Development of Hydrophobic and Superhydrophobic Coatings for Concrete Surfaces

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Abstract: Concrete is important materials in civil engineering constructions. It is being used in every part of the construction field. Durability of this important material is still a matter of great concern among civil engineers all over the world. Durability of concrete is affected mostly by intrusion of aggressive species from the immediate environment. Therefore it is an absolute necessary to block the pores, voids, capillaries, interconnecting pores and other surface defects of concrete surfaces. This can be achieved by proper coatings, particularly by superhydrophobic coatings (lotus leaf coating). In this study superhydrophobicity is achieved by using Silane, Siloxane, Silicone as binder with Nanosilica, Silica fume, Micro silica, TiO_2, etc. Nearly thirty different coatings were formulated and applied on concrete surfaces to study the hydrophobicity and superhydrophobicity. The best coatings were selected based on contact angles and roll on of water droplets and they never stick to the concrete surface. These coated surfaces are photo and video graphed and well established and discussed in detail.

Keywords: Hydrophobic, Superhydrophobic, Durability, Coatings, Nanosilica, Pores.

I. INTRODUCTION

Concrete is the required material in the world. Concrete plays an important role in construction field. There occurs penetration of water and other aggressive materials in to the concrete due to its porous nature which in turn causes expansion, cracking, scaling and crumbling in concrete [6]. This paper mainly describes to reduce such type of problems in concrete and also to increase the durability of concrete. There were several methods to make the concrete as the repellent one, in which superhydrophobic coating is the best. Both superhydrophobic and hydrophobic coatings were developed in this work. These coatings were applied on concrete surface by brush [10].

Various combinations of hydrophobic and superhydrophobic coatings were developed using the materials such as silane, siloxane, etc., with and without additives such as nanosilica, silica fume, TiO_2, ZnO [10]. Applying of such coatings, make the concrete as rough surface (due to formation of pillar and groove like structures on concrete surface [9]). This rough surface [2] is the main factor which makes the water droplets to flow out of the surface, thereby avoiding the penetration of water into the concrete which in turn makes it more durable.

In this paper, superhydrophobic and hydrophobic surfaces were created on different specimens such as square tiles, roof tiles and hollow core disc. And these coated specimens were subjected to different tests such as screening (by flowing of water on concrete surface), water droplet test, droplet absorption test, water absorption (core) test, contact angle measurement. By these methods the best superhydrophobic coatings were selected in this work.

II. ASPECTS OF SUPERHYDROPHOBICITY

The hydrophobicity of a material can be defined as its ability to repel water and it depends on the chemical composition of the concrete surface and the surface geometry. The contact angle between a drop of water and the surface is generally used as an indicator of hydrophobicity or wettability. When the contact angle is more than 90˚, then it indicates hydrophobicity, while if the contact angle is less than 30˚, then it denotes hydrophilicity, which is the tendency of a surface become wet or to absorb water [5]. The most important role of hydrophobic agents is the reduction of concrete water absorption. The minimum penetration 2mm is required. The fig.1 shows hydrophobic and superhydrophobic nature of water droplets and the conditions required.

Concrete is an example of a hydrophilic mesoporous material which absorbs water. The Superhydrophobicity corresponds to contact angle above 150˚ and surfaces with intermediate properties (with high contact angles between

120˚ and 150˚) above this typical values for hydrophobic materials are called "over hydrophobic" [10].

