EFFECT OF PARAFFIN WAX AS SELF CURING AGENT IN RECYCLED AGGREGATE BASED SELF COMPACTING CONCRETES (SCC)

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Abstract- Curing of concrete involves maintaining satisfactory moisture content during the early ages in developing the desired properties. The present research analyses the influence of hydrophobic chemical as self-curing agent (Liquid Paraffin Wax Light and Heavy) in recycled aggregate based Self Compacting Concrete (SCC). The analysis comprises of understanding the effect of self-curing compound in terms of parameters like water retention, compressive strength, porosity and sorptivity. The compressive strength of self-cured specimens closely matched those of conventional water cured specimens. The optimum dosages of light and heavy Liquid paraffin wax were found to be 0.1% by weight of cement. It has been observed that the use of self-curing chemicals in SCC facilitated better hydration and helped in enhancement of strength and durability perspectives.

Keywords- Self Compacting Concrete, Recycled Aggregate, Liquid Paraffin Wax, Compressive Strength, Sorptivity, Porosity

I. INTRODUCTION

As the natural resources are approaching the edge of their extinction, the concept of sustainability is gaining its prominence. This resulted in the search for alternate ways. One such alternative is use of recycled concrete aggregate materials with efficient methods in practice [1 and 2]. Recycling apart from providing the source of material also eliminate the problem of wastage disposal. Recycled materials include fine and coarse aggregates. Recycled aggregate contains old ITZ which accounts for pores acting as water reservoir. Pre-soaked recycled aggregates act as internal water reservoir pockets during hydration [3 and 4]. By moisture gradient, the water will be drawn into concrete paste matrix from these water reservoirs during hydration process. The presence of this extra water mitigates self-desiccation and cracks due to autogenous shrinkage. The usage of recycled aggregates has its advantages of reduced plastic, autogenous and drying shrinkage, enhanced hydration in cement rich mixes, increased compressive strength at later ages and reduction in the permeability of concrete [5]. In case of recycled aggregates due to the two-way hygral action the movement of water from the aggregates to the concrete portion enables to maintain the fresh properties due to the availability of this free water [6, 7, 8 and 9].

Compaction and curing have a significant impact on the fresh and hardened properties of concrete. Introduction of a novel type concrete, Self Compacting Concrete being compactable by its own weight, eliminate the difficulties related to compaction. Since the development of Self Compacting Concrete from 1980's, there were many researchers who investigated the standard specifications for attaining proper mix proportion [10 and 11]. SCC by virtue of its important fresh properties, requires more amount of powder content and high range water reducing admixtures / viscosity modifying admixtures [12, 13 and14]. Along with proper compaction at fresh stage, proper curing is highly essential during hardening stages. Curing is the process of maintaining optimum moisture content and temperature for proper continuation of hydration. The maintenance of optimum moisture content poses its difficulty due to the evaporation of water to the atmosphere and increased heat of hydration. It can be maintained externally by conventional curing techniques (spraying, membrane-curing, ponding, immersing and steam curing methods). But, these conventional curing techniques not only increase the cost of construction, also imposes difficulty in places where there is a shortage of water and inaccessible parts of building. The suggestible alternative to overcome the issues is 'internal curing technique' [16, 17, 18 and 19]. Introducing self curing chemicals in concrete, the researchers determined the enhanced properties (i.e. strength, durability and micro structure) of concrete [20, 21, 22, 23 and 24]. These self-curing agents can be hydrophilic such as Polyethylene Glycol and hydrophobic chemicals such as Liquid Paraffin Wax [25, 26, 27, 28 and 29].
"The influence of Liquid Paraffin Wax (LPW) in recycled aggregate based SCC" is the topic of our interest. LPW (heavy and light) is added along with water during mixing. As soon as the surface of the water molecule evaporates, paraffin wax molecules occupies them and prevents further evaporation, there by acting as sealing agent.

II. RESEARCH SIGNIFICANCE

The move towards sustainability and the search for more economic and efficient ways has led to the present research of use of self-curing agents in

recycled aggregates based SCC. Use of recycled aggregates as replacement for natural aggregates eliminates the problems of disposal and turns out to be more economical. SCC eliminates the problems of compaction, particularly in the case of high strength concrete. The usage of internal curing chemicals like paraffin wax in recycled aggregate based SCC turns out to be highly beneficial in places where, there is a scarcity of water and external curing is difficult, in regions where there is material scarcity and curing of inaccessible parts of the building.

