

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

PRANAV V<sup>1</sup>, ABHAY V<sup>1</sup>, SUYASH J<sup>1</sup>, SOHAM S<sup>2</sup>, RAKSHITH P<sup>3</sup>

<sup>1</sup>Department of Electronics and Communication Engineering, RV College of Engineering, Bangalore, India

<sup>2</sup>Department of Mechanical Engineering, RV College of Engineering, Bangalore, India

<sup>3</sup>Department of Information Science and Engineering, RV College of Engineering, Bangalore, India

Corresponding author: Pranav V (e-mail: pranavvv.ec24@rvce.edu.in).

**ABSTRACT** Pervious concrete is a sustainable construction material developed to mitigate urban issues such as stormwater runoff, reduced groundwater recharge, and surface flooding. This study focuses on the design and experimental evaluation of a pervious concrete mix aimed at achieving adequate mechanical strength while ensuring desirable permeability. The investigation involved selecting suitable aggregates, determining an appropriate water–cement ratio, and incorporating admixtures to enhance overall performance. Compressive strength, tensile strength, and permeability tests were conducted to assess the mix’s applicability in pavements and low-traffic areas. The results demonstrated that the proposed mix design offers a practical balance between structural integrity and permeability, highlighting its potential as an environmentally friendly alternative to conventional paving materials. Additionally, the paper discusses challenges encountered during mix design and implementation and suggests directions for future research to enable its effective use in large-scale applications.

**INDEX TERMS** Pervious concrete

## I. INTRODUCTION

**R**APID 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 groundwater 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 proportions for the rest of the materials used are given in table 1.

## III. TESTING METHOD

The samples were tested after 14 and 28 days for tensile and compressive strengths, 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

**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

**TABLE 2. Compressive and Tensile Strength**

	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

Results of the compressive and tensile tests at the end of 14 and 28 days of curing.

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

From the results, given by table 2, it is apparent that the amount of water used in the mix greatly affects the final strength of the concrete, with the ones having a lower water-cement ratio outperforming the ones with a higher water-cement ratio.

**TABLE 3. Permeability**

	14	28
Batch 1	2.90	1.73
Batch 2	1.93	1.15

Results of the permeability ( $mm/s$ ) tests at the end of 14 and 28 days of curing.

### V. CONCLUSION

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

If you have multiple appendices, use the \appendices command below. If you have only one appendix, use \appendix[Appendix Title]

### APPENDIX A FOOTNOTES

Number footnotes separately in superscript numbers.<sup>1</sup> Place the actual footnote at the bottom of the column in which it is cited; do not put footnotes in the reference list (endnotes). Use letters for table footnotes (see Table ??).

### APPENDIX B SUBMITTING YOUR PAPER FOR REVIEW A. FINAL STAGE

When your article is accepted, you can submit the final files, including figures, tables, and photos, per the journal's guidelines through the submission system used to submit the article. You may use *Zip* for large files, or compress files using *Compress*, *Pkzip*, *Stufit*, or *Gzip*.

In addition, designate one author as the “corresponding author.” This is the author to whom proofs of the paper will be sent. Proofs are sent to the corresponding author only.

### B. REVIEW STAGE USING IEEE AUTHOR PORTAL

Article contributions to IEEE Access should be submitted electronically on the IEEE Author Portal. For more information, please visit <https://ieeaccess.ieee.org/>.

Along with other information, you will be asked to select the subject from a pull-down list. There are various steps to the submission process; you must complete all steps for a complete submission. At the end of each step you must click “Save and Continue”; just uploading the paper is not sufficient. After the last step, you should see a confirmation that the submission is complete. You should also receive an e-mail confirmation. For inquiries regarding the submission of your article, please contact [ieeaccess@ieee.org](mailto:ieeaccess@ieee.org).

The manuscript should be prepared in a double column, single-spaced format using a required IEEE Access template. A Word or LaTeX file and a PDF file are both required upon submission in the IEEE Author Portal.

