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Technical Feasibility of the Reuse of Dry Concrete Slurry Waste in Concrete Fabrication

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ABSTRACT

Concrete slurry waste (CSW) is an industrial by-product retrieved in large quantities from ready-mix concrete plants. The present work aims to study the feasibility of the incorporation of this residue in the production of concrete to reduce the dilemma of its disposal on huge amounts, decrease the quantities of natural materials used in concrete assembly and produce a lower carbon footprint concrete. Hence, the CSW were divided into three parts, the first part contains the fraction of fine particles (< 80 µm) (residue 1), the second part contains the entire CSW (residue 2) and the third part contains the rest of CSW after the elimination of residue 1 by sieving (residue 3). Then, the introduction of CSW into concrete was achieved, on one hand, by replacing 2, 4, 6, 8 and 10% of cement by residue 1 and, on the other hand, by substituting 5, 10, 15, 20 and 25% of river sand and crushed sand by residues 2 and 3, separately. In order to qualify and analyze the behavior of this residues in the company of other components of concrete, several chemical and physical characteristics of CSW were evaluated. In addition, CSW were characterized by x-ray fluorescence (XRF), x-ray diffraction (XRD), fourier transform infrared spectrometer (FTIR) and scanning electron microscopy (SEM). The various constituents used in the manufacturing of concrete were characterized physically including particle size distribution, fineness modulus, cleanliness of the sand, flattening coefficient, hardness, apparent density and actual density to conclude the formulation used for the development of the specimens. In addition, the properties of fresh and hardened concretes were also investigated, including Abrams cone subsidence, density and compressive strength. The outcome of this study concludes that modest amounts of CSW improve the physical properties of concretes and consequently their compressive strength, especially at 90 days, whatever the type of martial being substituted. Thus, the introduction of residue 1 into the cement must not exceed 2%, the replacement of residue 2 by river and crushed sands can be done at rates up to 5 and 10%, respectively, while the residue 3 can only substitute river sand at a rate up to 10%.

Keywords: concrete slurry waste, concrete, physical-chemical and mineralogical characteristics, compressive strength.

INTRODUCTION

Lately the world has experienced a strong acceleration in the construction process, that was associated with an enormous demand for ready-mixed concrete [Garikapati and Sadeghian, 2020]. The acceleration of this process, accelerate likewise the production of a residue escorting the ready-mixed concrete production, which is concrete slurry waste (CSW) [Hossain et al., 2017]. CSW is a concrete waste generated in ready-mixed concrete plants. This residue is obtained from the sedimentation ponds collecting extra fresh concrete and wastewater of cleaning concrete mixers, trucks and work fields. It is mainly composed of hydrated/carbonated cement particles, fly ash, sand, gravel, and other hydraulic cementitious materials [Tang et al., 2020]. Because of its alkaline nature, CSW has been classified as a corrosive and harmful substance in many countries in Asia [Iizuka et al., 2012a] and Europe [Sealey et al., 2001].

The quantities of CSW extracted from sedimentation ponds are huge, since the CSW generated presents from 1 to 4 wt% of the annual production of ready-mix concrete produced in these companies [Correia et al., 2009; Iizuka et al., 2012a]. These quantities are predominately left over in free spaces with no management system nor disposal technology, witch, might damage the surrounding environment, especially water sources, due to its high pH value [Wang and Zhang, 2018; Xuan et al., 2016a]. Consequently, the current common destination of CSW, which is landfill, requires costly neutralisation treatment [Tam, 2008; Yoo et al., 2017]. Therefore, it is important to propose solutions to use or recycle this residue in a proper way respecting its alkaline nature [Xuan et al., 2016a].

Hence, many researches have been done on the recycling and reuse of CSW. Certain research has focused on unhydrated CSW as a substitute for sand in concrete or mortar [Correia et al., 2009; Zervaki et al., 2013], as a substitute for limestone filler in concrete or mortar [Audo et al., 2016], as a substitute for aggregates [Kou et al., 2012a], as soil stabilizers in road base [Zhang and Fujiwara, 2007], slurry-based geopolymer [Yang et al., 2010] and in glass-ceramics [Tian, 2007]. Other research has worked on dewatered CSW, known for its rich calcium-silicate content, that was used as a fresh cementitious paste to increase concretes mechanical strength [Xuan et al., 2016b], to produce partition wall blocks [Kou et al., 2012b] and to produce mortars [Zervaki et al., 2013]. More propelled studies indicate that CSW could be utilized as a sorbent to clarify water [Tsunashima et al., 2012], adsorb phosphorus [Iizuka et al., 2012b] and capture CO_2 [Iizuka et al., 2017].

This paper aims to incorporate CSW into the production line of ready-mix concrete in the same plants producing it, which allows to solve the dilemma of the disposal of this residue besides reducing the natural resources consumption in these companies. For that, the objectives of this work are to characterize the physicochemical properties of CSW and to assess the effect of its reuse on the technical properties of concretes.

MATERIALS AND METHODS

This study was carried out in the laboratory of the Zalagh concrete company and in the NBR Center of North laboratory, according to the specifications of the NM 10.1.008 standard.

Concrete slurry waste (CSW)

CSW used in this study was collected from Zalagh concrete company in Fez, Morocco. The collected samples, presented in Figure 1, were mixed then dried in an oven at 105 °C until a constant mass was obtained. Next, nearly 60% of the samples were sieved using an 80 µm sieve. Thus, the samples were divided into three parts, the first part contains the fraction of fine particles (< 80 µm) called residue 1 (R1), the second part contains the CSW without any sieving named residue 2 (R2) and the third part, called residue

Figure 1. Pictorial view of concrete slurry waste

3 (R3), contains the fraction remained after the removal of residue 1 by sieving (> 80 µm).

Several analyzes were done in order to characterize CSW. The particle size distribution was quantified according to the Moroccan standard NM 10.1.700. The absolute and apparent densities were determined according to the French standard NF P18-555. The humidity rate and the organic matter were measured on samples dried in the open air, in accordance with the French standards NF ISO 11465 and NF P94-055, respectively. The pH value of the dried samples was measured using a digital pH-metre. The pozzolanic activity was evaluated according to the standard NF P18-513.

