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Review Article

EFFECT OF DIFFERENT CURING REGIMES ON CAPILLARITY OF CONCRETE INCORPORATING LOCAL MATERIALS

Bengin M. A. Herki

[1]Faculty of Engineering, Soran University, Erbil, Kurdistan, Iraq
[2]College of Science and Engineering, Bayan University, Erbil, Kurdistan, Iraq

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Abstract
This paper reports an experimental study to investigate the effect of different curing regimes on the capillary water absorption (CWA) characteristics of concrete produced with locally available materials. Mechanical (compressive strength) and nondestructive test (ultrasonic pulse velocity) of concrete were also investigated. The engineering properties were conducted on concrete under three different curing regimes at different curing times of 2, 7 and 28 days. The three different curing conditions were water curing, dry curing and gunny-covered curing. According to the results obtained concrete under water curing condition demonstrated lower capillary water absorption (CWA) at 2 and 7 days ages and concrete under gunny-covered condition demonstrated lower CWA at 28 days age compared with the other curing conditions. It is interesting to see that the compressive strength (38 MPa) of concrete was almost the same at 28 days age under gunny-covered and water curing conditions.

Keyword: Capillary Water Absorption; Concrete; Materials; Strength; UPV

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INTRODUCTION

Concrete as a composite material is one of the most used and known material in the world. Nowadays, thousand tons of concrete is being used at different parts around the globe. Concrete as the most popular artificial material on earth has been used to build civilizations thousands of years ago. It has lots of advantages however, like any other material it has some disadvantages and limitations (Neville, 2011). Curing is the name given to procedures used for promoting the hydration process of cement, and consists of a control of temperature and of the moisture movement from and into the concrete (Neville, 2011). Curing may take place after the fresh concrete is being placed in the site, because the hydration of concrete takes time, it usually take days so curing must be done for a reasonable period of time in order concrete can achieve its initial strength and durability. However, many factors affect the development of mechanical and durability properties of concrete other than curing process. These factors include quality and quantity of cement used in the mix, grading of aggregates, maximum nominal size, shape and surface texture of aggregate, others include water/cement ratios, degree of compaction, and the presence or otherwise of clayey particles and organic materials in the mix (Ogah, 2016). In the study conducted by James, et al., (2011) reported that for the concrete that are subjected to extreme ambient the most important factor for the concrete in order to gain the design strength and the ultimate strength is a proper curing after placing and at the early stage of hardening meaning that the curing process is managed by the rate of hydration and the level of moist loose in the concrete.

There are various types of curing and of course the adoption of the particular condition depends on the environment and on the nature of work. There are six different types of curing including shading of concrete network, covering concrete with gunny bags, sprinkling of water, ponding method, membrane curing and steam curing which generally adopted around the globe. In the study conducted by James, et al., (2011) has been showed a summary of the effect of curing method on the compressive strength with curing age for all the curing methods of ponding, wet covering, sprinkling, plastic sheeting, and uncured type in the open air and cubes left uncured for two days before start curing. It was noticed that there was a significant increase in concrete strength with curing age depending on the curing method adopted. It was clearly shown the ponding curing gave highest compressive strength compared with other curing methods at the same curing age, because ponding curing is working on the improving the pore system of the concrete and lowering the permeability of the concrete which obviously results in a greater degree of hydration of cement and lowering the rate of moisture lose from the concrete cubes, and the specimens with totally uncured method gave the lowest compressive strength. Because the concrete was not cured so hydration process was not completely done that's why the concrete specimens didn't get its max strength. Since the specimen left total uncured gave the lowest result, this therefore suggests that curing is very important and necessary for all concrete structures especially in hot environments for example in very hot weather during summer and in very cold weather during winter conditions in Kurdistan Region-Iraq.

