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Durability of concrete with differential concrete mix design

M. N. Balakrishna, Fouad Mohamad, Robert Evans and M. M. Rahman

School of Architecture, Design and the Built Environment
Nottingham Trent University, Nottingham, NG1 4FQ, UK

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Abstract

Durability is the ability to last a long time without significant deterioration. A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement. The production of replacement building materials depletes natural resources and can produce air and water pollution. The research objective is to reinforce the importance of considering durability properties during the design phase. Concrete mixture designs are considered to have a profound effect on the performance of concrete structures once in application. The experimental work done in this research used a water absorption test to assess the potential durability characteristics of various concrete mix designs. Therefore, there is a need to quantify the water absorption characteristics in concrete structures, which is of most important factor. The present research work was made an attempt to interpret the concrete water absorption in ordered to characterize the different concrete mixtures design for in case of concrete cubes. In the present research work, water absorption test was carried out on concrete cubes to ascertain the rate of water absorption (sorptivity coefficient) characteristics on concrete density in designed concrete mixtures type. It's confirmed from the results that, the sorptivity coefficient is co-related with density of concrete by the power type of equation. In turn the average variation of sorptivity coefficient is more for in case of higher compressive strength and varied slump as when compared to varied concrete compressive strength and constant slump value. But in the case of lower compressive strength and constant slump, the sorptivity coefficient was slightly increases and it goes on decreases with increase in compressive strength and constant slump value. It's confirmed from the research work that for in case of constant concrete compressive strength and varied slump value, the rate of concrete density was slightly increased in concrete mix design as when compared to the concrete mix design with varied concrete compressive strength and constant slump value. The rate of concrete density was decreased in lower concrete compressive strength and constant slump values and goes on increases with increase in concrete compressive strength for in concrete mix design.

Keywords: Concrete, mixture proportion, grade of concrete, water-cement ratio, sorption, moisture content, concrete density.

1. Introduction

The moisture migration into the concrete structure is the leading cause of concrete degradation worldwide. There are two primary water transport mechanisms in the concrete. Considering water's powerful forces and then designing concrete structures to adequately resist the known effects of these two common water transport mechanisms is paramount to achieving durable structures. Designers, contractors, and owners need to thoroughly understand the differences in the mechanisms to ensure the structures they are building provided adequate problem-free service life of concrete structures. The two mechanisms listed by the magnitude of the challenge they impose are such as capillary absorption or sorptivity and Permeability. Most degradation processes encountered by concrete require water, dissolved chemicals, and the presence of oxygen. Dissolved salts (chlorides) or other deleterious chemicals can be rapidly transported to the steel reinforcement imbedded in the concrete through the capillary network. The resulting initiation of corrosion causes rebar to expand, breaking up the concrete it is embedded in. Additionally, in cases where water has permeated through a concrete substrate, it may damage concrete structures. In each case, the presence of water is detrimental. Preventing water from freely moving from the outside environment in which the concrete is placed into service to the interior of the concrete matrix is therefore a significant design concern worldwide. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years or longer. Because of their durability, most concrete and masonry buildings are demolished due to functional obsolescence rather than deterioration. However, a concrete shell or structure can be repurposed if a building use/ functional changes or when a building interior is renovated. Concrete, as a structural material and as the building exterior skin, has the ability to withstand nature's normal deteriorating mechanisms as well as natural disasters. Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired.

