Comparative assessment of self-compacting concretes (SCC) with fly ash and fine

Comparativo das propriedades do concreto auto-adensável (CAA) utilizando areia fina e cinza volante

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Abstract

This paper aims to contribute to decisions concerning the use of fine materials, responsible for the segregation resistance of self-compacting concrete (SCC). In this study, samples of SCC were prepared with fly ash, a pozzolanic waste, and fine sand that is a non-pozzolanic material, using the dosage method proposed by Tutikian-Dal Molin (2007) [1]. It was observed that the utilization of fly ash increased the resistance to compressive strength, mainly in more advanced ages, as well as the values of the elastic modulus and the propagation speed of ultra-sound waves. It has also decreased the penetration of chloride ions to the same strength values, where it was also observed that the final cost of the fly ash SCC was lower than the fine sand SCC for similar strength levels. Both dosage and performance diagrams were shown.

Keywords: self-compacting concrete (SCC), fly ash, fine sand, design method, performance diagram.

Resumo

O objetivo deste artigo é contribuir para a tomada de decisão sobre a definição do uso de materiais finos responsáveis pela resistência à segregação do concreto auto-adensável (CAA). Neste estudo, amostras de CAA foram dosadas com cinza volante, um material pozzolânico, e areia fina, que é um material não pozzolânico, utilizando o método de dosagem proposto por Tutikian & Dal Molin (2007) [1]. Foi observado que a utilização de cinza volante aumentou a resistência à compressão, principalmente nas idades mais avançadas, assim como os valores de módulo de deformação e velocidade das ondas de ultra-som. Também diminuiu a penetração de íons cloretos, para os mesmos valores de resistência em comparação com os CAA com areia fina e o custo final dos CAA com cinza volante foi inferior. Foram apresentados tanto os diagramas de dosagem como os de desempenho.

Palavras-chave: concreto auto-adensável (CAA), cinza volante, areia fina, método de dosagem, diagrama de desempenho.

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1. Introduction

Although concrete is the most widely used construction material in the world, nowadays it is no longer considered only the study of conventional concrete (CCV). The market and the construction techniques require concrete with special features. Helene (2005) [2] refers to the high strength, high performance, self-compacting, with high levels of additions and pozzolans, apparent, colourful, white, sustainable, among others.

Because of this tendency, it was developed in Japan, in 1988, a concrete which is capable of moving on its own and fill, without any intervention, the spaces in the form work: the self-compacting concrete (SCC) (REPETTE, 2005) [3]. The SCC is clearly one of the areas of the concrete technology has the greatest potential for development (PETERSSEN and REKNES, 2005) [4].

The two most important properties of SCC are the workability and stability, which depend on a satisfactory proportioning among all SCC components, including the fine materials, responsible for the stability of the mixture.

This article aims to contribute to the decision making about the definition of the use of fine materials responsible for the segregation resistance of SCC, using the dosage method proposed by Tutikian-Dal Molin (2007) [1]. To choose among the options offered by the market, the professional must examine the material characteristics, such as the cost of each component, the quantity availability and acceptable distances, the possibility to react chemically with water or products that hydrate the cement. If there is more than an option for a given item, it is advisable to use those that have already been used by the person responsible for the dosage. Yet, it should be taken into consideration that, currently, there are good options for fine, and many are from waste of the industries, which, if not used in the concrete, should be disposed under the strict environmental standards.

Hence, it was held an experimental work with two fine components highly used locally, at the Federal University of Rio Grande do Sul (UFRGS). Two SCC families were moulded, one with fly ash and one with fine sand, representing a pozzolanic and a non-pozzolanic fine.

2. Experimental program

According to Table 1, 2 cylindrical test specimens (10 x 20 cm) were moulded to test the compressive strength at 1, 7, 28 and 91 days, and 3 CT's elastic modulus to measure the propagation speed of ultra sonic waves, and 2 more CT's for testing concrete

with penetration to chloride ions, totalling 13 CT's per unit.

It was determined to all the families trend-line equations, along with the coefficient of determination. With this, dosage diagrams can be drawn, representing the resistance to compression, water/cement (w/c) ratio, proportion of the dry aggregates mass related to the mass of cement, and cement consumption per cubic meter of concrete. Performance diagrams can also be drawn, representing the compressive strength at 28 days, the elastic modulus, the penetration of chloride ions and the speed of ultrasonic wave. Following, through behavioural equations, all the parameters mentioned above were calculated for several compressive strength rates, plus the cost, and only then compare all concrete families.

