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Effect of External and Internal Salt of Self-Compacting Concrete Containing Lime Stone

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Abstract: This study outlines the effect of external salt and internal sulphate ($CaSO_4$) on the properties of Self-Compacting Concrete (SSC) containing lime stone. The effect of internal and external salts is combined with the process of wetting and drying. Three sets of mixes which are reference mix, mixes with internal sulphate and mixes exposed to external salts respectively are designed with the same mix proportion and maximum sized aggregate of 10 mm. In order to determine the self compactability features, different tests are adopted such as the slump flow, V-funnel and the L-box test. The mechanical properties studied in this study are the compressive strength and ultrasonic pulse velocity. Results show that the compressive strength of mixes with external salts is larger than mixes with internal sulphates for the ages of 28, 60, 90 and 180 days, respectively except for the age of 180 days achieved a higher compressive strength. Based on the obtained results, it is clear that it is possible to produce Self-Compacting Concrete (SCC) from local materials like limestone with good properties. The SCC is affected by salt attack and its effect by the process of wetting and drying but despite this fact, SCC still has good properties. The results indicated lime stone can improve salt resistance and can be used as portland cement replacement.

Key words: Self-compacting concrete, lime stone, sulphate salt, portland cement, slump flow, obtained

INTRODUCTION

Studies carried out around the mid-1980's and 1990's resulted in the invention of Self-Compacting Concrete (SCC) and High Volume Cement Replacement (HVCR) strategy which produces a major effect on the technique where concrete can be prepared (Meyer, 2009; Okamura and Ouchi, 2003). The reason is that SCC is responsible for a variety of chances to make use of natural and by-product materials as cement substitutes while the strategy of HVCR not just decreases the use of cement considerably but permits the production of concrete at a low cost as well.

SCC is a type of concrete which fills the formwork due to its capability to flow under its own weight completely even in the presence of dense reinforcement with no necessity for vibration while preserving homogeneity. The self-compacting ability is accomplished by means of large paste volume (Elahi *et al*., 2010) made possible by mixing cement with mineral additives such as Limestone Powder (LP), Fly Ash (FA), Silica Fume (SF), Ground-Granulated Blast-furnace Slag (GGBS), Rice Husk Ash (RHA), Meta-Kaolin (MK), etc. Combining mineral additives in SCC turned out to be capable of not merely regulating the cement content but also improving the fresh state properties (Nehdi *et al*., 2004). SCC needs higher material cost compared with traditional concrete, the additives low optimal level of cement replacement with respect to the incorporation of LP in SCC due to supply and properties issue (De, 2011).

Due to its most essential ingredient, portland cement, the concrete industry has suffered from an image of being environmentally unfriendly because it is associated with high consumption of fossil fuel and high emissions of CO_2 into the atmosphere (Chen and Liu, 2008). Nevertheless, incorporating mineral additives at their optimal levels, mostly between 10-20% (Glavind *et al*., 2005) is insufficient at any cost increase incurred. The additive of LP in this study is described to have the ability of decreasing cost and environmental impact due to it being used as a cement replacement and to improve all engineering properties. They have a preference to use materials which are easily available and have been effectively used in real structural applications such as LP, FA and SF and their bulk supply is assured. Fresh concrete properties using lime stone as an additive is studied recently (Najm *et al*., 2015). The aim of this

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study is to find the effect of internal sulphate and external salt on the cured SSC properties such as compressive strength and ultrasonic pulse velocity using local material lime stone powder.

MATERIALS AND METHODS

Effective production of SCC is achieved by more strict requirements on the material's selection, controlling and proportioning. Optimum proportions must be selected according to the mix design methods, considering the characteristics of all the materials used. The cement used in this study is Ordinary Portland Cement (OPC) Type (I) produced according to the Malaysian Standard MS 522 and agrees with BS EN 196. Local washed river sand as fine aggregate materials is used in this work. Sand sieve analysis was performed in accordance with B.S.887:1992.

