Durability Improvement of Concrete Structures by Wash-away of Chloride

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***ABSTRACT*:** Concrete structures are subjected to salt carried by air from sea side. This salt accumulates on concrete surfaces causing decreasing of concrete durability and life. At the same time rain washes away this accumulated salt. This processes changes the concentration distribution and the amount of accumulated salt on concrete surfaces. Water can be used in maintenance process to wash away this accumulated salt. Because of the importance of this desorption mechanism in increasing concrete durability and life, a detailed experimental work to understand this phenomenon must be conducted. Many factors are affecting this mechanism like concrete surface finish, attached salt conditions, and water flow conditions.

Rough and smooth concrete surface finish were examined to understand the surface finish effect on desorption rate. Two salt contact conditions were tested experimentally; dry and wet. In case of dry contact condition, concrete surface has a moisture percentage around 4.3%, and concrete wall is dry. It was found that salt is washed away mainly due to mechanical movement. Diffusion process occurs in this case, but removed salt amount by diffusion is very little compared to the one by mechanical movement and therefore it can be neglected. In case of wet contact condition, diffusion process is the dominant mechanism, and mechanical movement can be neglected. A comparison between washed away salt amounts for these two mechanisms is presented in this paper. The effect of water flow condition is studied by examining two water flow input methods. In the first method, salt is washed away by water flow. In the second method, salt is washed away by water impact. A comparison between all mentioned conditions and mechanisms is presented in this work to understand the effect of each factor to increase concrete durability and life against chloride attack.

KEYWORDS: salt attack, concrete durability, wash-away, thin water flow, water impact.

1. INTRODUCTION

Concrete structures in urban areas are subjected to many environmental actions. Air blows from sea side and carries very fine salt particles. These salt particles accumulate on surfaces like concrete structures. The accumulation process of these particles is called adsorption. Adsorption process can take days and weeks. Some of these accumulated salt particles can be washed away by rain (water flow). The washed away process of salt particles is called desorption. Desorption is a fast process as it takes seconds or few minutes (see El-Desouky, I.). The remaining portion of these accumulated salt particles is penetrating inside concrete causing rusting of reinforcement steel bars. This process is called absorption. Absorption is a very slow process as it takes years. The net result of these three environmental processes is affecting concrete structures durability (see El-Desouky, I.). As desorption process is the fastest process among the mentioned ones, it can be considered as the most important process among them. By studying this process, and knowing factors affecting it; concrete durability can be increased.

Many factors are affecting desorption process. Surface finish is an important key in this process. Smooth and rough concrete surfaces were tested to study the effect of surface finish. Another parameter which affects this process is the moisture content in the concrete surface structures. Dry and wet conditions were examined. Water impact angle and water flow method are key factors and were studied. Experimental works were conducted to study all these factors and to know the effect of each parameter.

2. EXPERIMENTAL SETUP

Water removes accumulated salt particles from concrete surfaces by two ways depending on how water touches the concrete surface. The first way is water flow. This happens when water is moving on concrete surface. It is the case for parts of concrete structures which are not subjected to direct rain impact, but water flows on them. The second way is water impact. This is the case for concrete structure parts which are subjected to direct rain drops. In reality, salt particles are removed by a combination of these two ways. In this section; experimental setup for each case will be described.

2.1 Thin Water Film Flow Experimental Setup

2.1.1 Conditions of Testing Room

The test should be conducted in calm room conditions. The air movement in testing room should be limited so that the water flow on the surface of a concrete plate specimen is not influenced. The temperature and the relative humidity of testing room are not specified.

2.1.2 Specimen

Fig. 1 shows dimensions of the used concrete specimen in case of film water flow. The used concrete specimen is 600x300x30mm. Steel guides are used to prevent water to flow from concrete sides. The used test is section is 450x200x30mm.

