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EXPERIMENTAL STUDY ON THE EFFECT OF RAINFALL ON FRESH CONCRETE

Ahmed S. El-amary[1, 2], Badr T. Alsulami[1] and Nidal M. W. AL-Bustami[1]
[1]Department of Civil Engineering, Taif University, Taif, KSA
[2]Department Civil Engineering, Al-Azhar University, Qena, Egypt
E-Mail: a.elamary@tu.edu.sa

ABSTRACT

AL-Taifregion, in the Kingdom of Saudi Arabia (KSA), can be classified as rainy region; however, during day the weather can be changed several times means rainfall at any time. Due to the advantage of concrete too many concrete structures executed and massive quantity of concrete cast every day, some of it can subject to rainfall. An experimental program has been carried out to investigate the influences of rainfall duration on the compressive strength of fresh concrete. Concrete mixture was designated and cast in standard cubes molds 150 *150* 150 mm as control compressive strength. Based on the mix quantities obtained from concrete mixture, seventy two cubes cast in three groups, each group has four subgroups with six cubes each. Three different rainfall started time from casting studied 15, 30, and 45 minutes each represented as group. Four duration of rainfall studied 10, 30, 45, and 60 minutes each represented as subgroups. Results of compressive strength test on cured specimens were used to obtain equations for prediction the influences of concrete compressive strength regarding to rainfall duration and starting time of rainfall from casting. From this research, the findings can get site decisions on whether to continue or suspend the construction based on the forecasted rainfall. On the other hand, if concrete subjected to rainfall after casting, the engineer will have an equation can be used as a guide to determine the new concrete compressive strength.

Keywords: fresh concrete, rainfall, concrete strength, rain duration.

1. INTRODUCTION

The most important material property in design of concrete structures which is routinely specified and tested by control specimens is the compressive strength of concrete. Different countries use various kinds of specimens in shape and size. Thus, compressive strength of concrete specimens with similar mixtures and different sizes and shapes are different. Most common shapes are cylindrical and cube specimens in which cube specimen with height 150mm and area 150x150mm is known as the standard specimen; consequently all specimens in this study will have the same dimensions of standard cubes. This part will present a literature review concerning about the research subject in the last twenty years.

It is noticed that, most of the previous study in the above mention subject were concerned with two main topics, Hydration and setting time and Cement paste and bleeding; with some other different research areas. Each will be presented separately as follow: Hydration and setting time various empirical tests are used to study the hardening and setting of cementitious materials. These are sometimes alternatively described as consistency or setting time measurements. These tests include the Vicat needle, penetrometers of various shapes and the proctometer also known as the Proctor needle, as stated by (Lootens and Flatt, 2007). Some of these techniques measure the penetration resistance (i.e. penetration force) under an imposed speed, while others measure the penetration depth for an imposed load. The recent developments in ultrasound spectroscopy performed by (Subramaniam and Wang 2010). (Schultz and Struble, 1993) allowed for the measurement of the evolutions of both shear and bulk elastic moduli during setting of cement paste. Based on these new techniques, recent papers showed the existence of a relation between shear yield stress and the empirical setting time measurements as stated by (Nachbaur *et al.* 2001). These correlations show that what was defined as initial setting time corresponds to a yield stress of the material of the order of a couple hundred kPa. Cement paste and bleeding; bleeding (i.e. the accumulation of water at the surface of the paste) of potentially usable fluid cement paste shall be neglectable. It results from the difference in density between cement grains and water. Bleeding, in the range of interest of industrial cementitious materials, cannot be described as the settlement of individual cement grains in a dilute system but rather as a consolidation process (i.e. the upward displacement of water through a dense network of interacting cement grains) (Josserand *et al.* 2006). The interactions between cement grains and permeability of freshly mixed cement pastes were therefore first order parameters of a cement paste resistance to bleeding. The bleeding phenomenon can be slowed down by the viscous nature of the interstitial fluid, which has to travel to the surface under the effect of gravity. Viscosity agents can therefore be used to reduce the amplitude of bleeding before setting as stated by (Khayat, 1998). They were able to thicken the interstitial water and slow down the bleeding phenomenon.

