Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 4(1): 121-125
© Scholarlink Research Institute Journals, 2013 (ISSN: 2141-7016)
jeteas.scholarlinkresearch.org

Permeability Coefficient and Porosity Characteristics of Bagasse Fiber Reinforced Concrete

Omoniyi, T. E and Akinyemi B.A.

Department of Agricultural and Environmental Engineering,
Faculty of Technology, University of Ibadan. Oyo State, Nigeria.
Corresponding Author: Omoniyi, T. E

Abstract
The durability of concrete structures is a major challenge facing concrete community today. Porosity and permeability played paramount roles in determining the durability of concrete. The inclusion of fibre reinforcement in concrete can enhance some of its engineering properties. This paper investigated the influence of bagasse fibre inclusion on the porosity and permeability of concrete. A series of laboratory porosity and permeability tests were carried out. The fibre length varied from 10mm to 25mm while the volume ranged from 0 to 5% of cement mass. The results proved that bagasse fibre inclusion increased the porosity and reduced the permeability slightly initially and increased it afterwards. At fibre volume of less than 3%, the influence of different lengths of fibre on water permeability shows that high porosity does not mean high permeability. The main factor which governs permeability is the void spaces interconnections.

Keywords: permeability, porosity, bagasse, fiber, cement and durability.

INTRODUCTION

According to Miloud (2005), permeability of concrete refers to the rate at which water or other substances (sulphates, chlorides ions, etc.) can penetrate the concrete. It plays an important role in the Long-term durability of concrete. Low permeability is an important requirement for hydraulic structures because concrete of low permeability will normally be strong and durable. A concrete, which readily absorbs water, may be susceptible to deterioration. Resistance to deterioration is determined largely by the ability of the cover zone concrete to resist the ingress of deleterious agents from the environment. Concrete is inherently a porous material. This arises from the use of water in excess of that required for the purpose of hydration in order to make the mix sufficiently workable, and the difficulty of removing all the entrapped air voids from the concrete during compaction. If the voids are interconnected, concrete becomes pervious; although with normal care concrete is sufficiently impermeable for most purposes.

Fiber–reinforced concrete is becoming an increasingly popular construction material due to its improved mechanical properties over unreinforced concrete and its ability to enhance the mechanical performance of conventionally reinforced concrete. Though much research has been performed to identify, investigate, and understand the mechanical traits of fiber–reinforced concrete, relatively little research has concentrated on the transport properties of this material.

Material transport properties, especially permeability, affect the durability and integrity of a structure. High permeability, due to porosity or cracking, provides ingress for water, chlorides, and other corrosive agents, thus compromising the ability of the structure to withstand loads, which eventually leads to structural failure. (Julie *et al*, 2001). The porous and brittle nature of concrete, when interacting with environmental actions such as weathering action, chemical attack, or external loadings, generally reduces its usable service life due to increased permeability, cracking and subsequent damage.(Chao,2008). At the root of these durability problems is the permeability of concrete structures in the cracked state.

Regardless of the reason for cracking, whether it be thermal loads, autogeneous or drying shrinkage, or mechanical loads, nearly all concrete structures crack during service life. Once this cracking takes place, the transport properties of the material change drastically and it is no longer reasonable to assume that durability life-spans based on uncracked properties will hold (Micheal and Victor, 2010).

In addition, the increased permeability caused by cracking can accelerate other deterioration processes such as freezing-and-thawing damage, again resulting in less-durable concrete.(ACI, 2010). Many solutions have been proposed for enhancing the sustainability of concrete, and the use of *fiber reinforced concrete* (FRC) is a promising one. Fiber is known to be an effective reinforcement to limit initiation and propagation cracks in concrete, as well as to enhance the performance of post-cracking response (ACI Committee 544, 2001).

Previous investigations have shown that, by adding fiber into concrete and using proper mix compositions, the ability of concrete to resist various environment effects can be greatly enhanced. Bhargave and Banthia, 2008 carried out compression tests on plain and fiber reinforced concrete cylinders to investigate the change in permeability due to increased micro-cracking under compression and the result showed that while a rapid increase in the permeability occurred for plain concrete beyond a certain threshold of compressive stress, the magnitude of the increase in the permeability remained small for the FRC. They also concluded that fibers will enhance the durability of concrete and lengthen its useful service life.

Little information is available on the effects of natural fibres addition on the permeability and porosity of a concrete and these parameters play important roles on long-term durability of concrete materials. The porosity of fibre reinforced concrete, as well as plain concrete, is an important characteristic, which determines to a large extent the mechanical properties of the concrete. High porosity is detrimental to the strength and permeability of a concrete, particularly if the pores are of large diameter and connected (Miloud, 2005).

