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Fresh Concrete subjected to rainfall - Level of formwork to concrete surface effect

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ABSTRACT

An experimental program carried out to study the effect of level of formwork on fresh concrete subjected to rainfall. Two different cases of fresh concrete subjected to rainfall studied; in the first case the level of formwork was higher than concrete surface level where in the second case, concrete surface was at the same level of formwork. Control compressive strength obtained from concrete mixture designated and cast in nine standard cubes molds 150 *150* 150 mm. Based on the designed mix quantities, hundred forty two cubes casted in tow main group. The first main group represented concrete with formwork level higher 50mm than concrete surface level, where the second main group represented concrete and formwork at the same level. Each one from the two main groups divided into three groups, each group divided into four subgroups with six cubes each. The three groups represented three different rainfalls started time from concrete casting 15, 30, and 45 minutes. The subgroup represented four durations of rainfall studied 10, 30, 45, and 60 minutes. From this study, the findings can get site decisions on, whether to continue or suspend the casting process based on the forecasted rainfall. On the other hand, it is concluded that, concrete compressive strength decreased from 5% to 25% in case of level of formwork higher than concrete surface level, where in case of concrete and formwork at the same level the reduction in compressive strength varied from 2% to 20% depend on time of rainfall from casting and rainfall duration.

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. All specimens in this study will have dimensions of standard cubes 150x150x150mm.

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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. 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 analyzing 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 (120 mmx200 mmx1800 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 behavior 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 level of formwork effect in concrete compressive strength using different rainfall duration and time of rainfall after casting. The research program will be concerned only with 150mm concrete element depth which is representing the common depth of concrete flat slab. The specimen divided into two main groups, the first with formwork level higher 50mm than concrete level where the second the level of formwork and concrete surface were the same. Each one from main groups divided into three subgroups based on the rainfall stating time after concrete casting (15, 30 and 45 minutes). The first subgroup represent rainfall started after 15 minutes from casting and the rainfall duration was 10, 30, 45 and 60 minutes. The second subgroup represents rainfall started after 30 minutes from casting and duration of rainfall as stated for subgroup one. The third subgroup represents rainfall started after 45 minutes from casting and the rainfall duration as stated for subgroup one. Hundred fifty one concrete compressive strength tests were conducted in this experimental program to determine the compressive strength of (9) control cubes and (142) cubes subjected to rainfall.

1.1 Research significance:

The technical and safety problems that arise when fresh concrete subjected to rainfall show the necessity for studying this subject as a 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.
- Take an idea about how can concrete compressive strength affected by level of formwork and duration of rainfall.

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.

- Two main groups of cubes casted, each one of the main group divided into three groups of cubes; each group from these three divided into four subgroups. Every subgroup has six cubes cast using the same designed quantities of materials per cubic meter obtained from control design mix.
- Each group from the three groups represents a sum of concrete cubes subjected to rainfall after 15, 30 and 45 minutes from casting. The subgroups represented by 10, 30, 45 and 60 minutes as duration of rainfall. 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 difference between formwork and concrete surface level, cube specimens 200 x 200 x 200 mm with two plywood plates 12.5 mm thickness inserted internally in front of each internal face of the cube to get clear internal dimension of samples 150x150mm as shown in Fig. 1. Where, for cubes represent the case of concrete and formwork at the same level; represented by standard cube with net dimensions 150 x 150 x 150 mm.

Fig. 1 Cubes with wooden formwork

2.3 Materials

In order to investigate the level of formwork effect on concrete compressive strength 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 35 MPa. The mix ratios by weight of cement were cement: sand: gravel: water 1:1.9:4.1:0.46. 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 1.2% 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 Fig. 2. In this apparatus the time of rainfall can controller by built up controller illustrated in Fig. 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 Fig. 2(b). The discharge of each sprinkler is checked by measuring the rainfall intensity of each using graduated beakers as illustrated in Fig. 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.

(a)

(b)

Rainfall Area	Rain simulation apparatus

Fig.2 Rainfall simulator apparatus

(a)

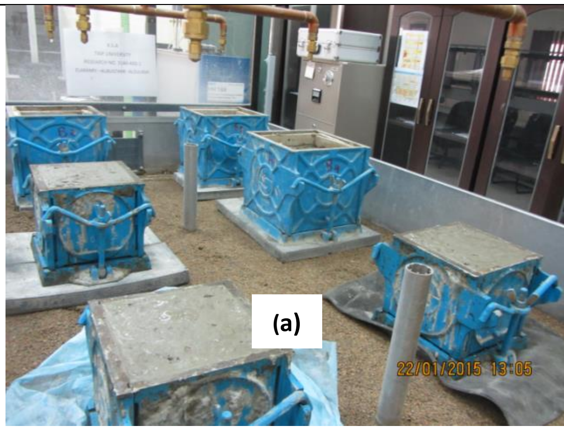
(b)