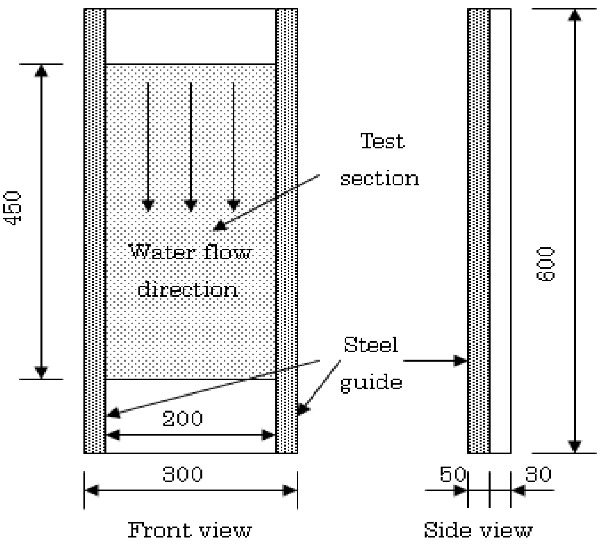

Fig. 1 Concrete plate specimen "film flow" (mm)

2.1.3 Measurement of Surface Moisture Content

Moisture meter is used to measure the surface moisture contents at several points. When the surface moisture contents was larger than 4.3% a drier was used to dry the surface till the surface moisture content reaches this value.

2.1.4 Salt Particles

Accumulated salt particles size on concrete structures is 0.01mm (see Sadatsuki, Y.). The used salt particles in this experiment must have the same size. To achieve this condition; NaCl grains were crashed using a mortar and pestle both made of steel. Crashed salt particles diameter must be measured using microscope. Crashing process should be repeated till the aimed salt particles size is achieved.

2.1.5 Attaching Salt Particles on Concrete Plate Specimen

Test section size of the concrete specimen used in this experiment was measured first (Fig. 1) to get the amount of accumulated salt in mg. It was assumed that the amount of accumulated salt on this specimen is the same as the salt amount on a concrete structure exposed to wind for 3 successive days and located 10m away from the seashore. This assumption is used as it normally rains every 3 days in Japan (see Kagi, I.). The amount of accumulated salt under these conditions can be calculated. It was found that this amount equals to 0.15mg/cm^2/day. By using this value (see Kagi, I.), the used salt amount was 405mg. After that this amount was sprinkled uniformly onto the surface of the concrete specimen which is placed horizontally. Unattached particles were removed by inclining the concrete plate specimen. These unattached particles were collected and sprinkled again on the concrete surface till all particles were completely attached to the concrete surface. In case of wet contact, the concrete plate specimen was kept in a constant temperature and humidity (20^{o}C, 80%RH) for 12 hours (see Sadatsuki, Y.).

2.1.6 Setting of Concrete Plate Specimen

Fig. 2 shows the setting of the used concrete plate specimen. Water hits the vertical wall from the top perpendicularly.

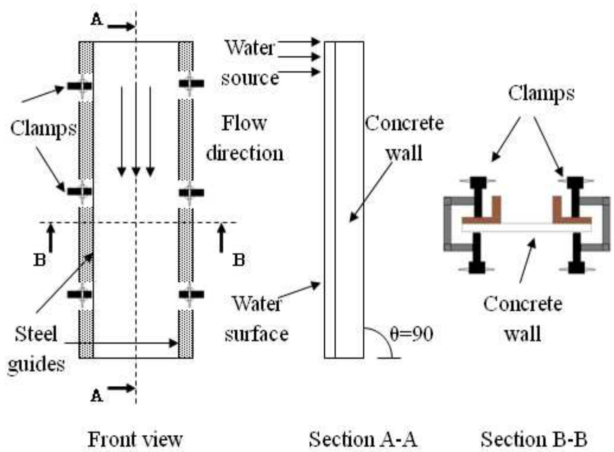

Fig. 2 Setting of concrete plate specimen “film flow”

2.1.7 Setting of Water

Fig. 3 shows the outlet flow for water in case of film water flow. Five holes of one mm diameter each are used. Average rain drop size is 1 mm before it hits the ground, and that is the reason for using this diameter size (see Sadatsuki, Y.). Water was kept at 20^{o}C. The used water flow rate is 3mL/s. This is the value in case of heavy rain.

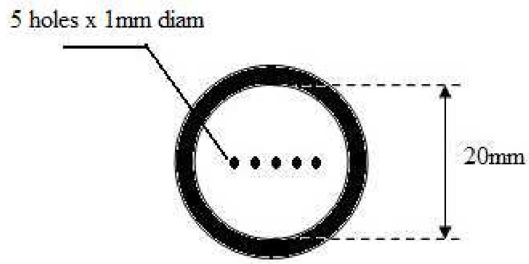

Fig. 3 Outlet for water flow

2.2 Water Drop Impact Experimental Setup

Testing room conditions, salt particles size, and specimen surface moisture contents are the same like film flow case.

