PHYSICO-MECHANICAL CHARACTERIZATION OF A COMPOSITE FROM SUGAR CANE STRAW PARTICLES AND ALTERNATIVE CEMENTS

CARACTERIZACIÓN FÍSICO-MECÁNICA DE UN COMPOSITE FABRICADO CON PARTÍCULAS DE PAJA DE CAÑA DE AZÚCAR Y CEMENTOS ALTERNATIVOS

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ABSTRACT: Nowadays, sugar cane bagasse has applications as an alternative fuel in most of the sugar cane industries. However, other residues like sugar cane straw particles (SCSP), produced by mechanized harvesting, may be interesting for several applications, as a fuel or as a non-conventional aggregate for cement composite production, in this case partially replacing mineral aggregates. In this research, the behavior of a composite utilizing SCSP (replacing 33% of the sand, by volume) combined with four types of inorganic matrices was evaluated, one of them based on ordinary Portland cement (OPC) and three alternative matrices containing pozzolans by OPC replacement, such as ground fly ashes (GFA) and spent fluid catalytic catalyst for petrol (FCC) (A:100%OPC; B:50%OPC+50%GFA); C:50%OPC+40%GFA+10%FCC and D:50%OPC+30%GFA+20%FCC). Composite performance was evaluated daily by non-destructive ultrasonic test (NDT) and, after 28 days, by flexure and compression tests. Results showed the influence of the composite age on ultrasonic pulse velocity (UPV), finding a stabilization on UPV values at 28 days; and also the great influence of the matrix type on composite mechanical performance. Flexural and compressive strengths of composites with matrix A showed superiority when compared to the alternative matrices. Among them, matrix D showed superiority. In a general way, 33% (by volume) sand replacement by SCSP sharply decreased the composite´s mechanical performance: bending strength (a reduction of 9% to 24%) and compressive strength (a reduction of 38% to 53%). For matrices containing pozzolans, the decrease in mechanical performance was significantly lower.

KEYWORDS: sugar cane straw residues, Portland cement composites, Non-destructive testing.

RESUMEN: Actualmente, el bagazo de caña de azúcar es empleado como combustible alternativo. Mientras tanto, otros residuos como partículas obtenidas de la paja (SCSP), generados en la cosecha mecanizada, pueden presentar interés para varias aplicaciones, como en la producción de combustible o como árido no convencional para la producción de compuestos cementicios, en este caso remplazando parcialmente los áridos. En esta investigación, se evaluó el comportamiento de composites de SCSP (remplazando 33% de arena, en volumen) combinado con cuatro tipos de matrices inorgánicas, una basada en cemento portland (OPC) y otras tres matrices alternativas basadas en la sustitución de OPC por puzolanas, tales como la ceniza volante molida (GFA) y el residuo de catalizador de petróleo (FCC): (A:100%OPC; B:50%OPC+50%GFA); C:50%OPC+40%GFA+10%FCC y D:50%OPC+30%GFA+20%FCC). El desempeño de los composites fue evaluado diariamente por ensayos no destructivos (END) por ultrasonido y, después de los 28 días de curado, por ensayos de flexión y compresión. Los resultados indicaron la influencia de la edad del compuesto en la velocidad del pulso ultrasónico (VPU), observándose su estabilización alrededor de los 28 días; y también la influencia del tipo de matriz sobre el desempeño mecánico del composite. La resistencia a flexión y a compresión de los composites de la matriz A fueron superiores a los de las matrices alternativas. De entre ellas, la matriz D mostró superioridad en relación a las matrices B y C. De una forma general, el remplazo de 33% de arena por SCSP disminuyó acentuadamente el desempeño mecánico del composite: resistencia a flexión (del 9% al 24%) y a compresión (del 38% al 53%). Para las tres matrices con puzolana, el descenso en el desempeño mecánico fue significativamente menor.

PALABRAS CLAVE: residuos de caña de azúcar, composites de cemento Portland, Ensayos no destructivos

1. INTRODUCTION

Brazil has one of the largest agricultural productions in the sugar cane industry worldwide, with about 9 million hectares and an average yield of about 80 metric tons per hectare. According to CONAB, a Brazilian supplier [1], 625 million metric tons of sugar cane were produced in 2010.

