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LABORATORY ANALYSIS OF CAPILLARY FLOW IN ROLLER-COMPACTED CONCRETE AND THE EFFECTS OF WATER-CEMENT RATIO, RESISTANCE, FREEZING AND THAWING OF CONCRETE ON IT

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ABSTRACT

Concrete as one of the most consumed building materials has been used nearly two centuries in the construction industry. The final properties of the concrete is a function of the components of its mix design and also an accurate estimate of behavioral characteristics and design of concrete optimized mix designs is one of the most important things in concrete projects that has much more importance in RCC concrete. That is why; transfer and capillary flow in RCC concrete and the impact of water-cement ratio, resistance, freezing and thawing of concrete have been analyzed in this research. The results of the these tests indicate a decrease in cement content of 330 to 400 kg/m^3 in the blend will cause a small increase in compressive strength, reduced water absorption and capillary water absorption in the mix. Also, reducing the cement content of 250 to 330 kg/m^3 will result in reduced compressive strength and increased capillary water absorption. The overall result is that optimized cement content in this research is 330 kg/m^3 that improves the quality of concrete as well reduces construction costs due to low consumption of cement. The lowest capillary absorption was for content 250 and water-cement ratio of 4.0 and the highest capillary absorption for content 400 and water-cement ratio of 5/0. At the time of concrete curing the rolling resistance cycle was increased that this strength is due to capillary absorption in comparison with the concrete cured in 7 days.

Keywords: roller-compacted concrete, capillary flow, compressive strength, freezing, concrete thawing.

INTRODUCTION

Concrete construction industry has had no significant change in last 70 years in Iran. Concrete construction industry has had no significant change in aboutv70 years, in such a way that when we take a look at the buildings, we think with cement and sand are mixed to make a concrete building. But science has proven that is not the case and many factors are needed to strengthen structure such as additives that cause strength of concrete. Concrete action is generally recognized with its strength and durability [1]. The reasons for exhaustion such as corrosion of bars buried in concrete by carbonation or penetration of chloride ions, freezing and thawing, sulfate attack, alkali-aggregate reaction jeopardize the function of these structures. Use of inappropriate materials or improper design, false layout details, inadequate quality control and processing inaccurate reduce the service life of structures or lead to expensive repair measures and impose high economic costs [2].

The question that arises is what relationship should be between the components forming concrete to achieve a good concrete and generally what are the features of a good concrete. The relationship between the components of the concrete is in physical and chemical properties as well as their mixing ratio. Because if materials or water and cement be mixed with right properties of concrete and be cured in right environment, certainly good concrete will be resulted and essentially good concrete is a concrete with desirable satisfactory compressive strength. Achieving a desired compressive strength means that other properties of concrete such as tensile strength, specific gravity, resistance to abrasion, impermeability, durability, resistance to sulfates will be improved in line with the compressive strength.

Although identifying materials used in the manufacture of concrete and also various properties of concrete is not easy, but we try to probe the general properties of materials and concrete.

Now, after more than 170 years since the emergence of Portland cement by an engineer from Leeds, concrete has experienced dramatic changes and improvements. Availability of materials, the relatively high durability and need to construction of large concrete structures such as buildings, bridges, tunnels, dams, docks, roads and other special structures have made this material very popular.

Now it is about three to four decades that use of this valuable material in special circumstances has been of interest to users. Now it is clear that only criteria of the level of resistance of concrete in different environments and different applications cannot be responsible for problems that occur in the long term in concrete structures.

For a few years the problem of reliability and durability of concrete in different environments, particularly corrosive to concrete and reinforced concrete has been of particular interest. Observing the destructions from physical and chemical factors in concrete in most parts of the world and with more intensity in developing countries has led to designing concrete with special features and necessary durability. In this regard, in some countries the specifications and guidelines for the design of high-performance concrete was prepared and designers and executives in some of the developed countries have been required to follow these guidelines.

Strength and durability features of concrete are directly affected by the number, type, size and distribution of pores in the cement paste, aggregates and cement paste and aggregate common level. On the other hand, the pores structure and their distribution in concrete are influenced by several factors, one of which is cement content in the mixture. If cement in the mixture is insufficient, the concrete is not compacted properly and a honeycomb texture with other surface flaws in it which can facilitate entry of damaging agents into it [3].

On the other hand, high amount of the cement with increased paste volume as the most important factor in concrete porosity will increase the total volume of the pores in the concrete [4]. Roller Concrete Dams as a new type of dam was introduced during the 1980s. This type of dams became popular across the world because of their low prices and time of construction. They had applications during 1990s and afterwards:

Cost and safety of these dams are same as classic dams'. RCC is a new way of implementation not new materials. A roller concrete mixed with soil that is implemented by the same methods. It is different because it contains aggregates larger than 4.3 inches (19 mm) as the coarsest aggregate and has similar properties to conventional concrete.

