Carbonation and Water Permeability of Foamed Concrete

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Abstract

This paper reports recent findings of a research programme focused on the carbonation and permeability of foamed concrete. The objective is to develop an environmental-friendly and economical material for sustainable construction on peat. A four-year study showed that the rate of carbonation is related to the permeability, time and density. A water permeability test system has been developed based on ISO/DIS7031 and a draft standard prepared. They are aimed at promoting concrete durability research. It features a dual-test method for the measurement of water permeability with the standard 150 mm test cube prior to the determination of compressive strength. The calibration of the test system is by means of a mature test cube of known water permeability. The test system plays complementary role to the existing methods of assessing durability such as carbonation test and rapid chloride permeability. The test method is non-destructive, convenient and reliable for assessing concrete durability in the laboratory at the mix design stage. It can be used subsequently for tests on concrete products and structures for rain water harvesting system. Information technology has been experimented to provide online skill training and the electronic publications of research findings to promote good concrete practice via a concrete innovation blog http://www.1.net.my and a concrete research portal http://www.it-lodge.com.

Keywords: *carbonation, water permeability, foamed concrete, draft standard.*

1.0 INTRODUCTION

Concrete durability research has been focused mainly on materials technology such as the use of fly ash, ground granulated blast furnace slag (ggbs), micro-silica and other cement replacement materials to achieve some desirable concrete properties notably reduced permeability [1-12].

This paper describes the development of a water permeability test system and a draft standard for the assessment of concrete durability performance with the standard 150 mm test cube prior to the determination of compressive strength. The system is suitable for foamed concrete research as the water pressure can be reduced so that leakages on the sides of the test cubes can be avoided.

2.0 RESEARCH PROGRAMME

The four-year research programme comprised laboratory study and field work to establish a relationship between carbonation depth with permeability, time and the density of foamed concrete. Test cubes and prisms were used in the study. A research station constructed with the TIA foamed concrete for carbon neutral concrete research located at UTHM is known as KUiK wall (Appendix A).

3.0 TEST SYSTEM

The test system is developed based on ISO/DIS 7031 [13]. It is a convenient and reliable method for assessing concrete durability in the laboratory at the mix design stage. The test system plays complementary role to the existing methods of assessing concrete durability such as carbonation test and rapid chloride permeability. The determination of water permeability of concrete cover is non-destructive and takes much shorter time compared to the water impermeability test in accordance with DIN 1048 [14]. The calibration of the test system is by means of a mature test cube of known water permeability. The test system is shown in Figure 1.

Figure 1. Water Permeability Test System

4.0 DRAFT STANDARD

A draft standard is proposed based on the test system developed. It describes the scope, reference documents, apparatus, test specimens, conditioning of test specimens, test procedure and test report. The draft standard is attached as Appendix B.

5.0 RESULTS

5.1 TIA Concrete

The innovative exploitation of bio-fuel to synthesis biomass silica and to produce clean renewable energy has been initiated since early 90s in Malaysia (Appendix C). Concrete test cubes were tested for water permeability with the test system prior to the determination of compressive strength at 28-days and 1-year. Investigation has been made on the effect of local micronized silica (TIA) on the properties of concrete. The influence of TIA containing some 60 % silica on the water permeability and compressive strength of grade 25 and grade 80 concrete have been discussed elsewhere [15]. The TIA concrete specimens generally showed reduced water permeability compared to the control. This dual-test approach together with the use of the TIA concrete mix design monograph offers simplicity and reliability of quality control in trial mix and during construction.

The appropriate use of TIA in accordance with the TIA concrete mix design monograph (Appendix D) tends to enhance strength development and reduce water permeability of concrete. Water permeability of around 1×10^{-13} m/s can be achieved for high strength concrete containing 5 % TIA. Concrete with reduced water permeability is suitable for concrete products and substructures subjected to constant water pressure such as the concrete rain water harvesting system.

5.2 Foamed Concrete

The average carbonation depth for 1800 kg/m^3 was 4.6 mm/year$^{0.5}$ and for 1300 kg/m^3 were 16.3 mm/year$^{0.5}$. This indicates that foamed concrete will exhibit higher carbonation in the natural environment compared to normal concrete**.** Figure 1 indicates that the carbonation depth is inversely proportional to the square root of density of foamed concrete ranging from 1300 to 1800 kg/m^3.