In São Paulo State, the Law 11211/2002 describes the procedures to be adopted until the prohibition of burning sugar cane straw in 2021, contributing to the mechanized harvesting development. As a result of these advances in environmental aspects, about 5% of the total mass of the plant remains in the soil (Sugar Cane Straw Particles, SCSP), leading to a waste of about 30 metric tons per hectare.

Besides the possibility of using this waste in a second generation ethanol production (from cellulose), it also shows properties that allow its application in the same way as bagasse as reinforcement for modifying pastes, mortars and concretes [2-5].

However, due to its chemical composition rich in extractives (sugars, phenolic compounds and tannins), most of the plant biomass has a strong chemical incompatibility with inorganic matrices, modifying or even inhibiting the hydration reactions of the binder [6-8].

The main drawback to be overcome is the chemical incompatibility between inorganic binder and lignocellulosic materials, as crop residues. As a first step, several treatments applied to the lignocelluosic materials have been proposed, including physical (drying and rewetting by Claramunt et al.[9]) and chemical ones by Almeida et al. [10]. The objective of these treatments is to eliminate or to minimize the lignocellulosic extractives content, allowing a proper binder hydration. Isolated or even combined catalysts may be employed to enhance cement hydration. Aiming to reduce chemical incompatibility between Portland cement and sugar cane bagasse, Sarmiento and Freire [2] applied a mineralization treatment to the waste (by double soaking in sodium silicate and aluminum sulfate solutions) enhancing the performance of the sugar cane bagasse-Portland cement composites.

The second strategy aiming to overcome this chemical incompatibility is modifying the matrixes nature, employing those less sensitive to the extractives' negative effects. This is the case for pozzolanic matrices that may perform better than ordinary Portland cement when lignocellulosic extractives are present.

Several researches were conducted with sugar cane bagasse fibers modifying Portland cement [2-5]. However, sugar cane straw particles (SCSP) obtained from mechanical harvesting can be considered as a new kind of residue for application in cement composites. This waste was employed to produce sugar cane leaf ashes (SCLA) that allow replacement of up to 10% of Portland cement [11]. However, the effect of SCSP used for partial aggregate replacement in cement-based composites has not been well studied.

The objective of this research was to evaluate the properties of a cement-SCSP composite. As a first step, composite hardening was surveyed using a non-destructive testing by means of ultrasound pulse velocity. On day 28, composites´ flexural and compressive strength were evaluated.

2. METHODOLOGY

2.1. Preparation of particles

Wastes from mechanized harvesting of sugar cane, provided by the Center of Sugar Cane Technology (CTC), located at Piracicaba - SP, Brazil, were mechanically processed. Residues were sieved and the following percentage distribution of particle size in the respective sieve openings were obtained: 13.44% (# 2.50 mm), 35.69% (# 1.25 mm), 33.09% (# 0.63 mm), 12.25% (# 0.315 mm), 1.55% (0.25 mm), 2.07% (# 0.125 mm) and 1.91% (bottom). Therefore, considering the distribution of mass retained in each sieve opening, this biomass can be considered more as a kind of saw-dust (or as particles) and not as a fiber, in terms of a cementicious matrices reinforcement.

2.2. Sand replacement

Bulk density of sugar cane straw particles (SCSP), at dry and non compressed conditions, is 77 $g.L^{-1}$. Considering normal sand, with a bulk density around 1500 $g.L^{-1}$, this study attempted to partially replace the sand (33%) by an equivalent volume of SCSP, corresponding to 24 g of its dry mass. This mass was enough for the manufacture of three prismatic specimens (40 x 40 x 160 mm^3).

2.3. Sugar cane straw particles (SCSP) treatment

Natural SCSP is inhibitory to the cement setting, preventing the binder's hydration reactions. Residual sugars and probably phenolic compounds and flavonoids, as detected by Walford et al. [12], are responsible for the lack of setting.

