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Performance of the addition of cane bagasse ash as a filler to produce self-compacting concrete

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ABSTRACT

The performance of the influence of cane bagasse ash (CBC) as filler in self-compacting concrete mixtures (CAC), added in a 0%, 5%, 10%, 15%, 20% and 25% with respect to weight of cement was evaluated. Ash characterization was performed by FTIR, FRX and XRD. The workability properties of CAC were determined by slump flow, J-ring, L-box, V-funnel, Visual Stability Index, and compressive strength tests. According to the results, the percentages of 10 to 20% in the CAC mixtures obtained a satisfactory performance, evidencing outstanding workability and compressive strength parameters compared to works like those published in the literature.
Keywords: self-compacting; bagasse ash; addition; filler; concrete.

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Contribution of each author
In this work, the author J. A. Zea contributed to the design of the investigation and the making of the laboratory tests (50%), the writing of the text (50%), analysis and discussion of the results (30%), and review (30%). The author A. López contributed to the design of the investigation and the making of the laboratory tests (20%), the writing of the text (30%), analysis and discussion of the results (30%), and review (30%). The author D. Hernández contributed with the writing of the text (10%), analysis and discussion of the results (20%) and revision (10%). The author J. E. Mandujano contributed to the design of the investigation and the making of laboratory tests (20%), analysis and discussion of the results (10%). The author J. A. Cabrera contributed to the design of the investigation and the making of the laboratory tests (10%), the writing of the text (10%), analysis and discussion of the results (10%), and review (30%).

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Desempeño de la adición de ceniza de bagazo de caña como filler para producir concretos autocompactantes.

RESUMEN

Se evaluó el desempeño de la influencia de la ceniza de bagazo de caña (CBC) como filler en mezclas de concreto autocompactante (CAC), adicionado en un 0%, 5%, 10%, 15%, 20% y 25% con respecto al peso de cemento. La caracterización de la ceniza se realizó mediante FTIR, FRX y DRX. Las propiedades de trabajabilidad del CAC fueron determinadas mediante ensayos de flujo de asentamiento, anillo J, caja en L, embudo V, Índice de Estabilidad Visual y resistencia a la compresión. De acuerdo con los resultados, los porcentajes de 10 al 20% en las mezclas de CAC obtuvieron un desempeño satisfactorio, evidenciando parámetros de trabajabilidad y resistencia a la compresión sobresalientes comparados con trabajos similares a los publicados en la literatura.

Palabras clave: autocompactante; ceniza; agroindustrial; adición; filler; concreto

Desempenho da adição de cinza de bagaço de cana como carga para a produção de concreto auto-adensável.

RESUMO

Foi avaliado o desempenho da influência da cinza do bagaço de cana (CBC) como carga em misturas de concreto autoadensável (CAC), adicionada de 0%, 5%, 10%, 15%, 20% e 25% em relação ao peso de cimento. A caracterização das cinzas foi realizada por FTIR, FRX e XRD. As propriedades de trabalhabilidade do CAC foram determinadas por slump flow, J-ring, L-box, V-funnel, Índice de Estabilidade Visual e testes de resistência à compressão. De acordo com os resultados, as porcentagens de 10 a 20% nas misturas de CAC obtiveram um desempenho satisfatório, evidenciando excelentes parâmetros de trabalhabilidade e resistência à compressão em relação a trabalhos semelhantes aos publicados na literatura.

Palavras-chave: auto-adensável; cinza; agronegócio; adição; enchimento; concreto.

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1. INTRODUCTION

The environmental management and the impulse of a sustainable development are constantly more usual along the years, the collective conscious has increased along with the potential problems that the grown of the construction industry causes on the environment. In general terms, construction is not an ecofriendly activity, considering the effects on the soil, the depletion of natural resources and production of residuals and several contaminants as anthropogenic emissions of CO_2 (Silva, et al., 2015).

We cannot deny the role that concrete has on human history, moreover Portland concrete created on early XIX century, which evolved and industrialized along with the times and showing to be the most used on XX century. However, some doubts about the use of this material have come out, related with its high cost and environmental impact that its production and extensive use generates. It is also notable the increase on the production of it that third world countries have experienced on last decades.

Mexican concrete industry is the second largest on Latin America, with an installed capacity around 64 million of tons and a total production if just under 40 million on 2019 (S&P Global, 2020). The main problem of this productions is that this process for the elaboration generates extensive amount of carbon dioxide (CO_2). Each ton of Compound Portland Concrete (CPC) produced emits 30% of this to the atmosphere (Méndez, 2008).

The industry of concrete production is one of the biggest industrial sectors that emit CO_2, responsible of the 5% to 8% of the emissions. The production on concrete has grown from 2.1 billion of tons on 2004 to 4.65 billion of tons on 2016. On its fabrication, approximately half of the emissions of CO_2 come from the fossil combustion, meanwhile the rest is emitted by the limestone calcination. Emissions also depend on the characteristics of the production, geographic location, technology, production efficiency, fuel selection for the oven and combination of energy sources used on the electricity generation (León & Guillén, 2020).