2.2.1 Specimen

Fig. 4 shows dimensions of the used concrete specimen in case of impact flow. The used concrete specimen is 300x300x30mm.

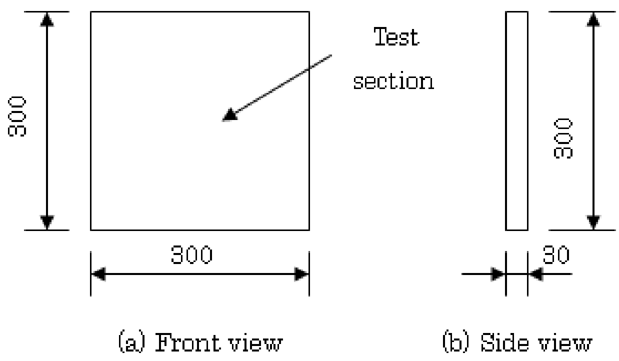

Fig. 4 Concrete plate specimen "impact flow" (mm)

2.2.2 Setting of Concrete Plate Specimen

Fig. 5 shows the setting of the used concrete plate specimen.

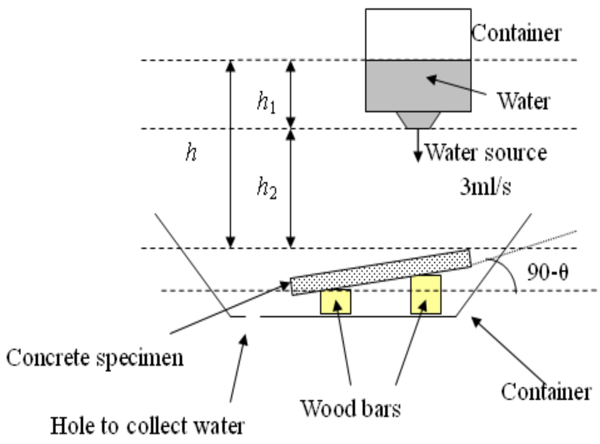

Fig. 5 Setting of concrete plate specimen "impact flow"

Values of h, h_1, and h_2 were determined so that water drops speed reaches the rain drop ultimate velocity "equals 4.8m/s" just before hitting the concrete wall (see Sadatsuki, Y.). These values can be obtained by:

i) $v^2 = v_o^2 + 2gh$ where v_o is the water free surface velocity (assumed to be zero), v is the ultimate rain drop velocity before hitting the concrete wall (equals 4.8 m/s), g is the gravitational acceleration (equals 9.8 m/s), h is the distance between the water free surface and the concrete specimen. From this equation h can be determined (h=1176mm).

ii) h_1 is adjusted so that the water flow rate is 3mL/s.

iii) h_2 can be calculated by: $h_2 = h - h_1$

2.2.3 Setting of Water

Fig. 6 shows the outlet water flow in case of impact drops. Water was kept at 20^{o}C. The used water flow rate is 3mL/s. This is the value in case of heavy rain.

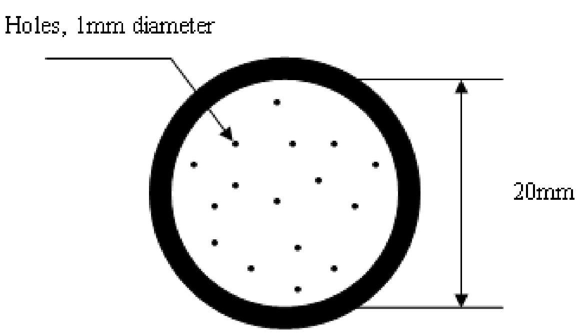

Fig. 6 Outlet of water flow

3. EXPERIMENTAL RESULTS

Two experiments at least were conducted for each set of the following conditions to study the effect of each parameter:

Table 1 Experimental parameters

Water input condition	Salt condition	Surface condition
Thin water flow	dry	smooth
		rough
	wet	smooth
		rough
Water drop impact	dry	smooth
		rough
	wet	smooth
		rough

Fig. 7 shows the amount of washed away salt from concrete surface for smooth and rough specimens under dry and wet conditions for film flow.

