

# Studying the Effects of Water to Cement Ratio on the Mechanical Properties of Concrete

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**INDEX TERMS** Pervious concrete

## I. INTRODUCTION

RAPID urbanization has led to extensive construction of impervious surfaces such as asphalt and conventional concrete pavements, which disrupt the natural hydrological cycle. These surfaces prevent water infiltration, resulting in increased surface runoff, urban flooding, and reduced ground-water recharge. In response to these environmental concerns, there has been a growing interest in sustainable construction materials that support stormwater management. One such material is pervious concrete, a special type of concrete with a high void content that allows water to pass through its structure.

Pervious concrete is composed of coarse aggregates, cement, water, and little to no fine aggregates. Its interconnected pore network enables infiltration of rainwater, making it suitable for sidewalks, parking lots, driveways, and low-traffic roads. In addition to hydrological benefits, pervious concrete can reduce the urban heat island effect, improve skid resistance, and contribute toward LEED (Leadership in Energy and Environmental Design) credits in green building certification systems.

Despite its advantages, the widespread use of pervious concrete has been limited due to challenges in achieving an optimal balance between permeability and mechanical strength. In this study, we focus on the effects of the water-cement ratio on the physical properties of pervious concrete. To this end, two batches of 6 pervious concrete cylinders, with the second batch having a lower water-cement ratio, were made, and tested for compressive strength, split tensile strength, and permeability. Superplasticizer (SP) was used to increase the workability of the mixes made with the second recipe.

## II. EXPERIMENTAL SETUP

Two batches of 6 cylinders each were cast. Common to both batches were the cementitious material which was a mixture of cement and fly-ash in the ratio of 4:1 by mass, coarse aggregates whose sizes ranged from 4.75-9.5 mm, and polypropylene fibres (PPF). The rest of the ingredients are given in table 1.

**TABLE 1. Mix Design**

	Batch 1	Batch 2
Cement, $kg/m^3$	280	280
Coarse Aggregate, $kg/m^3$	1420	1420
Fly-ash, $kg/m^3$	70	70
Water, $kg/m^3$	119	95.2
SP, % <sup>1</sup>	—	0.5
PPF, % <sup>2</sup>	0.2	0.2

<sup>1</sup> of cementitious material<sup>2</sup> of aggregates

### III. TESTING METHOD

The samples were tested after 14 and 28 days for tensile and compressive strenghts, and after 28 days for permeability.

#### A. COMPRESSIVE STRENGTH

The sample was placed in the universal testing machine (UTM) on one of its circular faces, and compressed. The pace rate was set to 1.8 KN/s. The compressive strength  $f_c$  is calculated with the formula

$$f_c = \frac{P}{A}$$

where  $P$  is the maximum force on the sample, and  $A$  is the area over which the force is applied.

#### B. TENSILE STRENGTH

The tensile strength was found using the Brazilian test, in which, the sample was placed horizontally, in between two metal bars oriented parallel to the axis of the sample, inside the UTM. The tensile strength  $f_t$  was calculated with the formula

$$f_t = \frac{2P}{\pi LD}$$

where  $P$  is the force at the point of failure, and  $L$  and  $D$  are respectively the length and the diameter of the sample.

#### C. PERMEABILITY

The tensile strength was found using a makeshift falling head permeameter. By measuring the time taken for the head to move from a height  $h_1$  down to  $h_2$ , the permeability  $k$  can be calculated using the formula

$$k = \frac{aL}{At} \ln \frac{h_1}{h_2}$$

where  $a$  is the cross-sectional area of the standpipe,  $t$  is the time taken for the head to fall from  $h_1$  to  $h_2$ , and  $L$  and  $A$  are the dimensions of the sample.

### IV. RESULTS

#### V. GUIDELINES FOR GRAPHICS PREPARATION AND SUBMISSION

##### A. TYPES OF GRAPHICS

The following list outlines the different types of graphics published in IEEE journals. They are categorized based on their construction, and use of color/shades of gray:

**TABLE 2. Compressive and Tensile Strength Results**

	Compressive, $Mpa$		Tensile, $Mpa$	
	14	28	14	28
Batch 1	5.62	7.49	0.71	0.85
Batch 2	8.02	10.08	1.15	1.33

**TABLE 3. Units for Magnetic Properties**

Symbol	Quantity	Conversion from Gaussian and CGS EMU to SI <sup>a</sup>
$\Phi$	magnetic flux	$1 \text{ Mx} \rightarrow 10^{-8} \text{ Wb} = 10^{-8} \text{ V}\cdot\text{s}$
$B$	magnetic flux density, magnetic induction	$1 \text{ G} \rightarrow 10^{-4} \text{ T} = 10^{-4} \text{ Wb/m}^2$
$H$	magnetic field strength	$1 \text{ Oe} \rightarrow 10^3/(4\pi) \text{ A/m}$
$m$	magnetic moment	$1 \text{ erg/G} = 1 \text{ emu}$ $\rightarrow 10^{-3} \text{ A}\cdot\text{m}^2 = 10^{-3} \text{ J/T}$
$M$	magnetization	$1 \text{ erg}/(\text{G}\cdot\text{cm}^3) = 1 \text{ emu/cm}^3$ $\rightarrow 10^3 \text{ A/m}$
$4\pi M$	magnetization	$1 \text{ G} \rightarrow 10^3/(4\pi) \text{ A/m}$
$\sigma$	specific magnetization	$1 \text{ erg}/(\text{G}\cdot\text{g}) = 1 \text{ emu/g} \rightarrow 1 \text{ A}\cdot\text{m}^2/\text{kg}$
$j$	magnetic dipole moment	$1 \text{ erg/G} = 1 \text{ emu}$ $\rightarrow 4\pi \times 10^{-10} \text{ Wb}\cdot\text{m}$
$J$	magnetic polarization	$1 \text{ erg}/(\text{G}\cdot\text{cm}^3) = 1 \text{ emu/cm}^3$ $\rightarrow 4\pi \times 10^{-4} \text{ T}$
$\chi, \kappa$	susceptibility	$1 \rightarrow 4\pi$
$\chi\rho$	mass susceptibility	$1 \text{ cm}^3/\text{g} \rightarrow 4\pi \times 10^{-3} \text{ m}^3/\text{kg}$
$\mu$	permeability	$1 \rightarrow 4\pi \times 10^{-7} \text{ H/m}$ $= 4\pi \times 10^{-7} \text{ Wb}/(\text{A}\cdot\text{m})$
$\mu_r$	relative permeability	$\mu \rightarrow \mu_r$
$w, W$	energy density	$1 \text{ erg/cm}^3 \rightarrow 10^{-1} \text{ J/m}^3$
$N, D$	demagnetizing factor	$1 \rightarrow 1/(4\pi)$

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.

<sup>a</sup>Gaussian units are the same as cg emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

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