The high consumption of the natural and energetic resources, emissions of CO_2, and other contaminants (Cachán, 2001) compromise the future possibilities for the use of this marvelous construction material. For reducing this situation, there is work on the reduction of its environmental impact by two sides; 1) Improve the efficiency of the processes on the production, trying to decrease the energetic intake and 2) optimize the concrete consumption (Águila & Sosa, 2008). This article is specially developed on the second side, with the support of several investigations and advances that the concrete technology has experienced on the last decades, potentialized by the use of modern visualization equipment and the evaluation of fine materials as the cement (Martirena, et al., 1997), and the existence of powerful chemic additives, additional minerals, natural additions and alternative materials that have extend considerably the possibilities of lowering the proportion of cement on the mixture without impact and even improving the properties of the concrete (Mehta, 2000; Nasvik, 2006).

Now, efforts are being made for taking to the practice strategies that control and regulate the supervision of subproducts, residuals and industrial waste with the purpose of preserving the environment. Nevertheless, on the industrial sector of the agro-industrial, the alternative solution to the generated wastes is the incineration, where the problem of reduction of volume is partially treated, however, other problems are generated by the dispersed particles on the air. Sugar cane is one of the main crops on several countries and all its production is estimated on more than 1500 million of tons (Dharanidharan, et al., 2015). In México we count with a national production of approximately 56 million of tons (SIAP, 2018).

Sugar industry is based on 54 sugarcane mills, distributed on 15 states and 267 Mexican municipalities. Specially, the state of Chiapas has the 5th national place on the production which represents the 5.5% of the total (SIAP, 2018). They´re two main sugarcane mills: "Belisario Domínguez y Pujiltic", located on the municipalities of Huixtla y Venustiano Carranza respectively, where the generation of residuals on the fabrics is one of the main pollution sources of this industry, besides of the release of wastewater and the emission of gasses and fine particles to the atmosphere.
The use of some ashes from agricultural wastes, provide advantages to concrete, both in the fresh and hardened state, as well as improving its durability. Among other additional advantages of its use, we find the reduction of production costs (optimization of cement uses) and the reduction of the environmental problems related with the management and final deposit of the agro-industrial wastes. Under this perspective, it has been studied the capacity of utilization and the influence of the addition as a filler for the CBC on the elaboration on de CAC on fresh and hardened state (Jiménez, 2013).
The CAC represent a revolutionary growth for the last decades on the construction with concrete sector. It could be described as the material with the ability of flowing and compacting by its own weight, and easily covering completely a falsework, even on the presence of a dense armor, without the need of any vibration, while keeps homogeneity and consistency. It is distinguished by its properties on fresh state: passing capacity (limited fluency), resistance to segregation (stability) and its capacity of filling (non-limited fluency) (Okamura y Ouchi, 2003). On the other hand, it is expensive due to the big amount of cement, which means a disadvantage taking into consideration the ecological impact it has. This situation leads to use fine materials as a replacement, most used are fly ash, silica fume, blast furnace slag, natural pozzolans and fine limestone. The use of these materials can reduce costs and brings an additional performance to CAC (Silva, et al., 2015).
The investigations of Sinde, et al. (2016), Petermann, et al. (2018) y Hien Le, et al. (2018), have determined that the additions on CBC, with characteristics of pozzolanic material, allow an optimization of the cement consumption. In addition, can also have effect on the characteristics and physical properties of the CAC. Nevertheless, they can have an adverse effect on the mechanical resistances of the CAC with CBC compared with the CAC without the industrial subproduct. That is the reason of the analysis in the performance that has the use of the CBC as filler on mixes of CAC on fresh and hardened state, to determine if it represents an option of taking advantage of the residuals, contributing on the mitigation of its accumulation on the environment.

2. METHODOLOGY

The component materials of the concrete were characterized as well as the CBC according to the current policies. Preliminary tests were made on concrete with and without CBC, to check the performance of self-compacting concrete. Lately the proportions for the final mixes used for the evaluation of the performing of CBC where stablished by testing self-compacting concrete (EFNARC, 2002) and the compression resistance

2.1 Required proportioning

2.1.1 Material Characterization

The ashes used for this investigation project were obtained from the sugarcane mill on Pujiltic, Chiapas. For using it, they were tested for chemical characterization of FTIR, FRX and DRX, which allowed the understanding of mineralogical composition of the material and its possibility of being pozzolanic.

The characterization of the coarse and fine aggregates was made according to the specifications of the Standard ASTM C33 (2018). Stone materials from the region were used, specifically quartz sand from the Santo Domingo River, with fineness modulus of 2.80, absorption 6.37% and density of 2.97. On the other hand, gravel was used for the coarse aggregate, it was crushed on ½", basalt and andesite type, with a density of 2.87, absorption of 2.69%, dry and compact volumetric weight of 1488 kg/m^3 and humidity of 0.89%. This deposit is located south-west of the city of Tuxtla Gutiérrez, Chiapas, Mexico. The cement used corresponds to type II, CPC 30R RS, brand "Cruz Azul".

The additive used for this investigation project is Master Glenium 3200, which is a high range water reductor additive classification type F, and according with the standard norm ASTM C494 (2020), it is classified as superplasticizer, since allows the reduction of mixing water by more than 12% for certain consistencies.