Ordinary treated water obtained from the main supply line of Perlis and Pinang is used throughout this work in mixing of concrete. Natural lumps of sulphate were used. They were dried to about 105°C for 24 h, cooled to room temperature, crushed by hand compactor then sieved using a No. 4 sieve. Sulphate amounts in concrete were changed by the addition of different weights of the previous mixture to get 1.2, 1.3, 2.3 and 3.4% of SO_3 by weight of sand. ADVD 181 is a high range water reducing polymer-based admixture which according to grace construction products was formulated in accordance with BS5075 Part 3:1985. The specific gravity of ADVD 181 is 1.2 and the addition rates vary from 195-375 mL/100 kg of binder materials. The Limestone Powder (LP) passing a 0.075 mm sieve is used in this study.

Concrete mixes: In order to achieve the scopes of this study, the research is divided into three sets which are shown in Table 1. These sets include nine mixes that depend on one reference mix in order to show the effect of internal and external salts.

Table 1: Mixture components and description

Mix symbols	Mix descriptions
L1	Reference mix without internal or external salts
L2	Mix with internal salt 3.4% of sand weight
L3	Mix with internal salt 2.3% of sand weight
L4	Mix with internal salt 1.3% of sand weight
L5	Mix with internal salt 1.2% of sand weight
L6	Mix with external salt NaCl 1.4%
L7	Mix with external salt Na_2So_4 0.97%
L8	Mix with external salt $MgSo_4$ 0.97%
L9	Mix with external salt $CaCl_2$ 1.4%

RESULTS AND DISCUSSION

Fresh properties of SCC: Workability tests are made on fresh concrete immediately after mixing including slump flow, V-funnel and L-box. SCC should possess at some level both filling and passing abilities as well as the resistance to segregation.

Slump flow and T50 cm test: Figure 1 and 2 show the results of slump flow test. The values of (D) represent the maximum spread (slump flow) while the values of T50 represent the time required for the concrete flow to reach a 50 cm diameter circle. The flowing ability of fresh concrete is described with slump flow investigated with the Abrams cone. The low water/powder ratio and the high fineness of limestone powder form a paste with high viscosity. During flowing neither segregation nor bleeding occurs. It is very clear from the results that all mixes are assumed to have a good consistency and workability from the filling ability point of view. However, these results show a wide range of variation. This variation illustrates the effects of the changes that are made in the mixes on the filling ability of SCCs. The T50 cm for all mixes is between 3-5 sec indicating a good deformability. This agrees with the EFNARC 2002.

V-funnel test: Table 2 shows the values of V-funnel test (flow time) which represent ability of the concrete to flow out of the funnel and they are used to determine the filling ability of SCC while the flow time at (T_5 min) value represents the same ability but after refilling the funnel and allowing concrete to discharge after 5 min after the first filling. Table 2 and 3 show that the time of flow through the V-funnel for all mixes is 6.1-15.3 sec which agrees with the acceptance criteria for SCC reported by EFNARC 2002 which allow time up to 20 sec. No blocking or segregation behavior is observed for all mixes. SCC mixtures are often characterized by their funnel time TV (which is often used as a degree of the apparent viscosity of mix) and their spread diameter D which stands for the filling ability.

The results obtained show that the V-funnel test is more sensitive to the change of the properties of the concrete mixes than the slump flow test. However, the measurement of the T50 value from slump flow test is more operators influenced than the measurement of the V-funnel flow time TV. Thus, from practical sight of view, it will be convenient to know a reliable relationship between the flow times T50 and the funnel time TV of the a SCC mixture.

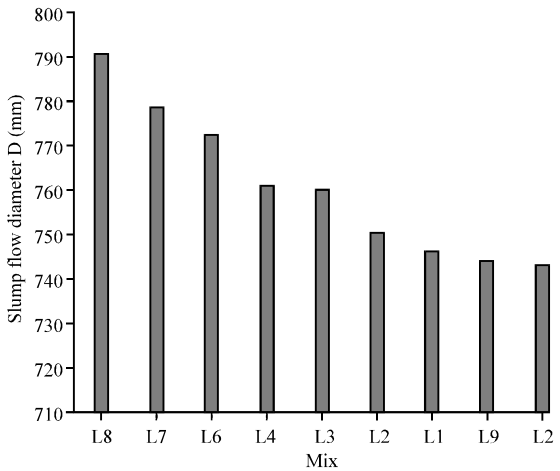

Fig. 1: Slump flow Diameter D (mm)