The effect of temperature on the capillary water absorption in different building materials at three different levels of temperature at (20°C, 25°C and 30°C) has been investigated by Karagiannis (2016). The study has shown that there is a linear relation between the capillary water rise and temperature for all building materials such as (brick, stones and hydraulic mortars). Although there was a difference in the linearity slope for each material but they have observed that when temperature increases the rate of capillary water absorption increases. In recently published study conducted by Maslehuddin, (2013) the effect of curing methods on shrinkage and corrosion resistance of concrete has been reported. Concrete samples were put under different curing conditions and were cured either by water ponding, covering with wet burlap, or by the application of curing compound. It was noticed that the maximum plastic shrinkage strain was noticed in those samples which were cured by covering them with plastic sheet. In an experimental study conducted by Gayarre, (2013) the ordinary concretes density value of two samples each under different curing condition has been reported. It showed that the sample which has been cured under open air condition gives a lower value than the one which is cured in controlled condition. It also reported the effect of both types of curing on the compressive strength of concrete although the compressive strength value of both samples were nearly the same at first 7-days but at the age of 28-days the specimen which was cured in controlled environment showed a higher compressive strength in the same period of curing than the one which was cured in the outdoor. Similar results reported by Safiuddin, (2007) and Ibrahim, (2013).

METHODOLOGY

Materials

This study experimentally investigated the effect of different curing conditions and times on the capillary water absorption (CWA) of concrete incorporating locally available materials produced in Kurdistan region of Iraq. Ordinary Portland cement of CEM I/ 42.5 R complied with EN 197-1:2011 were used which manufactured by Urmia cement company imported from Iran. This cement has been used in the study for both batches. The characteristic of the cement is shown in Table 1.

Table 1: Characteristics of Portland cement

Constitute	OPC (wt. %)	Constitute	OPC (wt. %)
Lime (CaO)	64.64	(C3S)	52.82
Silica (SiO2)	21.28	(C2S)	21.45
Alumina (Al2O3)	5.6	(C3A)	9.16
Iron Oxide (Fe2O3)	3.36	(C4AF)	10.2
Magnesia (MgO)	2.06	Loss on ignition	0.64
Sulphur Trioxide (SO3)	2.14	Lime saturation factor	0.92
Nitrous Oxide (N2O)	0.0		

Table 2: Particle size distribution of fine aggregate

Sieve size (mm)	Weight retained on each sieve (g)	Weight retained on each sieve (%)	Cumulative sieve (%)	Cumulative sieve weight passing (%)
4.75mm	143	14.3	14.3	85.7
2mm	302	30.2	44.5	55.5
1mm	166	16.6	61.1	38.9
500mic	292	29.2	90.3	9.7
250mic	86	8.6	98.9	1.1
Pan	11	1.1	100	0

For this investigation, locally available fine aggregates in Soran town, Erbil, Kurdistan, Iraq was used. The particle size distribution is shown in the Table 2.

The locally available natural coarse aggregate with maximum size of 12.5 mm was also used in present study. The physical property of the coarse aggregate were tested in laboratory including specific gravity and water absorption according to ASTM standard, the results are shown in Table 3. The particle size distribution is shown in the Table 4.

Table 3: Physical properties of natural coarse aggregate

Property	NCA
Bulk Specific Gravity(OD)	2.61
Water Absorption %	0.53
Particle Shape/Texture	Sub angular/Partially rough
Types	Crushed
color	Grey

Table 4: Particle size distribution of natural coarse aggregate

Sieve size	Weight retained on each sieve (g)	Weight retained on each sieve (%)	Cumulative sieve (%)	Cumulative sieve weight passing (%)
12.5mm	675	67.50	67.50	32.50
9.5mm	238	23.80	91.30	8.7
Pan	87	8.7	100	0

