THE EFFECT OF EFFECTIVE MICROORGANISM SOLUTION AS SELF-CURING AGENT ON PROPERTIES OF CONCRETE

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DEDICATION

This thesis is dedicated unreservedly to **my father Dr. Sufi Saleem Pervez Memon**, who not only taught me that the best kind of knowledge to have is that which is learned for its own sake but also encouraged me to have faith in my own potential and to never let the flame of hope flicker. It is also dedicated to **my mother Shahnaz Shaheen**, who taught me that if one step is taken at a time, even the greatest tasks can be accomplished. Her prayers and love gave me hope all along my stay in Malaysia. It is also dedicated to **my sisters Irum Pervez and Amrat Pervez** without whose moral support accomplishment of my work would have been mundane and tedious. It is also dedicated to **my late uncle Engr. Ameer Ahmed Memon** who encouraged me to pursue my education in a foreign country. **My wife Uroosa Memon** also deserves dedication because she has been a very compassionate partner, and her support and care has continuously strengthened my will and effort. This thesis was written during worldwide lockdown due to coronavirus pandemic. I would also dedicate it to all **front-line fighters** against **COVID-19** including doctors, nurses, police and all those people who lost their lives.

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ABSTRACT

The curing process ensures progress of hydration reactions which cause filling and discontinuity of capillary voids by hydrated compounds in newly placed concrete. In real practice, proper curing is a challenging task to achieve in structural elements such as inclined structures, high-rise buildings or structure with the thickness of concrete is large. Improper curing leads towards the poor quality of concrete. The objective and scope of the research is on examining the potential of Effective Microorganism (EM) solution as a self-curing agent to achieve the same or comparable properties of self-curing concrete (SCC) in air curing and normal concrete in water curing. The EM is eco-friendly bacterial solution used in agriculture. In methodology, three grades of concrete mixture were produced i.e. grade 30, grade 35 and grade 40 to analyse water loss from concrete and the effect of improper curing on concrete strength. The initial properties of tap water, EM solution and EM-water solution were investigated and identified. The optimisation of SCC with EM was based on the hardened properties of concrete. Six concrete mixtures were produced; one was normal concrete grade 30 (control) and other five mixtures were SCC in which the mixing water was replaced with EM by 5% to 25%. In order to determine the mechanism and internal composition of concrete in both curing regimes, microstructure analysis have been carried out. Results and discussion revealed that maximum water loss of 2% was recorded for grade 30. At the age of 28 days, the concrete sample in air curing experienced 23% less strength compared to samples in water curing. EM has low surface tension which makes it reliable for a self-curing agent. Thermal gravimetric analysis (TGA) results also showed that the EM evaporates at higher temperature than mixing water. The workability increased with increase of replacing percentage of water with EM. The slump testing was found in the range of 70–220 mm. The results also showed that the SCC with 10% of EM gave higher results of compressive strength of 53 MPa at 28 days in water curing. In air curing, SCC with 10% EM gained strength of 42 MPa, its strength was close to the strength of control concrete (43 MPa) in water curing. The water absorption and void of concrete were reduced with 10% of EM in SCC. Internal relative humidity (IRH) of SCC was found between 85-90% at 28 days with 10% EM, which is a favourable condition for complete hydration process compared to control concrete that ranges between 74-76% in air curing regime. It was noticed that the inclusion of 10% EM reduced temperature of SCC by 1-2°C. The 10% EM also showed 43% and 45% reduction in shrinkage and expansion, respectively in SCC as compared with control concrete. Result of the Scanning Electron Microscope-Energy Dispersive X-Ray (SEM-EDX) showed that concrete with 10% EM had a compact structure with fewer voids. TGA results revealed that 10% SCC gained 19% and 11% more C-S-H gel than control concrete in air curing and water curing, respectively. All the results showed that 10% of EM is the optimum value to get the desirable properties of SCC. Based on the findings, it is concluded that EM can be used in normal strength concrete to encounter improper curing as an efficient self-curing agent. The use of EM would not only contribute to the development of environmentally friendly materials, but also to the reduction of the emission of CO_2 and the depletion of the earth's natural resources. The novelty of this research is the EM solution used as a self-curing agent. The contribution in the field of self-curing concrete is that it helps concrete to achieve the desired properties by changing the physical characteristics of mixing water.

