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Comparative Assessment of Self-Compacting Concretes with and without Viscosity Modify Admixture

Comparação de Propriedades de Concretos Auto-Adensáveis com e sem Aditivo Modificador de Viscosidade

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Abstract

This paper aims to contribute to decisions concerning the use of viscosity modifying agents (VMA), which can be used as a partial substitute for fines, the elements responsible for increasing the resistance to segregation of self-compacting concrete (SCC). In this study, samples of SCC were prepared with and without the addition of a VMA using the mix design method proposed by Tutikian [1]. It was observed that the addition of a VMA increased compressive strength and in some cases also lowered chloride ion penetration within the same range of compressive strength values. It was also observed that the increased cost resulting from the use of a VMA was compensated by the use of a poorer mix, with similar strength levels.

Keywords: viscosity modify admixture (VMA), self-compacting concrete (SCC), cost, design diagram, ion chloride penetration.

Resumo

Este trabalho pretende dar uma contribuição para a tomada de decisão do uso dos aditivos modificadores de viscosidade (VMA), já que este componente substitui parcialmente os finos, responsáveis pela resistência à segregação do concreto auto-adensável (CAA). Foram dosados CAA com e sem a presença do VMA, através do método de dosagem proposto por Tutikian [1]. Observou-se que o VMA aumentou as resistências à compressão e diminuiu, em alguns casos, a penetração de íons cloretos, para a mesma faixa de resistência à compressão. Observou-se, também, que o aumento de custo provocado pelo aditivo foi compensado pela utilização de traços mais pobres, com os resultados finais similares.

Palavras-chave: *aditivo modificador de viscosidade (VMA), concreto auto-adensável (CAA), custo, diagrama de dosagem, penetração de íons cloretos.*

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1 Introduction

There are very few studies in Brazil on the use of self-compacting concrete (SCC). This lack of technical expertise in this area is compounded by concerns about the cost of type of concrete, which may be higher than that of vibrated concrete (VC) [2]. However, Ambroise et al. [2] tested some SCC samples which showed a cost increase of only 20% when compared with VC. If the cost reductions that resulted from eliminating placement and compacting operations had been accounted for, the final value would have probably been even lower. Grauers [3] states that the cost of SCC materials is only 10% higher than of materials used in VC for a similar compressive strength range.
According to Bernabeu [4], the use of SCC is an economically sound alternative in specific situations, such as when compacting or vibrating operations are difficult or when frames are too complex. However, for everyday use, a far-reaching study that addressed all these factors would be needed before the most cost-effective solution (SCC or CC) could be determined. In many cases, the savings represented by the use of SCC compensate for the higher cost of its components when compared with VC. Case studies in France and Sweden report final savings of 10% in structures built with SCC.
The development of special concrete types, particularly self-compacting concrete, which uses a high concentration of solid industrial by-products as fines, is a positive contribution to the sustainable development of concrete. The use of silica fume, fly ash, metakaolin, blast furnace slag and rice husk ash as cement substitutions provides significant environmental benefits because these are industrial by-products or wastes.
In addition, there is no need for mechanical compaction or vibration and the work environment can improve greatly. Physical labor becomes easier and the noise caused by compaction operations is eliminated. The use of SCC helps the civil construction sector to follow industrial production schemes by reducing labor costs and increasing structural quality, durability and reliability and by improving the safety of workers.
SCC can be classified into three types: fine (only the fine material reduces segregation), viscosity agent (only the viscosity modifying agent – VMA – reduces segregation) or combined (both components are present).
The use of VMAs in SCC is still limited, particularly because of the limited availability of technical expertise required for this process. In cases where the use of fine aggregates is limited by concerns of cost or technical limitations, the use of VMAs becomes mandatory.
Troli et al. [7] report a successful application of a VMA. In this case, a VMA was used in the composition of a SCC in a structure with massive concrete because it was necessary to reduce cement consumption. In massive concrete structures, cement consumption must be kept at the lowest possible level to minimize the formation of thermal cracks.
Viscosity modifying agents (VMAs) are water-soluble polymers that help increase concrete viscosity and stability [8]. They perform the same role as fine aggregates in concrete, so that the final mix will have few small particles, resulting in a material with a smaller specific area and lower water consumption. In other words, it is possible to obtain concrete samples with the same characteristics which may have smaller or identical water/binder ratios, but with greater fluidity or greater compressive strength without the onset of segregation.

Table 1 – Chemical analysis of the binders

Element	Cement (%)	Metakaolin (%)	Rice husk ash (%)
CaO	46.84	0.05	0.55
SiO_2	28.42	60.14	96.35
Al_2O_3	7.95	38.78	-
MgO	7.59	-	0.92
SO_3	6.38	-	-
Fe_2O_3	1.57	0.49	-
K_2O	1.24	0.52	2.17

2 Methods and Materials

Six SCC samples using three different fine aggregates were prepared, three of which received the addition of a VMA and three which were kept VMA free. The test program included determining compressive strength at 3, 7, 28 and 63 days, the cost of the compositions with the 30 MPa strength at 28 and 63 days and chloride ion penetration at 46 days. All tests were performed on two cylindrical test specimens measuring 10 X 20 cm. The three fine aggregates used were limestone, metakaolin and rice husk ash. These concretes were designed using the mix design method for SCC proposed by Tutikian [1]. This method uses the substitution (by weight) of one of the ingredients in conventional concrete (cement or sand) for a material with lower specific mass so that cohesion in SCC is increased. The first fine aggregate used was limestone, a non-pozzolanic material, so a choice was made to substitute this material for sand. In the other samples, cement was substituted because the fines used were pozzolanic materials. High early strength, sulfate-resistant Portland cement was used. Chemical analysis of the binders was carried out in the Ceramics Lab of the Federal University of Rio Grande do Sul (LACER) and results are shown in table 1. The unit mass and specific mass of these materials were determined using Brazilian standard NBR NM 23 [9] and results are shown in table 2. The fine aggregate was ordinary river sand. Crushed basalt rocks with a maximum size of 19 mm were used as coarse aggregate. Specific and unit mass values of fine and coarse aggregates are also shown in table 2 and the particle size distribution of these materials is shown in table 3. The specific mass of