It was observed, in calorimetric experiments, that the mineralization treatment of the SCSP by double soaking (first soaking the particles in 5% sodium silicate solution, followed by a second soaking in a 10% solution of aluminum sulfate), as initially reported by Sarmiento and Freire [2] for sugar cane bagasse, provides optimized conditions for cement setting.

For the cementing pastes (200 g of binder and 50 g of water), setting was obtained after 8.25 to 11.0 h and maximum temperatures reached 38.5 to 54.6 °C. On the other hand, with addition of SCSP to the matrices (200 g of binder, 15 g of SCSP and 80 g of water), despite the setting time decreased from 1.0 to 2.7 h, maximum temperature was only 26.2 to 31.0 °C. However, for mineralized SCSP, the setting time was closer to the Portland cement matrix (9.3 h) and the maximum temperature reached was 46.2 °C, denoting that this treatment was appropriate for cement setting.

Due to its hygroscopic nature, vegetable particles absorb a large amount of the chemical solutions, especially in the first soaking step (soaking in sodium silicate solution). Consequently, the final mass of the SCSP after treatment, was nearly twice (48 g) of its initial dry mass.

2.4. Properties of cement and pozzolans

Chemical composition of Portland cement and pozzolans, ground fly ash (GFA) and spent fluid catalytic cracking catalyst (FCC) are given in Table 1. It is well known that fly ashes from thermoelectric power plants do no react at early ages of curing when they are blended with Portland cement. The ashes used in this research were ground in order to increase their reactivity [13-14]. GFA had a mean particle diameter of 15.6 μm. The fluid catalytic cracking catalyst residue FCC was supplied by BP OIL España (Castellón, Spain). The original spent catalyst was ground: this mechanical treatment is necessary to activate the pozzolanic behaviour of the catalyst [15]. The FCC had a mean particle diameter of 17.1 μm. FCC is a very reactive mineral admixture, based on an aluminosiliceous nature [16] similar to metakaolin.

Table 1. Chemical composition of Portland cement and pozzolans (GFA and FCC).

Material	*Cement*	*GFA*	*FCC*
SiO_2	19.70	52.94	46.69
CaO	63.19	3.66	0.29
Al_2O_3	5.20	26.74	44.05
Fe_2O_3	3.02	7.85	0.54
MgO	2.04	1.74	0.92
Na_2O	0.10	<0.01	1.64
K_2O	1.07	3.93	0.15
SO_3	3.46	0.94	0.30
LOI[#]	2.02	2.03	1.50

[#]Loss on ignition

2.5. Matrices

Matrix **A** (Ordinary Portland Cement – OPC), consisting of Spanish cement grade CEM I-42.5, was used as the reference for the mortar production. Matrix **B** had 50% of cement replaced by ground fly ash (GFA). The matrices **C** and **D** were kept at the same percentage of cement (50%), but the remaining matrix was formed by combinations of GFA (40 and 30%) and a residue of a fluid catalytic cracking catalyst of petrol - FCC (10 and 20% respectively).

2.6. Manufacture of mortars

The European Standard [17] ratio of 1:3:0.5 (cement: sand: water) by mass was used. Three prismatic molds (40 mm x 40 mm x 160 mm) were filled with 450 g of cement; 1350 g of sand with a fineness modulus of 3.1, consisting of a mixture of three quartz aggregate fractions: 540.0 g fine, 472.5 g intermediate and 337.5 g coarse. The granulometric distribution for sand was (retained in sieve openings): 2.60% # 2.50 mm, 20.70% # 1.25 mm, 9.90% # 1.00 mm, 38.25% # 0.50 mm, 11.97% # 0.25 mm, 11.25% # 0.125 mm and 5.33% bottom. For each condition, six specimens were manufactured.

When the sand was replaced by SCSP, the same ratio between the sand fractions as described before was kept, 900 g of sand was mixed with 48 g of wet SCSP, corresponding to 33% of bulk sand replacement. Specimens remained in moist curing for 28 days, according to the European Standards [18].