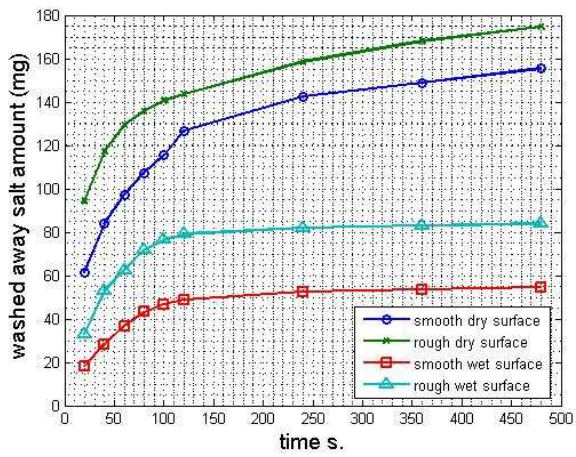

Fig. 7 Washed away salt amount "dry and wet water flow"

As it can be seen from this figure; the amount of washed away salt increases sharply during the first two minutes, and then increases gradually after that. The amount of washed away salt in case of rough surface is larger than the one in case of smooth surface in both cases dry and wet. Because of the importance of the first two minutes; they should be analyze precisely and separately.

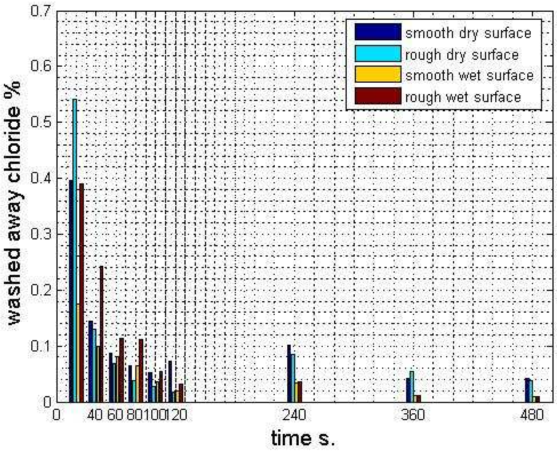

Fig. 8 Washed away chloride% “dry and wet water flow”

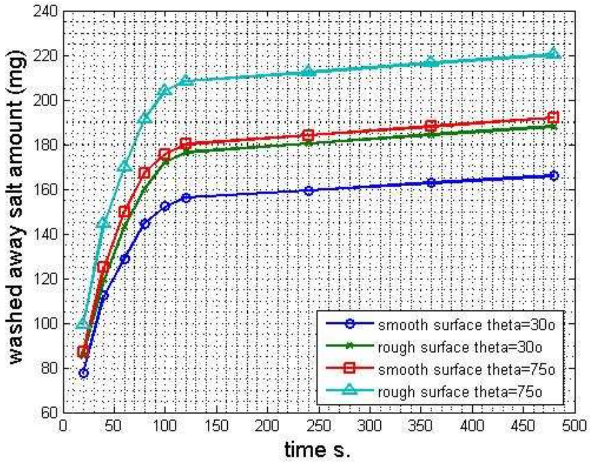

Fig. 9 Washed away salt amount "dry and impact water"

Fig. 8 shows the amount of washed-away chloride at a certain time to the total amount of washed-away chloride under same conditions for smooth and rough surfaces for dry and wet cases. Time interval in Fig. 8 is 20sec during the first two minutes and two minutes later. It can be seen that the washed away chloride percentage is large during the first twenty seconds and it is decreasing gradually for all cases. It can be noticed that washed away amount in case of wet condition is less than the one in case of dry condition.

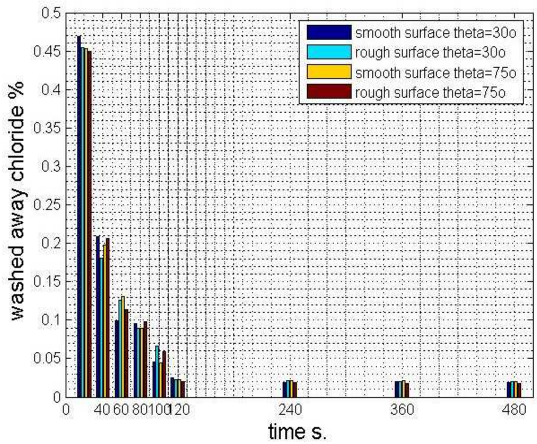

Fig. 10 Washed away chloride% “dry and impact water”

In case of wet condition, It can be seen that there is no sudden change in washed away chloride percentage with respect to time like the case of dry contact. This emphasizes that in case of wet contact condition salt transfers mainly by diffusion, and in case of dry condition salt particles are washed away mainly by convection; especially during the first twenty seconds.