2.1.2 Experimental design

Seven types of concrete mixtures were made according to the standard ACI-211.4R (2008):

One control mixture (CC-0%) used as reference for the design and other concrete mixture with fluidizing additive (CF-0%) with which the behavior and development of CAC was analyzed; the other five mixes have different percentages of CBC respectively to the cement weight: 5%, 10%, 15%, 20% y 25%, (table 1). Coarse aggregate was used with a maximum size of 12.7 mm (1/2'') and fine aggregate of river sand. All the mixes were designed according to the absolutes volumes method of the American Concrete Institute (ACI) (ACI-211.1., 2002), for which the relations on table 1 were considered.

Figure 1. Filling of cylinders with self-compacting concrete.

Table 1. Concrete mixtures designs.

Mixture design	Relation a/c*	Water (kg/m^3)	Cement (kg/m^3)	Cane bagasse ash (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Superplasticizer (% by cement weight)
CC-0% CBC	0.50	190.00	380.00	---	830.00	845.00	---
CF-0%CBC	0.50	190.00	380.00	---	830.00	845.00	2.00
CAC-5%CBC	0.48	190.00	380.00	19.00	830.00	845.00	2.00
CAC-10%CBC	0.45	190.00	380.00	38.00	830.00	845.00	2.00
CAC-15%CBC	0.43	190.00	380.00	57.00	830.00	845.00	2.00
CAC-20%CBC	0.42	190.00	380.00	76.00	830.00	845.00	2.00
CAC-25%CBC	0.40	190.00	380.00	95.00	830.00	845.00	2.00

CC= Concrete of Control, CF= Fluid Concrete, CAC= Self Compacting Concrete, CBC= Cane bagasse ash
Relation a/c where c* is the total cement material + CBC*

2.1.3 Test tubes preparation

A total of 196 cylindrical test tubes of 150 mm x 300 mm were manufactured. They were covered for 24 hours and lately cured by immersion on a saturated solution of calcium hydroxide, remaining in that condition until the date of the test stablished according to ASTM C31 (2008).

Table 2. Characteristics of the test tubes and testing times for mechanical proofs.

Test	Description	Time (days)	Number of cylinders
Compressive resistance	Cylinders: 150mm Ø x 300mm	7, 14, 28, 56, 90, 180, 360	196

Figure 2. Preparation of the cylinders for the essay.

In this process, a mixer with a capacity for a bag of cement was used, capacity of the mix of 255 l and with volume of 350 l. The total kneading time was 7 minutes. It is worth mentioning that due to the amount of mix it was necessary making two simultaneous concrete mixes.

2.1.4 Characterization for the mixes on their fresh state

All the mixes were made based on the *Specifications and guidelines for self-compacting concrete HAC* from EFNARC (2002). The settlement flow tests were used, settlement flow T_{50cm}, J-ring, L-box, funnel V at $T_{5minutes}$ (EFNARC, 2002) and Visual Stability Index (VSI) (ASTM C1611, 2018).

Figure 3. Mixtures on fresh state characterization for the evaluation of the elemental parameters of workability for a CAC.

2.1.5 Characterization of the mixtures in hardened state

Compression resistance

The test for the compression resistance were made according with the standard norm ASTM C39 (2004). In total, 196 test tubes were used for seven types of mixtures, from which 4 of each of them were proved at ages of 7, 14, 28, 56, 90, 180 and 360 days.

Figure 4. Test for the compression resistance sequence.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of the CBA and cement by FTIR

FTIR technique allows the qualitative analysis of the organic and inorganic samples, using these tests for quality control and/or investigation requirements. Figure 5 shows the spectrum FTIR of the cane bagasse ashes (CBA) and Portland cement. The analysis was made on the mid-infrared in the vibrational zone of 4000 to 600 cm^{-1}.