3. Constituent materials

The Tutikian-Dal Molin (2007) [1] dosage method, used in this work, allows the proportioning of concrete with any available material, provided meet some basic requirements. For the implementation of this experimental work materials which are abundant locally, economic and which have already been used by the construction industry for other purposes were selected. Thus, the concrete made may be reproduced and tested in the future.

The cement used was the CPV - RS (Portland cement of high early strength and resistant to sulphates). This cement was selected because it is acquired in the region and also for being the most widely used in industries of pre-cast, which is one of the places the SCC can be used with greater benefits.

Among the fine materials options, it was chosen one non-pozzolanic, the fine sand, and one pozzolanic, the fly ash. Both are commercially available and economical. Fine sand is an aggregate already used by some local companies, mainly concrete producers for the CCV composition and can be stored outdoors in relatively simple to construct structure, not requiring, for instance, great resources in the acquisition of a silo. Fly ash is a by-product of the coal industry and it has already been widely used in the cement industry, and may even partially replace the clinker. Fly ash is a pozzolanic material, then it chemically reacts with calcium hydroxide ($\text{Ca}(\text{OH})_2$), a component of cement hydration. $\text{Ca}(\text{OH})_2$ is a fragile crystal, lixiviation, which does not contribute in the compressive strength of the concrete. Therefore, it is considered a benefit the fact that this compound is consumed by fly ash, despite the fact it causes a slight decrease in the mixture pH, which can increase the carbonation rate of the concrete, resulting in a possible despassivation in the reinforcement.

Table 1 – Cylindrical test specimens

Tests realized	Tests norms	Ages Tested	Number of CT's/per age
Resistance to compressive strength	NBR 5739/94	1, 7, 28 and 91 days	2
Elastic Modulus	ASTM 469/94	28 days	3
Propagation of ultra-sound waves	-	28 days	3 (same as the modulus)
Penetration of chloride ions	ASTM 1202/97	56 days	2

Table 2 – Granulometric analysis

Diameter (%)	Cement (m _μ)	Fly Ash (m _μ)
Up to 10%	1,16	5,22
Up to 50%	9,15	39,91
Up to 90%	25,41	128,15
Average	11,61	56,54

The crushed basalt was chosen as the coarse aggregate, which is also commercially available in the region and proven effective in its role. River sand was used as fine aggregate and water was taken directly from the public water supply.

Finally, a third generation polycarboxylate based superplasticizer with solids content of 40% was used. This additive should reduce

Table 3 – X-Ray Fluorescence

Element	Cement (%)	Fly Ash(%)
CaO	65,71	3,02
SiO ₂	17,15	65,92
Fe ₂ O ₃	4,93	7,54
Al ₂ O ₃	4,54	18,71
SO ₃	3,88	0,25
MgO	1,44	0,29
K ₂ O	1,33	2,88
TiO ₂	0,58	1,35
SrO	0,27	-
P ₂ O ₅	0,12	0,05
MnO	0,05	-

Table 4 – Bulk density and unit mass of the materials used

	Cement	Fly Ash	Fine Sand	Regular Sand	Coarse Aggregates 9,5 mm	Coarse Aggregates 19 mm
Bulk density (kg/dm ³)	2,92	1,92	2,65	2,64	2,82	2,82
Unit Mass (kg/dm ³)	-	-	1,57	1,53	1,50	1,42

Table 5 – Granulometric analysis of the aggregates used

Sieve opening (mm)	Fine sand	Regular sand	Coarse Aggregates 9,5 mm	Coarse Aggregates 19 mm
	Accumulated Amount Retained (%)			
# 19	0	0	0	1
# 12,5	0	0	0	44
# 9,5	0	0	1	81
# 6,3	0	0	53	96
# 4,75	0	3	87	99
# 2,36	0	12	99	100
# 1,18	0	29	100	100
# 600 m _μ	0	54	100	100
# 300 m _μ	16	87	100	100
# 150 m _μ	93	98	100	100
Modulus of Fine	1,09	2,83	5,87	6,81
Maximum Dimension	0,6 mm	4,75 mm	9,5 mm	19 mm