The characterization of CSW by x-ray fluorescence (XF), x-ray diffraction (XRD), fourier transform infrared spectrometer (FTIR) and scanning electron microscopy (SEM), is performed on the fine fraction (< 80 µm).

Concrete components

The concrete used in this study is an ordinary concrete describing the majority of existing structures. It is composed of cement, river sand, crushed sand, two types of gravel (GI and GI) and water. The used cement is CPJ_{45} Portland cement according to the Moroccan standard NM 10.1.004. This cement has an ordinary strength at 28 days of 45 MPa, determined in accordance with the Moroccan standard NM 10.1.005. The chemical composition of this cement is determined using X-ray fluorescence analysis. Two types of sands (0/5) were used in this study:

- river sand (natural sand) – it is dune sand (rolled), coming from the region of Guercif, Morocco;
- crushed sand – from the Al Jaouda quarry, which is located in the province of Séfrou, Morocco.

The sands particle size distribution was computed according to the standard NM 10.1.700. The characterization of sands, including cleanliness of the sand, fineness modulus, apparent and real volumetric mass were determined according to the Moroccan standards NM 10.1.732, NM 10.1.700, NM 10.1.147 and NM 10.1.149, respectively.

The gravels used in this study are of a dolomitic limestone nature. Coming from the Al Jaouda quarry, two types of gravels were used according to their dimensions:

- Gravel (GI): characterized by an actual granular class of 6.3/16 mm;
- Gravel (GII): characterized by an actual granular class of 10/20 mm.

The gravels particle size analysis was measured in agreement with the Moroccan standard NM 10.1.700. The characterization of gravels (GI and GII) was determined according to the following Moroccan standards: Surface cleanliness of gravel [NM 10.1.169], Flattening coefficient [NM 10.1.155], Hardness [NM 10.1.138], Apparent volumetric mass [NM 10.1.147] and Real volumetric mass [NM 10.1.146].

Coming from a well in the property of Zalagh concrete, the water used to mix concretes is clean and does not contain harmful impurities. It is suitable water for the manufacturing of concrete and does not require any specific treatment.

Formulation of concrete

The concrete used in this study is a B_{25} concrete according to the Moroccan standard NM10.1.008. It is typified by a plastic workability of 6 mm in its fresh state, and a compressive strength of 25 MPa at 28 days. The concrete was formulated by the Dreux-Gorisse method using the results of the aggregates analyzes described above. The formulation obtained is offered in Table 1. Besides control concrete, five series of experiments of concrete-CSW were formulated according to the specifications of the NM 10.1.068 standard:

- Series 1 – presented the substitution of 2, 4, 6, 8 and 10% of cement by residue 1;
- Series 2 – presented the substitution of 5, 10, 15, 20 and 25% of river sand by residue 2;
- Series 3 – presented the substitution of 5, 10, 15, 20 and 25% of river sand by residue 3;
- Series 4 – presented the substitution of 5, 10, 15, 20 and 25% of crushed sand by residue 2;
- Series 5 – presented the substitution of 5, 10, 15, 20 and 25% of crushed sand by residue 3.

During the mixing of the concretes, the water was introduced gradually in order to maintain an Abrams cone slump of 6 mm (consistency class equal to S2). Subsequently, the specimens were immediately filled in cylindrical molds measuring 11 × 22 cm, compacted using a vibrator for 60 seconds, and kept at a temperature of 20 ± 1 °C. After 48 h, the specimens were removed from the molds and immersed in water at a temperature of

Table 1. Formulation obtained to make concrete specimens

Component	Cement (kg/m^3)	Water (L/m^3)	River sand (kg/m^3)	Crushed sand (kg/m^3)	Gravel (GI) (kg/m^3)	Gravel (GII) (kg/m^3)
Dosage	300	194.80	430.76	452.13	505.88	609.40

20 ± 1 °C. The specimens were tested after aging by 7, 28 and 90 days. An average of 3 concrete specimens was allowed for each test.

Characterization of concrete

To learn about the properties of concretes made from CSW, various tests were carried out, in its fresh and hardened state. In the fresh state, the slump was measured, according to the Moroccan standard NM 10.1.061, as soon as the concrete was mixed. It was used to ensure a plastic concrete for all mixes and to correct the calculated amount of mixing water if necessary. In the hardened state, the density and the compressive strength were determined in accordance with the Moroccan standards NM 10.1.072 and NM 10.1.051, respectively.

RESULTS AND DISCUSSIONS

Characterization of CSW

The particle size analysis, presented in the Figure 2, shows that CSW is classified in the granular class 0/25 mm with 28% of fine particles (< 80 µm). It contains 45% of fine grains with a diameter less than 0.63 mm, compared to river sand that has 91.8% and the crushed sand that does not exceed 26% of this fine grains. This result is normal, since CSW is a mixture of cement, sands and gravels.

The physical-chemical characteristics of CSW, presented in Table 2, show a low organic matter content, a high pH value and an average pozzolanic activity with a satisfactory lime adsorption capacity. The fineness modulus of CSW