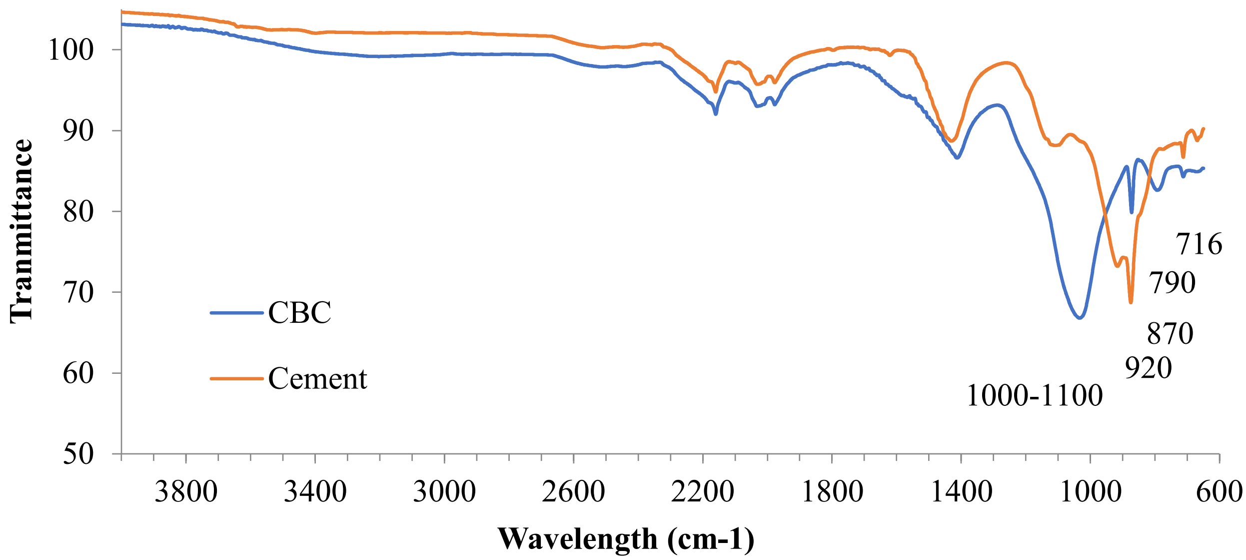

Figure 5. FTIR Spectrum, comparative of the CBC and CPC 30R

On the FTIR spectrum of the CBC shown on figure 5 it can be seen a strip on 1108 cm^{-1}, corresponding to the Silica (O-Si-O) (Sócrates, 2004). Meanwhile that in regions close to 1042 cm^{-1} there were detected signals corresponding to Si-O (Castaldelli, et al., 2016) and on the wavelengths of 1472 and 870 cm^{-1} it was related with the presence of carbonates (O-C-O) (Castaldelli, et al., 2016). Likewise, for the value of 870 was associated with the presence of SiOH, and at 716 cm^{-1} for K2O (Castaldelli, et al., 2016). Using this technique, it was possible to get an approach to the chemical composition of the sugarcane bagasse ash, showing it is mainly compounded of SiO2 and carbonates, which allowed an analysis using the XRD technique.

3.2 Chemical characterization of the cement and the CBC for FRX

The elemental characterization of the ashes and the cement was made under fluorescence of X-rays. For this, a pill was prepared taking 15 g of the sample (sifted ash with no. 200 mesh and cement), with 0.6 g of compacting gel. It is processed in a ring pulverized for a standard time stipulated by the laboratory. Once the sample has been pulverized, 6.6 g of each sample is weighed and taken to a press to form the pill, which is analyzed by the fluorescent X-ray MagixPro PW-2440 Philips equipment. FRX technique is based on bombarding the sample with X-rays (primary), which excite the atoms, that upon returning to their initial state, emit X-rays (secondary radiation) of determined wavelengths expressed as a mass/mass percentage.

On the Table 3 there are shown the chemical compositions of the CBC and the cement determined by the X-rays fluorescence technique (FRX). It was determined that compounds with the highest presence in the CBC are SiO_2, Al_2O_3 y Fe_2O_3 reaching a total value of 56.8 %. According to the standard norm ASTM C618 (2019), the sum of the compositions of de SiO_2, Al_2O_3 y Fe_2O_3 must be equal or superior to 70% for class N and F pozzolans. Even class C pozzolans are considered of 50% or more of said components, which is the possible classification of the ash used in this project. Other reported investigations on the literature have reached higher values than 70% from SiO_2, Al_2O_3 y Fe_2O_3 compounds, for the CBC (Teixeira et al., 2010). Besides, when CBC contains a high amount of silica (SiO_2) and alumina (Al_2O_3) it is classified as a class F ash, which presents a good pozzolanic activity and allows its use as a partial replacement of Portlan cement (Camargo, 2014). Nevertheless, the CBC used on this project contained a low amount of alumina (Al_2O_3) and high amount of CaO, as can be seen on table 3, which is considered with reduced pozzolanic properties given its components.

Table 3. Chemical characteristics of the CBC and CPC 30R.

Characteristics (%)	CBC	Cement
SiO_2	55.1	24.3
Al_2O_3	0.7	4.3
Fe_2O_3	1.0	3.0
CaO	39.7	58.8
MgO	1.1	1.4
K_2O	0.8	0.7
Na_2O	0.9	0.8

There is a belief, that given the burning procedure used in the sugar mill, to eliminate cane bagasse waste, the loss to fire of CBC samples may be high, since the wind disperses the ashes and generates a hydration to ashes particles when these are exposed to the atmosphere, besides the contamination that can be caused due to its transportation and storage. It must be said that this burning process is realized on an open-air dump at temperatures between 500 and 800 °C.