2.7. Non-destructive testing (NDT)

After 24 h of manufacture, specimens were demoulded. To apply the non-destructive test, electro acoustic sensors (30 mm diameter and a resonant frequency of 55 kHz) were positioned at the specimen's bases, previously prepared with vaseline. Propagation time (in μs) of the ultrasonic pulse was obtained using an ultrasound device Robotecno model H 2000. At early ages, the ultrasonic pulse velocity (UPV) was evaluated at 1, 2, 3, 6, 7, 8, 9, 10, 11, 13 and 14 days. Subsequently, UPV was evaluated only at 21 and 28 days. Four replications for each specimen were done.

2.8. Mechanical tests

After 28 days, half of the specimens were submitted to the static bending test (span of 100 mm), in a universal testing machine adopting a forward speed of 1 $mm.min^{-1}$. After the bending test, the compression test was performed, according to European Standards [17].

2.9. Statistical analysis

The independent variables were the matrices types (A, B, C and D) and the specimen's age (from 1 to 14 days, and at 21 and at 28 days, for UPV analysis); the dependent variables were: UPV, modulus of rupture (MOR) and compressive strength (CS). Data were prepared in an Excel spreadsheet and then exported to the Statgraphics Centurion 5.1 software. Analysis of variance (ANOVA) was performed and averages were compared by Tukey's test at 95% of statistical significance.

3. RESULTS AND DISCUSSION

3.1. Ultrasonic pulse velocity (UPV)

All of the independent variables (matrix types, replacement levels and the age of the specimens) had great influence on composite's UPV, as presented in Table 2. After 28 days, the UPV of cement reference specimen matrix A (3.51 $km.s^{-1}$) was greater than the others (matrix B– 3.12 $km.s^{-1}$; matrix C– 3.15 $km.s^{-1}$; matrix D– 3.17 $km.s^{-1}$). For higher ground fly ash (30% of GFA) replacement by spent catalyst FCC (20%), UPV was superior (3.17 $km.s^{-1}$) when compared with the other non-conventional matrices. Sand replacement by SCSP (at 33% by volume) strongly decreases the UPV (matrices average for sand replaced mortars: 3.01 $km.s^{-1}$; for non sand replaced mortars: 3.46 $km.^{-1}$) as a consequence of the great amount of voids produced in the composite´s structure. For OPC-based specimens, UPV increases quickly at first and after 7 to 14 days remains almost constant as reported by [19]. However, due to the pozzolanic nature of the other matrices (B, C and D), it was observed in later tests (21 and 28 days) UPV keeps increasing, as a consequence of the slow speed of the chemical reactions.

Table 2. Analysis of Variance for UPV - Type III Sums of Squares

Source	Sum of Squares	Degrees of freedom	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
Matrix	15.1108	3	5.03694	462.54	0.0000
Replacement	27.699	1	27.699	2543.59	0.0000
Age	53.2603	12	4.43836	407.57	0.0000
RESIDUAL	6.14179	564	0.0108897		
TOTAL (CORRECTED)	105.371	580			

All F-ratios are based on the residual mean square error.

Analyzing the influence of curing age on UPV values, an increase from 3.30 $km.s^{-1}$ at 7 days to 3.44 $km.s^{-1}$ at 14 days can be noticed. Also, at 21 and 28 days of curing, UPV values continued rising: 3.50 and 3.51 $km.s^{-1}$ respectively.

Figure 1a (only sand as aggregate) clearly shows the superiority of the UPV value's across the specimens from matrix A, when compared with those from pozzolanic matrices (B, C and D). This same trend is also observed at the UPV curves corresponding to the replacement of 33% sand by SCSP (Figure 1b). After

14 days, the curves corresponding to the pozzolanic matrices were closer to each other. This behavior can be possibly explained by the use of ultrasound equipment that was not sensitive enough to detect the recent increases in the UPV, which theoretically are still increasing due to the subsequent hydration reactions of the matrices. UPV decreases for all of the specimens when sand is replaced by SCSP, due to the formation of voids in the composite's structure, combined with the evaporation of free water. But it could also be provoked as a consequence of the great difficulty for the proper compaction of specimens.