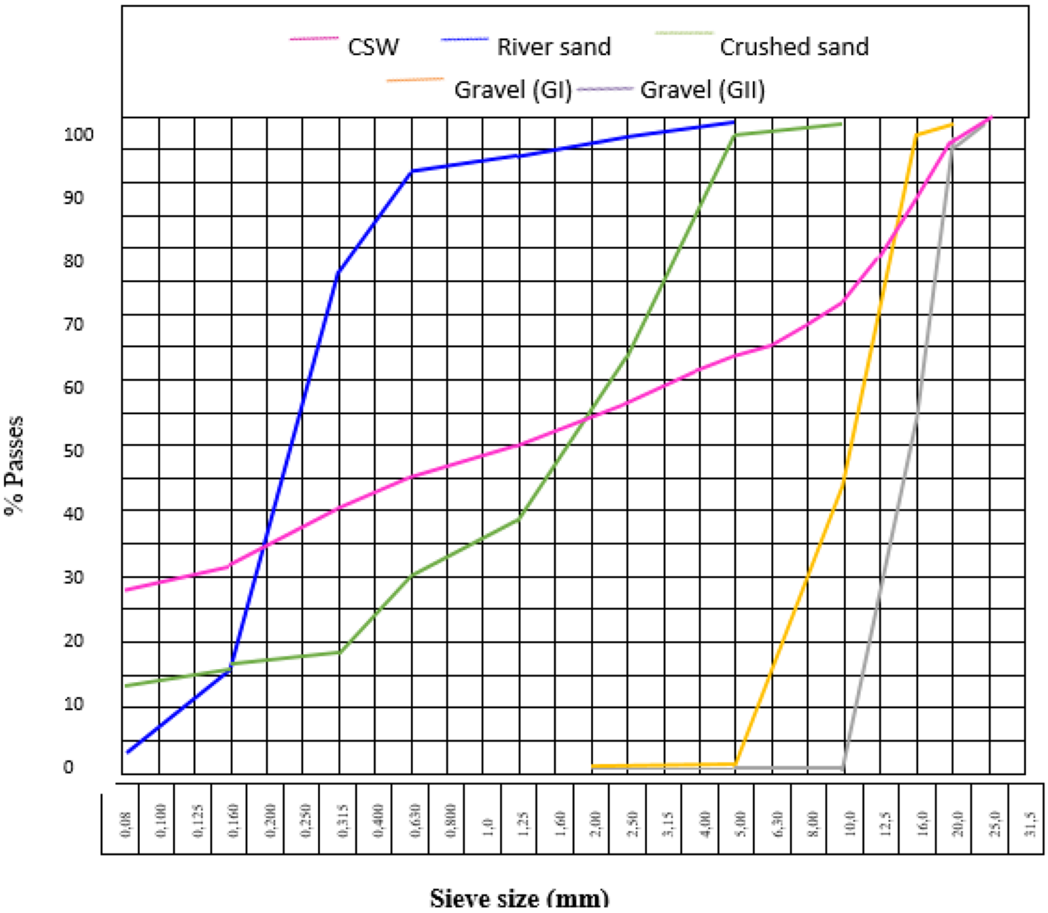

Figure 2. Particle size distribution of CSW, sands and gravels

Table 2. Physical-chemical characteristics of CSW

Humidity (%)	Organic matter (%)	Pozzolanic activities (mmole/L of CaO)	Real volumetric mass (t/m^3)	Apparent volumetric mass (t/m^3)	Fineness modulus (%)	pH
12.5	3.6	23.4	2.65	1.94	2.85	12.86

(Mf = 2.85) is comparable to that of sands. The chemical composition of CSW, provided by X-ray fluorescence test, is given in Table 3. CSW is mainly composed of CaO, SiO_2, Al_2O_3 and Fe_2O_3 in addition to small amounts of MgO, K_2O, SO_3, Na_2O and P_2O_5.

This analysis is performed on a fine fraction of CSW (< 80 µm), this fraction contains mostly cement and fine particles of sands and gravels deposited as a sediment in the bottom of the basins collecting concrete mixers washing water. So, the high content of CaO and SiO_2 is a logical outcome. Also, the sum of the contents of SiO_2, Fe_2O_3 and Al_2O_3 (44.27) is less than 70%, which confirms that CSW has an average pozzolanic activity [Patil et al., 2021]. Although CSW could be considered as a potential cementitious paste for its rich calcium-silicate, this character exists only in fresh CSW. However, due to the continual reuse of the water stored in the retention pond, the composition of CSW changes and become not proportional to the hydrated cement paste. Also, the exposure of CSW to CO_2 reduce its potential reactivity by transforming the calcium phase into calcium carbonate and incompact calcium silicate hydrates [Xuan et al., 2016b].

The performed X-ray Diffraction analysis has identified the mineral components in CSW as quartz, ankerite, calcite, dolomite, and berlinite (Figure 3). This composition reflects some residual constituents of cement and quartz from sand. After being exposed to aerial conditions, the cement hydration products presented in CSW such as $Ca(OH)_2$ were changing over time by

Table 3. Chemical analysis of CSW

Chemical compositions	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	TiO_2	LOI
Mass fraction (%)	29.75	9.34	5.18	33.93	0.91	2.14	0.89	1.36	0.24	0.18	15.54

Note: LOI – loss on ignition.

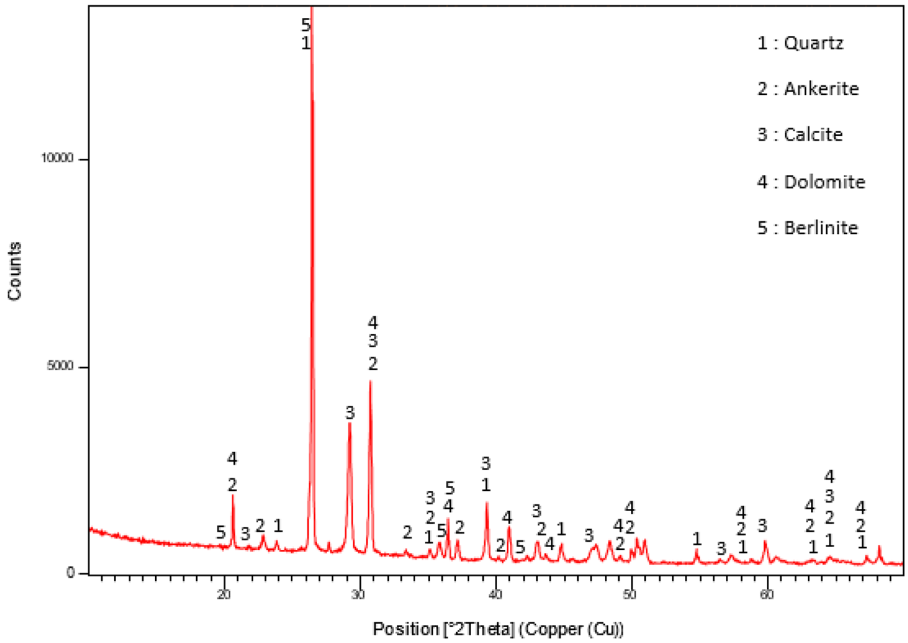

Figure 3. X-ray diffraction diagram of CSW

carbonation into calcite, which explains the absence of cement hydration products in this analysis [Keppert et al., 2021]. The high LOI content means that CSW includes more carbon particles. Also, the decomposition of $CaCO_3$ and calcium silicate hydrates increases the LOI [8]. Moreover, the XRD peaks are very fine, which shows that the crystallization is good and explains the average pozzolanic activity of this material compared to amorphous materials that show higher pozzolanic activities than crystalline ordered compounds [Nunes and Costa, 2021].

