RELATIONSHIP BETWEEN SORPTIVITY-DESORPTIVITY IN CONCRETE CUBES

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Abstract: *The quantity of water present in the concrete matrix controls many fresh and hardened properties of concrete such as workability, compressive strength, permeability and water tightness, durability and weathering, drying shrinkage and potential for cracking. Thus the limiting and controlling the amount of water present in concrete matrix as well as cement paste is important for both constructability and an extensive service life of concrete infrastructures. The successful key factor for making durable concrete is to limit its ability to transport fluids like water. 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 sorptivity, water de-sorption, relationship between water sorptivity-de-sorptivity within the concrete structures. Therefore, there is a need to quantify the sorptivity-de-sorptivity coefficient in concrete cubes which is of the most important factor in the concrete industries. The present research work is made an attempt to interpret the concrete sorptivity-de-sorptivity coefficient in ordered to characterize the different concrete mixtures design for in case of concrete cubes. Thus the objectives of this present research are such as: this research will examine the influence of concrete ingredients on the results of water sorptivity-de-sorptivity performed on concrete cubes with different mixtures proportion in which slump, and w/c ratio value is 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 sorptivity effect in designed different mixtures type.*

As from this research work that, it's possible to establish power type of equation between de-sorptivity coefficient and square root of time in designed mixtures type. The de-sorptivity coefficient is predominantly increased at an initial stage as when compared to longer time duration for in case of all mixtures type. It's also confirmed from the results that, the de-sorptivity coefficient is significantly decreased for in case of higher compressive strength and varied slump. But in the case of lower compressive strength and constant slump, the variation of de-sorptivity coefficient with square root of time is slightly higher and goes on decreases with increased compressive strength for in case of designed mixtures type. It's possible to establish polynomial type of equation between sorptivity-de-sorptivity coefficient ratio and square root of time in designed mixtures type from previous research work. The sorptivity-de-sorptivity coefficient ratio is predominantly decreased at an initial stage as when compared to longer time duration for in case of all mixtures type. It's also confirmed from the results that, the sorptivity-de-sorptivity coefficient ratio is significantly decreased for in case of higher compressive strength and varied slump. But in the case of lower compressive strength and constant slump, the variation of sorptivity-de-sorptivity coefficient ratio with square root of time is slightly higher and goes on decreases with increased compressive strength for in case of designed mixtures type. Sorptivity-de-sorptivity coefficient ratio and square root of time is correlated by linear type of equation in the present research work. Sorptivity/de-sorptivity coefficient ratio-time is predominantly significant in establishing the values of either desorption or sorption coefficient at any time duration for in case of designed concrete mixtures type.

Keywords: *Concrete, mixture proportion, grade of concrete, w/c ratio, slump, sorptivity coefficient, de-sorptivity coefficient*

1.0 Introduction

The primary mechanisms which is responsible for the deterioration of concrete structures includes such as the corrosion of reinforcing steel, cracking due to shrinkage, freezing and thawing, and chemical attack. Water is the principal agent responsible for the deterioration/ principal medium by which aggressive agents such as chloride/sulfate ions are transported into the concrete. Thus the water ingress and aggressive agent transport are the key factors which influence the long-term durability of concrete structure. There are many transport processes in concrete which includes such as capillary absorption, diffusion, permeation, and convection respectively. Capillary absorption describes water uptake in un-saturated concrete

