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FLEXURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS USING SUPER ABSORBENT POLYMER AS INTERNAL CURING

A Thesis Submitted to the Council of College of Engineering University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By

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DEDICATION

To my family

To my sons Zainab, Ahmed and Mustafa

To those absent in their bodies but present

in their souls

To my uncle Sami, my brother Ali and my dear

husband Wadhah

Allah may mercy them all

Baidaa Khdheer Ahmed

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Allah, for you is praise until it please you, and for you is praise when you become pleased, and for you is praise after you become pleased.

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ABSTRACT

The problems associated with increasing strength of concrete are the focus of a wide area of research. High and ultra-high strength concrete tends to develop early cracking. The lower the w/b the earlier and greater the development of autogenous shrinkage which increases with increasing compressive strength. This leads to internal cracking and weakening the performance of concrete. Providing the means of internal curing to solve the problem of autogenous shrinkage related to high and ultra- high strength concrete is limited to light weight aggregate LWA. Recently, the Super Absorbent Polymer SAP, which is considered to be smart materials that can hold and absorb water effectively and release it when needed in dry conditions, has been used for this purpose.

This study comprises two stages. The first stage includes the production of five concrete mixes with different strength levels (normal, high, very high and ultra-high strength). These are: reactive powder concrete RPC, modified reactive powder concrete MRPC, high strength concrete HSC, self- compact concrete SCC and normal strength concrete NSC. The properties of concrete in the fresh and hardened state are studied for the five concrete mixes with and without SAP addition. These properties include: workability for fresh concrete, compressive strength, (splitting and flexural) tensile strength, modulus of elasticity, autogenous and drying shrinkage. The second stage covers the effect of SAP addition on flexure behaviour of the reinforced concrete beam. Ten beams are casted, five for concrete mixes without SAP and the other five beams with SAP addition. Load carrying capacity, deflection and crack width has been investigated.

The results collected from the first stage reveal that the addition of SAP increases workability for mixes due to increased quantity of water in the mix. Addition of SAP reduces strength of concrete in term of compressive, splitting, flexural as well as modulus of elasticity up to 28 days. After 28 days, clear improve in compressive strength was recorded which belong to continuous hydration process due to availability of water from internal curing (with the addition of SAP) which promotes continuous development in compressive strength clearly at the age of 56 days. It is expected to gain more strength at ages after 56 days. SAP addition is found to reduce autogenous and drying shrinkage remarkably; for autogenous shrinkage the reduction is (64%, 46%, 42%, 62%, and 54%) and drying shrinkage reduction was (89.5%, 72%, 82%, 70% and 71%) for RPC, MRPC, HSC, SCC and NSC respectively. Results of the second stage reveal that the addition of SAP increases load carrying capacity for reinforced concrete beams of all types of concrete. Moreover, the deflection of the reinforced concrete beams containing SAP is reduced compared with reinforced concrete beams without SAP. The reduction in deflection is (9.4%, 8%, 20%, 23% and 12%) for RPC, MRPC, HSC, SCC and NSC respectively. The same results are attained for crack width which is improved due to SAP addition, the reduction is (12.5%, 11.8%, 13.7%, 13.3%, and 20%) for RPC, MRPC, HSC, SCC and NSC beams respectively. It can be concluded that it is possible to use SAP as internal curing agent in order to improve properties of concrete in general on the long term as it takes time in order to release water to maintain hydrations.

TABLE OF CONTENTS

Chapter III: Expermintal Work

Chapter IV: Results and Discussion

Chapter V:Finite Element Models

Chapter VI: Conclusions and Recommendations

Appendices

Arabic Abstract

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

3D	Three Dimensional
ACI	American Concrete Institute
ANSYS	ANalysis SYStem
AS	Autogenous Shrinkage
ASTM	American Society for Testing and Materials
B.S.	British Standard
CA	Coarse Aggregate
C-S-H	Calcium silicate hydrate
DC	Direct Current
EFNARC	European Federation of National Trade Associations Representing Concrete
FEM	Finite Element Method
HRWRA	High Range Water Reducers Admixture
HSC	High Strength Concrete
IC	Internal Curing
kN	Kilo Newton
LAN	Local Area Network
LCD	Liquid Crystal Display
LWA	Light Weight Aggregate
mm	Millimeter
MPa	Mega Pascal (N/mm^2)
MRPC	Modified Reactive Powder Concrete
NSC	Normal Strength Concrete
PF	Polyester Foil
pH	Potential of Hydrogen
ppm	Parts Per Million
RPC	Reactive Powder Concrete

rpm	Rotation per minute
SAP	Super Absorbent Polymer
SCC	Self Compact Concrete
SF.	Silica Fume
UHSC	Ultra-High Strength Concrete
UK	United kingdom
USB	Universal Serial Bus