SEM micrographs, presented in Figures 4, show that the surface of CSW is dense and smooth. This result could be attributed to the formation, precipitation and coverage of $CaCO_3$ on the particles surface of CSW due to the carbonation of cement hydration products [Xuan et al., 2016b]. The micrographs show also the presence of crystalline aggregates and anhydrous cement grains witch confirms that CSW has residual cement components available for further hydration or carbonation reactions.

Figure 5 illustrates the FTIR spectra of CSW. The absorption bands of silica appear at 1081, 777, and 449 cm^{-1} corresponding to the asymmetric stretching vibration of Si–O–Si, symmetric stretching vibration of Si–O–Si, and bending vibration of O–Si–O, respectively. The peak at 1181.23 cm^{-1} appears due to the silica polymerization in the C–S–H gel structure. The absorption at 2161, 1409 and 873 cm^{-1} is due to Ca–CO_3 bonds. The peak at 1969 cm^{-1} indicates the tensile vibration of O–C–O in carbonates, which was produced in the chemical reaction of (–OH) group with CO_2 in water [Jiang et al., 2022]. This

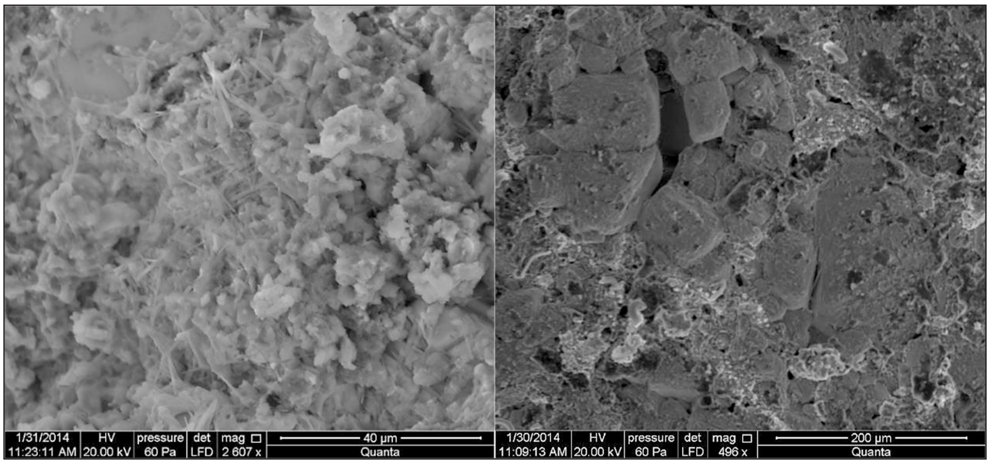

Figure 4. SEM micrograph of CSW

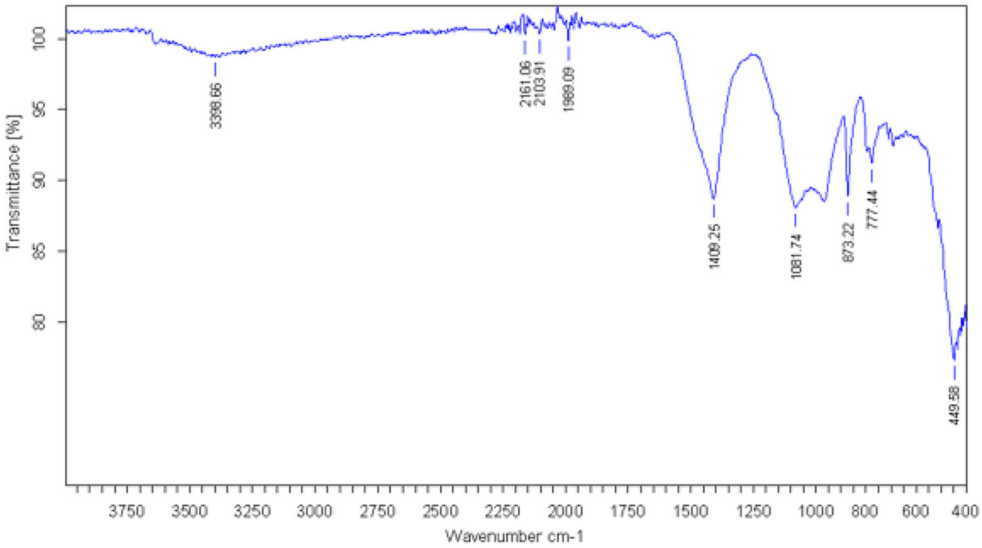

Figure 5. FTIR spectra of CSW

reaction is also proved by the vibration of (–OH) group at 3386 cm^{-1} [Wang et al., 2022]. These results confirm the presence of compounds such as C–S–H and $Ca(OH)_2$ in the CSW samples that were carbonated into calcium carbonate and calcium silicate hydrates. The FTIR results are in agreement with XRD findings.

Characterization of concrete components

The chemical composition of CPJ_{45} Portland cement, determined by X-ray fluorescence, is presented in Table 4. The particle size distribution of sands and gravels is showed in Figure 2, and their physical characterization is presented in Table 5 and 6, respectively. According to the Moroccan standard NM 10.1.271, these sands and gravels are qualified for making high quality concrete (category A).

In addition, the fineness modulus of CSW (Mf = 2.85) has an average value between the crushing sand (Mf = 3.39) which is considered as coarse sand and the river sand (Mf = 1.24) which is considered as fine sand. Thereby, the CSW can be added to correct the rate of fines in the sands if necessary.

Characterization of CSW-concretes

Substitution of cement by residue 1

To ensure the same workability for all specimens, a slump of 6 mm was targeted for all batches using Abrams cone. The Figure 6 shows the water demand of mixtures after correction. The amount of water added increases with the increase of residue 1 proportion replacing cement in the mixtures. This result may be due, on one hand, to the size of CSW particles used in this part of the study (< 80 μm), since the finer the particle size, the greater the volume of water necessary for the mixtures hydration, as the water must fill the intergranular voids before participating in the separation and lubrication of grains [Wang et al., 2022]. On the other hand, the particles shape of residue 1 in comparison with the shape of the cement particles could also increases the volume of water necessary for mixing [Wang et al., 2022; Naamane et al., 2016].