[Wilson, *et al,* 1999] due to the capillary forces. Diffusion describes the transport of moisture/dissolved ions as a result of a concentration gradient [Dullien, 1992]. Permeation describes the flow of a fluid (water/air) as a result of gravity or a pressure gradient [Yong, *et al*, 1992]. Convection/advection is the process that describes the transport of a solute (chloride/sulfate ions) as a result of the bulk moving water [Boddy, *et al,* 1999]. The analysis of transport processes in many concrete structures is complicated which may be due to numerous factors involved in transport mechanisms. In fact that, the concrete infrastructures are exposed to salts due to either a marine environment exposure or the application of de-icing salts to pavements, bridge decks, or parking lots [Spragg, *et al*, 2011]. In addition to that, an evidence of salt deterioration has been reported in masonry structures [Lubelli, *et al*, 2004], building stones [Birginie, *et al*, 2000], coastal structures [Berke, and Hicks, 1991] and concrete elements [Sutter, *et al*, 2006]. There are several mechanisms may be associated with de-icing salt damage which may include factors such as pressure that develops due to osmosis, crystallization, intermediate compounds, or the increase of the risk of frost damage due to the increase in the degree of saturation [Li, *et al*, 2012]. In addition to that, the de-icing salts are also responsible of chemical interaction within the concrete, resulting in leaching and decomposition of the hydrated cement products, accelerated concrete carbonation, or alkali-silica reaction [Wang, *et al*, 2006].As noted by researchers [Wojciech Kubissa, *et al*, 2016] that, the sorptivity is one of the important parameter which inform the durability performance of concrete structure. Sorptivity is depends on the composition of concrete mixture such as w/c ratio and the curing procedure. It's confirmed from the results, there is a clear (approximately linear) decrease of sorptivity values with distance from the upper surface of the element and also inform about the influence of the compaction method on the values of sorptivity. Sorptivity are measured by mass method/volumetric method in which concrete specimens are dried to the constant mass [Kubissa, *et al*, 2012].In which volumetric method is based on measuring the volume of water which penetrates the concrete at given time under the capillary forces through the surface equal to cross-section of glass cylinders with scaled pipettes through which water flows. Some researcher's points out that concrete sorptivity in the structure is different than the one tested with specimens being cured in a laboratory in the water or in other conditions as pointed by researcher [Kubissa, *et al*, 2014].

It's clear from the investigators [Walid Deboucha, *et al*, 2015] that, the Blast furnace slag (BFS) and natural pozzolana (NP) have been widely used as a partial cement replacement in concrete construction due to their cost reduction, improvement of the ultimate mechanical, and durability properties. It is possible to obtain the same or better strength grades by replacing cement with BFS up to 30% in concrete. However, the use of NP content reduced the compressive strength. Lower capillary water absorption for BFS or NP substitution is observed. An attempt is made by investigators [Roman Jaskulski, *et al*, 2016] that, in order to develop models that allow to predict sorptivity of concrete with recycled aggregate on the basis of the composition of the concrete is presented. It's clear the formulated models showed very good agreement of mean values and satisfactory compliance of the standard deviation of the results obtained from the simulation with the results obtained from the sorptivity tests. An extensive research is carried out by investigators [Bo Zhou, *et al*, 2016] on the hygro-thermal performances of three types of zeolite-based humidity control building materials (ZBHCMs). The experimental results indicated that the humidity control performance of ZBHCMs is strongly affected by the porosity and the pore diameter. The environmental temperature and the RH have considerable influence on the adsorption performance of ZBHCMs and De-sorption performance of ZBHCMs is affected more strongly by the ambient RH. Furthermore, the moisture diffusivity of unsaturated concrete is expressed so many decades before by [Bažant and Najjar, 1972] as a non-linear function of pore humidity and their proposed analytical model was in the same work calibrated with experimental data. It's later extended this model by researcher [Xi, *et al*, 1994] to include moisture capacity as a function of water-cement ratio, curing time, temperature and type of cement as the derivative of the adsorption isotherm. Thus there is need to investigate the effectiveness of rate of absorption (sorptivity) which is performed on the concrete cubes in order to establish relationship between sorptivity-de-sorptivity, and de-sorptivity-time.

2.0 Research Objectives

The water transport in a porous network like concrete is a complex criterion. This is due to the fact that, many different kinds of transport mechanisms in combination with various types of pores that typically appears in the same porous system. Therefore there is a need to study water transport mechanisms with different designed mixtures type in order to assess the sorptivity-de-sorptivity coefficient in concrete structures. The present research work is made an attempt to interpret the concrete water sorptivity-de-sorptivity coefficient-time respectively in ordered to characterize the different concrete mixtures design for in case of concrete cubes. Thus the objectives of this present research is to examine the influence of concrete ingredients on the results of concrete water sorptivity-de-sorptivity coefficient performed on concrete cubes with different mixtures proportion in which slump, and w/c ratio value is varied with constant compressive strength as in the first case and compressive strength, and w/c ratio value is 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 concrete water sorptivity coefficient in concrete cubes.

3.0 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 designated 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 designated as M4, M5, and M6. The overall details of the mixture proportions were to be represented in Table.1-2. Twelve concrete cubes of size (100 mm^3) were cast for each mixture and overall Seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used is crushed 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 respectively.