Rain time Controller	Calibration and measuring of rainfall intensity

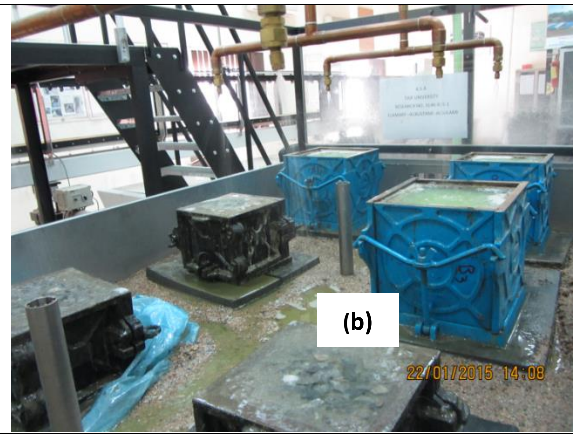
Fig. 3 Rain timer and calibration

2.5 Rainfall test procedures:

Rainfall test procedures controlled by two main factors, (1) time of rainfall after casting and (2) duration of rainfall. Three different rainfall starting time studied 15, 30 and 45 minutes after casting. The durations of rain were 10, 30, 45 and 60 minutes for each case rainfall starting time. A total of 78 compression rainfall tests conducted for each main group. Fig. (4) illustrated concrete samples before and during rainfall test.



Samples before rainfall test



Samples during rainfall test

Fig. 4. Concrete samples before and during rainfall test

Fig. (5) shows how the level of formwork during rainfall plays an important factor that may affect concrete compressive strength. It is noticed that when the level of formwork higher than concrete surface there is a chance to assembly water over fresh concrete surface during rainfall time as shown in Fig. 5(a). Where in Fig. 5(b) shows the case of formwork and concrete surface at the same level, in this case it is shown that concrete surface can be subjected to erosion due to rainfall.

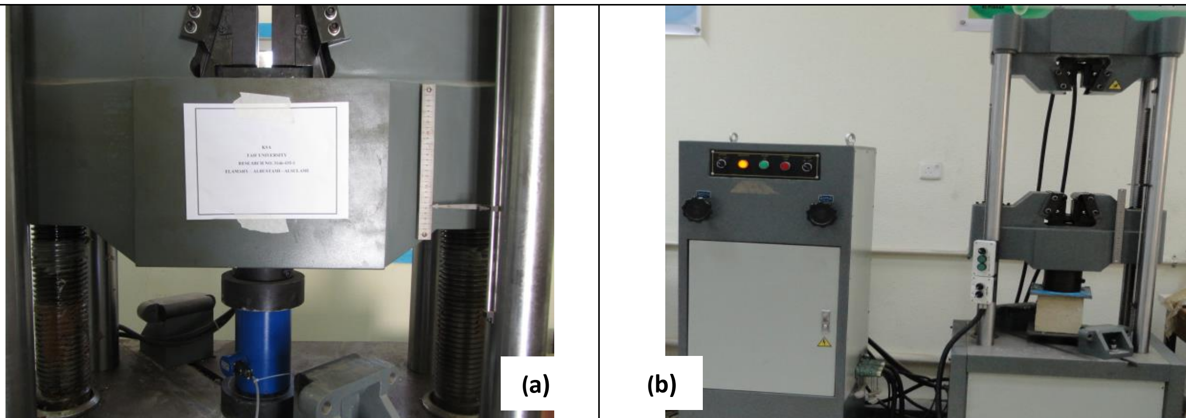
Samples with level of formwork higher 50mm than concrete surface level – during rainfall test

Samples with formwork and concrete surface at the same level – during rainfall test

Fig. 5. Concrete samples during test

2.6 Compressive test procedures:

For each case from the two main cases, a total of 78 compression strength tests were conducted to study the effect of level of formwork and rainfall duration on concrete strength using calibrated universal testing machine shown in Fig. 6. 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 Tables 1 and 2.



UTM Calibration test | Cube compression strength test

Fig. 6 Universal Testing Machine, calibration and testing

Average compressive strength for each subgroup and the percentage of reduction from control strength for the first main group of cubes (Level of formwork higher 50mm than concrete surface) are given in Table 1. The results in Table 1 indicate that the concrete compressive strength decreased due to rainfall; and the effect increased by increasing rainfall duration. The reduction from control compressive strength varied from 6% to 25%.