III. EXPERIMENTAL PROGRAM

The influence of self-curing agent in RASCC is analysed both in terms of fresh and hardened properties which give a perspective way of using LPW with recycled aggregates in SCC. The study consisted of casting and testing, two mixes (A and B). The parameters include grade of concrete, type of self curing agent (LPW Light, LPW Heavy), dosage of self curing agent (0, 0.1%, 0.5% and 1.0% by weight of cement), type of curing regime (water curing, no curing and self curing with LPW Light and LPW Heavy) and age of curing (7, 28, 56 and 90days).

3.1. Materials used:

a) Cement: Ordinary Portland Cement of 53 grade conforming to IS: 12269 [30] with specific gravity of 3.10 and specific surface area of 225m^2/kg was used.
b) Recycled fine aggregate (RFA): Recycled crushed fine aggregates conforming to zone-II of IS: 383 [31] was used in mix design of SCC and the physical properties are give as (bulk density 1.25 g/cm^3, fineness modulus 2.55, specific gravity 2.35 and water absorption 8.60 %)
c) Recycled coarse aggregate (RCA): Recycled coarse aggregate of maximum size 20mm conforming to IS: 383 [31] was obtained by crushing construction demolished waste used as coarse aggregate and the physical properties are given as (bulk density 1.42 g/cm^3, fineness modulus 7.15, specific gravity 2.54 and water absorption 5.68 %)
d) Water: Potable water was used in experimental work for both preparation of mix and curing of specimens.
e) Fly ash: The specific gravity of fly ash is 2.11 with its composition as silica-63.99%, silica-alumina ironoxide-92.7%, calcium oxide-1.71%, magnesium oxide-1.0%, sulfuric anhydride-0.73%, water soluble salts-0.04%. Loss of ignition of fly ash is 2.12% and pH is observed as 10.
f) Micro silica: Micro silica improves the strength of concrete at an optimum dosage. The specific gravity of micro silica is 2.23 and specific surface area is 20000m^2/kg. In mix A, 8% (by weight of cement) of micro silica was added to achieve high strength concrete.
g) Chemical admixtures: Poly-carboxylic Ether based high range water reducing admixture conforming to ASTM C 494 [32] was used as superplasticizer to improve the flow or workability.
h) Self curing agent: Hydrophobic Chemical (LPW Light and LPW Heavy) was used as self curing agent in this study. Light LPW is differentiated from Heavy LPW based on Viscosity. The physical properties of liquid paraffin wax (light and heavy) are presented in **Table 1**.

Properties	Light LPW	Heavy LPW
Specific Gravity at 25° C	0.820-0.860	0.850-0.880
Dynamic viscosity at 20° C: mPa.s	25-80	110-230
Appearance	Clear colour less liquid	Clear colour less liquid
Solubility in water	Insoluble	Insoluble
	Soluble in Benzene	Soluble in Benzene
Flash point (PMCC) : °C	Min. 150 °C	Min 200 °C

Table 1 Properties of LPW Light & LPW Heavy

3.2 Mix Proportions:

The mix proportions for two different strengths (A and B) of recycled aggregate based SCC are shown in **Table 2**. The trail mixes were arrived based on Nan Su method (Su et al., 2001) and various fresh property tests were performed as per EFNARC guidelines (33). If the performance was not satisfied, adjustments were made till all the properties were fulfilled.

Material	Quantity (kg/m^3)	
	Mix A	Mix B
Cement	500	430
Fine Aggregate	765	828
Coarse Aggregate	740	765
Water	190	194
Fly ash	110	180
Micro Silica	40	-
Super plasticizer	4.5	4.0

Table 2 Mix Proportions of Recycled Aggregate based Self Compacting Concrete

3.3 nomenclature of specimens:

The specimens were designated according to grade, type of Paraffin Wax and dosage. Liquid Paraffin Wax Light is designated as 'V', while 'P' is given for Liquid Paraffin Wax Heavy. 'N' represents no curing with 0% dosage and 'W' represents conventional water curing with 0% dosage respectively. The percentage of dosage is taken as 0, 0.1, 0.5 and 1.0 percent by weight of cement. For example RAV 0.1 represents Recycled aggregate SCC with higher grade containing curing compound of liquid paraffin wax Light (LPW Light) with a dosage of 0.1%. Similarly,

RBP 1.0 indicates specimen of medium grade RASCC self cured with LPW Heavy with 1.0% dosage by weight of cement.