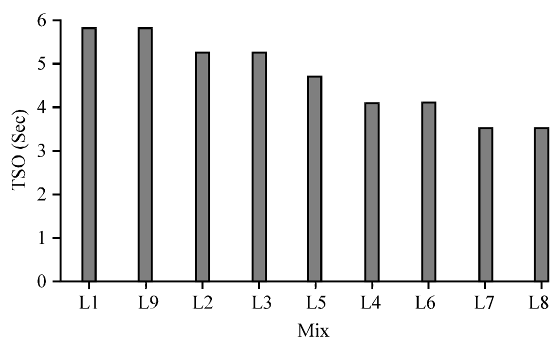

Fig. 2: Time required to pass (50 cm Dia.) circle (T50)

Table 2: Results of V-funnel tests

Mix symbols	Flow time (sec)	Flow time at T50 min (sec)
L1	6.5	8.5
L2	11.3	14.3
L3	9.0	13.2
L4	7.0	9.0
L5	9.8	15.3
L6	6.8	8.5
L7	6.1	8.3
L8	6.7	8.1
L9	6.3	7.7

Table 3: Result of compressive strength (MPa) for (150) mm^3 (fcu) and cylinder (150×300) mm (fc/)

	28 days		60 days		90 days		180 days	
Mix symbols	fcu	fc/	fcu	fc/	fcu	fc/	fcu	fc/
L1	34.3	19.8	30.0	17.4	38.95	31.1	41.7	33.9
L2	31.1	16.5	25.2	13.2	39.00	21.3	36.2	19.5
L3	33.9	25.9	23.5	19.4	42.60	23.6	33.6	18.6
L4	38.9	24.4	26.5	25.6	39.60	30.1	36.7	25.7
L5	43.2	25.3	31.2	18.1	33.70	28.3	51.2	31.5
L6	41.3	24.2	36.5	23.5	39.60	31.4	49.1	34.5
L7	44.0	23.4	33.6	17.4	42.30	29.7	45.8	37.2
L8	24.9	23.9	32.7	30.8	44.70	34.6	48.6	33.8
L9	23.8	21.8	33.8	29.4	41.40	35.1	49.9	34.2

L-box test: L-box test is used to measure the filling ability and the passing ability of the mixes. The L-box results are listed in Fig. 3. The value of (H2/H1) represents the blocking ratio. The values of T20 and T40 represent the times of the concrete flow to reach 20 and 40 cm, respectively. The values of blocking ratios are illustrated in descending manner and the values of T20 and T40 are plotted in Fig. 4 and 5 in ascending manner. The L-box results indicate good flow ability and show that the blocking ratio values for all mixes are >0.8 which is often considered in the EFNARC 2002 as the critical low limit.

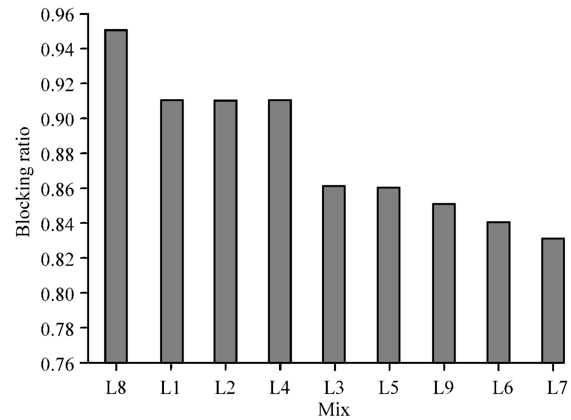

Fig. 3: Blocking ratio of L-Box

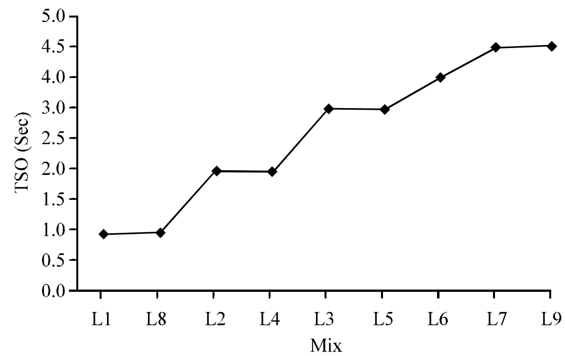

Fig. 4: L-box result at T20 (sec)