EXPERIMENTAL

Materials

The basic materials used to make the bagasse fiber reinforced concrete were:

Cement**:** Ordinary Portland cement was procured from the local market in Ibadan, Oyo State. The cement meets the specifications of the British Standards for ordinary Portland cement BS 12 (1991). It was stored in air-tight containers and was used up soon after delivery to prevent strength deterioration.

Sand**:** Sharp sand were obtained from the river flowing through the Nnamdi Azikiwe Hall while soft sand were obtained from a construction site at the Faculty of Technology both at the University of Ibadan. The sand was washed and dried to reduce the soluble matter and fine particle contents. Rounded and irregular-shaped sand pieces were chosen while flaky and elongated sand pieces were discarded. Sieve analysis (Table 1) was conducted on the aggregates in accordance with BS 8110 Part 1 (1997). The guidelines provided by Naik and Kumar (2001) were used to ensure optimum grading of the aggregates.

Table 1: Sieve Analysis

Sieve size	6 mm	8 mm
Above 2 mm	10%	20%
0.5 – 2.0 mm	45%	40%
Below 0.5 mm	45%	40%

Bagasse**:** Bagasse (Plate 1) was obtained locally from Hotoro in Kano, Kano State, Nigeria. The raw bagasse was received at about 30% moisture content. It was sun-dried for two weeks, manually depithed and further sun-dried for two weeks to a moisture content range of 7 – 10 %. For bagasse fiber reinforced concrete production purposes, part of the sun-dried bagasse was manually shredded to generate flakes (Plate 2) while the rest was hammer-milled to produce bagasse particles. Bagasse flakes were divided into three groups: short flakes (2.4 mm - 20 mm long), medium flakes (21 mm - 30 mm long) and long flakes (31 - 76 mm). The hammer-milled particles were passed through sieves of sizes 2.4 mm, 850 μm and 600 μm. Particles that passed through 2.4 mm but were retained on the 850 μm sieve were categorized as coarse particles while those that passed through 850 μm and were retained on the 600 μm sieve were classified as fine particles.

Plate 1: Unprocessed Bagasse

Plate 2: Processed Bagasse

METHODS

Mix Proportioning

Concrete mixes were designed to provide a slump of (60±10mm) for ease of handling, placing and finishing. The air content of all mixes was 3 ± 0.5%. The concrete mixes were determined by the absolute volume method as follows; Cement and Sand ratio: 1:3 and Water is 0.5 of cement mass.

Specimen Preparation and Conditioning

The factorial combination of the sand and water ratios gave a total of six treatments and three replications of each treatment were produced making a total of 18 samples. Bagasse contents were varied from 1% to 5% by mass of cement to determine the influence of bagasse mass fractions on the properties of reinforced concrete. The factorial combination gave a total of 15 treatments with three replications.

Bagasse fiber reinforced concrete production processes involved blending together of cement, sand, water, $CaCl_2$ and bagasse (flakes and particles). These constituent materials were batched in proportions determined in experimental design. Measured quantities of cement and sand were dry-mixed until a high level of uniformity was achieved. The water was slowly added while mixing was continued for about 10 minutes until uniform consistency and colour were achieved. Bagasse was added at the end of mixing cycle to minimize damage.

Porosity Test

Porosity was determined on 75 mm x 75 mm x 25 mm specimens using the method of vacuum saturation as described in RILEM CPC 11.3. The specimens were dried in the oven at 105 ± 3^{O}C until no change in measured weight was observed. The specimens were kept dry in a vacuum chamber for 3 hours before water was introduced to the chamber under vacuum . The vacuum was maintained for 6 more hours after which time the specimens were left in water for 18 hours. The saturated surface dried weight was then determined. For the fibre reinforced concrete, the water absorbed by the fibre was accounted for in the vacuum saturated weight so as to obtain the effective porosity. Porosity of a plain (control) mortar was also determined. The Porosity meter shown in Plate 3 was used for measuring the porosity of the samples.

The relationship between percentage porosity, bulk and solid densities was also used to estimate the percentage porosity as derived below:

Percentage Porosity = (volume of pores or voids/bulk volume) x100 = {(bulk volume – solid volume)/bulk volume} x100

$$= \left(1 - \frac{solidvolume}{bulkvolume}\right) \times 100$$

$$\% \ Porosity = \left(1 - \frac{bulkdensity}{solidvolume}\right) \times 100 \qquad (1)$$

Plate 3: Jecon Void or Porosity Meter

Water Permeability Coefficient Test

Permeability tests were conducted on unstressed fiber reinforced concrete specimen. Fiber volume fractions of 0,1,2,3,4,5% were used and two replicates were assessed for each fiber fraction. The fiber used was a virgin, fully purified, bagasse cellulose fiber with an average length of 25mm, collated and with a surface treatment to enhance their alkali tolerance and bond with concrete using $CaCl_2$. Permeability data are given in Table below where the bagasse fiber reinforced concrete with volume fractions of 0%, 1%, 2%, 3%, 4% and 5% were compared with the water permeability coefficient. It would be noticed from the bar chart that the bagasse fiber reinforcement was significantly effective in reducing the permeability of concrete.