Table 1: Compressive strength test results - group (1) Level of formwork 50mm higher concrete surface.

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	30.77	87.9%	32.00	91.4%	32.85	93.9%
Subgroup2	30	28.86	82.5%	30.62	87.5%	32.00	91.4%
Subgroup3	45	27.16	77.6%	28.92	82.6%	31.05	88.7%
Subgroup4	60	26.00	74.3%	27.56	78.7%	29.54	84.4%

Average compressive strength for each subgroup and the percentage of reduction from control strength for the second main group of cubes (concrete surface and formwork at the same level) are given in Table 2. The results in Table 2 indicate that the concrete compressive strength decreased due to rainfall; and the effect increased by increasing rainfall duration. The reduction from control compressive strength varied from 2% to 20%.

Table 2: Compressive strength test results group (2) concrete surface and formwork at same Level:

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	32.8	93.7%	33.2	94.9%	34.2	97.7%
Subgroup2	30	30.5	87.1%	31.9	91.1%	33.4	95.4%
Subgroup3	45	28.8	82.3%	30.1	86.0%	32.5	92.9%
Subgroup4	60	27.8	79.4%	28.7	82.0%	31.2	89.1%

3. EXPERIMET RESULTS AND ANALYSES

Fig. 7 Cube failure configuration

Fig. 7 shows the cube failure configuration after testing. Average compressive strength obtained from designed concrete mixture was 35 MPa used as control value. Figs. 8 to10 illustrate comparison between the compressive strength results obtained for cubes in group 1 (formwork level higher 50mm than concrete surface) and cubes in group 2 (concrete surface at the same level of formwork) at three different times of rainfall from end of concrete casting (15, 30 and 45 minutes). Each figure shows the comparison in four different duration of rainfall (10, 30, 45 and 60 minutes). As shown in Figs. 8 to10, concrete specimen with level of formwork higher than concrete surface show lower compressive strengths than specimen with concrete surface and formwork at the same level. 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, concrete compressive strength can be affected significantly by three factors, level of formwork, rainfall starting time after casting and rainfall duration.

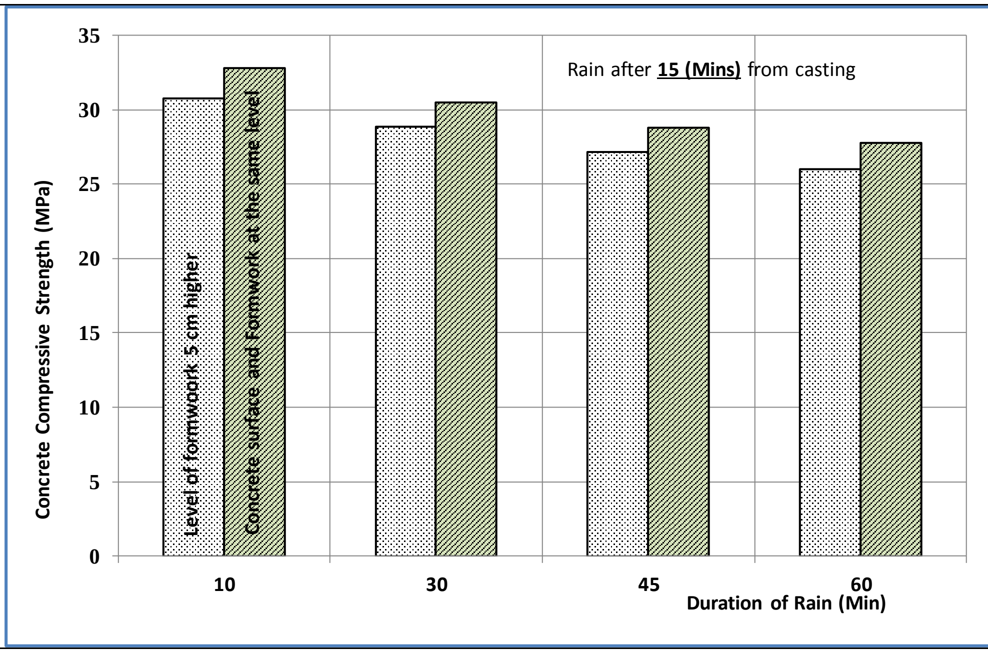


Fig. 8 Comparison between concrete samples with different level of formwork from concrete surface and subjected to rainfall after 15 minutes from casting