Figure 3 shows a linear relationship between carbonation depth and the water permeability of foamed concrete. The concrete cubes were exposed outside the research laboratory. The densities of the foamed concrete ranged from 1300 – 1800 kg/m^3. The R^2 value was 0.9973 and the equation was y = 0.0344x – 1.0158. A modified Currie's formula is proposed below:

$$d = \frac{kt^{0.5}}{\ell^{0.5}} \qquad \text{(Modified Currie's formula)} \qquad (1)$$

$$d = kt^{0.5} \qquad \text{(Currie's formula)} \qquad (2)$$

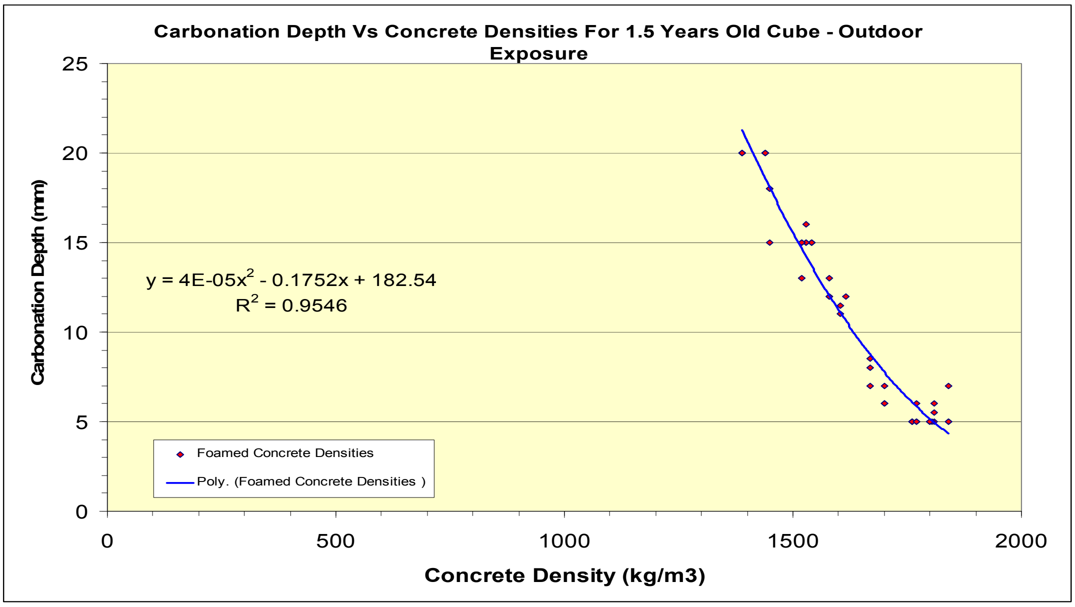

Figure 2. Relationship Between Carbonation Depth And Density of Foamed Concrete.

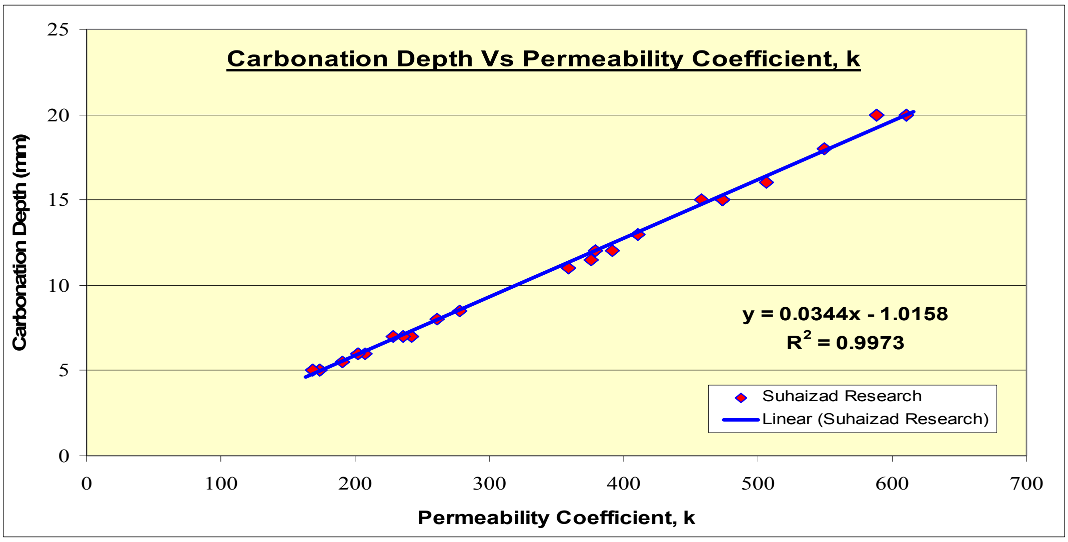

Figure 3. Relationship Between Carbonation Depth With Permeability Coefficient And Density For Foamed Concrete

