# DURABILITY OF CONCRETE PRODUCED FROM INTERNAL CURING CONCRETE AGGREGATE MANUFACTURED FROM INDUSTRIAL WASTE

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Degree of Master of Science

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## DECLARATION

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Prof. W.K. Mampearachchi.

## ABSTRACT

Modern buildings have made extensive use of Internal Curing (IC) for high-performance concrete (HPC). Nowadays, the rise of industrial waste has numerous negative repercussions on both society and the environment. Also, the building industry has seen numerous risks on the riverbank as a result of the increased demand for sand. Consequently, these issues can be resolved and the ineffective external curing of high-performance concrete with a lower w/c ratio can be reduced by replacing the fine aggregate with internal curing concrete aggregate (ICCA) made from industrial waste. Here, ICCA has previously been created using various industrial wastes. This study intends to evaluate the mechanical properties and durability of ICC constructed using two types of ICCA generated from waste materials to partially replace fine aggregate. Tests by the broadly accepted methods of mechanical and durability evaluations, such as compressive strength, workability, statistic modulus of elasticity, surface resistivity, rapid chloride ion penetration, water permeability, saturated water absorption, and initial surface absorption were conducted for industrial mix design, and high-performance mix design. Three types of curing samples; internal curing, external curing, and non-curing, were evaluated. The effects on durability and mechanical properties of concrete with these ICCA aggregates as a replacement material for fine aggregate are reported. ICC showed a 10 to 20 percent increment in a slump, 5 to 15 percent increment in compressive strength, 9 to 12 percent reduction in static modulus of elasticity, and a 9 to 17 percent increment in surface resistivity compared to the conventional concrete. Moreover, it showed lower penetration of chloride ion permeability, and lower initial surface absorption at 28 days. Further, ICC showed a slightly higher depth of penetration and saturated absorption initially and a reduction with time.

Keywords - durability, internal curing aggregate, internal curing, fine aggregate, mechanical properties, industrial waste.

## ACKNOWLEDGEMENT

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## LIST OF ABBREVIATIONS

ICCA - Internal Curing Concrete Aggregate

IC - Internal Curing

HPC - High-Performance Concrete

FA - Fly Ash

RSM - Reservoir Sediment Material

CCTW - Clay Calicut Tile Waste

WTS - Water Treatment Sludge

E - External Curing

N- Non-Curing

ISAT- Initial Surface Absorption test

RCPT- Rapid chloride-ion

SR- Surface Resistivity

# 1. CHAPTER 01- INTRODUCTION

## 1.1 Background

In the present construction business, concrete is a material that is frequently employed. As fine aggregates, both manufactured and river sand have been utilized to make concrete. Sand mining from riverbeds has many negative environmental and social effects on society as a result of the rising demand for river sand in the construction industry. Another significant problem in Sri Lanka is the hazardous disposal of industrial wastes. Consequently, making fine aggregate from industrial waste will be a practical way to address the social and environmental problems related with mining sand from river beads, and employing these industrial wastes as aggregate will significantly boost our nation's economy.

Over a thousand tonnes of fly ash, a byproduct of the Lakvijaya coal power station, are produced every day; however, this waste has not been significantly utilised to create a product with added value for the market and has instead been kept on the site. Also, keeping this material at the location is harming the environment in the neighborhood.

Moreover, reservoir sediment materials are frequently stored nearby for routine cleanup or dumped into the tank, which reduces the capacity of the reservoirs without appropriately utilizing them. Authorities are also seeking for a constructive approach to utilize the vast volume of drinking water treatment sludge waste that is currently being kept. Moreover, during the tile-making process, enormous volumes of red clay Calicut trash are produced; this waste can also be used in an efficient manner from an economic standpoint. Hence, research was done to create an aggregate from these industrial wastes (Tharshikan, 2021; Pradeep, 2021).

High-performance concrete is another concept of concrete that is produced to achieve higher strength and performance with a lower water-cement ratio. In high-performance concrete, autogenous shrinkage and early-age cracks are major issues because of the loss of design water due to various factors, such as evaporation. To overcome these issues, proper curing should be given to the concrete. Also, to achieve the intended performance, proper curing should be given to the concrete as per the requirements.

In concrete construction, proper curing is an essential requirement to achieve their design performance as well as durability properties by enhancing the hydration of cement paste. In construction industry, it has been achieved through external curing. Internal Curing is another method to achieve curing with several advantages. Concept of internal curing or self-curing is widely used method in other countries although it is new to Sri Lanka. Internal Curing Concrete Aggregate (ICCA) is known as self-curing aggregate which is an alternative for external curing. Efficiency of internal curing method depends on water absorption, water desorption microstructure, and spatial distribution of internal curing aggregate in concrete. If the aggregate possesses a water absorption value of more than 5 % and releases at least eighty (80) percent of the absorbed water under 95% humidity it can be considered ICCA. These products can give direct benefits such as reduction in autogenous shrinkage, a diminished rate of drying shrinkage, reduced elastic modulus, and improved hydration. Moreover, helps to achieve full hydration, eliminate the whole cost for external curing, save 20 % to 30%f river sand and minimize the permeability of concrete while increasing the concrete strength and durability. However, there are no natural sources for internal curing aggregate in Sri Lanka. Hence, three ICC aggregates were developed with Internal Curing properties through experimental results using three different industrial wastes (Bandara & Mampearachchi, 2021; Tharsikan, 2021; Pradeep, 2021). Therefore, when the part of the fine aggregate is changed with processed industrial waste as a new material in concrete, it is essential to check the mechanical and durability properties of concrete.

## 1.2 Problem Statement

To solve major issues such as increased demand for river sand as a fine aggregate in concrete industry and disposing the industrial wastes for example Fly Ash (FA), Reservoir Sediment Material (RSM), Clay Calicut Tile Waste (CCTW) and Water Treatment Sludge (WTS), three types of internal curing fine aggregates were produced, and their properties were already checked in previous research. For a long service lifetime of concrete with these internal curing fine aggregates as a alternative material in concrete in aggressive environment, durability and mechanical properties of these concrete should be studied carefully.

## 1.3 Objective

- To analyze the durability characteristics of internal curing concrete produced from replacing fine aggregates with ICCA manufactured from industrial waste.
- To analyze the mechanical properties and workability of internal curing concrete produced from replacing fine aggregates with ICCA manufactured from industrial waste.

## 1.4 Scope and limitation of the research

Among three types of these internal curing aggregates only two types of ICCA were evaluated due to the time limitation which are ICCA produced from Fly Ash and Reservoir Sediment material (RSM) and ICCA from Clay Calicut Tile Waste (CCTW). Moreover, CCTW ICCA and ICCA from drinking water treatment sludge possess nearly the same behavior and absorption desorption characteristics. Also, there was a significant amount of research carried out on internal curing concrete and their durability properties. Therefore, it is decided to testify the durability properties which are not conducted commonly in earlier research.

## 1.5 The arrangement of thesis

This report comprises of five sections which are introduction, literature review, methodology, result and discussion, and conclusion.

In the introduction chapter background of this research is discussed and it contains problem statement, objective and scope of this research study.

In the literature review chapter, reviewed literature about the high-performance concrete, raw industrial waste materials, curing of concrete, internal curing, shrinkage in high performance concrete, durability tests are broadly discussed.

Chapter 3 contains an explanation about the methodology for this research and chapter 4 explaining the obtained results and their discussion.

Chapter 5 contains the conclusion of this research and recommendations for upcoming studies.

# 2. CHAPTER 02 – LITERATURE REVIEW

## 2.1 General

This chapter contains a detailed literature review of HPC, shrinkage in concrete, curing, internal curing, raw industrial waste material and durability tests. Although a detailed literature review was carried out on durability test methods and mechanical tests, only the details of the required tests are discussed in this chapter.

## 2.2 High-Performance Concrete

High-performance concrete (HPC) has already become familiar in the concrete construction industry. Its design objective is to achieve better mechanical properties and developed confrontation against aggressive environments than conventional concrete (Tu et al., 2009). The American Concrete Institute (ACI) states HPC as "concrete collecting specific arrangements of performance and consistency conditions that could not be constantly achieved regularly with typical components and ordinary mixing and curing methods". Generally, HPC can be created by employing a lower W/C ratio, but it can also be created with chemical admixtures and supplementary cementitious materials. Compared to conventional concrete, more consideration should be given to HPC in terms of quality control and curing since it has a lower W/C ratio. If proper quality control and curing had not been given to the HPC, it would crack due to shrinkage. Even though the application of HPC is increasing (airport pavements, high-rise buildings, bridge decks, and piers, among others), the development of HPC is affected by its early-age cracking behaviour (Zhutovsky & Kovler, 2011).

Because HPC has a high cementitious content and a low w/c ratio, which makes it prone to volume change, autogenous shrinkage may be the main worry influencing HPC's durability. Numerous categories of shrinkage can appear in concrete, including shrinkage caused by plastic, chemicals, autogenous processes, drying, and carbonation (Wank et al., 2013). Plastic shrinkage, drying shrinkage, and autogenous shrinkage are assumed to be more significant when it comes to HPC.

Contraction in the volume of concrete, during which it is in a plastic state, causes plastic shrinkage. This shrinkage could be more susceptible if the amount of water lost from the exposed surface of the concrete is high. In HPC, capillary pores are very small since it has a low w/c ratio, so the amount of water that rises to the surface of the concrete by leaking is also comparatively low. Therefore, when water lost on the surface exceeds the water brought to the surface by bleeding, plastic shrinkage would happen. However, it can be considerably avoided if the loss from the surface of the concrete is prevented (Neville & Aitcin, 1998).

Here, drying shrinkage also causes a significant effect on the durability of HPC since all these shrinkages will end up as cracks. As a result, cracks allow harmful chemicals and impurities to enter the concrete, reducing the durability of the material. The primary reason for the shrinkage is water loss in the solidified concrete. In concrete, part of the design cost of mixing water for cement hydration and workability will be lost to evaporation. It will vaporise when the concrete surface is visible in a drying situation. As the water disappears, the concrete shrinks due to the extension of tension and pressure at the surface of the concrete (Rougelot et al. 2009). However, the drying shrinkage in HPC is considered very small because of the tiny capillaries and pores. Water in the capillary pores will be consumed because of cement hydration. As a result, the relative humidity in the concrete mixture will decrease, which will increase internal stresses and increase the risk of shrinkage and cracking (ACI [308-213] R-132013).

The W/C ratio in the concrete is a critical parameter; when it is lower than a critical value, it will lead to significant self-desiccation, which causes autogenous shrinkage. Further, this self-desiccation has a marked affection for low w/c ratios and high-strength concrete (Aitcin et al., 1977). Inner relative humidity in concrete reduces due to cement hydration and other complementary cementitious material reactions that utilize water, such as pozzolanic reactions (self-desiccation), and this process causes autogenous shrinkage (Holt, 2005). Here, self-desiccation creates interfacial menisci between the pore fluid and vapour in gradually smaller pores and accumulates the capillary pressure. This capillary pressure triggers a microscopic shrinkage called autogenous shrinkage (Hua et al., 1995). In high-performance concrete (HPC), early autogenous shrinkage is considered more dangerous than drying shrinkage due to the low water-to-cement ratio (Yang et al., 2020).

These shrinkages can induce cracks, which will adversely affect the durability and purpose of HPC. Therefore, mitigating these shrinkage cracks is an essential requirement to achieve the intended design outputs. There are several strategies that have been adopted by the construction industry to overcome this issue. Some of the strategies for shrinkage mitigation are given in Figure

2.1.

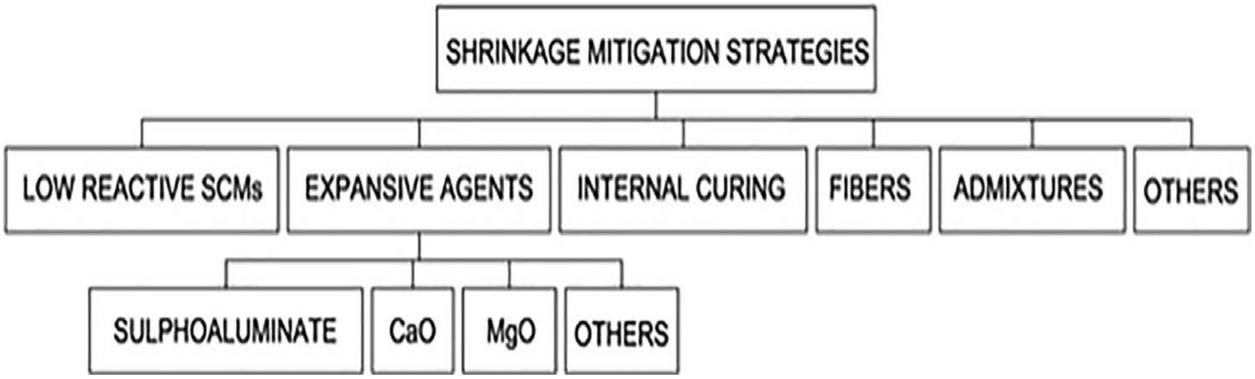



Figure 2-1: Shrinkage reduction strategies (Rodríguez et al., 2020).

Preventing the drop of the internal relative humidity of concrete is the concept behind these shrinkage reduction strategies. Moreover, curing is the conventional method that has been used globally to maintain the internal relative humidity in a preferable state, but it is not effective in HPC due to its low permeability.

## 2.3 Curing

In concrete construction, proper curing is an essential requirement to achieve their design performance as well as durability properties by enhancing the hydration of cement paste. In the construction industry, it has been achieved through external curing. As per ACI CT-13, curing is defined as "allowing hydraulic cement hydration and pozzolanic responses in freshly placed concrete." Some actions should be needed to keep moisture and temperature requirements, which help the mixture's potential properties develop". It can be achieved by either an external or internal method. Sufficient curing is essential in HPC because it will help to eliminate the troubles associated with shrinkage cracking and ensure the availability of water for hydration (McCarter & Saleh, 2001).

Several external curing methods have been adopted all over the world, and mainly there are two kinds of external curing available: water curing and sealed curing. In the water curing type, water ponding or water fogging, water spraying, and saturated covering methods are being adopted by the construction industry. Moreover, waterproof paper, plastic sheeting, and curing membrane are being adopted under the sealed curing type. In addition, chemical compounds such as wax, synthetic resin, and acrylic are being used for external curing. Also, curing with steam is one of the latest method that has been identified as more effective than conventional curing (Ramezanianpour et al., 2015).

## 2.4 Internal curing

Several experiments have already been conducted in the name of internal curing with different internal curing aggregate sources. Even though internal curing is a promising method, the availability of internal curing aggregate sources in Sri Lanka is very low, and there are still no natural sources for internal curing aggregates in Sri Lanka. However, in other countries, a substantial amount of research has been performed to build self-curing concrete from different sources. Pre-wetted lightweight aggregate is a widely used source among them, and several researchers have been performing tests on the durability of this lightweight aggregate (Zhutovsky and Kovler, 2012). Sufficient curing is not achievable in places where water scarcity is considered a major problem, and providing curing in high-rise buildings is nearly impossible or expensive for concrete works (Weber & Reinhardt, 1998). Moreover, due to contractors' poor understanding of curing and its importance, sufficient consideration is not given to curing at many pavement construction sites. As a result, the performance of structures will suffer and their life span will be reduced. Hence, the development of self-curing concrete will mitigate those problems and save a lot of money from ineffective external curing.

In high-performance concrete (HPC), early autogenous shrinkage is considered a more dangerous concern than drying shrinkage because it is produced at a low water-to-cement ratio and internal curing is a promising strategy to eliminate autogenous shrinkage. Moreover, the main consideration of IC is lowest autogenous shrinkage and greatest degree of hydration; with the introduction of internal curing, we can achieve full theoretical hydration (Yang et al., 2020). In addition, internal curing can be used for liquid ingress drops, and it will reduce the alkali-silica response (Beyene et al., 2017). Here, the curing water is provided by an internal source rather than an external source. When you provide the external curing, water cannot penetrate larger depths; it is only effective in several millimetres, but if it is provided by an internal source, it would be available throughout all the concrete areas.

