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WATER ABSORPTION CAPACITY OF CONCRETE CUBES WITH SORPTIVITY COEFFICIENT

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Abstract: *Quantity of water present in the concrete structural matrix controls fresh and hardened properties of concrete. Thus controlling the amount of water present in concrete structure and cement paste is important for extension of service life of concrete infrastructures. In order to devise realistic testing methods, that determine the ability of concrete to withstand water penetration requires an understanding of water mobility. In order to build durable oriented and practicable concrete structures, it is needed to be able to accurately predict the water absorption, and sorptivity coefficient within the concrete structures. The present research work was aim to determie the concrete water absorption to characterize the concrete mixtures design for in concrete cubes. Thus, this research will examine the influence of water absorption on rate of water absorption capacity (sorptivity coefficient) in the designed concrete mixes. For which slump, and w/c ratio value was vary with same compressive strength as in the first case and compressive strength, and w/c ratio value varied with same slump as in the second case. Seventy-two concrete cubes (100 mm^3) with different grades of concrete were prepared and evaluate the variation of water absorption on the sorptivity coefficient in the designed concrete mixes.*

In the present research work, water absorption test was conducted on concrete cubes to assess the rate of absorption characteristics on concrete sorptivity coefficient in designed concrete mixtures type. It's confirmed from the results that, the water absorption is co-related with sorptivity coefficient of concrete by the power type of equation. It's clear from the research work that for in case of constant concrete compressive strength and varied slump value, the rate of water absorption capacity (sorptivity coefficient) was slightly enhanced in concrete mix design as when compared to concrete mix design with differential concrete compressive strength and same 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 case of constant concrete compressive strength and varied slump value, the rate of water absorption was slightly increased in concrete mix design as when compared to the concrete mix design with varied concrete compressive strength and constant slump. 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. Water absorption is decreased in constant higher concrete compressive strength/varied slump value for in different concrete mixtures design and the sorptivity coefficient was observed to deceased in the concrete mix design respectively. Whereas, the rate of water absorption is increased in varied concrete compressive strength/constant slump value for in different concrete mixtures and the sorptivity coefficient was observed to increase in the concrete mix design respectively. It's also confirmed from the results that, the rate of water absorption and sorptivity coefficient was goes on mitigates with increase in the concrete compressive strength and constant slump value for in case of concrete mix design.

Keywords: *Mixture design, water/cement ratio, water, sorptivit , compressive strength of concrete, transport mechanism*

1.0 Introduction

The concrete infrastructures such as bridge decks, parking garages, pre-stressed concrete structures, steel structures, and marine structures may deteriorate when they are exposing to de-icing agents. The de-icing agents can be absorbed into the pores of concrete and modify the cementitious structure. De-icing agents' chemical reaction with cementitious matrix may result in the deterioration of concrete structures [W. Jones, *et al,* 2013]. Physical damage can occur due to processes exposure of concrete with a high degree of saturation to freeze-thaw cycles [Li, *et al*, 2012], scaling of concrete surfaces [Jacobsen, *et al*, 1997], crystallization of salt in concrete pores that produced internal stress [Scherer, *et al*, 1999], and expansive forces induced when a de-icing salt is used [Wang, *et al*, 2014]. The usage of de-icing salts can induce damage in cementitious materials [Marchand, *et al*, 1994] and this may be caused by the formation of Friedel's salt, Kuzel's salts [Collepardi, *et al*, 1994], calcium oxychloride, changes in the pore solution properties [Farnam, *et al*, 2014], or changes in the microstructure of hydration products [Pigeon, *et al*, 1986]. De-icing salt solution (dissolve calcium hydroxide), causing leaching which leads to an increase in permeability with reduction of concrete alkalinity [Muethel, 1997]. The increase in freeze-thaw damage due to usage of de-icing salts (Nacl) has been explained by the formation of an unexpected phases and the creation of osmotic pressures [Farnam, *et al*, 2014]. Concrete exposed de-icing salts exhibited changes in the concrete microstructure and these changes have been accompanied by a severe cracking and deterioration [Collepardi, *et al*, 1994]. The concrete infrastructures were deteriorating in different regions of the world without satisfying the stipulated service life. Therefore, there is a need to predict service life, which is a major task in the design of concrete infrastructures. In fact, the chloride concentration is a major cause of any early deterioration of reinforced concrete infrastructures. Because of this concrete deterioration, it may lead to cracking, spalling, and de-lamination of concrete cover, reduce load carrying capacity, and cross sectional area of reinforcement. Whereas, in the cold countries region it may lead to pre-mature deterioration of concrete infrastructures due to the application of de-icing salts on roads and concrete infrastructures. In fact, the bridge-decks were simultaneously expose to wetting-drying condition and, it has subjected to direct impact as well as repeated loading by continuous flow of traffic. Almost all the concrete structures were working under dry conditions. Even though most of the researchers have dedicated their efforts to study transport of chloride in concrete under wet conditions with limited publication data on dry concrete. In fact major diffusion models are applicable to the concrete structures that remains fully wet condition at all the times. They underestimate the amount of chloride penetrating a concrete structure, which is subject to wetting-drying for in case of splash/tidal zones of structures exposed to marine environment/highway structures exposed to de-icing salts. An experimental study is performing on the influence of water absorption in ordered to evaluate the effectiveness of concrete durability by researchers [Zhang, 2014]. In this way, reinforced concrete structures erected in an aggressive condition such as marine climate can be significantly extend for long time duration.