Figure 6 shows also the changes in the densities at the hardened stat of concretes with and without residue 1 after 7, 28 and 90 days. At different ages, the densities of all concretes have the same behavior observed by a slight increase between 7 and 28 days, followed by a decrease between 28 and 90 days. All densities are between 2391 kg/m^3 and 2492 kg/m^3, remaining within the normal average (between 2000 and 2600 kg/m^3). However, concretes with 2% of the residue 1 have higher densities than the control concrete, unlike concretes having a higher percentage of this residue. This result is due to the quantity of water absorbed during mixing, which is lower in the first case and greater in the second, compared to the control concretes. While knowing that the quantity of water absorbed during mixing is relative to the fraction of water evaporated after drying of the test pieces, hence influencing their densities.

The compressive strength values of concretes containing residue 1 at 7, 28 and 90 days are illustrated in Figure 7. Compared to the control concretes, a substitution rate of 2% of cement maintained the same compressive strengths of concretes. But, beyond this percentage, the mechanical strengths decreased sharply with the increase of the residue proportion by 12.48%, 26.74%, 50.66% and 57.75% for substitution rates of 4%, 6%, 8% and 10%, respectively. This result can be explained by the reduction of the reactivity of cement hydration products present in residue 1 due to the high water/solid ratio in the retention ponds and the prolonged exposure of CSW to CO_2 during drying, that could transform the calcium phase into calcium carbonate and

Table 5. Physical characterization of sands

Test	River sand	Crushed sand
Cleanliness of the sand (%)	72	79
Fineness modulus (%)	1.24	3.39
Apparent volumetric mass (t/m^3)	1.84	1.75
Real volumetric mass (t/m^3)	2.62	2.75

Table 4. Chemical analysis of cement

Chemical compositions	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	TiO_2	LOI*	Density (g/cm^3)
Mass fraction (%)	17.16	4.15	2.38	59.33	1.05	3.04	0.18	0.81	0.06	0.25	10.79	3

Note: LOI – loss on ignition.

Table 6. Physical characterization of gravels

Test	Gravel (GI)	Gravel (GII)
Surface cleanliness of gravel (%)	1.1	0.6
Flattening coefficient (%)	5	1.4
Hardness (%)	22	22
Apparent volumetric mass (t/m^3)	1.48	1.54
Real volumetric mass (t/m^3)	2.77	2.78

incompact calcium silicate hydrates. Thus, even with its high level of calcium silicate, residue 1 cannot react like a cement paste during mixing [Xuan et al., 2016a]. Consequently, the substitution rate of fine particles from CSW in cement must not exceed 2%.

Substitution of river sand by residue 2 and 3

Figure 8 presents the corrected amounts of water in mixtures and the densities of concretes substituting river sand by residues 2 and 3 at 7, 28 and 90 days. The total water amount added is higher in the control concrete and decreases with the increasing of the percentage of CSW in concretes for the two types of residues. This result may be due to a filler effect in the case of residue 2, since it is composed of more than 28% of fine particles that might fill the intergranular voids during mixing, thus resulting in an increase in the absorption coefficient of mixtures and consequently the reduction of the water/cement ratio [Wang et al., 2022]. This effect is not noticed in

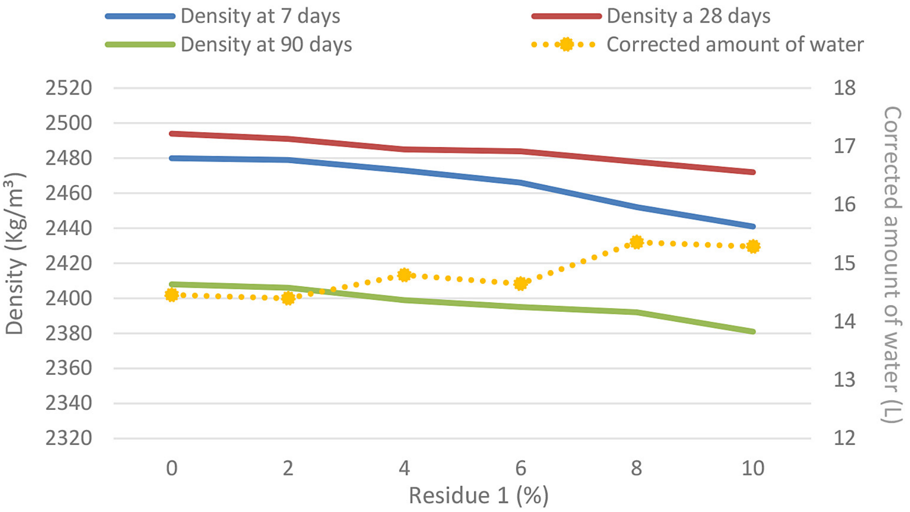

Figure 6. Corrected amounts of water in mixtures and densities in the hardened state of concretes substituting cement by residue 1 at 7, 28 and 90 days

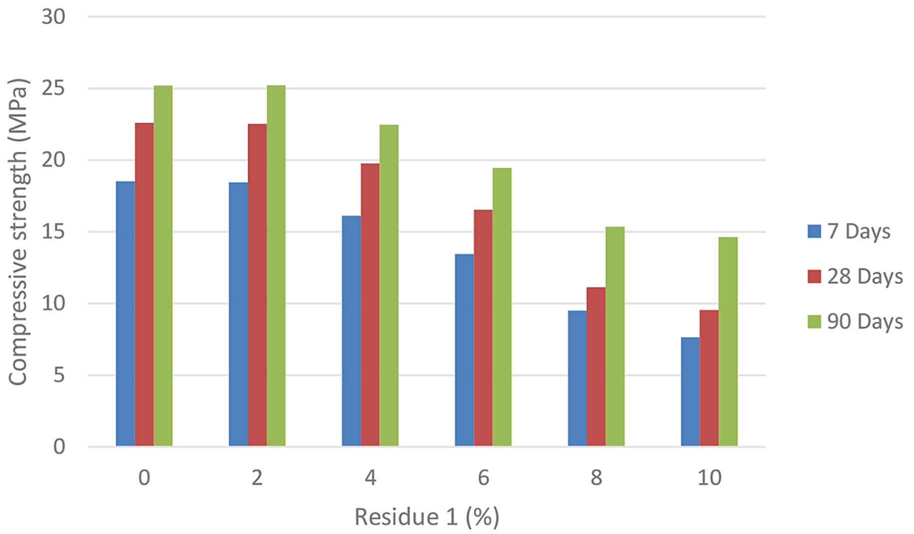

Figure 7. Compressive strengths of concretes substituting cement by residue 1 at 7, 28 and 90 days