Table: 1 (Variable: Slump & W/C value; Constant: Compressive strength)

Mix No	Comp/mean target strength(N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture 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 No	Comp/mean target strength(N/mm^2)	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA(Kg) 10 mm	Mixture 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 De-sorptivity coefficient

It's a phenomenon whereby a substance is released from or through a surface and in fact the process is the opposite of sorption. De-sorption is a process which involves the liberation of both absorbed and adsorbed water molecules. As the term sorption in concrete technology is used to describe both absorption and adsorption so desorption should be considered the opposite process where water is released from a concrete surface. Therefore, de-sorptivity is defined as a measure of the rate at which concrete releases water into a drying environment. The drying of a saturated concrete surface will develop menisci within the pore structure creating capillary tension will influence water transport. Therefore a de-sorptivity coefficient can be obtained from measuring uniaxial drying from a concrete surface in a constant temperature and humidity environment. The variation of de-sorptivity coefficient (D_s) with square root of time ($\sqrt{t}$) for in case of designed mixtures type [Balakrishna, *et al*, 2018] with their correlation equation as well as R^2 values is represented in (Table.3).

Table: 3De-sorptivity coefficient with time

MIX ID	Co-relation Equation	R^2
M1	$Ds = 111.99 (\sqrt{t})^{-1.142}$	0.9982
M2	$Ds = 129.24(\sqrt{t})^{-1.118}$	0.9979
M3	$Ds =106.97(\sqrt{t})^{-1.086}$	0.9989
M4	$Ds =175.91(\sqrt{t})^{-1.140}$	0.9970
M5	$Ds =94.68(\sqrt{t})^{-1.072}$	0.9923
M6	$Ds =110.97(\sqrt{t})^{-1.158}$	0.9967

The de-sorption coefficient was found to be increased (40 g/m^2/min$^{0.5}$) at initial time duration as when compared to longer time duration (0.3 g/m^2/min$^{0.5}$) in all mixtures type (M1-M6). The de-sorptivity coefficient was varied may be due to temperature, humidity, location dependent, slump value, w/c ratio, and pore structure degree of saturation. The desorption coefficient was the opposite phase of sorptivity coefficient. The de-sorptivity coefficient was investigated in all mixtures type (M1-M6) at different time interval for up to 28 days. The desorption coefficient was the rate of decrease of water absorption at each and every time interval which was depends on environmental conditions such as temperature, humidity, pore structure, compactness of concrete, and mixture proportion. The desorption coefficient test was carried out by simply exposed the concrete cubes to room temperature and noted their reduced weight at each time until it reaches equilibrium state. The variation in desorption coefficient was found to be varied in between ($De_{5\ min}$ = 43.96 g/m^2/min$^{0.5}$, and $De_{200.79\ min}$ = 0.312 g/m^2/min$^{0.5}$) for in case mixtures type (M1-M6) and ($De_{5\ min}$ = 43.17 g/m^2/min$^{0.5}$, and $De_{200.79\ min}$ = 0.286 g/m^2/min$^{0.5}$) for in case of mixtures type (M1-M3), as well as ($De_{5\ min}$ = 44.75 g/m^2/min$^{0.5}$, and $De_{200.79\ min}$ = 0.338 g/m^2/min$^{0.5}$) in mixtures type (M4-M6). Similarly the variation of average values of de-sorption coefficient, minimum, maximum, and standard deviation for in case of different mixtures type (M1-M6) is as represented in Table.4 respectively.

Table: 4 De-sorptivity coefficient with time

MIX ID	Average	Min, value	Max, value	STD
M1	8.41	0.24	41.74	11.55
M2	9.98	0.31	46.69	13.20
M3	8.80	0.31	41.10	11.60
M4	12.90	0.36	60.38	17.09
M5	8.04	0.30	36.46	10.49
M6	7.95	0.21	37.44	10.59

