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Original Research Article

VALORIZATION OF WASTE IN SAND CONCRETE BASED ON PLANT FIBRES

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Abstract

The introduction of treated plant fibres into sand concretes leads to a reduction in density, improved ductility and thermal conductivity, and makes sand concrete an environmentally friendly and ecological material. The recovery of waste in this type of material allows the production of new ecological and sustainable materials used either in the new construction or in the rehabilitation of old buildings. In this context, a comparative study was based on the valorisation of marble and ceramic waste as sand in sand concrete made from straw fibres. To carry out this study, we introduced these wastes at substitution rates of 10% and 20%, separated and mixed, and studied the development of the properties of these concretes (density, workability, air content, compressive strength and bending tensile strength) and their behaviour with respect to durability (capillary and immersion absorption and chloride penetration). The study shows that the recovery of this waste as sand in sand concrete based on straw fibres gives satisfactory results. The chemical resistance, thermal conductivity and microstructure are under study, the results of which will be the subject of another publication.

Keywords: sand concrete, wheat straw fibres, recovery, waste, marble, ceramics, substitution, performance, durability

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1. INTRODUCTION

The sand concrete lightened by the addition of plant fibres is an environmental and sustainable approach. These fibres help to improve the performance and behaviour of sand concrete, particularly with regard to lightness, thermal insulation and taking the environment into account while preserving the natural aggregates of concrete [1,2], where plant fibres partially replace the ordinary sand used in the concrete formulation. Lightened concrete is used for rehabilitation works and non-structural elements, such as those used in non-load bearing walls and thermal insulation [3].

The introduction of plant fibres into different matrices was the subject of several studies aiming at solving several problems related to the thermal and acoustic characteristics, as well as their renewable aspect [4]. The effect of the addition of wood chips on the thermal conductivity of sand concretes with the chip content ranging from 0 to 100 Kg/m3 was studied by Bederina et al. (2007) [5], whose results show a reduction in its density and an improvement of its thermal conductivity. Another study was performed by Belhadj et al. (2014) [2] on the effect of the separate and combined introduction of barley straw and wood chips on the physical and mechanical properties of sand concrete. They found that the combined incorporation of both types of fibre gives the best results with regard to shrinkage, thermal diffusivity, toughness and ductility. Li et al. (2006) reinforced concrete composites with hemp fibres. This reinforcement leads to a reduction in the density and absorption of water [6].

In another study, Taoukil et al. (2012) examined the effect of incorporation of wood wool on the thermo-physical properties of sand mortars with percentages ranging from 35 to 58%. They demonstrated that this incorporation decreases thermal conductivity, diffusivity, as well as compressive strength which makes is this material compatible as lightweight concrete [7]. Bederina et al. (2009) presented a study on the influence of the treatment of wood chips by the cement paste on the physico-mechanical properties of sand concrete. They found an increase in the mechanical strength without influence on the thermal conductivity, the shrinkage was reduced and adhesion was improved [8]. In the same sense, Sellami et al. (2013) studied green concrete reinforced with Diss fibres treated with boiling water to extract sugars; they have shown that this type of treatment leads to a considerable improvement in the mechanical properties of the studied composites [9]. Belhadj et al. (2015) studied the effect of incorporating barley straw on the thermo-physical properties of sand concrete for the construction of an exterior wall in arid regions, and found that the introduction of barley straw in sand concrete improves the thermal properties in terms of thermal conductivity and specific heat [10]. Merta and Tschegg (2013) used hemp fibre, elephant grass and wheat straw in concrete, and found an improvement in concrete toughness with a decrease in tensile strength. Most studies agree that the introduction of plant fibres lightens concrete, but with a detrimental effect on shrinkage and porosity, while the mechanical strength of hardened concrete remains acceptable [11]. However, several treatments have been proposed to reduce the negative effects of plant fibres in concrete such as heat, chemical and physical treatment.

Based on the previous paper, we developed sand concrete made of wheat straw fibres, in which we introduced waste as aggregates to valorize them and produce new lightweight and ecological materials used either in the construction of new buildings or in the rehabilitation of old ones.