In the late 1980's, sorptivity was used to describe the transport properties of concrete. Hardened concrete paste, consisting of cement, aggregates and voids, is rarely saturated in building materials. Often, permeability was used as a surrogate to durability but this is not entirely accurate. Permeability relates the movement of moisture through a saturated porous medium under a pressure gradient. The existence of a concrete structure under such conditions is considered highly unlikely and so sorptivity becomes a more accurate characteristic to describe the durability of a concrete structure. In contrast to fully saturated materials, where capillary forces are absent, capillary absorption becomes the primary cause of liquid ingress into concrete structures. In above-ground structures, the sun and wind dry the exposed region of concrete while the core remains at a higher degree of saturation. This differential in saturation creates capillary forces that become the dominant transport mechanism [McCarter 1993]. Sorptivity testing on concrete was shown to be sensitive to compaction. Prolonged ramming of specimens increased bulk density and decreased porosity. With prolonged ramming, sorptivity plots exhibited a curvature. This finding brought forward the concept that elimination or reduction of large pores created this non-linearity [Hall and Raymond Yau 1987]. Application of the sorptivity test to concrete became more important as there was a worldwide concern about the poor durability of concrete structures, the most dominant form of deterioration being the corrosion of steel reinforcement due to the ingress of moisture through the surface skin of concrete. Sorptivity has been shown to be sensitive to the quality of the cover skin of concrete members and has proven effective in revealing poor placing and finishing techniques in the field [McCarter 1993]. Further support was given to sorptivity testing as it was discovered that testing was also sensitive to the depth of concrete. Specimens that were tested at different depths for sorptivity gave different results, which could be indicative of signs of segregation or bleeding due to poor construction practices [Khatib and Mangat 1995].

The concrete is a mixture of cementious material, aggregate, and water. Aggregate is commonly considered inert filler, which accounts for 60-80% of the volume and 70-85% of the weight of concrete. Although aggregate is considered inert filler, it is a necessary component that defines the concrete's thermal and elastic properties and dimensional stability. The compressive aggregate strength is an important factor in the selection of aggregate. When determining the strength of normal concrete, most concrete aggregates are several times stronger than the other components in concrete. Other physical and mineralogical properties of aggregate must be known before mixing concrete to obtain a desirable mixture. These properties include shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight. These properties along with the water/cementitious material ratio determine the strength, workability, and durability of the concrete. The surface texture of aggregate can be either smooth or rough. A smooth surface can improve workability, yet a rougher surface generates a stronger bond between the paste and the aggregate creating a higher strength. The grading or size distribution of aggregate is an important characteristic because it determines the paste requirement for workable concrete. This paste requirement is the factor controlling the cost, since cement is the most expensive component. It is therefore desirable to minimize the amount of paste consistent with the production of concrete that can be handled, compacted, and finished while providing the necessary strength and durability. The required amount of cement paste is dependent upon the amount of void space that must be filled and the total surface area that must be covered. When the particles are of uniform size the spacing is the greatest, but when a range of sizes is used the void spaces are filled and the paste requirement is lowered. The more these voids are filled, the less workable the concrete becomes, therefore, a compromise between workability and economy is necessary. Although aggregates are most commonly known to be inert filler in concrete, the different properties of aggregate have a large impact on the strength, durability, workability, and economy of concrete. These different properties of aggregate allow designers and contractors the most flexibility to meet their design and construction requirements. An experimental program was carried out by [Suresh Thokchom, 2009] to study the effect of water absorption, apparent porosity and sorptivity on durability of fly ash based geopolymer mortar specimens in sulphuric acid solution. Specimens containing lesser alkali were found to possess higher apparent porosity, water absorption and water sorptivity. After 24 weeks in sulphuric acid solution, specimens still had substantial residual compressive strength ranging from 29.4% -54.8%. Specimens with higher water absorption, porosity and water sorptivity lost more strength than those with lesser corresponding values. The research aims at evaluating the effects of cement-types and wet-curing period on the resistance of concrete to leaching and leakage, based on compression, water absorption, and acid attack tests. To meet this objective, 54 concrete specimens with a grade of C-30 and water to cement ratio of 0.53 were casted in to two groups, each subjected to 3-, 7-, 10-, and 28-days wet curing. The first group comprised 27 cubes made from OPC, while the second made from PPC. The finding showed that the selection of well cured-OPC and 10 days cured-PPC for concrete water tanks could be the cause for deterioration associated with leaching and leakage in concrete water retaining structures. The study contributes to the design of water storage structures [Matiwos Tsegaye and Abebe Dinku, 2018]. Sorptivity is an index of moisture transport into unsaturated specimens, and recently it has also been recognized as an important index of concrete durability [Dias, 2000] and during this process, the driving force for water ingress into concrete is capillary suction within the pore spaces of concrete, and not a pressure head [Hall, 1989]. Sorptivity testing is more representative of typical field conditions. Some experts have suggested that the method can also be used to measure the total pore volume of capillary and gel pores in the concrete [Mohr, 2004]. Martys and Ferraris have shown that the sorptivity coefficient is essential to predict the service life of concrete as a structural material and to improve its performance [Martys and Ferraris, 1997].