Table 6 – Fine Sand SCC Unit proportion

Family	proportion					w/c	H (%)	Adt (%)	α (%)
	c	af	ar	b9	b19				
3	1	0,60	0,96	0,79	0,65	0,36	9,10	0,47	64,00
4	1	0,80	1,28	1,06	0,86	0,42	8,44	0,47	61,60
5	1	1,00	1,60	1,32	1,08	0,53	8,92	0,47	60,00
6	1	1,20	1,92	1,58	1,30	0,71	10,19	0,47	58,86
7	1	1,40	2,24	1,85	1,51	0,77	9,61	0,47	58,00

Subtitle: c – cement; af – fine sand; ar – regular sand; b9 – grave 9,5 mm; b19 – grave 19 mm; H – humidity; adt – additive; α mortar proportion

Table 7 – Material Consumption Calculated for fine sand SCC

Family	Bulk Density (kg/m ³)	Cement (kg/m ³)	Fine Sand (kg/m ³)	Regular Sand (kg/m ³)	Grave 9,5 mm (kg/m ³)	Grave 19 mm (kg/m ³)	Water (kg/m ³)	Additive (kg/m ³)
3	2381	546	327	524	431	355	199	2,57
4	2367	437	349	559	463	375	184	2,05
5	2354	360	360	576	475	389	193	1,69
6	2342	304	364	583	480	395	216	1,43
7	2338	267	373	597	493	403	205	1,25

the mixing water in approximately 20%. However, in the case of SCC, the additive is used to increase the workability of the concrete, at the same w/c ratio.

Table 2 illustrates the particle size analysis of cement and fly ash, while the X-Ray fluorescence can be observed in table 3. Tests were conducted at LACER (Laboratory of Ceramics) at UFRGS.

Table 4 illustrates the bulk densities and unitary masses of the materials used, while Table 5 shows the particle sizes of aggregates. The bulk densities of cement and fly ash were determined according to ABNT NBR NM 1.23 [5], the bulk densities of aggregates (fine sand and regular sand) were performed through the ABNT NBR NM 52/03 [6] while the ABNT NBR NM 53/03 [7] normalized the test bulk density of coarse aggregates. The unitary masses were obtained through ABNT NBR 7251/82 [8] and particle size analysis was obtained following the procedure of ABNT NBR NM 248/03 [9].

4. Dosage for SCC

The dosage for SCC has followed a step-by-step, according to the method mentioned. From the determined aggregates proportions, conducted through the packaging of every two, it could

calculate the proportions of the concrete unit and simply mix them to determine the w/c ratio, the content of superplasticizer and to mould CT's as a means of reference for future trials.

The unit proportion of SCC with fine sand are shown in Table 6, while the consumption of materials are shown in table 7. It was necessary to mix five points to obtain the range 25 MPa to 50 MPa for the compressive strength at 28 days (f_{ck} between 20 and 45 MPa). The calculations of the consumptions of the components of concrete have been performed, based on concrete fresh density. It is observed that the content of dry mortar ranged from 58.0% to 64.0%, but these proportions can be considered from the same family, therefore, plotted on the same curve of dosage to maintain the proportions between the aggregates fixed. The content of superplasticizer, which should be constant for all proportions, was maintained at 0.47%, to preserve the ability of SCC to be economically viable.

The high levels of dry mortar may be indicative of a low modulus of elasticity, but this fact will be discussed in the results. In table 8 it can be observed the properties of fresh concrete. The tests chosen were the slump-flow, V-funnel and L-box, to characterize the

Table 8 – Fresh Fine Sand SCC Properties

Family	slump flow (mm)	V-funnel (s)	L-box (I_2/I_1)
3	680	9	0,90
4	690	9	0,95
5	680	10	0,90
6	660	11	0,90
7	670	10	1,00

Table 9 – Fly Ash SCC Unit proportion

Family	proportion					w/c	H (%)	Adt (%)	α (%)
	c	cv	ar	b9	b19				
3	1	0,30	1,08	0,89	0,73	0,38	9,45	0,46	59,50
4	1	0,40	1,44	1,19	0,97	0,43	8,62	0,46	56,80
5	1	0,50	1,80	1,49	1,22	0,51	8,50	0,46	54,91
6	1	0,60	2,16	1,78	1,46	0,60	8,57	0,46	53,71
7	1	0,70	2,52	2,08	1,70	0,66	8,21	0,46	52,75
8	1	0,80	2,88	2,38	1,94	0,72	7,97	0,46	52,00

Subtitles c – cement; cv – fly ash; ar – regular sand; b9 – grave 9,5 mm; b19 – grave 19 mm; H – humidity; adt – additive; α – mortar proportion