3.2 Variation of de-sorptivity and sorptivity coefficient

The sorptivity and de-sorptivity coefficient increases gradually at three stages which follows square root of time and linearly proportional to each other. It's observed from results that, the linearity proportional ranges between 0-50 min, 50-100 min, and 100-200 min. The ratio of sorptivity to de-sorptivity coefficient values range between 0.0023-0.15 at short and long time duration in all mixtures type (M1-M6). The sorptivity and de-sorptivity coefficient follows linearity of proportional, this may be due the fact that, both the coefficients directly proportional to cumulative water absorption (mass gain), mass loss, and inversely proportional to square root of time. Therefore, the sorptivity coefficient is equal to de-sorptivity coefficient which follows linearity of proportion. The variation of sorptivity to de-sorptivity ratio coefficient was evaluated at different time interval in all mixtures type (M1-M6) with their correlation equations and R^2 value as shown in Table.5. The ratio varies due environmental conditions and location. Actually the rate of absorption was not suddenly increased/decreased in turn depends on concrete matrix, and mixture proportion, but rate of absorption was increases gradually with time duration. Similarly, the rate of decrease of water from any structure was not so easy due to proper pore structure formation, compactness and concrete mixture design. In fact, rate of desorption was very slow in all mixtures type. From this ratio, it's possible to predict time duration in any designed mixtures type in turn it's possible to interpret the particular mixture type characteristics such as compressive strength, slump, w-c ratio, Fine-coarse aggregate volume fraction, cement paste and concrete matrix. The variation in sorptivity-desorption coefficient ratio was found to be varied in between ($S/D_{5\ min}$ = 0.023, and $De_{200.79\ min}$ = 0.166) for in case mixtures type (M1-M6) and ($S/D_{5\ min}$ = 0.022, and $S/D_{200.79\ min}$ = 0.167) for in case of mixtures type (M1-M3), as well as ($S/D_{5\ min}$ = 0.024, and $S/D_{200.79\ min}$ = 0.166) in mixtures type (M4-M6). The variation of average values of sorption coefficient, minimum, maximum, and standard deviation for in case of different mixtures type (M1-M6) is as represented in Table.6 respectively [Balakrishna, *et al,* 2018].

Table: 5 Sorptivity/de-sorptivity coefficients ratio with time

MIX ID	Co-relation Equation	R^2
M1	$S/Ds = -5E.06\ (\sqrt{t})^2+0.0018\sqrt{t}$	0.9502
M2	$S/Ds = -4E.06\ (\sqrt{t})^2+0.0017\sqrt{t}$	0.9945
M3	$S/Ds = -4E.06\ (\sqrt{t})^2+0.0015\sqrt{t}$	0.9274
M4	$S/Ds = -3E.06\ (\sqrt{t})^2+0.0016\sqrt{t}$	0.9534
M5	$S/Ds = -7E.06\ (\sqrt{t})^2+0.0022\sqrt{t}$	0.9003
M6	$S/Ds = -4E.06\ (\sqrt{t})^2+0.0018\sqrt{t}$	0.9512

Table: 6 Sorptivity coefficients with time

MIX ID	Average	Min, value	Max, value	STD
M1	0.098	0.022	0.188	0.066
M2	0.092	0.024	0.173	0.061
M3	0.075	0.021	0.139	0.047
M4	0.093	0.024	0.186	0.066
M5	0.090	0.025	0.185	0.059
M6	0.104	0.024	0.210	0.073