Mix Proportion

The mix was prepared according to absolute volume mix design method. The required amount of each material to prepare the concrete mix was calculated based on the standards. The mix proportion used for the present experimental study was (1: 2.5: 3.5) more specifically (1) cement, (2.5) fine aggregate and (3.5) coarse aggregate. The amount of required materials are shown in the below. 10% of the total weight of the mix was added to work as a backup for materials that are being loosened during the mixing process. The water to cement ratio (W/C) used for was 0.5 and kept constant for all mixes. For ease of demoulding before filling the cubes with concrete the interior side of all moulds were oiled. Casting of the cubes were put in three layers each layer was compacted 25 times by using a rod and the outer side of the cube was being hammered by a plastic hummer to free cube from air bubbles. 27 cubes were prepared and 9 of them were divided into half by using a metal sheet and to be used for CWA test. Cubes were covered by plastic sheets and kept in a room temperature for 24h, after the period of 24h the cubes were ready to be demoulded. Cubes were demoulded using a water pump pressure. After that cubes were dived into three groups based on their curing method, group one was put in the water tank, group two was covered with gunny bag and the last group were put in outside environment till the day of the test at different curing times of 2, 7, 28 ages.

TESTING METHODS

Slump Test

Slump test is assessing the consistency of fresh concrete. It is being used in order to check whether the used amount of water which has been added to the mix is correct or not. It is used to determine the workability of fresh concrete and it is being measured right after the concrete is being mixed. This test is being carried out according to the BS EN 12350-2, testing fresh concrete.

2.3.2 Compressive Strength

For performing this test for each curing age a set of six concrete cube of 150*150*150mm were tested for curing ages of 2, 7 and 28 days two cubes for each curing methods of water curing, dry curing and gunny-covered curing, each cube was put in its curing condition till the day of the test, and the test was performed according to the standards. The test was carried out in a standard compression machine of 2000KN capacity, the load applied at a rate of 0.5 MPa/s.

Ultrasonic Pulse Velocity

Ultrasonic measurements are used in structural engineering to determine material properties, detect defects and assess deterioration (Yaman, 2001). Ultrasonic pulse velocity (UPV) is a long-established, non-destructive test method which determines the velocity of longitudinal (compressional) waves (Neville, 2011). UPV test in concrete is done in order to determine the uniformity of concrete, cavities, crucks and defects also the presence of voids, honeycomb and discontinuities. This test has been carried out at different ages of concrete curing according to BS EN 12504-4:2004. While performing this test direct transmission method was used to measure the velocity, using a portable ultrasonic non-destructive digital indicating tester on 150 x 150 x 150mm cube specimens as shown in Fig. 1. The equipment is consisted of two metallic transducers one for transmitting the velocity and the other one for receiving the pulse.

Fig. 1: UPV Instrument

Capillary Water Absorption

After the mix was being prepared moulds of 150*150*150mm size was used and it was divided into half by using a piece of steel (Figs. 2 and 3). The mix was casted and the cubes were demoulded after 24h of casting then for each curing age 2 days, 7 days and 28 days six cubes were prepared two for each curing condition. Specimens of 150×150×75mm size were used for the CWA test. These specimens were cured in different curing conditions until testing. Saturated Surface Dry (SSD) specimens were kept in a hot air oven at 100ºC until a constant weight was attained. For the CWA test, the absorption of water by the concrete specimens was determined by measuring the increase in the mass resulting from water absorption as a function of time when only one surface of the specimen is exposed to water on a support device (Herki et al., 2013). The schematic diagram of the CWA (moisture migration) test setup used is shown in Fig. 4. During the test period, weight gain was monitored at intervals of 1, 3, 5, 7, 10, 20, 30, 45, 60, 120, 180, 1440 and 2880 minutes. The water level was kept constant throughout the test. The CWA values are the average of two test samples. The weight (g) of water absorbed per unit area (mm^2) was plotted against the square root of time (minute). The units are in g/mm^2 min½. Water curing by putting the cubes in the water tank, dry curing by putting the cubes in the open space where it is being in contact with the outdoor weather and away from the rain or from any water curing, gunny bag curing by covering the cubes with gunny bag and cubes were cured by spraying water on the covered gunny 3 times daily. After each curing period cubes were made oven dry condition by putting in the oven for 48 hours as shown in fig in temperature of 105+-5 C till it reaches the condition were the weight loss percentage is less than 0.01 percentage. Every day the cubes which were in the oven were being weighted 4 times daily. After the drying process was over each sample was covered with a plastic bag so there is no more moisture losing and they were being prepared for capillary water absorption test. A metallic trey was filled with water and a support has been put in the trey so the cubes can rest on the level of water was just in touch with a surface of the cube after the samples were rested on the support weighting process starts, according to the time table specified it starts from 1 min and ends after 48 hours for each specified time weight of cubes were recorded. This process was repeated after 7 days of curing and after 28 days of curing. After the test was started water was being added to the trey to be insure that the surface of the cubes were in touch with the water. The rise of water from the capillaries of concrete was obvious and clearly seen as it is being shown in Figs. 2 and 3.