The research was carried out to study the influence of water absorption on the durability of concrete materials. After 28-days curing, compressive strength, permeability, sulfate attack, and chloride ion diffusion of concrete samples were investigated. As a result, both of surface sorptivity and internal sorptivity have no clear relationship with compressive strength. Results obtained also showed that only surface water absorption related to the performance of concrete including permeability, sulfate attack, and chloride ion diffusion. Furthermore, chloride ion diffusion coefficient has exponent relation to surface water absorption with higher correlation coefficient. However, no apparent relationship was found between internal water absorption and durability like impermeability, resistance to sulphate attack, and chloride ion diffusion [S. P. Zhang and L. Zong, 2014]. The results showed that, moist sand curing method produced concrete specimens with the highest 28-day compressive strength of 30.5N/mm^2 followed by the burlap curing method with a value of 24.4N/mm^2. Air curing method showed a 15% reduction in strength after 21-days thereby resulting in the lowest 28-day compressive strength of 17.8 N/mm^2. It was concluded that there exists a weak positive correlation between density and compressive strength of concrete specimens [Akeem Ayinde Raheem, 2013]. There are many factors affect the development of strength of concrete and durability. These factors include quality and quantity of cement used in a mix, grading of aggregates, maximum nominal size, shape and surface texture of aggregate (Arum and Alhassan, 2005), water/cement ratios, degree of compaction [Aluko, 2005] and the presence of clayey particles and organic matter in the mix [Arum and Udoh, 2005]. Furthermore, the scope of this study is methods of curing concrete. Results indicated that the concrete sorptivity decreased by 42.7% when cement content was increased from 350 kg/m^3 to 450 kg/m3 for specimens cured in water for 28 days at 20^0 C. Also, for the same cement content, utilization of 10% SF as a partial replacement of cement resulted in sorptivity decrease by 64.5% and 68.3% with cement content (350kg/m ^{3}- 450kg/m^3) respectively, for specimens cured in water for 28 days at 20^0 C. Although specimens stored in air experienced 11.6% loss in compressive strength, the sorptivity increased by 80.4% while permeability increased by nearly 345.3%. Specimens with lower sorptivity possessed lower permeability, and higher compressive strength [Esam Elawady, 2014]. Concrete must ensure satisfactory compressive strength and durability. The mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength and fewer number of voids and porosity. Smaller the voids in concrete, it becomes less permeable to water and soluble elements. So, water absorption will also be less and better durability is expected from this type of concrete. In this paper an experimental program conducting on compressive strength, density, absorption capacity and percent voids of hardened concrete is described. The comparisons on test results are presented with respect to time. It was observed from the experiment that, strength and density increase with maturity of concrete and percent void and absorption capacity decreases with time. Better results were obtained from stone aggregate concrete than brick aggregate concrete in cases of all of the tests [Shohana Iffat, 2015].

2. Research objectives

The importance of water absorption as a durability-based material property has received greater attention only after the revelation that water-induced corrosion is the major problem for concrete durability. The present research work is made an attempt to interpret the concrete water absorption in ordered to characterize the different concrete mixtures design. Thus, the objectives of this present research are such as; first, this research will examine the influence of conditioning such as uni-directional exposure of concrete cubes surface to water absorption in order to evaluate different mixtures proportion. In which slump, and w/c ratio value was varied with constant compressive strength as in the First case and compressive strength, and w/c ratio value varied with constant slump as in the Second case. Seventy-two concrete cubes (100 mm^3) with grades of concrete ranges from 25-40 N/mm^2 were prepared and evaluate the water absorption characteristics in different concrete mixtures design.