Despite the application of internal curing aggregate in Sri Lanka, many countries have already used this internal curing in different projects successfully. It has been used in bridge deck construction applications in past years in countries like New York, Georgia, Indiana, and North Carolina. Also, it was observed that it has reduced plastic shrinkage cracking and other casual cracking, especially in HPC bridge decks (Streeter et al., 2012; Schlitter et al., 2010; Delatte and Crowl, 2012).

Another important application of internal curing is pavement construction. In the past few years, several pavements have been built with great success. For example, nearly 190000 cubic yards of internally cured concrete were used in a paving project in Hutchins in January 2005; it is considered one of the largest projects that have utilised the advantages of lightweight aggregate (Villarreal and Croaker, 2007). And other successful projects such as State Highway 121 north of Dallas, the High Early Strength ICC Off Ramp of I-635 in Mesquite, Texas, and the Kansas US 54 Expansion in 2014 are good examples of successful internal curing pavement construction.

Internal curing can be described as "the method by which the hydration of cement maintains due to the accessibility of inside water that is not consider as mixing water" (ACI, 2013). Through internal curing, sufficient moisture for hydration is provided within the concrete system. Internal curing is achieved by the Internal Curing Concrete Aggregate (ICCA) that is imputed proportionally to the concrete mixture. Comparatively, in internal curing and external curing, water cannot penetrate a larger depth in high-performance concrete due to low permeability. But internal curing sources are provided inside the concrete by a so-called water reservoir from ICCA. Therefore, water can be available all over the concrete, and hydration can be achieved throughout the whole concrete structure. Figure 2.2 describes the aforementioned procedure.

These ICCA aggregates are being used as a partial replacement for coarse aggregate and fine aggregate based on the ASTM C1671 calculation. There are so many sources available to perform as an ICCA. Further, as per the ASTM C1761 standard, these aggregates should possess a water absorption value greater than 5 percent and should release minimum 85 percent of the absorbed water at 94 percent relative humidity and 25 degrees Celsius. Lightweight aggregate (LWA) from natural sources such as pumice and zeolite, expanded clay, expanded shale, super absorbent polymers, waste ceramics, recycled aggregate, fly ash, and ground-granulated blast furnace slag are some ICCA that has been used all over the world to achieve internal curing (Yang et al., 2020). However, these sources of internal curing aggregate are not available all over the world, especially in Sri Lanka, where internal curing aggregate is a new topic. Initially, burnt clay pieces were investigated as an internal curing concrete aggregate in Sri Lanka (Bandara & Mampearachchi, 2021).

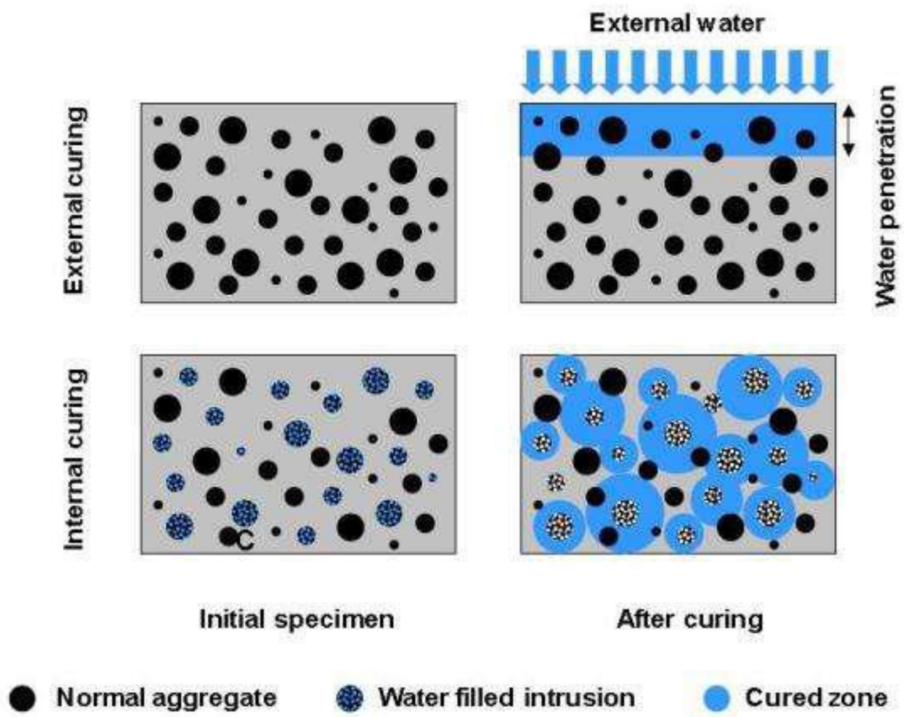



Figure 2-2 Comparison of internal curing and external curing (Castro et al., 2010)

## 2.5 Factors affecting the internal curing.

The efficiency of internal curing changes on several factors; mainly, water absorption and water desorption value are significant parameters that have been affecting the efficiency of internal curing. However, these factors can be categorised into three main categories: the sum of internal curing water, qualities of internal curing materials, and immigration space of internal curing water. Since the benefits of internal curing depend on their performance, proper care should be given to these factors, and by improving these factors, better performance could be achieved. When each of these factors does not meet its intended specification, it will lead to issues such as slump loss, segregation, lack of adequate moisture, and dryer mixer (Chetana Rao, 2013). Figures 2–3 indicate the root factors and their cofactors that can stimulus the efficiency and performance of internal curing.

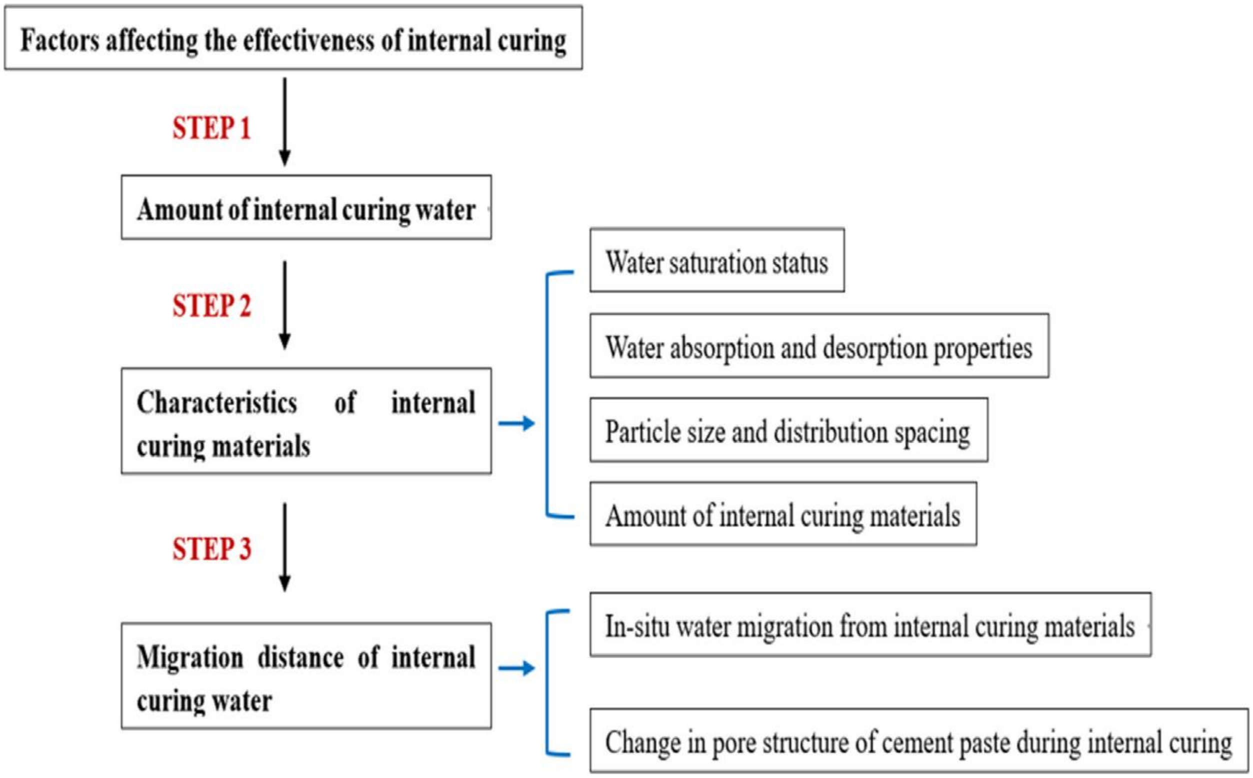



Figure 2-3 Factors affecting the effectiveness of internal curing (Yang et al., 2020)

The amount of IC water required for sufficient hydration is calculated based on the equation given in the ASTM C1761 standard for water desorption greater than 85 percent as per this standard. Moreover, the Castro-modified equation can be used for finding the required amount of internal curing aggregate in oven-dry conditions for lower desorption value aggregates. This chapter is discussed separately. Also, characteristics of internal curing materials such as water saturation position, water absorption and desorption possessions, particle size and distribution spacing, and the amount of IC materials are major factors that can affect the efficiency of internal curing. To ensure the migration of internal curing water to the extended level, particle size distribution is important. The migration distance of ICCA depends on the pore organization of the cement mix and the distribution spacing of these ICCA among the concrete paste (Lura et al., 2006). When consideration is given to the internal cure, the above-mentioned factors should be analysed very carefully, and with proper care, optimum utilisation of these aggregates can be achieved.

## 2.6 Durability of internal curing aggregates

Durability is an essential requirement in concrete for long-term service life, and in the current construction industry, more consideration is given to durability due to prevailing adverse environmental conditions. Even though the mechanical properties are increased with this internal curing, their durability properties also must be analyzed. In previous research, many of them have analysed the durability of internal-cured concrete with different internal curing sources.

Earlier durability of internal concrete has been checked with lightweight aggregate (LWA) as an ICCA; it shows that there has been development in resistance to chloride penetration, but that it varied with the w/c ratio, with slight improvement attained with a lower w/c ratio. Moreover, improvements in autogenous and drying shrinkage were observed, sorptivity and mass loss were increased with the use of internal curing, and air permeability was increased. So, durability properties were not corrupted with the inclusion of ICCA in concrete (Zhutovsky & Kovler, 2011). Also, it was observed that internally cured mortar mixtures with saturated ICCA can suggestively reduce or eradicate plastic shrinkage, and even twenty percent of saturated ICCA in cement mortar and twenty-five percent of saturated ICCA in concrete mixtures as an alternative for normal aggregate were able to avoid the autogenous shrinkage significantly (Schlitter et al., 2010; Bentur et al., 2001).

Internal curing of concrete with recycled aggregate showed significant improvements in durability properties such as freeze-thaw resistance, dynamic modulus of elasticity, and delay of cracking, even though a minor reduction in compressive strength was observed (El-Hawary & Al-Sulily, 2020). Moreover, it was observed that Internal Curing Concrete with Expanded Clay (ICCA) will reduce the chloride ion permeability by thirty percent compared to conventional concrete (Hijazin and Lopez, 2009).

## 2.7 Raw Waste materials

The dumping of industrial waste is considered a critical trouble in the current situation since it can adversely affect the environment and might cause severe contamination of groundwater. In this research, four types of industrial raw waste materials have been considered for use as internal curing aggregates, such as fly ash, reservoir sediment material, water treatment sludge, and clay calendered tile waste. These industrial wastes were considered to be converted into ICCA by different manufacturing processes.

### 2.7.1 Fly Ash

Fly ash is a byproduct from the coal power plant, and usually, during this combustion process of coal, two types of byproducts are delivered, which are fly ash and bottom ash. By raw material type, FA can be categorized as either class C or class F. These class C and class F types contain different chemical compositions. In Sri Lanka, at the Norochcholai coal power plant, nearly 1000 metric tonnes of fly ash are produced per day as waste material, and a large portion of this fly ash is stored at the plant without any means of disposal. Moreover, a limited amount of FA has been used in beneficial ways such as blended cement manufacturing, soil stabilisation works, and the manufacturing of paving blocks. FA contains tiny particles, nearly 1 m to 100 m, so it should be accumulated to be used as an aggregate (Biernacki et al., 2008). There are several methods available to accumulate FA, and they are called the hardening process. They are sintering, auto calving, and cold bonding (B Bijen, 1986). Moreover, among these methods, sintering is considered an effective method since it can eliminate the unburned carbon and ammonia present in the FA (Fox, 2005).

FA possesses a low plasticity character; thus, its plasticity should be increased for use as an aggregate. In the aggregate industry, some binding materials have been used to increase the plasticity of FA, such as bentonite, lime, and corn syrup. However, reservoir sediment material (RSM) can also be used as a binding material (Tharshigan, 2021).

### 2.7.2 Reservoir Sediment Material (RSM)

RSM is a waste material that is usually dredged from water reservoirs and dumped near the reservoirs without proper utilization. It is considered by many that this sedimentation is reducing the capacity of reservoirs as it usually covers 23 percent to 35 percent of the total capacity (Dharmasena, 1992). Moreover, it is widely available all over the country. Hence, it can be easily found in large scales for aggregate preparation. This sedimentation material cannot be used in both embankment construction and road construction because it comprises a high amount of silt particles (Nawagamuwa & Senarathna, 2018). Therefore, utilising it in the production of internal curing aggregate will be the best solution to dispose of this waste with proper usage.

### 2.7.3 Clay Calicut tile waste and Water Treatment Sludge

These two wastes exhibit approximately the same behaviours based on their chemical composition. However, it varies when its raw materials change. These two raw waste materials can be obtained in larger amounts in Sri Lanka since they have been stored at the sites without any means of disposal.

## 2.8 Durability tests

A broad literature review was conducted on concrete tests on mechanical properties and durability properties to select suitable tests for this research. Since mechanical properties such as compressive strength and workability tests are very common in practice, a literature review on other referred properties is attached to this part.

The surface resistivity test is an economical, time-saving, and non-destructive way to assess the electrical resistivity of concrete. This test can be used to assess the resistance to chloride ion penetration of concrete in laboratory conditions (AASHTO T 358-15). Further, the surface resistivity test can be used as an alternative method for the rapid chloride penetrating (RCP) test since it has been successfully correlated with the RCP test (Chini, Muszynski, & Hicks, 2003). There have been several methods adopted around the world to measure the surface resistivity of concrete; among them, the Wenner probe method is the most widely accepted method to measure the surface resistivity of concrete against chloride ion penetration, and it is also called the four-point method. Therefore, Wenner four point was selected to check the surface resistivity against chloride ion permeability in this research. Table 2-1 helps to find the level of resistivity of samples against chloride-ion penetration.

Table 2.1: Chloride ion penetration based on Surface Resistivity (AAHSTO T-358-15).

| DIN 1048 3-days Depth of penetration (mm) | Water permeability |
|---|---|
| < 30 | Low |
| 30 – 60 | Average |
| > 60 | High |

The water permeability of concrete is one of the significant parameters used to evaluate the durability of concrete. There are several methods available to measure the water permeability character of hardened concrete, such as the saturated water absorption test (ASTM C 642-81), the sorptivity test (ASTM C 1585), the water permeability test (BS EN 12390-8), and the initial surface absorption test (BS 1881-208). The aforementioned tests can be used to evaluate the durability parameters of concrete, such as the durability of rebar, frost resistance, weathering, water absorption, water permeability, and porosity. Many researchers have considered permeability as a direct factor in evaluating the long-term durability of concrete structures. Further, these tests evaluate processes like absorption and capillary effects, pressure differential permeability, and ionic and gas diffusion, where liquid, gas, and ions can be penetrated into the concrete (Baweja, 1993).

The water penetration test helps to understand the porous connectivity of concrete when a structure is subjected to higher pressure, like in water-retaining structures. Since this ICCA contains relatively higher porosity, it was decided to conduct this test to analyse it. Generally, in this test, the depth of penetration will be measured under an application of 500 kPa plus or minus 50 kPa pressure at a hardened concrete surface (BS EN 12390-8:2000). When we consider the quality of concrete related to this test, the table below will help us understand its behavior. Table 2.2 helps to understand the level of water penetration at higher pressure.