Table 2 – Specific and unit mass values of fine and coarse aggregates		
	Specific mass (kg/dm³)	Unit mass (kg/dm³)
Cement	2.93	-
Limestone filer	2.81	-
Metakaolin	2.42	-
Rice husk ash	1.94	-
Sand	2.64	1.52
Gravel	2.84	1.43

fine and coarse aggregates was determined in accordance with Brazilian standards NBR NM 52 [10] and NBR NM 53 [11], respectively, while their unit mass was determined in accordance with Brazilian standard NBR 7251 [12]. The particle size distribution was determined using Brazilian standard NBR NM 248 [13]. For these tests, the sample was collected in accordance with Brazilian standard NBR NM 26 [14]. A third generation polycarboxylate superplasticizer agent and a viscosity modifying agent were used. The characteristics of these materials were supplied by the manufacturer. The pH of the superplasticizer ranges from 5 to 7, with specific mass between 1.067 and 1.107 kg/dm³ and solids content between 38 and 42% [15]. The VMA is an aqueous solution of high molecular weight polymers with specific mass ranging between 0.98 and 1.02 kg/dm³ and pH from 9 to 10.5 [15]. Table 4 shows the compositions of dry components by weight and the consumption of materials per cubic meter of concrete. The amount of VMA ranged from 0.80% to 1.00% by binder weight and the amount of fine aggregates decreased significantly when the SCC with VMA is compared with the SCC without VMA.
The self-compactin proprieties are in table 5.

3 Results

3.1 Compressive Strength

Table 6 shows compressive strength values at 3, 7, 28 and 63 days in accordance with Brazilian standard NBR 5739/94 [16], as well as the increase in strength over this period. A significant increase in strength was observed in the SCC sample with limestone filler and VMA from 7 to 28 days in all compositions tested.
Figures 1 to 6 show the mix design graphs for each of the concrete samples, with adjusted compressive strength values from table 6. These graphs are the final aim of the mix design method and correlate compressive strength, w/b ratios, cement:aggregate proportions (1:m) by weight and binder consumption per cubic meter to a specific workability. The figures show the improvements provided by the use of a VMA: the SCC sample with a VMA showed significantly lower w/b ratios for the same cement:aggregate proportions. In other words, to achieve a specific strength value, it is possible to use poorer compositions with a VMA and in this way make up for the higher cost of this additive. Figures 1 to 6 also show that higher compressive strength values were obtained in the SCC samples with a VMA when compared with the samples of plain SCC (without a VMA) for the same proportions of dry components by weight. The mix design graphs and the parameters that had been calculated earlier were determined using Abrams' mathematical model (3, 7, 28 and 63 days), Lyse's equations and binder consumption by the '1:m' proportion, which are found in table 7. These equations allow users to calculate all components in a desired composition by using a starting point e.g. the w/b ratio. It should be noted that the determination coefficients were nearly always greater than 0.90.

3.2 Cement Consumption

Figure 7 shows cement consumption in kg/m³ for SCC compositions with compressive strength = 30 MPa at each age of break (3, 7, 28 and 63 days). The consumption was calculated using the equations adjusted for binder consumption. Pozzolanic fines act as partial cement substitutes and a significant decrease in cement consumption was observed in SCC samples with the non-pozzolanic fine aggregate (limestone) when compared with the SCC samples with pozzolanic fines (metakaolin and rice husk ash).

Table 3 – Particles distribution of coarse and fine aggregates		
Sieves (mm)	Coarse aggregate	Fine aggregate
	Material Accumulated (%)	Material Accumulated (%)
# 19.00	0	0
# 12.50	41	0
# 9.50	74	0
# 4.80	97	1
# 2.40	100	5
# 1.20	100	15
# 0.60	100	39
# 0.30	100	82
# 0.15	100	99
FM	6.71	2.41
MSA	19 mm	2.4 mm

Table 4 – Consumptions of dry components by weight and the materials consumption in kg/m³