3.4 casting and curing:

The inner side of cast iron mould was lubricated thoroughly using lubricating oil. The concrete was filled in the mould and the specimens were de-moulded after 24 hours of casting. The specimens were cured under specific regime up to the required age of curing. Three types of curing regimes were considered i.e. conventional water curing, no curing and self-curing with hydrophobic (LPW light and LPW heavy) chemicals. Under conventional water curing, the specimens were immersed in water after 24hrs of casting up to specified age of testing. The self cured and no cured specimens were kept at room temperature (27 ± 2°c) up to specified age of testing.

IV. RESULTS AND DISCUSSIONS

4.1. Fresh Properties of SCC:

Fresh property tests viz: H-flow, T_{50mm}, J-Ring, L-box, V-funnel and V_{5min} were conducted as per EFNARC specifications [34] to satisfy the requirements for passing ability, filling ability and resistance to segregation. The fresh properties of RA based SCC with hydrophobic chemicals were presented in **Table 3**. The values of H-flow indicated that there is a decrease in flowability of SCC with increase in dosage of LPW and as well as increase in viscosity of LPW.

Property	EFNARC Range	Designation	Plain SCC	LPW Light (V)			LPW Heavy (P)		
			0%	0.1%	0.5%	1.0%	0.1%	0.5%	1.0%
H- Flow (mm)	550-850	Mix A	700	690	685	675	665	655	645
		Mix B	750	745	730	705	690	675	670
T_{50cm} (sec)	2-5	Mix A	2.89	3.11	3.15	3.25	3.37	3.54	3.69
		Mix B	2.66	2.87	3.01	3.21	3.26	3.33	3.47
J-Ring (mm)	0-10	Mix A	6.0	7.0	7.5	8.0	8.0	9.0	10.0
		Mix B	5.0	6.0	6.0	7.0	7.0	8.0	9.0
L-Box (h_2/h_1)	0.8-1.0	Mix A	0.93	0.90	0.89	0.87	0.85	0.84	0.83
		Mix B	0.94	0.91	0.90	0.89	0.89	0.88	0.87
V-Funnel (Sec)	6-12	Mix A	10.05	10.10	10.80	10.90	11.25	11.46	11.75
		Mix B	9.15	9.29	9.67	10.50	10.60	11.44	11.82
V_{5min} (sec)	6-15	Mix A	10.50	11.00	11.80	12.50	13.00	13.77	14.00
		Mix B	10.04	10.50	10.90	11.30	11.42	11.92	12.45

Table 3 Fresh properties of RA based SCC with Hydrophobic Chemicals

4.2. Water Retention Test:

Loss of moisture due to evaporation through the surface of concrete can be measured through water retention test, by periodically evaluating the mass of the concrete cube of 150mm x 150mm x 150mm specimens. Taking the initial mass of each specimen as the reference, mass loss in SCC cubes were calculated at 3, 7, 14, 21, 28, 56 and 90 days and are plotted against the age of curing. Water retention of the cube has been analyzed in terms of Normalized Evaporation Ratio.

Fig 1 shows the average mass loss in RA based SCC mixes A and B self cured with LPW Light (V). It was observed from the graphs that there was rapid mass loss in the initial 7 days of curing and gradual decrease in mass loss was observed as age of curing proceeds. It was also noted from the mass loss values of 2 mixes (A and B) that the mass loss is relatively high for no cured specimens compared to self cured specimens. The maximum water retention with minimum mass loss was observed with 0.1% of LPW Light in all the mixes (A and B). **Fig 2** presents the average mass loss in RASCC specimens of mixes of A and B, self cured with LPW Heavy (P). The similar results were obtained as LPW Light. The optimum dosage of LPW Heavy is 0.1% of mass of cement for all the three mixes (A and B).

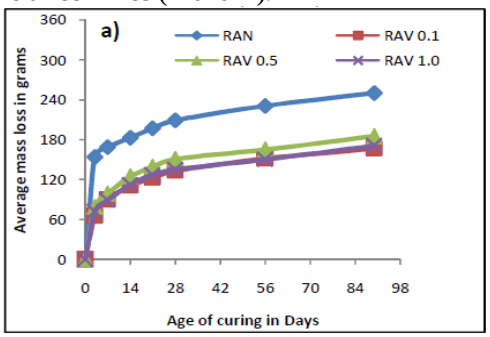


Fig 1 (a): Average mass lossVs Age of curing in Mix A RASCC with (LPW Light)