Table 2.2 Water penetration test result details (Baweja, 1993)

| Chloride-ion penetration | SR Test | |
|---|---|---|
| | 100*200 mm cylinder sample (KOhm-cm) | 150*300 mm cylinder sample (KOhm-cm) |
| Extreme | <12 | <9.5 |
| Modest | 12-21 | 9.5-16.5 |
| Low | 21-37 | 16.5-29 |
| Very Low | 37-254 | 29-199 |
| Insignificant | >254 | >199 |

A saturated water absorption test was selected to evaluate the water absorption of concrete samples by capillary effects since our aggregate possesses higher porosity. Also, to ensure the results of the water penetration test, this test might be helpful since, with the water penetration test alone, the durability of concrete cannot be assessed (ASTM 642-81).

The Rapid Chloride-ion Penetration Test was selected to evaluate the chloride-ion penetration into the concrete. This test has been criticised by many researchers for its lack of scientific basis, accuracy level, and destructive testing method (Shi, 2003). However, many researchers have been using this test to evaluate the chloride ion permeability of hardened concrete. This test can be done according to ASTM 1202 or ASSHTO T277 standards, which are commonly used in practice. However, there might be a higher variation between different test results for the same sample even with a small deviation in the casting process. Moreover, this test should be carried out very carefully since any leakage during the process will lead to a deviation in the results. Tables 2.3 help to identify the level of chloride ion penetration into the concrete.

Table 2.3 RCPT results indications ASTM C1202

| Charge Passed (coulombs) | Chloride Ion Penetrability |
|---|---|
| >4,000 | Extreme |
| 2,000–4,000 | Modest |
| 1,000–2,000 | Low |
| 100–1,000 | Very Low |
| <100 | Insignificant |

Initial Surface Absorption Test (ISAT) helps to estimate the properties of concrete, such as quality of surface, frost resistance, and weathering action (Baweja, 1993). Here, the water will be introduced to the concrete surface at a head pressure difference of 200 mm, which is considered a field condition (BS 1881-208:1996). Our ICC aggregate possesses higher absorption; therefore, aggregate at the surface of concrete can absorb water, which will affect the quality of the concrete. Hence, it should be evaluated to identify the consequences. Moreover, obtained results will help to understand how susceptible this concrete surface is to harsh environments. Table 2-4 indicates the quality of the concrete surface evaluation based on the obtained results in this test.

Table 2.4 ISAT test results indication (Baweja, 1993)

| ISAT absorption After 1 hour (ml/m2.sec) | Concrete Quality |
|---|---|
| < 0.10 | Good |
| 0.1 - 0.2 | average |
| > 0.20 | poor |

# 3. CHAPTER 03 – METHODOLOGY

## 3.1 General

The overall methodology of this research is elaborated in this chapter, which is shown in figure 3.1. The methodology starts with a literature review as a major step in getting to know important aspects such as what is internal curing concrete, the mechanical and durability properties of concrete, and previous research on internal curing aggregates. Moreover, a thorough literature review was carried out on laboratory works that should be conducted on produced ICC with ICCA, which is produced from industrial waste. The details regarding these ICCAs were gathered from previous research that was conducted to produce an ICCA. Furthermore, the gathered information was used to produce the ICCA that is required for this research. As a result, two types of ICCA aggregates were produced from industrial wastes such as FA, RSM, and CCTW. A literature review was discussed in detail in the previous chapter regarding raw materials, HPC, and tests and laboratory experiments that were conducted in this research. Hence in this chapter, the procedures of each other sector are going to be discussed under their respective titles.

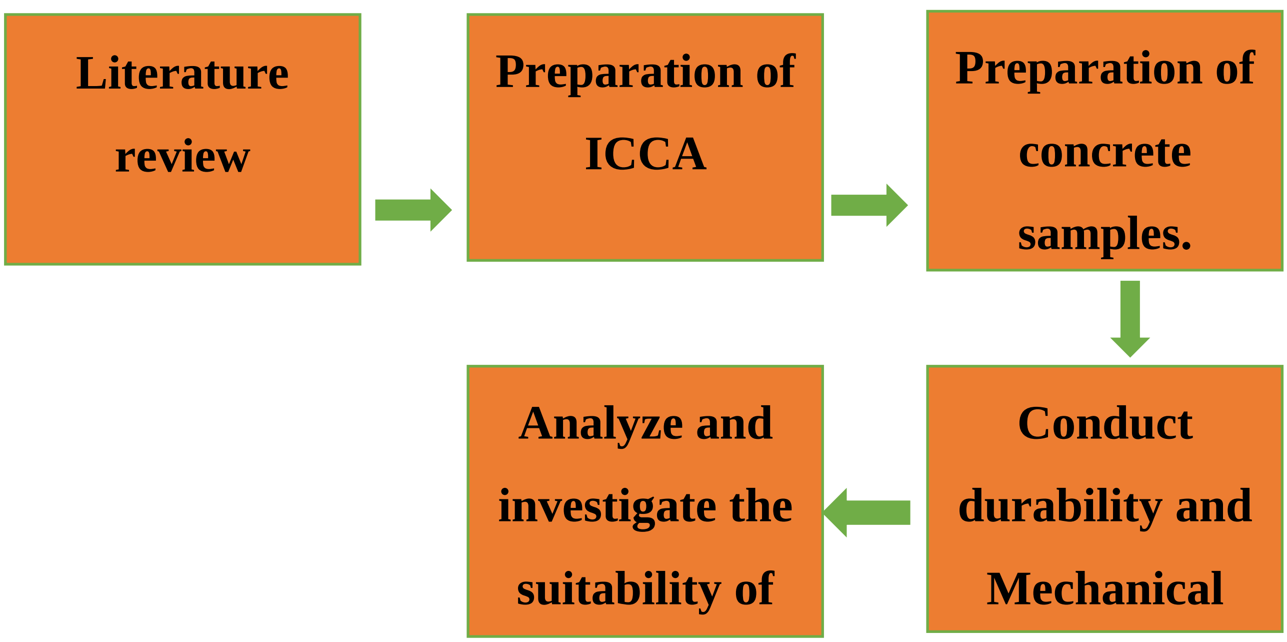



Figure 3-1 Propose methodology.

## 3.2 PREPARATION OF ICCA

Procedures and methodology to produce ICCA from industrial wastes were analysed in earlier studies. In this research, due to time limitations, only two types of ICCA were decided to be analysed in the context of durability and mechanical properties of concrete. Therefore, ICCA produced from industrial waste such as RSM and FA with a water absorption value of 24.1 percent and ICCA produced from CCTW with a water absorption value that varies from 12 percent to 21 percent were considered in this research. It was observed that the procedure for manufacturing ICCA from wastes such as WTS and CCTW is similar, as are the absorption and desorption values. In addition, tile waste ICCA can be easily obtained from the industry. Hence, it was decided to consider both aggregates.

## 3.3 PREPARATION OF FLY ASH ICCA

FA was brought to the site from the location of the Lakvijaya coal power plant, Nooraichcholai, and Puttalam; RSM was collected from an irrigational reservoir located in Kurunagale district, and according to its chemical composition, it was found to be Class F type FA. The proportion of FA and RSM was found to be 80–20 percent to obtain the optimum water absorption and desorption values from previous research (Tharshigan, 2021). Figure 3.2 shows the FA and RSM that were used in this research.


Figure 3-2 Fly Ash and Reservoir Sediment Material

Firstly, the collected RSM was allowed to dry in the sunlight in an open place, then it was crushed and sieved through the 0.6-mm sieve to avoid debris and unwanted materials. Subsequently, FA and RSM were mixed based on the aforementioned proportion.

Secondly, sufficient water was added to the FA and RSM to increase the plasticity of the mix, and clay paste was prepared. Then, the prepared clay paste was sent through the mechanical pugmill to eliminate air content and increase compaction; after that, the expelled clay paste from the pugmill was manually cut into 12–15 mm clay plates by the needle as shown in figure 3.3. After that, the obtained plates were placed into the oven to dry at a temperature of 110 plus or minus 5 degrees Celsius to eliminate the excess water in the cast plates.


Figure 3-3 Prepare clay paste through the pugmill.

Finally, oven-dried clay plates were sent to the industry kiln and sintered at a temperature of 1000 degrees Celsius. It was mentioned in the previous research that with the 1000-degree Celsius heating temperature, a maximum water absorption value of 21.4 percent can be achieved for this ICCA. However, with lower heating temperatures, internal curing properties can be achieved. Even in this research, a heating temperature of 1000 degrees Celsius has been used to produce ICCA since it has a lower desorption value of 74 percent, as mentioned in the previous research.

Figure 3-4 Sintered and Sieved Fly Ash ICCA

Then, sintered clay plates were crushed and sieved through a 4.75-mm sieve to achieve fine ICCA aggregate, as shown in Figure 3.4. Moreover, fine particles smaller than 150 m were avoided to overcome particle loss during the soaking procedure. Here, manual crushing was used to crush the plates due to the unavailability of a mechanical crusher.

## 3.4 PREPARATION TILE WASTE ICCA

The preparation method for ICCA aggregate from CCTW was discussed in the PhD research of M. M. H. W. Bandara, and the same method was discussed in the MSc research of K. I. Pradeep to prepare ICCA from WTS (Bandara & Mampearachchi, 2019; Pradeep, 2021). However, in this research, the ICCA was directly obtained from industry with the water absorption value, which varies from 12 to 21as discussed in the MSc research of K. I. Pradeep to prepare ICCA from WTS. However, in this research, the ICCA was directly obtained from industry with the water absorption value, which varies from 12 to 21%, concerning heating temperatures ranging from 900 to 1100 degrees Celsius. The obtained CCTW internal curing aggregate is given in Figure 3.5 which was obtained directly from the industry in this research.

Figure 3-5 Red clay Calicut Tile ICCA

## 3.5 PREPARATION OF CONCRETE SAMPLES

Two mix designs have been considered to check the mechanical and durability properties of ICC as a alternative material for fine aggregate. Here priority was given to the mix design, which is often used in the current construction industry for pavement construction as normal concrete, and the other one with higher strength, which is considered to evaluate high-performance concrete. The main objective of this research is to evaluate the properties of ICC by comparing them with conventional concrete. Therefore, for the same mix design, conventional concrete and ICC concrete were produced to compare their values. Estimation of the ICCA amount that is required for internal curing is conducted with an equation that is given in the ASTM standard. Further, the same number of fine aggregates were replaced in conventional concrete to produce the ICC, and in some places, an adjustment has been made in the W/C ratio to avoid segregation. Because normally the ICCA increases workability.

### 3.5.1 Materials

Two types of cement were used in each mix design to check their hydration and reaction with ICCA. Hence, Portland Pozzolana Cement (PPC), which contains 25 percent dration and reaction with ICCA. Hence, Portland Pozzolana Cement (PPC), which contains 25 percent FA, was considered in normal concrete because it has been widely used in pavement construction nowadays, while grade 43 Ordinary Portland Cement (OPC) was used in high-performance concrete mix design. Crushed stone with a largest size of 20 mm was taken as coarse aggregate.

Manufactured sand has been considered a fine aggregate for normal mix design since it is widely used as a replacement material for river sand as well as becoming more common in recent industrial mixes, and river sand has been considered a fine aggregate for HPC mix design. To achieve the required properties, admixtures have been added to both mix designs; Sika 316 and Sika 2055 were used for normal concrete and HP concrete mix designs, respectively. Here, the normal concrete mix design was designed to experiment with the ICCA produced from CCTW waste, and the HP concrete mix design was designed to evaluate the properties of the ICCA produced from industrial wastes such as FA and RSM. The water absorption value of FA Internal curing aggregates are higher at 21.4 percent; therefore, they have been selected for HP mix design since mix design has a higher cement content compared to common concrete. The properties of fine aggregate that are used in this research are provided in tables 3.1 and 3.2.

Table 3.1 Particle size distribution of used Fine aggregates.

| **Sieves** | **ICCA passing %** | **River Sand passing %** | **M Sand passing %** |
|---|---|---|---|
| 9.5 mm (3/8) | 100 | 100 | 100 |
| 4.75 mm (#4) | 99 | 99 | 96.4 |
| 2.36 mm (#8) | 63 | 97 | 80.5 |
| 1.18 mm (#16) | 31 | 84 | 58.3 |
| 600 um (#30) | 12 | 44 | 41.6 |
| 300 um (#50) | 4 | 17 | 25.6 |
| 150um (#100) | 1 | 2.5 | 13.2 |
| Pan | NA | NA | NA |

Table 3.2 Water absorption values of used fine aggregates.

| Aggregate type | FA ICCA | CCTW ICCA | M sand | River sand |
|---|---|---|---|---|
| Water absorption value % | 21.4 | 12 - 21 | 0.85 | 1.35 |

### 3.5.2 Mix Design

As above mentioned, two mix designs were considered in this research as per the DOE mix design method, and for each mix, design adjustments have been made to produce ICC according to the given specifications. In the normal concrete mix, grade 30 and 25 concretes were designed to evaluate what is normally used in industry, here called industrial mix design. Moreover, when the ICCA was introduced to this industrial mix, the W/C ratio was reduced by 0.02 to avoid segregation. Whereas, in an HP concrete mix, mixes with W/C ratios of 0.45, 0.42, and 0.38 were designed and evaluated, which is considered a high-performance mix design. Here, we limited the target strength to 50 KN/mm2 because we wanted to check the types of concrete that are commonly used in local constructions. Therefore, in this research, two mix designs were considered: one is an industrial mix design, and the other is a high-performance mix design. In addition, in both mixed designs, different types of ICCA have been used to evaluate. Details of both mixed designs are given in Tables 3-3 and 3-4. Here, 25 to 30 percent of the fine aggregate has been replaced with ICCA.

Table 3.3 Industrial mix design with CTW ICCA

| Mix type | Cement (kg/m3) | Water (kg/m3) | W/C ratio | Fine Aggregate (kg/m3) | Coarse Aggregate (kg/m3) | plasticizer (kg) SIKA 2055 | ICCA (kg/m3) |
|---|---|---|---|---|---|---|---|
| **M1** | 452 | 204 | 0.45 | 690 | 1034 | - | - |
| **M1 I** | 452 | 204 | 0.45 | 491 | 1034 | - | 199 |
| **M2** | 452 | 190 | 0.42 | 690 | 1034 | 2.26 (0.5%) | - |
| **M2 I** | 452 | 190 | 0.42 | 491 | 1034 | 2.26 (0.5%) | 199 |
| **M3** | 475 | 181 | 0.38 | 675 | 1080 | 2.38 (0.5 %) | - |
| **M3 I** | 475 | 181 | 0.38 | 465 | 1080 | 2.38 (0.5%) | 210 |

Water absorption of ICCA = 12 %

Water desorption value of ICCA = 87 %

Table 3.4 High-performance mix design with Fly Ash ICCA

| Mix type | Cement (kg/m3) | Water (kg/m3) | W/C ratio | Fine Aggregate (kg/m3) M sand | Coarse Aggregate (kg/m3) | Admixture (ml) Sika 316 | ICCA (kg/m3) (SSD) |
|---|---|---|---|---|---|---|---|
| M1 | 355 | 172 | 0.48 | 837 | 1086 | 3550 | - |
| M1 I | 355 | 172 | 0.46 | 607 | 1086 | 3550 | 258 |
| M2 | 340 | 172 | 0.51 | 843 | 1095 | 3400 | - |
| M2 I | 340 | 172 | 0.49 | 623 | 1095 | 3400 | 247 |

Water absorption of ICCA = 21.4 %

Water desorption value of ICCA = 72 %

### 3.5.3 Amount of ICCA calculation

The calculation of the required amount of ICCA to achieve the full hydration of cement has been estimated according to ASTM 1761 for CCTW internal curing aggregate because it satisfied the requirement provided in the standard as it has a water desorption value of more than 85 percent and a water absorption value greater than 5 percent.