Table 10 – Material Consumption Calculated for fly ash SCC

Family	Bulk Density (kg/m ³)	Cement (kg/m ³)	Fine Sand (kg/m ³)	Regular Sand (kg/m ³)	Grave 9,5 mm (kg/m ³)	Grave 19 mm (kg/m ³)	Water (kg/m ³)	Additive (kg/m ³)
3	2343	535	161	578	476	391	202	2,46
4	2333	430	172	619	511	417	185	1,98
5	2330	358	179	644	533	437	183	1,65
6	2323	306	183	660	544	446	183	1,41
7	2304	266	186	671	554	452	175	1,22
8	2301	237	189	682	564	459	170	1,09

SCC. Observe that all values are within the parameters established by Tutikian (2004) [10] and ABNT NBR 15823 [11].

The same packing, previously employed, has been used to the fly ash mix, instead of fine sand. With the values all the features of this SCC family can be calculated.

The basis to calculate the consumption of materials represented in table 9 was the specific mass determined in fresh concrete, which was also considered for the fly ash SCC. In table 10 proportions per unit can be found. For this concrete family, it was necessary a dosage of 6 to determine the curves of strength and performance. The content of the superplasticizer was very close to those used in the SCC with fine sand at 0.46% while the content of the dry mortar was lower, ranging between 52% and 59.5% due to the fact that the ash content is slightly higher related to the total aggregates, compared with those of another family. The ratio w/c and moisture remained in the expected range, with the exception of the proportion 1:8, which indicates that the concrete was drier than the others, as it can be seen in Table 11, which shows the results of the workability tests for the family of fly ash SCC.

Table 11 shows the properties of fresh concrete. To characterize the fresh fly ash SCC, the slump flow, V-funnel and L-box tests were chosen. Observe that all values are within the parameters established by Tutikian (2004) [10] and ABNT NBR 15823 [11].

5. Results

Table 12 summarizes the results of the concrete hardened state for the family fine sand SCC. Something interesting occurred, that is, there was an increasing resistance to compression between the ages of 28 to 91 days, with a few points presenting values 60% plus higher, with an average of 53%, a fact that normally does not occur to concrete without pozzolan, although the cement used, CPVRS, contains about 15% of fly ash in its composition. The val-

Table 11 – Fresh Fly Ash SCC Properties

Family	slump flow (mm)	V-funnel (s)	L-box (I_2/I_1)
3	750	7	1,00
4	730	6	1,00
5	710	8	0,95
6	700	8	0,90
7	710	9	0,95
8	700	9	0,85

Table 12 – Hardened Fine Sand SCC Results

proportion 1:m	w/c	Compression Strength (MPa)				Ec (GPa)	US (m/s)	Cl (C)
		1 day	7 days	28 days	91 days			
1:3	0,36	43,1	63,9	73,3	95,0	40,6	4910	2825
		42,8	64,5	70,5	93,2	40,6	4860	3066
		-	-	-	-	40,0	4900	-
1:4	0,42	31,9	52,8	60,2	89,9	37,4	4897	3321
		33,1	53,0	59,5	94,2	38,3	4872	3054
		-	-	-	-	36,8	4835	-
1:5	0,53	21,7	40,1	44,7	69,5	35,9	4762	4091
		20,7	39,8	46,9	76,8	32,6	4774	3825
		-	-	-	-	34,6	4774	-
1:6	0,71	14,0	29,7	35,8	61,6	30,3	4680	4590
		15,9	28,2	36,9	57,4	28,5	4657	4617
		-	-	-	-	30,0	4668	-
1:7	0,77	10,6	24,1	27,3	42,7	24,1	4429	5451
		10,4	23,8	28,4	40,0	22,7	4424	5751
		-	-	-	-	20,9	4429	-

Subtitles: Ec – elastic modulus; US – propagation of ultrasonic waves; Cl – ion chloride penetration.

ues of elastic modulus and the propagation speed of ultrasound waves were growing as the proportions became richer and covered all the expected range, following the compressive strength, as expected. The penetration of chloride ions was high for this family, whereby moderate for the richest proportions and high for the proportions 1:5, 1:6 and 1:7, according to the classification proposed by ASTM 1202/97 [12].

Table 13 shows the behaviour equations and correction factor for the family of fine sand SCC.