The results indicate that the carbonation depth is inversely proportional to the square root of the foamed concrete density. Therefore, the engineering properties of foamed concrete especially the carbonation depth and permeability coefficient, k for foamed concrete can be predicted from its density. This new finding needs further exploration and verification to gain acceptance in future.

6.0 INFORMATION TECHNOLOGY

The information technology (IT) revolution appears to be the most significant global transformation since the Industrial Revolution beginning in the mid-eighteenth century.

The integration of material science and IT is expected to generate a dramatic increase in investment in technology, which will further stimulate innovation.

In order to promote collaborative research activities between organizations situated at different localities, IT has been experimented to promote concrete durability research through online skill training and the electronic publications of research findings. A concrete research portal http://www.it-lodge.com has been developed incorporating some experimental web-enabled applications with Lab VIEW [16]. It enables test results to be monitored online. As a result, experimental process and data can be viewed and monitored by research team members anytime, wherever IT infrastructure and facilities have been set up.

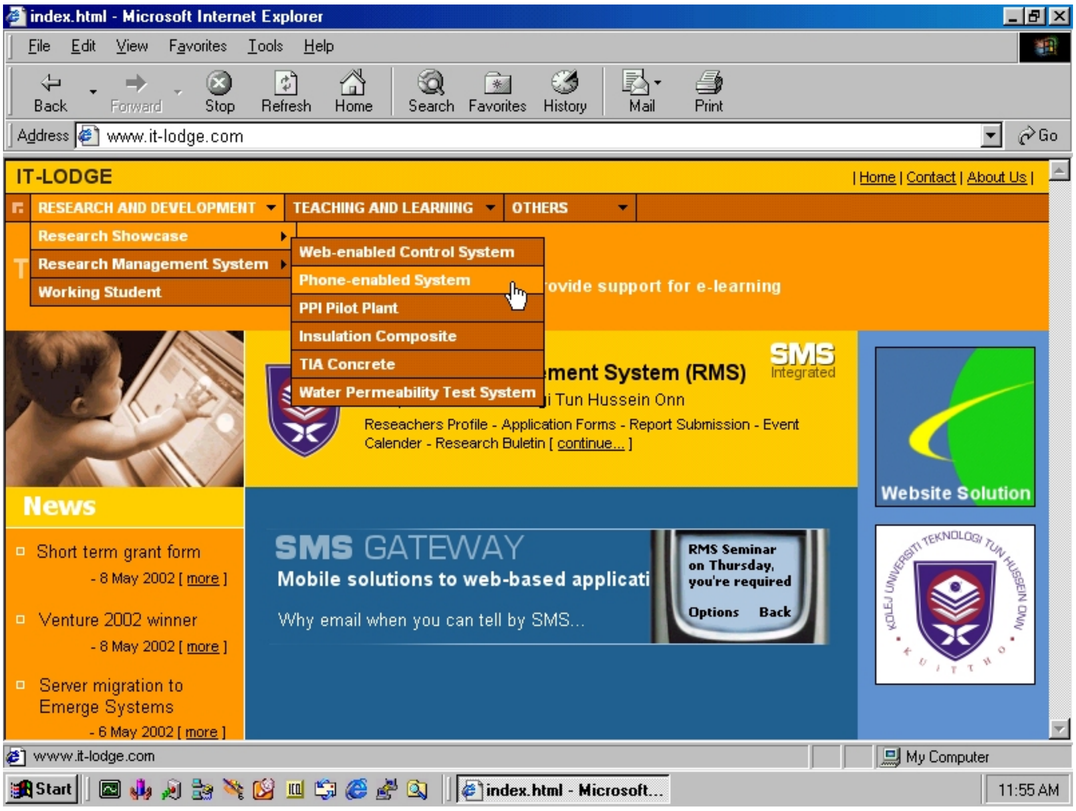

Figure 4. Link of http://www.it-lodge.com.