*Equation 3-1: ICCA amount calculation for ICCA with more than 80 % desorption.*

$$\boldsymbol{M_{agg}} = \frac{\boldsymbol{Cf} \times \boldsymbol{CS} \times \propto_{\boldsymbol{max}}}{\boldsymbol{S} \times \boldsymbol{\varphi}} \quad \text{- ASTM C1761}$$

- $M_{Agg}$ = Mass of (dry) fine ICCA needed per unit volume of concrete (kg/m3 or lb./yd.3),
- Cf = Cement factor (content) for the concrete mixture (kg/m3 or lb./yd.3),
- CS = Chemical shrinkage of cement (g of water/g of cement or lb./lb.),
- $\propto_{\boldsymbol{max}}$= Expected degree of hydration of cement,
- S = Degree of saturation of aggregate (0 to 1)
- $\phi$ = Absorption of IC aggregate (kg water/kg dry ICCA or lb./lb.).

In this equation for a normal concrete mix, chemical shrinkage (Cf) for PPC type cement was considered as 0.07, and the expected degree of hydration is considered as 1, since full hydration of cement was expected by internal curing in this research. Moreover, the degree of saturation (S) has been taken as 1 because all the aggregates were applied in a surface-saturated condition. As it was mentioned above, the water absorption value of ICCA is considered 0.12, and according to the equation, the desorption value is negligible because if the desorption rate value is higher than 85 percent, the aggregate will release more than enough water for internal curing. Thus, this factor is not considered in the equation that is given in the ASTM standard.

On the other hand, for fly ash ICCA, the water desorption value is 74 percent, which is less than 85 percent. Therefore, the above-mentioned equation must be modified. Hence, Castro's modified equation was adopted to calculate the required amount of internal curing aggregate.

Equation 3-2 ICCA amount calculation for ICCA with less than 80% desorption

$$\boldsymbol{M_{agg}} = \frac{\boldsymbol{Cf} \times \boldsymbol{CS} \times \boldsymbol{\propto_{max}}}{\boldsymbol{S} \times \boldsymbol{\varphi} \times \boldsymbol{\psi}}$$

$\psi$ = Desorption factor (desorption of ICCA aggregate at the 94-percentage internal relative humidity)

For the HP mix, the only difference is the addition of the desorption factor, which is 0.74, and the water absorption value is considered to be 0.214, besides all the other factors remaining the same as in the normal mix.

## 3.6 ACHIEVE SSD CONDITION OF ICCA

Appropriate saturation of the ICCA is needed to confirm the appropriate performance of internally cured concrete. Therefore, ICCA should be uniformly wetted and absorb optimal amounts of water. Saturation was achieved by submerging the ICCA into the water tanks for a minimum of 24 hours. However, it can be achieved by spraying water on the stockpile with a sprinkler system. It was also checked, and it achieved the SSD condition by submerging it in water. Here in my research, ICCA aggregate was soaked for 48 hours, after which those aggregates were spread on the nonabsorbent surface and allowed to dry for 10 to 15 hours in gentle moving air to remove excess moisture from the surface. Then a water absorption test was conducted according to ASTM 128 to make sure the surface saturated dry condition of aggregate had been achieved.

### 3.6.1 Procedure

- To measure the water absorption, more than 500 g of sample was taken in different locations and kept on an inclined, nonabsorbent surface to allow the excess water to drain.
- Subsequently, they were placed in the commercial-grade brown paper towels and spread, and padding was done with another small size of brown paper (paper tissue can also be used to speed up the padding process).
- A small brush was used to remove stuck materials during the padding process, and the spreading and padding process was repeated until a dry, saturated surface was

achieved.where the bottom brown paper was continuously replaced if it became too damp or dirty to absorb moisture.

- The above-mentioned procedure was conducted until no moisture appeared on the paper towel, and it has been concluded as an SSD condition.
- After that, the sample was weighed immediately to the nearest 0.1 g and recorded as $W_{ssd}$. Subsequently, the sample was placed in the oven and dried to a constant weight at 110 degrees Celsius for more than 24 hours.
- Then the oven-dry sample was recorded as Wod, and the weight of the container was also determined to the closest 0.1 g. Finally, the water absorption value was estimated from the below-mentioned equation.
- Similarly, water absorption value can be easily obtained with a moisture analyzer, which is available at the site without the equation.

*Equation 3-3 Water absorption calculation*

$$W_{LWA}=\frac{W_{SSD}-W_{OD}}{W_{OD}}$$

-ASTM C1761

$W_{LWA}$= Mass of water released at 94 % relative humidity

## 3.7 SAMPLE CASTING

Samples for each test were cast according to the ASTM C31 standard. Internal curing of the concrete batching has been conducted as per the given specifications. Firstly, ICCA aggregate was soaked in water to obtain SSD condition. Then those samples were allowed to dry in an open space with gentle moving air for 10 to 15 hours. Secondly, calculated ICC aggregate was batched into the mechanical concrete mixer; after that, fine aggregate was batched, and both were authorised to blend for two minutes to get the proper mixing. Thirdly, the coarse aggregate was added and mixed for 1 minute. Subsequently, cement was included and mixed for additional minute.

Figure 3-6 Materials arrangement for concrete sample batching

*Figure 3-7: casting of concrete samples*

Finally, admixture was included into the portion of the mixing water and inserted into the mixture in two stages as parts. Moreover, the mixing procedure was done for 7 to 8 minutes after the inclusion of water. Whereas the same procedure was carried out for conventional concrete without ICC aggregate. Figures 3.6 and 3.7 show the casting of concrete samples for this research.

Table 3.5: Concrete samples details for industrial mix design with CTW ICCA.

| Mix type | Remarks | Casted Samples (mm) |
|---|---|---|
| **M1** | Normal concrete with 0.51 W/C ratio | 48 cubes (150×150×150) |
| | | 12 cylinders (100 ×200) |
| **M2** | Normal concrete with 0.48 W/C ratio | 48 cubes (150×150×150) |
| | | 12 cylinders (100×200) |
| **M1 I** | Internal Curing concrete with 0.49 W/C ratio | 24 cubes (150×150×150) |
| | | 6 cylinders (100×200) |
| **M2 I** | Internal Curing concrete with 0.46 W/C ratio | 24 cubes (150×150×150) |
| | | 6 cylinders (100×200) |

Tables 3.5 and 3.6 show the prepared sample lists for testing of normal concrete and HPC, respectively. The above-mentioned concrete samples were cast for tests such as compressive strength, statical modulus of elasticity, initial surface absorption, water penetration, saturated water absorption, rapid chloride ion penetration, and surface resistivity tests. Here, approximately four hundred 150mm×150mm×150mm cubes were cast, including trial mixes to identify the required amount of admixture. In addition, more than a hundred 100mm ×200mm and more than forty 150mm ×300mm size cylinders were cast to check the mechanical and durability properties of internal curing concrete. Every sample castings were done based on ASTM and BS standards as per the requirements.

Table 3.6: Sample details of High-performance mix design.

| Mix Type | Remarks | Samples to be casted |
|---|---|---|
| **M1** | Normal concrete with 0.45 W/C ratio | 42 cubes (150mm×150mm×150mm) |
| | | 12 cylinders (100 mm ×200 mm) |
| | | 12 cylinders (150 mm ×300 mm) |
| **M2** | Normal concrete with 0.42 W/C ratio | 42 cubes(150mm×150mm×150mm) |
| | | 12 cylinders (100 mm ×200 mm) |
| | | 6 cylinders (150 mm ×300 mm) |
| **M3** | Normal concrete with 0.38 W/C ratio | 42 cubes (150mm×150mm×150mm) |
| | | 12 cylinders (100 mm ×200 mm) |
| | | 6 cylinders (150 mm ×300 mm) |
| **M1 I** | Internal Curing concrete with 0.45 W/C ratio | 21 cubes (150mm×150mm×150mm) |
| | | 6 cylinders (100 mm ×200 mm) |
| | | 3 cylinders (150 mm ×300 mm) |
| **M2 I** | Internal Curing concrete with 0.42 W/C ratio | 21 cubes (150mm×150mm×150mm) |
| | | 6 cylinders (100 mm ×200 mm) |
| | | 3 cylinders (150 mm ×300 mm) |
| **M3 I** | Internal Curing concrete with 0.38 W/C ratio | 21 cubes (150mm×150mm×150mm) |
| | | 6 cylinders (100 mm ×200 mm) |
| | | 3 cylinders (150 mm ×300 mm) |

## 3.8 Curing of samples

Curing is essential for concrete to achieve the intended performance, and it helps to improve the hydration process. This research aims to compare the results of different curing conditions, such as internal curing, conventional curing, and nom-curing. Internal curing was provided with different internal curing aggregates manufactured from industrial wastes, and conventional curing was given by submerging the samples in the curing chambers until they reached their prior ages. Moreover, non-curing was achieved by keeping the sample in the laboratory without providing any curing conditions. These three types of curing conditions were chosen to evaluate the efficiency of internal curing provided by manufactured ICCA. Therefore, in every grade of conventional concrete, one part was allowed to soak in the curing tank to obtain conventional curing, and other parts were kept in the laboratory without any curing conditions. Internal curing samples were also kept in the laboratory without any other curing condition to assess the worst field condition. Hence, after the demolding procedure, these three categories of curing samples were subjected to their respective curing conditions until their testing days. Figures 3.8, 3.9, and 3.10 show testing samples for respective curing conditions.


Figure 3-8: External curing concrete samples.

Figure 3-9: Internal curing samples.

Figure 3-10: Non-curing samples.

### 3.9 Mechanical and Durability tests

Checking the mechanical and durability properties is essential when an alternative material has been used in concrete because it will affect those properties, either positively or negatively. Therefore, when we replace the fine aggregate with ICCA, their behaviours should be analyzed, and that is a major objective of this research as well. In this research, compressive strength and workability are selected as mechanical properties to check, as well as the static modulus of elasticity, which has been checked additionally for high-performance concrete mix samples. Moreover, to check the durability properties of concrete, tests such as initial surface absorption, water penetration, saturated water absorption, rapid chloride ion penetration, and surface resistivity tests have been considered.

When we considered the selection of durability tests, more consideration was given to the permeability-related tests because these ICC aggregates are highly absorbent, which is more than ten percent. Hence, in this research, ion permeability, water permeability, and water absorption by capillary action were checked. Furthermore, the drying shrinkage of these IC concrete samples was initially intended to be carried out, but it was analysed many times in previous research and positive results were observed in all of them; thus, this test was omitted due to time restrictions.

Also, the saturated water absorption test was selected to ensure the results obtained in the water penetration test because with water penetration test results alone, we cannot conclude the results. Here are some durability tests that were not considered in previous research on internal curing concrete. However, major tests related to durability were conducted. All tests that were carried out in this research are discussed in detail in their respective headings below.

#### 3.9.1 Compressive strength

The compressive strength of concrete was checked according to the BS 1881–116:1983 standard to assess its ability to resist specific compressive forces. During this test, the same W/C ratio factors, such as quality control, production method, and quality of the concrete material, were kept under control for all the samples to avoid any other variations. The compressive strength was checked at the ages of 7, 14, 28, and 56 for each mix design. Further, for each specific age, three 150mm150mm150mm cubic samples were checked, and an average has been taken. The load was applied gradually over the specimens at a rate of 140 kg/cm2/minute, and the load at which the specimen failed was noted as its failure load, as it is shown in figure 3.11. And the surface area of the applied load was measured, and compressive strength was noted by dividing the force by the surface area.


Figure 3-11: Compressive strength test.

## 3.10 Workability

The ease with which the person can work with concrete can be defined as workability," and this can be measured by the slump cone test. During each batching of concrete samples, the workability of each mix was measured by the BS 1881-102:1983 standard. Here, metallic cone moulds with a size of 30 cm in height, 20 cm in bottom diameter, and 10 cm in top diameter were selected. Then it was kept on a flat steel base plate, and the inner surfaces of the mould and base plate were coated with mould oil to avoid sticking concrete to their surfaces.

Concrete was poured into the mould in three stages immediately after the completion of the mixing procedure. In each of the three stages, one-third of the cone was filled and tamped by the steel rod, which had dimensions of 60 cm in height and 16 mm in diameter. Moreover, for compaction, 25 blows were given by the rod in every stage of filling. Subsequently, after the top layer was tamped, the surface of the top was levelled with the trowel, and the mould was removed by hoisting it gradually in the perpendicular path. Finally, the variation in level between the peak of the mould and that of the maximum point of the settled concrete was determined and noted as its workability. Here, for each specific mix type, the slump was checked more than three times, and the range of the slump value was noted as the workability of that mix since workability changes with climate and material moisture for every batching. Figure 3.12 shows the workability test that was done in this research.

Figure 3-12: Workability test.

### 3.11 Static modulus of elasticity

The static modulus of elasticity helps to understand how much concrete can deform elastically, so it is an important mechanical parameter to be analyzed. In this research, only high-performance concrete mix samples were submitted to the modulus of elasticity test. This test was conducted by ASTM C469. 150 mm300 mm cylindrical samples were cast for each mix type and tested at the age of 28 days. Firstly, one sample was subjected to a compressive strength test and a failure load was noted, then three cylindrical samples were selected to test for each mix type.

The system of clamps was installed in the specimen, which contains the compressometer that can measure the vertical displacements. Also, the setup was installed so that the sample stays in the middle of the compressometer. Then the setup was placed in a compressive strength test machine, and load was employed at a pace of 2 KN/sec up to 40 percent of ultimate load that was measured in the compressive strength test earlier. At the beginning of the loading process, the dial gauge was set to zero, and then for every 5 KN compressive load increment, the dial gauge reading was noted down. After that, deformation was obtained from the dial gauge reading, and it was changed to strain by dividing it by the original length. Finally, stress against strain was plotted, and the static modulus of elasticity was attained according to the equation given in the standard. Figure 3.12 describes the procedure of the static modulus of elasticity test, which was done in this research.

Figure 3-13: Static modulus of elasticity test.

### 3.12 Surface resistivity test (SR test)

The SR test is a simple and widely used method to analyse the resistivity of concrete against chloride ion permeability, and there are several methods available to conduct the surface resistivity test. Here, Wenner's four-point method was used to measure the surface resistivity by RILEM TC 154, the EMC standard. Specimens with dimensions of 100 mm and 200 mm were cast and tested at the ages of 7, 14, 21, and 28 days. In every age group, three samples were tested, and an average was taken. This test can be conducted only at saturated surface conditions; thus, internal curing and non-curing samples were soaked in water before the testing to achieve saturated surface conditions.

Firstly, each specimen was marked at the locations of 0, 90, 180, and 270 degrees, and the centre of the longitudinal surface was also marked. At the beginning of the tests, a sample was taken from the curing tank, and excess water on the surface was wiped out with a towel. Subsequently, the specimen was set up on the sample holder, and the reading was taken at the 0 degree mark, as shown in figure 3.13. Then the sample was rotated 90 degrees, and another reading was taken. As above mentioned, a total of eight readings were taken for every sample, and in this way, for one mix type, 24 readings were taken, and the average has been taken.

Figure 3-14: Surface Resistivity test.

### 3.13 Initial surface absorption test (ISAT)

This test is usually conducted to evaluate the quality of a concrete surface on 150mm  150mm  150mm cubic samples. The rate of water absorption on the surface was measured at a steady head of 200 mm, which is considered a general field condition. This test was conducted according to the BS 1881-part 1 standard. Three samples were checked for every mix design at the ages of 7 and 28 days, and the average has been taken as the final results. This test can be done for either an oven-dried sample or a non-oven-dried sample. However, in this test, we have done experiments with oven-dried samples.

