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Multi-variable statistical analysis for scaling resistance of concrete containing GGBFS

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Abstract

This study examines the laboratory de-icing salt scaling performance of concrete containing varying amounts of GGBFS as cement replacement. Using experimental results of concrete tested in accordance with ASTM C 672 and MTO LS-412 reported in the literature, a statistical analysis was carried out to evaluate the significance of several mix design variables, surface finishing, type of de-icing salt and duration of curing. Specifically, two multi-variable statistical models were developed to estimate the salt scaling resistance of the finished surface and the formed surface of concrete containing GGBFS as cement replacement. The models' results show that (i) w/b ratio and ratio of OPC/binder are statistically significant, (ii) mass loss is not singularly dependant on the amount of OPC, GGBFS and total binder content, however their effect is captured by the ratio of OPC/binder, (iii) entraining air is not a controlling variable for the scaling resistance of the formed surface, (iv) type of de-icing salt affects the surface scaling, (v) both finishing procedure and curing regime are statistically significant for the finished surface, and (vi) resistance of concrete containing GGBFS to salt scaling improves with age. Results also revealed that the previously reported inconsistencies in the scaling resistance of concrete containing GGBFS are due to the differences in the performance of the finished and formed surface and to the uncovered fact that mass loss does not depend on the binder content as typically reported but rather on the ratio of OPC/binder.

Keywords: Concrete; Durability; Freeze–thaw; GGBFS; Salt scaling; Statistical analysis

1. Introduction

The use of ground granulated blast furnace slag (GGBFS) as partial cement replacement in concrete has gained considerable attention over the years. Using GGBFS as cement replacement reduces the cost of construction materials, promotes recycling and waste minimization and in most cases improves concrete durability. Afrani and Rogers [1] reported that at least 50% substitution is considered necessary to prevent damage due to alkali silica reaction, and to achieve acceptable sulphate resistance the slag content needs to replace ordinary Portland cement (OPC) by at least 60% [2]. In contrast, the salt scaling resistance of concrete does not improve with high percentages of GGBFS used as cement replacement based on experiments conducted in accordance with ASTM C 672 [3] and MTO LS-412 [1,4–8]. In some cases, however, it has been reported that at low replacement percentages (20–25%) concrete gains resistance compared to OPC concrete, but in other studies the opposite was found [5–8].

The intent of this paper is twofold: (1) to provide insight into the factors that influence laboratory salt scaling performance of concrete and to quantify their significance based on statistical models; and (2) to examine the causes of the reported inconsistencies in the scaling resistance of concrete containing GGBFS. The statistical analyses are based on laboratory test results reporting the de-icing salt scaling performance of concrete containing GGBFS as cement replacement tested in accordance with ASTM C 672 and MTO LS-412. Based on scaling data reported in

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the literature, the influence of the mix design variables on scaling performance is described and evaluated statistically by single variable and multi-variable regression analyses. Two models were developed; the first model estimates the cumulative mass loss for the finished surface and the second one for the formed surface. Using these models, the influence of several factors, namely, mix design variables, curing regime, finishing procedure, type of salt and the age of the concrete are assessed on the basis of their statistical significance.

2. Salt scaling resistance test

Five laboratory test methods exist for evaluating the salt scaling resistance of concrete, namely ASTM C 672-92: Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to De-icing Chemicals; MTO LS-412: Ministry of Transportation Ontario Laboratory Testing Manual Test Method LS-412; CDF: Capillary Suction of De-icing Solution and Freeze–thaw Test [9,10]; SS 13 72 44: the Boras Method from the Swedish Standard [11]; and BNQ NQ 2621-900 Determination de la Resistance a l'ecaillage du Beton soumis a des Cycles de Gel-Degel en Contact avec des Sel Fondants [12]. When comparing the laboratory test methods, it is evident that MTO LS-412 and ASTM C 672 test methods specify curing and preconditioning procedures that are different compared to the other three tests. The tested surface for scaling is sensitive to curing regime and sample preparation, and recognizing that the objective of this review is to evaluate the influence of various variables on the surface scaling, this analysis has been restricted to the laboratory tests conducted in accordance with ASTM C 672 and MTO LS-412 [1,7,8,11].

According to ASTM C 672, the sample size should have a minimum surface area of at least 460 cm^2 and a thickness of at least 75 mm. The MTO LS-412 procedure specifies a sample size of 300 mm × 300 mm × 75 mm, or an equivalent surface area. At 20–24 h after casting, the specimens are de-moulded and placed into moist storage conditions for 13 days, in which the temperature and relative humidity (RH) are 23 ± 2 °C and at least 95%, respectively. Thereafter, the specimens are air cured for 14 days at a temperature of 23 ± 2 °C and RH of 50 ± 5%.