SCC	Dry components consumption										Consumption in kg/m³ of materials									
	1:m	C	MC	CCA	FC	AR	BR	w/b	SP	VMA	b	C	MC	CCA	FC	AR	BR	w/b	SP	VMA
FC without VMA	1:3	1.00			0.55	0.57	1.88	0.49	0.65		518	518			285	295	974	0.49	3.37	
	1:4.5	1.00			1.05	0.87	2.59	0.78	0.65		361	361			379	312	933	0.78	2.35	
	1:6	1.00			1.35	1.36	3.29	0.81	0.65		298	298			403	406	981	0.81	1.94	
	1:7.5	1.00			1.65	1.86	4.00	1.01	0.65		243	243			402	452	972	1.01	1.58	
FC with VMA	1:3	1.00			0.50	0.62	1.88	0.41	0.70	1.00	540	540			270	335	1015	0.41	3.78	4.86
	1:4.5	1.00			0.70	1.22	2.58	0.59	0.70	1.00	386	386			270	471	996	0.59	2.70	3.86
	1:6	1.00			1.00	1.71	3.29	0.78	0.70	1.00	300	300			300	513	987	0.78	1.95	3.00
	1:7.5	1.00			1.40	2.11	3.99	1.12	0.70	1.00	237	237			331	499	944	1.12	1.77	2.13
MC without VMA	1:3	0.60	0.40			1.12	1.88	0.57	0.75		486	292	194			545	914	0.57	3.65	
	1:4.5	0.70	0.30			1.92	2.59	0.60	0.75		378	265	114			725	978	0.60	2.84	
	1:6	0.70	0.30			2.71	3.29	0.81	0.75		293	205	88			793	963	0.81	2.20	
	1:7.5	0.70	0.30			3.51	4.00	1.03	0.75		238	167	71			835	951	1.03	1.79	
MC with VMA	1:3	0.75	0.25			1.12	1.88	0.46	0.85	0.80	517	387	129			579	971	0.46	4.39	4.13
	1:4.5	0.75	0.25			1.92	2.59	0.56	0.85	0.80	385	289	96			737	995	0.56	3.27	3.08
	1:6	0.75	0.25			2.71	3.29	0.80	0.85	0.80	294	220	73			796	967	0.80	2.50	2.35
	1:7.5	0.75	0.25			3.51	4.00	1.03	0.85	0.80	238	179	60			835	952	1.03	2.03	1.91
CCA without VMA	1:3	0.50		0.50		1.12	1.88	0.50	0.80		489	244		245		548	919	0.50	3.91	
	1:4.5	0.50		0.50		1.92	2.59	0.58	0.80		372	186		186		712	962	0.58	2.98	
	1:6	0.50		0.50		2.71	3.29	0.71	0.80		296	148		148		801	973	0.71	2.37	
	1:7.5	0.50		0.50		3.51	4.00	1.19	0.80		226	113		113		792	903	1.19	1.81	
CCA with VMA	1:3	0.65		0.35		1.12	1.88	0.42	0.85	0.90	516	335		181		578	970	0.42	4.38	4.64
	1:4.5	0.65		0.35		1.92	2.59	0.47	0.85	0.90	392	255		137		750	1013	0.47	3.33	3.53
	1:6	0.65		0.35		2.71	3.29	0.82	0.85	0.90	289	188		101		782	949	0.82	2.45	2.60
	1:7.5	0.65		0.35		3.51	4.00	0.84	0.85	0.90	247	161		86		866	987	0.84	2.10	2.22

Legend: C- cement; MC- metakaolin; CCA- rice husk ash; FC- limestone filer; AR- sand; BR- gravel; w/b – water/binder ratio, in mass; SP- superplasticizer; VMA- viscosity modify admixture; b- binders.

Table 5 – Self-compacting proprieties of SCC

SCC	Slump Flow Test (mm)	V-Funnel Test (s)	L-Box Test (h_2 / h_1)	U-Box Test (h_2 – h_1) mm
FC without VMA	630	7	0.90	20
FC with VMA	610	7	0.95	25
MC without VMA	650	8	0.95	20
MC with VMA	660	7	0.90	15
CCA without VMA	700	9	0.90	15
CCA with VMA	710	8	0.90	15

Legend: MC- metakaolin; CCA- rice husk ash; FC- limestone filer; VMA- viscosity modify admixture.

Table 6 – Compressive strengths values at 3, 7, 28 and 63 days								
SCC	**3d**	**7d**	**28d**	**63d**	**3/7**	**3/28**	**7/28**	**28/63**
FC without VMA	35.1	38.3	43.0	44.7	0.92	0.81	0.89	0.96
	12.6	15.8	21.4	21.2	0.79	0.59	0.74	1.01
	12.8	15.9	18.6	21.4	0.80	0.69	0.86	0.87
	7.8	9.7	11.6	13.0	0.80	0.67	0.83	0.90
FC with VMA	37.9	46.1	57.4	61.2	0.82	0.66	0.80	0.94
	22.7	25.0	59.2	58.7	0.91	0.38	0.42	1.01
	13.5	13.4	41.0	41.3	1.01	0.33	0.33	0.99
	6.9	7.6	25.7	29.5	0.91	0.27	0.30	0.87
MC without VMA	20.0	28.3	39.3	37.5	0.71	0.51	0.72	1.05
	19.5	27.9	33.6	35.3	0.70	0.58	0.83	0.95
	9.8	14.5	15.4	21.8	0.68	0.63	0.94	0.71
	5.2	8.7	14.0	15.8	0.60	0.37	0.62	0.89
MC with VMA	32.0	32.2	45.4	38.3	0.99	0.71	0.71	1.19
	23.5	30.7	37.6	41.6	0.77	0.62	0.82	0.90
	11.4	13.4	17.7	20.7	0.85	0.64	0.76	0.85
	5.7	8.8	13.5	12.8	0.65	0.42	0.65	1.05
CCA without VMA	16.1	22.1	32.1	39.6	0.73	0.50	0.69	0.81
	11.4	15.9	26.2	33.4	0.72	0.44	0.61	0.78
	7.6	10.4	20.5	25.8	0.73	0.37	0.51	0,80
	2.3	4.6	10.3	13.1	0.49	0.22	0.45	0.79
CCA with VMA	32.8	38.8	55.2	55.8	0.85	0.59	0.70	0.99
	29.0	32.9	42.6	54.9	0.88	0.68	0.77	0.78
	6.2	10.2	17.5	19.0	0.61	0.36	0.58	0.92
	7.1	10.8	18.6	16.4	0.65	0.38	0.58	1.13

Legend: C- cement; MC- metakaolin; CCA- rice husk ash; FC- limestone filer; VMA- viscosity modify admixture.