First, the apparatus was calibrated as described in the standard, and the capillary tube was scaled for 180 divisions based on the calibrated radius; here, each division represents 0.01 $ml/m^2/sec$. Then samples were oven dried at a temperature of 105  5 °C for 24 hours until they reached a constant mass. Subsequently, they were kept in the open space to bring them into ambient temperature, and the temperature at the testing surface was measured during the test. Then the sample was tightly fixed in the chamber, and all the inlet and outlet flexible tubes were connected. After that, the reservoir was filled and set up at a distance of 200 mm plus or minus 20 mm from the concrete surface. Then, the reservoir valve was opened, and the initial time was noted down. All the air bubbles that were trapped inside the capillary tube were eliminated during the test.

From the initial time, reading was taken at intervals of 10 minutes, 30 minutes, and 1 hour. At this specific time interval, the reservoir valve was closed, and the stopwatch was started when the meniscus reached the zero mark at the capillary tube. After 5 seconds, the number of divisions that the meniscus had moved in the capillary tube was recorded. If the 5-second reading was less than 3, two minutes of reading were taken, and if it was between 3 and 9, one minute of reading was taken. In addition, if it was between 10 and 30, then 30 seconds of reading were taken. Figure 3.14 shows the apparatus arrangement for this ISAT test.

Then all readings at 10 minutes, 30 minutes, and an hour were converted to 1-minute readings to conclude the final results. Finally, the initial water absorption value of concrete was noted at intervals of 10, 30, and 1 hour, and temperature correction was applied by multiplying them with the factors given in the standards.

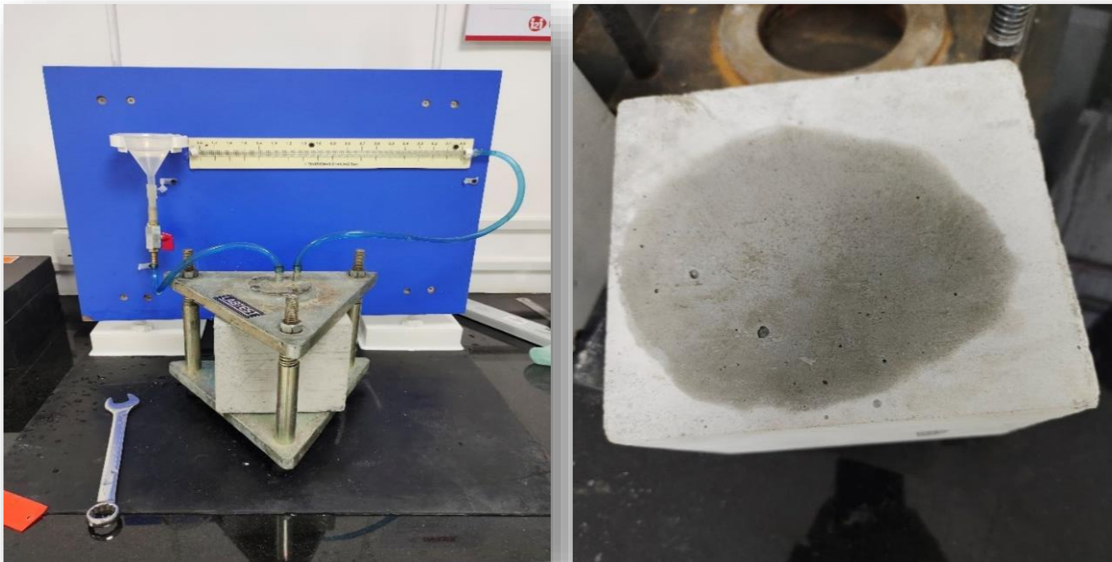


Figure 3-15: saturated water absorption test.

## 3.14 Water penetration test

This test helps to understand the durability of concrete based on the water penetration depth of hardened concrete under constant pressure. Three 150mm  150mm  150mm size samples for each mix were checked, and average results have been taken by DIN 1048-part 5 of the German standard. Moreover, the test was conducted between the ages of 28 and 56 days, since this test cannot be done at an early age. In the beginning, specimens were oven-dried at 105  5 °C for 24 hours to see the depth of penetration, and they were kept in the open to bring them to ambient temperature. Then all the samples were fixed tightly in the testing chamber and sealed with a material made of rubber in such a approach that the cast surface was vertical to the testing surface.

After the specimen was stationed in the chamber, water was applied to the specimen at a pressure of 500 kPa plus or minus 50 kPa for a period of 72 hours plus or minus 2 hours. After the specific time, water pressure was released, and the specimen was removed from the chamber. Then the excess water was wiped out, and samples were placed in the compressive testing machine to be split into two halves from the center. Subsequently, within a minute, water spots were marked by the marker in split samples to measure the depth of penetration. Finally, the highest distance between the top of the concrete surface and the water surface has been considered the depth of penetration for that sample. In this way, three samples were checked, and the average has been taken for the final result, as shown in figure 3.15.

Figure 3-16: Water permeability test.

### 3.15 Rapid Chloride ion penetration test

The rapid chloride ion penetration test gives the direct amount of charge that passes through the concrete sample, which generally indicates the amount of chloride ion penetration into the concrete sample. Moreover, this test is widely used as a durability test in the concrete industry. This test and surface resistivity tests are related. However, this test cannot be done at the early age of concrete, as per the standard. In this test, 50-mm-high and 100-mm-diameter samples were checked at the ages of 28 and 56 for each mix type by ASTM 1202. First, 100-mm-diameter and 200-mm-high samples were cast and allowed to reach their respective curing conditions. Then, in every sample, two pieces of 100 mm  50 mm samples were cut and painted with waterproof coating, and in each age group, a total of three samples were checked for every category. After that, painted samples were allowed to dry for more than 2 hours until they became nonsticky, then samples were subjected to conditioning. In the conditioning procedure, at the beginning, samples were kept inside the vacuum desiccator, and the vacuum pump was started to work for 3 hours at a pressure of less than 1 mm Hg while the desiccator was fully sealed. Subsequently, water was poured into the desiccator until it covered the entire sample, and the pump was allowed to run for one more hour. At the end of conditioning, the pump was stopped, and samples were allowed to be kept underwater for 18 hours plus or minus two hours.

Secondly, samples were taken out of the desiccator, and water on the surface was wiped out with a towel. Then, they were fixed between two cells and covered with a rubber cover. Also, specimens were sealed with sealant to avoid moisture movement. Then, both cells were filled with solutions of NaCl and NaOH, here one cell was filled with 0.3 % NaCl, and the other one was filled with 0.3 N NaOH. Finally, electrical connections were made, and samples were subjected to a 60 V current. This test was carried out for 6 hours and at the end of the test, the total amount of charge passed through each sample was noted by the use of computer-aided software. The results were

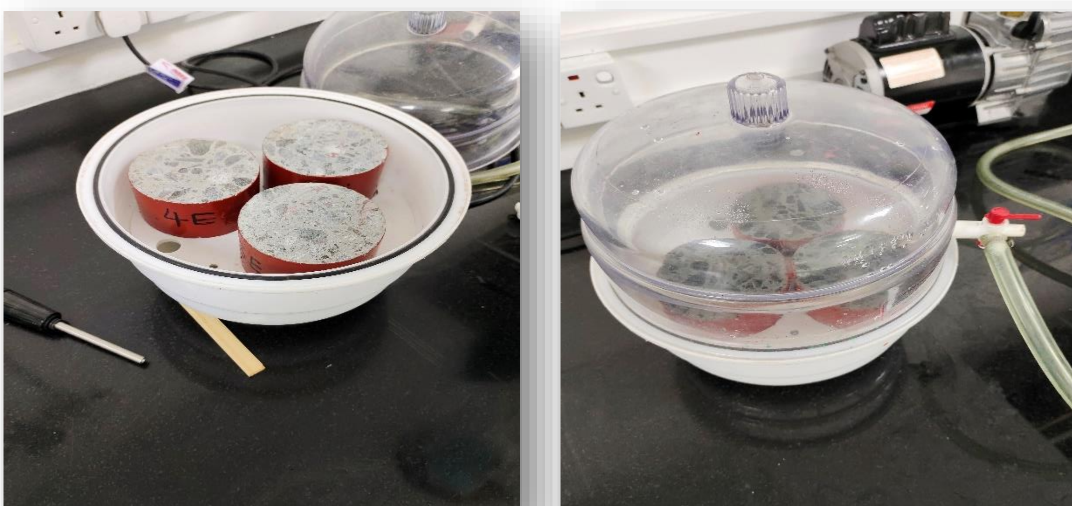


Figure 3-17: Seasoning in RCPT test.

calibrated to standard size according to the given equation in the standard. Figure 3.17 and figure 3.18 show the arrangement of the RCPT test apparatus and sample

Equation 3-4 Calibration equation for obtained results in RCPT test.

$$Q_S = Q_x(\frac{95}{x})^2$$

-ASTM C1761

$Q_S$= Charge passes through the 95 mm diameter sample

$Q_X$= Charge passes through the x mm diameter sample

x = Diameter of non-standard sample

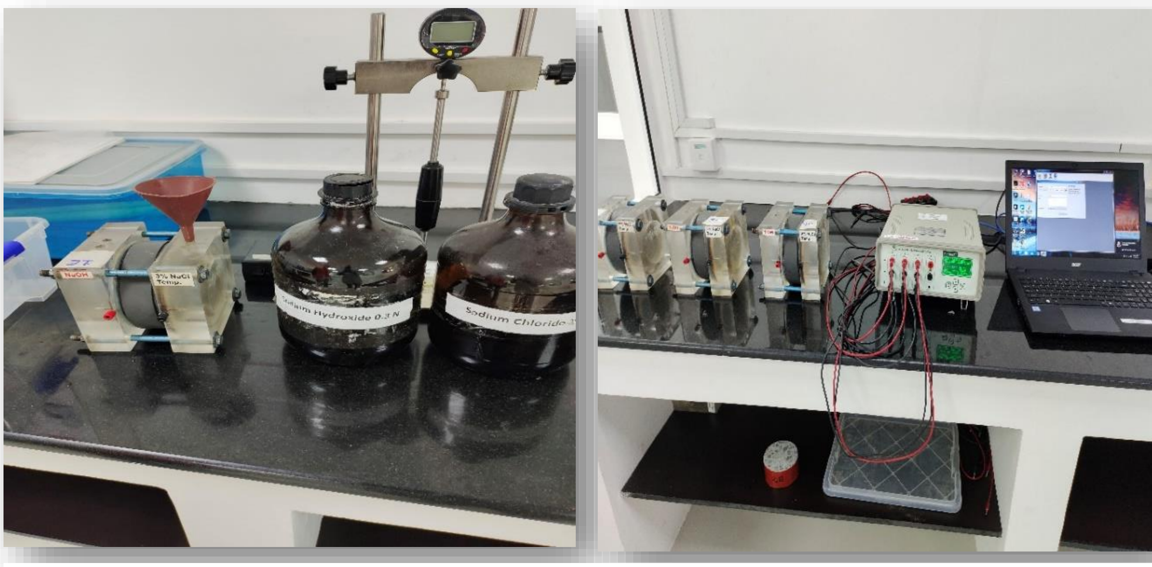



Figure 3-18: Testing of RCPT samples.

### 3.16 Saturated water absorption test

A saturated water absorption test is usually carried out for evaluating the water absorption of concrete by capillary action without pressure differentiation. In addition, this test is useful to understand the results of the water penetration test. Three 150mm 150mm 150mm cubic samples were checked at the ages of 7 and 28, and an average has been taken. Firstly, samples were oven dried at a temperature of 105  5 °C for more than 24 hours until they reached the constant mass shown in figure 3.19. Subsequently, they were kept in the open space to bring them to ambient temperature. Secondly, the mass of dry samples was determined and noted. Then, samples were soaked in the water until it reached a constant mass; after that, they were taken out and the excess was wiped out with a towel. Finally, the weight of the saturated sample was determined and observed. Then the water absorption value was measured with the equation given in the standard.

$$\text{Percentage water absorption} = \frac{W_s - W_0}{W_o} \times 100 \text{ Where,}$$

$W_s$= weight of the specimen at fully saturated condition

$W_0$ = weight of oven dried specimen.

Figure 3-19: Saturated water absorption test.

# 4. CHAPTER 04 – EXPERIMENTAL RESULTS AND DISCUSSION

## 4.1 General

All the findings and obtained results on conducted experiments are discussed in this chapter. Here tests results of workability, compressive strength, surface resistivity, rapid chloride ion penetration, initial Surface absorption test, water penetration test and saturated water absorption test results are discussed on their respective headings. Each test contains three sample types which are External Curing (EC), Internal Curing (IC) and Non-Curing (NC). Moreover, here two sets of mix designs were considered, one for industrial mix design with Calicut tile waste ICCA and another one for high performance concrete with Fly Ash ICCA. In addition to that, in industrial mix design, two grades were considered which were grade C25 and C30 with W/C ratios of 0.51 and 0.48 whereas in high-performance mix design, three mix were evaluated with W/C ratios of 0.45, 0.42 and 0.38.

## 4.2 Workability

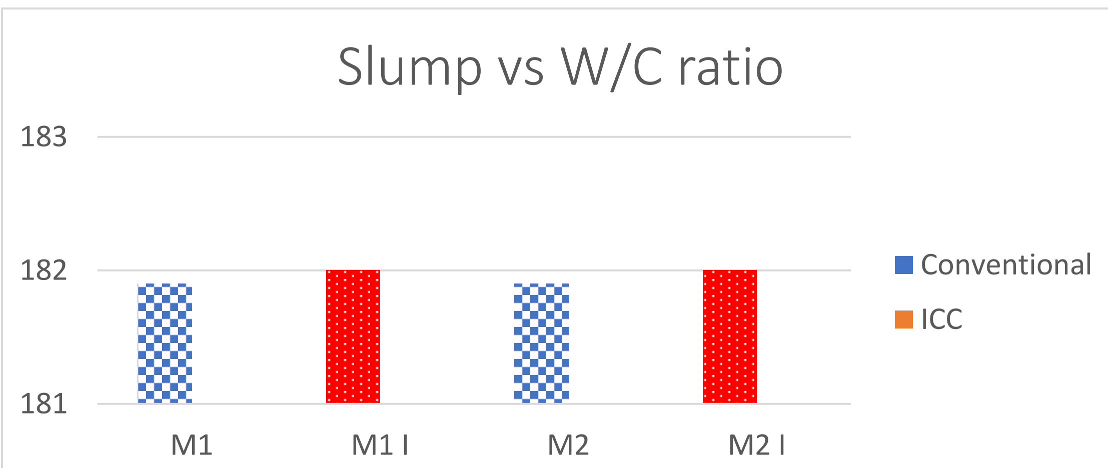



Figure 4-1 Slump values of industrial mix with CTW ICCA

Here for industrial mix, a higher slump value was noticed compared to traditional mix even after W/C ratio was reduced by 0.02 for ICC mix. This happened because of the additional water released by the ICCA during the batching. Therefore, by reducing W/C ratio more strength gaining can be achievable for approximately same workability. Moreover, it was observed that increment in slump value is reduced with a reduction in W/C ratio. However, there is no big difference for mix with higher W/C ratio values.

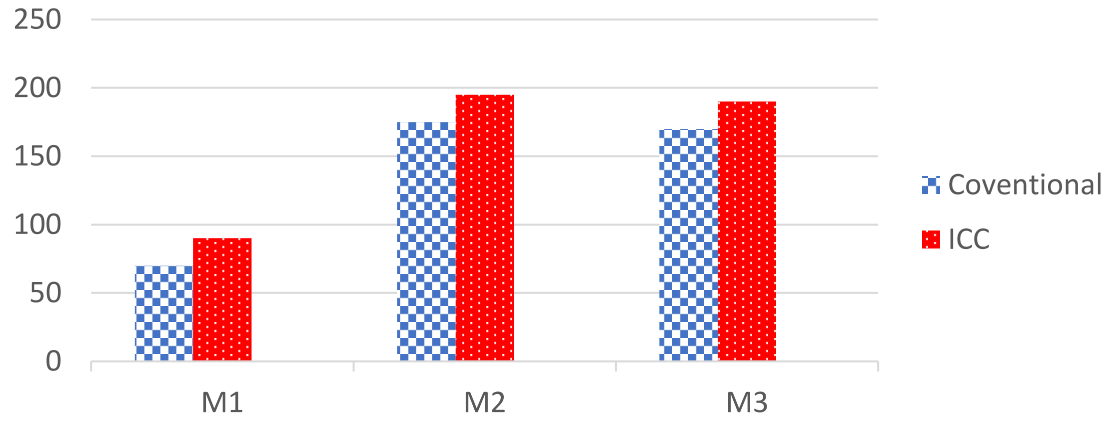



Figure 4-2: Slump details of high-performance mix with FA ICCA.