When the concrete is 28 days old, the top surface of the sample is covered with 6 mm of salt solution, which is retained by a watertight dike. The de-icing solution is specified as 3% NaCl in MTO LS-412, and 4% $CaCl_2$ in ASTM C 672. The specimens are subjected to 50 freeze–thaw cycles, with one cycle lasting for 24 h. Within a cycle, the specimen is in the freezing condition for 16–18 h at −18 ± 2 °C based on MTO LS-412 or −17.8 ± 0.8°C based on ASTM C 672. The samples are then placed in the thawing condition for 6–8 h at 23 ± 2 °C based on MTO LS-412 or 23 ± 1.7 °C according to ASTM C 672 and a 50 ± 5% RH. The dry mass of the flaked off concrete is measured every five cycles at which time the salt solution is washed off and replaced.

3. Single variable linear regression

The resistance of concrete to salt scaling has been shown to depend on a number of internal and external factors namely, water-to-binder (w/b) ratio, cementing material, entrained air content, test surface, curing regime and finishing techniques [13]. Table 1 provides a summary of the experimental results that were included in the statistical study [1,5–8,14,15]. The concrete samples were tested following the procedures of either ASTM C 672 or MTO LS-412. The corresponding concrete contains 0–9% entrained air, and 0–60% GGBFS as cement replacement. The w/b ratio ranges from 0.25 to 0.65.

3.1. Water-to-binder ratio

The salt scaling resistance of concrete is affected by the w/b ratio, since it influences the volume, the distribution and connectivity of capillary pores. For concrete with the same w/b ratio, research has shown that increasing the percentage of GGBFS yields a decrease in the permeability value and an equal or greater 28-day compressive strength [16]. Low permeability bars the entry of liquid and ions thus decreasing the potential for frost damage [17]. However, it has also been reported that the reduction in permeability of the paste can be harmful because large hydraulic pressures are likely to develop as water is forced out of the capillaries upon freezing [11]. Scaling resistance has been reported to improve with lower w/b ratio for both the OPC concrete and for concrete containing GGBFS as cement replacement [8,18,19].

Fig. 1 presents the influence of w/b ratio and tested surface on the scaling losses. For both finished and formed surfaces, the trend lines show that mass loss increases as the w/b ratio and the percentage of GGBFS increase. The exception to this trend is the result corresponding to the formed surface with 1–40% GGBFS. For this series, the trend line shows that the mass loss decreases as the w/b ratio increases from 0.35 to 0.45. This anomaly is due to the limited number and range of test data.

Closer examination of Fig. 1 shows that the trend line shifts upward and the slope of the trend line increases when the percentage of GGBFS increases for the finished surface. In contrast, results of the formed surface, 0% GGBFS and 41–60% GGBFS show that the trend line shifts upward but with minimal changes to the slope of the line. This indicates that the interaction between the cumulative mass loss and w/b ratio is different for the two surfaces and that the mass loss is not linearly proportional to the percentage of GGBFS.

3.2. Cementing material

The hydration rate of concrete containing GGBFS is slower than that of OPC concrete. This difference affects the setting time, finishing time and curing time of the concrete [1,6,7,16,20]. However, with an adequate finishing