SYMBOLS

Δ_u	Deflection of Ultimate Load / mm
A_b	Area of bar / mm^2
A_o	The area of concrete surrounding each reinforcing bar. / mm^2
A_s	Area of Flexural Reinforcement (Steel) / mm^2
E_c	Modulus of Elasticity of Concrete / MPa
E_s	Modulus of Elasticity of Steel / MPa
E_t	Strain hardening modulus / MPa
P_u	Ultimate Load of the Beam / kN
U_x	Horizontal Displacement in x-direction / mm
U_y	Deflection or Vertical Displacement / mm
V_c	Shear in Concrete / kN
V_s	Shear in Steel / kN
d_c	The distance measured from the centroid of tensile steel to the extreme tensioned fiber. /mm
f_c'	Compressive Strength of Standard Cylinder at 28 days/ MPa
f_{ct}	Splitting Strength of Concrete / MPa
f_{cu}	Compressive Strength of Standard Cube / MPa
f_r	Modulus of Rupture / MPa

f_s $0.6Pu$ / kN

f_y Yield Stress / MPa

w_c Crack Width / mm

ε_o Strain at ultimate compressive strength (f_c')

CRD Difference between the comparator reading of the specimen and the reference bar at any age

D_{avg} Average base diameter /mm

D_o Original base diameter /mm

G Length of shrinkage sample /mm

h Depth of the Cross Section / mm

specimen and the reference bar / mm

ΔLx Length change of shrinkage sample /mm

Ω Ohm/unit of electrical resistance/ ($kg.m^2/s^3.A^2$)

L Beam Span / mm

P Applied Load / kN

b Width of Concrete Cross Section / mm

d Effective Depth / mm

β The ratio of distance between neutral axis and extreme tension face to distance between neutral axis and centroid of reinforcing steel.

σ Stress / MPa

ε Strain

ρ Reinforcement Ratio

CHAPTER ONE
INTRODUCTION

1.1 HighStrength Concrete

When regarding high strength concrete (HSC), we must initially define the meaning of "high strength". The perception of what level of compressive strength constitutes "high strength" has as been constantly revised upwards over the past 20 years or so (FIP-CEB, 1990). And it continues rising in the near future.

A simple definition is "concrete with a compressive strength greater than that covered by current codes and standards". In UK high strength would include concrete with compressive strength of 60 MPa or more.In Norway the design code that includes concrete with compressive strength that obtains from cube test up to 105 MPa (Helland, 1997).

The ACI Committee 363R-92 has to explain an applicable range of concrete strength for its uses. The immediate interest of Committee 363 shall be concretes have stated compressive strengths for design of (41 MPa) 6000 psi or more . However, experience shows that in most cases, the special measures recommended should be applied to concrete with compressive strength greater than about (55 MPa)8000 psi(ACI363 2R-98).

In the past several years, improvements have occurred in concrete technology, one of the materials developed in recent years is ultra-high strength concrete (UHSC) has a compressive strength greater than 21,750 psi (150) MPa (Allena & Newtson, 2011).

1.1.1 Application of High Strength Concrete

High strength concrete (HSC) has been used in many structures that constructed around the world. The most widespread use has been in the columns of high rise buildings, especially in Australia, North America, Germany and South-east Asia (CEB, 1994). Columns constructed from high strength concrete, often with reduced reinforcement is an economical solution, save heavily loaded elements in high-rise buildings. Using high strength concrete for production of columns leads to reducing the dimensions of this column. This helps constructing high rise buildings of up to hundreds meter with wide internal spaces.

Another application of high strength concrete technology has been in offshore structures that use concrete with ever increasing strength for many years.

Bridges,in particular, prestressed concrete bridges have also made use of the benefits of high strength concrete (HSC), for example foot bridge near Tokyo incorporates (100) MPa of concrete. High strength concrete enables the span of a bridge beam to be increased or to reduce the number of beams required for a given span. This can lead to reduce the unit cost(Price, 1999).

1.1.2 Advantages of High Strength Concrete

1- The concrete put into service at much earlier age, for example using the pavement at 3- days.
2- Reducing column dimension and increasing internal space so as high- rise building can arise.
3- To build the super-structures of long- span bridges and to improve the durability of bridge decks.
4- To satisfy the specific needs of special applications such as durability, flexural strength, and modulus of elasticity. Some of these uses include dams, marine foundations , grandstand roofs, parking garages, and heavy duty industrial floors.

1.1.3 Disadvantage or Problems Related to HSC and UHSC

1- High strength concrete is more expensive or costly than normal strength concrete.
2- The collapse of high strength concrete can be sudden (i.e. sudden failure) because the failure will be in coarse aggregate not around it. Fibers need to be used to overcome this case.
3- HSC and UHSC mixture containing high amount of cement and low water-cement ratio needs particular curing. The cement hydration occurs rapidly in the first days after the concrete mixing is complete. Evaporation leads to decrease water which may cause delay or prevent hydration process. If there is a loss in the amount of water in concrete, shrinkage takes place which creates tensile stress that leads to cracking. To solve this problem, concrete needs additional water. Curing concrete with water by external curing can penetrate concrete only few millimeters from external surface (due to dense low porosity material) and the interior of concrete remains uncured and undergoes substantial self-desiccation (Bentz & Weiss, 2011), then concrete need internal curing . The difference between external and internal curing is shown in Figure (1-1).