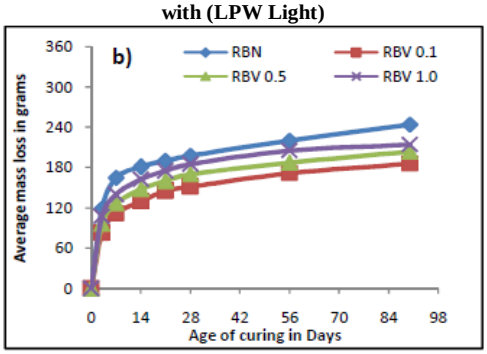


Fig 1 (b): Average mass lossVs Age of curing in Mix BRASCC with (LPW Light)

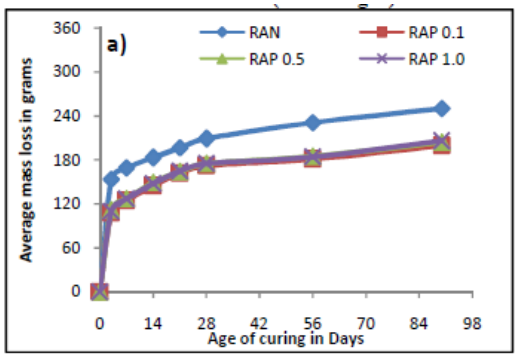


Fig 2 (a) Average mass loss Vs Age of curing in Mix A RASCC with LPW Heavy

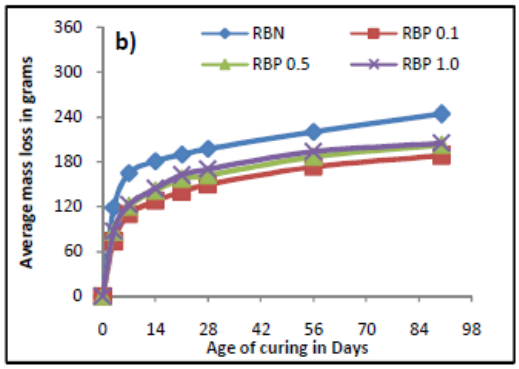


Fig 2 (b) Average mass loss Vs Age of curing in Mix B RASCC with LPW Heavy

4.3 compression strength test:

Compressive strength test was carried out on hardened concrete cubes of size 150mm × 150mm × 150mm as per IS:516 (BIS, 1999) using 2000kN Compression Testing machine. Three cubes in each batch were tested after certain curing period of 7, 28, 56 and 90 days. Compression strength can be calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area. Average of three values was taken as the representative strength of that specific batch. The compressive strength results of Recycled aggregate based SCC self cured with LPW Light and Heavy are presented in **Tables 4 and 5**. The results indicated that compressive strength of conventional water cured specimens was maximum compared to no cured and self cured specimens. However, the addition of self curing chemicals (LPW Light and LPW Heavy) at optimum dosages (0.1%) obtained almost equal values as that of conventional water cured specimens at 28days. While the no cured specimens attained lower strength for all the mixes compared to self cured and water cured specimens. From tables it can be observed that the values of compressive strength ratios were moderately high for self cured specimens than no cured specimens. The decrease in compressive is 4% and 5% in Mix A-RASCC with optimum dosage (0.1%) of LPW Light and LPW Heavy. For mixes B, the loss in compressive strength was 8% and 10% with 0.1% LPW Light and 7% and 6% with 0.1% LPW Heavy respectively. The values indicated that both self curing agents with optimum dosage of 0.1% achieved on par strengths as that of conventional water cured specimens.

Specimen	7 Days	28 Days	56 Days	90 Days
RAW	44.51	59.43	63.02	64.05
RAN	36.03	53.08	53.02	54.08
RAV 0.1	**41.57**	**57.02**	**60.57**	**61.52**
RAV 0.5	39.05	55.05	55.08	56.03
RAV 1.0	39.02	54.52	55.04	56.52
RAP 0.1	**40.57**	**56.55**	**58.51**	**60.01**
RAP 0.5	35.53	53.57	54.57	55.59
RAP 1.0	39.02	56.05	55.07	57.52

Table 4 Average compressive strength (MPa) of Mix A-RASCC

Specimen	7 Days	28 Days	56 Days	90 Days
RBW	41.56	51.57	55.05	57.54
RBN	33.58	42.54	46.58	48.57
RBV 0.1	**38.02**	**50.57**	**53.53**	**56.08**
RBV 0.5	37.59	45.54	49.56	53.03
RBV 1.0	34.54	44.04	47.07	52.03
RBP 0.1	**38.55**	**50.56**	**52.58**	**54.57**
RBP 0.5	34.54	48.57	50.59	51.58
RBP 1.0	36.07	49.59	51.59	52.54