3. Experimental program

In the present research work, six different mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm^3). Three of the mixtures type were concrete cubes (100 mm^3) with a compressive strength 40 N/mm^2, slump (0-10, 10-30, and 60-180 mm), and different w/c (0.45, 0.44, and 0.43). These mixtures were designate as M1, M2, and M3. Another Three of the mixtures type were concrete cubes with a compressive strength (25 N/mm^2, 30 N/mm^2, and 40 N/mm^2), slump (10-30 mm), and different w/c (0.5 0.45, and 0.44). These mixtures were designate as M4, M5, and M6. The overall details of the mixture proportions were represented in Table 1-2. Twelve concrete cubes of size (100 mm^3) were casted for each mixture and overall, seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crush stone with maximum nominal size of 10 mm with grade of cement 42.5 N/mm^2 and fine aggregate used was 4.75 mm sieve size down 600 microns for this research work.

Table 1
Variable: slump and W/C value; constant: compressive strength

Mix ID	Comp/mean target stg, N/mm^2	Slump (mm)	W/C	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mix proportions
M1	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40/47.84	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

Table 2
Variable: compressive strength and W/C value; constant: slump

Mix ID	Comp/mean target stg, N/mm^2	Slump (mm)	W/C	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mix proportions
M4	25/32.84	10-30	0.50	3.84	1.92	5.98	17.04	1:1.55:4.44
M5	30/37.84	10-30	0.45	4.27	1.92	6.09	16.50	1:1.42:3.86
M6	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87

3.1 Sorptivity test

It's defined as a measure of the capacity of the medium to absorb/desorb liquid by capillarity. The sorptivity is widely used in chacterizing soils and porous construction materials such as brick, stone, and concrete respectively. The sorptivity coefficient is increases at initial time duration, this may be due to unsaturated pore structure, and in turn the rate of absorption is more at that time. As time increases, the rate of absorption goes on decreases with increased time duration indicates that, pore structure may be reached fully saturated condition. Sorptivity test is a very simple technique that measures the capillary suction of concrete when it comes in contact with water. The sorptivity test is performed in accordance with the [ASTM C 1585]. This test is used to determine the rate of absorption (sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water ingress of unsaturated concrete by capillary suction during an initial contact with water. The rate of sorption is the slope of the best-fit line to the plot of absorption against square root of time. The cubes (100 mm^3) after casting were immersed in water for about 28 days curing. Prior to the test, specimens were placed in a desiccator's oven at temperature (50 ±2ºC) for 3 days. After that, specimens were put in contact with water from one surface with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating [Balakrishna, *et al*, 2018]. The sorptivity test is carried out on 72 concrete cubes in all six mixtures type (M1-M6) and noted the rate of water absorption at consecutive time interval like (5 min, 10 min, 15 min, 20 min and up to 28 days). In which [ASTM C1585] is commonly used to determine the absorption and rate of absorption of water in unsaturated hydraulic cement concretes. The results confirm that, the water absorption testing is considerably influenced by sample preparation. Samples that were conditioned in the oven at 105^0 C do not appear to follow a similar trend as when compared with specimens conditioned in chambers at lower temperatures for longer time duration. The absorption is also influenced by the volume of paste in the samples. The experiments show that, a lack of control on moisture content or lack of consideration of the material composition may lead to a misunderstanding of the actual absorption behaviour.

3.2 Density of concrete cubes

The compressive strength of concrete mixes was found to increase with age of concrete and w/c ratio. Increased w/c ratio leads to increase in compressive strength, however increase in w/c ratio leads to decrease in aggregate content followed by decrease in density of concrete mix as per researchers [Mohammed Abas salem, *et al*, 2015]. The test was carried out in accordance with BS 12390-7, density of hardened concrete after 28 days of curing and noted their weight. The 72 designed concrete cubes with six mixtures type (M1-M6) were immersed in water with one surface exposed to water as well as noted weights of concrete cubes at consecutive time interval (5 min, 10 min, 15 min, 20 min and up to 28 days).