Table 1
Summary of experimental data used in statistical analysis

Author	OPC (kg/m^3)	GGBFS (kg/m^3)	GGBFS/Binder (%)	w/b ratio	Entrained air (%)	Scaling loss (kg/m^2)	Tested surface
Afrani et al. [1]	415	0	0	0.39	4.0	0.41	Finished
	415	0	0	0.39	4.0	0.27	
	311	104	25	0.39	5.6	0.42	
	311	104	25	0.39	5.6	0.54	
	311	104	25	0.39	5.6	0.46	
	311	104	25	0.39	5.6	0.18	
	311	104	25	0.39	5.6	0.27	
	208	208	50	0.38	4.9	1.13	
	208	208	50	0.38	4.9	1.67	
	208	205	50	0.38	4.9	3.23	
Bilodeau et al. [5]	268	0	0	0.55	8.2	0.25	Finished
	268	0	0	0.55	7.0	0.64	
	206	69	25	0.55	9.1	1.55	
	203	68	25	0.55	9.2	1.64	
	200	67	25	0.55	6.0	1.85	
	133	133	50	0.55	5.1	2.20	
	132	132	50	0.55	8.4	2.48	
	132	132	50	0.55	7.3	2.52	
Bleszynski [6]	420	0	0	0.42	5.3	1.10	Finished
	273	147	35	0.42	7.2	2.70	
	210	210	50	0.42	5.6	3.52	
	420	0	0	0.42	5.3	0.27	Formed
	273	147	35	0.42	7.2	0.70	
	210	210	50	0.42	5.6	1.20	
Boyd [7]	281	94	25	0.45	6.0	0.10	Formed
	281	94	25	0.45	7.5	0.16	
	281	94	25	0.45	9.0	0.19	
	244	131	35	0.45	6.0	0.43	
	244	131	35	0.45	7.5	0.26	
	244	131	35	0.45	9.0	0.24	
Chidiac et al. [15]	360	0	0	0.38	Not air entrained	0.4	Formed
	270	180	25	0.38		0.5	
	180	180	50	0.38		1.47	
	270	180	40	0.38		0.81	
	180	270	60	0.38		2.44	
Sakai et al. [8]	512	0	0	0.25	4.5	0.20	Formed
	380	0	0	0.35	4.5	0.20	
	311	0	0	0.45	4.5	0.50	
	260	0	0	0.55	4.5	0.50	
	226	0	0	0.65	4.5	1.00	
	306	250	45	0.25	4.5	0.20	
	225	184	45	0.35	4.5	0.20	
	176	144	45	0.45	4.5	0.50	
	145	119	45	0.55	4.5	0.80	
	123	100	45	0.65	4.5	1.80	
	512	0	0	0.25	4.5	0.10	Finished
	380	0	0	0.35	4.5	0.40	
	311	0	0	0.45	4.5	1.00	
	260	0	0	0.55	4.5	1.40	
	226	0	0	0.65	4.5	1.50	
	306	250	45	0.25	4.5	0.00	
	225	184	45	0.35	4.5	1.00	
	176	144	45	0.45	4.5	2.20	
	145	119	45	0.55	4.5	3.60	
	123	100	45	0.65	4.5	4.20	
Talbot et al. [14]	387	0	0	0.4	6.9	0.55	Finished
	387	0	0	0.4	6.9	0.72	
	320	80	20	0.4	5.0	0.28	
	320	80	20	0.4	5.0	0.56	
	237	158	40	0.4	6.4	2.70	
	237	158	40	0.4	6.4	3.61	

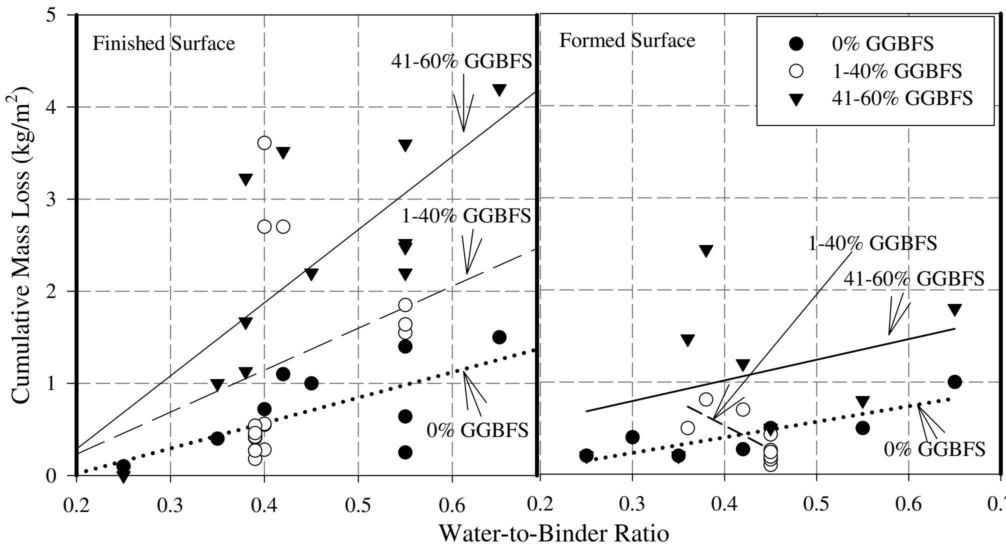

Fig. 1. Influence of water-to-binder ratio on the finished and formed surface.

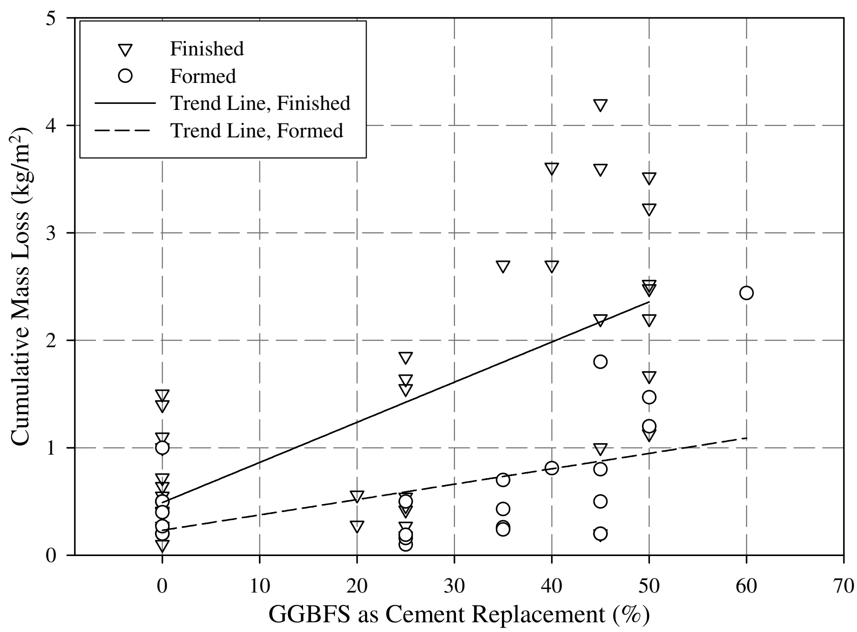

Fig. 2. Influence of percentage of GGBFS on the finished and formed surface.