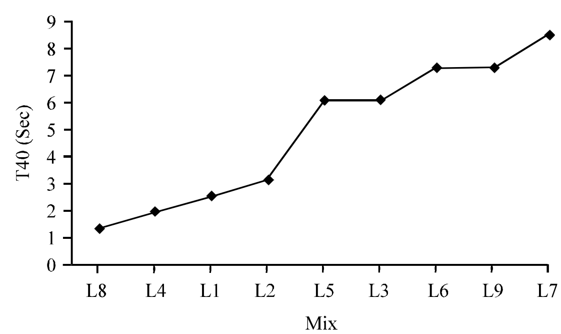

Fig. 5: L-box result at T40 (sec)

Hardened SCC properties: Since, no segregation or bleeding is shown with the fresh state, SCC mixes should, theoretically have improved hardened properties. In order to study these hardened properties of SCC developed in this study, 549 specimens of various types are cast after a series of fresh self-compactability concrete tests. All the concrete specimens are cast in molds without being mechanically consolidated. All of the samples are demolded after 24 h then either cured in water, water solution and exposed to cycles of wetting and drying until the date of testing.

Compressive strength: The compressive strength is one of the most important properties of hardened concrete. National and international codes generally use the value of compressive strength for the classification of concrete. In order to study the effect of internal and external salts combined with cycles of wetting and drying on the compressive strength of SCC, standard cubes measuring 150 mm and cylinders measuring (150×300) mm are used. Each compressive strength reading is the average reading of three tested samples. The compressive strength results are listed in Table 3 which show test at 28, 60, 90 and 180 days gained from cylinders and cubes. The value of compressive strength for cylinders is less than for cube because of slenderness of the specimens. The effect of external salt of 1.4% NaCl, 0.97% Na_2SO_4, 0.97% $MgSO_4$ and 1.4% $CaCl_2$ on compressive strength with age for all concrete mixes is shown in Fig. 6 and 7. It appears that the compressive strength of mixes with external salts is larger than mixes with internal sulphates by about 2.7, 15 and 5.4% for 28, 60 and 90 days, respectively. At age 180 days, the compressive strength of mixes with internal sulphates is larger than mixes with external salts by about (4.5%) while the reference mix (L1) shows results lower than the mixes in Set (No. 1) and Set (No. 2). At age 28-60 days, it is clear there is reduction in compressive strength. This is due to the essence of sulphate attack which leads to the formation of calcium sulphates (gypsum) and calcium sulpho-aluminate (ettringate). Both products occupy a greater volume than the compounds which they replace so that the expansion of hardened concrete takes place reducing the compressive strength for the mixes. For 60-90 days there is an increase in compressive strength because the presence of hydration products fill the pores of concrete and that will reduce the effect of salts attack and mitigate the damages caused by salts attack. For the age of 180 days, there is a continuity of strength increase except for L2-L4 where a reduction in compressive strength is exhibited because the amount of sulphate in these mixes is greater than the other mixes. In addition, the effect of wetting and drying effect on the samples at early ages is greater than the later ages.