The use of a VMA in some cases resulted in an increase in cement consumption while in other cases the opposite behavior was observed. It cannot be said that the use of a VMA results in increased or decreases cement consumption for a specific compressive strength level.

3.3 Cost

For the sake of comparison, a compressive strength value of 30 MPa at 28 and 63 days was selected. Equations were then used to calculate the other parameters in the composition so that the cost of each SCC composition could be determined. The price of cement was US$ 0.133/kg, rice husk ash was US$ 0.34/kg, metakaolin was US$ 0.20/kg, sand was US$ 0.004/kg, limestone filler was US$ 0.027/kg, crushed basalt was US$ 0.006/kg, the superplasticizer agent was US$ 5.00/kg and the VMA was US$ 1.67/kg. The cost of rice husk ash is an estimate based on freight costs because this material was not commercially available at the time of this study.
Figure 8 shows the cost of different SCC compositions with compressive strength = 30 MPa at 28 days. It can be seen that the cost of SCC with metakaolin and rice husk ash (with and without the VMA) was nearly identical, i.e. the higher cost of the additive was cancelled out by the

Figure 1 – Mix design graph for SCC with limestone filer without VMA

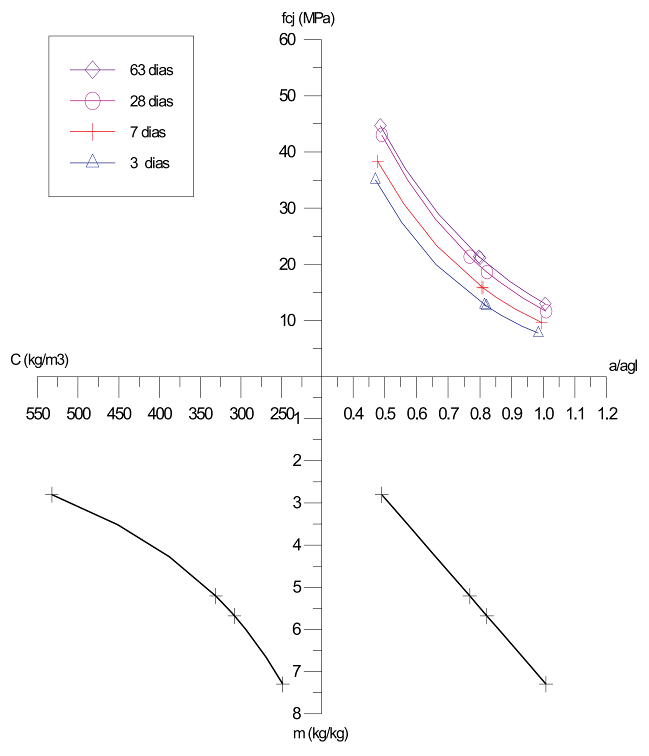


Figure 2 – Mix design graph for SCC with limestone filer with VMA

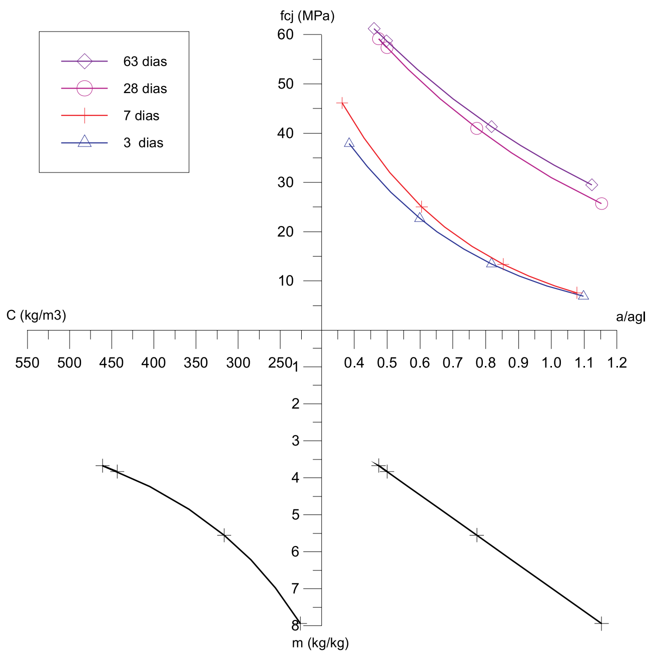


Figure 3 – Mix design graph for SCC with metakaolin without VMA

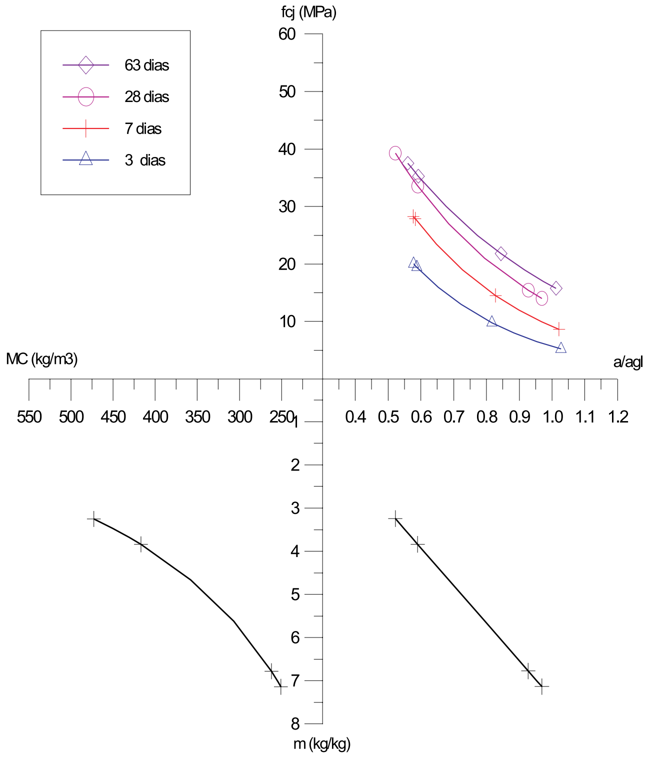


Figure 4 – Mix design graph for SCC with metakaolin with VMA

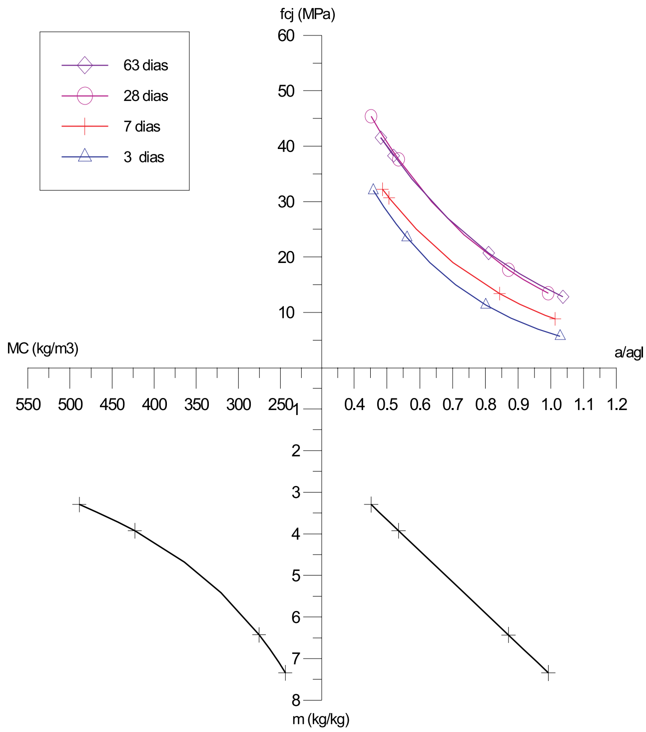


Figure 5 – Mix design graph for SCC with rice hush ash without VMA

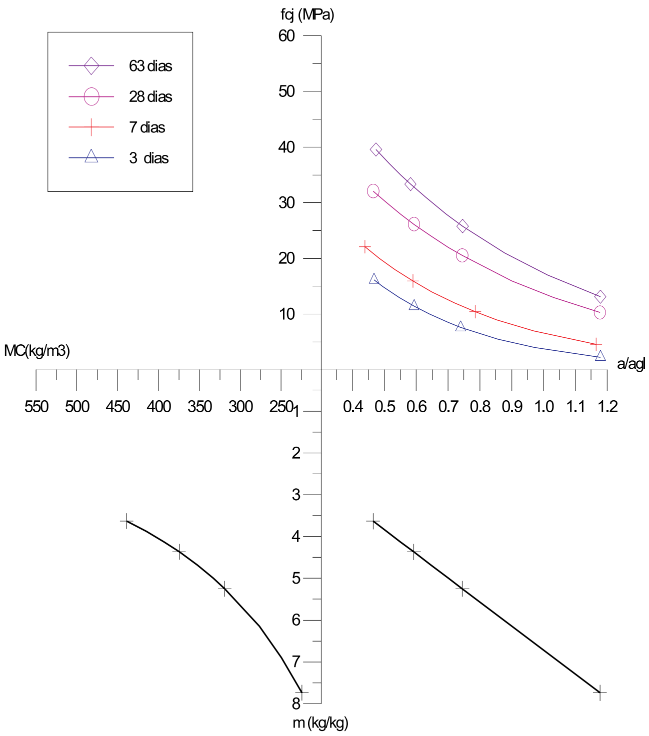
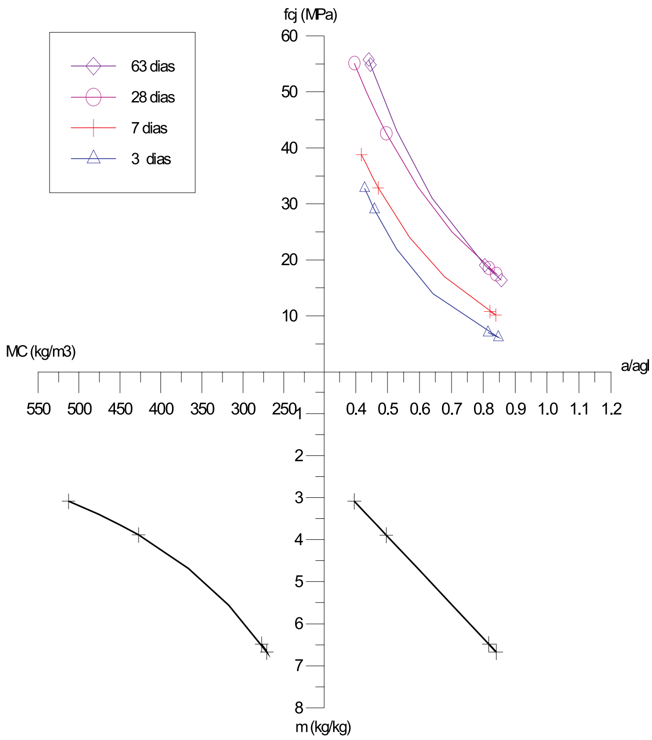


Figure 6 – Mix design graph for SCC with rice husk ash with VMA



lower cost of the binders. This shows it is possible to prepare a SCC composition with a VMA at a similar cost to a SCC composition without a VMA for a specific compressive strength range with a smaller consumption of fines, which greatly reduces the occurrence of pathological manifestations that is observed when fine aggregates are used as binders. The cost of SCC with limestone filler and VMA was 35% lower than that of the SCC without the VMA because of the increase in compressive strength shown by SCC with limestone without the VMA from 7 to 28 days.