In High performance concrete mix, for IC sample, significant increment has been observed in slump value compared to the traditional concrete. For W/C ratio 0.45, even though water reducing admixture was not used, slump has increased by approximately 30 percent. However, for 0.42 and 0.38 W/C ratios, increment in slump has recorded as approximately 15 percent. This reduction in increment percentage has occurred due to the introduction of water reducing admixture. This increment in slump will help to achieve additional strength by reducing the W/C ratio with the constant cement substance because it is not part of the mixing water.

## 4.3 Compressive strength

Obtained results of compressive strength test for industrial mix are given in below figure 4.3. Here, M1 E, and M2 E represent the samples of 0.48 and 0.51 external curing samples while M1 N and M2 N represent their non-curing samples. Whereas M1 I and M2 I indicate the internal curing samples with w/c ratio of 0.46 and 0.49 respectively.

In this industrial mix compressive strength results, it can be clearly seen that the non-curing samples show lower compressive strength value at 7, 14 and 28 days compared to internal curing sample and external curing samples because there is not enough water to fully hydrate the cement due to the loss of water by evaporation and other loss. However, if we consider the 7 days samples, it shows nearly same as external curing samples because at the beginning there might be enough water for required hydration. Moreover, if we consider the internal curing samples, it indicates higher compressive strength than external curing samples because this ICCA will release the water all over the concrete at lower humidity and this water induces the hydration of cement. Therefore, we can achieve higher strength with the same or slightly higher flow.

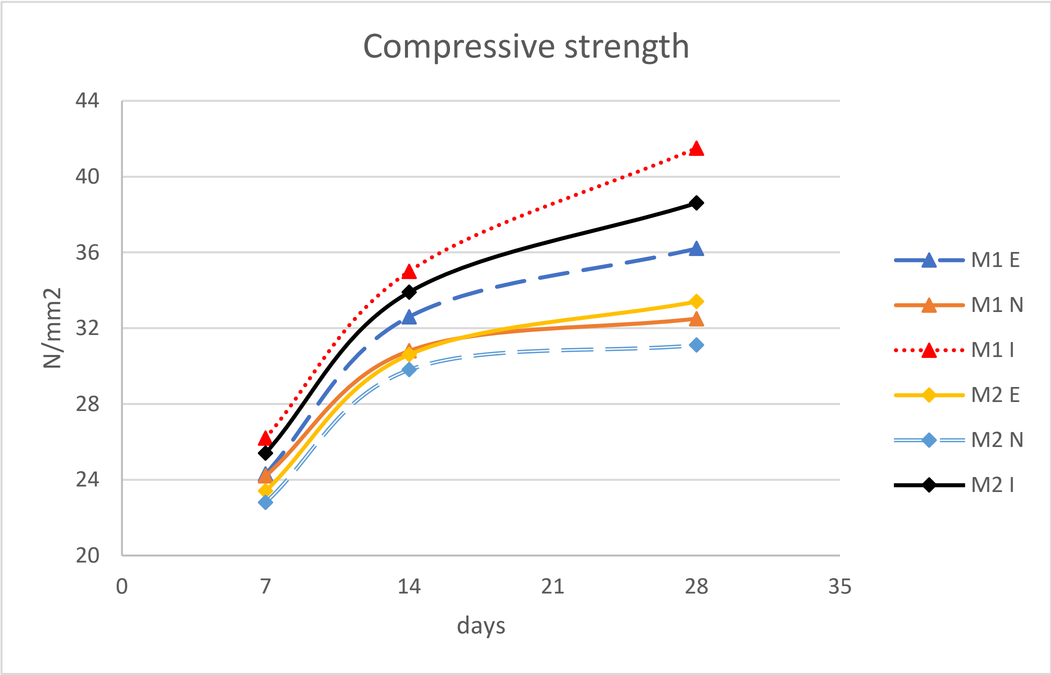



Figure 4-3 Comparison of industrial mix compressive strength values

As per figure 4.3 compressive strength gradually increases for internal curing concrete especially grade 25 (M2 I) internal curing samples show higher compressive strength value than grade 30 (M1 E) external curing samples. Therefore, contractors who use this ICCA can reduce the cement content and can get financial benefit. As per obtained results, at the end of 28 days internal curing samples show nearly 12 percent to 15 percent increment in compressive strength while maintaining the same slump value of concrete. This slump is obtained due to the water release by this ICCA during the mixing which is not part of the mixing water of concrete.

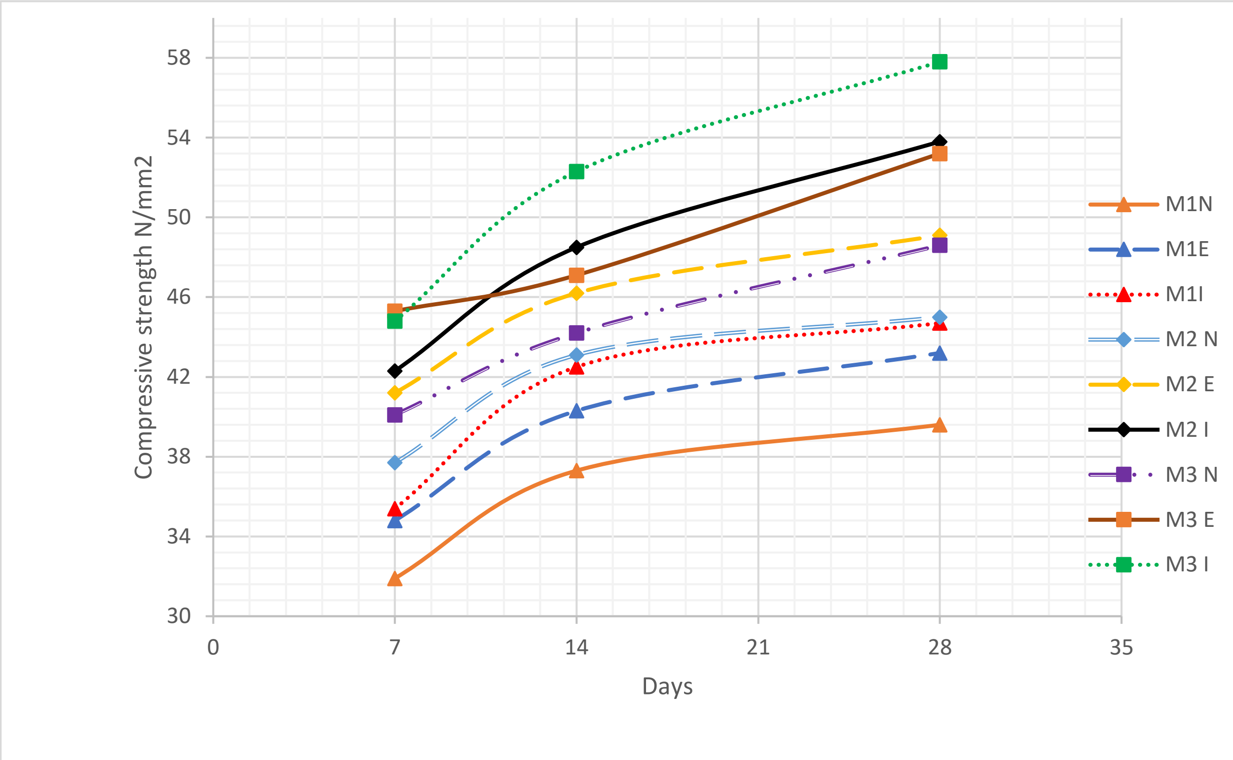



Figure 4-4 Comparison of high-performance concrete mix compressive strength results

As it was discussed earlier for industrial mix design, high performance mix also indicated the same behavior. However, here the increment rate in the compressive strength of concrete has increased with the reduction of W/C ratio as it is shown in figure 4.4. At 7 days internal curing samples and external curing samples show approximately same strength and non-curing samples display lower value due to loss of water by evaporation at early age. Moreover, for lower W/C ratio mix, significant deviation was observed in compressive strength between internal curing and non-curing samples even at 14 days because for the traditional concrete when W/C ratio is lower, external water cannot be penetrated through the concrete. However, in internal curing samples water is available throughout the whole concrete for hydration. That is why internal curing concrete samples provide higher strength than external curing samples. At the end of 28 days internal curing samples indicate 5 to 9 percent increment in compressive strength compared to external curing samples without adjusting the W/C ratio. It means with higher slump value than traditional concrete internal curing concrete gave higher compressive strength.

## 4.4 Surface Resistivity

The surface resistivity test results of industrial mix design at the ages of 7, 14, 21 and 28 days for external curing, non-curing and internal curing samples as well as their comparisons are explained in figure 4.5.

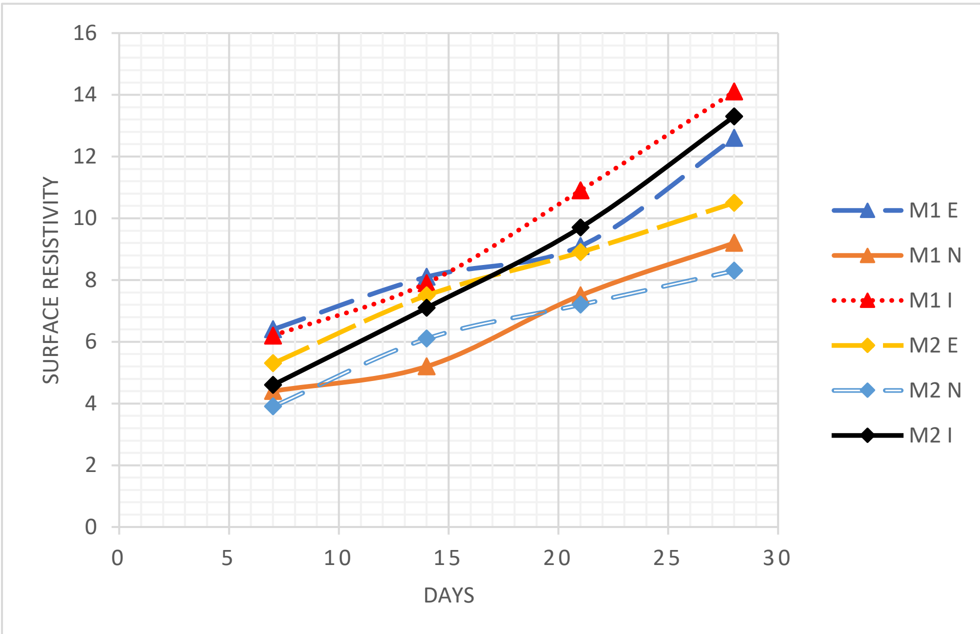



Figure 4-5 Comparison of SR test values of industrial mix

Surface resistivity test for the industrial mix with red clay ICCA indicated that higher restriction against chloride ion permeability was obtained for internal curing samples in industrial mix design. At early ages of 7 days and 14 days, external curing samples showed higher resistivity compared to the internal curing samples. In contrary, non-curing samples showed lower resistivity among three types of samples. It is identified that due to the connectivity of pores in the ICCA during early ages, these internal curing samples indicated lower resistance. However, it showed higher value than non-curing samples. Also at 14 days, difference of resistivity value between internal curing samples and external curing samples have been reduced significantly and showed nearly same value. In 28 days, it was clearly observed that internal curing samples showed significantly higher resistivity than external curing samples as shown in figure 4.5 because interconnectivity of pores in internal curing samples was reduced due to induced hydration of cement particles.

Therefore, we can say that this red clay ICCA helps to achieve higher hydration as well as it provides more durability to the concrete.

When we see the test results of high-performance concrete samples with fly ash ICCA as it is shown in figure 4.6. It showed rapid improvement in resistivity even at 14 days since this ICCA possess higher water absorption value of 24.1 percent. Moreover, when we consider the W/C ratio, the increment rate of resistivity against the permeability increases when W/C ratio decreases because when the W/C ratio reduces this ICCA behaves more effectively. Further, we can conclude that for both ICC aggregates durability against permeability of this internal concrete is increased compared to the conventional concrete.

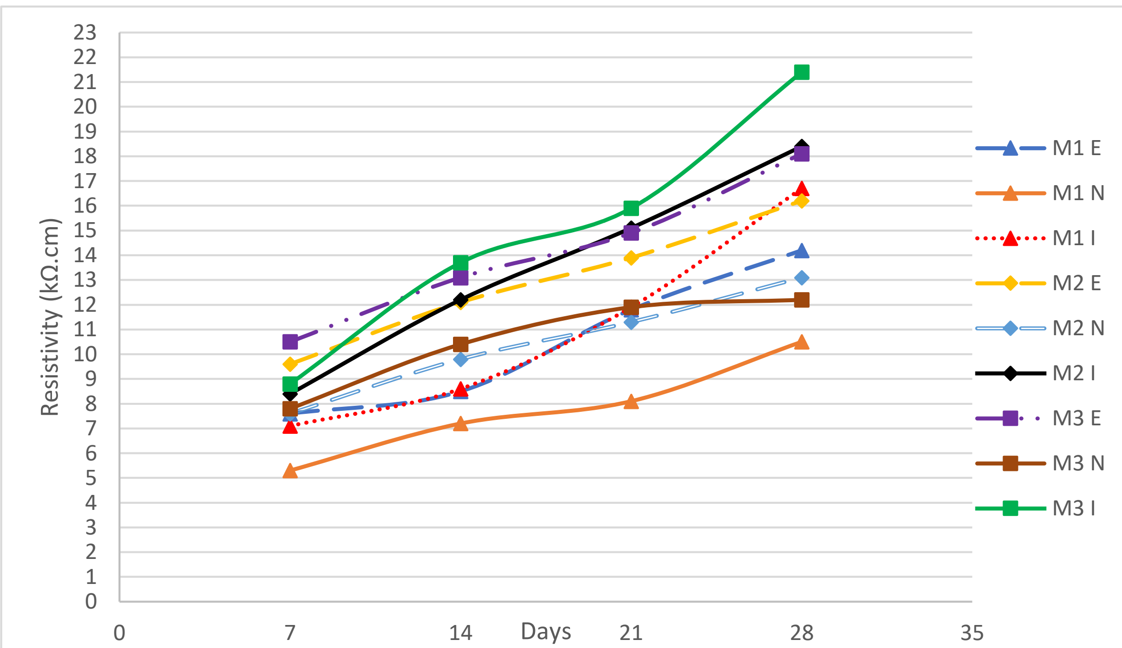



Figure 4-6Comparison of SR test values of High-performance concrete

## 4.5 Rapid Chloride Permeability Test Results

RCPT test results of industrial mix design indicated that at 28 days internal curing samples showed lower chloride ion permeability compared to external curing and non-curing samples. Moreover, non-curing samples showed the highest permeability of chloride ion as it showed in surface resistivity test because in non-curing samples interconnected pores are high compared to internal curing samples and external curing samples. Comparison of RCPT test results are explained in figure 4.7.