<sup>1</sup>It is recommended that footnotes be avoided (except for the unnumbered footnote with the receipt date on the first page). Instead, try to integrate the footnote information into the text.

### C. FINAL STAGE USING IEEE AUTHOR PORTAL

Upon acceptance, you will receive an email with specific instructions

Designate the author who submitted the manuscript on IEEE Author Portal as the “corresponding author.” This is the only author to whom proofs of the paper will be sent.

### D. COPYRIGHT FORM

Authors must submit an electronic IEEE Copyright Form (eCF) upon submitting their final manuscript files. You can access the eCF system through your manuscript submission system or through the Author Gateway. You are responsible for obtaining any necessary approvals and/or security clearances. For additional information on intellectual property rights, visit the IEEE Intellectual Property Rights department web page at [http://www.ieee.org/publications\\_standards/publications/rights/index.html](http://www.ieee.org/publications_standards/publications/rights/index.html).

## APPENDIX C IEEE PUBLISHING POLICY

The general IEEE policy requires that authors should only submit original work that has neither appeared elsewhere for publication, nor is under review for another refereed publication. The submitting author must disclose all prior publication(s) and current submissions when submitting a manuscript. Do not publish “preliminary” data or results. To avoid any delays in publication, please be sure to follow these instructions. Final submissions should include source files of your accepted manuscript, high quality graphic files, and a formatted pdf file. If you have any questions regarding the final submission process, please contact the administrative contact for the journal. author is responsible for obtaining agreement of all coauthors and any consent required from employers or sponsors before submitting an article.

The IEEE Access Editorial Office does not publish conference records or proceedings, but can publish articles related to conferences that have undergone rigorous peer review. Minimally, two reviews are required for every article submitted for peer review.

## APPENDIX D PUBLICATION PRINCIPLES

Authors should consider the following points:

- 1) Technical papers submitted for publication must advance the state of knowledge and must cite relevant prior work.
- 2) The length of a submitted paper should be commensurate with the importance, or appropriate to the complexity, of the work. For example, an obvious extension of previously published work might not be appropriate for publication or might be adequately treated in just a few pages.
- 3) Authors must convince both peer reviewers and the editors of the scientific and technical merit of a paper;

the standards of proof are higher when extraordinary or unexpected results are reported.

- 4) Because replication is required for scientific progress, papers submitted for publication must provide sufficient information to allow readers to perform similar experiments or calculations and use the reported results. Although not everything need be disclosed, a paper must contain new, useable, and fully described information. For example, a specimen’s chemical composition need not be reported if the main purpose of a paper is to introduce a new measurement technique. Authors should expect to be challenged by reviewers if the results are not supported by adequate data and critical details.
- 5) Papers that describe ongoing work or announce the latest technical achievement, which are suitable for presentation at a professional conference, may not be appropriate for publication.

## APPENDIX E REFERENCE EXAMPLES

- *Basic format for books:*  
J. K. Author, “Title of chapter in the book,” in *Title of His Published Book*, xth ed. City of Publisher, (only U.S. State), Country: Abbrev. of Publisher, year, ch. x, sec. x, pp. xxx–xxx.  
See [1], [2].
- *Basic format for periodicals:*  
J. K. Author, “Name of paper,” *Abbrev. Title of Periodical*, vol. x, no. x, pp. xxx–xxx, Abbrev. Month, year, DOI: 10.1109.XXX.123456.  
See [3]–[5].
- *Basic format for reports:*  
J. K. Author, “Title of report,” Abbrev. Name of Co., City of Co., Abbrev. State, Country, Rep. xxx, year.  
See [6], [7].
- *Basic format for handbooks:*  
*Name of Manual/Handbook*, x ed., Abbrev. Name of Co., City of Co., Abbrev. State, Country, year, pp. xxx–xxx.  
See [8], [9].
- *Basic format for books (when available online):*  
J. K. Author, “Title of chapter in the book,” in *Title of Published Book*, xth ed. City of Publisher, State, Country: Abbrev. of Publisher, year, ch. x, sec. x, pp. xxx–xxx. [Online]. Available: <http://www.web.com>  
See [10]–[13].
- *Basic format for journals (when available online):*  
J. K. Author, “Name of paper,” *Abbrev. Title of Periodical*, vol. x, no. x, pp. xxx–xxx, Abbrev. Month, year. Accessed on: Month, Day, year, DOI: 10.1109.XXX.123456, [Online].  
See [14]–[16].
- *Basic format for papers presented at conferences (when available online):*  
J.K. Author. (year, month). Title. presented at abbrev. conference title. [Type of Medium]. Available:

site/path/file

See [17].

- *Basic format for reports and handbooks (when available online):*

J. K. Author. "Title of report," Company. City, State, Country. Rep. no., (optional: vol./issue), Date. [Online] Available: site/path/file

See [18], [19].

- *Basic format for computer programs and electronic documents (when available online):*

Legislative body. Number of Congress, Session. (year, month day). *Number of bill or resolution, Title*. [Type of medium]. Available: site/path/file

See [20].

- *Basic format for patents (when available online):*

Name of the invention, by inventor's name. (year, month day). Patent Number [Type of medium]. Available: site/path/file

See [21].

- *Basic format for conference proceedings (published):*

J. K. Author, "Title of paper," in *Abbreviated Name of Conf.*, City of Conf., Abbrev. State (if given), Country, year, pp. xxxxxx.

See [22].

- *Example for papers presented at conferences (unpublished):*

See [23].

- *Basic format for patents:*

J. K. Author, "Title of patent," U.S. Patent x xxx xxx, Abbrev. Month, day, year.

See [24].

- *Basic format for theses (M.S.) and dissertations (Ph.D.):*

1) J. K. Author, "Title of thesis," M.S. thesis, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

2) J. K. Author, "Title of dissertation," Ph.D. dissertation, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

See [25], [26].

- *Basic format for the most common types of unpublished references:*

1) J. K. Author, private communication, Abbrev. Month, year.

2) J. K. Author, "Title of paper," unpublished.

3) J. K. Author, "Title of paper," to be published.

See [27]–[29].

- *Basic formats for standards:*

1) *Title of Standard*, Standard number, date.

2) *Title of Standard*, Standard number, Corporate author, location, date.

See [30], [31].

- *Article number in reference examples:*

See [32], [33].

- *Example when using et al.:*

See [34].

## ACKNOWLEDGMENT

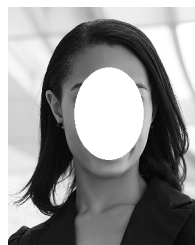
The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments. Avoid expressions such as "One of us (S.B.A.) would like to thank . . . ." Instead, write "F. A. Author thanks . . . ." In most cases, sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.