Figure 9 shows that at 63 days the cost of SCC with the VMA and compressive strength = 30 MPa was 8% higher when metakaolin was used and 15% higher when rice husk ash was used. This is due to the increase in strength observed in the

Figure 7 – Cement consumption (kg/m³) of SCC with fc=30 MPa, at each age of break

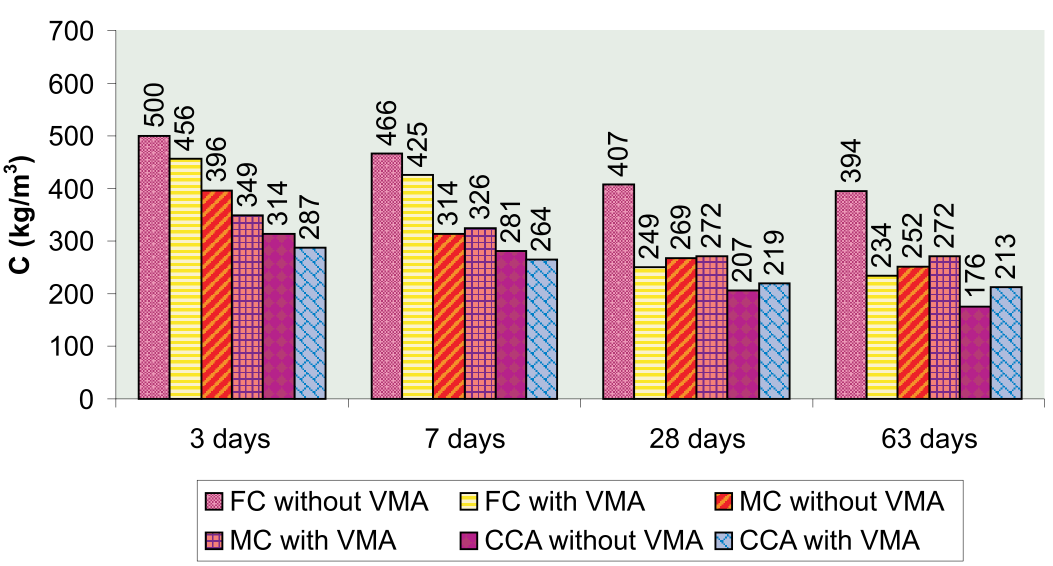


Figure 8 – Cost of SCC with fc=30 MPa at 28 days

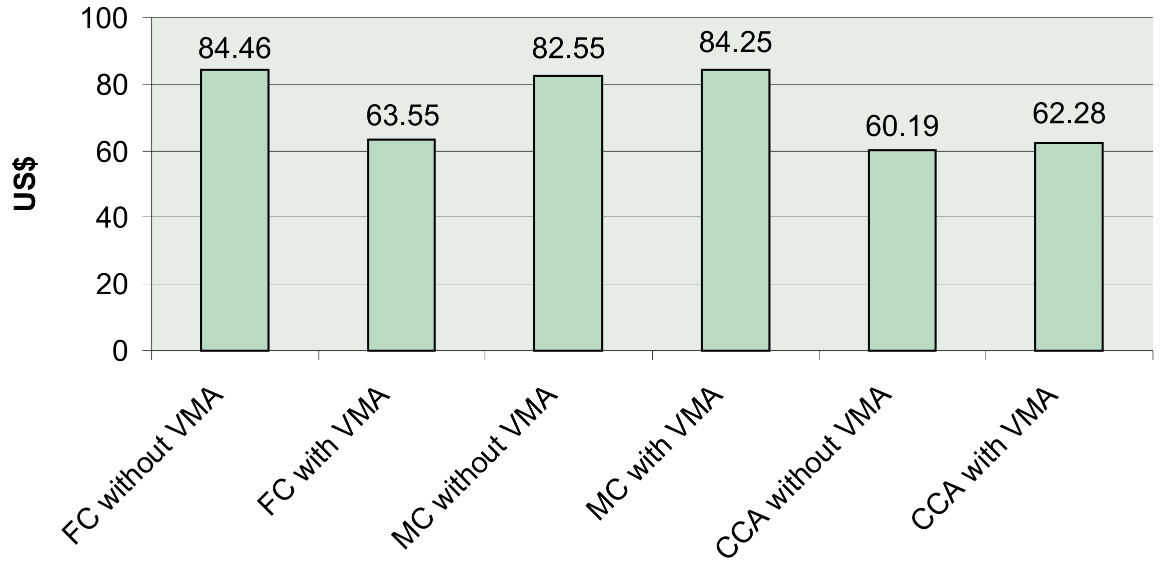
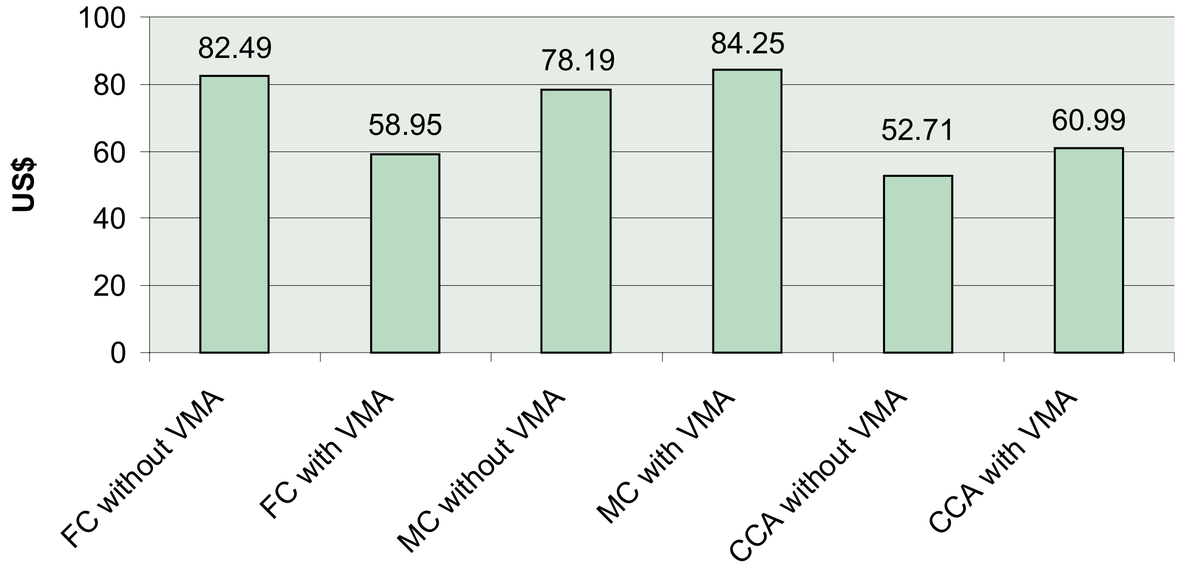