In this paper, we valorised marble and ceramic waste as a substitute for aggregates in sand concrete because the ceramic products industry in Algeria has grown significantly in recent years, and contributed significantly to the sector of construction, whether by red ceramics or white ceramics. During the year 2018, a total of 150 million square meters of ceramics were produced [12] (Bouderba 2018). In addition, large quantities of ceramic waste are thrown into the wild due to the poor quality of the said product found during packaging and shipping at the production facilities. However, other quantities of ceramic waste are also being dumped as a result of the redevelopment of houses. In 2016, the National Waste Agency identified 11 million tonnes of inert waste (ceramics and scrap) [13]. Similarly, it is noted that during quarrying, cutting and sawing of rock blocks (especially granite and marble), a very large quantity of waste is dumped into the ground in the form of aggregates and powders [14]. These wastes pose a threat to the environment and health of people. Waste recycling processes are one of the most widely used environmental and sustainable solutions in the world as they constitute the appropriate ways to give new life to these wastes and reduce their environmental impacts. They also give us some advantages such as protecting natural resources, saving energy, contributing to the economy, reducing waste and investing for the future, and it can also be seen as a sustainable approach to solid waste management [15].

Several studies have been conducted on the reuse of marble and ceramic waste in the form of fines and aggregates in concrete and mortar. Alves et al. (2014) evaluated the effect of incorporating fine recycled ceramic aggregates (brick and ceramic sanitary ware) partially replacing natural fine aggregates at rates of 20 to 100% on the mechanical properties of concrete [16]. They have found that the crushed bricks lead to an improvement in structural performances and contrary to those given by the ceramic granulates. Higashiyama et al. (2012) studied the effect of the use of fine aggregate and ceramic waste powder as a partial substitution of natural fine aggregates and cement respectively on the compressive strength and penetration resistance of chloride ions of a mortar [17]. They found an improvement in these characteristics in comparison to the ordinary sand mortar, especially at the 20% partial substitution rate of cement with ceramic powder. The use of ceramic sanitary waste as aggregates (fine and coarse) in concrete has been studied by Halicka et al. (2013). They showed an improvement in mechanical strength and abrasion resistance [18]. Farinha et al. (2015) studied the behaviour of cement mortars with the volume substitution of natural aggregates with recycled fine aggregates (ceramic sanitary ware) with percentages from 0 to 20%, the results were very positive [19], especially at a substitution rate of 20%. Improving the performance of a cement mortar by adding very fine recycled aggregates of red ceramics was studied by Silva et al. (2009). They found that the substitution of 10% of ordinary fine aggregates with fine aggregates recycled in the mortar leads to a general improvement in its performance [20]. Hebhoub and Belachia (2011) studied the valorization of marble waste aggregates in the concrete composition with total and partial incorporation from 0 to 100% [21], they found an improvement in compressive and tensile strength as well workability of concrete. Belaidi et al. (2012) examined the effect of the substitution of marble powder on the properties of self-compacting concrete, in percentage different from 10 to 40%. They presented an improvement in workability of concrete with a negative effect on compressive strength [22]. Aliabdo et al. (2014) evaluated the possibility of reusing marble dust as a partial substitution of cement and sand in concrete; the results found indicate an improvement in the physical and mechanical properties of concrete [23]. In the same sense, Sardinha et al. (2016) tested the durability of concrete containing marble slurry; the results show that the increase in the cement and marble sludge content negatively affects the durability of concrete [24]. An experimental study was conducted by Hebhoub et al. (2014) on the partial and total substitution of the standard sand with marble waste sand in the composition of the mortar. The results show that the introduction of marble waste in the mortar leads to an improvement in density with a decrease in workability [14], thus a good compressive strength in the short term. Djebien et al. (2018) reused marble waste as sand in self-compacting concrete, they found that substitution of marble waste reduces density and air content, and ensures cohesion and resistance to segregation [25].

