on the graphs as ER axis increases considerably due to the 70% slag replacement samples. Moreover, the trends obtained for all setups was almost the same (although the ER values were different due to distinct geometric factors).

For the three setups, the higher the PC replacement by slag, the higher the ER over time. Surface ER increased 1703.49%, and 202.14% for the 70%, and 35% slag replacement, respectively, when compared to the control limestone sample with 0% replacement at 28 days (Figure 3). Likewise, the bulk ER increased 1585.01%, and 207.82% for the 70%, and 35% slag replacement (Figure 4). Moreover, the internal ER increased 903.25%, and 35.0% for the 70%, and 35% slag replacement, respectively, when compared to the control limestone sample with 0% at 180 hours (Figure 5). These results are somehow expected since it is widely known that concrete mixtures incorporating SCMs present a better microstructure (i.e. lower porosity) for the same water-to-cement ratio when compared to conventional concrete due to a large amount of C-S-H formed while the pozzolanic reactions.

Conversely, a substantial decrease in compressive strength was observed while slag replacement. A decrease of 54.64% and 25.76% for 70%, and 35% replacement, respectively was obtained when compared to the conventional PC concrete at 28 days (Figure 6). As it was highlighted in the literature review, a binary mixture composed of PC and slag tends to have a longer hydration kinetics and thus take more time to develop CSH, which might explain its lower strength gain over time.

A two-way ANOVA was performed to appraise the influence of the binder type on both ER and compressive strength results as per Table 4. Analyzing the data, one notices that all the ER and compressive strength results may considered significant for the binder type, meaning that the replacement of PC for slag statistically influences on both ER and compressive strength results for a confidence level of 5%.

The coarse aggregate had a minor influence on both ER and compressive strength, regardless the setup used. Comparing the granite coarse aggregate samples with the limestone ones, granite samples yielded on average a 9.04 % and 3.11% decrease for bulk ER and compressive strength, respectively. On the other hand, concrete made of granite presented an average increase of 0.70%, for the surface ER.

As for the binder type, a two-way ANOVA was performed to appraise the influence of the aggregates nature on both ER and compressive strength results as per Table 5. Differently from the binder type, the results found for different aggregates were not considered statistically significant, which means that the variability observed in the results seems to come from other factors such as concrete heterogeneity, etc. Moreover, based on the calculated bulk k of 4.15 cm (1.63 in), and a probe spacing of a = 3.81 cm (1.5 in) which results on surface k factor of 23.93 cm (9.42 in), a theoretical surface and bulk resistivity ratio can be calculated based on Eq. (3).

$$\frac{\rho_{surface}}{\rho_{bulk}} = \left(\frac{R_{surface}}{R_{bulk}}\right) 5.76 \tag{3}$$

The theoretical value for $\frac{R_{surface}}{R_{bulk}}$ is 0.33 [4]. Thus, applying this value on equation 5 it was determined the theoretical value between surface ER resistivity and bulk ER:

$$\frac{\rho_{surface}}{\rho_{bulk}} = 0.33 * 5.76 = 1.90 \tag{4}$$

Finally, an experimental ratio between surface ER and bulk ER (i.e. average of surface ER divided by bulk ER of all mixtures analyzed at 3, 7 and 28 days) was determined to be 1.88 with a standard deviation of 0.23. This value is in accordance with the theoretical ratio between surface ER and bulk ER of 1.90. Furthermore, a strong R^2 of 0.992 was found in the linear regression between surface ER and bulk ER, as per (Figure 7).

This slight difference between theoretical and experiment ratios can be explained by the difference on test procedures (i.e. path of ER) of each ER test. Moreover, Surface ER has shown more reliable results due to the fact that the operator may rotate the sample and get a more reliable and constant readings from the samples, avoiding thus outliers. Otherwise, on the bulk ER only one single measurement is performed as the whole sample is measured. Therefore, this procedure may be slightly more variable and thus present some outliers. This phenomenon can also be noticed on the difference between the Figure 2 and 3 at 28 days, for 70% slag replacement samples; the bulk ER at 28 for the SG70 sample is slightly inferior due to one outlier sample that was used to determine the average value used in the graph. Hence, although different binders, CA and test procedures were used in this experiment, ER proved to be an effective technique to assess the strength gain over time of concrete with or without SCMs. Further analyses are still need though to create constitutive models according to the SCM type used and amount of replacement selected.