7.0 DESIGN FOR PERFORMANCE

The development of a non-destructive test system to determine the water permeability of concrete cover is towards achieving quality assured concrete products for waterproofing applications and to address concrete durability problems [24-25]. The test system offers a holistic approach to achieve controlled water permeability concrete for durable concrete construction.

8.0 CONCLUSION

The proposed water permeability test system and the draft standard enable the values of water permeability of a concrete as the durability performance indicator. It is to be assessed at the early stage on the standard 150 mm concrete test cube for the determination of water permeability prior to the standard test for compressive strength will provide useful information on concrete durability.

The development of local micronized silica with controlled silica content and fineness is aimed at achieving controlled water permeability in concrete. The appropriate application of material processing technology, test method together with the innovative exploitation of wastes in concrete for infrastructure development is expected to alleviate the escalating ash proliferation and disposal problems, towards improving the quality of life and conservation of the environment.

The proposed modified Currie's formula for foamed concrete of densities ranging from 1300 kg/m^3 to 1800 kg/m^3 is expected to renew interest in the subject of sustainability with CO_2 uptake with foamed concrete.

The application of IT to promote good concrete practice offers several advantages. Skill training related to the test method may be offered online. The real-time test data can be monitored online with the latest information and communication technology. The water permeability of a concrete structure can be monitored regularly in-situ. The need to design for durable concrete construction and quality control of concrete structures throughout their designed life span is emphasized.

9.0 ACKNOWLEDGEMENT

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Appendix A

Appendix B

DRAFT STANDARD

Determination of water permeability of concrete cover

1 Scope

This standard specifies a method for the determination of the water permeability of concrete cover as a durability performance indicator. It covers concrete of grades ranging from 20 to 80 MPa.

2 Referenced documents

The following documents contain provisions which constitute some of the provisions of this draft standard.

- BS 6089: 1981, "Guide to Assessment of Concrete Strength in Existing Structures", British Standard Institution, London, 1981.
- ISO/DIS 7031 Concrete hardened - Determination of the depth of penetration of water under pressure.
- MS 26: Part 1:1991 Section Eight: Method for making test cubes from fresh concrete

3 Apparatus

The apparatus comprises a pressure chamber with provisions for the accurate measurement of pressure, temperature and the volume of water permeating into the concrete cover to be tested for water permeability.

A computerized data acquisition system is preferred for the real-time display of the value of water permeability against time. A permanent record of the ambient air temperature, humidity and the water temperature is to be kept while the test is in progress.

4 Test specimens

The test should preferably be performed on a 150 mm concrete cube. Cored or sawn specimens from existing concrete structures should be taken from locations determined by a professional civil or structural engineer together with the relevant authorities. The principle of sampling, accuracy and tolerance shall be in accordance with information contained in the referenced documents. It is recommended that at least three test specimens be used in each test.

5 Conditioning of test specimens

The test specimens should be placed on raised wire gauze and conditioned at between 65 - 80% RH and around 26 - 33^{o}C and tested at 28 days. The duration of moist curing after the specimens are de-moulded should be similar to the actual curing conditions of the concrete products or structures.

6 Test Procedure

- The test should preferably be conducted on test specimens of age 28 days. Specimens of other ages may be chosen according to special conditions or requirements.

- The density of the test specimens should be determined before the test.

- Careful setting up of the apparatus is necessary to prevent any seepage of water from the concrete cover in contact with the pressure chamber. If water leakage occurs, the test shall be stopped.

- The water pressure is recommended to be between 1.5 bar and 4 bar depending on the quality of concrete specimens to be tested.

- The apparatus should be calibrated with a mature concrete test cube of known value of water permeability and conditioned for the calibration.

- The duration of calibration test is preferably not less than 1 hour. However, the duration may be reduced if the calibration test results indicate that a steady flow condition has occurred.