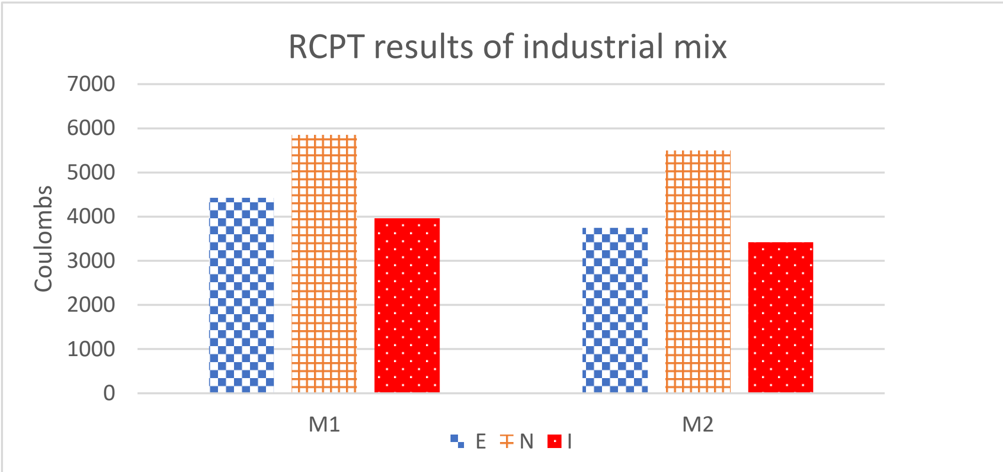



Figure 4-7 Comparison of RCPT results of industrial mix

As per figure 4.7, internal curing samples contain lower inter connectivity pore structures compared to external curing samples hence permeability of chloride ions through the internal curing samples comparatively low. Moreover, in non-curing samples interconnective pores are higher due to poor hydration of cement particles since there is water loss due to evaporation and other factors. Here we can see that chloride ion penetration of grade 25 internal curing concrete falls from high to moderate due to the presence of internal curing. In addition, grade 30 concrete samples also showed great improvement in resistivity against chloride-ion for internal curing samples. Therefore, RCPT test results of industrial mix design with CCTW ICCA indicates that this red clay ICCA is increasing the durability of concrete. Application of this ICCA reduces the chloride ion permeability from high to moderate according to ASTM standard.

If considering the test results of high-performance mix as it shows in the figure 4.8, it follows same behaviours as industrial mix design as non-curing samples show higher amount of penetration of chloride ions and internal curing samples show lower amount of chloride ion penetration which is even lower than external curing samples. These results help to ensure the results from surface resistivity test since these both tests are correlated. It is also indicated that inclusion of this ICCA reduces the chloride ion penetration from high to moderate due to the induced hydration of concrete by internal curing water. Therefore, it concludes that Internal curing concrete is more durable than external curing concrete in the name of chloride ion penetration which is major consideration in durability.

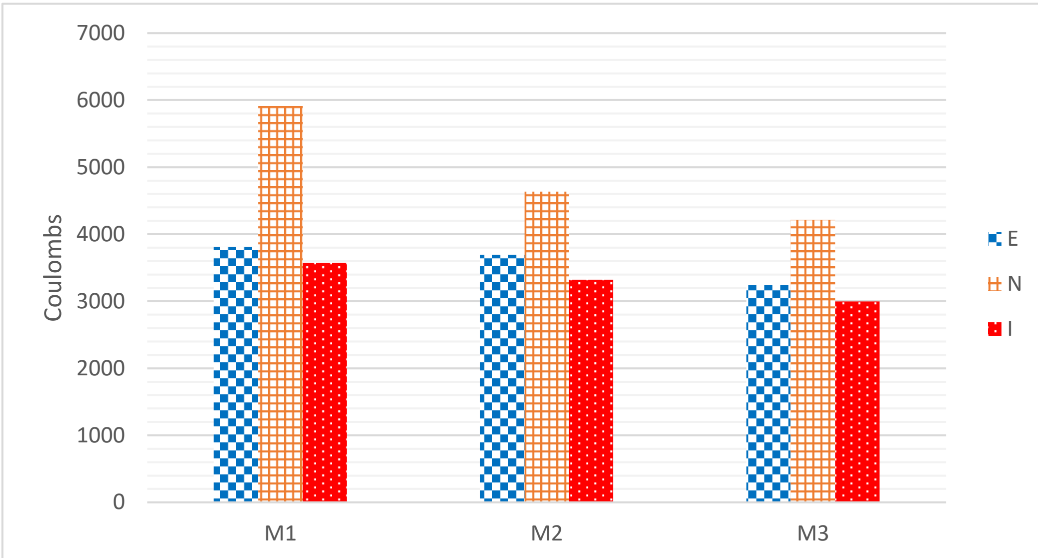
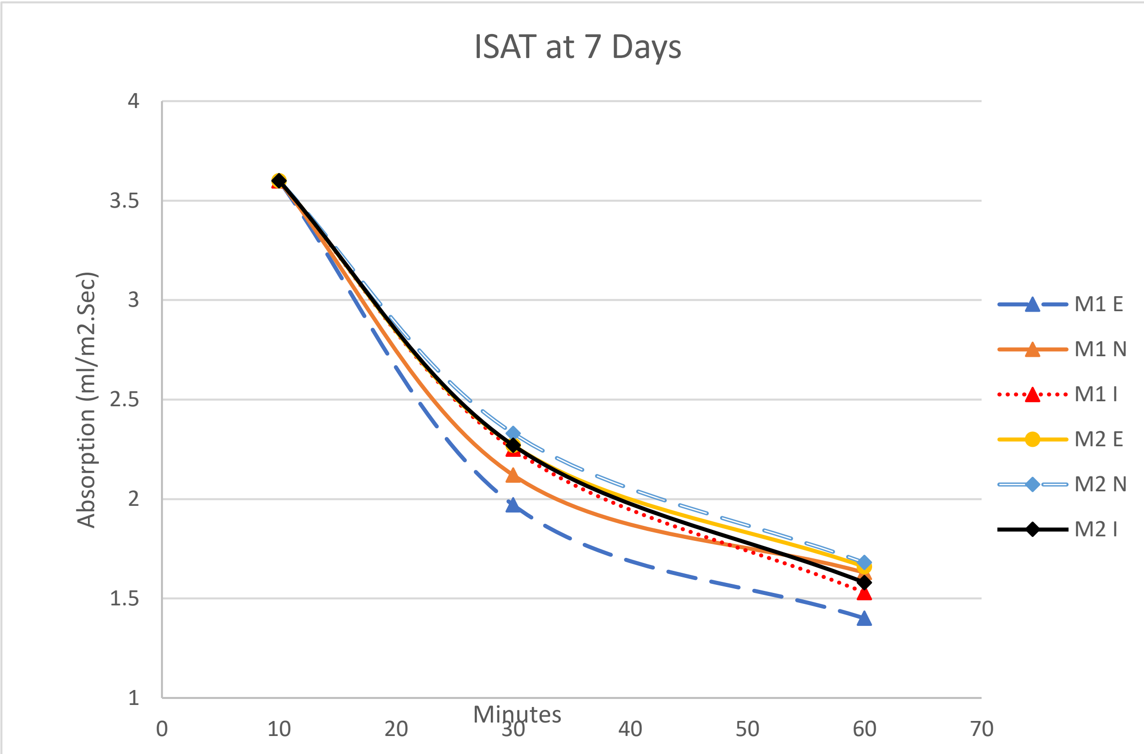


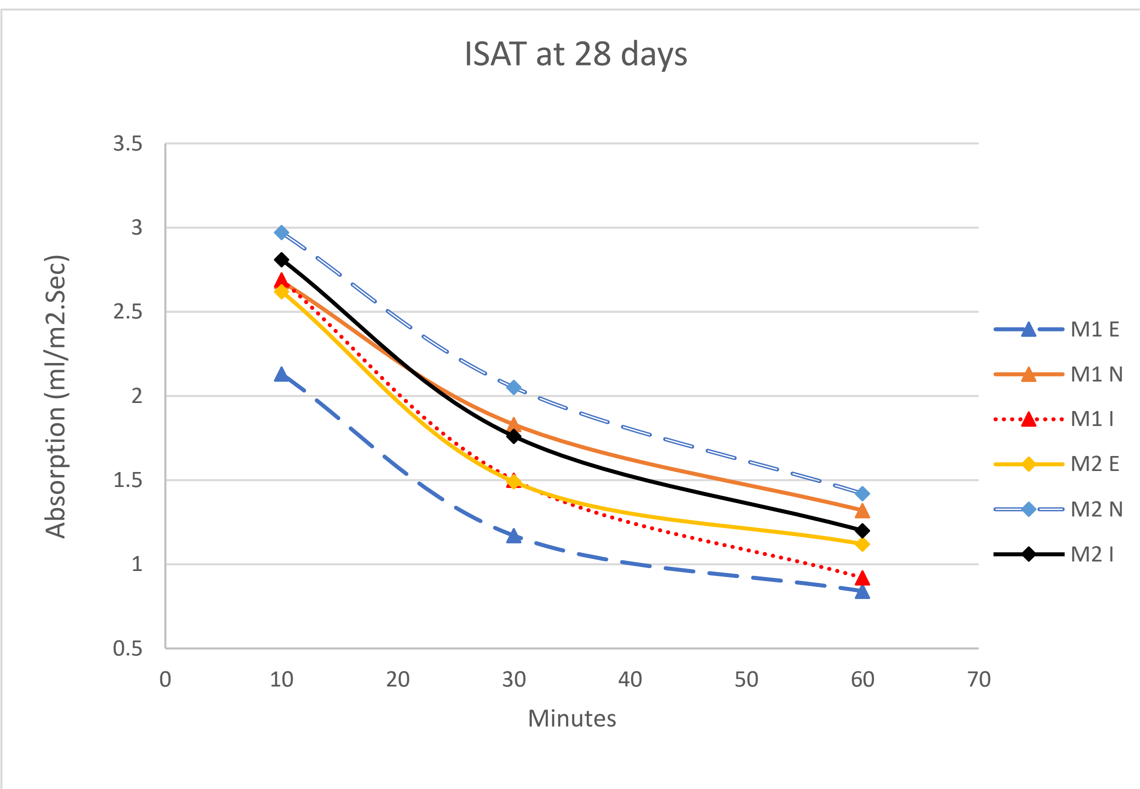

Figure 4-8 Comparison of RCPT results of High-performance concrete mix

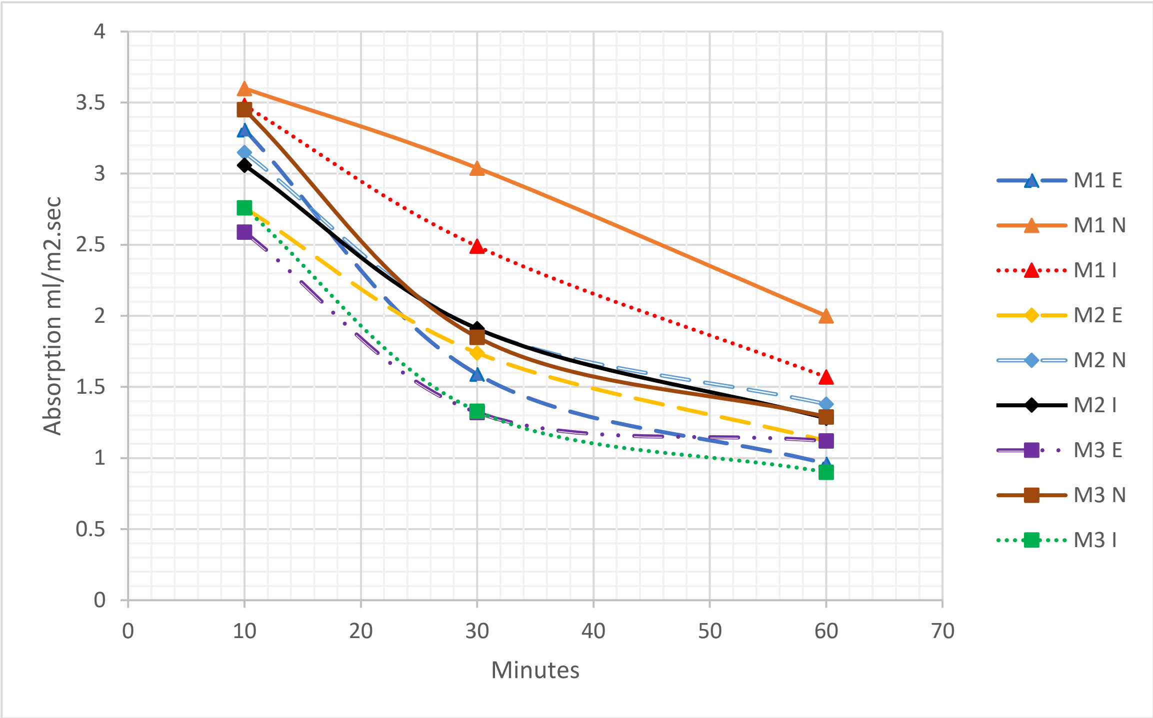
### 4.6 Initial surface absorption test results

As it shows in the below figure 4.9 for industrial mix samples, at 7 days, 10 minutes reading showed maximum initial absorption value of 3.6 ml/m2.sec for all internal curing, external curing and non-curing samples since it is the maximum reading that can be measured in the apparatus. However, 30 minutes reading and 1 hour reading indicated that lower absorption rate for external curing sample and higher initial absorption value for internal curing sample even higher than the non-curing samples at 7 days because in the early ages there is a higher interconnectivity of pores which located in the inside of ICCA. These pores may be connected with concrete pore structures. Therefore, ICCA which is located in the surface of concrete absorbed higher water and it leads to higher initial surface absorption.

However, when you see the 28 days results, even though internal curing samples showed higher absorption at 10 minutes reading, 30 minutes and 1-hour readings indicated lower absorption value nearly same as external curing samples. As usual non-curing samples showed higher initial absorption compared to other samples due to the poor hydration. Hence, we can say that this red clay ICCA shows higher absorption at early ages because of higher absorption of ICCA at the surface. However, when hydration takes place, initial absorption reduces as well as durability increases.





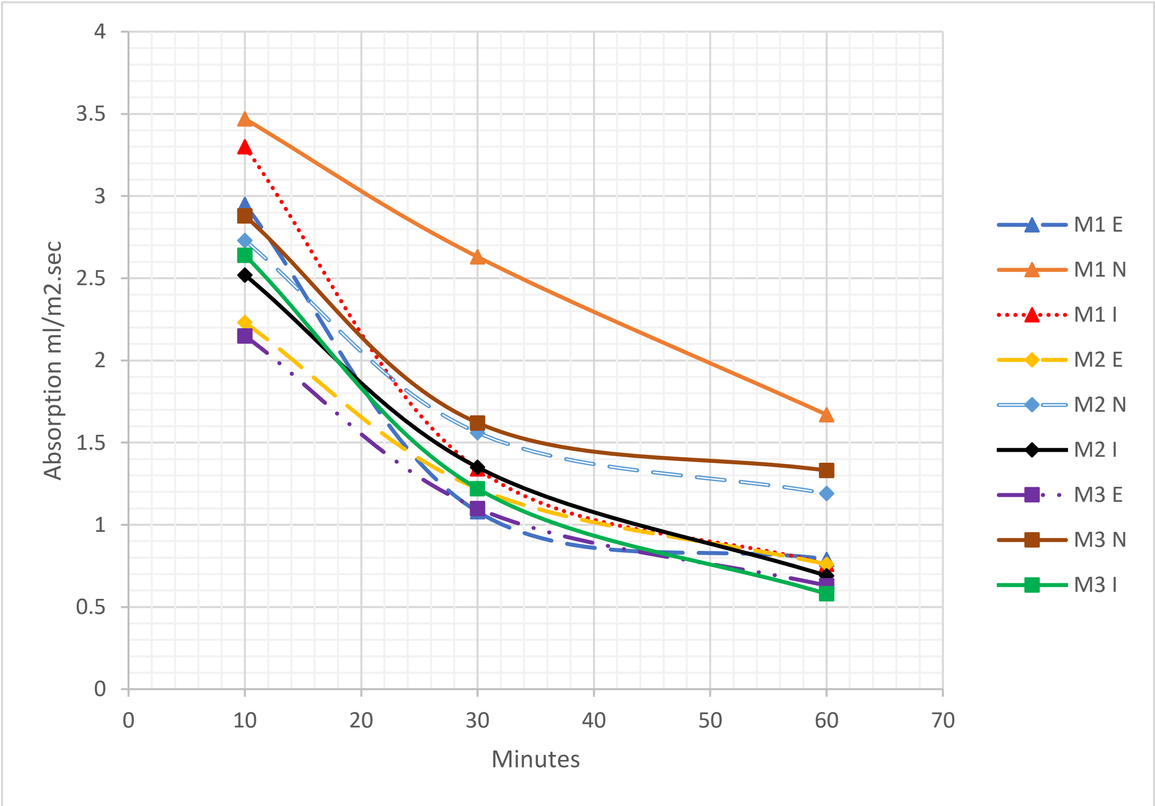




Figure 4-10 Comparison of ISAT test results of high-performance mix with FA ICCA at 7 days.