This test was carried out using the DARCY'S law to determine the coefficient of water permeability by flow which is continuous:

$$K_{1D} = \frac{Q.X}{A.h} \qquad (2)$$

where:
Q = volume flow rate (m^3/s)
A = cross sectional area of the test specimen (m^2)
h = head of water (m)
X = specimen thickness in the direction of thickness (m)
K = permeability coefficient. Also the water coefficient by penetration was carried out using VALENTA'S law:

$$K_{1V} = \chi_{p}^{2}\frac{V}{2.h.t} \qquad (3)$$

where:
K_{1V} = Water permeability coefficient (m/s)
χ_p^2 = depth of penetration (m)
V = volume of voids filled by water in the penetrated zone

t = time to penetrate to depth
h = applied pressure.

The two coefficients calculated from equation 2 and 3 are divided for a specific fluid flowing through a specific porous medium. To compare the permeability of concretes obtained from tests using different liquids it is necessary to define the "intrinsic permeability" K_i, which should depend only on the pore structure of the concrete:

$$K_{1C} = Q.\ \chi.\ \eta\ /\ A\ (P_1 - P_2) \qquad (4)$$

Where:
K_{1C} = intrinsic permeability of concrete (m^2)
η = viscosity of liquid
P_1 = upstream pressure (N/m^2)
P_2 = downstream pressure (N/m^2) (Miloud, 2005)
$P_1 - P_2$ = pressure differential = $h\rho g$, P = density (kg/m^3) and g = 9.81 m/s
Substituting for $P_1 - P_2$ in equation 4

$$K_{1C} = Q.\ \chi.\ \eta\ /\ A\ h\ \rho\ g \qquad (5)$$

Then, $K_{1C} = K_{1D}\ \eta / \rho\ g$; water $\rho = 1000 kg/m^3$, hence $K_{1C} = K_{1D}.\ 10^{-3}/1000.9.61 = 1.02.\ 10^{-7}.\ K_{1D}$
For water therefore, the intrinsic permeability coefficient in units of m^2 is approximately 10^{-7} times the Darcy coefficient in units of m/s.

Therefore using the empirical equations for the permeability coefficient which were proposed by Hedegaard *et al*, 1992.

$$K_w = \exp\{-4.3(\frac{c+0.31f}{w}) + 4.0\}$$

Where :
K_w = water permeability coefficient (m/s)
c = cement content of concrete (kg/m^3)
w = water content of concrete (kg/m^3)
f = rice ash content of concrete (kg/m^3)

RESULTS AND DISCUSSIONS

Porosity Test Results and Discussion

A plot percent porosity versus bagasse mass is shown in Figures1 and 2 using Table 2. It was observed that porosity increased with mass of bagasse. The relationship is linear (R^2 value of 0.9855). The relationship between the percent porosity and bagasse content using Microsoft excel is given as $y = 1.8953x - 0.41$. The increase in porosity with increasing bagasse mass can be explained by the fact that, bagasse particles in addition to being porous can absorb water. The high value of porosity with increase in bagasse content may be due to the tendency of the particles to clump together while mixing, entrapping water filled spaces, which consequently turn into voids. Increased bagasse mass enhances the potential for fibre bailing and clumping.

Table 2: Influence of Bagasse Mass on Porosity

Percentage of bagasse	Porosity (%)
1	1.85
2	3.11
3	5.13
4	6.81
5	9.48

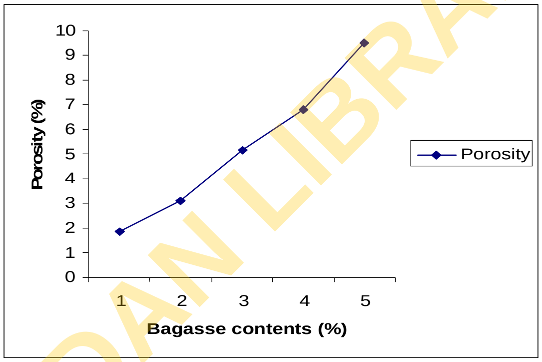

Figure 1: Influence of Bagasse Mass on Porosity

$y = 1.8953x - 0.41$ and $R^2 = 0.986$

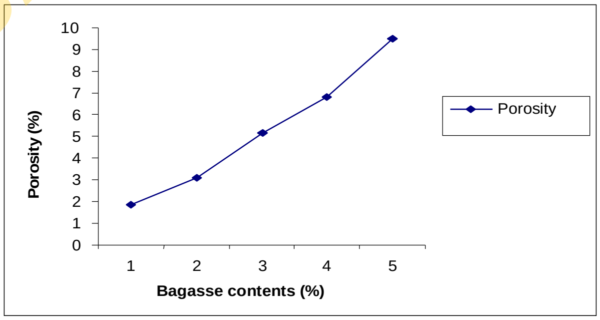

Figure 2: Influence of Bagasse Mass on Porosity (Linear)