7 Test report

The test report should contain the following mandatory and optional data:

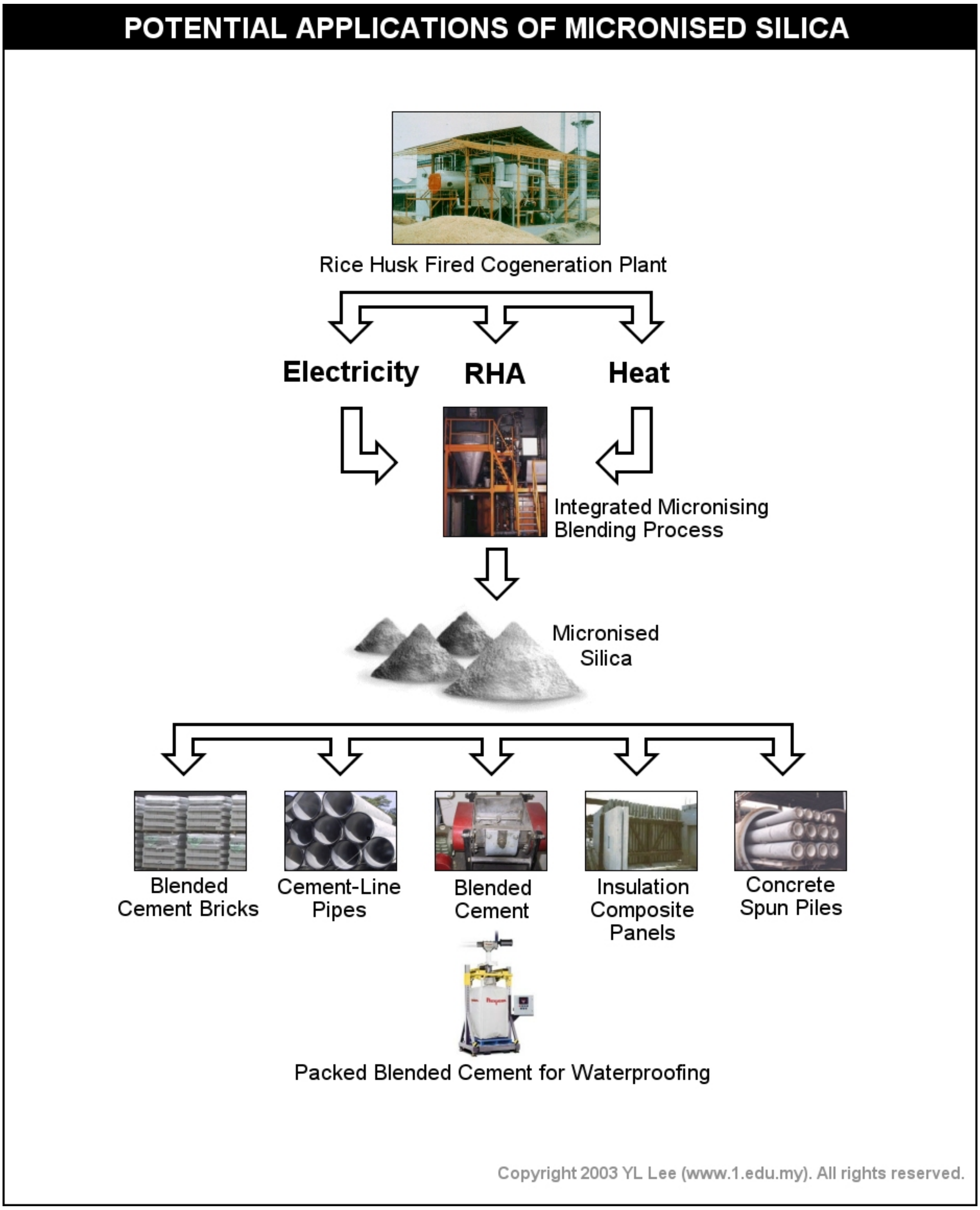
Mandatory data:

- Apparent density
- Conditions of curing and storage
- Shape and dimensions of the test specimens
- Age of concrete at the time of test
- Type of water used for the test
- Temperature and relative humidity in the test chamber
- Direction of application of water pressure in relation with the direction of casting or mould filling.
- Any deviation from the procedure specified.

Optional data:

- Computer printout from data acquisition system
- Sketches or photograph of the test specimen and while the test is in progress.