Fig. 2: Specimen water uptake

Fig. 3: CWA test setup

RESULTS

Compressive Strength

The compressive strength of the concrete samples at the age of 2, 7, 28 days for different curing conditions is shown in the Fig. 4 below. The mentioned result in the table below is concluded after taking the average of two concrete samples for each curing condition. The compressive strength of the sample after 2 days of curing is relatively the same for all curing conditions and the value is ranged between12.50 and12.73MPa. The reasons why the results are the same is due to the incompleteness of hydration process and it is clear that the cubes are at the first stage of the hydration process. However, the development of the compressive strength of the cubes after 7 days of curing is being noticed that there is a slight difference between concrete samples for different curing conditions. Because the hydration process has developed more compared with the hydration process after 2 days of curing that's why the difference is being noticed, the compressive strength is ranged from 20.92 to 22.39 MPa. Finally our samples have reached the max compressive strength after 28 days the compressive strength ranged from 30.71 to 37.86 MPa. The reason of this clear difference results between the different types of curing is that the hydration process has reached its final stages and there is a little or no cement remained to be hydrated by water. As a result of this study it was obtained that by increasing the curing age the compressive strength increases too which means they are directly proportional to curing time. Same results have been reported by James, et al., (2011). The most effective curing condition mentioned above is covering the cube by using the gunny bag cause it has given the highest compressive strength, respectively unlike the result that was obtained by Safiuddin , et al., (2007) which wet curing was the best curing condition when it comes to gaining strength, our fault might be due to improper drying process of cubes because the oven sizes was very small and there was not same drying period for every cubes. Wet curing is also a good way for obtaining a good result cause there is a very slight difference between the strength developed in cubes that has been cured with gunny bag and wet curing condition, however the dry curing is not very desirable when it comes to development of compressive strength in the concrete samples, as Ibrahim, et al., (2013) has mentioned in their research.

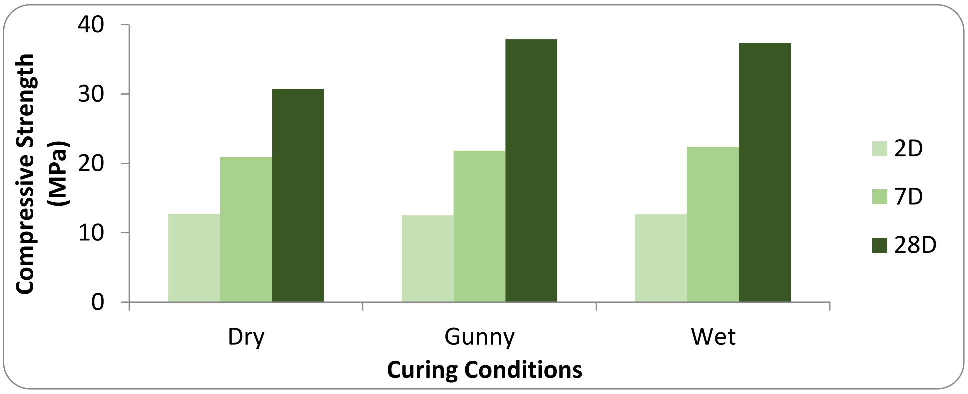

Fig. 4: Compressive strength of concrete under different curing conditions and times