This may reduce the practical consequences of bleeding and make them neglectable from an industrial point of view. (Lei and Jonathan, 2010) studied the roller-compacted- concrete (RCC), this study based on laboratory experiments with simulated RCC construction under artificial rainfalls. The results detail the impact of rainfall on RCC's rollability, water content, vibrating compaction value, density, and bonding strength between RCC lifts. Reducing water content was studied as a countermeasure to mitigate such impacts. In the experiments, the optimal water content of 95 kg/m^3 was used in preparing the concrete mixture and the actual measured water content was 97 kg/m^3 as measured from the samples. The results indicate that the actual water content had increased due to rainfall; and the increase was more significant for more intense rainfalls. If the water content below the surface exceeds 101 kg/m^3, the point was impacted by the rainfall. At the rainfall intensities of 2.6, 5.0, and 8.0 mm/h, the impacted depths from the surface were 100, 150, and 175 mm, respectively. The impacted depth clearly increased with the rainfall intensity.

(Khorshidi *et al*. 2014) studied the effects of magnetic water on different properties of cement paste including fluidity, compressive strength, time of setting and etc. For production of magnetic water, three devices including an AFM called device(made in UAE) ,a device marked AC(made in Germany) and finally a device was designed and made in Concrete Laboratory of Sahand University of Technology) had been used. The results show that, intensity and direction of magnetic field, velocity and time of water passing through magnetic device, and amount and type of Colloidal particles had direct effects on properties of magnetic water and using such a water in making cement paste, increases its fluidity and compressive strength up to 10%.

(Kaustav and Bishwajit, 2014) presented proposes of numerical scheme for analysing the evolution of moisture distribution in concrete subjected to wetting-drying exposure caused by intermittent periods of rainfall. The proposed paradigm was based on the stage wise implementation of non-linear finite element (FE) analysis, with each stage representing a distinct phase of a typical wet-dry cycle. The associated boundary conditions had been constituted to realize the influence of various meteorological elements such as rain, wind, relative humidity and temperature on the exposed concrete surface. The reliability of the developed scheme had been demonstrated through its application for the simulation of experimentally recorded moisture profiles reported in published literature. A sensitivity analysis had also been carried out to study the influence of critical material properties on simulated results. The proposed scheme was vital to the service life modelling of concrete structures in tropical climates which largely remain exposed to the action of alternating rains. (Jiachun and Peiyu, 2013) they measured adiabatic temperature increases of four different concretes to understand heat emission during hydration at early age. The temperature-matching curing schedule in accordance with adiabatic temperature increase was adopted to simulate the situation in real massive concrete. The specimens under temperature-matching curing were subjected to realistic temperature for first few days as well as adiabatic condition. The mechanical properties including compressive strength, splitting strength and modulus of elasticity of concretes cured under both temperature-matching curing and isothermal 20^o C curing were investigated. The results denoted that comparing temperature-matching curing with isothermal 20^o C curing, the early age concretes mechanical properties were obviously improved, but the later mechanical properties of concretes with pure portland and containing silica fume were decreased a little and still increased for concretes containing fly ash and slag. On this basement they used an equivalent age approach evaluates mechanical properties of early age concrete in real structures, the model parameters were defined by the compressive strength test, and could predict the compressive strength, splitting strength and elasticity modulus through measuring or calculating by finite element method the concreted temperature at early age. (Yingfang *et al*. 2014) studied the behaviour of deteriorated reinforced concrete (RC) beams attacked by various forms of simulated acid rain. An artificial rainfall simulator was firstly designed and evaluated. Eleven RC beams (120mm x 200mm x 1800 mm) constructed in the laboratory. Among them, one was acting as a reference beam and the others were subjected to three accelerated corrosion methods, including immersion, wetting-drying, and artificial rainfall methods, to simulate the attack of real acid rain. Acid solutions with pH levels of 1.5 and 2.5 were considered. Next, ultrasonic, scanning electron microscopy (SEM), dynamic, and three-point bending tests performed to investigate the mechanical properties of concrete and flexural behaviour of the RC beams. It concluded that the designed artificial simulator can be effectively used to simulate the real acid rainfall. Both the immersion and wetting-drying methods magnify the effects of the real acid rainfall on the RC beams.