Appendix C


POTENTIAL APPLICATIONS OF MICRONISED SILICA
Rice Husk Fired Cogeneration Plant
Electricity
RHA
Heat
Integrated Micronising Blending Process
Micronised Silica
Blended Cement Bricks
Cement-Line Pipes
Blended Cement
Insulation Composite Panels
Concrete Spun Piles
Packed Blended Cement for Waterproofing
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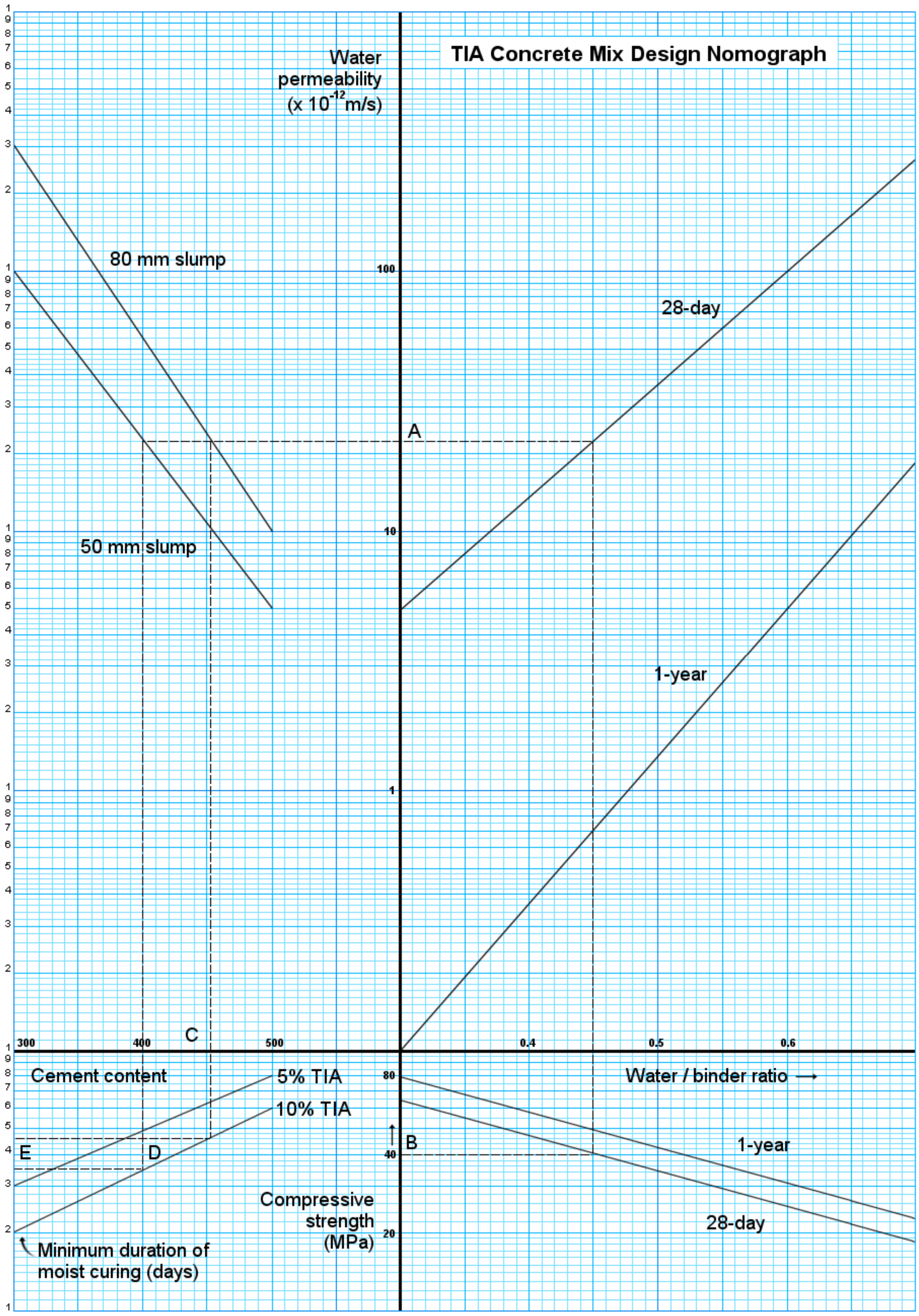
Appendix D


TIA Concrete Mix Design Nomograph
Water permeability (x 10⁻¹² m/s)
100
10
1
80 mm slump
50 mm slump
28-day
1-year
A
C
300
400
500
0.4
0.5
0.6
Cement content
5% TIA
10% TIA
Water / binder ratio →
80
40
20
B
1-year
28-day
E
D
Compressive strength (MPa)
Minimum duration of moist curing (days)