In Figure 1, it is represented the dosage diagram for the family of fine sand SCC, determined by the behaviour equations as seen on Table 13. This graph represents the compression strength at various ages, the unit proportion 1:m, the cost and consumption of cement and mortar content, which varies according to the method used. The diagram should be used only for approximations, because for precise calculations it is used behaviour equations. It is regarded that the cost curve proves adequate only to their own determinations, and can not be used as a passageway for the mortar content. The graph should always be used clockwise from the compressive strength or counter-clockwise, from the mortar content.

In Figure 1, a proportion for any mixture wanted from an initial requirement can only be obtained approximately, such as the compressive strength. Thus, it allows to streamline the dosage process and have a broader view of the whole behaviour of the family, within the range of studied values. It is observed in Figure 1, a large growth, already reported, of the compressive strength from 28 to 91 days, as of 1 to 7 days. It can also be observed that the slope of the cost curve does not follow the consumption of cement, that is, there is not a proportional increase in values with an increasing consumption of cement, when the mixture becomes richer. The ta-

ble at the bottom of Figure 1 determines the proportion that should be used among aggregates, fine sand (af), regular sand (ar), grave 9.5 mm (b9, 5) and 19mm grave (b19), for any point within the range studied.

Finally, Figure 2 shows a diagram of performance for this same family, which represents the relationships between the compressive strength with elastic modulus, this one with speed of propagation of ultrasound waves the other one with chloride ion penetration. Obviously the diagram should be used in a clockwise direction and for approximations.

Finally, the results of the properties in the hardened fly ash SCC family is presented, as shown on table 14. As it has already occurred previously, it was used the highest values of compressive strength, elastic modulus and speed of propagation of ultrasound waves and the lowest values for the penetration of chloride ions.

The compressive strength values were high, if compared with the previous family, getting in the two richer proportions at 80 MPa after 28 days. These high results were caused probably due to the fact that the method proposed considers the fly ash as an aggregate, and by a more efficient packaging, something beneficial for those who choose pozzolans as fine material.

Another interesting fact is the small increase of the compressive strength from 28 to 91 days. As it was used fly ash, pozzolan, which reacts for longer (over 28 days), it would be expected a higher growth, which had not occurred.

The results of the elastic modulus and propagation speed of ultrasound waves increased together with the compression resistance, even though these mixtures present a higher content of mortar, which could affect the modulus, especially. It can be

observed that the test of the propagation speed of ultrasound waves showed a high variability when compared with other tests. This fact was not new, since that is what usually occurs in this essay. And as for the other family, the behaviour of the elastic modulus was exponential in respect to the compressive strength, and the linear equation was repeated for the other two properties of the performance diagram.

The penetration of chloride ions was low, all the proportions considered of low penetration, according to the clause ASTM 1202/97 [12]. Following, Table 15 presents the behavioural equations and the correlation coefficient for all the properties of fly ash SCC.

It was observed that in the correlation coefficient values were all above 0.94, increasing the reliability of the behavioural equations and, consequently, of the subsequent calculations.

Figure 3 contains a graph of strength for this family of SCC, noting this graph correlates the compressive strength at various ages compared with the w/c, with a unit proportion: 1:m, with the cost and consumption of cement and with the variable content of mortar. The chart should always be used in a clockwise direction from

the compressive strength or counter-clockwise, from the content of mortar. The cost curve can not be used as a passageway for the content of mortar. The axis 'y' positive represents, at the same time, compressive strength and mortar content, while the axis 'x' negative is divided between the cement consumption and cost.

In the dosage chart it can be observed that the compressive strength growth was more significant between 1 and 7 days, but with a similar increase among the other ages, reaching high values at 28 and 91 days. At this point it can be noticed that a variable content of mortar, new to the proposed method, and the cost curve, making its determination easier for any point on the diagram. Another facility for further measurements is the representation in the second quadrant, of the aggregates percentage, compared to the total 'm'.

Figure 4 has a performance diagram for the fly ash SCC family. These curves correlate the compressive strength, the modulus of deformation, the propagation speed of ultrasonic wave and the penetration of chloride ions. It must be used in a clockwise direction.