procedure and curing regime, the mechanical and physical properties of concrete containing GGBFS are found equal or superior to those of OPC concrete [16,20]. Exception has been the salt scaling damage to concrete containing GGBFS [11,16,21]. The mass loss due to scaling for varying percentages of GGBFS reported in the literature is shown in Fig. 2. Although the results do not fit a straight line, the trend lines show an increase in mass loss with an increase in amount of GGBFS. Bleszynski et al. [6] and Afrani and Rogers [1] reported that the delay in setting time of GGBFS is a major contributor to the scaling damage.

The trend lines of Figs. 3 and 4 show the influence of OPC content and binder (OPC + GGBFS) content on the cumulative mass loss, respectively. The results reveal that as the amount of OPC and binder content increases, the mass loss decreases. They also show that the slope of the trend line is steeper for the finished surface in comparison to that of the formed surface. This clearly shows a difference in the scaling resistance of the finished and formed surface. The results also indicate that the interplay between the OPC content, binder content and GGBFS as cement replacement on scaling damage is neither linear nor apparent. This observation suggests that a multi-variable analysis is required to determine their respective influences.

3.3. Entrained air content

An effective air void system is necessary for freeze–thaw durability of concrete. The air void system should have a

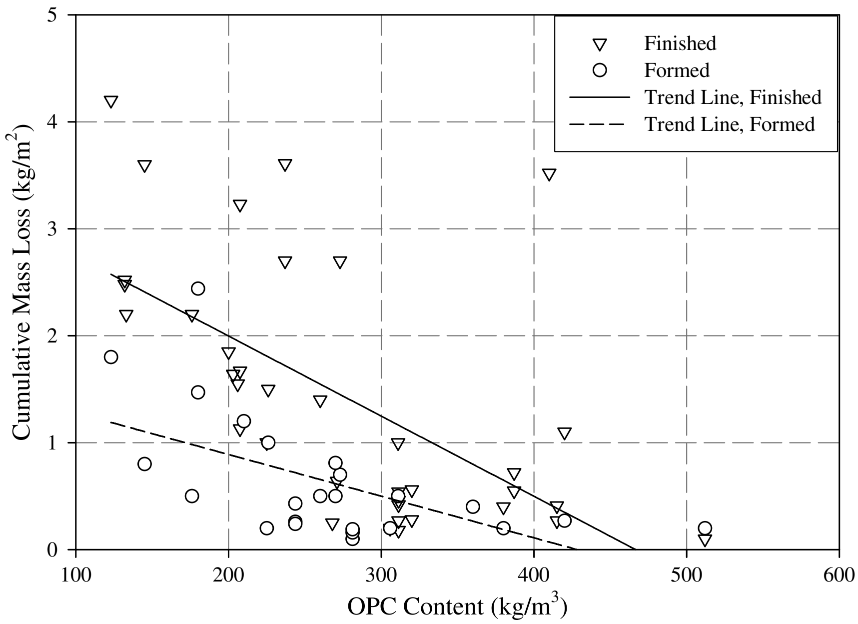

Fig. 3. Influence of OPC content on the finished and formed surface.