ABSTRAK

Proses pengawetan memastikan kemajuan tindakbalas penghidratan yang menyebabkan pengisian dan ketakselanjaran rongga kapilari oleh sebatian terhidrat dalam konkrit yang baru. Dalam praktik sebenar, pengawetan yang sempurna adalah tugas yang mencabar untuk dicapai dalam elemen struktur seperti struktur condong, bangunan tinggi atau struktur dengan ketebalan konkrit yang besar. Pengawetan yang tidak betul menyebabkan kualiti konkrit yang rendah. Objektif dan skop penyelidikan adalah untuk mengkaji potensi Mikroorganisma Berkesan (EM) sebagai agen pengawetan sendiri untuk mencapai sifat yang sama atau setanding dengan konkrit pengawetan sendiri (SCC) dalam pengawetan terbuka dan konkrit normal dalam pengawetan air. EM adalah larutan bakteria mesra alam yang digunakan dalam pertanian. Dalam metodologi, tiga gred campuran konkrit dihasilkan iaitu gred 30, gred 35 dan gred 40 untuk menganalisis kehilangan air dari konkrit dan kesan pengawetan yang tidak betul terhadap kekuatan konkrit. Sifat awal air paip, larutan EM dan larutan air EM dikaji dan dikenal pasti. Pengoptimuman SCC dengan EM adalah berdasarkan kepada sifat konkrit keras. Enam campuran konkrit dihasilkan; satu adalah kelas konkrit normal 30 (kawalan) dan lima campuran lain adalah SCC di mana air bancuhan diganti dengan EM sebanyak 5% hingga 25%. Untuk menentukan mekanisme dan komposisi dalaman konkrit dalam kedua-dua sistem pengawetan, analisis struktur mikro telah dilakukan. Hasil dan perbincangan menunjukkan bahawa kehilangan air maksimum 2% dicatatkan untuk konkrit gred 30. Pada usia 28 hari, sampel konkrit dalam pengawetan terbuka mengalami kekurangan kekuatan 23% lebih sedikit dibandingkan dengan sampel dalam pengawetan air. EM mempunyai ketegangan permukaan yang rendah yang menjadikannya boleh dipercayai untuk agen pengawetan sendiri. Hasil analisis gravimetrik termal (TGA) juga menunjukkan bahawa EM mengwuap pada suhu yang lebih tinggi berbanding air bancuhan. Kebolehkerjaan meningkat dengan peningkatan penggantian peratusan air dengan EM. Ujian runtuhan konkrit didapati dalam jarak 70-220 mm. Hasilnya juga menunjukkan bahawa SCC dengan 10% EM memberikan hasil kekuatan mampatan 53 MPa yang lebih tinggi pada umur 28 hari dalam pengawetan air. Dalam pengawetan terbuka, SCC dengan 10% EM memperoleh kekuatan 42 MPa, kekuatannya hampir dengan kekuatan konkrit kawalan (43 MPa) dalam pengawetan air. Penyerapan air dan lompang dalam konkrit dikurangkan dengan 10% EM di SCC. Kelembapan relatif dalaman (IRH) SCC didapati antara 85-90% pada umur 28 hari dengan 10% EM, yang merupakan keadaan yang baik untuk proses penghidratan lengkap berbanding dengan konkrit kawalan yang berkisar antara 74-76% dalam pengawetan terbuka. Telah diperhatikan bahawa kemasukan 10% EM menurunkan suhu SCC sebanyak 1-2°C. EM 10% juga menunjukkan pengurangan pengecutan dan pengembangan masing-masing 43% dan 45%, di SCC dibandingkan dengan konkrit kawalan. Hasil mikroskop elektron Pengimbasan-X-Ray (SEM-EDX) menunjukkan bahawa konkrit dengan 10% EM mempunyai struktur yang padat dengan lebih sedikit lompang. Hasil TGA menunjukkan bahawa 10% SCC memperoleh gel C-S-H 19% dan 11% lebih banyak daripada konkrit kawalan dalam pengawetan terbuka dan pengawetan air. Semua hasil menunjukkan bahawa 10% EM adalah nilai optimum untuk mendapatkan sifat SCC yang diinginkan. Berdasarkan penemuan tersebut, dapat disimpulkan bahawa EM dapat digunakan dalam konkrit kekuatan normal untuk menyelesaikan pengawetan yang tidak betul sebagai agen pengawetan sendiri. Penggunaan EM tidak hanya akan meningkatkan perkembangan bahan yang mesra alam, tetapi juga untuk pengurangan pelepasan CO_2 dan pengurangan sumber alam. Keaslian dalam penyelidikan ini adalah penggunaan EM sebagai agen pengawetan sendiri. Sumbangan dalam bidang konkrit pengawetan sendiri adalah ia membantu konkrit mencapai sifat yang diinginkan dengan mengubah ciri fizikal air campuran.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BDP	-	Baby Diaper Polymers
BS	-	British Standard
BS EN	-	British Standard European Norm
C-A-S-H	-	Calcium Aluminium Silicate Hydrate
CH	-	Calcium Hydroxide
COBCB	-	Crushed Over Burnt Clay Bricks
C-S-H	-	Calcium Silicate Hydrate
DO	-	Dissolved Oxygen
DOE	-	Department of Environment
DTA	-	Differential Thermal Analysis
EDX	-	Energy Dispersive X-Ray
EM	-	Effective Microorganism
EMAS	-	Effective Microorganism Activated Solution
HPC	-	High-Performance Concrete
IC	-	Internal Curing
IRH	-	Internal Relative Humidity
ITZ	-	Interfacial Transition Zone
LECA	-	Lightweight Expanded Clay Aggregate
LWA	-	Lightweight Aggregates
NS	-	Natural Sand
OPC	-	Ordinary Portland Cement
PCA	-	Porous Ceramic Aggregates
PCCA		Porous Ceramic Coarse Aggregates
PEG	-	Polyethylene Glycol
PVC	-	Polyvinyl Chloride
RH	-	Relative Humidity
RHA	-	Rice Husk Ash
SAP	-	Superabsorbent Polymers