SUMMARY AND CONCLUSION REMARKS

Three distinct ER setups along with compressive strength tests were used in this research to study the influence of the binder and coarse aggregate type on their results over time. The main findings obtained in this work may be found hereafter:

1- The coarse aggregate presented a minor influence on the 3 ER procedures evaluated in this work. The same conclusion can be drawn to compressive strength.
2- The percentage of Portland cement (PC) replacement by slag had a major influence on all three ER test methods assessed, as well as on compressive strength results gathered. The former might be attributed to the better quality of the hydrated products formed in binary mixtures (i.e. PC + slag) when compared to conventional PC mixes, whereas the latter may be explained by the longer hydration process that takes place for PC mixes with high slag replacements. Therefore, it should be noted the importance of knowing the raw materials used and mix-proportioning whenever analyzing concrete ER on the field.
3- The results gathered from all 3 ER setups seems to correlate quite well. However, the surface ER evidenced to be the most reliable test method as per the influence of preferential ions percolation paths on the concrete sample.

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Table 1- Aggregates used in this study

Aggregate Identification	Designation (location)	Aggregate Type	Specific gravity (Kg/l) / (lb/ft³)	Dry-rodded unit weight (kg/l) / (lb/ft³)	Absorption (%)
Coarse	Ottawa, ON, Canada	Magmatic granite rock	3.01 / 187.91	1.70 / 106.13	0.4
Coarse	Ste-Adèle, QC, Canada	Sedimentary limestone rock	2.73 / 170.43	1.57 / 98.01	0.4
Fine	Ottawa, ON, Canada	Natural sand	2.65 / 165.43	-	0.83

Table 2- CGBS and PC chemical composition and specific gravity

Chemical composition (%)	Slag	Portland cement GU Type I
CaO	34.07	61.50
SiO_2	32.21	19.20
Al_2O_3	9.98	4.80
Fe_2O_3	0.33	3.10
SO_3	0.44	3.90
MgO	10.94	3.20
Loss of ignition	-1.57	2.10
Na_2O_{eq}	0.65	0.60
Specific gravity (Kg/L) / (lb/ft³)	2.90 / 181.04	3.03 / 189.16

Table 3- Concrete mixture proportions

Concrete Mix-proportions	Materials	Materials Kg/m³ (lb/ft³)		Materials L/m³ (ft³/m³)	
		Granite	Limestone	Granite	Limestone
Control (0% GGBS replacement)	**Cement**	368.80 (23.02)	368.8 (23.02)	121.72 (4.30)	121.72 (4.30)
	Slag	0	0	0	0
	Fine aggregate	762.30 (47.59)	742.30 (46.34)	287.02 (10.14)	279.50 (9.87)
	Coarse aggregate	1054.22 (65.81)	975.17 (60.88)	350.00 (12.36)	357.50 (12.63)
	Water addition	227.65	230.63	221.28	221.28

		(14.21)	(14.40)	(7.81)	(7.81)
	Air content (%)	2 (0.13)	2 (0.13)	20 (0.71)	20 (0.71)
35 % GGBS replacement	**Cement**	239.72 (14.97)	239.72 (14.97)	79.12 (2.79)	79.12 (2.79)
	Slag	129.08 (8.06)	129.08 (8.06)	44.51 (1.57)	44.51 (1.57)
	Fine aggregate	757.21 (47.27)	737.23 (46.02)	285.11 (10.07)	277.59 (9.80)
	Coarse aggregate	1054.22 (65.81)	975.17 (60.88)	349.98 (12.36)	357.50 (12.63)
	Water addition	206.34 (12.88)	209.31 (13.07)	221.28 (7.81)	221.28 (7.81)
	Air content (%)	2 (0.13)	2 (0.13)	20 (0.71)	20 (0.71)
70 % GGBS replacement	**Cement**	110.64 (6.91)	110.64 (6.91)	36.51 (1.29)	36.51 (1.29)
	Slag	258.16 (16.12)	258.16 (16.12)	89.02 (3.14)	89.02 (3.14)
	Fine aggregate	752.14 (46.95)	732.16 (45.71)	283.20 (10.00)	275.68 (9.74)
	Coarse aggregate	1054.22 (65.81)	975.17 (60.88)	349.98 (12.36)	357.50 (12.63)
	Water addition	206.31 (12.88)	209.28 (13.06)	221.28 (7.81)	221.28 (7.81)
	Air content (%)	2 (0.13)	2 (0.13)	20 (0.71)	20 (0.71)