Table 7 – Equation and determination coefficients of SCC

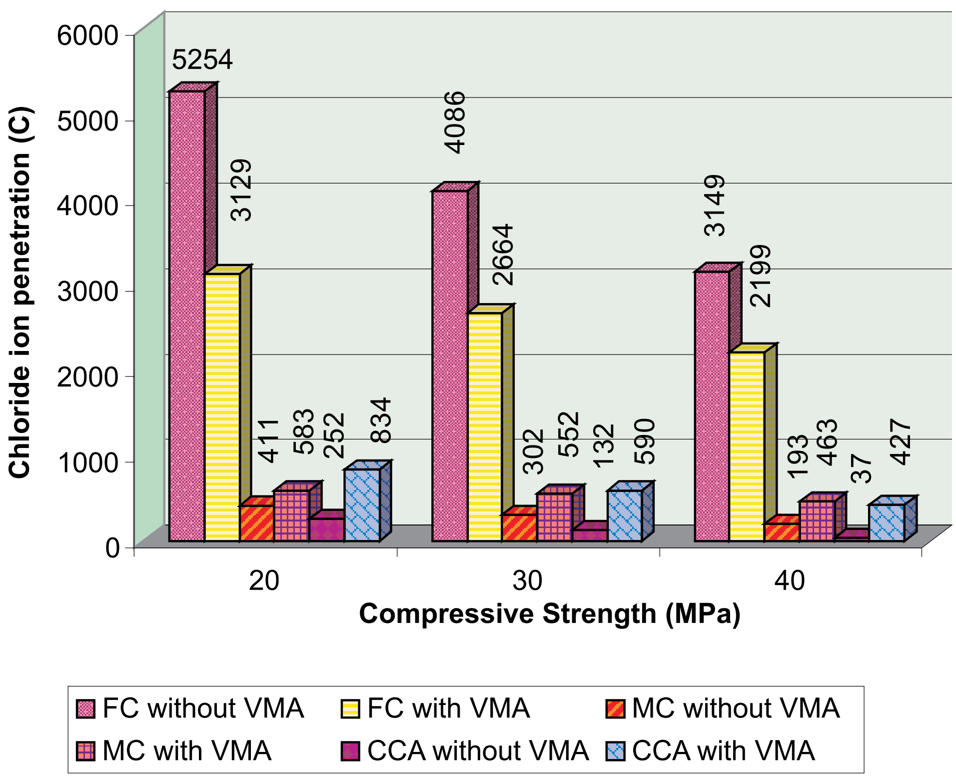
SCC	Abrams´s Law				Lyse´s Law	MC X m
	3d	7d	28d	63d		
FC without VMA	$fc3 = \frac{139.25}{18.78^{a/c}}$	$fc7 = \frac{136.71}{14.34^{a/c}}$	$fc28 = \frac{148.22}{12.45^{a/c}}$	$fc63 = \frac{141.87}{10.76^{a/c}}$	$m = 8.6617 * a/c - 1.4412$	$C = \frac{2099.1}{m + 1.1329}$
	R^2=0.98	R^2=0.99	R^2=1	R^2=1	R^2=0.92	R^2=1
FC with VMA	$fc3 = \frac{94.91}{10.88^{a/c}}$	$fc7 = \frac{115.19}{12.43^{a/c}}$	$fc28 = \frac{105.97}{3.42^{a/c}}$	$fc63 = \frac{101.63}{3^{a/c}}$	$m = 6.2929 * a/c + 0.6876$	$C = \frac{1902.9}{m + 0.4602}$
	R^2=0.99	R^2=1	R^2=0.92	R^2=0.96	R^2=0.97	R^2=1
MC without VMA	$fc3 = \frac{113.16}{19.98^{a/agl}}$	$fc7 = \frac{131.25}{14.27^{a/agl}}$	$fc28 = \frac{130.89}{10.01^{a/agl}}$	$fc63 = \frac{109.62}{6.77^{a/agl}}$	$m = 8.7123 * a/agl - 1.306$	$MC = \frac{2073.4}{m + 1.1339}$
	R^2=1	R^2=0.99	R^2=0.87	R^2=0.99	R^2=0.92	R^2=1
MC with VMA	$fc3 = \frac{128.09}{20.55^{a/agl}}$	$fc7 = \frac{106.71}{11.7^{a/agl}}$	$fc28 = \frac{125.43}{9.47^{a/agl}}$	$fc63 = \frac{115}{8.28^{a/agl}}$	$m = 7.4818 * a/agl - 0.0808$	$MC = \frac{1973.8}{m + 0.7375}$
	R^2=1	R^2=1	R^2=0.97	R^2=0.95	R^2=0.97	R^2=1
CCA without VMA	$fc3 = \frac{58.86}{15.86^{a/agl}}$	$fc7 = \frac{56.99}{8{,}68^{a/agl}}$	$fc28 = \frac{67.28}{4.92^{a/agl}}$	$fc63 = \frac{82.95}{4.78^{a/agl}}$	$m = 5.7592 * a/agl + 0.9594$	$MC = \frac{1886.9}{m + 0.6659}$
	R^2=0.99	R^2=0.97	R^2=0.99	R^2=0.99	R^2=0.84	R^2=0.99
CCA with VMA	$fc3 = \frac{179.6}{53.04^{a/agl}}$	$fc7 = \frac{146.79}{24.04^{a/agl}}$	$fc28 = \frac{153.64}{13.28^{a/agl}}$	$fc63 = \frac{205.12}{19.12^{a/agl}}$	$m = 8.0675 * a/agl + 0.1070$	$MC = \frac{2054.7}{m + 0.9171}$
	R^2=0.99	R^2=0.99	R^2=0.99	R^2=0.99	R^2=0.87	R^2=0.99