The results obtained by these researchers gave us an idea about the possibility of producing sand concrete lightened by wheat straw fibres containing the marble waste from the Fil-fila quarry (waste powder Fig. 1) and the waste of ceramic sanitary parts (Fig. 2) as sand partially replacing the ordinary sand and to study the effect of their reuse on the properties of concrete in the fresh and hardened state.

Fig. 1. Pierced marble powder

Fig. 2. Ceramic waste

2. USED MATERIALS

2.1. Wheat straw fibres

Wheat straw (WS) fibres were obtained in the agricultural fields when harvesting wheat, they are also considered as vegetable waste. They are recovered and cut 3.5 cm long in a tubular form with a diameter of about 1-4 mm (Fig. 3), and then heat treated with boiling water at a temperature above 70°C for one hour to extract the hemicelluloses inside, and dried for 28 days. These fibres have an absolute density equal to 506 Kg/m^3.

2.2. Cement

Cement CEM I, class 42.5 coming from the Ain kbira-Sétif cement plant (East of Algeria) with an absolute density of 3.22 g/cm^3 and a Blaine specific surface of 3000 Cm^2/g.

2.3. Sand

- Dune sand DS, class 0/1, rolled nature, from Collo East of Algeria.
- Marble waste sand MS (weathered thrown powder), class 0/2, crushed nature, from Fil-fila quarry, East of Algeria.
- Ceramic waste sand CS, class 0/2, crushed nature obtained by crushing and sieving the washbasin wastes. The properties of sands are presented in Table 1 and the grain size curves of three sand types are presented in Fig. 4.

According to the properties, we can say that:

- The highest density is given by marble waste sand while ceramic waste sand gives the lowest density.

- The sand equivalent shows that the three sand types are clean and allowable for quality concretes, especially in the case of dune sand which is very clean with a value of 86.30%.
- The three sand types used are characterized by a continuous particle size distribution.
- The fines content of ceramic waste and marble waste sands are 17% and 15% respectively compared to dune sand, which requires a low water dosage [26].
- Marble waste sand is characterized by the lowest fineness modulus, which indicates fine sand, increased workability at the likely expense of resistance [27].
- Ceramic waste sand has fineness modulus close to the optimal value, it gives good workability and good strength [28].
- The high absorption value of dune sand and marble waste sand indicates a high-water demand, which can adversely affect the durability of the concrete in an aggressive environment and can cause a loss of flow fluidity of fresh concrete [29]. The lowest absorption is given by ceramic waste sand.
- Dune sand and ceramic waste sand contain a high percentage of silica (SiO_2) of 94.09% and 76.86% respectively, which can slow down the hardening process, and helps achieve high strengths in the medium and long term and improves the durability of concrete.
- In addition to silica, ceramic waste sand contains alumina Al_2O_3 (21.90%), which contributes to concrete setting; on the other hand, it negatively affects the chemical stability and promotes the attack by sulphates [26].
- Marble waste sand consists mainly of $CaCO_3$ with a percentage of 98.67%. This element is responsible for improving the cohesion of the cement matrix and leads to an increase in mechanical strength at a young age [28,26, 27].

2.4. Fines

Fines F used in this study are fine limestones from the quarry of Ben Azouz-East of Algeria, more than 70% passes the sieve, 0.08mm, with an absolute density of 2.74 g/cm^3.

2.5. Superplasticizer

Superplasticizer SP used is of the Polyflow SR 5400-SOLU EST type, in accordance with standard EN 934-2. It is a super high water softener for concrete, is introduced in the form of a light brown liquid with density that varies from 1.07 ± 0.02. The chemical properties of sand, fine limestone and cement are presented in Table 2.