Ultrasonic Pulse Velocity

The time taken by the wave to travel from one side of concrete to the opposite side of the sample is being indicated by the porosity of the concrete, hence that ultrasonic pulse velocity (UPV) depending largely on the pore system and the density of concrete. Fig. 5 shows the result of the UPV test at different curing ages for three different curing conditions. As the previous test the results are taken in average of test on two cubes, it is clear that as the age of curing increases for different curing conditions the hydration process develops more which means that the cavities and pores in the concrete decreases, hence that the results of UPV test increases and gives a better result as curing age increases. This study shows that wet curing is the best between the three conditions mentioned above when it comes to UPV test. Similar results were reported by Ghosh, (2018), Pierre, (2016), Mohammed Rahman, (2016), Aziz Hasan, (2016) and Safiuddin, et al., (2007).

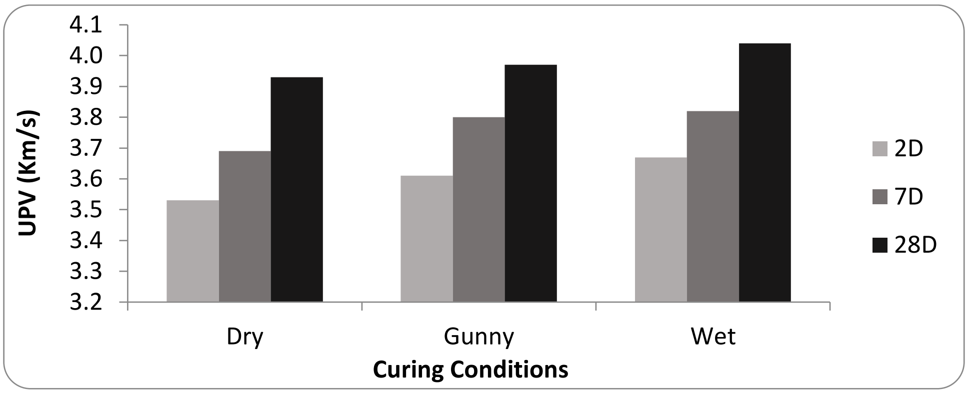

Fig. 5: UPV of concrete under different curing conditions

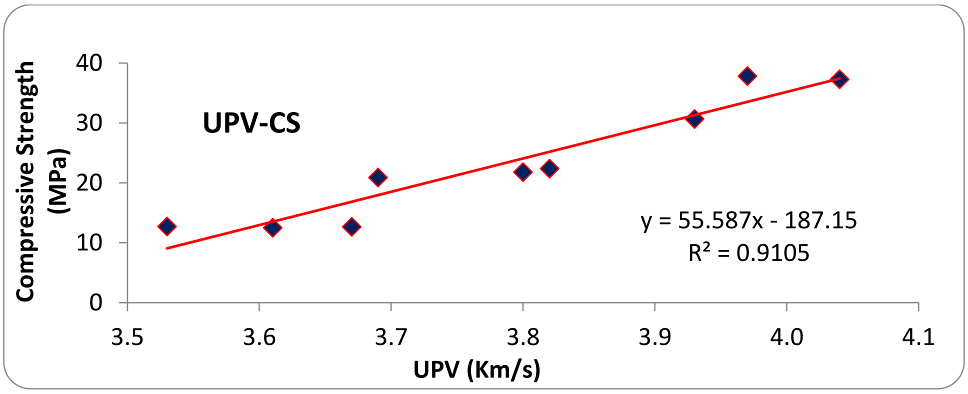

Fig. 6: Correlation between strength and UPV

Fig. 6 shows the correlation between compressive strength and UPV of concrete under different curing conditions and different curing times similar to what Aziz Hasan, et al., (2016) reported, the correlation is being described by a function as shown below.

Equation: Y=55.587X-187.15 $R^2 = 0.9105$
This equation shows a strong correlation ($R^2 = 0.9105$) where X representing UPV (km/s) and Y is the compressive strength (MPa).