UPV changes were most evident at the early stages and tend to stabilize with increasing age of the specimens, according to an asymptotic curve. Later (14 and 28 days), there is still a small increase for the UPV for every specimen of non-conventional matrices (B, C and D), due to the slower hydration reactions of the pozzolans, when compared with ordinary Portland cement (matrix A).

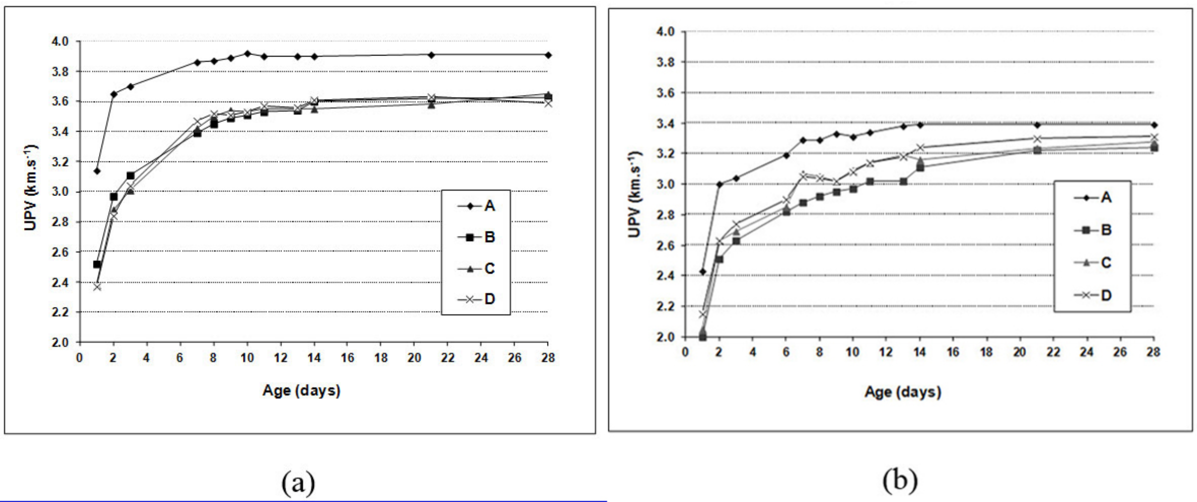


Figure 1. Ultrasonic pulse velocity (UPV) over time (age in days) for: a) mortar with sand (0%); b) mortars with sand replacement (33%) by SCSP

A – 100% OPC; B – 50% OPC + 50% GFA

C – 50% OPC + 40% GFA + 10% FCC

D – 50% OPC + 30% GFA + 20% FCC

3.1.1. Mathematical model

Considering the tendency of stabilization of the UPV over time, a mathematical model (1) was adopted, representative of various physical phenomena, as described previously by [19] aiming to evaluate the UPV over time for saw-dust cement composites.

$$v_i = v_{max} * [1 - \exp(\alpha + \beta * i)] \qquad (1)$$

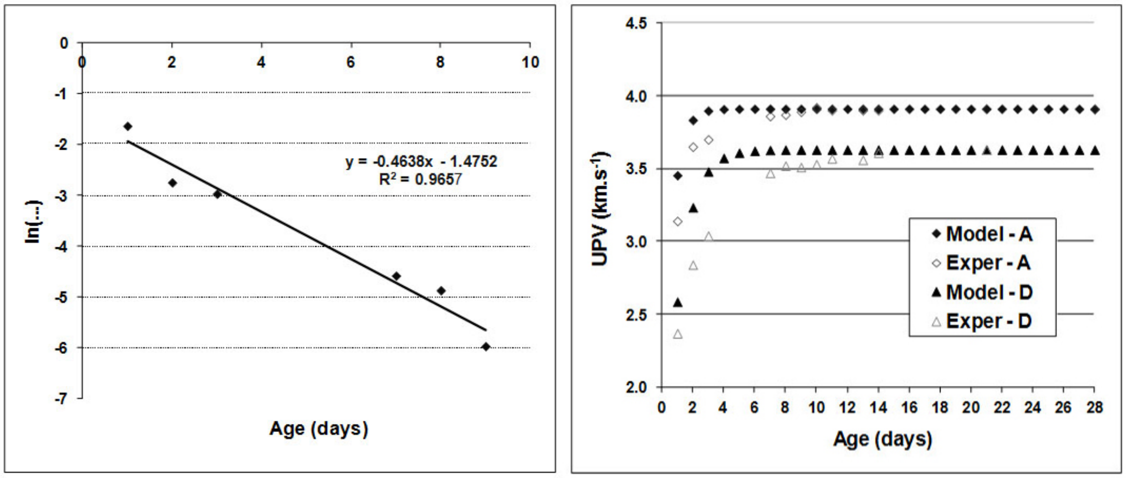
where i is the age of specimens (days); v_i is UPV at age i; v_{max} is the maximum empirical UPV, obtained usually after 28 days, and α and β are coefficients obtained by linear regression.

