Permeability coefficient by the falling head test

Although increasing permeability means increasing drainage rates, these high drainage rates are unnecessary for the rate of rainfall in France. Increasing the permeability implies a higher void content which in turn results in decreased load bearing capacity. This decreased compressive strength could result in a shorter life for the pavement and could also result in increased frequency and severity of surface distresses such as raveling and joint failure.

Fig. 12 shows the relationship among porosity, compressive strength and permeability coefficient of the pervious concrete pavers. Fig. 12 shows that as the permeability increases exponentially as a function of porosity, the strength linearly decreases. According to the correlation coefficient (R) values, the relations among these parameters are very strong.

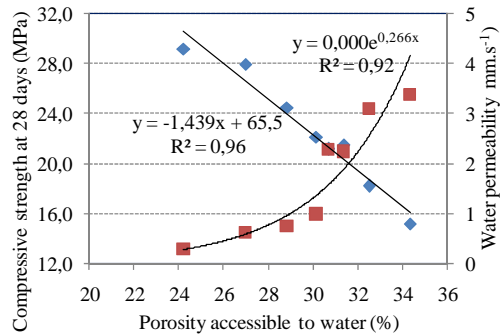


Fig. 12 Relationship among the porosity, the compressive strength and the water permeability

#### E. Abrasion Resistance, Slip Resistance and the Freezing and Thawing Durability

The slip resistance, abrasion resistance and freezing and thawing durability of the materials were measured and shown in Table IV. It can be seen that the CPCP and SPCP has a very good skid resistance. SRT-values of the order of 90 indicate that there is no risk of slip in wet weather.

TABLE IV  
ABRASION RESISTANCE, SLIP RESISTANCE AND THE FREEZING AND THAWING DURABILITY

ID	% SBP	Number of freezing and thawing cycle (days)	Length abrasion (mm)	SRT-values (°)
PCP1-0	0	85	29.59	86.69
PCP1-20	20	49	25.53	86.80
PCP1-40	40	40	28.22	87.00
PCP1-60	60	28	25.41	86.27
PCP2-0	0	150	29.09	89.85
PCP2-20	20	78	26.16	86.80
PCP2-40	40	69	28.93	88.35
PCP2-60	60	52	26.16	83.97

According to Table IV, the length of abrasion of pervious concrete with or without shells is greater than 23mm. Yang found almost the same values [3]. Indeed, because of the specific texture of porous pavers, aggregates are easily loosened from the surface of concrete. Standard EN 1338 requires for traditional pavers length less than 23mm. This regulation applies to the pavers that drains of water through joints or the 4 corners, while, for the pavers studied in this research, the drainage is on the surface of the pavers.

In agreement with Table IV, pervious concrete based on SBP present weak durability to attacks freeze/thaw compared to the control concrete. Pavers subjected to freeze/thaw cycles are kept saturated as saying that in reality, the pavers are rarely seen in saturation capacity of drainage. Indeed, in a sufficiently saturated specimen, draining concrete degradation is mainly due to the hydraulic pressure. An increase of 9% in volume from the transformation of the water into ice [18] leading to a great force on the walls of the pores. In addition, resistance to freezing/thawing is related to the tensile strength.

Moreover, in the case of pervious concrete based shell, the connection between the grains (gravel and shells) is very low;

the result from a fall frost thaw resistance was observed. In addition, the shells have a high content of chloride ion, portlandite is easily dissolved in the reaction [19]:  $2 \text{NaCl} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCl}_2 + 2 \text{NaOH}$ . This solution leads to a rapid deterioration of the cement matrix.

#### IV. CONCLUSION

The objective of this paper is to characterize porous concretes different shell percentage and percentage of cement. Based on the results of the study presented in this article, the valorization of shellfish as an aggregate in the composition of pervious concrete pavers seems to be relevant. More detailed, the main results of this work are:

- The concrete based on shells are comparable to that of the control concrete without shell strength. Pervious concrete based shells are used for applications with low traffic.
- All concrete mixed have a firm consistency (slump equal zero). This makes them able to unmold immediately concrete in prefabrication.
- The content of cement paste strongly influences the mechanical, physical and hydraulic behavior of pervious concrete with or without shell. The control concrete of type 2 does not seem appropriate for a substitution of scallops 2/4mm because after the replacement, the permeability of the concrete is still low. The compositions of pervious concrete from the control concrete of type 1 provide a good compromise between permeability and mechanical strength. In this case, a high rate of substitution is possible.
- Mechanical strength, porosity and water permeability are related parameters. The water permeability increases exponentially with the porosity as saying that the relationship between porosity and mechanical strength is linear.
- The freeze / thaw durability of concrete based on shell is smaller compared to the control concrete, the resistance decreases with increasing the amount of shell incorporated.
- The content prohibited dirt, organic matter content and chloride content of shellfish are high. These elements influence and hydration of cement and affect the strength of concrete.