Table 13 – Fine Sand SCC Behaviour Equations and r^2

Property	Behaviour Equation	R^2
Compression Strength (Abram Law)	1 day $f_{cj1d} = \frac{126,71}{22,67^{a/c}}$	0,97
	7 days $f_{cj7d} = \frac{141,22}{9,64^{a/c}}$	0,99
	28 days $f_{cj28d} = \frac{151,22}{8,20^{a/c}}$	0,97
	91 days $f_{cj91d} = \frac{195,704}{6,10^{a/c}}$	0,91
Unit proportion 1:m (Lyse's Law)	$m = 8,7958 * a / c + 0,0691$	0,97
Cement consumption/ m^3	$C = \frac{2066}{m + 0,7615}$	1,00
Cost	$Cu = C * (0,467 + 0,0164 * m)$	1,00
Dry Mortar	$\alpha = 0,0214 * C + 53,324$	1,00
Elastic Modulus	$Ec = \frac{\log(f_{cj28d}) - 0,8463}{0,0243}$	0,96
Propagation of ultrasonic waves	$US = 29,245 * Ec + 3748,5$	0,97
Ion chloride penetration	$Cl = - \frac{(US - 5493,9)}{0,1813}$	0,99

Subtitles: f_{cj1d} – characteristic compression strength at 1 day; f_{cj7d} – characteristic compression strength at 7 days; f_{cj28d} – characteristic compression strength at 28 days; f_{cj91d} – characteristic compression strength at 91 days; Ec – elastic modulus; US – propagation of ultra sound waves; Cl – ion chloride penetration

Figure 1 - Fine Sand SCC Dosage Diagram

6. Comparative

In this item the costs and properties of two families for the same concrete compressive strength at a certain age will be compared. The ages of 1, 7, 28 and 91 days will be used, and the costs for these mixtures compared, as well as the modulus of elasticity, the propagation speed of ultrasound wave and the penetration of chloride ions.

The values that will be used for comparison vary according to the rupture age, as it also changes the needs. That is, the compressive strength of the concrete for one day is not the same for 28 days, as in the early ages of the cement, where it was searched only for an elastic modulus, by checking the initial de-mould resistance, in the case of conventional work, or when drawing out parts in the industry of prefabricates. It is known that the mixture will reach the highest resistance in later ages, and will meet the minimum requirements of ABNT NBR 6118/03 [13] for reinforced and pre-stressed concrete. Following, the compression strength of 10, 20 and 30 MPa for 1 day, 20, 30 and 40 MPa for 7 days and 40, 50 and 60 MPa for 91 days for the comparisons were fixed. The age of 28 days, as it is more regarded by designers and other professionals, will be standard for comparisons with the elastic modulus,

propagation speed of ultrasound wave and chloride ion penetration. Therefore, the compressive strength of 25, 30 and 40 MPa is determined, since they are equivalent to the compressive strength characteristic used, normally 20 to 35 MPa.

It is important to mention that these values were chosen by analysing the most common uses of concrete in the works, but other values could be chosen, depending on the implementation and professional opinion. With the behaviour equations already determined, it is simple to calculate the mixtures for any resistance, therefore it would be sufficient to recalculate for the other values.

6.1 Compressive Strength

Table 16 shows all costs of the concrete studied, allowing comparisons. In the last column, the cost differences between the fine sand SCC and the fly ash SCC were calculated.

The fine sand SCC has always presented higher costs compared to the fly ash SCC, for all ages in all the bands of resistance. This cost increase was significant, particularly in the most employed compressive strength, 28 days, reaching almost 15% increase. Figure 5 depicts the same data of table 16, however in a better way of viewing.

6.2 Elastic Modulus , ultrasound and chloride ion penetration

Table 17 shows the results of modulus of elasticity (E_c), velocity of propagation of ultrasound waves and the penetration of chloride ions for both types of concrete with the compressive strength of 25, 30 and 40 MPa at 28 days.

It is observed that the fine sand SCC showed the modulus of elasticity, the speed of propagation of ultrasound waves and the lower penetration of chloride ions higher than the fly ash SCC. Therefore, it can be stated, for the materials used in this study that the technical performance of the SCC with fly ash was higher than those SCC with fine sand.

Figure 6 depicts the same data of table 17, but a better way of viewing. The results of elastic modulus were multiplied by 1000 to have a better view on the scale used.

7. Conclusions

After performing this work, mainly the experimental part, it can be concluded that for the materials used, the fly ash showed always

higher results than the fine sand, both economically and technically. Besides permitting more economical production of SCC, the use of fly ash also resulted in superior values of elastic modulus and propagation speed of ultrasound wave, and inferior to chloride ion penetration produced by fine sand SCC.