Equation (1) can be transformed into (2):

$$\ln [(v_{max}-v_i)/v_{max}] = \alpha + \beta * i \qquad (2)$$

Figure 2a shows an example of the logarithmic variation of the UPV at age i, for matrix A, compared with the maximum value (28 days), as described in Eq. 2. The curves of experimental and theoretical UPV, for matrices A and D, are depicted in Figure 2b. It is clear that the mathematical model fits the experimental data better for older samples.

should be equal to zero for the initial conditions (0 days), however, in reality it means a "delayed" UPV. At the first measurement (age of 1 day), there is a partially consolidated matrix structure, which allows the detection of the ultrasonic pulse signal. The higher the absolute value of α coefficient, the more consolidated the structure is at the time of the first measurement of the propagation time. In turn, β coefficient means a "slowdown", i.e. the higher its absolute value, the faster the convergence of UPV toward the maximum (v_{max}). In most cases, this value was obtained at the age of 28 days, mainly for the composites from non-conventional matrices.



(a) (b)

Figure 2. a) α and β - coefficients of the mathematical model for matrix A. b) Theoretical and experimental UPV curves for matrix A (100% OPC) and D (50% OPC + 30% GFA + 20% FCC).

Table 3 presents the estimated coefficients of the mathematical models for the UPV ($km.s^{-1}$) as a function of time (days). Coefficient α theoretically

3.1.2. Matrix type analysis

Considering the significant effect of the nature of the matrices on the behavior of the UPV, the analysis of variance (ANOVA) was conducted separately for each one of them (Table 4). Results corroborated the same behavior as explained for Table 2, showing the influence mainly of the sand replacement by SCSP on UPV. For all types of matrix, sand replacement by volume (33%) by SCSP decreased sharply the UPV. With the same sand replacement in FCC based matrices, UPV tends to stabilize approximately at 3.00 $km.s^{-1}$ (Figure 3).

UPV changes were evident at early ages, but this trend is not so clear in the intermediate zone from 7 to 14 days. In appropriate curing conditions, the hydration reactions evidently remains over time, but the increments produced at the UPV magnitude were not so significant to detect the changes with the equipment employed.

Table 3. Mathematical model (Eq. 1) coefficients of UPV ($km.s^{-1}$) with the age (in days) for the matrices with reference mortar and with 33% sand replacement by SCSP

Matrix	***A***		***B***		***C***		***D***	
Replacement	0%	33%	0%	33%	0%	33%	0%	33%
v_{max}	3.91	3.47	3.63	3.24	3.65	3.28	3.63	3.31
α	-1.87	-1.45	-1.04	-0.8	-1.55	-1.22	-0.97	-0.86
β	-0.33	-0.18	-0.25	-0.19	-0.15	-0.16	-0.28	-0.21
r^2	0.94	0.94	0.97	0.95	0.80	0.94	0.95	0.95