Roller compacted concrete is a zero-slump concrete that is stiffed with a vibrating roller. Two types of RCC are being used in the construction, bulky RCC with low-grade of cement in the construction of dams and large structures such as retaining walls, heavy bases and embankments where high strength isn't required and RCC with relatively high-grade of cement, for rapid implementation of highway pavement layers and similar coatings where high mechanical strength and abrasion is required. The main advantage of this type of this concrete is its low cost. Cement content plays an important role in concrete performance. In this research its effect on resistance and water absorption of rolling concrete is studied, followed by capillary effect of freezing and thawing cycle resistance of the concrete.

MATERIALS AND METHODS

a) Materials

Cement used in this study is type 2 Portland cement that its specifications are provided in Table 1. Fine aggregate is a combination of natural sand and gravel crushed limestone, while the lime broken aggregate in two nominal sizes (19mm, 12/5) is used as coarse aggregate. Table-2 shows the characteristics of used aggregates. For optimal performance a carboxylate ultra-lubricant was used in concrete mixtures.

Table-1. Specifications of cement in roller concrete.

Physical and mechanical specifications		Chemical specifications (%)	
3.1	Density	21.44	SiO_2
0.1	Dilatation (%)	4.52	Al_2O_3
3570	Cement fineness	3.69	Fe_2O_3
Compressive strength kg/cm^2		63.54	CaO
		1.48	MgO
250	3 days	0.52	Na_2O
376	7 days	0.72	K_2O
502	28 days	2.26	SO_3

Table-2. Specifications aggregation and physical properties of aggregates.

fine aggregate	Coarse aggregate		Sieve size (mm)
	Fine sand	Coarse sand	
100	100	100	19
100	100	52.7	12.5
100	46.3	272.51.7	9.5
95.4	1.5	5	4.75
75.5	0.6	2.3	2.36
51.5	−	−	1.18
27.1	−	−	0.6
9.5	−	−	0.3
1.9	−	−	0.15
0.6	−	−	0.075
2.667	2.596	2.607	Saturation density with dry surface
1.9	2.2	2	Water absorption capacity (%)

b) The experimental mixtures

The required time that concrete must be kept at the maximum temperature is so that it finally reaches maturity of 5544° C.hr. The whole cycle of accelerated samples processing in temperatures of 50, 60, 70 and 80 degrees will be 95, 83, 74 and 67 hours. First, each of the mix designs has been named with the letter M. accelerated Specimens with the letter A and the control specimens were named C. After this, the letters will be mentioned for accelerated curing temperature, cement content and water-cement ratio respectively (e.g. M60-350.45, A60-350.45 and C60-350.45). Prepared sample is shown in Figure-1.

Figure-1. Prepared cubic samples for testing.

Mixtures of concrete were studied in three water-cement ratios of (4/0.45/0, 5/0). Four mixed with cement grades of 250, 330, and 400 kg/m^3 were made for each water-cement ratio. To remove the effect of particle size on the test results, the grain of aggregates combination was identical in all projects. Concrete slump in all mixtures was kept between 140 to 180 mm as much as possible by using super lubricants. At first the effect of cement proportion on the compressive strength in 7 and 28 and 42-day periods and then the effect of water absorption at different times and capillary effect have been investigated. Finally, resistance of freezing and thawing cycle due to the capillary effect was studied.

DISCUSSIONS

a) Concrete strength tests

According to the standard BS 1818: part 116 [5], in order to determine the compressive strength of the mixture, tests was done on three 100 mm cubes of rollers concrete aged 7, 28 and 42 days. These cubic tests were brought out of cases after 24 hours and were immersed in a pool of water at a temperature of 20 ± 2°C. Testing device is shown in Figure-2.

Figure-2. Apparatus for determining compressive strength of concrete RCC cube samples.

The results of these experiments are shown in Figures 3, 4 and 5.

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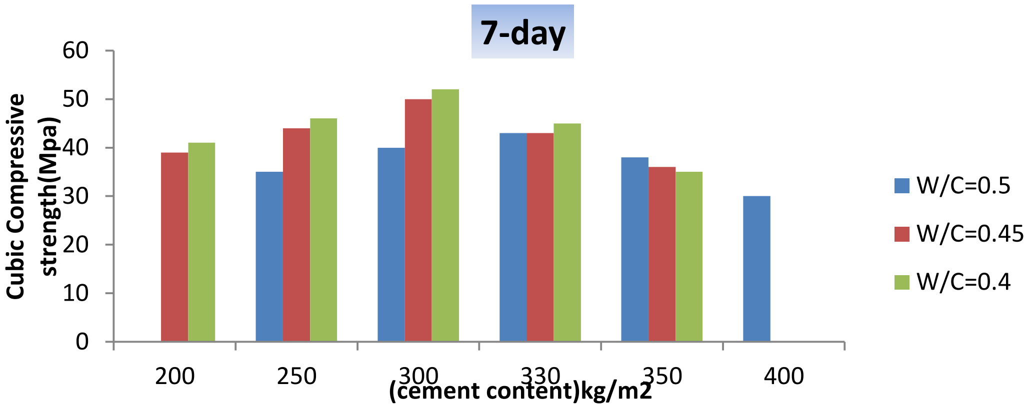

Figure-3. The relationship between the roller concrete compressive strength with cement content (7-day sample).