Table 4- Slag replacement Two-way ANOVA

Test	P-value	Status
Bulk ER	0.00	Statically significant
Surface ER	0.00	Statically significant
Internal ER	0.00	Statically significant
Compressive strength	0.00	Statically significant

Table 5- Coarse aggregate Two-way ANOVA

Test	P- value	Status
Bulk ER	0.587	Not statically significant
Surface ER	0.998	Not statically significant
Internal ER	0.124	Not statically significant

Compressive strength	0.422	Not statically significant

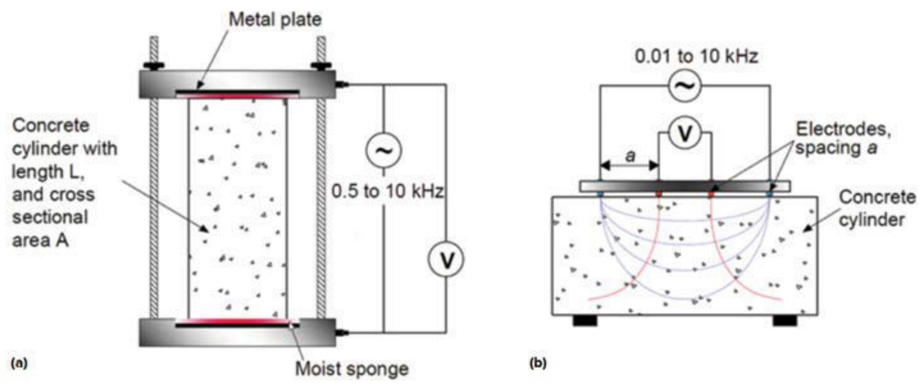

Fig. 1- Electrical resistivity measuring techniques: (a) two-point uniaxial method; (b) four-point method [11].

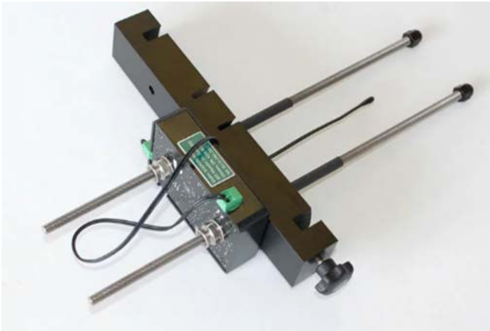

Fig. 2- Internal ER sensor setup [12].

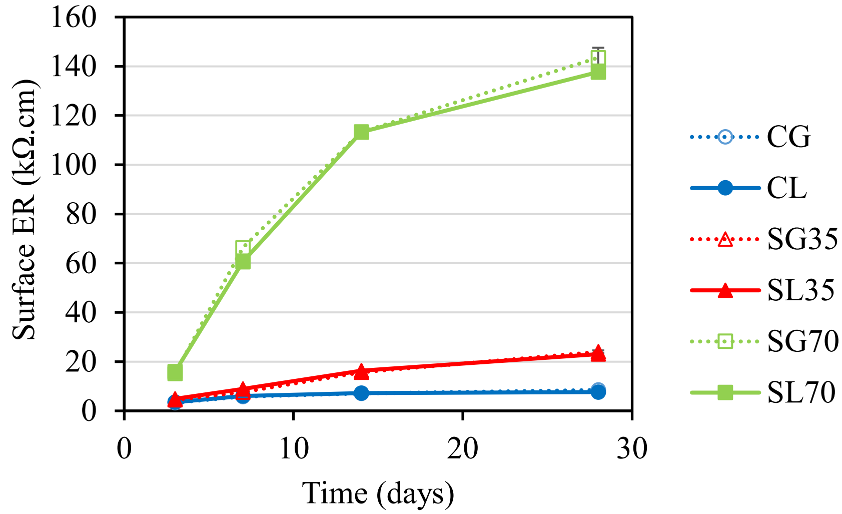

Fig. 3- Evolution of Surface ER over time of the six mixtures investigated.