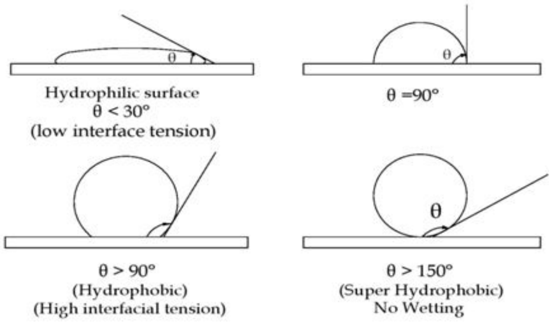

Fig. 1 Hydrophilic, Hydrophobic and superhydrophobic

The water contact angle with a solid surface can be measured by goniometer or tensiometer. Superhydrophobic surfaces with roughness patterns imposed over large roughness patterns as shown in fig.1 have generated interest due to their potential in industrial applications (mainly for self cleaning). These surfaces mimic the "***Lotus Leaf***" surface, which is well known for its superhydrophobicity and self cleaning properties. Mimicking living nature for engineering applications is called "biomimetics" [7] and this biomimetic approach can be used to synthesize hydrophobic and superhydrophobic concrete.

III. EXPERIMENTAL INVESTIGATION

A. Materials

In order to investigate the effect of superhydrophobic coating, different type of specimens were cast and different types of combination of chemicals were selected for the purpose of coating on the specimen surface. The selected coatings include the type of water-repellent materials (silane, silicone emulsion, siloxane, etc,).

1) Preparation of water droplet test/droplet absorption/water contact angle specimens

For water droplet test, square tile of size 100x100x10mm were cast with cement mortar ratio of 1:3 and water cement ratio of 0.4. Twenty eight numbers of square tiles were cast, cured and coated with different combinations. Droplet absorption test was developed in CSIR-CECRI.

Roof tiles of size 225x225x15mm were selected and coated for water droplet test.

2) Preparation of specimen for water absorption test (core test)

Hollow core specimen of size 83x50mm with inner core size 40x25mm was cast with cement mortar ratio of 1:3 and water cement ratio of 0.4. Specimen was coated with different combination of chemicals. Water absorption (core) test was also developed in CSIR-CECRI.

3) Preparation of coating combinations

Various combinations were selected for superhydrophobic coatings by using the materials such as Silane, Siloxane, Latex and Silicone emulsion with and without additives such as Nanosilica, silica fume, TiO_2, Al_2O_3, ZnO. Twenty eight numbers of coating combinations were developed by using the above mentioned chemicals and additives.

B. Methods

Different methods of test were conducted for coated specimens. And through which the results were obtained.

1) Chemical combinations

1. Silane
2. Silane + Nanosilica
3. Silane + Nanosilica + TiO_2
4. Silane + Nanosilica + Al_2O_3
5. Silane + Nanosilica + TiO_2 + Al_2O_3
6. Siloxane
7. Siloxane + Nanosilica
8. Siloxane + Nanosilica + TiO_2
9. Siloxane + Nanosilica + Al_2O_3
10. Siloxane + Nanosilica + TiO_2 + Al_2O_3
11. Silicone emulsion
12. Silicone emulsion + Nanosilica
13. Silicone emulsion + Nanosilica + TiO_2
14. Silicone emulsion + Nanosilica + Al_2O_3
15. Silicone emulsion + Nanosilica + TiO_2 + Al_2O_3
16. Silicone emulsion + Silane
17. Silicone emulsion + Silane + Nanosilica
18. Silicone emulsion + Silane + Nanosilica + TiO_2
19. Silicone emulsion + Silane + Nanosilica + Al_2O_3
20. Silicone emulsion + Silane + Nanosilica + TiO_2 + Al_2O_3
21. Silicone emulsion + Silica fume
22. Silicone emulsion + Silica fume + TiO_2
23. Silicone emulsion + Silica fume + TiO_2 + ZnO
24. Latex
25. Latex + Nanosilica
26. Latex + Nanosilica + TiO_2
27. Latex + Nanosilica + Al_2O_3
28. Latex + Nanosilica + TiO_2 + Al_2O_3

2) *Water droplet test*

Fig. 2 Water droplet on coated surface of square tiles

The Coatings were applied on the surface of square specimens of size 100x100x10mm. After allowed it to dry, the water droplets were poured on the surface of the coated specimens as shown in fig 2. The coated specimens were visually observed for movement of water droplet on concrete surface, and the best coatings were screened through this test. Same test was carried out on the roof tiles with best coatings as shown in fig 3.