Capillary Water Absorption

The capillary water absorption (CWA) of the concrete under different curing times and three different curing conditions is being shown in the Figs. 7-9. CWA is defined as the rate of water absorption per unit area and is expressing the tendency of the concrete to transmit the water through capillarity. The results are the average taken of two cubes for each age and each curing condition.

CWA-2Days

After two days of curing the cubes were cured in dry condition as it is shown in the Fig. 7 below. At the early stage of the test there is a very sharp increase in the water absorption from the 1st min until 24 hours and from the 24 hours of the test till 48 hours there is a very slight increase in the absorption of water the total weight of water which was absorbed by the cubes from the beginning of the test till the end of it was (229.5g), CWA for wet and gunny bag curing of cubes from beginning of the test till 24 hours the water absorption of the cubes is very fast and noticeable after that period the absorption rate decreases automatically and there is a slight increase in the water absorption the as shown in figure below the total weight of water absorbed by the cubes for wet curing was (189.5g) and for the cubes which were covered in gunny bag (205g) (Yazicioglu, 2010).

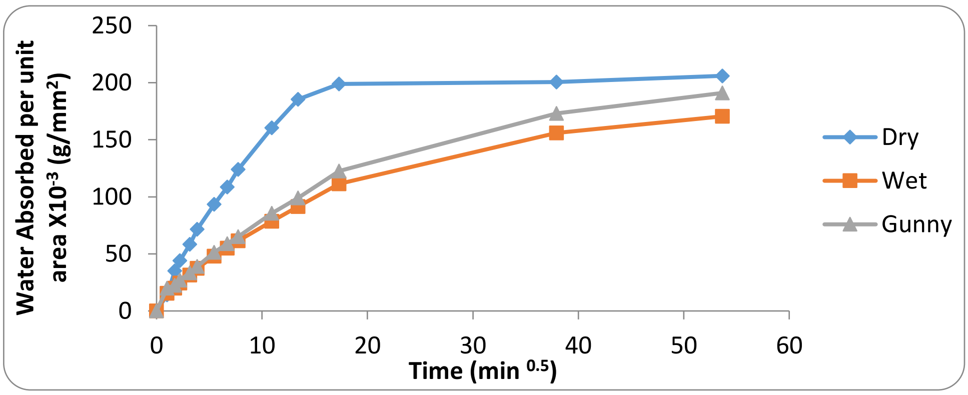

Fig. 7: CWA of concrete under different curing conditions-2 days age

CWA-7Days

After 7 days of curing again CWA test was run on the cubes by following the same process of 2 days after curing. Water Absorption for 7 days dry conditioned cubes as it is shown in the Fig. 8 there is a sharp increase in the absorbed water from the start point of the test to the 5th hours and it can be seen clearly, after that the increasing rate is very low till the 48 hours of the test period the total weight gained by the dry cubes was (206g). For the gunny bag and wet cured cubes the water absorption is increasing with a moderate rate till the 5th hour of the test as shown in figure below after that there is an increasing in the absorption rate till the end of the test, the water absorbed by wet and gunny bag cured cubes respectively, (170.5g) and (191g). Similar results were reported by Karagiannis, (2016), Basheer, (2001) and Javier Castro, (2011).