SCC	-	Self-Curing Concrete
SEM	-	Scanning Electron Microscopy
SF	-	Silica Fume
SP	-	Superplasticizer
SSA	-	Saturate Surface Area
SSD	-	Saturate Surface Dry
TDS		Total Dissolved Solids
TGA	-	Thermal Gravimetric Analysis
UHPC	-	Ultra-High-Performance Concrete
UPV	-	Ultrasonic Pulse Velocity
USA	-	United States of America
UTM	-	Universiti Teknologi Malaysia
XRD	-	X-Ray Diffraction
XRF	-	X-Ray Fluorescence

LIST OF SYMBOLS

%	-	Percentage
µs/cm	-	Micro siemens Per Centimetre
^{0}C	-	Centigrade
A	-	Area of Specimens
a	-	Exposed Area of The Specimens
a.u.	-	Relative Emission Intensity
Al_2O_3	-	Aluminium Oxide
$Ca(OH)_2$, P	-	Calcium Hydroxide, Portlandite
$CaCO_3$, C	-	Calcium Carbonate, Calcite
CaO	-	Calcium Oxide
CO_2	-	Carbon Dioxide
D	-	Density of Fresh Concrete
d	-	Cross-Sectional Diameter of Specimens
d	-	Density of Water
E	-	Ettringite
F	-	Maximum Load
f_c	-	Compressive Strength
f_{cf}	-	Flexural Strength
f_{ct}	-	Splitting Tensile Strength
H	-	Height of Specimens
H_2O	-	Water
Hr	-	Hours
I	-	The Sorptivity Absorption
KCL	-	Potassium Chloride
L	-	Length of Specimens
l	-	Distance Between the Lower Roller
L_o	-	Original Length
m	-	Meter
M	-	Weight of Specimens
M	-	Moisture Loss