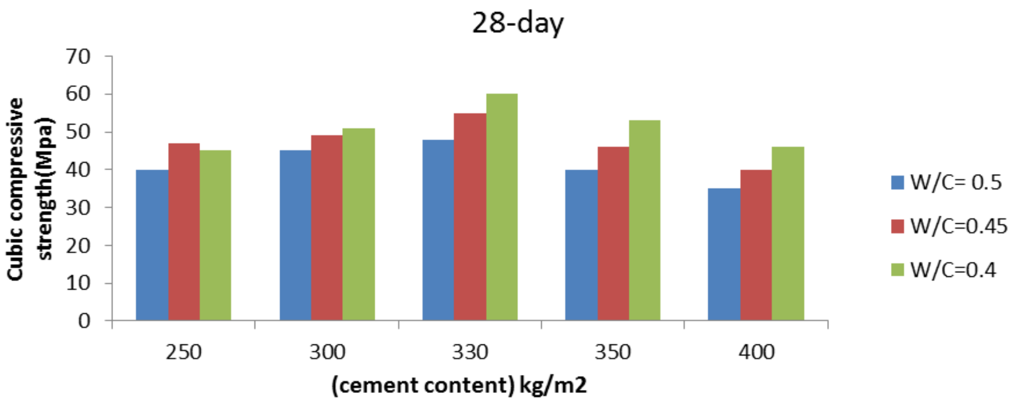

Figure-4. The relationship between the roller concrete compressive strength with cement content (28-day sample).

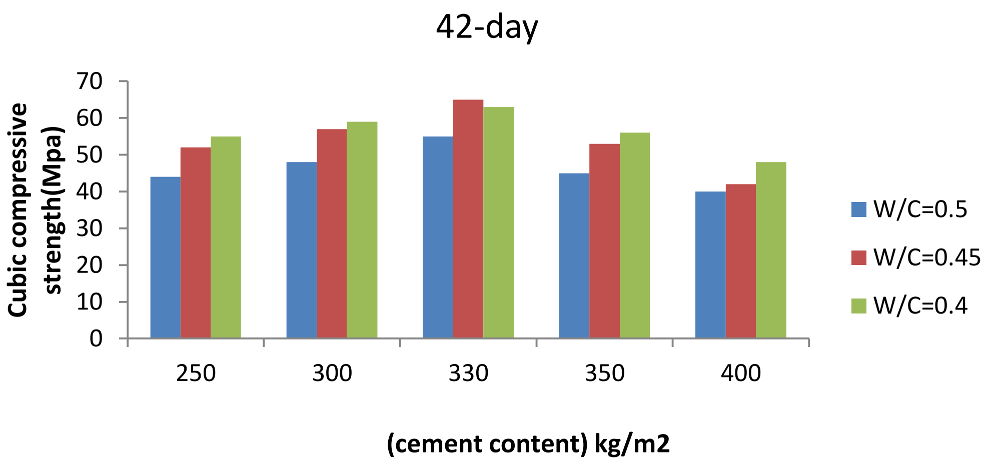

Figure-5. The relationship between the roller concrete compressive strength with cement content (42-day sample).

Figure-6 shows the compressive results of cubes versus cement content. The diagram indicates that in each of the water-cement ratios, reducing the cement content in the mix of 330 to 400 kg/m^3 increases the compressive

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strength. This increase is more tangible in water-cement ratios of 4.0, 45/0. Also this figure shows that reducing the cement content from 325 to 330 kg/m^3 caused a reduction in the compressive strength of roller concrete on all water-cement ratios. This decrease in strength which is more considerable in water-cement ratio of 4.0 can be attributed to too much reduction of paste to surround the aggregates and reduce its ability to attach the aggregates together. Similar results have been observed in previous studies [7].

Generally compacted concrete strength is considered as one of the most properties and provides an image of the concrete quality.

Strength, reliability and volume changes in stiffed concrete paste depend highly on the physical structure of compositions achieved from hydration of cement and relative volume changes.