In this study, based on the rainfall reported in Taif, a comprehensive experimental program is conducted to investigate the rainfall duration effects in concrete compressive strength. The specimen divided into three groups based on the rainfall stating time after concrete casting (15, 30 and 45 minutes). The first group represent rainfall started after 15 minutes from casting and the rainfall duration was 10, 30, 45 and 60 minutes. The second group represents rainfall started after 30 minutes from casting and duration of rainfall as stated for group one. The third group represents rainfall started after 45 minutes from casting and the rainfall duration as stated for group one. Seventy eight concrete compressive strength tests were conducted in this experimental program to determine the compressive strength of the control cubes and cubes subjected to rainfall. Finally the Least-Square Method (LSM) is employed for the results of the experimental program toobtain the rainfall duration effect on concrete compressive strength.

1.1 Research significance

The technical and safety problems that arise when fresh concrete subjected to rainfall show the necessity for studying that subject in our research project.

The objectives of this study can be summarized as:

- To get a real data about the strength of fresh concrete if it is subjected to rainfall.
- Obtain an easy way to decide if the fresh concrete subjected to rain water can resist the future applied loads or not.
- Proposed an equation represent the relation between the concrete compressive strength and duration of rainfallbased on starting time of rainfall after casting.

1.2 Taif rainfall data

Daily meteorological data at Taif station No. 41036 was obtained from the Saudi Geological Survey. The analysis of the rainfall data for a period of 14 years showed that the maximum daily precipitation occurred was of intensity of 4.3 mm/hr.

2. EXPERIMENTAL PROGRAM

2.1 Procedures

- Design a concrete mix using the available sand, gravel and cement to determine the control compressive strength of concrete at age 28 days.
- Cast three groups of cubes each group has four subgroups. Each subgroup has six cubes cast using the same designed quantities of materials per cubic meter obtained from the design mix.
- Each group from the main three groups represents a sum of concrete cubes subjected to rain after 15, 30 and 45 minutes from casting. The subgroups represented by 15, 30, 45 and 60 minutes as duration of rain. The maximum time after casting considered 45 minutes due to results of initial setting test conducted to cement samples using Vicat needle.

2.2 Specimen design

To simulate the wooden formwork used in casting concrete structures, cube specimens 200 x 200 x 200mm with 12.5 mm thickness two plywood plates inserted internally above cube base and in front of each face of the cube as shown in Figure-1, wooden formwork simulated and a standard cube with net dimensions 150x 150x 150mmwas performed.

Figure-1. Cubes with wooden formwork.

2.3 Materials

In order to investigate compressive strength of concrete subjected to rainfall after casting, a concrete mixture designed to determine control strength. Mixture proportioning is designed to obtain average standard 28-days compressive strength of concrete cubes approximately 30 MPa. The mix ratios by weight of cement were cement: sand: gravel: water 1:2.1:4.2:0.48. Natural fine and coarse aggregates with maximum size 19 mm are used in the mixtures. Bulk specific gravities of coarse and fine aggregates are 2.67 and 2.71 and their water absorptions are 1.3% and 1%, respectively. Ordinary locally-available Portland cement having a specific gravity of 3.15 was employed in the casting of the specimens. A laboratory concrete mixer is used for mixing the concrete mixtures for five minutes. Standard steel cubes (150x 150 x 150 mm) specimens as the control specimens are cast with mechanical vibration. Same producers will be followed for all other specimens before subjected to rainfall. After casting, the control molded specimens are stored in the casting room for 24 hours and then are demolded and transferred to the curing cabinet, where all the rest of three groups specimen are subjected to rainfall after 15, 30 and 45 minutes from casting and demolded after 24 hours before curing.