2.0 Research Objectives

The importance of water absorption has received greater attention in which water induced corrosion is the major problem for concrete durability. The present research work is aim to determine the concrete water absorption to characterize the concrete mixtures design for in concrete cubes. Thus the objectives of the present pilot program are to examine the influence of concrete water absorption on the results of rate of water absorption (sorptivity coefficient) in different concrete mixtures type. For which slump, and w/c ratio value varied with same compressive strength as in the first case and compressive strength, and w/c ratio value varied with same slump as in the second case. Seventy-two concrete cubes with different grades of concrete were prepared and evaluate for the rate of water absorption with sorptivity coefficient in the designed concrete mixes.

3.0 Experimental program

In this pilot program, six different concrete mixtures type were prepared in total as per [BRE, 1988] code standards with concrete cubes of size (100 mm^3). Three of the mixtures types were concrete cubes (100 mm^3) with same compressive strength, differential slump, and w/c .These mixtures were designate as M1, M2, and M3. Another three of the mixtures type were concrete cubes with a different compressive strength, constant slump (10-30 mm), and different w/c. These mixtures were designate as M4, M5, and M6. The overall details of the mixture proportions were represent in Table.1-2. Overall seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crush stone with (10 mm), grade of cement 42.5 N/mm^2, and fine aggregate used was 4.75 mm sieve size down 600 microns for the present research program.

Table: 1 (Variable: Slump & 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 & 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) 10mm	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 Water absorption test

The water cured concrete cubes (28 days) were then oven dried at 50 ±2ºC for 3 days until the mass became constant and again weighed. This weight was noted as the dry weight (W1) of the concrete cube. Specimens were kept in contact with water from one surface with water level not more than 5 mm above the base of specimen. Flow of water from the peripheral surface is prevented by sealing it properly with non-absorbent coating for a specified time interval as per [ASTM C 1585] with their arrangement as shown in Fig.1. Then this weight is noted as the wet weight (W2) of the concrete cube.

Fig.1 Water absorption in concrete cubes

$$\text{Water absorption } (\%) = \left[\frac{W2 - W1}{W1}\right] X100$$

The rate of water absorption test is carried out on 72 concrete cubes with size (100 mm^3) in all six mixtures type (M1-M6). as per ASTM C1585. The results confirm that, the water absorption testing is considerably influenced by sample preparation. Concrete specimens that were conditioned do not appear to follow a similar trend as against with specimens conditioned in chambers at lower temperatures for longer time duration and it's also influenced by the volume of paste in the samples. Water absorption is increased (49.76%) at time duration 5 min as against to initial time duration 0 min in mixtures type (M1-M6). The water absorption (87.98%) is predominantly increased at longer time duration (28 day). The absorption (48.91-50.57%) at 0 min as well as (87.82-88.13%) at 28 days is little bit varied as when compared to different mixtures type (M1-M3) and (M4-M6). Similarly, the water absorption is more increased in mixture type (M4) for lower compressive strength with constant slump value. Also the water absorption is goes on decreased with increased compressive strength in case of mixture type (M5), but increased with compressive strength in mixture type (M6) at an initial stage as well as at longer time duration at 28 day. The variation of average water absorption is slightly increased with constant higher compressive strength and varied slump value. It's higher with lower compressive strength and constant slump value and its goes on decreases with increased compressive strength [Balakrishna, *et al*, 2018].