In general, when it comes to rolling concrete strength it means the concrete strength against desired pressure. Roller concrete compressive strength depends on many factors such as porosity of concrete, hydration levels, water-cement ratio, aggregates quality, aggregate-cement ratio, maximum size of aggregate, concrete age, temperature, and concrete's density. Porosity of concrete depends on water-cement ratio and the degree of hydration. The more complete hydration of the concrete is less porous and concrete strength of rolling concrete is higher. Also, less water-cement ratio means less porosity and a higher strength. As concrete age increases the degree of hydration and roller concrete strength is generally increased. By increasing the temperature at a constant moisture content, strength of concrete increases in the same period. For a fixed ratio of water to cement, a low content mixture gives a higher roller concrete strength. This means that if cement paste forms a smaller portion of the concrete volume, porosity of the concrete will be lower and its strength is higher.

In the following image the effect of w/c on compressive strength of cubic samples is shown. As it is specified compressive strength has decreased with increasing water-cement ratio. This reduction was observed for all three curing time.

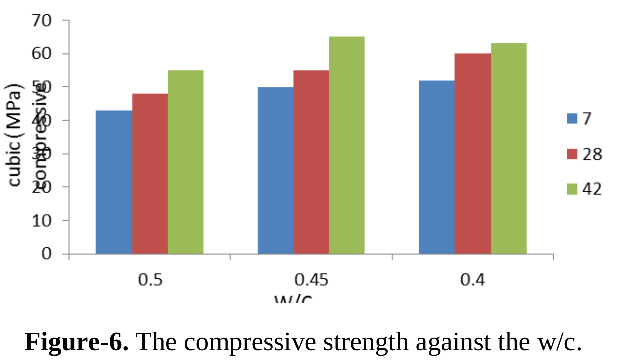

Figure-6. The compressive strength against the w/c.

2. THE VOLUMETRIC WATER ABSORPTION

Volumetric water absorption of each mixture was determined by emulating the standard of [6ASTM C 642] on three 100 mm cubic specimen. After 27 days of being kept in the water. These test specimens were transformed inside a ventilated oven with temperature of 45° C. After about 14 days, the dry weight was measured so that the weight difference in the weighting with 24 hour intervals was less than 1.0% of the average weight of the dried specimen. Then the dried specimens were immersed in water so that the water level was within 25 ± 5 mm above the surface of specimen. Specimen was brought out of the water at intervals of 5.0, 3, 24 and 72 hours and were weighed after removing the water by the cloth. Thus, having the weight of specimen in dry state and their weight at mentioned intervals, percent of adsorbed water proportion to the dry specimen weight was measured in each of the times. Figures 7, 8 and 9 show the volumetric water absorption and Table-3 shows the results of it.

Figure-7. Water absorption in cubic samples after 3 hours.

Figure-8. Water absorption in cubic samples after 24 hours.

Figure-9. Water absorption in cubic samples after 72 hours.

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Table-3. Percent of the Water absorption for 7 hours.

content	**Cement percent**		
7 hours	**0.4**	**0.45**	**0.5**
400	3.5	3.6	4.5
330	2.7	2.8	4.35
250	2.3	2.5	2.7

The results of volumetric water absorption are shown in Figures 10 to 12.

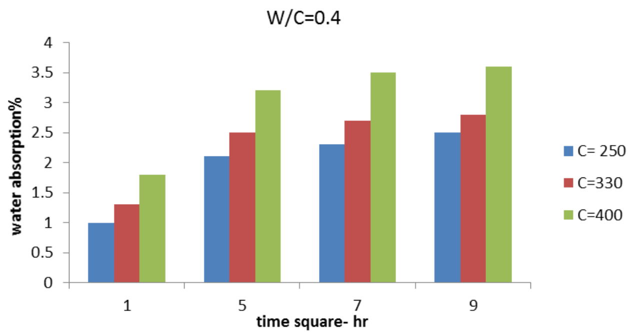

Figure-10. Average percent of water absorption volume samples w/c=0/4.

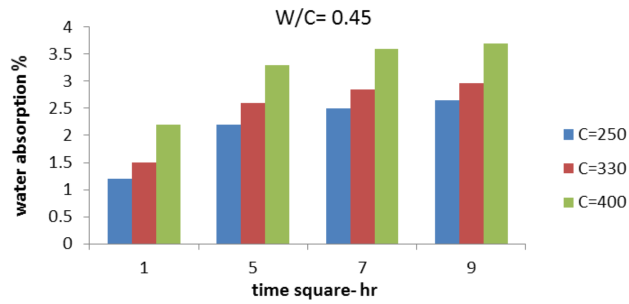

Figure-11. Average percent of water absorption volume samples w/c=0.45.

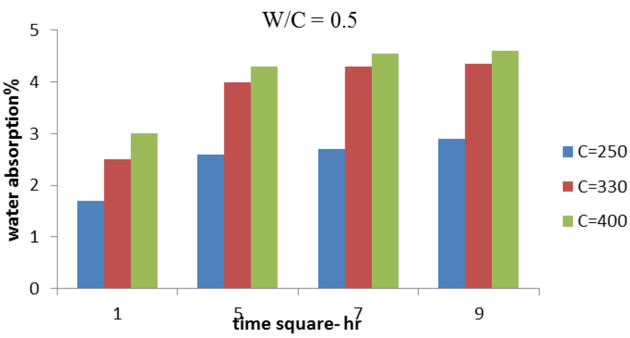

Figure-12. Average percent of water absorption volume samples w/c=0/5.