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Figure 2 – Fine Sand SCC Performance Diagram

Table 14 – Hardened Fly Ash SCC Results

proportion 1:m	w/c	Compression Strength (MPa)				Ec (GPa)	US (m/s)	CI (C)
		1 day	7 days	28 days	91 days			
1:3	0,38	43,0	66,3	84,2	88,0	38,2	4910	480
		42,8	66,4	80,0	89,0	41,0	4932	450
		-	-	-	-	40,0	4900	-
1:4	0,43	36,8	63,3	80,0	84,9	37,7	4910	500
		37,9	62,6	79,9	89,0	38,4	4738	600
		-	-	-	-	34,8	4822	-
1:5	0,51	28,6	50,9	60,9	73,6	36,8	4860	612
		26,1	50,1	62,6	76,8	32,4	4850	620
		-	-	-	-	34,9	4872	-
1:6	0,60	19,5	36,8	49,9	63,5	34,3	4859	720
		19,1	35,1	52,3	61,7	31,0	4802	675
		-	-	-	-	31,3	4798	-
1:7	0,66	14,8	31,2	33,6	47,0	29,9	4810	780
		15,2	27,0	36,4	42,3	30,5	4750	775
		-	-	-	-	30,4	4780	-
1:8	0,72	11,6	28,7	37,7	45,4	29,0	4760	1000
		12,3	28,6	38,5	40,0	28,5	4750	868
		-	-	-	-	27,9	4750	-

Subtitles: Ec – elastic modulus; US – propagation of ultrasonic waves; CI – ion chloride penetration.

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Table 15 – Fly Ash SCC Behaviour Equations and r^2

Property		Behaviour Equation	R^2
Compression Strength (Abram Law)	1 day	$f_{cj1d} = \frac{191,16}{45,48^{a/c}}$	1,00
	7 days	$f_{cj7d} = \frac{194,446}{15,125^{a/c}}$	0,98
	28 days	$f_{cj28d} = \frac{237,30}{13,88^{a/c}}$	0,95
	91 days	$f_{cj91d} = \frac{223,56}{9,24^{a/c}}$	0,94
Unit proportion 1:m (Lyse's Law)		$m = 14,127 * a / c - 2,2532$	0,99
Cement consumption/ m^3		$C = \frac{2116,2}{m + 0,934}$	1,00
Cost		$Cu = C * (0,4658 + 0,0205 * m)$	1,00
Dry Mortar		$\alpha = 0,0251 * C + 46,038$	1,00
Elastic Modulus		$Ec = \frac{\log(f_{cj28d}) - 0,607}{0,0326}$	0,96
Propagation of ultrasonic waves		$US = 13,426 * Ec + 4387,3$	0,96
Ion chloride penetration		$Cl = -\frac{(US - 5112,9)}{0,3955}$	0,98

Subtitles: f_{cj1d} – characteristic compression strength at 1 day; f_{cj7d} – characteristic compression strength at 7 days; f_{cj28d} – characteristic compression strength at 28 days; f_{cj91d} – characteristic compression strength at 91 days; EC – elastic modulus; US – propagation of ultra sound waves; Cl – ion chloride penetration

Figure 3 – Fly Ash SCC Dosage Diagram

Figure 4 – Fly Ash SCC Performance Diagram

Table 16 - Comparative of compression strength at 1, 7, 28 and 91 days

Age (days)	fcj (MPa)	Fine Sand SCC	Fly Ash SCC	Cost difference (%)
1 Day	10	151,44	141,80	6,8
	20	189,52	177,70	6,7
	30	225,91	214,12	5,5
7 Days	20	145,39	133,28	9,1
	30	171,05	155,85	9,8
	40	197,82	180,24	9,8
28 Days	25	146,26	131,13	11,5
	30	157,55	139,91	12,6
	40	180,84	158,01	14,4
91 Days	30	128,17	125,94	1,8
	40	143,61	130,30	10,2
	50	159,57	147,52	8,2

Figure 5 - Compression strength Comparative at 1, 7, 28 and 91 days

Figure 6 - Comparative of E_c , ultrasound and chlorides for f_{cj} of 25, 30 and 40 MPa Table 17 - E_c , ultrasound and chlorides results

f_{cj} (MPa)	CAA AF	CAA CV	CAA AF	CAA CV	CAA AF	CAA CV
	Ec (GPa)		Ultrasound		Chlorides	
25	22,70	23,21	4412	4701	5965	612
30	25,96	26,69	4508	4746	5440	929
40	31,10	30,52	4658	4797	4610	798