Fig. 9 and Fig. 10 are for impact flow for dry smooth and rough surfaces for two different impact angles $\theta=30^o$, 75^o. As it can be seen, the amount of removed salt is larger than any other case. Mechanical movement is dominant in this case especially during the first few seconds.

Fig. 11 and Fig. 12 are for impact water for wet smooth and rough concrete surfaces with $\theta=30^o$, 75^o.

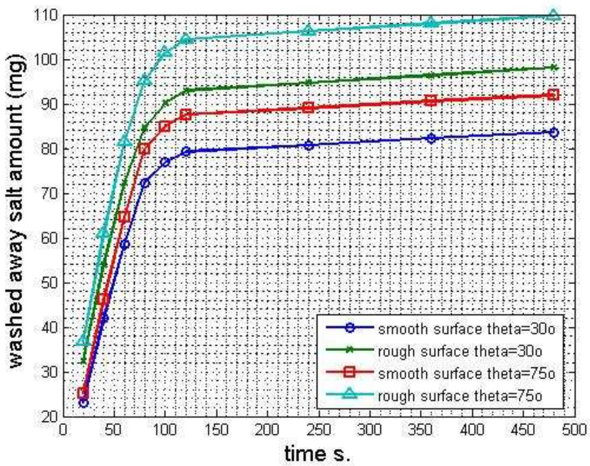

Fig. 11 Washed away salt amount "wet and impact water"

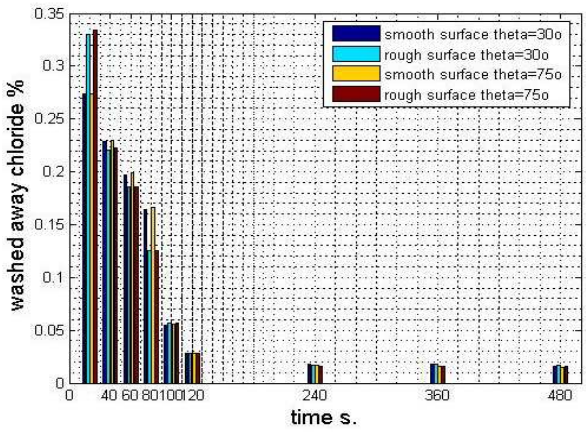

Fig. 12 Washed away chloride% "wet and impact water"

4. CONCLUSIONS

Results during the first two minutes are summarized in Table 2.

Table 2 Washed away salt amount

Exp. case	Washed away chloride (mg)/ percentage (%)	Washed away chloride ratio (mg/cm^2)
Smooth, dry, flow	132.51 (32.71%)	0.15
Rough, dry, flow	146.25 (36.11%)	0.16
Smooth, wet, flow	48.87 (12.07%)	0.05
Rough, wet, flow	78.96 (19.49%)	0.08
Smooth, dry, impact ($\theta=30^o$)	156.19 (38.56%)	0.17
Rough, dry, impact ($\theta=30^o$)	176.50 (43.58%)	0.20
Smooth, dry, impact ($\theta=30^o$)	180.02 (44.45%)	0.20
Rough, dry, impact ($\theta=75^o$)	208.31 (51.43%)	0.23
Smooth, wet, impact ($\theta=75^o$)	79.28 (19.58%)	0.08
Rough, wet, impact ($\theta=75^o$)	92.91 (22.94%)	0.10
Smooth, wet, impact ($\theta=75^o$)	87.53 (21.61%)	0.09
Rough, wet, impact ($\theta=75^o$)	104.46 (25.79%)	0.11

The following can be concluded:

1) Washed-away salt is mainly removed during the first two minutes.

2) The amount of washed away salt by impact is larger than the amount of washed away salt by water flow.

3) Salt is easily to be washed away if the surface is dry and/or rough.

4) Salt is mainly washed away by mechanical movement in case of dry condition especially during the first few minutes. In case of wet condition, salt is mainly washed away by diffusion.

5) In case of impact flow, as the impact angle increases the amount of washed away salt increases in case of dry wall condition. For wet condition, impact angle is slightly affects the washed away amount.

6) By water input of heavy rainfall for 8 minutes, at least 13.46% and 20.68% of salt is washed away.

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