Volumetric water absorption of cubes results are plotted in the figure below. In this figure it can be seen in a constant water-cement ratio, reducing the cement content in the mix of 250 to 400 kg / m^3 reduces the absorption of water. This reduction is greater in the water-cement ratio of 5/0.

The main reason could be the reduction of the volume of cement paste that causes porosity in the mix. Besides, the main cause of this increase may be attributed to blocking and tortuous paths of the aggregates flow due to increase in the volume of the mixture. The following figure shows that reducing the cement content from 250 to 330 kg/m^3 causes poor absorption in water-cement ratios of 45/0 and 5/0. This increase in is more considerable in water-cement ratio of 4.0 was; it could be due to the increase in transition zones volume in mixture and leak effects. In other words, increases in the transition zone volume can be formed by increasing the volume of aggregates in the mixture. Due to higher porosity of the transition zone in comparison with dough mass in conventional concrete and also attachment to each other and leakage effects will cause increase the water absorption is roller concrete. Therefore, the determination of water absorption indicates more pore volume in rolling concrete, thus reducing the cement content in the mix causes reduction of pore volume of the mixture. Therefore the entry of harmful agents to the concrete will be decreased. The result can be seen in Figures 13 to 15.

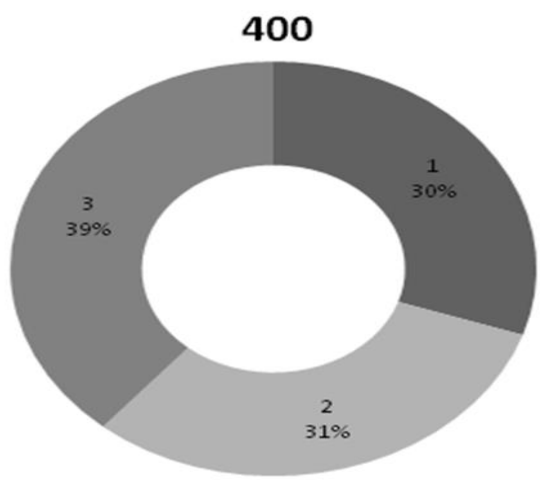

Figure-13. Capillary water absorption percent for content 400.

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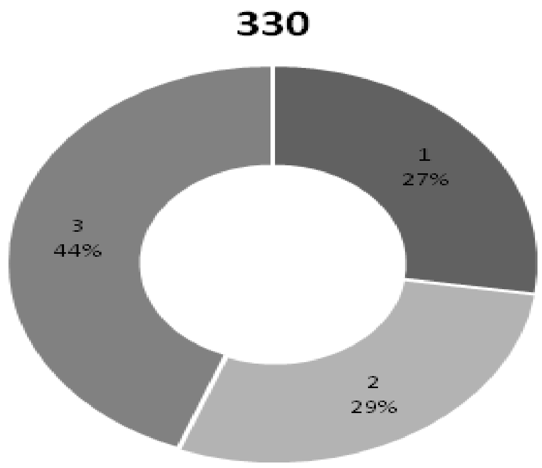

Figure-14. Capillary water absorption percent for content 330.

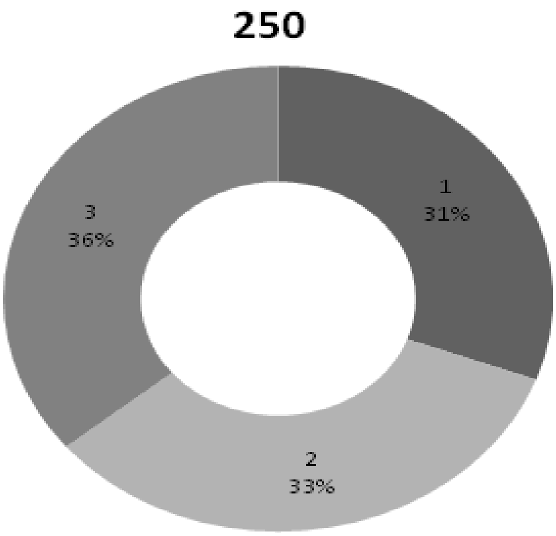

Figure-15. Capillary water absorption percent for content 250.

As in the above diagrams show (No. 1 on the W/C=0/4, No. 2 of the W/C=0/45 and No. 3 of the W/C=0/5) by reducing the content of cement from 400 to 250 causes an increase in effect of water on capillary absorption. Water-cement ratio also had an effect on capillary absorption, as increased water-cement ratio causes more capillary absorption. The least capillary absorption is of content 250andwater-cement ratio of 4.0. The highest capillary absorption is of content 400 and water-cement ratio of 5.0.