M_1	-	Weight of Empty Mould
M_2	-	Weight of Mould with Concrete
M_3	-	Oven Dried Weight of Specimens on Measuring Day
M_a	-	Apparent Weight of Specimens in Water after Immersion
M_b	-	Weight of Saturate Surface Dry Specimens in Air after Immersion
$M_{cylinder}$	-	Weight of Empty Cylinder
M_d	-	Oven Dried Weight of Specimens in Air
M_{fluid}	-	Weight of Fluid
Mg/L	-	Milligrams Per Litre
mm	-	Millimetre
mN/m	-	Millinewtons Per Meter
MPa	-	Megapascal
mPa.s	-	Millipascal. Second
M_s	-	Saturate Surface Dry Weight of Specimens in Air
m_t	-	The Change in Specimens Weight
N	-	Newton
Ø	-	Diameter
ppt	-	Parts Salt Per Thousand Parts Water/ Part per Thousand
Sec/s	-	Seconds
SiO_2, Q	-	Silicon Dioxide, Quartz
T	-	Time
V	-	Volume of Specimens
V	-	Voids
Vol_{fluid}	-	Volume of Fluid
W	-	Width of Specimens
W	-	Water Absorption
Ω.cm	-	Ohm-Centimetre
ρ	-	Density of Hardened Concrete
ρ_f	-	Density of Fluid

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is the primary construction material that is widely used in the modern world today. As the soul of infrastructure is concrete, so nowadays, the modern construction organization has demanded almost 12 billion tons of concrete for infrastructure (Kurtis et al., 2007). Concrete is believed to be modified with different types of materials to improve its properties and use for various construction applications. The main problem with reinforced concrete structures in the construction industry is cracks and the corrosion of steel reinforcement. These problems arise due to porous or high permeability of concrete. The porosity of concrete is attributable to the not fully hydrated cement caused by the loss of water during hardening due to evaporation. The evaporation occurs due to improper curing, which tends to happen mostly where the elements of the concrete structure are in incline or angel position and the retention of water on the concrete surface is problematic. Improper curing also occurs in the concrete structure of areas where there is a lack of water (e.g. desert). Concerning that, in enhancing the quality of hardened concrete, the concept of self-curing concrete is being examined. There are many systems of self-curing and the system that is commonly applicable in concrete technology is a water reservoir system or known as internal curing (Trtik et al., 2011). First, internal curing was called water entrained concrete using lightweight aggregates (Philleo, 1991). The self-curing aggregates are placed within the concrete to maintain a satisfactory moisture content, temperature and increase the water retention capacity of concrete, which means no external water is needed for curing (El-Dieb, 2007; Jau, 2011; Kevern and Farney, 2012). Another system, in which chemical admixtures such as surface tension reducing admixture is used to retain the water and reduce concrete evaporation. It is also termed autogenous curing (Zhutovsky et al., 2004). This topic has received much attention in the field of concrete engineering (Henkensiefken and Weiss, 2009). According to ACI

308 committee, "*internal curing refers to the proce* *occurs because of the availability of additional internal water that is not a part of the mixing water*" (308R-16, 2016).