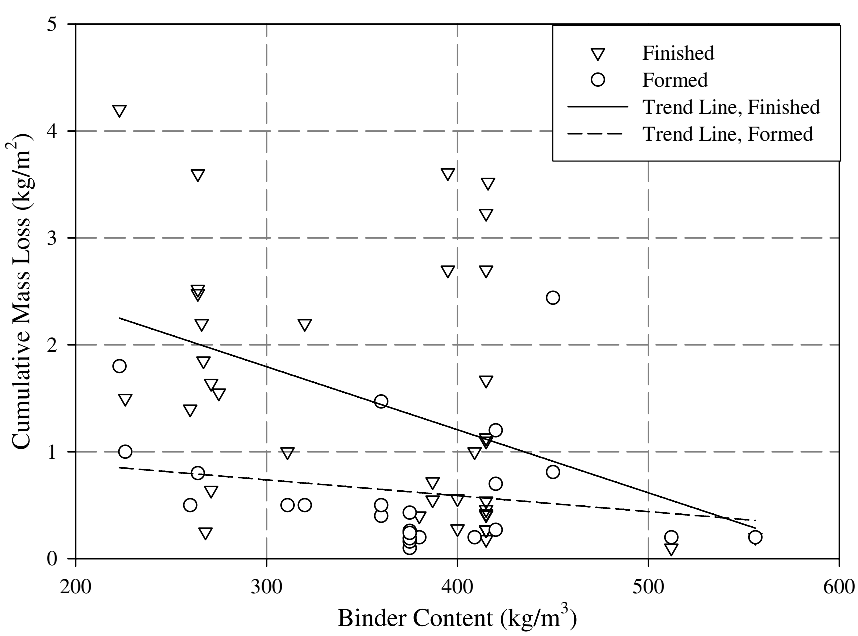

Fig. 4. Influence of binder content on the finished and formed surface.

sufficient volume to accommodate the freezable water and should contain a large number of small, closely spaced voids [11,18,22]. It is well recognized that damage due to freeze–thaw cycles can be suppressed by entraining 5–7% air by volume of concrete [22]. However, air entrained concrete is still susceptible to scaling damage due to surface scaling [11,22,23]. Test results have shown that an adequately air entrained concrete is vulnerable to surface scaling damage since it also depends on the type or quality of finishing and curing techniques applied [6]. Moreover, scaling test results have revealed that there is no clear correlation between the spacing factor and the scaling resistance for OPC concrete or concrete containing GGBFS as cement replacement [5,19]. Boyd [7], on the other hand, has reported that the air content of the concrete influences the degree of scaling, however he also stated that the data shows no specific relationship or trends for the series of mix compositions investigated. Linear regression shown in Fig. 5 shows no correlation between the entrained air content and the mass loss for the finished surface. For the formed surface, the general trend shows that mass loss decreases slightly as the percentage of entrained air

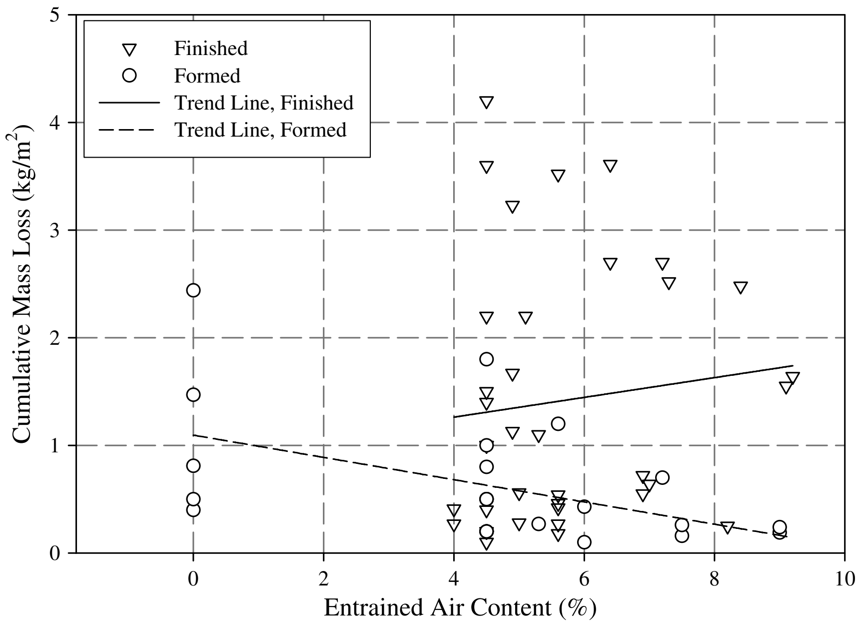

Fig. 5. Influence of entrained air content on the finished and formed surface.

increases. This indicates that entraining air is not a controlling factor for the finished surface and that it has some positive effects on the scaling resistance of the formed surface.

3.4. Test surface

The composition and mechanical properties of concrete are known to be different at the cover in comparison to the core [24,25]. The concrete "skin", which ranges in thickness from 5 to 15 mm, generally contains a higher paste fraction and a higher w/b ratio than the core concrete. This difference leads to different behaviour during freezing and thawing of the top surface, the interior, and the bottom surface of the concrete. Also, when comparing the effects of curing conditions on the exposed top surface to the concrete core, it is known that the water evaporation of the exposed surface influences the quality of the concrete skin. As a result, one expects the concrete core (sawn or formed surface) to be less susceptible to environmental factors and thus be more resistant to damage during freezing and thawing than the top (finished) surface [8,18,26,27]. This is further supported by the data presented in Figs. 1–5, which show that the salt scaling resistance of concrete containing varying amounts of GGBFS cement exhibits less scaling loss when the formed surface was tested as compared with the finished surface.