3. THE CAPILLARY WATER ABSORPTION

Height of the water in the container was chosen in such a way that it reaches only 5±1 mm above the floor of the cubes. Throughout the experiment water level was kept constant and container of specimens had a lid. Capillary water absorption measurement was done at intervals of 3, 6, 24 and 72 hours from the time the specimens were put into water. When weighing the specimens were removed from the water and were put on a surface that was not absorbing water for 60±5 seconds and then their weight was measured. Respectively, with having weight of specimen in dry state and at any time interval, the water absorption rate per area unit was calculated from Equation 1:

$$)1(i_t = \frac{m_t - m_0}{A}$$

Where i_t is water absorption per unit area at time *t* in *mm* or *gr/mm2*, m_0 and m_t are the weight of dried specimen and weight of specimen at time *t* on *gr*, and *A* is the area of the specimen in contact with water in mm^2.

Figures 16 to 19 show the results of this test.

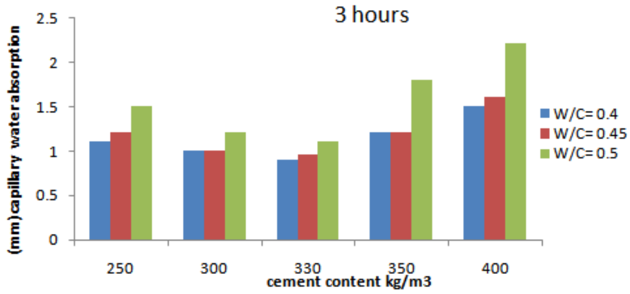

Figure-16. Average capillary water absorption in the samples 3 hours.

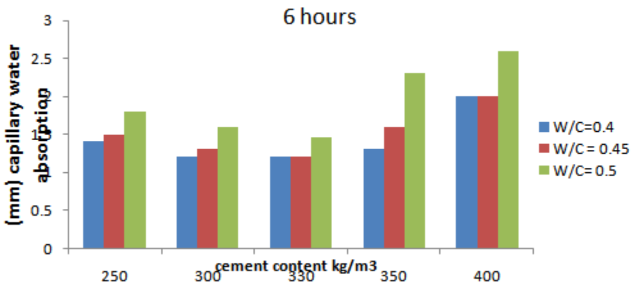

Figure-17. Average capillary water absorption in the samples 6 hours.

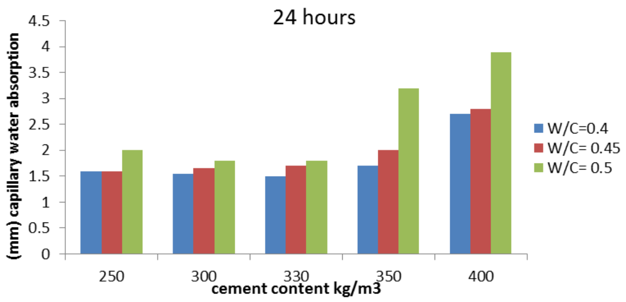

Figure-18. Average capillary water absorption in the samples 24 hours.

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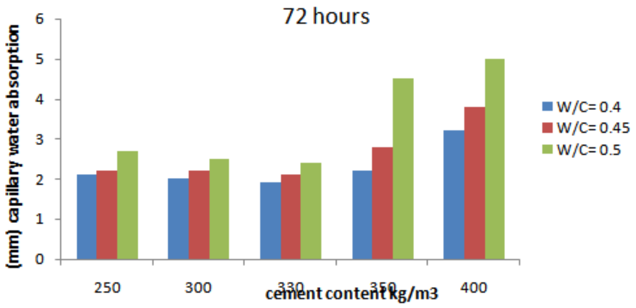

Figure-19. Average capillary water absorption in the samples 72 hours.

In the above chart we can see that the capillary water absorption of mixtures is similar to their volumetric water absorption. Mixtures with cement content of 330 kg/m3 shows the lowest capillary water absorption in all the water-cement ratios. This implies that smaller pores and poor connection among them in this mixtures.

It is expected that the reduction of cement content in the mixture from 330 to 400 kg/m3 with reduced connectivity between the pores in the mixture would stop damaging agents in the surface layers and less access to the inner layers of concrete. Similarly, there will be such results in an increase in cement content of 250 to 330 kg/m3; however, changes will be minimal in this case.

