

RESEARCH ARTICLE

# Experimental Study on Hardened and Transport Properties of Pervious Concretes: Effect of Elevated Temperature Curing Regime

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## INTRODUCTION

### General

The unfavorable influence of usual concrete pavement as a non-permeable material for water and air has led to improve a new class of concrete, namely, pervious concrete. The parking areas, walk ways, light traffic roads, and shoulders can be made from pervious concrete. The interest of researchers was attracted to make further studies on the pervious concrete due to the ability to let water to flow through itself to recharge ground water and reduce storm water runoff to minim level (Tennis et al., 2004). The usefulness in decreasing the runoff water, increasing water quality, improving pavement skid resistance during storm incidents by rapid drainage of water, as well as descending the on-site noise level makes this type of concrete to be used very widely. Those characteristics of pervious concrete considered as an environmental friendly material in usage of pavement (Bing et al., 2008). Properly designation of pervious concrete makes it to have

## ABSTRACT

Investigation to improve the performance of the pervious concrete is required through possible modifications in its properties, as it is utilized in different applications through civil engineering projects, especially in pavements. To save time and costs, such pavements should serve and explore to the traffic and the users as soon as possible. Concretes should be cured for at least 28 days to gain sufficient strength to withstand applied loads. To shorten this period, studying the properties of plain pervious concrete in terms of the mechanical properties and the permeability was undertaken. Single sized natural coarse aggregate conducted at constant water-to-cement ratio of 0.27 with cement content of 450 kg/m<sup>3</sup>, four curing period and two curing system (moist and steam) as experimental parameters were followed in this study. The results compared the two systems of curing for plain pervious concrete samples to show the effects of high temperature regime on the mechanical and permeability properties. The elevated temperature improved the mechanical properties in earlier ages but has no effect on the permeability while the steam curing resulted in an increase in modules of elasticity.

**Keywords:** Mechanical properties; Transport properties; Permeability, steam curing; Pervious concrete

an excellent serviceability while exposed to cold weather. The pervious concrete contains small amount of sand and microfiber, which makes the production to be proper in strength and durability (Wang et al., 2006). In addition, the structure of the pervious concrete allows heat to pass through it that causes snow and ice to melt, thus leads reduction of unsafe road conditions, thus decreases the necessity for deicing salts (Shehata, 2010).

Permeable concrete (PC) is manufactured at a water-to-cement ratio of 0.25–0.35 (almost 0.27) without using fine material or <10% of the largest single size coarse aggregate (Kevern et al., 2006). Rate of porosity of the pervious concrete is 15–25%, with compressive strength of 3–30 MPa, and the rate of permeability is 0.025–0.61 cm/s. Furthermore, the unit weight of pervious concrete (PC) is as low as 70% of the conventional concrete. Since the aggregate occupies as high as 80% volume in the concrete, the aggregate appeared to be much more efficient than the latter on the mechanical and durability behavior of the former (NRMCA 900, 2004).

Strength development rate is sharply increased due to elevated temperature curing regime (steam curing) at atmospheric. Because of its impact on strength development, mainly it is applied for precast concrete products such as masonry block, pipe, pre-stressed beams, and wall panels and can also be used for indoor cast-in-place structures. In the precast concrete industry, steam curing enables speed-up of production by faster turning of mold and formwork, shorter curing period before shipping or pre-stressing, and less damage to the product being handled. The detrimental effect of steam curing is due to the coarse pore structure, which can enhance microcracking and retard the creation of ettringite (Radjy and Richards, 1973; Heinz and Ludwig, 1987; Taylor, 1997). Curing temperature shows its impact on cement mortars and concretes properties and this has been the issue of many studies. It is evident that the high curing temperature immediately after casting promotes the growth of mechanical properties at early age, but adversely affects the strength on late age. Mouret et al. (2003) were reported that the concrete cured at 35°C had lower 28-day compressive strength when compared to the same concrete cured at 20°C by 10%. According to the study of Verbeck (1968), when the curing temperature was raised from 20°C to 50°C, 28% strength reduction was achieved. This falling at a later age strength was shown the faster initial hydration rate at higher temperatures that retard subsequent hydration and causes a heterogeneous spreading of hydration products.

This research reports an experimental study on the performance of pervious concretes exposed to elevated temperature regime. The main aim of this paper to observe the influence of steam curing on pervious concrete compared to conventional curing. This research will help those plants that work with pervious concrete, by applying steam curing to accelerate the production and this scheduling the time requirements to open the roads and park areas earlier for use (saving time and more economy). Mainly pervious concrete (PC) used in areas which need fast runoff, generally, it reduces the amount of untreated runoff discharging into storm sewers and directly recharge ground water to maintain aquifer levels. This study deals with two parameters, pervious concrete exposed to steam curing and water curing.