4.0 Discussion about Results

The concrete infrastructures such as buildings, bridge decks and harbours, parking places, pre-stressed concrete structures, and steel structures may deteriorate due to de-icing agents, water ingress, and aggressive chemicals in the cold countries region respectively. The concrete infrastructures deterioration is considered to be as one of the major factors that could significantly change the long-term performance of concrete structures. It is well-known fact that, the deterioration rate not only depends on material compositions and construction processes, design criteria, maintenance, and protection methods but also relies on the on-going climatic environmental effect during the service phase of the concrete infrastructures life cycle. Therefore there is a need to study water transport mechanisms with different designed mixtures type in order to assess the sorptivity-de-sorptivity coefficient in concrete structures. The present research work is made an attempt to interpret the variation of concrete water sorptivity-de-sorptivity coefficient ratio with time respectively in ordered to characterize the different concrete mixtures design for in case of concrete cubes. As observed from the present results that, the de-sorptivity coefficient is slightly higher for in case of constant higher concrete compressive strength and varied slump value. De-sorptivity coefficient is predominantly higher for in case of lower concrete compressive strength and constant slump value, but its goes on reduced with increased concrete compressive strength and constant slump value respectively. The variation of sorptivity-de-sorptivity coefficient ratio with square root of time for in case of designed mixtures type with their linear type of correlation equation as well as R^2 values is represented in Figs.1-6 respectively. It's also observed from the present results that, the sorptivity-de-sorptivity coefficient ratio is slightly higher for in case of constant higher concrete compressive strength and varied slump value. The de-sorptivity coefficient is slightly higher for in case of lower concrete compressive strength and constant slump value, but its goes on reduced with increased concrete compressive strength and constant slump value respectively. It's observed from the results that, the sorptivity-de-sorptivity coefficient ratio is slightly increased with increased higher concrete compressive strength, and constant slump value respectively. Furthermore, the variation of sorptivity-de-sorptivity coefficient ratio is linearly varied with square root of time duration in all designed mixtures type respectively. The rate of desorption was higher at initial time duration (1day) as when compared to longer time duration (28 days) which in turn depends on concrete matrix, slump, mixture proportion, concrete compressive strength, and w/c ratio. The rate of desorption was higher in lower concrete compressive strength with constant slump. The rate of desorption was goes on increases with increase in concrete compressive strength and time duration. The rate of desorption was observed to be higher in the range at initial time duration (M1:2.07, M2:2.60, M3:2.29, M4:3.32, M5:2.08, and M6:2.02) as when compared to longer time duration (M1:0.23, M2:0.30, M3:0.31, M4:0.35, M5:0.45, and M6:0.20) at 28 days. The rate of desorption was goes on increases with increase in concrete compressive strength and time duration. The rate of sorption was also observed to be higher in the range at initial time duration (M1:0.00017, M2:0.0002, M3:0.00015, M4:0.00023, M5:0.00018, and M6:0.00017) as when compared to longer time duration (M1:4.5E-05, M2:5.4E-05, M3:4.3E-05, M4:6.6E-05, M5:4.7E-05, and M6:4.4E-05) at 28 days.