4. THE FREEZING AND THAWING TESTS

The pores in roller concrete become saturated of water- more than 90 percent- when freezing. Water experiences about 15 percent volume expansion during freezing. If capillary pores and digs in the concrete become saturated during freezing, the expansion will cause tensile forces applied and leads to breakage and cracking of the cement matrix. This destruction occurs almost at all concrete layers from external surface into the inner surface. The rate of progression of damage depends upon the number of cycles of freezing and thawing, saturation degree of structure during solidification, porosity of concrete and the conditions of exposure to radiation. The walls which are exposed to snow or water injection, horizontal slabs made of roller concrete in contact with water, and vertical walls that are in the path of the water are usual locations for the damage caused by constant freezing and thawing. If roller concrete exposed to light from the south, it experiences a half cycle of melting at a day a half cycle of freezing at night. In contrast, exposure to sunlight from the north may be only cause one cycle of freezing and thawing in the winter; therefore it experiences far less destructive situation. Finding out the rolling concrete durability in different conditions needs to provide this situations and too much time is required which usually impossible to carry out research in real world. To determine if a roller concrete acts appropriately in such circumstances we need short-term experiments. Aggressive factors are escalated (accelerated) in these tests or not-accelerated experiment in ordinary conditions are done that the comparison criterion varies in this latter situation. If some short-term tests related to durability and exposed to factors other than the desired factor is used and with respect to experience in real projects and measures are provided in laboratory researches. An example of a short-term accelerated testing against aggravating factor is abrasion test of ASTM C1293. An example of a short-term not accelerated experiment in exacerbated conditions is freezing and thawing test. Among the short-term tests of durability which is not exposed to major factor is water absorption or water absorption capillary can be named. Perhaps the shrinkage test is related to durability. Test of permeability is also associated with durability. Figure shows capillary effect on the resistance of freezing and thawing cycle of 7 and 28 and 42 days samples, respectively. As it can be seen, the cyclic resistance of rolling concrete is about 80% of compressive strength that the cycle of freezing and thawing is reduced by increasing capillary resistance value.

The results of these tests are shown in Figures 20 to 25. Figure shows capillary effect on the resistance of freezing and thawing cycle of 7 and 28 and 42 days samples, respectively. As it can be seen, the cyclic resistance of rolling concrete is about 80% of compressive strength that the cycle of freezing and thawing is reduced by increasing capillary resistance value.

The results of these tests are shown in Figures 20 to 25.

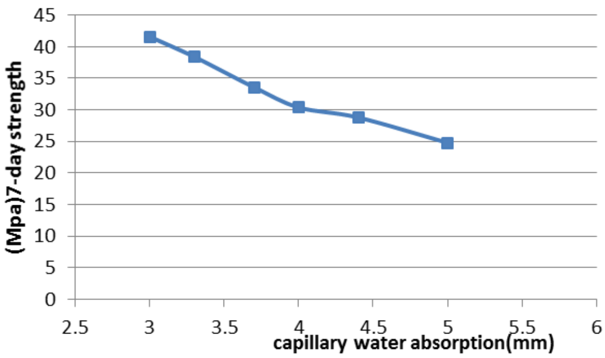

Figure-20. The capillary effect on cycle strength of rolling concrete (7-day).

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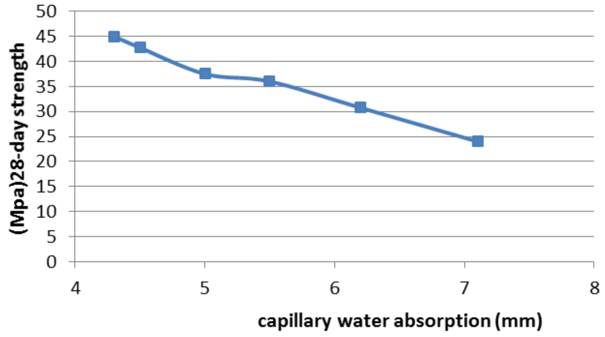

Figure-21. The capillary effect on cycle strength of rolling concrete (28-day).

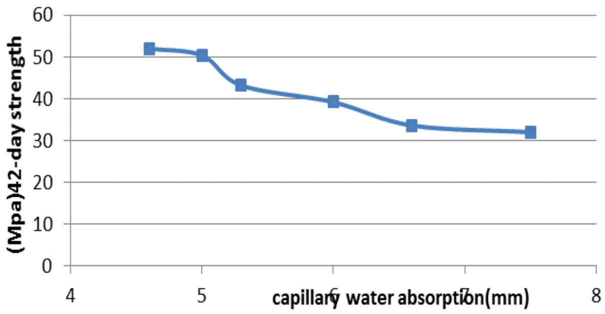

Figure-22. The capillary effect on cycle strength of rolling concrete (42-day).