3.2 Interpretation of sorptivity coefficient

This coefficient is defined as a measure of medium capacity to absorb or de-sorb liquid by capillarity and its predominantly used in characterization of soils and porous construction materials (brick, stone, and concrete) respectively.

$$\text{Sorptivity coefficient (S)} = \frac{\mathrm{i}}{\sqrt{\mathrm{t}}}$$

- $\boldsymbol{S}$ = sorptivity in mm
- $\boldsymbol{i}$ = cumulative absorption at time (t), m/s
- $\sqrt{\boldsymbol{t}}$ = square root of elapsed time in min
- I= Δ w/Ad
- Δ w= change in weight = W2-W1
- A= surface area of the specimen through which water penetrated
- d= density of water

The sorptivity coefficient (rate of water absorption) is found to be increased at initial time duration (0.0009-0.0011 $m/min^{0.5}$) as when compared to longer time duration (4.2E-05-5.4E-05 $m/min^{0.5}$). 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 in turn indicates that, pore structure may be reached fully saturated condition. Sorptivity coefficient is increased at initial time duration with decreased cumulative water absorption in all mixtures type as against to longer time interval. Sorptivity coefficient at initial time duration is found to be in the range (0.0009-0.0014 $m/min^{0.5}$) and (4.5E-05-5.5E-05 $m/min^{0.5}$) at final time duration. Cumulative absorption varied at an initial stage between (0.002-0.003 m) at an early time duration and (0.008-0.013 m) at longer time duration. Finally, the sorptivity coefficient is decreases with decreased rate of cumulative absorption at longer time duration in turn it indicates that, the pore structure reaches fully saturated condition in all mixtures type. The sorptivity coefficient is decreased as when compared to initial time duration (5-10) min. In fact there is decrease in sorptivity coefficient (21.89%) at 10 min as when compared to initial time (5 min) for in case of mixtures type (M1-M6). Similarly, Sorptivity coefficient is goes on decreases gradually at certain point, it reaches parabolic pattern, and afterwards it reaches equilibrium (28 days) in turn sorptivity coefficient is found to be decreased (95.18%). Whereas at 1 day, the increase in sorptivity coefficient is found to be 82.07% for in case of all mixtures type (M1-M6). The sorptivity coefficient for in case of mixtures type (M1-M3) at initial time (10 min) is found to be increased (21.32%) as when compared to time (5 min). Similarly, at 10 min, there is an increase in sorptivity coefficient (22.46%) as when compared to time (5 min) for in case all mixtures type (M4-M6). The rate of absorption is always more at an initial time duration because of differential gradient is exists between higher to lower concentration gradient section, where there is a variation in the rate of absorption up to certain time duration after that, it reaches parabolic pattern which is very smooth flow of rate of absorption. Once it reaches that, pore structure, cement paste, and concrete matrix reaches fully saturated condition in turn finally the sorptivity coefficient reaches equilibrium state. Thus in the present research work water absorption test was conduct on concrete cube to evaluate the effectiveness of water absorption on rate of absorption capacity (sorptivity coefficient) in the designed concrete mixes [Balakrishna, *et al*, 2018].

4.0 Discussion about Results

The deterioration of concrete is caused by the movement of aggressive agents into the concrete, physical/chemical reaction within its internal structure leads to an extensive damage to the concrete structures. The one of the most important properties of a good quality concrete is low permeability which in turn resists ingress of water. Permeability relates to the size of the pores, distribution and importantly their continuity. Permeability is not necessarily directly related to absorption and it has been related to w/c ratio of concrete. The lower the sorptivity value, the higher the resistance of concrete towards water absorption. It's mainly depends on the pore distribution and micro structural properties of concrete [Abdul Razak, *et al*, 2004]. The cumulative water absorption of the concrete mixtures decreases with the decrease in w/cm ratio for the concrete due to less amount of water in the mix, results into denser concrete.

Concretes with lower w/cm ratio have lower water absorption for the mixtures and sorptivity values are least due to lower amount of water in the mix, results 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 and mechanical properties of concrete are highly influenced by its density. Thus the minimum w/c ratio is desirable to maintain appropriate compressive strength and durability of the concrete. By proper curing, it's possible to reduce the rate of moisture loss and provides a continuous source of moisture required for the hydration which reduces the porosity [Alamri, 1988].