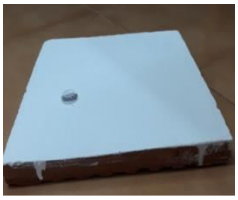

Fig. 3 Water Droplet on coated surface of roof tile

3) *Droplet Absorption test*

The best coatings from the water droplet test were selected for this test. The water droplets were poured on surface of the coated specimens and covered with closed bottles to avoid the evaporation of water droplets. The specimens were visually observed for 24 hours and the size of the water droplets was examined.

4) *Water Absorption (core) test*

Fig. 4 Measuring weight of dry and filed specimen

Fig. 5 Filled hollow core specimen

Cylindrical disc specimens of size 83x50mm with hollow core at the center of size 40x25mm were selected and coated with best coatings. Dry weight of the coated specimens was noted initially and then the hollow core region was filled with water as shown in fig 4 and fig 5. The decrease in water level in the hollow core due to water absorption was noticed at regular intervals by refilling the hollow core for every1 hour up to 24 hours.

5) *Contact Angle Measurement*

The water contact angles [5] of the specimens were determined by using Optical contact angle OCA 35 Goniometer as shown in fig 7. The water droplet was poured on the concrete surface of the coated specimen by the instrument as shown in the fig 6. The volume of droplet is 8µl.

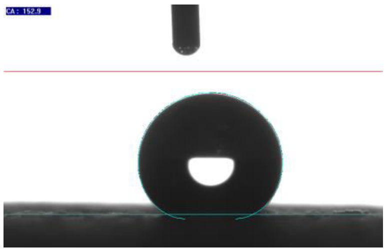

Fig. 6 Instrumental view of water droplet for contact angle measurement

IV. RESULT AND DISCUSSION

A. *Water Droplet test*

From this test, the best coatings were selected based on the movement of water droplet on the coated surface. Thirteen combinations were selected as best. The selected combinations are shown in the table 1.

TABLE 1

RESULT OF WATER DROPLET TEST

S.No	Actual Description Number	Combinations
1	2	Silane + Nanosilica
2	4	Silane + Nanosilica + Al_2O_3
3	11	Silicone emulsion
4	12	Silicone emulsion + Nanosilica
5	13	Silicone emulsion + Nanosilica + TiO_2
6	14	Silicone emulsion + Nanosilica + Al_2O_3
7	15	Silicone emulsion + Nanosilica + TiO_2 + Al_2O_3
8	17	Silicone emulsion + Silane + Nanosilica
9	18	Silicone emulsion + Silane + Nanosilica + TiO_2
10	19	Silicone emulsion + Silane + Nanosilica + Al_2O_3
11	20	Silicone emulsion + Silane + Nanosilica + TiO_2 + Al_2O_3
12	21	Silicone emulsion + Silica fume
13	23	Silicone emulsion + Silica fume + TiO_2 + ZnO

B. *Droplet Absorption test*

The best coatings from water droplet test were examined for water absorption. As a result 7 best coatings were selected are shown in table 2.

TABLE 2

RESULT OF DROPLET ABSORPTION TEST

S.No	Actual Description Number	Combinations
1	17	Silicone emulsion + Silane + Nanosilica
2	20	Silicone emulsion + Silane + Nanosilica + TiO_2 + Al_2O_3
3	14	Silicone emulsion + Nanosilica + Al_2O_3
4	23	Silicone emulsion + Silica fume + TiO_2 + ZnO
5	18	Silicone emulsion + Silane + Nanosilica + TiO_2
6	19	Silicone emulsion + Silane + Nanosilica + Al_2O_3
7	21	Silicone emulsion + Silica fume

C. *Water Absorption (core) test*

The treatment with superhydrophobic coatings indicated lower water absorption in related to untreated sample. This test was carried on the best coatings with time duration of half hour up to 8hours was noted. And 24 hours absorption reading was noted. Results are shown in the table 3.