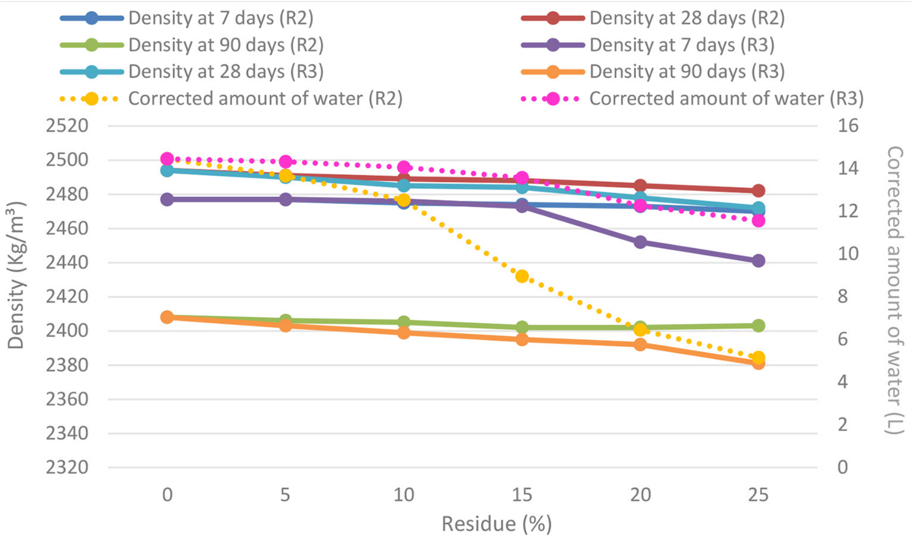

Figure 8. Corrected amounts of water in mixtures and densities in the hardened state of concretes substituting river sand by residue 2 and 3 at 7, 28 and 90 days

the case of mixtures containing residue 3 (without fine particles) that absorb more water compared to mixtures containing residue 2. However, mixtures with residue 3 consume less water in comparison with the control concrete, since the river sand contains a higher fraction of fine grains (< 0.63 mm) compared to residue 3. This reduction in the water demand of mixtures containing residue 2 and 3 should promote densities and therefore mechanical resistances of concretes [Cao, 2023; Jiang et al., 2022]. In fact, compared to control concretes, all densities decrease slightly with the increase of the percentage of substitution, although they remain in the recommended range (between 2000 and 2600 kg/m^3). This reduction is more noticed in concretes containing residue 3, especially after 28 and 90 days. Thus, the higher densities of concretes containing residue 2 compared to those containing residue 3 could be explained by the lower quantity of water absorbed by the mixtures in the first case, and consequently an inferior quantity of water is evaporated after drying the specimens. The compressive strengths of concretes containing residue 2 and 3 are presented in Figures 9 and 10, respectively. For all ages, the mechanical strengths of concretes with 5% of residue 2 improved by 0.54, 1.32 and 2.50% at 7, 28 and 90 days, respectively. This improvement, more noticed with the extension of the residence time of the specimens, can be attributed

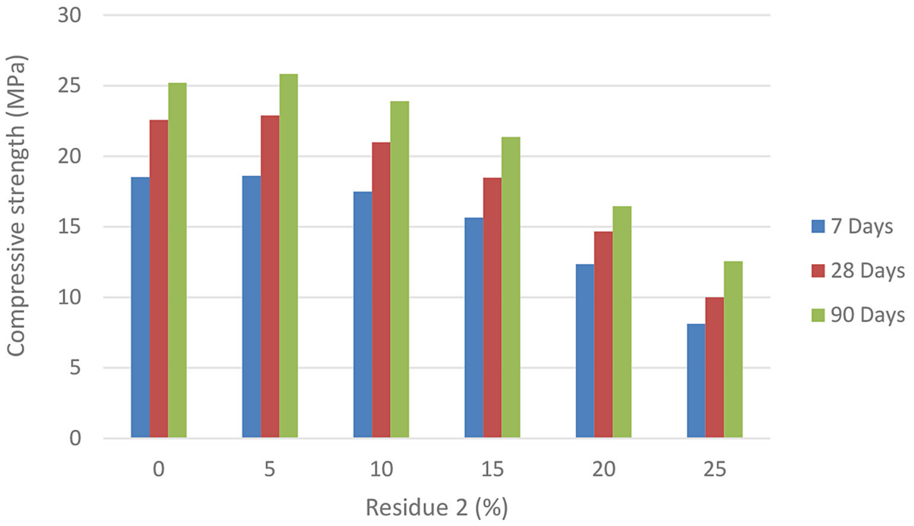

Figure 9. Compressive strengths of concretes substituting river sand by residue 2 at 7, 28 and 90 days

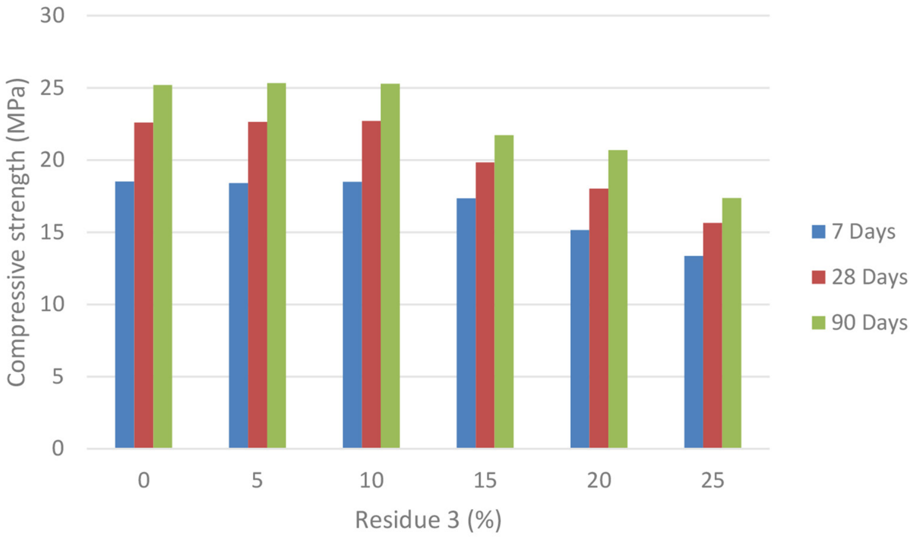

Figure 10. Compressive strengths of concretes substituting river sand by residue 3 at 7, 28 and 90 days