Mortar/concrete surface is exposed to wetting by water, then the cumulative water absorption (normalized to the exposed surface area) is proportional to the square root of elapsed wetting time as confirmed by investigator [Hall, 1989]. An initial rate of ingress observed to be decreases as the water has accessed all the capillary pores. The decrease in gradient of the straight line portion of the water uptake versus square root of time indicates that sorptivity is now occurring via the finer pores [Martys, and Ferraris, 1997]. In dry/partially dry mortars/concretes, the predominant mechanism in the water absorption is the capillary suction, which in turn material begins to be saturated [Martys, and Ferraris, 1997]. Materials with extremely coarse pore structure experience little capillary suction and may show significant deviation from linearity after prolonged wetting. The sorptivity will depend on the initial water content and its uniformity throughout the specimen under test [Neville, 1995]. Thus in the present research work water absorption test was conducted on concrete cubes in order to evaluate the effectiveness of absorption on the rate of water absorption capacity (sorptivity coefficient) in the designed concrete mixes. It was found that the compressive strength of PFRC increased and the sorptivity of PFRC was decreased with respect to normal concrete. The addition of PET fibers in concrete tends to restrict water propagation in the concrete and causes reduction in sorptivity [Nibudey, *et al*, 2014]. Similarly previous studies on cement concrete had shown that specimen with higher sorptivity recorded lesser durability [Sabir, *et al*, 1998]. It was noticed that specimen with higher sorptivity recorded lesser retention of compressive strength after 24 weeks immersion in sulphuric acid [Suresh Thokchom, *et al*, 2009]. Test results indicated that concrete sorptivity decreased by 42.7% when cement content was increased from 350 kg/m^3-450 kg/m^3 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% respectively, for specimens cured in water for 28 days at 20^0 C [Esam Elawady, *et al*, 2014]. The water absorption and sorptivity of fly ash and hypo sludge concrete shows lower water absorption and sorptivity than conventional concrete. The water absorption and sorptivity of M25 fly ash and hypo sludge concrete is higher water absorption and sorptivity than M40 grade concrete [Jayeshkumar Pitroda, 2015]. Thus there is need to investigate variations in the sorptivity coefficient in the concrete cubes in order to characterize different designed mixtures type in the present research work. The combined variation of water absorption with sorptivity coefficient at different time interval for in concrete designed mixtures type is as shown in Figs.2-8 respectively. It's possible to establish a relation between the water absorption and sorptivity coefficient in concrete cubes with power type of equation.