Table 4. Analysis of Variance for UPV - Type III Sums of Squares

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
MAIN EFFECTS- **Matrix A**					
Replacement	11.7826	1	11.7826	1684.61	0.0000
Age	6.37719	12	0.531432	75.98	0.0000
RESIDUAL	0.944228	135	0.00699428		
TOTAL (CORRECTED)	19.6227	148			
MAIN EFFECTS - **Matrix B**					
Replacement	7.78767	1	7.78767	1354.76	0.0000
Age	14.8995	12	1.24163	216.00	0.0000
RESIDUAL	0.747288	130	0.00574837		
TOTAL (CORRECTED)	24.5665	143			
MAIN EFFECTS-**Matrix C**					
Replacement	4.62601	1	4.62601	926.11	0.0000
Age	17.2994	12	1.44162	288.61	0.0000
RESIDUAL	0.649361	130	0.00499509		
TOTAL (CORRECTED)	23.6358	143			
MAIN EFFECTS-**Matrix D**					
Replacement	4.08426	1	4.08426	754.34	0.0000
Age	16.8325	12	1.40271	259.07	0.0000
RESIDUAL	0.703868	130	0.00541437		
TOTAL (CORRECTED)	22.5764	143			

All F-ratios are based on the residual mean square error.

3.2. Modulus of Rupture on Bending - MOR

Prepared mortars were tested by bending after 28 days of curing. The effect of the sand replacement (33% by volume) by SCSP on the composite´s MOR was different according to the matrix nature (Table 5).

For ordinary Portland cement (matrix A) and its partial replacement (50%) by ground fly ash (matrix B), MOR decreases strongly (24% and 30%, respectively) when sand is replaced by SCSP (Figure 4); however, for the other non conventional matrices (C and D), this tendency is less clear and, additionally, for matrix D, the average value was higher (5.29 MPa) than that of the reference (4.92 MPa).

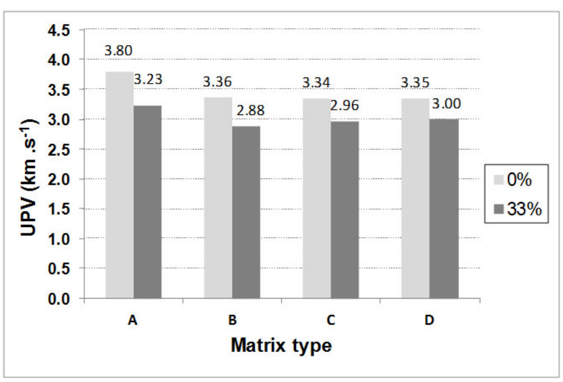


Figure 3. Sand replacement effect on UPV for the matrices
A – 100% OPC; B – 50% OPC + 50% GFA
C – 50% OPC + 40% GFA + 10% FCC
D – 50% OPC + 30% GFA + 20% FCC

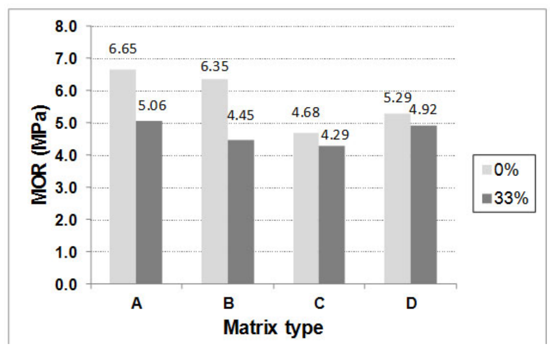


Figure 4. Effect of the sand replacement on modulus of rupture (MOR)
A – 100% OPC; B – 50% OPC + 50% GFA
C – 50% OPC + 40% GFA + 10% FCC
D – 50% OPC + 30% GFA + 20% FCC

3.3. Compressive strength (CS)

Prepared mortars were tested by compression at 28 days of curing. The composite's compressive strength depends strongly on the sand replacement and on the matrix type (Table 6), decreasing strongly (38% to 53%) when sand is replaced by 33% of SCSP for all matrix types (Figure 5).

Despite the high replacement level of Portland cement in pozzolan containing mortars, CS values for mortars B, C and D are very acceptable. Thus, for mortars without sand replacement by SCSP, reference mortar (A) had 38.52 MPa, whereas pozzolan containing mortars were in the 26-32 MPa range. These values for pozzolan mortars are significantly higher than 19MPa (half of the CS value for the reference mortar), suggesting an important contribution of pozzolans at 28 days of curing.