3.3 Mineralogical composition

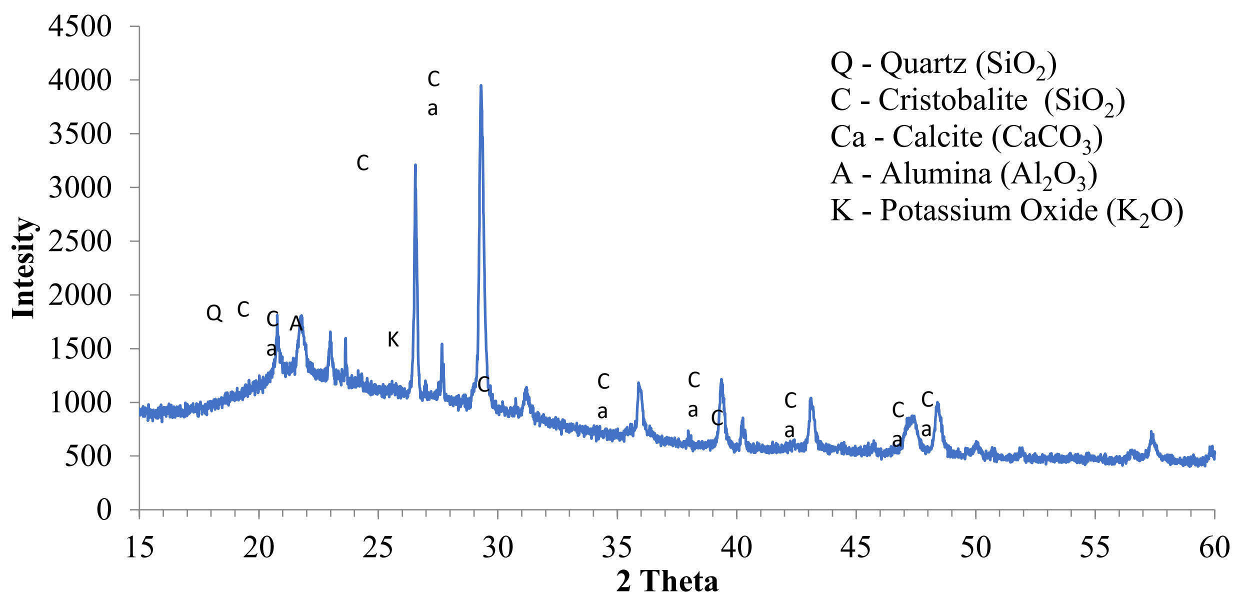

Figure 6. Diffractogram of the CBC obtained in the region.

The mineralogical composition of the CBC was determined by the Diffraction by X-rays technique (DRX), through a BRUKER branded equipment, with a scanning speed of 5°/min and passing of 0.020 grades. In figure 6, it is shown the sample of spectrum of DRX, where it can be observed that the CBC show amorphic characteristics due to a lifting of about 15 y 35 (2θ) from line base; said behavior meant that CBC could present certain pozzolanic reduced activity, which could be used in certain amount as additional material to Portland cement (Martirena, et al., 1998).

3.4 CAC tests on fresh state

The results obtained from the tests made on the CAC mixtures on its fresh state are reported in the following tables (4, 5, 6, 7 and 8). On table 4, they are shown the results of the diameter (D_f) of settlement fluency and the time (T_{50cm}) obtained from the test on the different mixtures. The diameters D1 and D2 were measured over the circular extension of the concrete mix, perpendicularly directed to each other. According to the results obtained, it was determined that the mixtures with additions CBC at 10%, 15% and 20% showed better fluency performance, since the settlement flows and time were consistent with specification on the EFNARC (2002).

Table 4. Summary of settlement fluency and T_{50cm} tests

Mixture	D_1 (cm)	D_2 (cm)	D_f (cm)	Settlement Flow by Adams cone (EFNARC, S., 2002)	T_{50} (s)	Settlement flow test T_{50cm} (EFNARC, S., 2002)
Control Concrete	---	---	---	Minimum: 65 cm Maximum: 80 cm	---	Minimum: 2 seconds Maximum: 5 seconds
Fluid Concrete	57.0	59.0	58.0		9.21	
CAC - 5% CBC	45.0	46.0	45.5		10.23	
CAC - 10% CBC	69.0	69.0	69.0		2.90	
CAC - 15% CBC	69.0	71.0	70.0		3.22	
CAC - 20% CBC	68.0	68.0	68.0		3.74	
CAC - 25% CBC	69.0	70.0	69.5		4.27	

In table 5, there are shown the results for the extension test with J-ring. The reported information corresponds to perpendicular diameters (D_1 y D_2) of the circumference extension of the concrete and its average (D_f); measured heights on the inside (H_1) and the exterior (H_2) of the J-ring as well as the internal and external thickness (A1 and A2) of the settlement of the concrete mix. These results show that the mixture with 20% CBC had the best performance for this test.

Table 5. Summary of tests on J-ring

Mixture	D_1 (cm)	D_2 (cm)	D_f (cm)	H_1 (Interior) (cm)	H_2 (Exterior) (cm)	A_1 (cm)	A_2 (cm)	Heights differences (cm)	Heights differences (EFNARC, S., 2002)
Control Concrete	---	---	---	---	---	---	---	---	Minimum: 0 cm Maximum: 1.0 cm
Fluid Concrete	52.0	54.0	53.0	8.0	11.0	4.0	1.0	3.0	
CAC - 5% CBC	48.0	51.0	49.5	8.0	11.0	4.0	1.0	3.0	
CAC - 10% CBC	64.0	65.0	64.5	8.0	10.0	4.0	2.0	2.0	
CAC - 15% CBC	47.0	47.0	47.0	8.5	11.0	3.5	1.0	2.5	
CAC - 20% CBC	59.0	57.0	58.0	10.0	11.0	2.0	1.0	1.0	
CAC - 25% CBC	69.0	68.0	68.5	9.5	11.0	2.5	1.0	1.5	

Obtained results for the fluency time (T) and the heights (H_1 y H_2) from the tests on L-box are shown on table 6, in this test, the purpose was to evaluate the fluidity performance of the concrete through an L-type formwork and its self-leveling ability. According to the relation H_2/H_1, it was determined that the concrete mixtures with 10%, 20% y 25% of CBC presented a better behavior. Can be said that las two had the best performance.