## REFERENCES

- [1] G. O. Young, "Synthetic structure of industrial plastics," in *Plastics*, 2<sup>nd</sup> ed., vol. 3, J. Peters, Ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15–64.
- [2] W.-K. Chen, *Linear Networks and Systems*. Belmont, CA, USA: Wadsworth, 1993, pp. 123–135.
- [3] J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," *IEEE Trans. Electron Devices*, vol. ED-11, no. 1, pp. 34–39, Jan. 1959, 10.1109/TED.2016.2628402.
- [4] E. P. Wigner, "Theory of traveling-wave optical laser," *Phys. Rev.*, vol. 134, pp. A635–A646, Dec. 1965.
- [5] E. H. Miller, "A note on reflector arrays," *IEEE Trans. Antennas Propagat.*, to be published.
- [6] E. E. Reber, R. L. Michell, and C. J. Carter, "Oxygen absorption in the earth's atmosphere," Aerospace Corp., Los Angeles, CA, USA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1988.
- [7] J. H. Davis and J. R. Cogdell, "Calibration program for the 16-foot antenna," Elect. Eng. Res. Lab., Univ. Texas, Austin, TX, USA, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.
- [8] *Transmission Systems for Communications*, 3<sup>rd</sup> ed., Western Electric Co., Winston-Salem, NC, USA, 1985, pp. 44–60.
- [9] *Motorola Semiconductor Data Manual*, Motorola Semiconductor Products Inc., Phoenix, AZ, USA, 1989.
- [10] G. O. Young, "Synthetic structure of industrial plastics," in *Plastics*, vol. 3, Polymers of Hexadromicon, J. Peters, Ed., 2<sup>nd</sup> ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15–64. [Online]. Available: <http://www.bookref.com>.
- [11] *The Founders' Constitution*, Philip B. Kurland and Ralph Lerner, eds., Chicago, IL, USA: Univ. Chicago Press, 1987. [Online]. Available: <http://press-pubs.uchicago.edu/founders/>
- [12] The Terahertz Wave eBook. ZOmega Terahertz Corp., 2014. [Online]. Available: [http://dl.z-thz.com/eBook/zomegaebookpdf\\_1206\\_sr.pdf](http://dl.z-thz.com/eBook/zomegaebookpdf_1206_sr.pdf). Accessed on: May 19, 2014.
- [13] Philip B. Kurland and Ralph Lerner, eds., *The Founders' Constitution*. Chicago, IL, USA: Univ. of Chicago Press, 1987, Accessed on: Feb. 28, 2010. [Online] Available: <http://press-pubs.uchicago.edu/founders/>
- [14] J. S. Turner, "New directions in communications," *IEEE J. Sel. Areas Commun.*, vol. 13, no. 1, pp. 11–23, Jan. 1995.
- [15] W. P. Risk, G. S. Kino, and H. J. Shaw, "Fiber-optic frequency shifter using a surface acoustic wave incident at an oblique angle," *Opt. Lett.*, vol. 11, no. 2, pp. 115–117, Feb. 1986.
- [16] P. Kopyt et al., "Electric properties of graphene-based conductive layers from DC up to terahertz range," *IEEE THz Sci. Technol.*, to be published. DOI: 10.1109/THZ.2016.2544142.
- [17] PROCESS Corporation, Boston, MA, USA. Intranets: Internet technologies deployed behind the firewall for corporate productivity. Presented at INET96 Annual Meeting. [Online]. Available: <http://home.process.com/Intranets/wp2.htm>
- [18] R. J. Hijmans and J. van Etten, "Raster: Geographic analysis and modeling with raster data," R Package Version 2.0-12, Jan. 12, 2012. [Online]. Available: <http://CRAN.R-project.org/package=raster>
- [19] Teralyzer. Lytera UG, Kirchhain, Germany [Online]. Available: [http://www.lytera.de/Terahertz\\_THz\\_Spectroscopy.php?id=home](http://www.lytera.de/Terahertz_THz_Spectroscopy.php?id=home), Accessed on: Jun. 5, 2014.
- [20] U.S. House. 102<sup>nd</sup> Congress, 1<sup>st</sup> Session. (1991, Jan. 11). *H. Con. Res. 1, Sense of the Congress on Approval of Military Action*. [Online]. Available: LEXIS Library: GENFED File: BILLS
- [21] Musical toothbrush with mirror, by L.M.R. Brooks. (1992, May 19). Patent D 326 189 [Online]. Available: NEXIS Library: LEXPAT File: DES