There are three different categories of self-curing associated with concrete, the first one is self-curing agents that store water during or before mixing. The second one is internal sealing which is similar to external sealing that prevents the moisture loss from concrete (Kovler et al., 2007). The third is the use of a liquid solution that decreases the concrete evaporation rate. Highly absorptive material that will readily desorb water into the cement pore structure can be used as a self-curing agent (Babcock and Taylor, 2015). Mostly self-curing agents are superabsorbent polymers or pre-wetted lightweight aggregates (Trtik et al., 2011). Self-curing in concrete can influence its properties by replacing a certain amount of normal weight aggregate with pre-wetted lightweight aggregate (Cusson, 2008; Lura et al., 2006). The effectiveness of self-curing process in concrete can be based on three factors: volume of self-curing water provided and water/cement ratio, the mass of lightweight aggregates and cement content used for self-curing (El-Dieb, 2007), and particle size of lightweight aggregates (Michael et al., 2012). Self-curing practice in concrete is performed to improve mechanical and durability properties (Cleary and Delatte, 2008).

A few decades ago, the self-curing system was developed to overcome the shrinkage problem in high-performance concrete without compromising its strength and durability characteristics with a low water-to-cement ratio (Lura et al., 2004; Sarbapalli et al., 2016; Trtik et al., 2011). Self-curing is also used to mitigate autogenous shrinkage in repair mortars (Bentz et al., 2004; Geiker et al., 2004), and solve the problems which accrued in heat-cured concrete (Nie et al., 2016). Self-curing technology is gradually transferring nowadays from laboratory to field application (Henkensiefken and Weiss, 2009).

In the construction industry, the traditional method of curing uses a lot of fresh water from different sources (Sarbapalli et al., 2016). Contrary, the central concept of the self-curing system increases the retention capacity of mixing water within the concrete, enabling enhanced cement hydration and producing dense concrete that is less permeability than conventical concrete (El-Dieb, 2007; Michael et al., 2013). The internal water within concrete is also evenly distributed by self-curing agents (Zhutovsky and Kovler, 2017).

1.2 Problem Background

The strength is the ability to resist force. With-regard to concrete for structural purposes it can be defined as the unit force required to cause a rupture. Strength is a good index of most of the other properties of practical importance. In general, stronger concretes are stiffer, more watertight, and more resistant to weathering and load. Strength is taken as the criterion of concrete quality. Durability of concrete is the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired.

The basic requirement for proper concrete is to achieve its desired strength and durability properties. Sometimes, however, these desired concrete properties cannot be achieved during construction due to lack of water or improper curing. Even if a mix contains adequate water for hydration, still initial w/c ratio can be reduced if any loss of moisture occurs from concrete due to improper curing. The moisture loss leads to a lower degree of cement hydration , and the porous zone around the aggregates that results in concrete develops unsatisfactory properties such as reduced compressive strength and higher porosity (Jau, 2011)

The strength and durability of concrete is directly related to the structure of the hydrated cement paste. Air produces voids in concrete. Excess water evaporates in concrete, leaving the voids in the concrete. Consequently, as the w/c ratio increases, the porosity of the cement paste in the concrete also increases. As the porosity increases, the compressive strength of the concrete decreases. Resulting in low-quality concrete which cannot hold the structural load. Here question arises on how to solve or mitigate this problem in the construction industry? So, self-curing of concrete is one of the methods that can be used to solve this core problem.

Curing is the most important factor in meeting the requirement of standardised concrete and maintaining its hydration. Curing of concrete is defined as providing sufficient moisture, temperature, and time for the concrete to achieve the desired properties for its intended use (Cusson et al., 2010; Dhir et al., 1994; Kerby, 2013). Curing can be performed in multiple ways. It is widely distributed among traditional methods like pond curing, membrane curing, steam curing and gunny bags curing.

As the problem of desired concrete properties revolves around traditional curing techniques that are not always effective, so the self-curing system is used to reduce the risk of cracking and self-desiccation. It provides water through super-absorbent polymers, pre-wetted lightweight aggregates to complete hydrating cement paste, and larger pore of lightweight aggregates (LWA) that will lose water first during hydration in concrete (Bentz, 2009; Castro et al., 2010; Golias et al., 2012; Henkensiefken et al., 2011; Jensen and Hansen, 2001; Lura et al., 2007; Lura and Kovler, 2007; Philleo, 1991; Rößler et al., 2014; Zhutovsky et al., 2004). Further, traditional curing also requires a lot of water to be sprayed on concrete, which needs labour; so the self-curing technique is also used to make construction economical (Jau, 2011).