4. Discussion about results

The deterioration of concrete is caused by the movement of aggressive gases/ liquids from the surrounding environment into the concrete which is followed by physical/chemical reaction within its internal structure, and that leads to an extensive damage to the concrete structures. The one of the most important properties of a good quality concrete is low permeability. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and even in the aggregate. Permeability relates to the size of the pores, their distribution and most importantly their continuity. As a result, permeability is not necessarily directly related to absorption. It has been related to water-cement ratio of concrete. The lower the sorptivity value, the higher the resistance of concrete towards water absorption. It's mainly depending on the pore distribution and micro structural properties of concrete as noted by the researchers [Abdul Razak, *et al*, 2004]. The cumulative water absorption of the concrete mixtures decreases with the decrease in w/cm ratio for all the concrete due to less amount of water in the mix, resulting into dense concrete. Concretes with lower w/cm ratio have lower water absorption for all the mixtures. The sorptivity values are least due to lower amount of water in the mix, resulting in lower porosity. The higher the porosity of the specimens causes the reduction of pervious concrete density, which in turn that affects the compressive strength. The higher level of porosity can be resulted from the higher level of water absorption that exceeds the required limit of water infiltration. Moreover, the mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength and fewer number of voids and porosity. Smaller the voids in concrete, it becomes less permeable to water and soluble elements. The water absorption will also be lesser and better durability is expected from this type of concrete mixture proportion. Thus, the minimum water-cement ratio is desirable to maintain appropriate compressive strength and durability of the concrete. The water is usually provided externally by curing/internally by using water saturated porous aggregates. By proper curing, reduces the rate of moisture loss and provides a continuous source of moisture required for the hydration that reduces the porosity and provides a fine pore size distribution in concrete as pointed out by [Alamri, 1988]. There is need to investigate in the sorptivity coefficient with concrete dry density in the concrete cubes in order to characterize different designed mixtures type in the present research work. Thus, the variation of sorptivity coefficient-density of concrete cubes for in case of different designed mixtures type is as shown in Figures 1-7 respectively. It's possible to establish a relation between the density-sorptivity coefficients in concrete cubes with power type of equation. It's observed from the results that, the average rate of water absorption (sorptivity coefficient) is varied in the different concrete mixtures design (M1-0.00029, M2-0.00034, M3-0.00027, M4-0.00042, M5-0.00030, and M6-0.00029) m/min$^{0.5}$ respectively. Whereas the minimum as well as maximum values (sorptivity coefficient) were varied in the range (M1:4.48E-05-0.00092, M2:5.37E-05-0.0011, M3:4.34E-05-0.0008, M4:6.59E-05-0.0014, M5:4.72E-05-0.0009, M6:4.37E-05-0.00091) m/min$^{0.5}$. Also, the standard deviation was varied in the designed concrete mixtures type (sorptivity coefficient) as in the following range (M1-0.00029, M2-0.00032, M3-0.00025, M4-0.00041, M5-0.00027, and M6-0.00027) respectively. It's confirmed from the research work that for in case of constant concrete compressive strength and varied slump value, the rate of water absorption (sorptivity coefficient) was slightly increased in concrete mix design (M1-M3) as when compared to the concrete mix design (M4-M6) with varied concrete compressive strength and constant slump value. The rate of water absorption was increased in lower concrete compressive strength and constant slump values and goes on decreases with increase in concrete compressive strength for in concrete mix design (M4-M6).

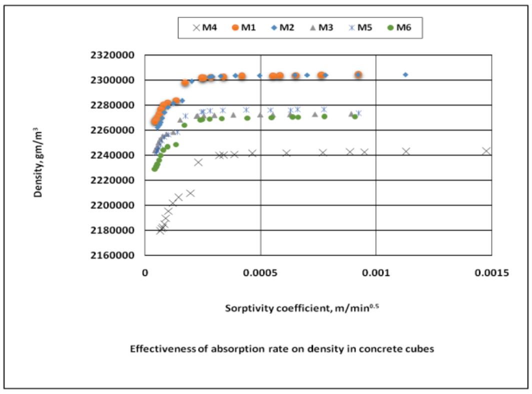

Fig. 1. Sorptivity coefficient in mix type.