2.4 Rainfall simulation

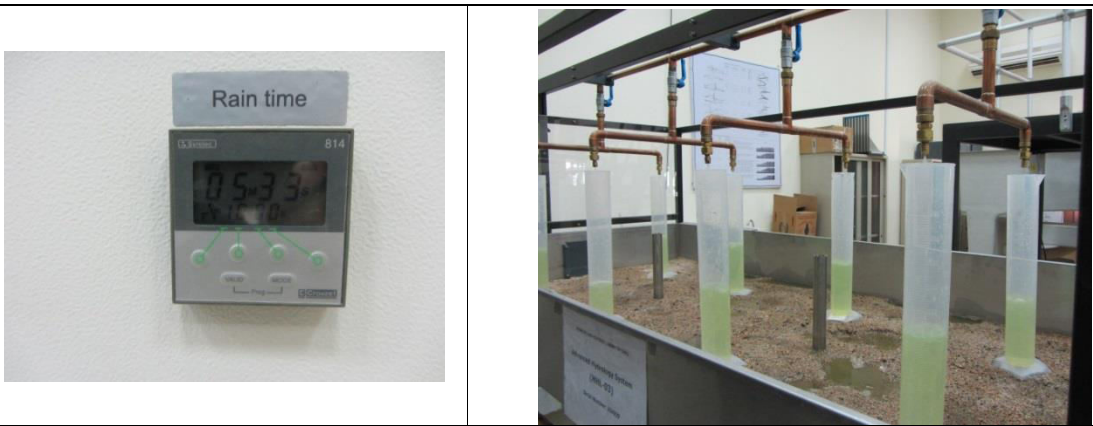
According to the provision of meteorology in KSA, rainfall can be classified in different ways. One of these ways is the rainfall intensity. In this study the rain simulated using the rainfall simulator apparatus produced by GUNT shown in Figure-2. In this apparatus the time of rainfall can controller by built up controller illustrated in Figure-3(a). The rain can be simulated by sprinklers controlled by valves these sprinklers provided by water lifted by pump connected to plastic water tank placed in the bottom part of the apparatus as shown in Figure-2(b). The discharge of each sprinkler is checked by measuring the rainfall intensity of each using graduated beakers as

ARPN Journal of Engineering and Applied Sciences

illustrated in Figure-3 (b). On the other hand, the height of water in a certain time is measured to determine the rainfall intensity in apparatus test area and it was equivalent to almost 3.9 mm/hr.

Rainfall area	Rain simulation apparatus

Figure-2. Rainfall simulator apparatus.



Rain time controller	Calibration and measuring of rainfall intensity

Figure-3. Rain timer and calibration.

2.5 Test producers

A total of 78 compression strength tests conducted to study the effect of rainfall duration on concrete strength using calibrated universal testing machine shown in Figures 4 and 5. The experiments were conducted at two different variables, rainfall starting time from casting and rainfall duration. After 28 days of curing, load control compressive strength test based on ASTM C39 with constant load rate of 3 kN/s is conducted for all of the specimens and the results are given in Table-1.

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(a) Specimen under rainfall

(b) Cubes demolded and curing

Figure-4. Specimen during test and curing.

UTM Calibration test

Cube compression strength test

Figure-5. Universal testing machine, calibration and testing.

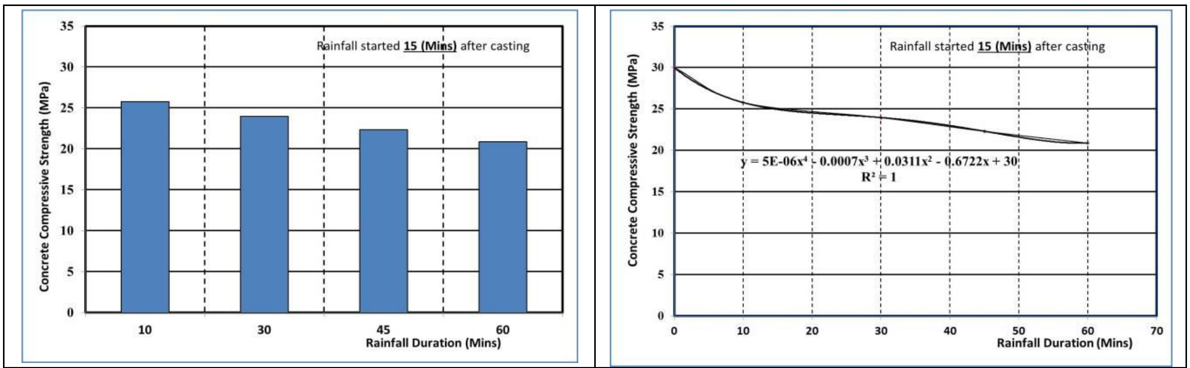
Table-1. Compressive strength test results.