Water Permeability Coefficient Results and Discussion

Bagasse fiber addition to concrete at low fibre volume (1% to 2%) decreases the water permeability coefficient as shown in Figure 3. When the fibre value exceeded 3% there was an increment in the water permeability coefficient. The water permeability of a plain concrete was found to be 4.02 x 10^{-19} m^2. At fibre volume of 1% and 2% the water permeability reduced to 4.0 x 10^{-19} m^2 and 3.7 x 10^{-19} m^2 respectively. As the 2% volume was exceeded the water permeability coefficient increased to 6.71 x 10^{-19} m^2, 14.93 x 10^{-19} m^2 and 26.41 x 10^{-19} m^2 for 3.0, 4, and 5% fiber volume respectively.

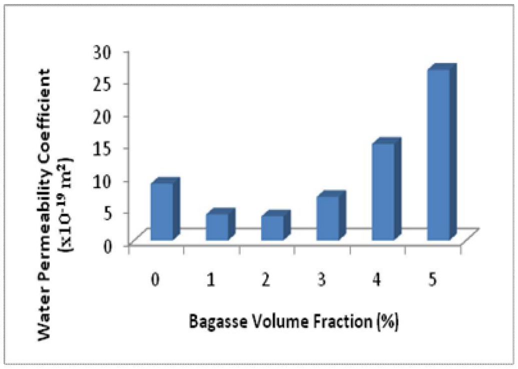

Figure 3. Comparison between Water Permeability and Bagasse Volume fraction

CONCLUSIONS

This study sought to determine the influence of bagasse inclusion on porosity, water permeability and material durability of concrete. It demonstrated that bagasse fibre reinforcement can help to improve the durability of concrete by reducing the permeability at low fibre volume. At bagasse fiber volume fraction of 1%, and 2% the effects of the fiber with 3 different lengths on water permeability shows that high porosity does not mean high permeability. The main factor which governs the permeability is the void spaces linkage. As durable building materials are continuously being sought for lasting constructed facilities, bagasse fibers at low volume when properly treated can enhance the durability by reducing the water permeability of concrete.

REFERENCES

Darcy, H.P. Les fontaines publiques de la ville de Dijon. Paris, Dalmont, 1856, Pp. 19 – 20.

Valenta, D. The permeability and durability of concrete in aggressive conditions, Proceedings of the 10th International Congress on Large Dams, Montreal, 1970. Pp 103 -117.

ACI Committee 2001, “Guide to Durable Concrete,” ACI 2001.2R-01, American Concrete Institute, 2001.

ACI Committee Report 2010, Report on the “Physical Properties and Durability of Fiber-Reinforced Concrete” , American Concrete Institute. Published March 2010.

Bhargave, A. and Banthia, N., “Permeability of Concrete with Fiber Reinforcement and Service Life Predictions,” Materials and Structures, Vol. 41. pages, 363-372, 2008.

British Standards BS 12 (1991) Specification for Portland Cement ...of internal ceramic and natural stone wall tiling and mosaics in normal conditions: BS 8297:2000-Code of www.techstreet.com/cgi bin/detail?product_id=10445

British Standards BS 8110 1 (1997) Structural use of concrete. Code of practice for design and Method for making test cubes from fresh concrete: BS 8110-3:198-Structural www.techstreet.com/cgi-bin/detail?product_id=19257

Chao, S.-H. (2008), "Achieving “Green” Concrete through the Use of High Performance Fiber Reinforced Concrete," ASCE Texas Section Fall Meeting, Addison, Dallas, October 3rd, 2008.

Julie Rapoport, Corina-Maria Aldea, Surendra P. Shah, Bruce Ankerman and Alan F.Karr, Permeability of Cracked Steel fiber – reinforced concrete, National Institute of Statistical Sciences Publication, Technical Report No 115, Jan 2001.

Micheal and Victor 2010 – accessed from www.icf11.com/proceeding/EXTENDED/4539.pdf

Miloud, B. (2005). Permeability and Porosity Characteristics of Steel Fibre Reinforced Concrete. Asian Journal of Civil Engineering (Building and Housing) Vol. 6, No. 4(2005) pp. 317 – 330.

Naik, T.R. and Kumar R. (2001): Experimental Investigation on Water to Cementitious Materials Ratio of Cement Mortar Containing Fly Ash. Report No. CBU-2001-20: pp 1 - 22