## EXPERIMENTAL STUDY

### Materials

#### *Cement*

The used cement was CEM I type Portland cement with specific gravity of 3.14 and Blaine fineness was determined as 328 m<sup>2</sup>/kg for making ready the concrete examine samples utilized in determination of mechanical properties.

### *Aggregate*

Pervious concrete contains little or no fine aggregate in the mixture. Natural coarse aggregate passed through 12.5 mm and held on a 10 mm sieve was used, which considered as a single size aggregate. Larger aggregate may not be fitted as it may cause the surface to be too coarse, which may not be allowable for local codes in respect to surface roughness. Aggregate from natural source or crushed can be used. Mostly, less compaction work is required for rounded aggregate than crushed aggregate. If temperature expectation increased, then the aggregate should be remained wet or saturated surface dry. When dry aggregate is employed, absorption and moisture content must be taken into account because permeable concrete mixed design works at low w/c ratio. The excessive drying which formed due insufficient amount of free water may cause inadequate compaction. Conversely, if too much water is used, the paste/mortar becomes too thin, the bond between the aggregate becomes inappropriate, and the penetration of the paste/mortar occurs which it is called seepage. The consequence of lower permeability rates of the system comes from the paste/mortar seepage. The ratio of 4:1–5:1 is used for aggregate and cement ratio. Keeping of the air void content should be taken into consideration to provide a sufficient water flow rate when fine aggregate or sand is used. Compressive strength will be developed using fine aggregate but might lead to reduction in permeability rate. The specific gravity of 2.7 kg/m<sup>3</sup> for aggregate was used, natural source aggregate with uniform size provided by sieving.

### *Water*

The same water conforms the standard requirements for conventional concrete can be employed for the production of pervious concrete. The special requirement regarding water quality is not needed. Pervious concrete has the same water content as conventional concrete. Testing has concluded that the best dispersion of cement paste/mortar and best coating of aggregate particles are the water/cement ratio in the range of 0.27–0.35.

### *Mix Proportion*

Gap graded aggregates almost has single or dual size coarse aggregates are using in producing pervious concretes to get a concrete has a proper permeability, while well-graded aggregates are producing very low permeable concretes. Such kind of concretes have minimum or zero slump work ability due to using with restricted w/c ratio, the reason affecting the compression strength of concrete.

Higher strength concrete parallel to higher permeability concrete is the goal of any researchers working on the pervious concrete, so a single size of aggregate passing sieve (12.5) mm and retained sieve (10) mm used in this research

with a w/c ratio of 0.27, air voids percentage of 15%, and a cement content of 400 kg/m<sup>3</sup>. Table 1 shows the percentages and weights of each material in 1 m<sup>3</sup> pervious concrete.

**Curing Conditions**

This study introduces two curing methods, namely, standard curing (water curing) and elevated temperature curing regime (steam curing). Under standard curing conditions, concrete samples are taken out of the mold 1 day after pouring and then stored in water at ± 2°C until the test date. Under the steam curing condition, the heat treatment cycle is applied for the fresh samples in the molds, as illustrated in Figure 1. In this study, the steam curing cycle had a total duration 20 h including 2 h of heating, 17 h of exposure the maximum temperature of 70°C, and 1 h cooling. The humidity in the steam curing box was above 90%, the steam cured specimens after removing from the molds, were stored in water until the date of testing.

**Test Methods**

*Compressive strength test*

Compressive strength test was conducted according to ASTM C39, it is very significant test that concrete characteristics can be defined by applying compression loads. The indication of good quality concrete can be decided by applying this single test.

*Splitting tensile test*

According to ASTM C496, splitting tensile is considered as most fundamental and important characteristics. The split tensile strength test of a concrete cylinder is a process of determining the tensile strength of concrete. Concrete

is poor in tension because of its brittleness and has no resistance to direct tension. When subjected to tensile force, cracks will be generated in the concrete. Consequently, it is essential to indicate the tensile strength of the concrete to define the load that the concrete member may crack.

*Flexural tensile test*

Tensile strength of concrete can be measured by flexural strength. The resisting of concrete beam and slab of unreinforced to failure bending can be measured through flexure tensile test. The span length of concrete beam minimum should be equal to 3 times the depth. In literature, modulus of rupture (MR) is referred to flexural strength, which is measured in psi (MPa) unit and is defined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading). Samples of beam must be properly prepared in the field. Vibration is applied to consolidate in accordance with ASTM C 31 and tap sides to remove air pockets. Drying the surface of the beam should not be allowed. Sawing beams from a slab and applying flexure test are not preferred. Reduction in flexural strength is observed by sawing beams and this should be avoided.