Table 6. Summary of tests L-box

Mixture	T_{60} (s)	H_1 (cm)	H_2 (cm)	H_2/H_1	Relation H_2/H_1 (EFNARC, S., 2002)
Control Concrete	---	---	---	---	Minimum: 0.8 Maximum: 1.0
Fluid Concrete	42.2	23.5	11.5	0.49	
CAC - 5% CBC	103.1	---	---	---	
CAC - 10% CBC	21.2	10.0	8.5	0.85	
CAC - 15% CBC	11.4	12.5	9.5	0.76	
CAC - 20% CBC	8.6	9.0	8.0	0.89	
CAC - 25% CBC	4.2	9.0	8.0	0.89	

Table 7 shows the results of flow time and the flow at 5 minutes ($T_{5minutes}$), obtained through the V funnel test. Most of the flow time results obtained for each concrete mixture were below the limits specified by EFNARC (2002). In the same way, it was determined that the concrete mixtures with 20% and 25% of CBC presented smaller values on the flow time, turning into the closest ones to the reference minimum of 6 seconds. For the V funnel test at $T_{5minutes}$, the resistance to segregation of the concrete was evaluated, so after 5 min rest the concrete mixtures were between an acceptable range, however, only the mixtures of 10%, 15%, 20% and 25% accomplish with the 2 criteria of this trial.

Table 7. Summary of V funnel test and V funnel at $T_{5minutos}$

Mixture	Flow time	V Funnel (EFNARC, S., 2002)	Flow time $T_{5minutos}$ (s)	V funnel at $T_{5minutos}$ (EFNARC, S., 2002)
Control Concrete	---	Minimum: 6 seconds Maximum: 12 seconds	---	Minimum: 0 seconds Maximum: +3 seconds
Fluid concrete	13.8		3.4	
CAC - 5% CBC	12.5		1.8	
CAC - 10% CBC	9.7		3.0	
CAC - 15% CBC	11.1		1.2	
CAC - 20% CBC	8.7		2.8	
CAC - 25% CBC	6.5		2.7	

Table 8. Summary of Visual Stability Index

Mixture	Value	Value for the evaluation of VSI (ASTM C1611, 2018)
Control Concrete	---	• Stable. No segregation= 0 • Slight exudation, no segregation= 1 • Slight mortar halo (<1 cm). Notable exudation= 2 • Mortar halo (>1 cm) and considerable segregation= 3
Fluid concrete	2	
CAC - 5% CBC	3	
CAC - 10% CBC	1	
CAC - 15% CBC	0	
CAC - 20% CBC	0	
CAC - 25% CBC	1	

On the other hand, it was also determined that the Visual Stability Index (table 8) according to the standard norm ASTM C1611 (2018), in which the CAC mixtures with 15% and 20% of CBC not presented segregation nor exudation, showing a stable behavior along the realization time of several tests and a more homogeneous consistency.

According with the observed results in tables 4, 5, 6 and 7, it can be said that the CAC mixture with 20% addition of CBC as filler had the best performance according to the specifications and guidelines for self-compacting concrete – HAC de EFNARC (2002) the standard ASTM C1611 (2018). Even though, it was considered that the mixtures with 10% and 15% show that can fulfill with certain consistency and workability parameters.

3.5 Compressive resistance test.

On figure 7 and table 9, there are shown the compressive resistance results at 7, 14, 28, 56, 90, 180 and 360 days for all the mixtures, where it can be seen that the compressive resistance of mixtures with 10%, 15% and 20% of CBC achieved higher resistances than the control and fluid mixture, even though the use of materials with pozzolanic characteristics can lower resistance on the first 28 days (López, et al., 2010); however, if the humidity and proper conditions are guaranteed to promote the hydration reactions of the cement and the pozzolanic reactions of the CBC (Neville and Brooks, 1998), concrete resistance with CBC could be superior to a concrete without CBC for ages of 28 days or older. Through the mixtures that were elaborated for this study, it was verified the effect of the increase in resistance after 28 days, which was noticeable higher in the mixtures of CAC with CBC of 10%, 15% and 20%, showing the pozzolanic effect reduced from ashes. For mixtures with 5% and 25% of CBC this effect was not seeing, which is related to the lost in pozzolanic capacity of the CBC.