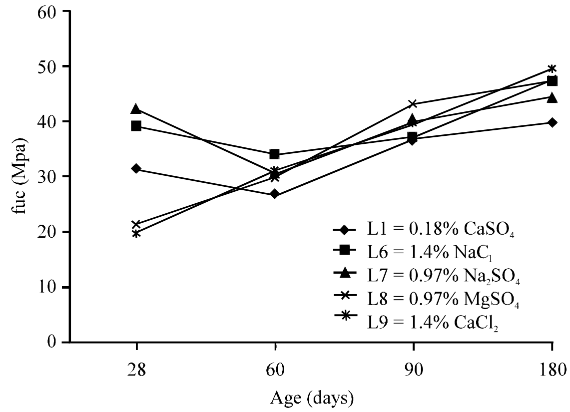

Fig. 6: Compressive strength of cubes (FCU) external salts and L1

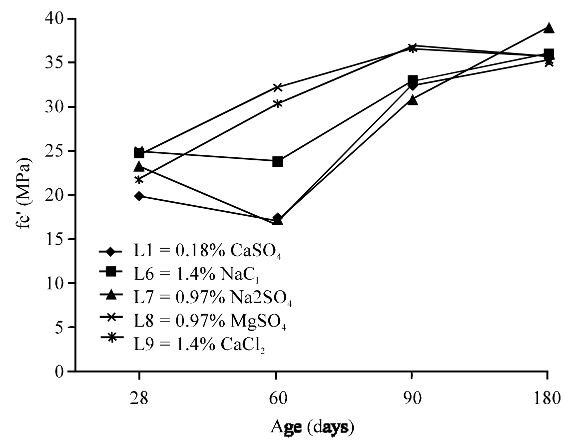

Fig. 7: Compressive strength of cylinder (FCU) for external salts and L1

Table 4: Results of Ultrasonic Pulse Velocity tests (UPV) (km/sec)

	Ultrasonic Pulse velocity results (km/sec) with age			
Mix symbols	28 days	60 days	90 days	180 days
L1	4.7	4.6	4.6	4.8
L2	4.6	4.3	4.9	4.6
L3	4.7	4.6	4.7	4.7
L4	4.7	4.5	4.7	4.7
L5	4.8	4.6	4.7	4.9
L6	4.7	4.7	4.6	4.8
L7	4.7	3.5	4.8	4.9
L8	3.9	4.6	4.7	4.8
L9	3.7	4.7	4.9	4.8

Ultrasonic pulse velocity: The results of UPV test measured on cubes for ages 28, 60, 90 and 180 days are shown in Table 4. The values of UPV for external salts attack range between 3.7-4.7, 3.5-4.7, 4.6-4.9 and 4.8-4.9 km/sec for internal sulphates attack and the results of UPV range between 4.3-4.8, 4.3-4.6, 4.7-4.9 and 4.6-4.9 km/sec for the same ages while for the reference

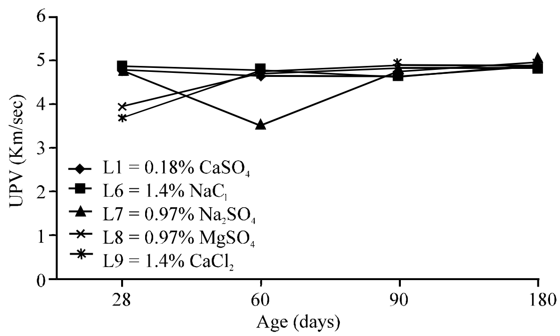

Fig. 8: Results of (UPV) for external salts and L1

mix (L1), the results are 4.2, 4.6, 4.6 and 4.8 km/sec for the same ages above. Ultrasonic pulse velocity values are useful for checking homogeneity of concrete monitor the strength development of concrete. Figure 8 shows the effect of external salt on ultrasonic pulse velocity for standard cubes measuring (150 mm) at different ages. At early (28-60) ages the effect of internal and external salts combined with cycles of wetting and drying leads to reduce the pulse velocity because there is discontinuity between internal particles of samples while at other ages the pores filled with the products of hydration which increase the pulse velocity except L2- L3 and L4.

CONCLUSION

Based on the results of this study and in view of the experimental conditions, limitations of the laboratory circumstances of the local materials used, it can be concluded that by using the slump flow, V-funnel and L-box, SCC mixes achieve consistency and self-compactable under their own weight without any external vibration or compaction. The values of compressive strength for cube (fcu) for internal sulphates are about 31.1-43.7, 23.1-31.2, 33.7-42.6 and 33.6-51.2 MPa at 28, 60, 90 and 180 days, respectively. For external salts, the values are about 23.8-44.0, 32.7-36.5, 39.6-44.7 and 45.8-49.9 MPa for the same ages. While the values of reference mix L1 are 33.4, 30, 38.9 and 41.7 MPa at the same ages above. The values of compressive strength for cylinder (fc) for internal sulphates are about 16.6-25.5, 13.4-25.6, 21.3-30.1 and 18.6-31.5 MPa at 28, 60, 90 and 180 days, respectively. For external salts, the values are about 21.7-24.2, 17.4-30.8 and 33.8-37.2 MPa for the same ages. While the values of reference mix L1 are 19.8, 17.4, 31.1 and 33.9 MPa at the same ages above. However, SCC flows into formwork and through reinforcement under its own weight so no external vibration is required.

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