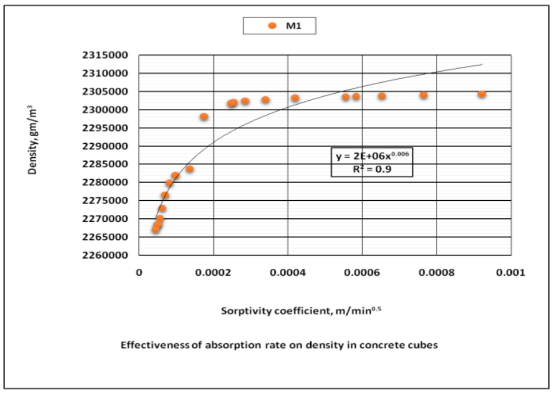

Fig. 2. Sorptivity coefficient in mix type 1.

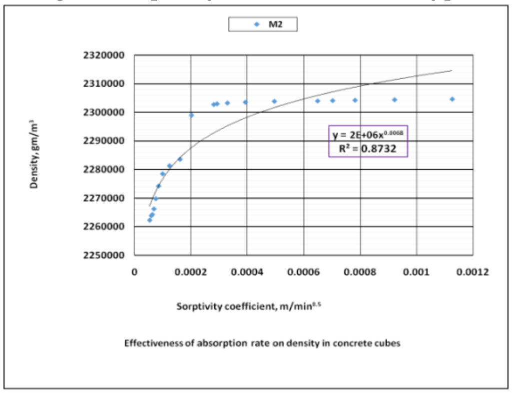

Fig. 3. Sorptivity coefficient in Mix type 2.

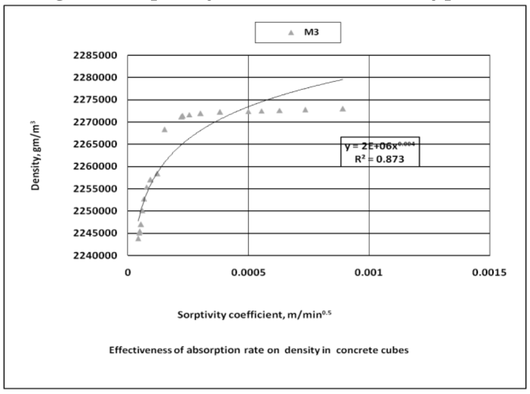

Fig. 4. Sorptivity coefficient in Mix type 3.

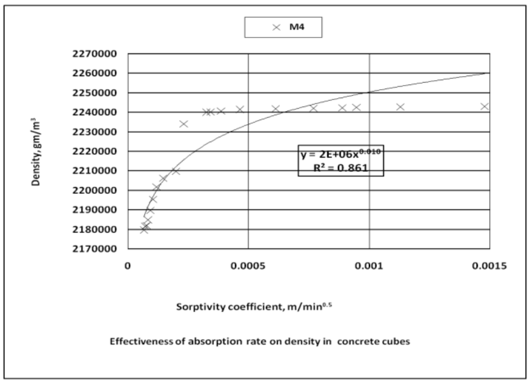

Fig. 5. Sorptivity coefficient in Mix type 4.

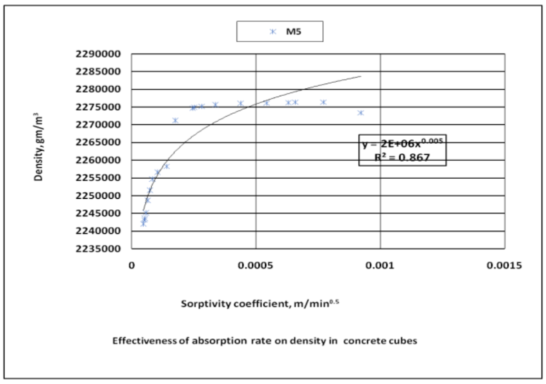

Fig. 6. Sorptivity coefficient in Mix type 5.

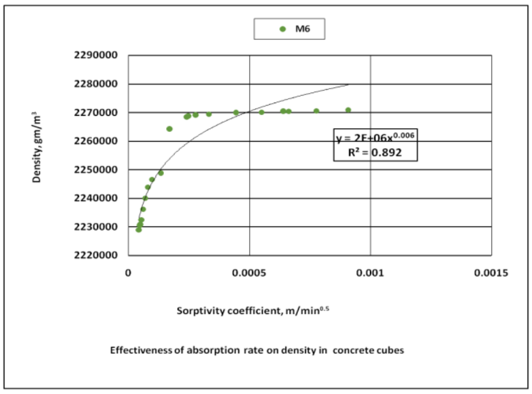

Fig. 7. Sorptivity coefficient in mix type 6.