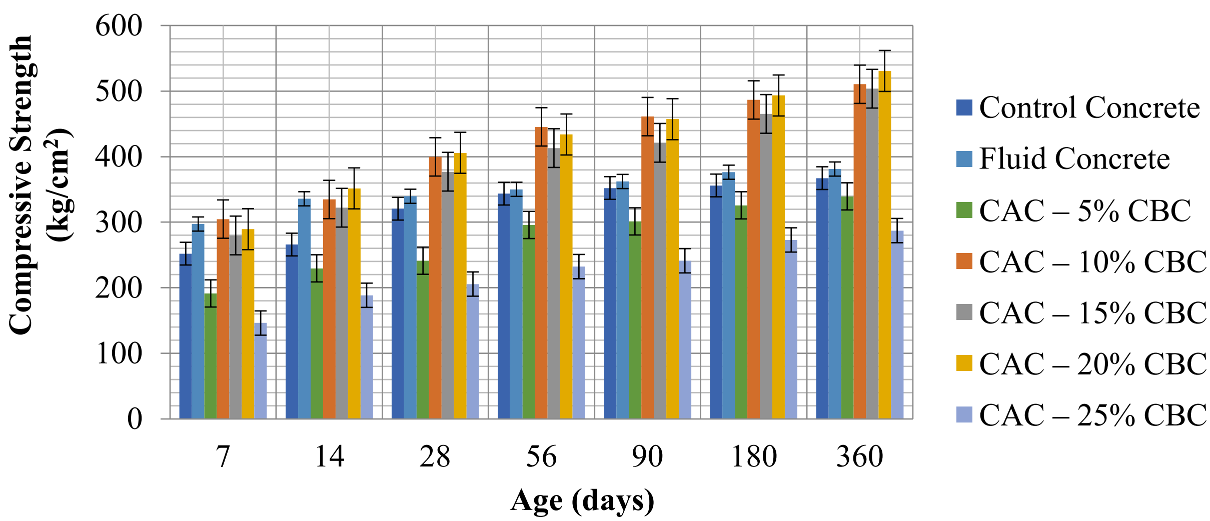

Figure 7. Average compressive resistance values of self-compacting concrete mixes.

3.6 Comparison of test results for self-compacting concrete

The tests done for each concrete mixture are analyzed on this section, for which they correspond to settlement flow test, T_{50cm} test, J-ring test, L-box test, V funnel test and V at $T_{5minutos}$ and compression resistance at 28 days. The results achieved in this investigation project were compared with obtained ones in similar works of self-compacting concrete. For this purpose, only the three best mix designs from this work were considered, as well as the results of other research projects with similar mix designs, the information is shown in table 10.

Table 9. Proportion of materials used for the designs of self-compacting concrete mixtures according to each research project

Mix design	Relation a/c	Water (kg/m³)	Cement (kg/m³)	Cane Bagasse Ash (kg/m³)	Rice ash/ Quarry dust (kg/m³)	Fine aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Superplastifying (% on cement weight)
CAC-10%CBC	0.45	190.00	380.00	38.00	-	830.00	845.00	2.00
CAC-15%CBC	0.43	190.00	380.00	57.00	-	830.00	845.00	2.00
CAC-20%CBC	0.42	190.00	380.00	76.00	-	830.00	845.00	2.00
10B-2SP*	0.41	225.00	500.00	50.00	-	875.00	750.00	2.00
15B-2SP*	0.39	225.00	500.00	75.00	-	875.00	750.00	2.00
20B-2SP*	0.37	225.00	500.00	100.00	-	875.00	750.00	2.00
MRB-10**	0.43	194.00	405.00	11.25	33.75/315	735.00	650.00	2.00
MRB-15**	0.43	194.00	382.50	22.50	45/315	735.00	650.00	2.00
MRB-20**	0.43	194.00	360.00	37.75	56.25/315	735.00	650.00	2.00
SCC-10B***	0.41	225.00	550.00	50.00	-	963.00	750.00	2.00
SCC-15B***	0.39	225.00	550.00	75.00	-	963.00	750.00	2.00
SCC-20B***	0.37	225.00	550.00	100.00	-	963.00	750.00	2.00

Concrete mixtures with 10, 15 and 20% addition of bagasse ash and 2% superplasticizer additive, the nomenclatures are described according to each of the cited authors. Only the samples that present significant similar proportions to the ones on this research work were selected.
* Akram et al. (2009) 10, 15 y 20% Bagasse-2% Superplastifier
** Narashimhan et al. (2014) Mix Replacement of Bagasse- 10, 15 y 20%
*** Amjad et al. (2015) SCC -15,20B (Self Compacting Concrete- 10, 15 y 20% Bagasse Ash)

Table 10. Results of the tests made on the different mixtures of self-compacting concrete according to each author.

Mix concrete	Settlement flow (mm)	Settlement Flow test T_{50cm} (s)	Test on J-ring (difference mm)	Test on J-ring "D_f" (mm)	Test on L-box (H_2/H_1)	Test V funnel (s)	Test V funnel to $T_{5minutos}$ (s)	Compressive strength at 28 days (kg/cm²)	Relation a/c
CAC-10%CBC	690	2.90	20	645	0.85	9.70	3.00	399.63	0.45
CAC-15%CBC	700	3.22	25	470	0.76	11.10	1.20	377.04	0.43
CAC-20%CBC	680	3.74	10	580	0.89	8.70	2.80	405.86	0.42
10B-2SP*	490	>10	-	-	Blocked	14.00	6.00	387.49	0.41
15B-2SP*	420	>10	-	-	Blocked	18.00	Stuck	407.89	0.39
20B-2SP*	330	>10	-	-	Blocked	>20	Stuck	397.69	0.37
MRB-10**	630	6.00	10	480	0.80	14.00	-	420.53	0.41
MRB-15**	615	7.00	10	505	0.80	17.00	-	423.79	0.43
MRB-20**	600	7.00	13	535	0.70	19.00	-	402.17	0.43
SCC-10B***	474	6.00	-	-	0.70	14.00	6.00	254.93	0.41
SCC-15B***	425	unfulfilled	-	-	0.00	18.00	Stuck	285.52	0.39
SCC-20B***	313	unfulfilled	-	-	0.00	Stuck	Stuck	244.73	0.37