*Modulus of elasticity test*

The modulus of elasticity measures according to ASTM C469 which is known as Young’s modulus (E). It is a material property that defines its stiffness, which is the most significant properties of solid materials. Mechanical deformation incorporates energy into the material. Energy is resiliently stored or it is plastically dissipated. Stress-strain curve is used to summarize the stored energy in the materials. Strain is defined as elongation or contraction per unit length and stress is described as force per unit area.

*Permeability test*

The permeability coefficient of permeable concrete was determined by the falling head technique (ASTM D 2434-68, 2008) using a specially made water permeable device. Cylindrical specimens were first tightly wrapped with a latex membrane to prevent water from leaking along the sides, allowing water to flow through the cross-section of the sample. The upper part of the test samples was attached to a glass tube. The permeability test was carried out under a fall of 400–300 mm. Four readings were taken per each specimen, and average of them was taken. Then, according to Darcy’s law, the permeability coefficient (k) of pervious concrete assuming laminar flow was evaluated by the following formula.

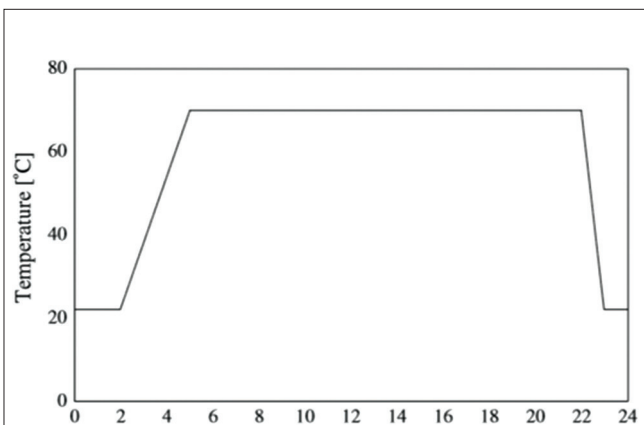
$$k = \left( \frac{a \times L}{A \times t} \right) \ln \left( \frac{b1}{b2} \right)$$

The coefficient of permeability (mm/s), the cross-sectional area of the pipe (mm<sup>2</sup>), the length of the specimen (mm), the cross-sectional area of the specimen

**Table 1: Details of concrete mixtures**

Mix ID	W/C	Cement content Kg/m <sup>3</sup>	Water content Kg/m <sup>3</sup>	Coarse aggregate content Kg/m <sup>3</sup>	Air voids %
*SCPC	0.27	400	108	1672	15
**WCPC	0.27	400	108	1672	15

\*Steam cured pervious concrete, \*\*water cured pervious concrete



**Figure 1: Schematic representation of elevated temperature curing regimes**

(mm<sup>2</sup>), the time taken for the head to fall from  $h_1$  to  $h_2$  (s), initial water head (mm), and the final water head (mm) are denoted in the above equation as  $k$ ,  $a$ ,  $L$ ,  $A$ ,  $t$ ,  $h_1$ , and  $h_2$ , respectively.

## RESULTS AND DISCUSSION

### Mechanical Properties

#### Compressive strength

The compressive strength results of pervious concrete for both normal curing and steam curing are shown in Figure 2. A noticeable positive effect of steam curing on pervious concrete can be observed. The samples which cured by steam had a compressive strength of 7.53 MPa in 1 day age, while the samples which left in air for the first 24 h had 6 MPa in 1 day age.

In 3 days age, the steam cured pervious concrete samples had compressive strength of 12.7 MPa, while the water cured samples had 7.6 MPa of compressive strength at the same period of time. After 28 days, the difference between the results of steam cured and water cured had been decreased, at 28 days, the steam cured samples had 18.85 MPa while the water cured samples had 17.6 MPa.

In early age, it is found that the compressive strength of steam cured samples is much more higher than the normal cured samples, but in later age, the differences of their compressive strength had been decreased, this means that the steam curing is very helpful for speeding up the productions of concrete, especially for precast. It helps to save time and money.

#### Splitting tensile strength

The result of splitting tensile strength of pervious concrete is demonstrated in Figure 3, the split tensile strength of the pervious concrete is generally constant for both steam and conventional curing, as shown in Figure 3.

At 3 days age, the tensile strength of steam cured samples was 0.9 MPa, while at the same period of time, the water

cured samples had tensile strength of 0.73. At 28 days age, the tensile strength of pervious concrete for steam cured sample was 0.89 and 0.71 MPa for the water cured samples after the same period of time.

According to the results obtained from the tensile splitting tensile strength test, steam curing gives a little more tensile strength to the pervious concrete than normal curing. In conclusion and according to the results that were gained, “time” did not have any considerable influence on the tensile strength.