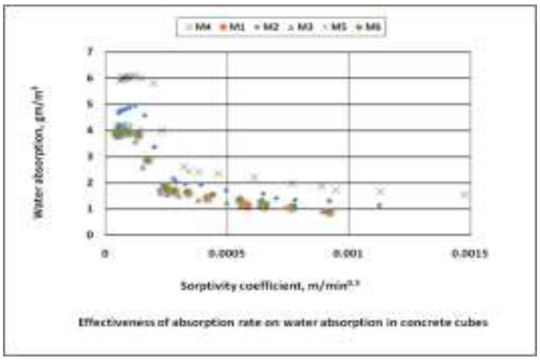

Fig.2 Rate of absorption in DCC concrete cubes

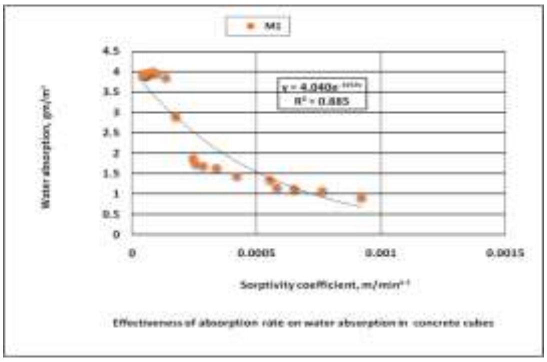

Fig.3 Rate of absorption in PSC concrete cubes

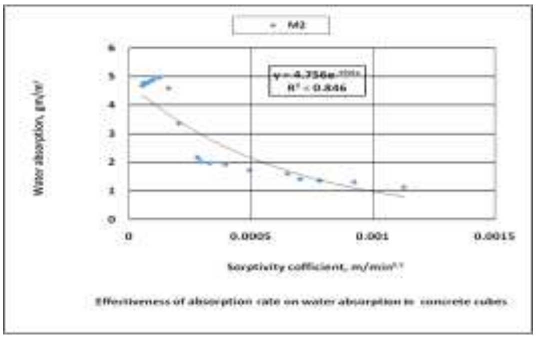

Fig.4 Rate of absorption in concrete cubes

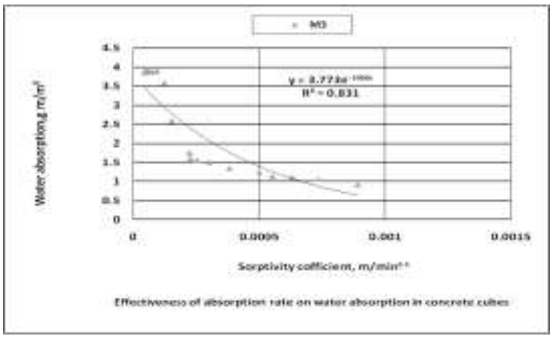

Fig.5 Rate of absorption in PSC concrete cubes

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 were 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 differential concrete compressive strength and same slump. Rate of water absorption was enhanced 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). Furthermore, it's possible to interpret the variations in the rate of water absorption capacity (sorptivity coefficient) and water absorption of concrete at different time intervals in the concrete mix design (M1-M6) as representing in the Figs.9-10.