- [22] D. B. Payne and J. R. Stern, "Wavelength-switched passively coupled single-mode optical network," in *Proc. IOOC-ECOC*, Boston, MA, USA, 1985, pp. 585–590.
- [23] D. Ebehard and E. Voges, "Digital single sideband detection for interferometric sensors," presented at the 2<sup>nd</sup> *Int. Conf. Optical Fiber Sensors*, Stuttgart, Germany, Jan. 2–5, 1984.
- [24] G. Brandli and M. Dick, "Alternating current fed power supply," U.S. Patent 4 084 217, Nov. 4, 1978.
- [25] J. O. Williams, "Narrow-band analyzer," Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, USA, 1993.
- [26] N. Kawasaki, "Parametric study of thermal and chemical nonequilibrium nozzle flow," M.S. thesis, Dept. Electron. Eng., Osaka Univ., Osaka, Japan, 1993.
- [27] A. Harrison, private communication, May 1995.
- [28] B. Smith, "An approach to graphs of linear forms," unpublished.
- [29] A. Brahms, "Representation error for real numbers in binary computer arithmetic," IEEE Computer Group Repository, Paper R-67-85.
- [30] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.
- [31] Letter Symbols for Quantities, ANSI Standard Y10.5-1968.
- [32] R. Fardel, M. Nagel, F. Nuesch, T. Lippert, and A. Wokaun, "Fabrication of organic light emitting diode pixels by laser-assisted forward transfer," *Appl. Phys. Lett.*, vol. 91, no. 6, Aug. 2007, Art. no. 061103.
- [33] J. Zhang and N. Tansu, "Optical gain and laser characteristics of InGaN quantum wells on ternary InGaN substrates," *IEEE Photon. J.*, vol. 5, no. 2, Apr. 2013, Art. no. 2600111.
- [34] S. Azodolmolky et al., "Experimental demonstration of an impairment aware network planning and operation tool for transparent/translucent optical networks," *J. Lightw. Technol.*, vol. 29, no. 4, pp. 439–448, Sep. 2011.



**SECOND B. AUTHOR** (M'76–SM'81–F'87) and all authors may include biographies. Biographies are often not included in conference-related papers. This author became a Member (M) of IEEE in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year the degree was earned. The author's major field of study should be lower-cased.

The second paragraph uses the pronoun of the person (he or she) and not the author's last name. It lists military and work experience, including summer and fellowship jobs. Job titles are capitalized. The current job must have a location; previous positions may be listed without one. Information concerning previous publications may be included. Try not to list more than three books or published articles. The format for listing publishers of a book within the biography is: title of book (publisher name, year) similar to a reference. Current and previous research interests end the paragraph.

The third paragraph begins with the author's title and last name (e.g., Dr. Smith, Prof. Jones, Mr. Kajor, Ms. Hunter). List any memberships in professional societies other than the IEEE. Finally, list any awards and work for IEEE committees and publications. If a photograph is provided, it should be of good quality, and professional-looking. Following are two examples of an author's biography.



**FIRST A. AUTHOR** received the B.S. and M.S. degrees in aerospace engineering from the University of Virginia, Charlottesville, in 2001 and the Ph.D. degree in mechanical engineering from Drexel University, Philadelphia, PA, in 2008.

From 2001 to 2004, he was a Research Assistant with the Princeton Plasma Physics Laboratory. Since 2009, he has been an Assistant Professor with the Mechanical Engineering Department, Texas A&M University, College Station. He is the

author of three books, more than 150 articles, and more than 70 inventions. His research interests include high-pressure and high-density nonthermal plasma discharge processes and applications, microscale plasma discharges, discharges in liquids, spectroscopic diagnostics, plasma propulsion, and innovation plasma applications. He is an Associate Editor of the journal *Earth, Moon, Planets*, and holds two patents.

Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

**THIRD C. AUTHOR, JR.** (M'87) received the B.S. degree in mechanical engineering from National Chung Cheng University, Chiayi, Taiwan, in 2004 and the M.S. degree in mechanical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 2006. He is currently pursuing the Ph.D. degree in mechanical engineering at Texas A&M University, College Station, TX, USA.

From 2008 to 2009, he was a Research Assistant with the Institute of Physics, Academia Sinica, Tapei, Taiwan. His research interest includes the development of surface processing and biological/medical treatment techniques using nonthermal atmospheric pressure plasmas, fundamental study of plasma sources, and fabrication of micro- or nanostructured surfaces.

Mr. Author's awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).

• • •