#### Flexural tensile strength

The results of flexure tensile strength are demonstrated in Figure 4. According to the results, we found that the steam curing had negative influence on the flexure tensile strength of pervious concrete, Figure 4 displays the effect of curing method on flexure tensile strength at different period of times. The flexure strength values between 1.8 and 4.0 MPa were achieved. After 3 days of mixing, the steam cured samples gave 1.86 MPa as flexure tensile strength while water cured samples gave 2.26 MPa. In 28 days age, the steam cured samples had 3.45 MPa of flexure tensile strength but water cured sample had 4.07 MPa at the same period of time. According to the result of the test, it is found that the water curing has better influence than steam curing on pervious concrete due to it is flexure tensile strength.

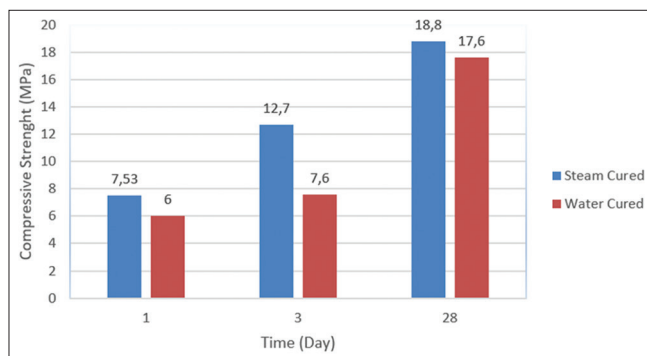


Figure 2: Compressive strength exposed to steam and water curing

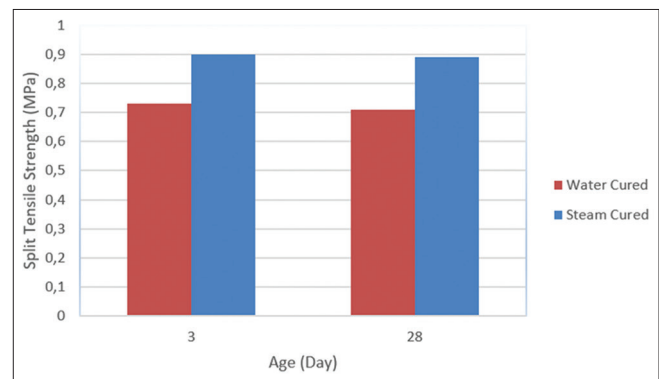


Figure 3: Splitting tensile strength exposed to steam and water curing

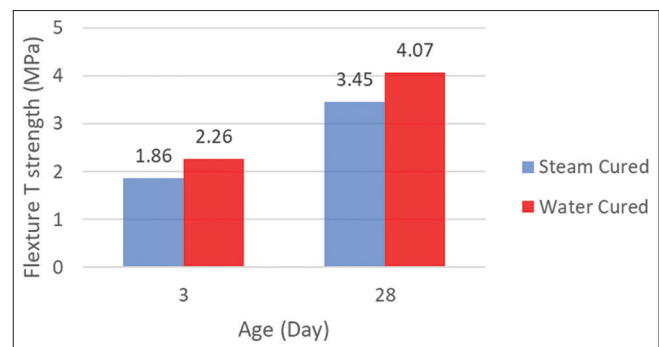


Figure 4: Flexure strength exposed to steam and water curing





Figure 5: Modulus of elasticity test

### Modulus of elasticity

Depending on the previous studies, it is found that age has no influence on modulus of elasticity that is why one sample age has been selected for modulus of elasticity testing, in the steam cured samples, it was found that the modulus of elasticity was 8.15 MPa while the water cured samples had 4.53 MPa as modulus of elasticity. Figure 5 shows the modulus elasticity test.

### Transport Property

#### Permeability

Since a uniform size of aggregate has been used in this study, same values of permeability were achieved at different period of times. Variation of permeability values depends on the voids between concrete particles; greater aggregate size will lead to more voids in the concrete and vice versa. Through this study, it is found that the permeability of the mix was 0.475 cm/s.

## CONCLUSION

Samples prepared and tested according to ASTM specifications for permeability and mechanical properties of pervious concrete through compressive strength, net flexural strength, tensile splitting strength, and modulus of elasticity, results showed that:

1. Steam curing improves the mechanical properties of pervious concrete especially at the earlier age.

2. Mainly pervious concrete using in parking and traffic light roads, so the steam curing gives good results at 3 days age which is higher than normal curing about (60%) and this scheduling the time requirements to open the roads and the park areas earlier for use (saving time and more economy).
3. Negative trend shown in flexural strength when steam curing followed, the normal curing gives better flexural strength.
4. Regarding the splitting tensile strength, steam curing gives higher values than normal curing and without significant change in values due to age. This will lead to the bond improvement of interfacial transition zone.
5. Elevated temperature region (steam curing) improves the modulus of elasticity by 80%.
6. Steam curing saves time, cost and provides desirable results.

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