Figure 9 – Cost of SCC with fc=30 MPa at 63 days



samples without the VMA from 28 to 63 days, which was not seen in the samples of SCC with the VMA. This is probably because lower w/b ratios were used in the latter, causing it to reach its maximum strength faster. Once again, the sample of SCC with limestone filler and the VMA was cheaper than the same sample without the VMA (a 42% difference in cost).

Figure 10 – Chloride ion penetration at 46 days



3.4 Chloride Penetration

The chloride ion penetration test based on the measurement of the total electrical charge passed was carried out in accordance with ASTM C 1202/97 [17]. Figure 10 shows a comparison of chloride penetration values for compressive strength levels of 20, 30 and 40 MPa in each one of the SCC types with limestone filler, metakaolin and rice husk ash. The same figure shows the values found in the tests, while table 8 shows the equations and determination coefficients used to calculate additional variables. It can be observed that all determination coefficients exceeded 0.90, which increased the reliability of the results.
Figure 10 shows a comparison of chloride ion penetration values for all SCC formulations. It can be observed that the samples with metakaolin and rice husk ash showed chloride penetration values far lower than that of the samples with limestone filler, which is an aggregate. This is probably due to the fact that the pozzolanic addition results in physical and chemical changes that seal the concrete pore structure and react with the calcium hydroxide resulting from the cement hydration reaction. According to the ASTM standard used, chloride penetration is classified as high if the total charge passed is greater than 4000 C, moderate if it is between 2000 C and 4000 C, low if it is between 1000 C and 2000 C, very low if it is between 100 C and 1000 C and negligible if lower than 100 C. The values found show that the SCC with limestone filler without the VMA had high or moderate chloride penetration, while the same composition with the VMA showed only moderate chloride penetration. The SCC with metakaolin and rice husk ash showed very low chloride penetration.

4 CONCLUSIONS

The experimental work in this study showed that:

a) The SCC with the VMA achieves higher compressive strength values than the SCC without the VMA for the same 1:m proportion;
b) For a given 1:m proportion, the addition of a VMA makes it possible to use lower w/b ratios when preparing SCC;
c) It was not possible to determine the influence of the VMA on cement consumption in SCC with the same compressive strength because some samples showed lower cement consumption while others showed an increase in this factor, regardless of the addition of the VMA;
d) The SCC with pozzolanic fillers showed significantly lower cement consumption than the SCC with non-pozzolanic fillers for a given compressive strength range;
e) The higher cost of the VMA can be cancelled out by the use of poorer compositions for the same compressive strength range;
f) It was not possible to assess the influence of the VMA on chloride ion penetration because SCC samples with the same compressive strength showed an increase in chloride penetration while others showed a reduction in this factor, regardless of the addition of the VMA;
g) The penetration of chloride ions is significantly reduced in the SCC with pozzolanic fines when compared with the SCC with non-pozzolanic fines for a given compressive strength range.

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Table 8 – Equation and determination coefficients of SCC to chloride ion penetration

CAA	Equações	R^2	CAA	Equações	R^2
FC without VMA	$fc = 10^{-6} * Cl^2 - 0.0179 * Cl + 86.446$	0.96	MC with VMA	$fc = 0.0003 * Cl^2 - 0.417 * Cl + 168.8$	0.99
FC with VMA	$fc = -0.0215 * Cl + 87.273$	0.98	CCA without VMA	$fc = 0.0001 * Cl^2 - 0.1219 * Cl + 44.391$	0.90
MC without VMA	$fc = -0.0914 * Cl + 57.609$	0.94	CCA with VMA	$fc = 5 * 10^{-5} * Cl^2 - 0.1122 * Cl + 78.793$	1

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