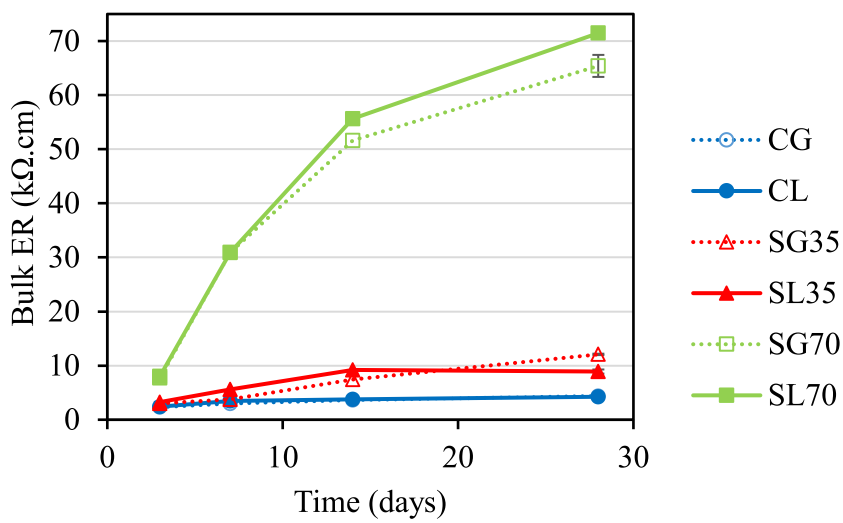

Fig. 4- Evolution of Bulk ER over time of the six mixtures investigated

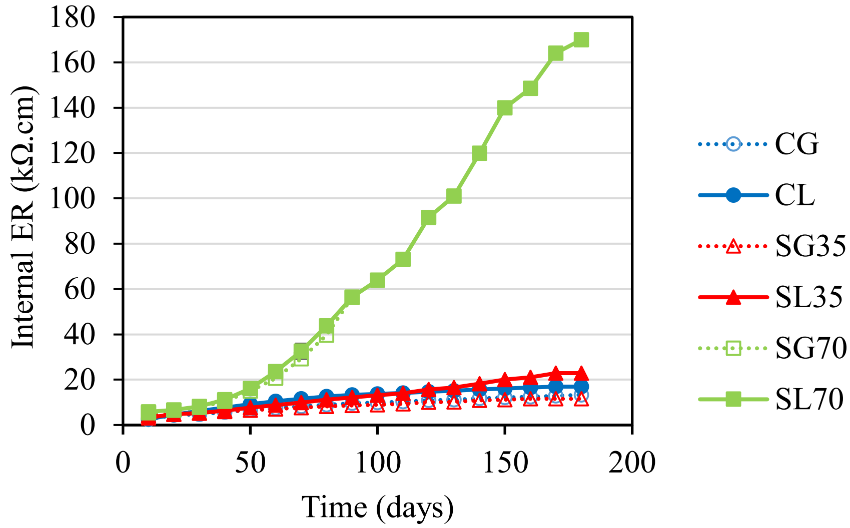

Fig. 5- Relationship between Internal ER and time of the six mixtures studied

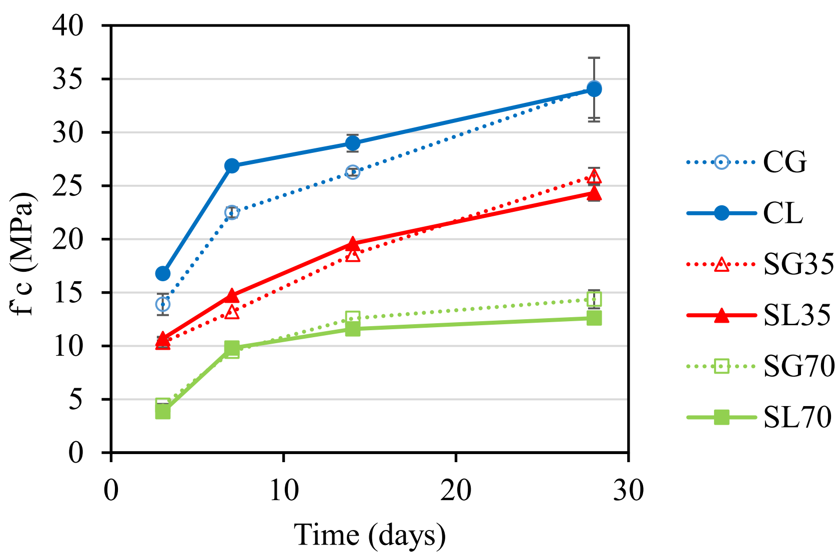

Fig. 6- Relationship between compressive strength and time