Rainfall started / **Rainfall duration** (mins)		**15 mins from casting**		**30 mins from casting**		**45 mins from casting**	
		Average compressive strength (MPa)	**% from control strength**	**Average compressive strength** (MPa)	**% from control strength**	**Average compressive strength** (MPa)	**% from control strength**
Subgroup1	10	25.8	86%	27.0	90%	27.9	93%
Subgroup2	30	24.0	80%	25.7	86%	26.9	90%
Subgroup3	45	22.3	74%	24.0	80%	26.1	87%
Subgroup4	60	20.9	70%	22.0	73%	25.6	85%

3. EXPERIMENT RESULTS AND ANALYSES

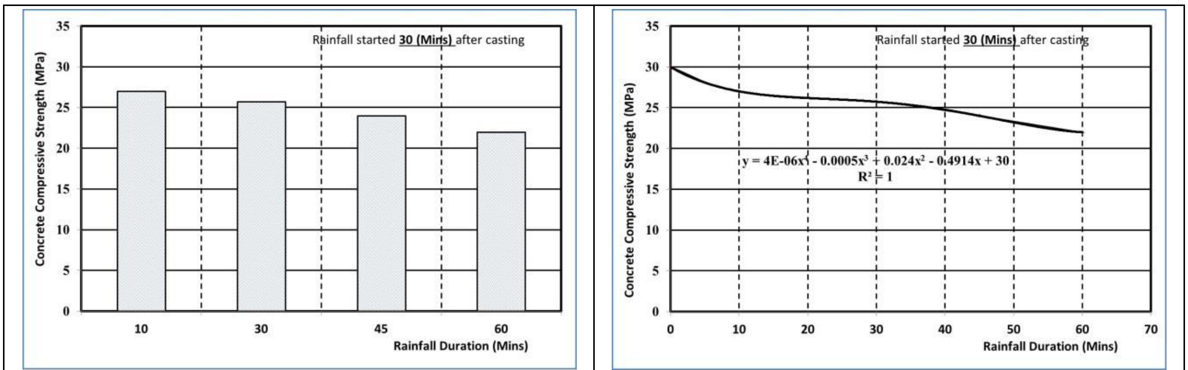
Figure-6. Cube failure configuration.

Average compressive strength for each subgroup and the percentage of reduction from control strength are given in Table-1. The results in Table-1 indicate that the concrete compressive strength has decreased due to rainfall; and the effect increase is more significant for more rainfall duration. Figure-6 shows the cube failure configuration after testing. In the experiments, the average compressive strength obtained from concrete mixture design was30 MPa was used as control value. Figures 7-9 illustrate the relationship between concrete compressive strengths of standard cubes and rainfall duration started after three different times from casting. As shown in Figures 7-9, concrete specimen show lower compressive strengths than control standard cube specimens. Generally, the difference between the compressive strengths of cubes subjected to rainfall and the control cubes significantly affected by the starting time of rainfall from casting and its duration. Therefore, it can be said that in rainy areas fresh concrete compressive strength can be affected significantly by two important factors, rainfall starting time after casting and rainfall duration.