Table 5. ANOVA Table for MOR by Sand Replacement

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups – **Matrix A**	3.77627	1	3.77627	29.41	0.0056
Within groups	0.513667	4	0.128417		
Total (Corr.)	4.28993	5			
Between groups - **Matrix B**	4.34721	1	4.34721	20.96	0.0196
Within groups	0.622267	3	0.207422		
Total (Corr.)	4.96948	4			
Between groups - **Matrix C**	0.232067	1	0.232067	0.62	0.4741
Within groups	1.48987	4	0.372467		
Total (Corr.)	1.72193	5			
Between groups - **Matrix D**	0.201667	1	0.201667	0.65	0.4659
Within groups	1.24447	4	0.311117		
Total (Corr.)	1.44613	5			

All F-ratios are based on the residual mean square error.

Additionally, it is noticeable that the reduction in the CS value for sand replaced mortars is lower for pozzolan containing mortars compared to the matrix A mortar: thus, the reduction for A matrix composite was 18 MPa, whereas the reduction for D matrix was only 15 MPa. Taking into account that for pozzolan containing composites the amount of OPC was reduced by 50%, it can be established that alternative matrices had an excellent behavior.

Table 6. ANOVA Table for CS by Sand Replacement

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups - **Matrix A**	979.213	1	979.213	202.69	0.0000
Within groups	48.3105	10	4.83105		
Total (Corr.)	1027.52	11			
Between groups -**Matrix B**	748.13	1	748.13	1079.61	0.0000
Within groups	6.92962	10	0.692962		
Total (Corr.)	755.06	11			
Between groups -**Matrix C**	302.706	1	302.706	304.89	0.0000
Within groups	9.92842	10	0.992842		
Total (Corr.)	312.634	11			
Between groups -**Matrix D**	613.899	1	613.899	365.22	0.0000
Within groups	16.8092	10	1.68092		
Total (Corr.)	630.708	11			

All F-ratios are based on the residual mean square error.

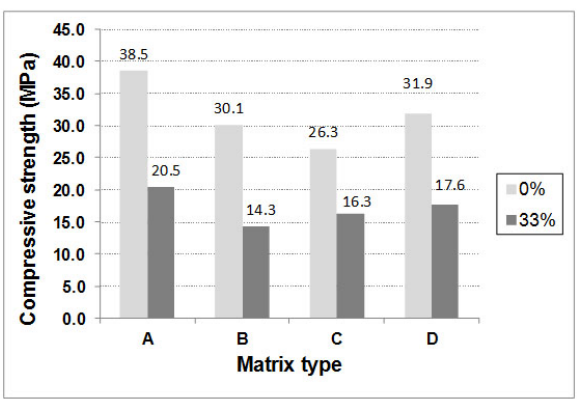


Figure 5. Effect of the sand replacement on compressive strength (CS)
A – 100% OPC; B – 50% OPC + 50% GFA
C – 50% OPC + 40% GFA + 10% FCC
D – 50% OPC + 30% GFA + 20% FCC

4. CONCLUSIONS

Sugar cane straw particles (SCSP) show a great potential to partially replace mineral aggregates for cement mortar production. Despite its extractives content, SCSP's mineralization (by a soaking in sodium silicate solution followed by a soaking in aluminum sulfate solution) was an efficient alternative to allow proper cement hardening. Non-destructive testing (NDT) by ultrasound pulse velocity (UPV) applied to the composites was sensitive enough to determine the hardening of the composites in the first stages. For pozzolanic matrices, UPV still increases after 28 days as a consequence of pozzolanic reactions. The composite's properties depend on the matrix type, showing a superiority of OPC when compared to the alternative matrices. The partial replacement of sand (33% by volume) by SCSP strongly affects the composite's performance. Thus, bending strength showed a reduction of 9% to 24%, and compressive strength showed a reduction of 38% to 53%. For matrices containing pozzolans, the decrease in mechanical performance was significantly lower. Good performance was achieved for mortars with alternative matrices, finding a similar compressive strength values after 28 days in mortars with sand replacement by SCSP.

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