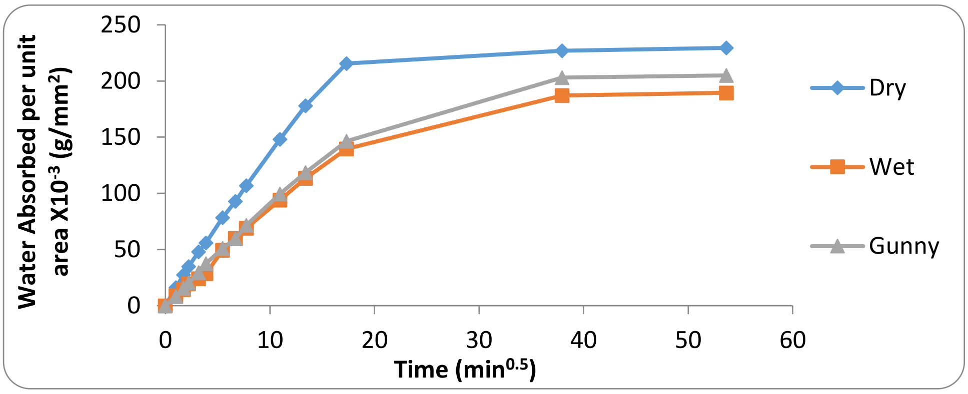

Fig. 8: CWA of concrete under different curing conditions-7 days age

CWA-28Days

For 28 days age of curing again CWA test was performed, capillary absorption for 28 days dry cured cubes as shown in the Fig. 9 below from the start of the test to the 5th hour there is a rapid rise of the water absorbed by the cubes after that from the 5th hours to the 48th hour of the test the rate of absorption slows down sharply and there is slight increase the total water absorbed by the cube was (193.5g). For both gunny bag and wet cured condition as it is shown in the Fig. 9 there is a very slow increasing in the rate of water absorption till the 5th hours of the test, after that till the end of the test the rate of water absorption increases significantly, the water absorbed by cubes for both cured condition is respectively as follow (157g) was absorbed by wet cured cubes and (118.5g) was absorbed by gunny bag cured cubes.

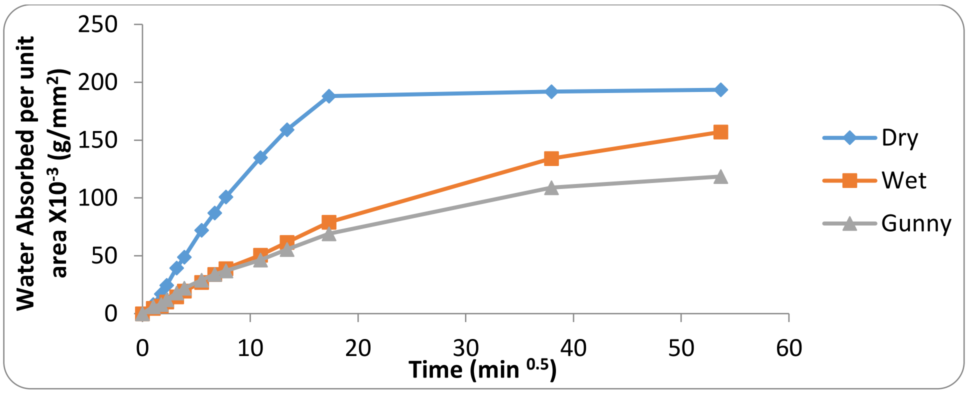

Fig. 9: CWA of concrete under different curing conditions-28 days age

CONCLUSION

By analysing the data obtained from the capillary water absorption (CWA) experiments it is clear that for all curing ages dry cured cubes has the highest absorption compared to other conditions and we can conclude that as the curing age increases for all cubes and for every curing conditions the CWA of the concrete decreases. The reason is as the curing times increases hydration process develops more and which leads to minimizing in the pore system and reduce capillary pore size that's why the amount of water absorbed through capillarity deceases when the curing age increases. Also, when relative humidity increases the CWA of the cubes decreases similar to the results obtained by Castro, et al., (2011). It was also determined that when temperature increases the CWA of the concrete increases. Similar results reported by Karagiannis, at el., (2016). As mentioned earlier, the CWA as indicated by rate of water absorbed per unit area decreases when curing time increases as expected; this is accompanied by an increase in compressive strength and UPV. It is interesting to see that the concrete under wet curing condition demonstrated lower CWA at 2 and 7 days ages and concrete under gunny covered condition demonstrated lower CWA at 28 days age compared with the other curing conditions. Due to the incompleteness of hydration process, concrete engineering properties under different curing conditions at early ages were almost the same. It is interesting to see that the compressive strength of concrete was almost the same at 28 days age under wet and gunny covered curing conditions. Dry curing condition demonstrated lower compressive strength and UPV, and higher CWA than the other two curing conditions as expected. However, the UPV values were higher under wet curing condition than the other two curing conditions.

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