Table 5 Average compressive strength (MPa) of Mix B-RASCC

4.4. Open porosity test:

In determining the resistance to degradation of concrete and its role in protecting the embedded steel, the presence of capillary pores plays a vital role. The presence of old and new ITZ in recycled aggregates makes concrete vulnerable to durability, however proper curing and continuous supply of water for hydration makes the developed ITZ stronger and denser. The effect of self curing on durability of RASCC can be studied by open porosity test. As per ASTM C642 [34] open porosity is determined and by using the following equation:

$$p = \frac{(W_{ssd} - W_d)}{(W_{ssd} - W_w)} \times 100\% \qquad \text{Eq. (1)}$$

where p is the porosity (100%), W_{ssd} = specimen weight in saturated surface-dry (SSD) condition; W_d = specimen dry weight; W_w = weight of the saturated submerged specimen.

Table 6 presents the porosity values of RASCC mixes A and B cured with conventional water curing, no curing and self curing. The values of porosity indicated that increase in grade of concrete resulted in decrease porosity. The conventional water cured specimens achieved minimum porosity compared to no cured and self cured specimens; it is attributed to better formation of C-S-H gel even at ITZ zone. While in case of no cured specimens maximum porosity was obtained which is due to evaporation of moisture. The self cured specimens with optimum dosage (0.1%) of LPW light and Heavy in all the mixes achieved low porosity than no cured specimens. It clearly indicates the role of self curing agents in Recycled aggregate based SCC in improving the durability of concrete.

Sample	Recycled Aggregate – SCC: Porosity (%)	
	Mix A	Mix B
W	13.23	15.15
N	17.44	20.17
V 0.1	15.97	18.25
V 0.5	17.29	20.53
V 1.0	16.28	20.17
P 0.1	16.05	19.06
P 0.5	18.56	22.09
P 1.0	17.11	22.57

Table 6 Porosity values of RASCC

4.5. Sorptivity test:

The sorptivity test is an easily measured material property which characterizes the tendency of a porous material to absorb and transmit water by capillary. The rate of absorption (sorptivity) of water is determined by obtaining the increase in mass of a specimen due to absorption of water as a function of time when only one surface of the specimen is exposed to water. Sorptivity is determined according to ASTM C1585 [35]. The schematic diagram of sorptivity test is shown in **Fig 4**. The sorptivity was determined by using the Eq. (2).

$$\frac{i}{\sqrt{t}} = S \qquad \text{Eq. (2)}$$

i = Water absorption coefficient
Δw = Amount of water absorbed in (g)
A = C/section of specimen in contact with water (mm^2)
d = Density of water (10^{-3} g/mm^3)
t = Time (min)
S = Sorptivity coefficient of the specimen ($mm/min^{0.5}$)

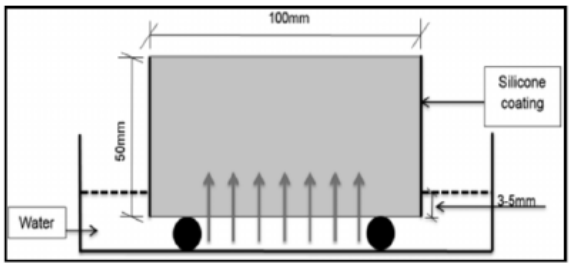


Fig 4 Experimental setup of sorptivity test

Figs 5 and 6 depict the plots of cumulative water absorption against square root of time for recycled aggregate based SCC mixes A and B subjected to no curing, water curing and self-curing with hydrophobic chemicals (LPW Light and LPW Heavy). The water absorption was observed to be maximum in case of medium strength concretes (Mix B) compared to high strength concretes (Mix A). This is true in case of all the curing regimes i.e. conventional water curing, no curing and self curing. It can also be noted from the figures that addition of optimum dosages (0.1%) of LPW (Light and Heavy) in SCC resulted in a decrease in the cumulative water absorption. In case of Mix A - RASCC specimens self cured with optimum dosages (0.1%), there is a decrease in sorptivity of 30.4% with LPW Light and 25.2% with LPW Heavy compared to no cured specimens. In Mix B, the addition of optimum dosage (0.1%) self curing compounds decreased the sorptivity values by 32.5% with LPW Light and 32.5% with LPW Heavy compared to no cured specimens.