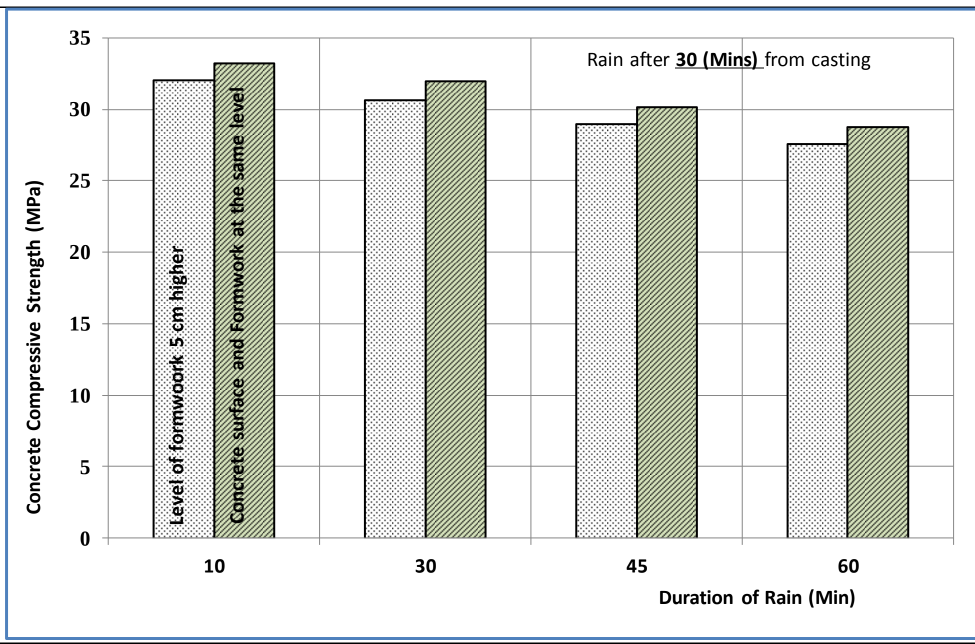


Fig. 9 Comparison between concrete samples with different level of formwork from concrete surface and subjected to rainfall after 30 minutes from casting

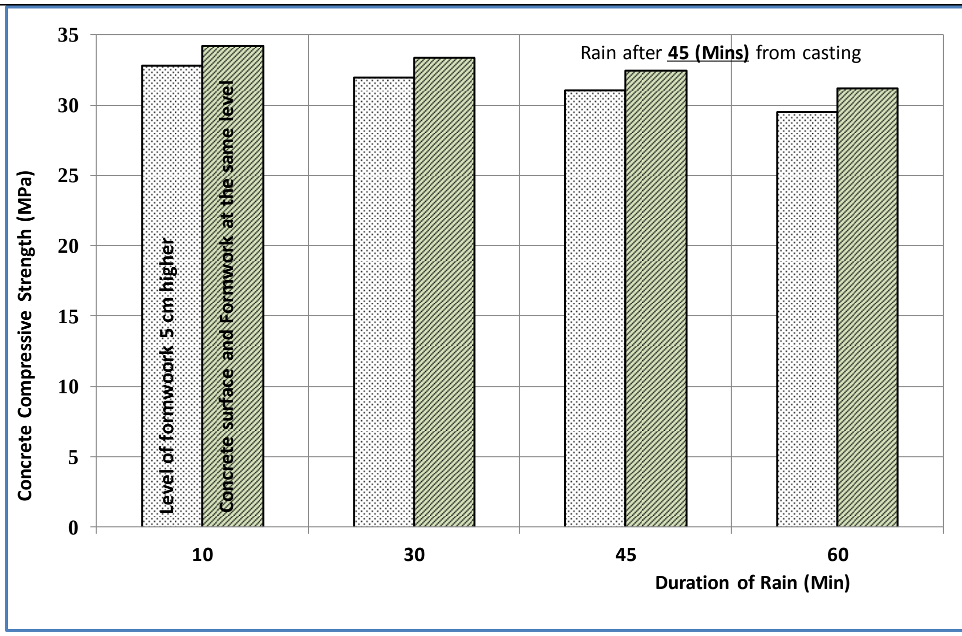
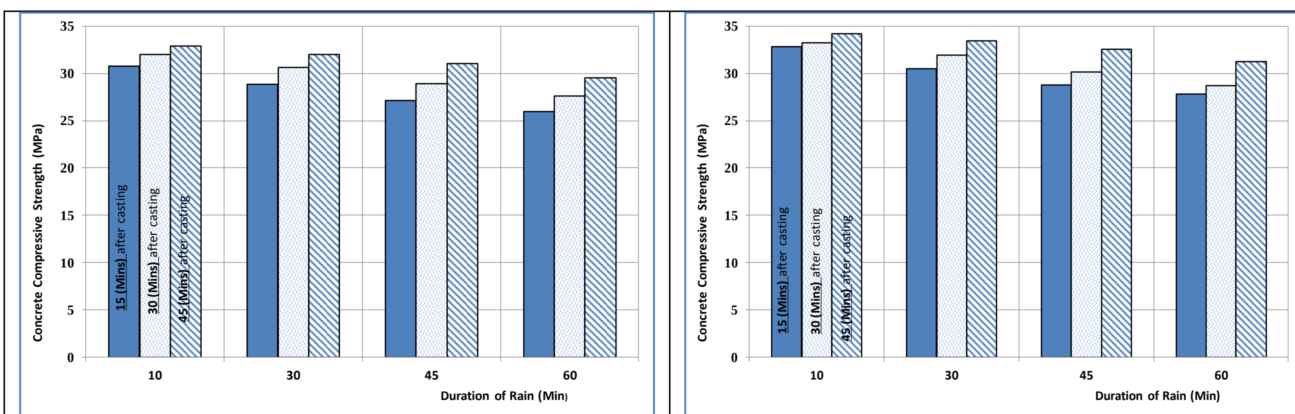