In the study by Bleszynski et al. [6], the finished surface proved to have poor and inconsistent scaling resistance for concrete mixes containing OPC alone and with GGBFS as cement replacement. All of the concrete specimens failed, including the control concrete (0% GGBFS). Large differences in the scaling results between the duplicate slabs were also observed, up to 59% in one case. When the formed surface of the same specimens was tested, all of the mixes passed the scaling acceptance limit, except for the concrete containing 50% GGBFS. This performance is also supported by Chidiac et al. [15].

3.5. Curing regime and finishing techniques

Curing is one of the most important factors to influence durability, and scaling is no exception [1,7,8,11,18]. Good curing ensures proper cement hydration and influences the pore structure of the concrete surface. Sakai et al. [8] observed that a period of moist curing for 1 day compared to 3 days, provided a coarser pore structure of the concrete and an increased amount of scaling. Moreover, Talbot et al. [14] observed that a curing period of 14 days and 28 days did not influence the scaling resistance of the finished surface significantly. These results suggest that there are no added benefits from a scaling resistance perspective to moist cure the concrete for more than 14 days.

Afrani and Rogers [1] performed five combinations of curing regimes and finishing techniques for the initial 14 days. They concluded that OPC concrete and concrete containing 25% GGBFS performed well for all of the curing and finishing techniques applied. However, the concrete containing 50% GGBFS content failed the scaling test for all of the curing and finishing techniques, and it was suggested that this might have been a consequence of an inadequate curing period.

4. Multi-variable linear regression analyses

Single variable linear regression analyses of each mix design variable shown in Figs. 1–5, have captured a small amount of the variability of the scaling resistance results.

Table 2
Results of the multi-variable linear regression analyses

Variable (i)	'Finished' model		'Formed' model	
	β_i	Confidence level (%)	β_i	Confidence level (%)
1. Air content	−0.0809	45.3	−0.0679	48.2
2. OPC content	0.0054	53.6	0.0026	43.1
3. Binder content	0.0004	9.4	−0.0004	14.7
4. OPC/binder ratio	−0.0553	95.7	−0.0218	81.6
5. w/b ratio	0.0901	99.9	0.0390	98.5
6. De-icing salt	−0.0120	89.5	0.0029	57.7
7. Curing procedure	0.0045	72.9	−0.0021	25.3
8. Finishing procedure	0.0133	98.7		
8. Age of concrete			−0.0067	59.9

The poor fit provided the motive for conducting a multi-variable linear regression analysis to predict the response measured in accordance with MTO LS-412 and ASTM C 672, and to quantify the statistical significance of the studied variables.

The general form of the multiple linear regression models is

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_p x_p + \varepsilon \tag{1}$$

where y = response; β = regression coefficients; p = number of regressor variables; x = regressor variable and ε = residual or disturbance. The 'fit' model was developed to estimate the parameters by satisfying the optimization problem, namely to minimize the sum of the squared residuals (SS_E). The objective function therefore becomes

$$S = \sum \varepsilon^2 = SS_E \tag{2}$$

Two models for predicting the cumulative scaling mass loss corresponding to 50 freeze–thaw cycles were developed; the first model employs the experimental data reported for the salt scaling test conducted on the formed surface and the second one for the finished surface. The models account for the variable parameters within each concrete mix design, interaction terms and indicator variables. Although all of the experimental studies used in this analysis were conducted in accordance with ASTM C 672 or MTO LS-412, some differences in test procedures were accounted for in the model by using indicator variables. The indicator variables account for the type of de-icing salt used (NaCl or $CaCl_2$), deviations in curing practices from the specifications, age of the concrete when the scaling resistance test began, and finishing procedures.

The scaling performance of the finished surface and the formed surface is expressed as an eight-parameter model, i.e.

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 \tag{3}$$

where y is the cumulative mass loss after 50 freeze–thaw cycles (kg/m^2), x_1 the air content (%), x_2 the OPC (kg/m^3), x_3 the binder content (OPC + GGBFS) (kg/m^3), x_4 the ratio of OPC/binder (%), x_5 the ratio of w/b (%), and x_6, x_7, and x_8 are indicator variables with values expressed as 0% or 100%. For both models, x_6 represents the type of de-icing salt used. Variable x_7 accounts for the differences in the curing procedure. For the finished surface, the variable x_8 considers the finishing time and use of curing compound. For the formed surface, the variable x_8 accounts for the age of concrete when the scaling resistance test is conducted.

This regression analysis included 37 data points for the finished surface and 24 data points for the formed surface. Using multiple linear regression analysis, the regression coefficients of the models developed for the finished and formed surfaces are given in Table 2. For the finished surface, the regression line is fit with a coefficient of determination (R^2) of 0.70, which suggests that 70% of the original variability has been explained. For the tests conducted on the formed concrete surface, 72% of the variability in the data is captured by the fit model. Fig. 6 presents the predicted cumulative mass loss after 50 cycles against the measured mass loss for both the finished and formed surface. The diagonal line represents the predicted response equal to the experimental measured response. The statistical significance of the regressor variables was evaluated and the corresponding values are provided in Table 2.