If we consider the ISAT results of high-performance mix, at 7 days as it given in figure 4.10, internal curing samples show slightly higher 10 minutes absorption than external curing samples and less 10 minutes absorption than non-curing samples but there is no significant variation. However, in 30 minutes reading and one hour reading we can see significant deviation in readings as internal curing samples show higher absorption than external curing samples and less absorption than non-curing samples because in the early ages there is a higher interconnectivity of pores which are located inside of ICCA. Therefore, ICCA which is located in the surface of concrete absorbed higher water. When we see the 28 days results even at 30 minutes reading, internal curing samples absorb nearly same surface water as external curing samples. Considering the 1 hour reading internal curing samples absorb less water than external and non-curing samples because of reduction in interconnectivity of pore structure in concrete due to the hydration.

## 4.7 Water permeability test

Table 4.1 shows the depth of penetration values from water permeability test at 28 days and 56 days.

Table 4.1: Depth of water penetration of industrial mix with CTW ICCA.

| **Type** | **W/C Ratio** | **Water permeability at 28 days (mm)** | **Water permeability at 56 days (mm)** |
|---|---|---|---|
| M1 E | 0.48 | 117.3 | 102.6 |
| M1 N | | Flow through | 142 |
| M1 I | 0.46 | 122 | 105 |
| M2 E | 0.51 | 91 | 64 |
| M2 N | | Flow through | 122 |
| M2 I | 0.49 | 94 | 69 |

Table 4.1 shows 28 days and 56 days depth of penetration of concrete samples under higher pressure. From the above results we can see that approximately the same depth of penetration obtained for internal curing samples and external curing samples. Whereas non-curing samples showed higher penetration even at 28 days water passed through the whole depth of concrete samples. Here internal curing samples indicated slightly higher depth of penetration at higher pressure compared to external curing samples due to the pore structure of this ICCA because when higher pressure is applied to this ICCA, there might be a leakage through the ICCA. However, it is not bigger than non-curing samples. Therefore, we can say that this ICCA improves the quality of concrete when it comes to durability.

Table 4.2 Depth of penetration for high-performance mix with FA ICCA

| **Type** | **W/C Ratio** | **Water permeability at 28 days (mm)** | **Water permeability at 56 days (mm)** |
|---|---|---|---|
| M1 E | | 67 | 62 |
| M1 N | | 129.5 | 117.2 |
| M1 I | | 82.3 | 71.7 |
| M2 E | | 53 | 46.3 |
| M2 N | | 100.4 | 92.5 |
| M2 I | | 73 | 58 |
| M3 E | | 51 | 50.4 |
| M3 N | | 91.4 | 84.4 |
| M3 I | | 77 | 65.2 |

Based on table 4.2, the High-performance mix design also indicated that, inclusion of this ICCA as a partial replacement for the fine aggregate will reduce the water penetration at higher pressure compared to the non-curing samples. However, depth of penetration under higher pressure for internal curing samples is slightly more than external curing samples as it is given in the table because when higher pressure is applied to these concrete samples, water passes through the pores inside the aggregate as well. However, due to the better hydration of cement particles, the depth of penetration is significantly smaller than the non-curing samples. Therefore, when we use this ICCA for water retaining structures it is better to examine the penetration of water on required pressure.

## 4.8 Saturated water absorption test results

The below figure 4.11 gives results of saturated water absorption value of concrete samples at 7 days and 28 days. Here at 7 days internal curing samples showed higher absorption value than external curing sample and lower absorption value than non-curing samples because at early ages there will be a path to water penetrate through the concrete surface. In addition, this ICCA will absorb higher water due to their pore structure. However, after 28 days internal curing samples showed lower absorption than external curing samples and non-curing samples because due the hydration of concrete, interconnected pores gets closed thus there will be no path for water to penetrate into the concrete. Therefore, rate of absorption reduces with age of concrete for internal curing samples. Further, non-curing samples showed higher absorption among three types of samples because there will be higher pore structure inside the concrete samples due to incomplete hydration.

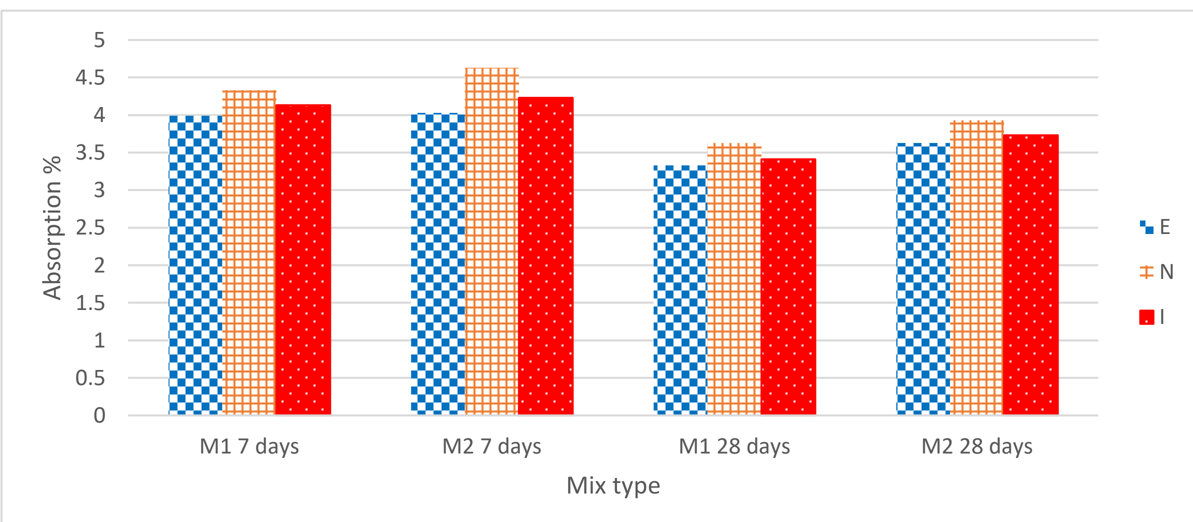



Figure 4-11 Comparison of SWA test results of industrial mix CTW ICCA

When we refer the saturated water absorption test results of high-performance concrete samples with fly ash internal curing aggregate as it shows in the below figure 4.12, 7 days saturated water absorption values of high-performance mix indicates that internal curing samples show lesser absorption than non-curing samples and slightly higher absorption than external curing samples. Reason for this result is at an early age this ICCA will absorb more water from outside when it leaves the water for cement hydration since it has higher water absorption value.

However, in 28 days  internal curing samples show nearly same absorption as external curing samples because when hydration occurs, all the path for penetration of water to inside the concrete will be closed due the induced hydration. Which means less amount of water will be penetrated through the concrete compared to other concrete samples. Moreover, from the initial surface absorption test we can conclude that water will not penetrate through the higher depth. Therefore, we can say that this internal curing concrete can be considered as more durable than external curing concrete.

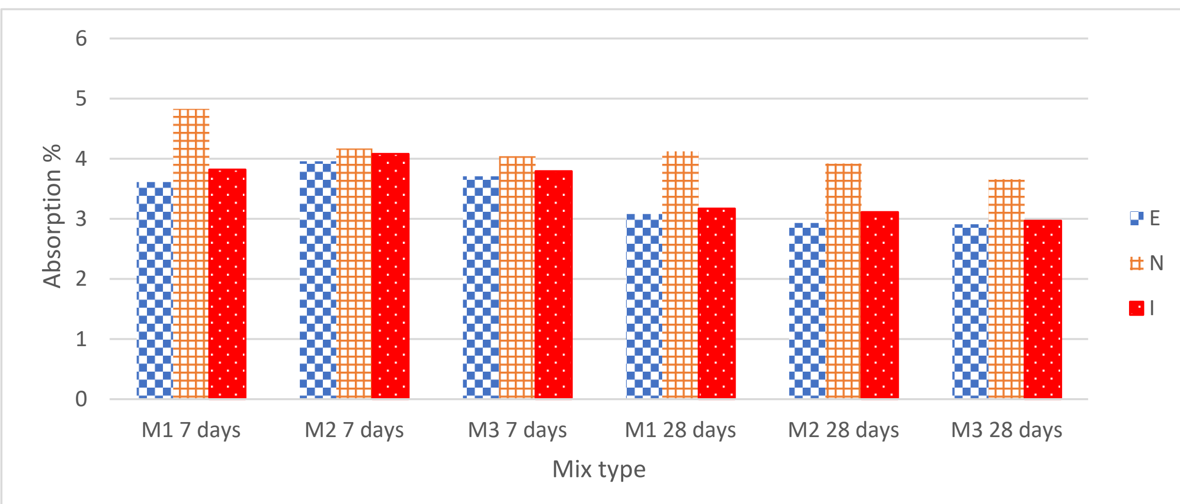



Figure 4-12 Comparison of SWA test results of high-performance mix with FA ICCA

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### 4.9 Statistic elastic modulus of elasticity test results

According to Figure 4.13, we can say that there is significant drop in the static modulus of elasticity when we add this ICCA in to the concrete as it is reduced by 11.5 percent to 13.5 percent compared to external curing samples. This effect was encountered in earlier research as well with different internal curing aggregates. Also, non-curing samples showed a 9 percent to 12 percent reduction in static modulus of elasticity compared to the external curing samples. This reduction in internal curing samples static modulus of elasticity Compared to the external curing samples cannot be concluded as negative impact until we check the tensile strength of these concrete samples. However, when we see the compressive strength of these samples, internal curing samples show higher compressive strength than external curing samples. Therefore, it cannot be portrayed as a negative impact until we check the tensile strength of concrete samples. Normally, when we apply ICCA, tensile strength reduces according to earlier research. Therefore, if it occurs here as well it will be more advantages to this aggregate.

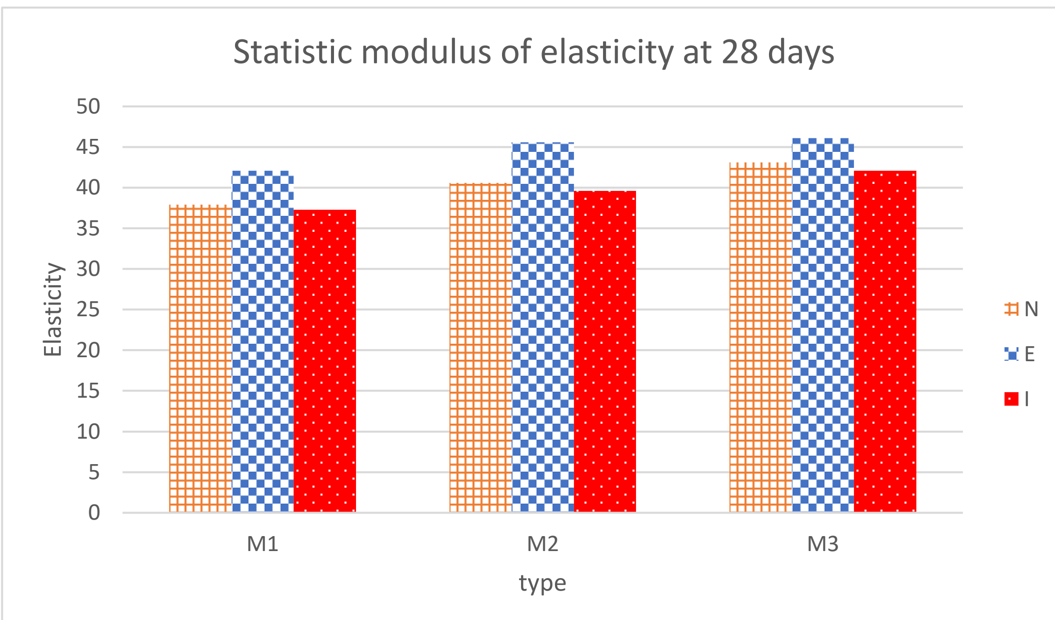


Figure 4-13 comparison of Statistic modulus of elasticity test results of High-performance mix

# 5. CHAPTER 5- CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In summary, target of this research was to examine the mechanical and durability characteristics of internal-curing concrete that included ICCA as a partial subtitute for fine aggregates made from industrial waste. Among three types of ICCA aggregates, ICCA produced from Fly Ash and Reservoir Sediment Material, and ICCA produced from Red Clay Calicut tile waste were selected for this research to analyze since this Red Clay Calicut ICCA and water treatment sludge ICCA acquire slightly the similar properties and behavior. To check mechanical properties, Compressive strength, workability, and statistic modulus of elasticity tests were selected, and to check the durability properties Surface resistivity, Rapid Chloride ion Permeability, Initial Surface Absorption, water penetration, and saturated water absorption tests were conducted. Moreover, to compare the effect of internal curing of this ICCA in concrete, three types of curing samples were evaluated which are internal curing samples, external curing samples, and non-curing samples.

When used in place of some of the ICCA fine aggregate in concrete, these ICCA aggregates boost workability by 15% to 20%. As a result, we can further reduce the W/C ratio and increase strength. Additionally, due to the induced hydration by the internal curing action, employing these ICCA aggregates as a substitute material for fine aggregate significantly boosts the compressive strength of concrete by 5 to 15%. As a result, we can use less cement to economically reach the desired strength. The Fly Ash ICCA static modulus of elasticity test revealed that when we use this ICCA as a partial replacement for fine aggregate, the static modulus of elasticity will decrease. Nonetheless, it was frequently observed in past studies using different internal curing aggregates as ICCA it gave same reduction in elasticity. But, here we experienced the increment in compressive strength and reduction in modulus of elasticity, hence, the tensile strength of this concrete should be checked and evaluated.

When it comes to the durability of internal curing concrete with these internal curing aggregates, these ICCAs increase the durability of the concrete considerably. Surface resistivity test results showed that these ICCAs increase the resistivity of internal curing concrete by 9 to 17 percent at 28 days. Moreover, rapid chloride ion penetration test results showed the same results as the surface resistivity test since there was a substantial decrease in chloride ion penetration when we apply these ICCA as a replacement material for fine aggregate. Further, initial surface absorption test results showed that, even though internal curing samples absorb higher water initially, it reduces with time, and at 28 days surface absorption reduces significantly and shows great resistance against surface absorption which shows great frost resistance. Also, water penetration test results showed a slightly higher depth of penetration for internal curing concrete compared to external curing conventional concrete. However, results showed that internal curing concrete achieved lower depth penetration than non-curing concrete samples. Therefore, although it showed better results, internal curing concrete with these ICCAs should be analyzed before it is used in the water retaining structures. Also, saturated water absorption test results showed that external curing samples and internal curing samples have given approximately the same saturated water absorption values. Thus, we can say that internal curing aggregate with ICCA aggregates is more durable than conventional external curing concrete.

It is clear that using these ICCA aggregates to substitute fine aggregate in concrete will be more cost-effective and provide a solution to the existing demand for river sand. The mechanical qualities and durability of internal curing concrete will increase when these ICCA are used as replacements for fine aggregate.

## 5.2 Recommendations

In this research, only a partial amount of these ICCA was replaced in concrete which is required for internal curing, and we achieved better results. Therefore, further research should be conducted to check the optimum level of replacement amount. Also, the tensile strength of internal curing concrete is to be checked for further evaluation. To produce the internal curing concrete with this ICCA specification is drafted thus for more details review that specification.

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