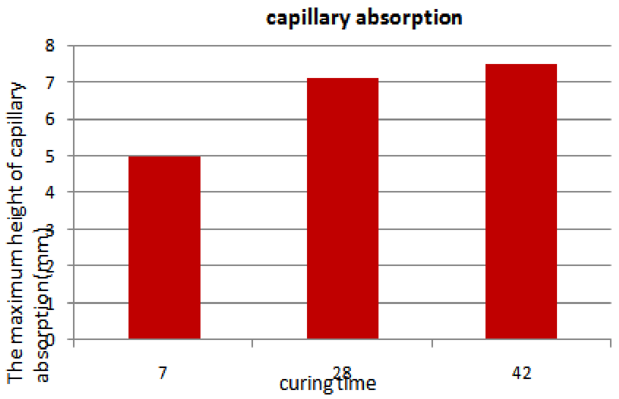

Figure-23. The maximum height of capillary absorption against curing time and strength of cyclic rolling concrete.

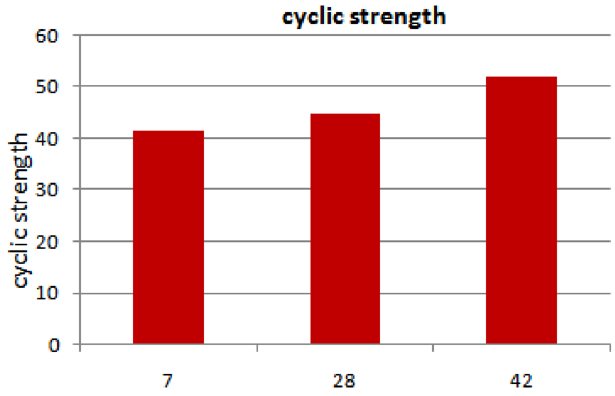

Figure-24. Roller compacted concrete cycle strength against curing time.

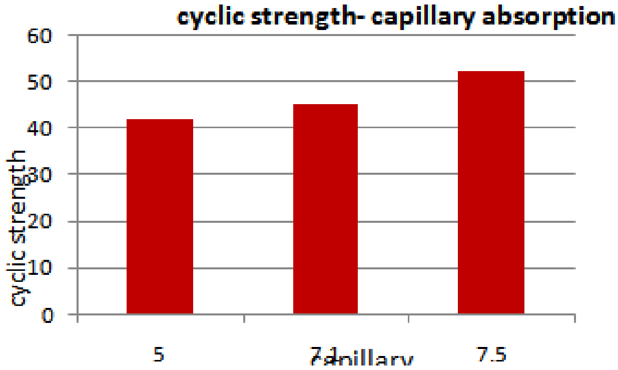

Figure-25. Roller compacted concrete cycle strength and capillary absorption.

As seen in the above diagrams, cycle of rolling concrete strength will be increased by increasing the time of curing of rolling concrete which is due to higher capillary absorption in comparison with concrete cured in 7 days.

CONCLUSIONS

Maintaining restrictions about the maximum size (19mm), fixed gradation the aggregate composition and water-cement ratio of 4.0 to 5.0, the results of study may be summarized as:

a) Reduction of cement content in the mixture from 330 to 400 kg/m3 causes a slight increase in compressive strength in throughput. By reducing the water-cement ratio is more significant, the effect of cement content on compressive strength.

b) Reduction of cement content from 330 to 400 reduces volumetric water absorption and capillary water absorption in the mixture. The effect of cement content on water absorption in water-cement ratio of 0.5 is greater.

c) By reducing the cement content from 250 to 330 kg/m3 due to insufficient amount of paste around the aggregates: compressive strength decreases and capillary water absorption increases and volumetric water absorption somewhat increases except in water-cement ratio of 4.0, but there will not be significant change in other water-cement ratios.

d) 4. As a result of the water-cement ratios of 4.0 to 5.0 it can be expected to reduce cement content from 330 to 400 kg/m3 enhances strength and durability performance of concrete. However, a further reduction from 250 to 330 kg/m^3 reduces strength roller concrete. So it seems that the optimum cement content in this research is 330 kg/m3, which in besides improving the quality of concrete reduces construction costs due to low consumption of cement.

e) By reducing the cement content from 400 to 250, the effect of water ratio on capillary absorption will be increased. Water-cement ratio also had an effect on capillary absorption; increased water-cement ratio causes more capillary absorption. The lowest capillary absorption belongs to content of 250 and water-cement ratio of 4.0. The highest capillary absorption belongs to content of 400 and water-cement ratio of 5.0.

f) Cycle strength of rolling concrete will be increased by increasing its curing time which is due to the more absorption than concrete cured in 7 days.

REFERENCES

Ahmad S. 2003. Reinforcement corrosion in concrete structures, its monitoring and service lifeprediction - a review. Cement and Concrete Composites. 25, pp. 459-471.

Kolias S. and Georgiou C. 2005. The effect of paste volume and of water content on the strength and water absorption of concrete. Cement and Concrete Composites, 27, pp. 211-216.

BS: 1881: part 116. 1993. Methods for determination of compressive strength of concrete cubes. British Standard Institution.

ASTM C 642-97. 1997. Standard test method for density, absorption, and voids in hardened concrete. Book of ASTM Standards, American Society for Testing and Materials.