to the development of pozzolanic reactions in theses mixtures [Patil et al., 2021]. While beyond this percentage the mechanical resistances decreased with the increase of the substitution rate by 7.08, 18.20, 35.07 and 55.75% for rates of 10, 15, 20 and 25%, respectively at 28 days. This result can be explained by the increase in the fine particles fraction (< 80 µm) in concretes. The presence of this fraction at the interface in free form during mixing could, at high rates, hinder the generation of hydrated calcium silicate gel, and consequently lead to a reduction in mechanical properties of concrete [Kochova et al., 2017]. Also, and since we have suggested that the fine particles of residue 2 will play the role of a filler in mixtures, a poor adhesion between these particles and the rest of the constituents of concrete is possible, especially since these mixtures did absorb a lesser amounts of water, which will induce a drop in the mechanical resistance. In addition, despite that the alkaline nature of residue 2 is beneficial for the dissolution of concrete constituents during mixing, it could increase the risk of expansion of hardened concretes by promoting the formation of $Mg(OH)_2$, which will negatively influence mechanical resistance, especially at high dosages [Frohard, 2014].

The results found in Figure 12 show that the mechanical strength values of concretes with residue 3 remain comparable to those of the control concretes up to a substitution percentage of 10%, which proves the negative influence of the fine particles of residue 2 on the formation of hydrated calcium silicates and on the adhesion of grains during mixing. But, beyond this rate, the mechanical resistance begins to drop with the increase of the percentage of substitution. This result may be due to a disturbance in the hydration of residue 3 concretes caused by the alkaline nature of CSW and leading to a low water absorption during mixing. Which confirms that the level of alkalis must not exceed a certain threshold in cementitious mixtures [Frohard, 2014]. Thus, we can conclude that the best substitution rates for river sand are 5% for residue 2 and 10% for residue 3.

Substitution of crushed sand by residue 2 and 3

The corrected amounts of water and the densities of concretes substituting crushed sand by residue 2 and 3 are given in Figure 11. In the hardened state, all densities experienced a slight increase between 7 and 28 days followed by a decrease between 28 and 90 days. As in the case of river sand substitution, the mixtures with residue 2 consume less water in comparison with the control concrete, and this consumption always decreases with the increase of the percentage of substitution. This discovery confirms the filler effect of residue 2, which is better noticed in this case, especially after concretes hardening, since they marked higher densities than the control concrete. This densification of the microstructure in concretes having residue 2 should slow down the propagation of microcracks during mechanical tests, and therefore have a positive effect on the compressive strengths of these concretes [Jiang et al., 2022]. On the other hand, the water demand of residue 3 mixtures becomes comparable or slightly higher to the control concretes and the densities decreases with the increase of substitution

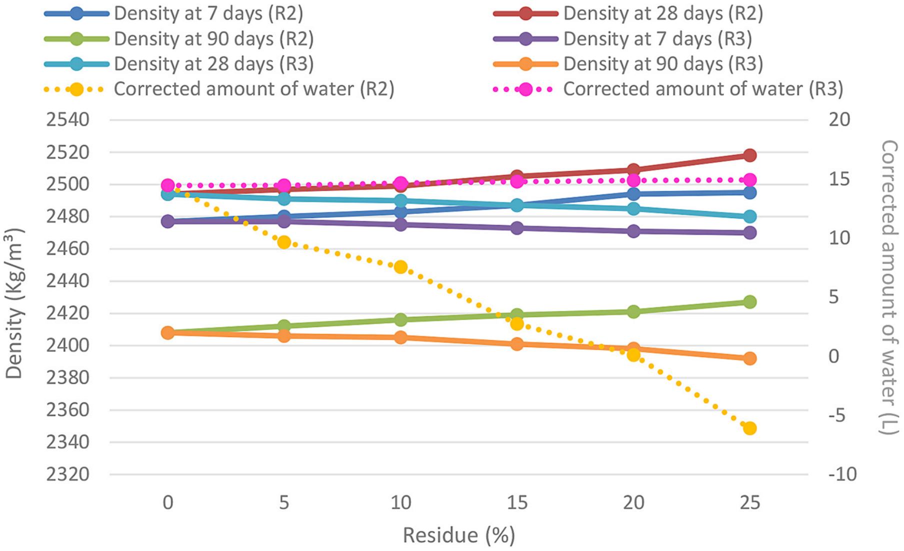

Figure 11. Corrected amounts of water in mixtures and densities in the hardened state of concretes substituting crushed sand by residue 2 and 3 at 7, 28 and 90 days

percentage, unlike residue 2 mixtures. This consequence can be explained by the size distribution of residue 3 particles, which contains more fine grains and at the same time coarser particles in comparison with crushed sand. Figures 12 and 13 illustrate the compressive strength values of concretes containing residue 2 and 3 at 7, 28 and 90 days. The results show that once the replacement rate of residue 2 reaches 10%, the development rate of concretes strengths becomes faster and touches its maximum, exceeding the control concretes strengths by 5.24, 6.2 and 10.63% at 7, 28 and 90 days, respectively. This result can be justified by the better compactness of these concretes and the good development of pozzolanic reactions that required longer periods to fully develop [Patil et al., 2021; Naamane et al. , 2016]. Thus, concretes prepared with low percentages of residue 2 have good physical properties [Jiang et al., 2022; Chen et al., 2022]. The drop in the compressive strength of concretes containing more than 10% residue 2 shows a certain imbalance in the physical properties of these concretes that might be due to the presence of high content of fine particles besides the high alkalinity of CSW [Kochova et al., 2017; Frohard, 2014]. Another factor can work against the development of mechanical strengths in this case, which is the presence of a content of organic matter in residue 2, that even at a low percentage, can influence the hydration of the cement [Naamane et al., 2014].