Self-curing is used for both normal and high-performance concrete for good multiple reasons. Even though normal concrete contains enough water for the hydration of cementitious material but mostly concrete is not cured properly and loses moisture (Espinoza-Hijazin and Lopez, 2011). In high-performance concrete (HPC), improper curing and self-desiccation lead to moisture loss which results in autogenous shrinkage at an early age of concrete. This results in decreased relative humidity in HPC, creates stress inside the concrete and causes concrete to crack. Thus, the durability properties of concrete are affected (Rößler et al., 2014; Shen et al., 2015; Zhang et al., 2015). Another main reason for using the self-curing technique in high-performance concrete is due to the low water-cement ratio for the mixture. Self-curing technology provides a source of moisture that promotes complete hydration of the cementitious materials (Villarreal and Crocker, 2007; Zhutovsky and Kovler, 2017). Moreover, when continuous curing is difficult for the concrete used at heights, vertical members, sloped roofs, pavement, and also where the thickness of concrete is large, self-curing plays its pivotal role (Chand et al., 2014).

The internal relative humidity is also playing a significant role in the concrete to achieve favorable properties. Due to low water to cement ratio in the concrete or moisture loss from concrete, reduction in the internal relative humidity of concrete occurs. The desirable internal relative humidity required for complete hydration is a minimum of 85% especially in early concrete age. Internal relative humidity would not be beneficial for the hydration process if it is below 85% (Rahimi-Aghdam et al., 2019). Thus, self- curing technique is seen can be used in enhancing the concrete properties because it also retains internal relative humidity in early concrete periods (Shen et al., 2015).

One of the essential purposes of curing is to maintain the temperature within concrete. Concrete should not reach high temperatures at early age as it causes the concrete to lose moisture at a rapid rate and results in the thermal crack (Junaid et al., 2015) which ultimately leads toward low strength and durability of concrete. Self-curing has also reliably addressed temperature issues of concrete.

Many research works have been acknowledged for self-curing in high-performance concrete but not so much work has been carried out for normal-weight concrete. With the help of the self-curing technique, researchers have solved multiple problems relating to the strength and durability of concrete. Hence, to further assessing the concept of self-curing in concrete the study of a new method using selected self-curing agent for the self-curing process in the normal-weight concrete is focused.

1.3 Problem Statement

Traditional curing is challenging to apply for a long period of time. A lot of water during conventional curing process is wasted and evaporates. Sometimes traditional curing in some parts of the structure is challenging to be done due to access problem. Improper curing of concrete reduces the hydration process, leading to lower quality of concrete, and more numbers and large size of voids in concrete. The greater number of voids provide less durable concrete. Improper curing reduces the internal relative humidity and increases the temperature of concrete, resulting in more shrinkage of concrete leading to micro cracks inside the concrete. The above problems strongly affect the strength characteristics of concrete. Oduola (2010) carried out statistical case study on several collapse buildings in Nigeria. The case study was based on about 86 cases of building collapse reported between 1985 and November 2006. Case study statistics clearly show that improper curing of concrete at an early age due to poor workmanship is the most important factor among all factors, particularly responsible for poor concrete quality in building construction. Collapses due to improper curing at an early age are not only limited to Nigeria, but also occur worldwide, such as Algeria, Uganda's East African countries, Kenya, Thailand, South Africa and several other African and Asian countries (Ekolu and Ballim, 2006; Kian, 2004). Some of the materials used in research works as self-curing agents are natural, recycled, polymers, and chemicals. They are not readily available everywhere and depend on location, beside the chemicals made of self-curing agents are not eco-friendly. Current self-curing agents are highly porous in nature such as lightweight aggregates, resulting in more concrete voids and decreased concrete compressive strength. The present self-curing agents depend on nature, so it goes through industrial processes for its final shape, resulting in more environmental effect due to carbon dioxide. In the field of self-curing concrete, the acquisition of current self-curing agents also harms natural resources that lead them to non-eco-friendly materials.