The 'goodness of fit' of the multiple linear regression models was assessed by inspection of the residual plots. The residual, which is the measured mass loss minus the predicted mass loss, was plotted against each of the regressor variables to check the adequacy of the form of the model. The residual plots did not suggest any evidence of lack of fit of the model since no discernable patterns were detected. The residual was also plotted against the fitted value of y and did not reveal outliers or inadequacies, which suggests that a good fit for the number of data used in this study. The statistical significance of each regressor coefficient is evaluated and discussed in Section 5.

5. Discussion

5.1. Entrained air content

For both models, the regressor coefficient associated with air content, β_1, is found statistically insignificant up

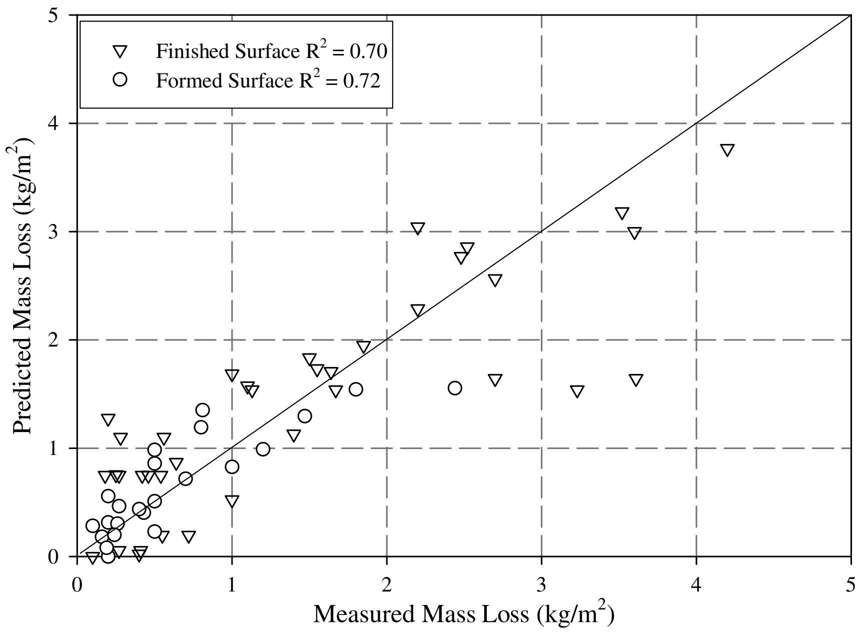

Fig. 6. Experimental measured cumulative mass loss vs. estimated mass loss after 50 freeze–thaw cycles based on multiple linear regression analysis.

to the 50% confidence level. This finding is consistent with the reported literature where no correlation between the entrained air content and the scaling resistance has been found [5,7,19].

5.2. OPC content, binder content and OPC/binder ratio

The regressor coefficient associated with the OPC content, β_2, is evaluated to be statistically insignificant at the 54% confidence level for the 'finished' model and 43% for the 'formed' model. For both surfaces, the total binder content is also found to be statistically insignificant implying that it is not a controlling factor for scaling resistance. However, the coefficient associated with the ratio of the OPC/binder content, β_4, is statistically significant at the 96% and 82% confidence levels for the 'finished' and 'formed' models, respectively. From Table 2, the negative sign of the coefficient β_4 indicates that scaling decreases as this ratio increases. These results are consistent with the trends reported in Figs. 2–4, where the scaling resistance tends to decrease as the amount of GGBFS increases and as the amount of OPC decreases. In order to under-