Fig. 10 Comparison between concrete samples with different level of formwork from concrete surface and subjected to rainfall after 45 minutes from casting

The relation between duration and concrete compressive strength plotted in Fig. 11 for each one of the two main groups. In this figure, three bars representing the starting time of rainfall after casting (15, 30 and 45 minutes) shown in every rainfall duration (10, 30, 45 and 60 minutes). Fig. 11(a) shows average compressive strength obtained for the first main group of samples (level of formwork higher 50mm than concrete surface. Fig. 11(b) shows average compressive strength obtained for the second group of samples (Concrete surface and formwork at the same level).



Level of Formwork 50 mm higher than concrete surface level	Concrete surface and formwork at the same level

Fig. 11. Comparison between rainfall duration effect on concrete compressive strength

In order to study the effect of formwork level from concrete surface on the final concrete compressive strength when subjected to rainfall after casting, the different between percentages of obtained compressive strength from designed strength (35 MPa) shown in Tables 1 and 2 are listed in columns a, b and c in Table 3. Based on the rainfall duration, the averages of these differences in each time of rainfall after casting shown in columns a, b and c are calculated. From this analytical analysis it can be concluded that, in case of concrete elements with formwork higher 50mm than concrete surface; almost 5% additional reduction in concrete compressive strength can be arisen due to rainfall regardless rainfall duration.

Table 3: Different between percentages of new concrete compressive strength from designed in both cases of formwork level from concrete surface:

Rainfall started time / Rainfall Duration (mins)	15 mins after casting	30 mins after casting	45 mins after casting	Average reduction in compressive strength due to increased level of formwork [(a+b+c)/3]
	Different between % of compressive strength (a)	Different between % of compressive strength (b)	Different between % of compressive strength (c)	
10	5.79%	3.43%	3.85%	4.36%
30	4.68%	3.65%	4.01%	4.11%
45	4.69%	3.36%	4.14%	4.07%
60	5.16%	3.25%	4.74%	4.38%

4. CONCLUSION REMARKS

An experimental simulation produced for predicting the effect of level of formwork to concrete surface on compressive strength of fresh concrete subjected to rainfall. Using 150mm concrete element depth (standard cubes) and 200mm or 150mm formwork depths, three different rainfalls starting time from end of concrete casting studied (15, 30 and 45 minutes). Four different rainfall durations 10, 30, 45 and 60 minutes were studied in each case of the three cases of rainfall starting time after casting mentioned above. From this experimental work the following conclusions can be drawn:

- Concrete compressive strength can be affected by three main factors if it subjected to rainfall during fresh stage, level of formwork to concrete surface, rainfall starting time from fresh concrete casting time and duration of rainfall.
- Compressive strength of fresh concrete subjected to rainfall can be decreased from 5% to 25% from designed compressive strength due to rainfall in cases of level of formwork higher than concrete surface.

- Compressive strength of fresh concrete subjected to rainfall can be decreased from 2% to 20% from designed compressive strength due to rainfall in case of concrete surface and formwork at the same level.
- Concrete surface with the same level of formwork can be subjected to erosion due to rainfall more than concrete surface with level of formwork higher than it.
- Regardless of rainfall duration, almost 5% as an additional reduction in concrete compressive strength from designed compressive strength can be arisen due to rainfall in case of concrete elements formwork performed higher 50mm than concrete surface.

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