1.4 Research Objectives

The research objectives of this work are as follows:

(i) To characterize the physical and chemical properties of EM solution to be used as a self-curing agent.

(ii) To identify the optimization of different concrete grades on the basis of water loss and strength due to improper curing.

(iii) To evaluate the fresh and hardened properties of normal and self-curing concrete and determine the optimum level of EM solution to be used.

(iv) To assess the water transport, internal properties as well as microstructure of EM self-curing concrete mix.

1.5 Scope and limitation of the study

The focus of the research is on examining the potential of EM solution as a self-curing agent to achieve the same or comparable properties of self-curing concrete in air curing with normal concrete in water curing.

The first phase of research proceeds with the characterization of EM solution. In the second phase, primarily three grades of concretes are manufactured: grade 30, grade 35, and grade 40. These contributed to study on the behaviour of water loss and its effect on strength due to improper curing. This step shifted focus on Grade 30 solely. Trial mixes were carried out to determine the favorable air curing system. This was performed inside and outside the laboratory to get consistent and reliable results.

In the third phase, the fresh and hardened properties of the normal (control) and effective microorganism mixture for self-curing concrete are investigated. In this phase, two curing systems are applied: one is wet curing, and the second is air curing (inside the laboratory). Effective microorganism is used to replace part of the mixing water for Grade 30 concrete to get the optimum percentage.

The fourth phase investigates the permeability properties, internal relative humidity, internal temperature, and microstructure properties which are carried out on the optimized EM self-curing concrete, and normal (control) concrete in air and water curing. The microstructure test is performed to determine the physical mechanisms of self-curing effect of EM. Microstructure test is conducted at 3, 7 and 28 days and hardened properties are investigated at 3, 7, 28, 56 and 90 days

The series of tests carried out in this study are based on methods specified in either British Standards (BS), American Society for Testing and Materials (ASTM), International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM), or implemented techniques in the reviewed literature.

1.6 Significance of study

The self-curing technique has not been used widely in the construction industry. In this research, effective microorganism as green eco-friendly material is used as a self-curing agent. This material is also readily available in many countries. This research contributes to the knowledge in the area by introducing a new concrete mixture with a newly introduced self-curing agent in concrete. This study assesses the use of effective microorganism (EM) as self-curing agent that will result in better strength and durability of normal concrete. Previously, self-curing technique adversely affected the compressive strength of concrete compared to water curing technique. As a self-curing agent, the EM solution is expected to have less adverse effect on the compressive strength of the self-curing concrete.

1.7 Thesis organization

Chapter 1 presents an overview and the rationale for undertaking this research. Additionally, this chapter provides a brief overview of the introduction, background problem, problem statement, research gap, objectives, scope and limitations, and project significance.

Chapter 2 provides a review of the literature about the self-curing concrete. This chapter also includes the mechanism of different self-curing agents and their effects on hardened properties.

Chapter 3 provides a detailed explanation of the components, specimens preparation, and research procedures used in the experiment.

Chapter 4 examines the properties of EM solution and includes the results for optimisation of different grades. Also, analysis the behaviour of concrete under effect of improper curing.

Chapter 5 contains the results of the fresh and hardened properties of normal and self-curing concretes.

Chapter 6 describes the microstructure results of optimized normal and self-curing concrete in the water and air curing system. It also includes permeability properties, internal relative humidity, and temperature. This chapter contains Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray Analysis (EDX), Thermogravimetric analysis (TGA) and X-Ray Diffraction (XRD).

Chapter 7 shows the conclusions of this research and recommendations for further investigation.

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