Compressive strength Vs rainfall duration | Curve representing relationship (LSM)

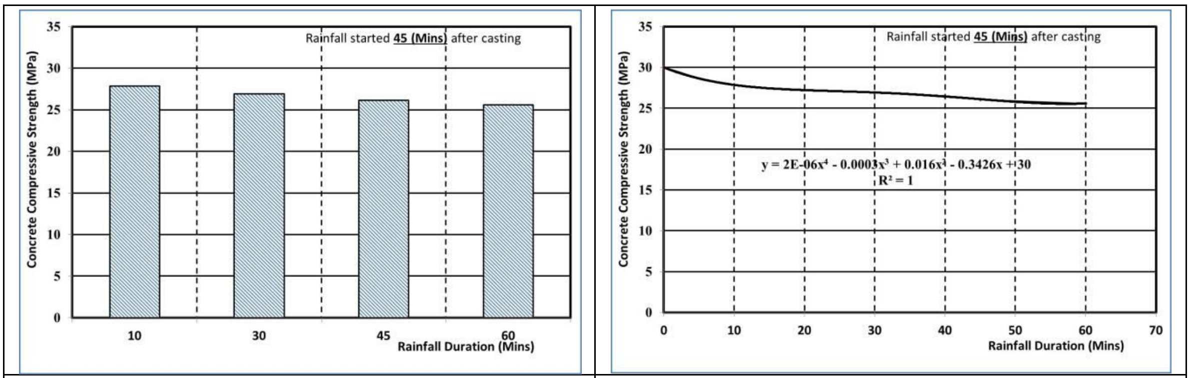
Figure-7. Concrete compressive strength and rainfall duration (rainfall started 15 mins after casting).



Compressive strength Vs rainfall duration | Curve representing relationship (LSM)

Figure-8. Concrete compressive strength and rainfall duration (rainfall started 30 mins after casting).

ARPN Journal of Engineering and Applied Sciences



Compressive strength Vs rainfall duration	Curve representing relationship (LSM)

Figure-9. Concrete compressive strength and rainfall duration (rainfall started 45 mins after casting).

In order to obtain the correlation between the reduction in concrete compressive strengths and duration of rainfall when it started after certain time from casting, regression analysis consisting types of curve-fittings are carried out on the results. Strengths are evaluated using a least square method (LSM). R-squared value for each case is given to indicate the accuracy of related curve-fitting as illustrated in Figures 7-9. Therefore, equations of form

$$f_{cuR15} = 5 * 10^{-6} * R_d^4 - 7 * 10^{-4} * R_d^3 + 0.031 * R_d^2 - 0.672 * R_d + f_{cu} \quad (1)$$

$$f_{cuR30} = 4 * 10^{-6} * R_d^4 - 5 * 10^{-4} * R_d^3 + 0.024 * R_d^2 - 0.491 * R_d + f_{cu} \quad (2)$$

$$f_{cuR45} = 2 * 10^{-6} * R_d^4 - 3 * 10^{-4} * R_d^3 + 0.016 * R_d^2 - 0.343 * R_d + f_{cu} \quad (3)$$

can be extracted from this study to obtain the concrete compressive strength after rainfall.

Where

f_{cuR15} - is the concrete compressive strength affected by rainfall; if rainfall started 15 minutes after casting (MPa).
f_{cuR30} - is the concrete compressive strength affected by rainfall; if rainfall started 30 minutes after casting (MPa).
f_{cuR45} - is the concrete compressive strength affected by rainfall; if rainfall started 45 minutes after casting (MPa).
R_d - is the duration of rainfall by minutes.
f_{cu} - is the designed concrete compressive strength after 28 days(MPa).

4. CONCLUSION REMARKS

An experimental simulation produced for predicting the effect of rainfall on fresh concrete compressive strength. Three different rainfall started time from end of concrete casting studied. Four different rainfall duration 10, 30, 45 and 60 minutes were studied in each case if rainfall starting time from casting. From this experimental work the following conclusions can be drawn:

- The effect of rainfall starting time from fresh concrete casting time and duration of rainfall are two important factors have to be taken into consideration in the rainy region.
- Fresh concrete compressive strength can be decreased from 10% to 30% from designed compressive strength due to rainfall effect.
- Equations for prediction the compressive strength of fresh concrete considering the effect of rainfall starting time and rainfall duration were achieved using LSM method.

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