TABLE 3

Time (hrs)	Quantity of water added in ml						
	control	1	2	3	4	5	6
Initial	42	37	35	34	35	45	40
1	11	-	-	1	2	-	-
2	2	-	1	2	5	-	1
3	4	-	1	-	6	-	2
4	3	-	-	3	7	-	4
5	1	-	-	-	7	-	2
6	-	-	-	-	-	-	-
7	1	1	-	2	8	1	6
8	2	1	2	3	5	1	-
24	21	3	3	14	24	3	30

RESULTS OF WATER ABSORPTION TEST

D. *Contact angle test*

Contact angle of the selected best specimen were determined by using Goniometer. The results are shown in the table 4.

TABLE 4

RESULTS OF CONTACT ANGLE MEASUREMENT

Specimen No	Contact angle			Final result
	Trial 1	Trial 2	Trial 3	
2	160.3	161.2	154.1	161.2
12	162.9	152.5	155.8	162.9
14	162.0	155.1	156.1	162.0
17	159.8	164.5	161.2	164.5
18	157.7	154.7	154.3	157.7
19	152.9	154.7	157.7	157.7
20	160.2	159.8	162.9	162.9
21	164.8	161.7	156.7	164.8
23	159.1	157.0	157.5	159.1

TABLE 5

REMARKS OF COATINGS

Specimen no	Combinations	Remarks
1	Silane	Hydrophobic
2	Silane + Nanosilica	Superhydrophobic
3	Silane + Nanosilica + TiO_2	Hydrophobic
4	Silane + Nanosilica + Al_2O_3	Hydrophobic
5	Silane + Nanosilica + TiO_2 + Al_2O_3	Hydrophobic
6	Siloxane	Hydrophobic
7	Siloxane + Nanosilica	Hydrophobic
8	Siloxane + Nanosilica + TiO_2	Hydrophobic
9	Siloxane + Nanosilica + Al_2O_3	Hydrophobic
10	Siloxane + Nanosilica + TiO_2 + Al_2O_3	Hydrophobic
11	Silicone emulsion	Hydrophobic
12	Silicone emulsion + Nanosilica	Superhydrophobic
13	Silicone emulsion + Nanosilica + TiO_2	Hydrophobic
14	Silicone emulsion + Nanosilica + Al_2O_3	Superhydrophobic
15	Silicone emulsion + Nanosilica + TiO_2 + Al_2O_3	Hydrophobic
16	Silicone emulsion + Silane	Hydrophobic
17	Silicone emulsion + Silane + Nanosilica	Superhydrophobic
18	Silicone emulsion + Silane + Nanosilica + TiO_2	Superhydrophobic
19	Silicone emulsion + Silane + Nanosilica + Al_2O_3	Superhydrophobic
20	Silicone emulsion + Silane + Nanosilica + TiO_2 + Al_2O_3	Superhydrophobic
21	Silicone emulsion + Silica fume	Superhydrophobic
22	Silicone emulsion + Silica fume + TiO_2	Hydrophobic
23	Silicone emulsion + Silica fume + TiO_2 + zno	Superhydrophobic
24	Latex	Hydrophilic
25	Latex + Nanosilica	Hydrophilic
26	Latex + Nanosilica + TiO_2	Hydrophilic
27	Latex + Nanosilica + Al_2O_3	Hydrophilic
28	Latex + Nanosilica + TiO_2 + Al_2O_3	Hydrophilic

V. CONCLUSION

Seven coatings (14, 17, 18, 19, 20, 21, and 23) were selected as the best coatings. The combination of silicone emulsion with silane with additives such as Nanosilica, TiO_2, Silica fume and Al_2O_3 showed good results as superhydrophobic nature. The test results are shown in fig 5.

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