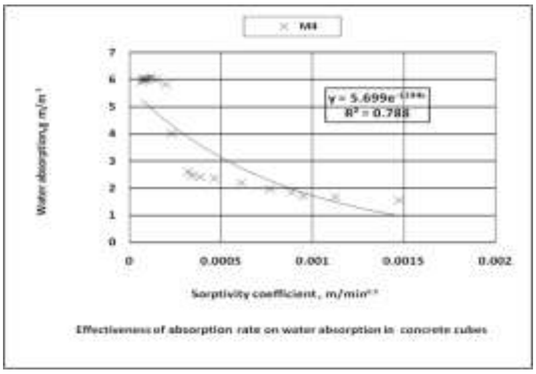

Fig.6 Rate of absorption in concrete cubes

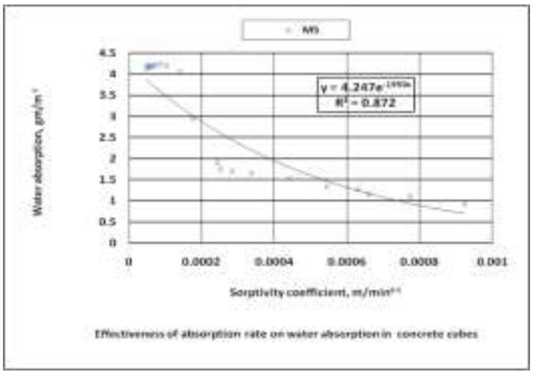

Fig.7 Rate of absorption in concrete cubes

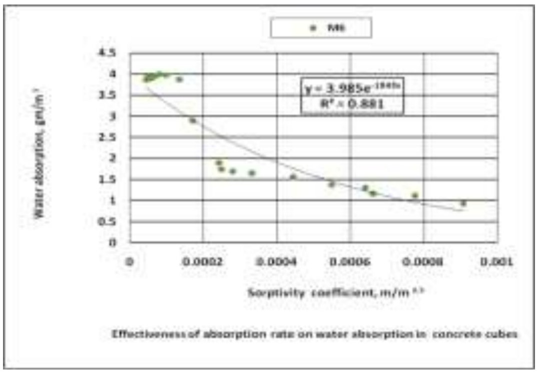

Fig.8 Rate of absorption in concrete cube

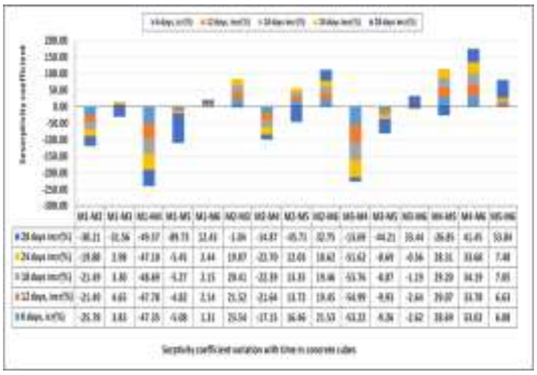

Fig.9 Sorptivity coefficient in Mixes type

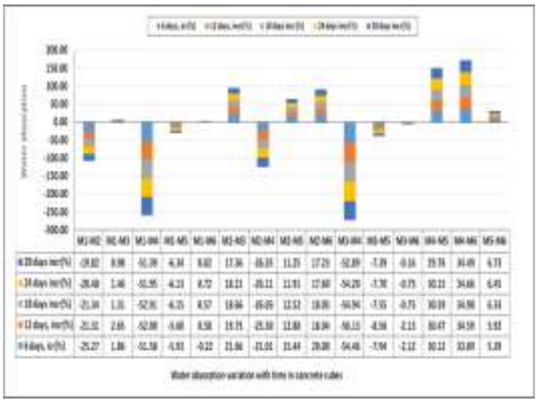

Fig.10 Rate of absorption in Mixes type

The average rate of water absorption is varied in the different mixtures design (M1-2.62, M2-3.14, M3-2.52, M4-3.93, M5-2.74, and M6-2.63) gm/m³ respectively. Whereas the minimum as well as maximum values (water absorption) were varied in the range (M1:0.92-4.01, M2:1.13-4.96, M3:0.91-3.90, M4:1.54-6.08, M5:0.93-4.23, M6:0.92-3.99) gm/m³. Also the standard deviation were varied in the designed concrete mixtures type (water absorption) as in the following range (M1-1.28, M2-1.58, M3-1.27, M4-1.97, M5-1.38, and M6-1.26) 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 was slightly enhanced 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 enhancement in concrete compressive strength for in concrete mix design (M4-M6). Water absorption rate is decreased in constant higher concrete compressive strength/varied slump value for in different concrete mixtures type (M1-4, M2-4.5, M3-3.5) gm/m³ and the sorptivity coefficient was observed to deceased in the concrete mix design (M1- >0.0005, M2- >0.001, M3- <0.01) m/min$^{0.5}$ respectively. Whereas, its observed from the results that, water absorption rate is increased in varied concrete compressive strength/constant slump value for in different concrete mixtures (M4-5.9, M5-3.9, M6-3.55) gm/m^3 and the sorptivity coefficient was observed to increase in the concrete mix design (M4- 0.0015, M5- >0.0008, M6- <0.0008) m/min$^{0.5}$ respectively. It's also confirmed from the results that, the rate of water absorption and sorptivity coefficient was goes on mitigates with enhancement in the (compressive strength and constant slump value) for in case of concrete mix design (M4-M6).

5.0 Conclusions

- In the present research work, water absorption test was conducted on concrete cubes to assess the rate of absorption characteristics on concrete sorptivity coefficient in designed concrete mixtures type.

- It's confirmed from the results that, the water absorption is co-related with sorptivity coefficient of concrete by the power type of equation. It's clear from the research work that for in case of constant concrete compressive strength and varied slump value, the rate of water absorption capacity (sorptivity coefficient) was slightly increased in concrete mix design (M1-M3) as when compared to the concrete mix design (M4-M6) with varied concrete grade and same slump. Rate of water absorption was enhanced 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).

- It's noted from the present work that for in case of constant concrete grade and varied slump, rate of water absorption was slightly enhanced in concrete mix design (M1-M3) as when compared to the concrete mix design (M4-M6) with varied concrete grade and same slump value. Rate of water absorption was increased in lower concrete compressive strength and constant slump values and goes on decreases with increase in concrete grade for in concrete mix design (M4-M6).

- Rate of water absorption is decreased in constant higher concrete compressive strength/varied slump value for in different concrete mixtures type (M-M3) and the sorptivity coefficient was observed to deceased in the concrete mix design (M1-M3) respectively. Whereas, it's observed from tthe results that, the water absorption rate is increased in varied concrete compressive strength/constant slump value for in different concrete mixtures design (M4-M6) and sorptivity coefficient were observed to increase in the concrete mix design (M4-M6) respectively. It's also confirmed from the results that, the rate of water absorption and sorptivity coefficient was goes on mitigate with enhancement in the concrete grade and constant slump value for in case of concrete mix design (M4-M6).