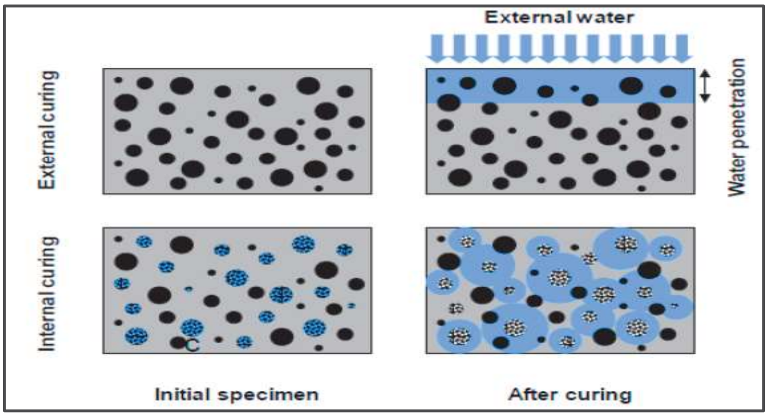

Figure (1-1) Difference between external and internal curing

1.2 Curing of Concrete

Curing is the maintenance of satisfactory moisture content and a temperature in concrete for a period of time immediately following placing hand finishing. So that the desired properties may develop. (Kosmatka et al., 2002).

Concrete needs curing to get attractive promoted properties , curing has a great impact on freshly mixed and hardened concrete. Curing is important in order to:

- obtain a good hydration process.
- obtain desired properties of concrete.
- be less permeable.
- More durable and resists abrasion better.
- obtain less shrinkage so less cracking.
- better to withstand freezing and thawing.

There are two categories of curing ,external and internal curing.

1.2.1 Methods of Internal Curing

There are presently two main methods for internal curing (IC). The first method is by using of pre wetted Light Weight Aggregate (LWA) and the second is by using super absorbent polymer (SAP). This study concentrates on internal curing by using super absorbent polymer.

1.2.2 Super Absorbent Polymers

In 1997, Hansen and Jensen initiated a series of experiments involving a new curing technologyconcept called "water entrainment", and it is similar to "air entrainment". It can be achieved by using super absorbent polymer (SAP) particles as a concrete admixture. SAP is polymeric materials and it has the possibility to absorb a large quantity of liquid reaches to 100-400 g/g dry from the surrounding environment and retain within their structure. Super absorbent polymer (SAP), is therefore, considered to be "smart materials ", which can change their properties according to an external stimulus. When exposed to water, they swell but when they are subjected to dryness, they reversibly shrink and retain the water to surrounding (Jensen, 2013).

1.3 Research Justification

High strength concrete and ultra-high strength concrete are produced with low water- to- cement ratio (w/c) and high content of cement. It needs amount of water to complete the hydration of cement because the consuming of free water leads to the presence of unhydrated particles, or to maintain 100 percent relative humidity within the concrete. Therefore, the concrete interior suffers many problems.Internal stresses and higher shrinkage lead to cracking and,at the end, failure in the structure.To reduce this problem,internal curing is used for concrete. Smart materials SAP, which are added to concrete as a percentage from weight of cement is used for internal curing in this study.

1.4 Research Objectives

1- Producing different types of high strength concrete (HSC).
2- Producing ultra-high strength concrete (UHSC) with compressive strength ≥150 MPa.
3- Investigating the applicability of using super absorbent polymer (SAP) with concrete having internal curing (IC) and studying its effect on reducing shrinkage (dry and autogenous).
4- Studying the effect of addition SAP as internal curing(IC) on flexural behaviour of reinforced concrete beams.
5- Comparing numerical and experimental results for testing beams (using ANSYS program).

1.5 Thesis Layout

Chapter one – is an introduction about HSC, uses of high strength concrete, it's advantage, the problem that occur when using HSC and UHSC, Internal curing and superabsorbent polymer.

Chapter two – contains the literature review which deals with the use of SAP with concrete, its effect on mechanical properties and structural behaviour of reinforced concrete beams.

Chapter three – describes experimental work, the performed and described tests include compressive strength, splitting/ flexural strength, autogenous and drying shrinkage, modulus of elaticity and flexural behaviour of reinforced concrete beam. All of the tests are done two stages with and without internal curing by using SAP.

Chapter four – shows that, the results that have been obtained from experimental work will be analyzed and discussed.

Chapter five – illustrates the Finite Element Analysis (FEA) of the tested beams then the numerical results are compared with experimental results.

Chapter six – views the conclusions that are reaches at from this work and some recommendations for future research work.