Concrete mixtures with 10, 15 and 20% addition of bagasse ash and 2% superplasticizer additive, the nomenclatures are described according to each of the cited authors. Only the samples that present significant similar proportions to the ones of this research work were selected.
* Akram et al. (2009) 15 y 20% Bagasse-2% Superplastifier
** Narashimhan et al. (2014) Mix Replacement of Bagasse-10, 15 y 20%
*** Amjad et al. (2015) SCC -15,20B (Self Compacting Concrete-10, 15 y 20% Bagasse Ash)

Information presented on table 11 corresponds to mixture designs that contain similitudes on its proportions, which were described on table 10, and are compared to each other according with their dressings and are discussed as follows:
The mixtures compared with the works of the authors Akram et al. (2009), Narashimhan et al. (2014) and Amjad et al. (2015), correspond to mixtures designs with different percentages of sugarcane bagasse ash addition (0, 5, 10, 15, 20 y 25%) and a super-plastifying additive in a 2% according to cement weight. The performance of these mixtures was compared with mixtures of this investigation with 10%, 15% and 20% addition of CBC. From the compared data, can be said that the settlement flow test presented acceptable results for the selected mix designs, since the mixes must be within the minimum range of 650 and maximum of 800 mm, with times of settlement T_{50cm} of 2 s as minimum and 5s maximum (EFNARC, 2002). According to the results on table 11, CAC and MRB concrete are the only two concrete mixtures that accomplish with settlement flow tests, however, for the flow extension time $T_{50cm,}$ only the concrete mixtures tagged as CAC complies, meanwhile the concrete mixtures of the other three authors didn't qualify for said test.
Using the J-ring test, it was obtained the height difference value of the mixture between the internal and external part of the ring, which should not exceed 10 mm. The results presented in table 11 for this test were only made on the CAC and MRB mixtures, in which can be observed that the CAC-20%CBC, MRB-10 and MRB-15 mixtures complies satisfactorily.
Through the L-box test, and the results of the height ratio (H_2/H_1) shown in table 11, it was determined that the CAC-10%CBC, CAC-20%CBC and MRB-15 mixtures were the only ones that were within the acceptable values with 0.85, 0.89 and 0.80 respectively (knowing that the range of the H2/H1 ratio must be between 0.8 to 1). The other concrete mixes did not pass this test, in fact some mixes clogged and did not flow as required for a CAC.
In the V funnel test, is acceptable a time from 6 to 12 seconds, allowing an evaluation of the filling capacity of the mixtures. Where the concrete mixtures CAC-10%CBC, CAC-15%CBC and CAC-20%CBC were those that were within the acceptable limits for this test, while the other samples exceed the indicated time. In relation to the V funnel test at $T_{5minutos}$, that allows the evaluation of the property of resistance to segregation, the admissible range is stablished from 0 to +3 seconds. It can be observed that the studied mixtures results meet with said requirement, while the ones reported in the literature did not meet this requirement.
The compressive resistance results at 28 days shown in table 11 correspond to a/c ratios that are relatively similar or close to those considered in this investigation. The mechanical resistances obtained for the CBC mixtures at 28 days are close to 400 kg/cm^2 with an average cement amount of 380 kg/m^3; for the mixtures reported with the labels of 10B, 15B and 20B-2SP they behaved like the mixtures with CBC but with an average cement amount of 500 kg/m^3. On the other hand, the mixtures identified as MRB had a mechanical resistance observed above 400 kg/cm2 with cement contents from 360 to 405 kg/m^3; as well as for the mixtures named as SCC, which reached resistances of around 250 kg/cm^2 for cement contents of 550 kg/m^3.
Although the results show resistances close to the proposed a/c ratios, some mixes do not meet the CAC properties, even though they have higher cement content, so regardless of the manufacturing process, it is required an appropriate design and criteria to achieve the desired characteristics of a CAC. The mechanical resistances presented in the comparison show appropriate resistances according to their designs, however those presented in this work meet almost all the specifications of a CAC. The other authors obtained better results in cases of dosages with higher contents of superplasticizers and/or lower contents of bagasse ash.

4. CONCLUSSIONS

- This investigation shows that it is possible the design of a CAC with local materials incorporating an agro-industrial waste such as CBC with dosages of 10%, 15% and 20%, which mostly satisfy with the elementary workability parameters of a CAC such as: filling capacity, passing capacity and segregation resistance. For which there were made several tests such as: settlement flow test and test of T_{50cm} , J-ring test, L-Box test, V funnel test and V at $T_{5minutos}$ and Visual Stability Index. The mixture with the best performance had proportion with 20% of CBC.
- Regarding the compressive resistance, it is observed that the use of CBC as a filler represents favorable advantages, specifically for proportions of 10%, 15% and 20% of CBC, where its compressive resistance increased with respect to the control mixture.
  The use of CBC as a filler makes possible to optimize cement consumption and modify the mix dosage to use A/C ratios lower than those required, which helps lowering the environmental impact by implementing agro-industrial waste and improving consistency, workability, and resistance of the finished concrete.

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