It is absolutely essential with pervious concrete that a very delicate balance which be struck between the strength of the concrete and its draining capacity. This research was conducted to establish an optimum content of SBP that could be added to the pervious concrete, without altering the balance between the strength and the permeability. The compressive strength results showed that up to a 40% replacement of natural aggregate with SBP cause one acceptable loss in compressive strength. On the other hand, at 60 % replacement and higher there was a significant decrease in compressive strength. In additional, the research also clearly shows that the replacement of 60 can be reached when the cement content in pervious concrete is about 23%. Although pervious concrete is expected to not have very high compressive strengths, the

concrete still needs to be strong enough to hold static loads in parking lots without raveling.

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#### REFERENCES

- [1] ACI 522R-10, Report on Pervious Concrete. American Concrete Institute, Farmington Hills, Michigan, 2010, 38p.
- [2] Tennis P.D, Leming M.L, Akers D.J., Pervious concrete pavements. Technical report, EB302.02. Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland; 2004, 32p.
- [3] Jing Yang J., Jiang G., Experimental study on properties of pervious concrete pavement materials, *Cement and Concrete Research*, Vol.33, 2003, pages 381–386.
- [4] Montes F, Haselbach, L.H., Measuring Hydraulic Conductivity in Pervious Concrete. *Environmental Engineering Science*, Vol. 23, 2006, pages 960-969.
- [5] National Union of Industry Careers and Building Materials. <http://www.unicem.fr>, Accessed: 19th December 2011.
- [6] Halm, H. J. 1980. "Concrete Recycling." *Transportation Research News*, Vol. 89. Transportation Research Board. Washington, D.C. pp. 6-10.
- [7] France Agri Mer. Les filières pêche et aquaculture en France, Edition 2011, 2011, 36p.
- [8] Nguyen, D.H, Boutouil M., Sebaibi N., Leleyter L., Baraud F., valorization of seashell by-products in pervious concrete pavers, Paper recently accepted for publication in *Construction and Building Materials*.
- [9] NF EN12390-3. Testing hardened concrete — Part 3: Compressive strength of test specimens, 2003, 18p.
- [10] NF EN1338. Concrete paving blocks - Requirements and test methods, 2010, 68p.
- [11] AFGC-AFREM. Proceedings of technical meeting AFPC-AFREM, Toulouse, France; 1997, 238p.
- [12] Das BM. Principles of Geotechnical Engineering, 7th edition, Publisher: Wadsworth, Inc, 2010, 683p.
- [13] Schaefer VR, Wang K, Suleiman MT, Kevern J. Mix design development for pervious concrete in cold climates. Technical report. National Concrete Pavement Technology Center, Iowa State Univ., Ames, Iowa; 2006.
- [14] NF EN 1097-2. Tests for mechanical and physical properties of aggregates. Part 2: Methods for the determination of resistance to fragmentation, 2010, 38p.
- [15] NF EN 933-3. Tests for geometrical properties of aggregates. Part 3: Determination of particle shape - Flakiness index, 2012, 15p.
- [16] PTV122. Technical specifications for permeable concrete paving blocks and slabs, 2nd edition; 2005.
- [17] Florida Department of Transportation, "Florida method of test for measurement of water permeability of compacted asphalt paving mixtures," Designation FM 5-565, 2012.
- [18] Antonin Fabbri A., Physics and mechanics of cementitious media submitted to frost action, Ph.D. Thesis, University of Marne-La-Vallée, 2006, 282p.
- [19] Sutter, L., Karl Peterson, L., Gustavo Julio-Betancourt, G.J., Doug Hooton, D, Van Dam, T., Smith, K., 2008, The Deleterious Chemical Effects of Concentrated Deicing Solutions on Portland Cement Concrete, Michigan Tech Transportation Institute, 65p.