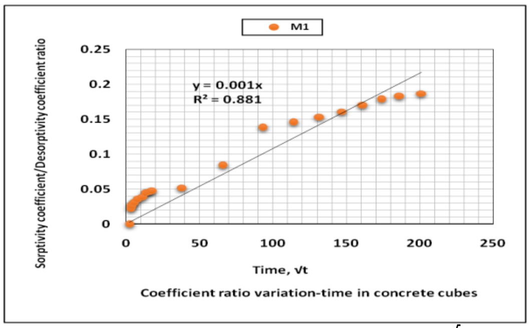

Fig.1 Sorptivity/de-sorptivity coefficient-√t

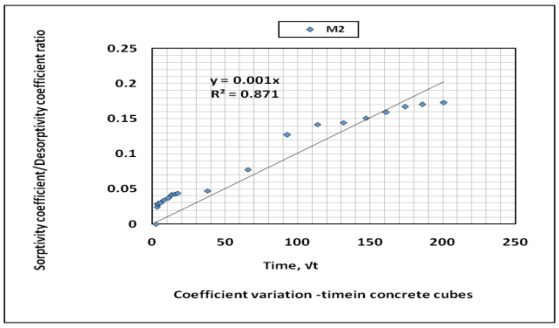

Fig.2 Sorptivity/de-sorptivity coefficient-√t

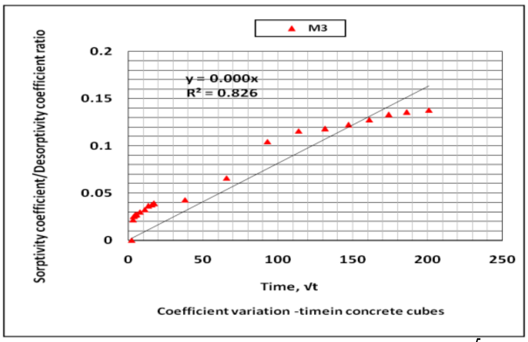

Fig.3 Sorptivity/de-sorptivity coefficient-√t

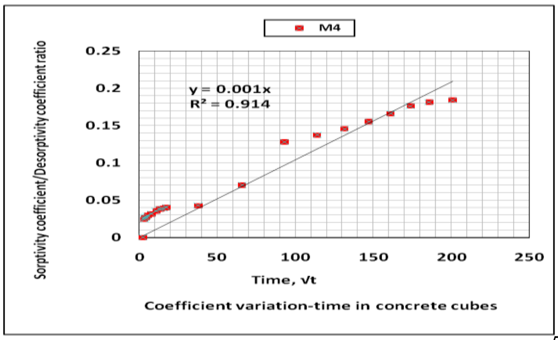

Fig.4 Sorptivity/de-sorptivity coefficient-√t

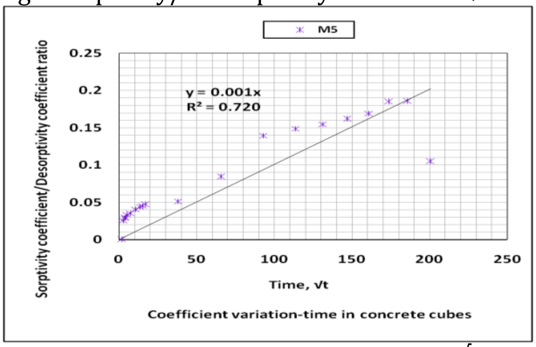

Fig.5 Sorptivity/de-sorptivity coefficient-√t

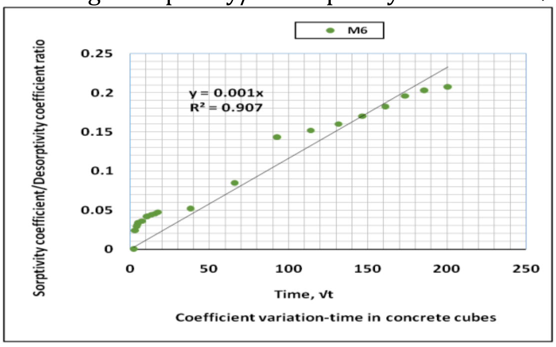

Fig.6 Sorptivity/de-sorptivity coefficient-√t

Its possible to interpret, compare, and analysed the variation of sorptivity/desorptivity coefficient ratio increase in the specified concrete mix design (M1-M6) at different time duration (6, 12, 18, 24, and 28 days) as representing in the Fig.7 respectively. The variation of sorptivity-desorptivity coefficient ratio was interpreted (increase) at different time intervals (12, 18, 24, and 28 days) as agaisnt time interval (6 day) as representing in the Fig.8 for in case of designed concrete mixtures type(M1-M6).

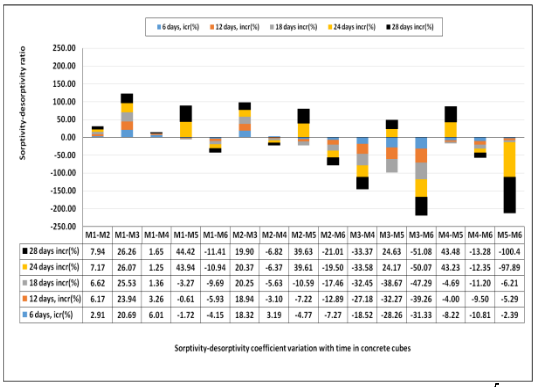

Fig.7 Sorptivity/de-sorptivity coefficient ratio-√t

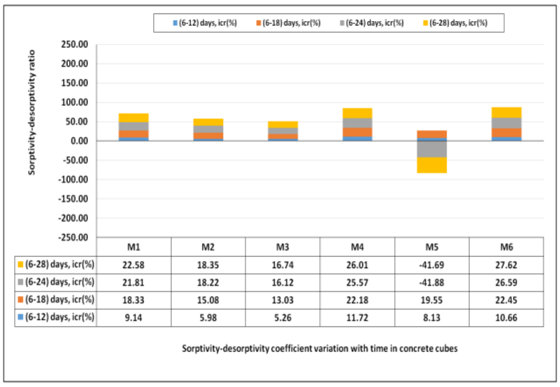

Fig.8 Sorptivity/de-sorptivity coefficient ratio-√t

Its also possible to compare, and analysed the variation of desorptivity/sorptivity coefficient increase/decrease in the specified concrete mix design (M1-M6) at different time duration (6, 12, 18, 24, and 28 days) as representing in the Fig.9-10 respectively. The variation of desorptivity-sorptivity coefficient was interpreted (increase/decrease) at different time intervals (6, 12, 18, 24, and 28 days) for in case of designed concrete mixtures type(M1-M6).