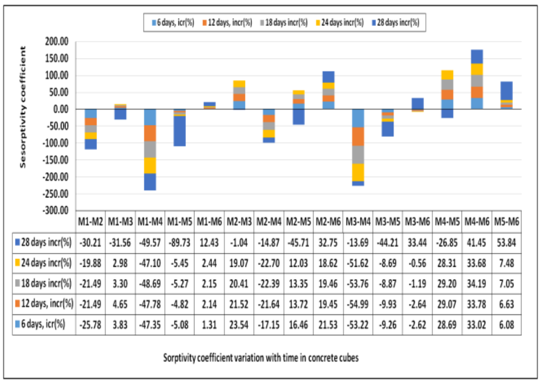

Fig. 8. Comparison of sorptivity coefficient in mixes type.

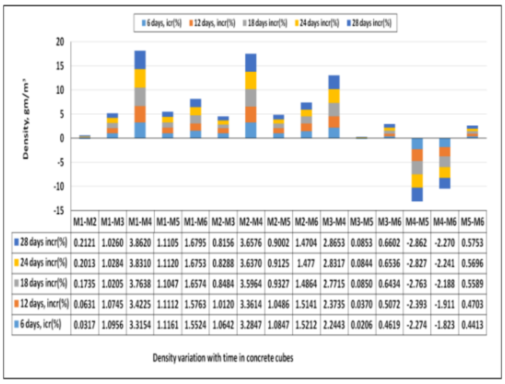

Fig. 9. Comparison of density in mixes type.

It's observed from the results that, the average rate of concrete density is varied in the different concrete mixtures design (M1-22, 89991, M2-22, 88994, M3-22, 62230, M4-22, 19153, M5-22, 63437, and M6-22, 54984) gm/m^3 respectively. Whereas the minimum as well as maximum values (concrete density) were varied in the range (M1:2267086-2304390, M2:2262277-2304555, M3:2243825-05-2272971, M4:2179531-2243183, M5:2241910-2276356, M6:2229011-2270940) gm/m^3. Also, the standard deviation was varied in the designed concrete mixtures type (concrete density) as in the following range (M1-15097.92, M2-17069.71, M3-11470.90, M4-26027.68, M5-13851.85, and M6-16943.69) respectively. It's confirmed from the research work that for in case of constant concrete compressive strength and varied slump value, the rate of concrete density was slightly increased in concrete mix design (M1-M3) as when compared to the concrete mix design (M4-M6) with varied concrete compressive strength and constant slump value. The rate of concrete density was decreased in lower concrete compressive strength and constant slump values and goes on increases with increase in concrete compressive strength for in concrete mix design (M4-M6). Furthermore, it's possible to interpret the variations in the rate of water absorption as well as density of concrete at different time intervals in the concrete mix design (M1-M6) as representing in the Figures 8-9.

5. Conclusion

In the present research work, water absorption test was carried out on concrete cubes to ascertain the rate of water absorption (sorptivity coefficient) characteristics on concrete density in designed concrete mixtures type. It's confirmed from the results that, the sorptivity coefficient is co-related with density of concrete by the power type of equation. In turn the average variation of sorptivity coefficient is more for in case of higher compressive strength and varied slump as when compared to varied concrete compressive strength and constant slump value. But in the case of lower compressive strength and constant slump, the sorptivity coefficient was slightly increases and it goes on decreases with increase in compressive strength and constant slump value. It's confirmed from the research work that for in case of constant concrete compressive strength and varied slump value, the rate of concrete density was slightly increased in concrete mix design as when compared to the concrete mix design with varied concrete compressive strength and constant slump value. The rate of concrete density was decreased in lower concrete compressive strength and constant slump values and goes on increases with increase in concrete compressive strength for in concrete mix design.

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