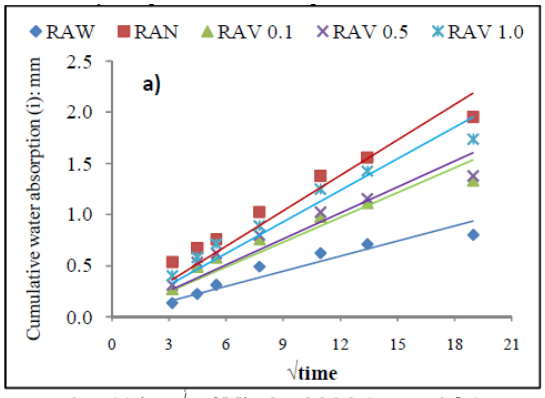


Fig 5 (a) i vs √t of Mix A RASCC (LPW Light)

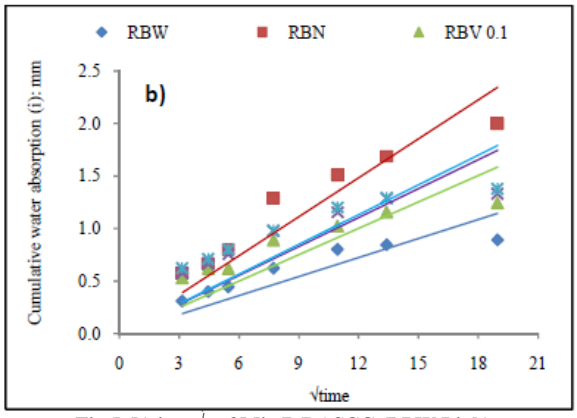


Fig 5 (b) i vs √t of Mix B RASCC (LPW Ligh)

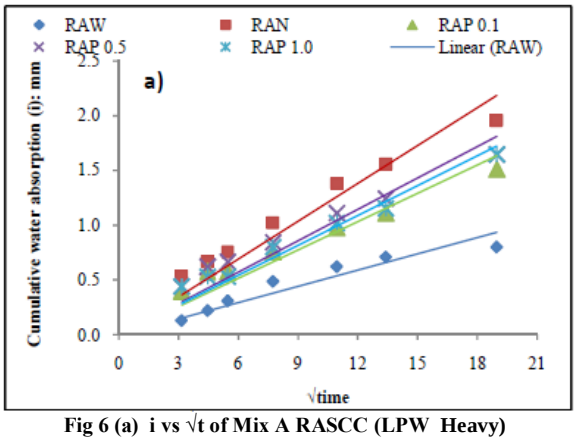


Fig 6 (a) i vs √t of Mix A RASCC (LPW Heavy)

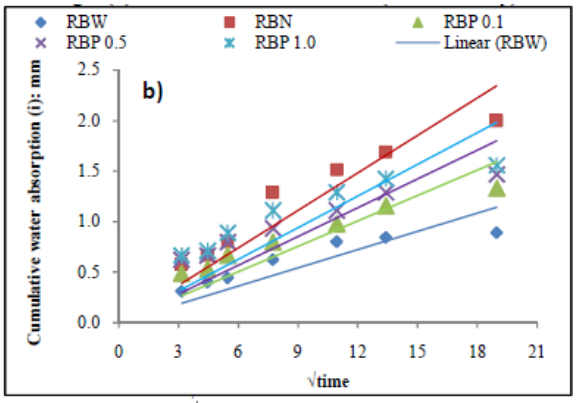


Fig 6 (b) i vs √t of Mix A RASCC (LPW Heavy)

CONCLUSIONS

The study on influence of hydrophobic chemicals in RASCC concluded the following:

1) Liquid Paraffin Wax Light & Heavy can be used effectively to cure recycled aggregate based self compacting concretes. The properties were superior to those of no cured mixes and were on par with water cured specimens.
2) From water retention test, it was noted that the optimum dosage of hydrophobic chemicals (LPW Light and LPW Heavy) was 0.1%. With this dosage, the compressive strength values attained was close to those of water cured Recycled Aggregate based specimens.
3) There is a decrease in porosity with increase in grade of concrete. However, the porosity was decreased with use of self curing chemicals in recycled aggregate based SCC specimens compared to no cured specimens.
4) With optimum dosages of hydrophobic chemical (0.1% LPW Light and 0.1% LPW Heavy), the sorptivity was the lowest compared to other dosages (0.5% and 1.0%). However, high strength SCC mixes (Mix A) exhibited the lowest sorptivity.

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