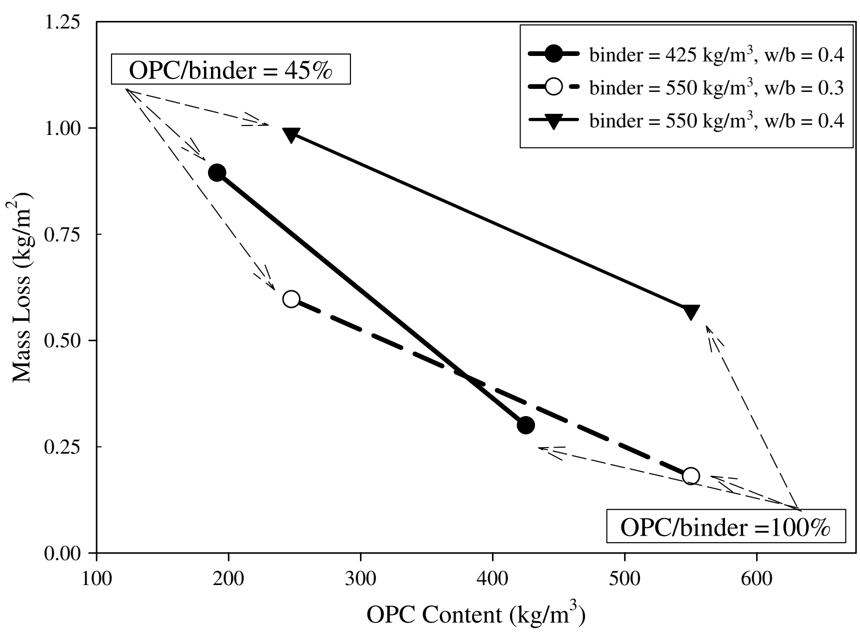

Fig. 7. Influence of cementing material proportions on mass loss based on statistical model for the formed surface.

stand the interplay between the three coefficients, β_2, β_3 and β_4, their effect is reproduced in Fig. 7, corresponding to the 'formed' model. The predicted mass loss is based on concrete with an OPC/binder ratio ranging from 45% to 100%, with no entrained air content, cured in accordance with the MTO LS-412 or ASTM C 672, and tested at 28 days. The results show that for constant binder content, the cumulative mass loss increases as the w/b ratio increases, the amount of OPC decreases, and also as the OPC/binder ratio decreases. Moreover, the results show that the difference in mass loss between 100% and 45% OPC/binder mixes is greater for the concrete with a binder content of 425 kg/m^3 in comparison to the 550 kg/m^3 concrete. These results indicate that the scaling resistance does not solely depend on the total binder content since its value is a function of both the OPC content and the OPC/binder ratio. This indicates that the interaction between the three variables, OPC, GGBFS and the total binder content, is best captured by the coefficient representing OPC/binder ratio. These results are consistent with the test results reported in the literature.

5.3. Water-to-binder ratio

For both models, the positive sign of the coefficient β_5 shows that the cumulative mass loss increases as the w/b ratio increases. The regressor coefficient associated with the w/b ratio is statistically significant at greater than 98% confidence levels for both test surfaces. The value of β_5 is larger for the finished surface (0.0901) as compared to the formed surface (0.0390), which shows that the influence of the w/b ratio is more detrimental on the scaling resistance for the finished surface in comparison to the formed surface. Moreover, the results of Fig. 7 show the same pattern, i.e. increasing the w/b ratio from 0.3 to 0.4 leads to increases in the mass loss.

5.4. Indicator variables

The regressor coefficient associated with the type of deicing salt is found to be statistically significant at 89% and 58% confidence levels for the 'finished' and 'formed' models, respectively. Although only one study used $CaCl_2$, the results do correlate with what have been reported in the literature.

The curing regime is evaluated to be statistically significant for the finished surface, 73% and statistically insignificant for the formed surface. And, for the finished surface, the finishing procedure is statistically significant to the 99% level. This reveals that the scaling resistance is highly sensitive to the type of finishing procedure and curing regime and that the curing regime is not statistically significant for the formed surface. This finding also correlates with what have been reported in the literature, i.e. the curing method and finishing procedure have a direct effect on the surface microstructure and durability of the concrete [1,7,8,11,28].

The influence of the age of the concrete at the time of testing is found to be statistically significant at 60% confidence level for the formed surface. The negative sign of the regressor coefficient indicates that conducting the scaling resistance test at 4 months increases the scaling resistance as compared to testing at 28 days. This finding confirms that the hydration of concrete continues and its positive effect is detected at 4 months.

6. Conclusions

According to the results obtained from the single and multi-variable linear regression analyses of the scaling resistance of concrete containing GGBFS tested according to MTO LS-412 and ASTM C 672, the following conclusions are drawn:

1. Scaling resistance of the formed surface differs from that of the finished surface of concrete containing GGBFS. Accordingly, two statistical models were derived to predict their respective mass loss due to surface scaling.
2. The w/b and OPC/binder ratios are controlling variables for the salt scaling resistance of both the finished and formed surface of the concrete.
3. Scaling resistance of concrete containing GGBFS as cement replacement increases when the ratio of OPC/binder increases. Furthermore, the amount of OPC, GGBFS and total binder do not singularly control the mass loss, and that their effect is captured by the OPC/binder ratio.
4. The non-apparent interplay between OPC, GGBFS and total binder content has led to the reported inconsistencies in the salt scaling performance of concrete containing GGBFS.
5. Entraining air is not a controlling variable when considering the salt scaling resistance of the finished surface. This implies that although entrained air improves the freeze–thaw resistance of concrete core, it does not provide additional resistance to the salt scaling of the concrete surface.
6. Exposure of concrete surface to different types of deicing salt, NaCl and $CaCl_2$, yields different mass loss.
7. Curing regime and finishing technique control only the finished surface's salt scaling resistance.
8. Resistance of concrete containing GGBFS to salt scaling improves with age.

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