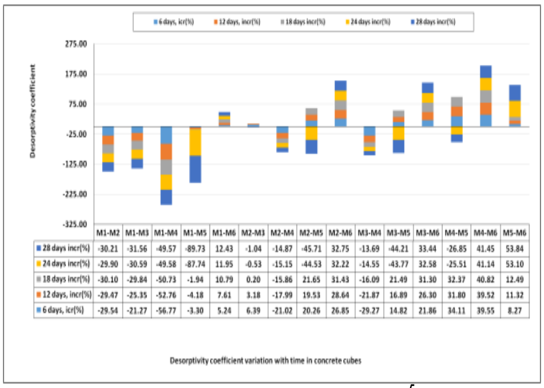

Fig.9 De-sorptivity coefficient-√t

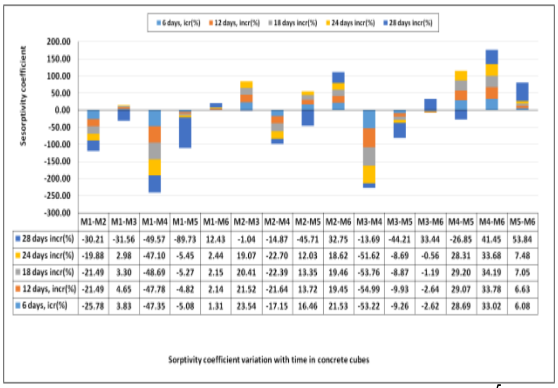

Fig.10 Sorptivity coefficient-√t

The variation of desorptivity/sorptivity coefficient (increase/decrease) was analysed in the specified concrete mix design (M1-M6) at different time duration (12, 18, 24, and 28 days) as when compared to time duration (6 day) as representing in the Fig.11-12 respectively.

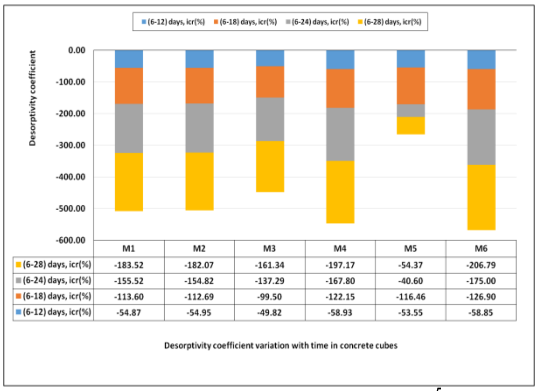

Fig.11 Desorptivity coefficient-√t

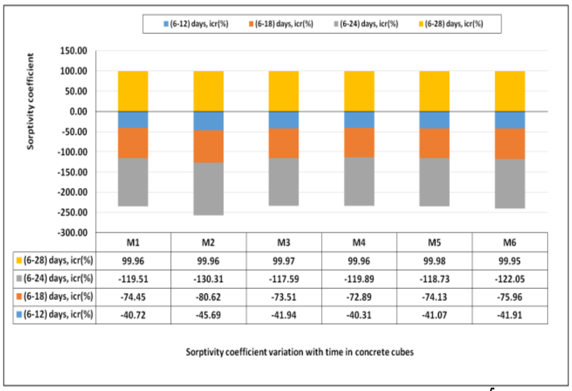

Fig.12 Sorptivity coefficient-√t

5.0 Conclusions

- As from this previous research work that, it's possible to establish power type of equation between de-sorptivity coefficient and square root of time in designed mixtures type. The de-sorptivity coefficient is predominantly increased at an initial stage as when compared to longer time duration for in case of all mixtures type. It's also confirmed from the results that, the de-sorptivity coefficient is significantly decreased for in case of higher compressive strength and varied slump. But in the case of lower compressive strength and constant slump, the variation of de-sorptivity coefficient with square root of time is slightly higher and goes on decreases with increased compressive strength for in case of designed mixtures type.

- It's possible to establish polynomial type of equation between sorptivity-de-sorptivity coefficient ratio and square root of time in designed mixtures type in the previous research work. The sorptivity-de-sorptivity coefficient ratio is predominantly decreased at an initial stage as when compared to longer time duration for in case of all mixtures type. It's also confirmed from the results that, the sorptivity-de-sorptivity coefficient ratio is significantly decreased for in case of higher compressive strength and varied slump. But in the case of lower compressive strength and constant slump, the variation of sorptivity-de-sorptivity coefficient ratio with square root of time is slightly higher and goes on decreases with increased compressive strength for in case of designed mixtures type.

- In the present research work, sorptivity-de-sorptivity coefficient ratio and square root of time is correlated by linear type of equation in the designed mixtures type. Sorptivity/de-sorptivity coefficient ratio-time is predominantly significant in establishing the values of either desorption or sorption coefficient at any time duration for in case of designed concrete mixtures type.

6.0 References

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