6.0 References

1. Abdul Razak, H., Chai H. K. and Wong H. S. (2004). Near surface characteristics of concrete containing supplementary cementing materials, Cement and concrete composites, 26(7):883-889.
2. Alamri, A. M. (1988). Influence of curing on the properties of concrete and mortars in hot climates, PhD Thesis; Leeds University, UK.
3. Balakrishna.M .N, Fouad Mohammad, Robert Evans, and Rahman. M. M. (2018). Assessment of sorptivity coefficient
4. in concrete cubes, Discovery Publication, 54(274):377-386.
5. Collepardi. M, Coppola. L, and Pistolesi. C. (1994). Durability of concrete structures exposed to CaCl2 based de-icing salts, in: V.M. Malhotra (Ed.), Durab. Concr. ACI SP-145, 3rd CANMET/ACI Int. Conf, 107–120pp.
6. Esam Elawady, Amr A. El Hefnawy, Rania A. F. Ibrahim. (2014).Comparative study on strength, permeability and sorptivity of concrete and their relation with concrete durability, IJEIT, Issue 4, 4:132-139.
7. Farnam. Y, Bentz. D, Sakulich. A, Flynn. D, and Weiss. J. (2014). Measuring freeze and thaw damage in mortars containing de-icing salt using a low-temperature longitudinal guarded comparative calorimeter and acoustic emission, Adv. Civ. Eng. Mater. 3:316–337.
8. Hall. C. (1989). Water sorptivity of mortars and concrete: a review, Mag.Concrete.Res, 41:51-61.
9. Jones. W, Farnam. Y, Imbrock. P, Sprio. J, Villani. C, and Olek. J. (2013). An overview of joint deterioration in concrete pavement: Mechanisms, solution properties, and sealers.
10. Jacobsen. S, Sœther. D, and Sellevold. E. (1997). Frost testing of high strength concrete: Frost/salt scaling at different cooling rates, Mater. Struct. 30:33–42.
11. Jayeshkumar Pitroda. (2015). Assessment of sorptivity and water absorption of concrete with partial replacement of cement by Fly ash and Hypo sludge, IJARESM, Issue II, I:33-42.
12. Li. W, Pour-Ghaz. M, Castro. J and Weiss. J. (2102). Water absorption and critical degree of saturation relating to freeze-thaw damage in concrete pavement joints, J. Mater. Civ. Eng. 24:299–307.
13. Marchand. J Sellevold. E. J, and Pigeon. M. (1994). The de-icer salt scaling deterioration of concrete-An overview, in: V.M. Malhotra (Ed.), Third Int. Conf. Durab. Concr., Nice, France, 1–46pp.
14. Muethel. R. W. (1997). Investigation of calcium hydroxide depletion as a cause of concrete pavement deterioration.
15. Martys. N, and Ferraris. C. (1997). Capillary transport in mortars and concretes, Cem.Concr.Res, 27 :747-760.
16. Neville, A. M. (1995). Properties of Concrete, 4th edition (Longman, England).
17. Nibudey. R. N, Nagarnaik. P. B, Parbat. D. K, and Pande. A. M. (2014). Compressive strength and sorptivity properties of pet fibre reinforced concrete, IJAET, Issue 4, 7:1206-1216
18. Pigeon. M, and Regourd. M. (1986). The effects of freeze-thaw cycles on the microstructure of hydration products, Durab. Build. Mater. 4 :1–19.
19. Scherer. G. (1999). Crystallization in pores, Cem. Concr. Res. 29:1347–1358.

20. Sabir. B. B, Wild. S, and O'Farrel. M. (1998). A water sorptivity test for mortar and concrete
21. Materials and structures. 31: pp.568-574.
22. Suresh Thokchom, Partha Ghosh and Somnath Ghosh .(2009). Effect of water absorption, porosity, and sorptivity on durability of Geopolymer mortars, ARPN Journal of Engineering and Applied Sciences , (4)7:28-32.
23. Teychenné, D. C, Franklin. R. E, and Erntroy. H. C. (1988). Design of normal concrete mixes, Second edition, BRE.
24. Wang. Z, Zeng. Q, Wang. L, Yao. Y, and Li. K. (2014). Corrosion of rebar in concrete under cyclic freeze–thaw and Chloride salt action, Constr. Build. Mater. 53:40–47.
25. Zhang. S. P, and Zong. L. (2014). Evaluation of relationship between water absorption and durability of concrete materials, Advances in materials Science and Engineering, Article ID 650373, 8 pages,