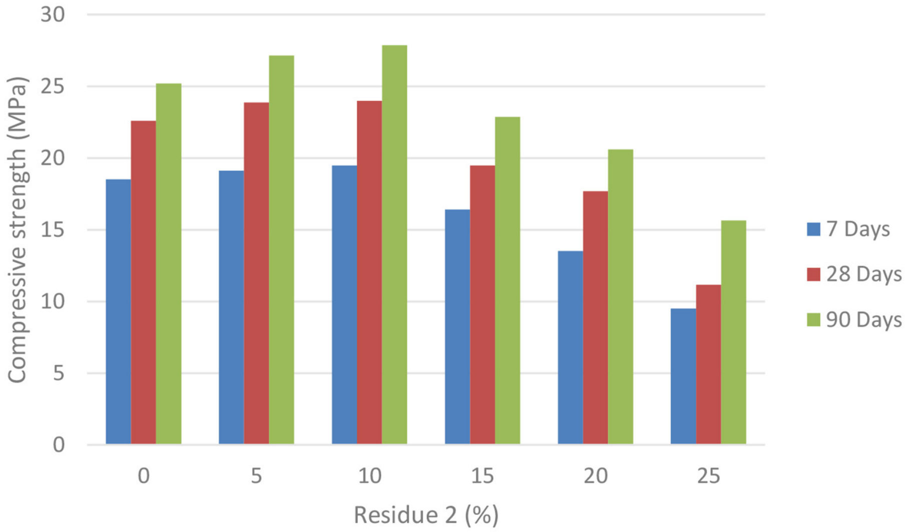

Figure 12. Compressive strengths of concretes substituting crushed sand by residue 2 at 7, 28 and 90 days

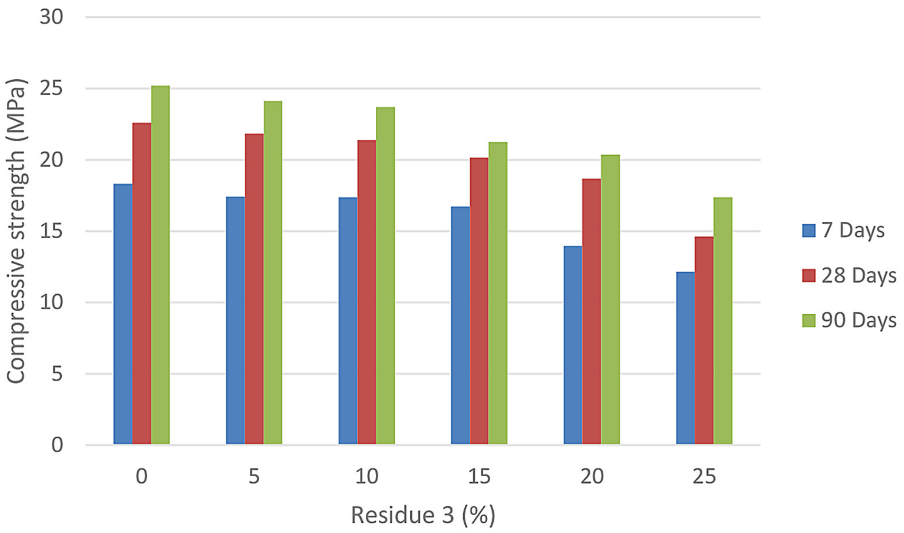

Figure 13. Compressive strengths of concretes substituting crushed sand by residue 3 at 7, 28 and 90 days

Figure 13 shows that, unlike river sand, the substitution of crushed sand by residue 3 negatively influenced the mechanical strengths at all ages and whatever the replacement percentage. This result seems to be attributed to a poor adhesion between the grains of residue 3 and the rest of concrete constituents, which induced a drop in the strength by 3.27, 5.31, 10.76, 17.31 and 35.34% for substitution rates of 5, 10, 15, 20 and 25%, respectively, compared to the control concretes at 28 days. The difference between these results and those obtained during the substitution of river sand shows the influence of the particle size and the nature of sands used (naturel or crushed) on the mechanical resistance of the specimens [Rajput, 2018]. In addition, the role played by high-content alkalis is more obvious in this case, especially at high substitution rates, which promote the formation of $Mg(OH)_2$, and consequently increases the risk of cracks forming in the specimens after hardening [Frohard, 2014]. Thus, it is recommended to substitute crushed sand with residue 2 up to a rate of 10% and to introduce residue 3 only as a substitute for river sand.

CONCLUSIONS

In order to assess the technical feasibility of producing B_{25} class concrete containing dried concrete slurry waste, multiple series of experiments have been carried out on CSW and CSW-concretes. The CSW were divided into three types of residues, then its incorporation into concrete mixtures was realized by replacing 2, 4, 6, 8 and 10% of cement by residue 1 on one hand and 5, 10, 15, 20 and 25% of river sand and crushed sand by residues 2 and 3, separately, on the other hand. The results acquired by this study reveal that:

The CSW used has a high fine particles content exceeding 28% of the material passing through 0.08 mm sieve, a low organic matter content, a high pH value and an average pozzolanic activity. It is mainly composed of CaO, SiO_2 and Al_2O_3 that form the majority of the mineral components of this material, which are quartz, ankerite, calcite, dolomite, and berlinite.

The density in the hardened stat of CSW-concretes is related to the water/cement ratio of mixtures in the fresh stat, and subsequently to the fine particles content in CSW. The accurate ratio of fine particles serves to reduce pores and microcracks in CSW-concretes, which improves the physical properties and consequently the mechanical resistance of these concretes. But, a higher percentage of fine particles might hinder the generation of hydrated calcium silicate gel, resulting the reduction of the mechanical properties of concretes.

Generally, the compressive strength of concretes made with low percentage of CSW is slightly higher than that of the control concrete, especially at 90 days. This positive effect noticed at 90 days is due to the development of pozzolanic reactions that help also in the elimination of pores and voids in concretes. Nonetheless, if the addition percentage of CSW becomes higher, the compressive strength drops remarkably at all ages. The best results are obtained for a substitution rate of cement by 2% of residue 1, river sand by 10% of residue 3 and crushed sand by 10% of residue 2.

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