Fig. 3. Wheat straw fibres

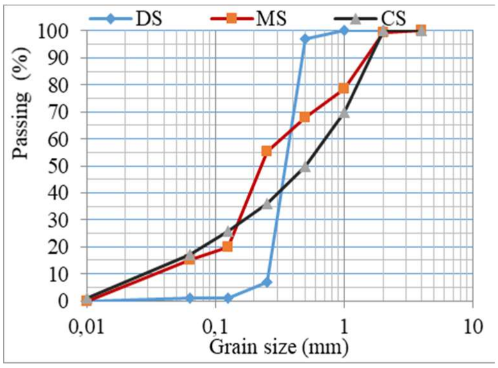


Fig. 4. Granulometric curves of the sands

Table 1. The properties of different fractions used

Physical characteristics	**DS**	**MS**	**CS**
Apparent density g/cm^3	1.52	1.61	1.38
Absolute density g/cm^3	2.59	2.66	2.43
Sand equivalent %	86.30	67.11	66.29
Value of blue methylene %	0.7	0.6	0.25
Absorption %	3.35	4.95	1.26
Fineness modulus %	1.95	1.79	2.20
Fines content %	1	15	17

Table 2. Chemical compositions of different materials used

Chemical characteristics	**Cement**	**DS**	**MS**	**CS**	**F**
CaO	*63.69*	*0.80*	*55.29*	*1.52*	-
Al_2O_3	4.55	2.36	0.14	21.90	-
Fe_2O_3	5.03	1.15	0.09	0.60	-
SiO_2	20.90	94.09	0.53	76.86	-
MgO	-	0.14	0.20	0.28	-
Na_2O	0.18	0.20	-	1.11	-
K_2O	0.33	0.58	0.01	1.39	-
Cl-	0.001	-	0.025	-	0.21
SO_3	2.08	0.01	0.04	-	--
$CaCO_3$	-	-	98.67	-	84.60
SO_4	-	-	-	-	--
Loss on ignition	0.70	-	43.40	-	-
Insoluble residue	0.75	-	0.035	-	-
Free CaO	0.75	-	-	-	-

3. EXPERIMENTAL PROGRAM AND TESTS CARRIED OUT

3.1. Experimental program

In the experimental program we chose wheat straw fiber-based sand concrete (SCWS) [4] based on the paper by Bederina et al. (2012), Belhadj et al. (2016) [1] as a reference concrete. Then we substituted the ordinary sand with marble waste sand and ceramic waste sand. To do this, three formulations were made:

- In the first formulation (SCWS-M), we substituted the ordinary sand with marble waste sand MS at rates of 10% and 20%.
- In the second formulation (SCWS-C), we partially replaced the ordinary sand with ceramic waste sand CS at rates of 10% and 20%.
- The third mixed formulation (SCWS-MC) containing a mixture of marble waste sand and ceramic waste sand MC partially replaces the ordinary sand at rates of 10% and 20%.

The formulation of the mixtures was made by Sablocrete method (Sablocrete 1994) [29] with the fixed parameters which in this study are the straw fibre dosage, the adjuvant dosage, the dosage in fines and the ratio W/C and the variable parameters are substitution rates. Different compositions of the mixtures for the three formulations are given in Table 3.

Table 3. Compositions of mixtures

Formulations	**DS (Kg/m^3)**	**CEM I (Kg/m^3)**	**W (l/m^3)**	**F (l/m^3)**	**SP (%)**	**WS (Kg/m^3)**	**MS (Kg/m^3)**	**CS (Kg/m^3)**
SCWS-0	*1130.94*	400	260	246.6	1	8	-	-
SCWS -10M	*1017.58*	400	260	246.6	1	8	120.51	-
SCWS-20M	*904.76*	400	260	246.6	1	8	241.03	-
SCWS-10C	*1017.58*	400	260	246.6	1	8	-	106.09
SCWS -20C	*904.76*	400	260	246.6	1	8	-	212.21
SCWS -10MC	*1017.58*	400	260	246.6	1	8	60.25	54.79
SCWS -20MC	*904.76*	400	260	246.6	1	8	120.51	106.09

3.2. Tests performed

The tests carried out on the different formulations are:

- Workability, measured by subsidence and cone of Abrams in accordance with standard NF EN12350-2.
- Density in fresh concrete in accordance with standard NF EN 12350-6.
- Air content measured by a concrete air meter in accordance with standard NF EN 12350-7.

- Flexural tensile strength at the age of 2.7, 14, 28 and 90 days measured on prismatic samples of 7x7x28 cm^3 preserved in water in accordance with standard NF EN 12390-5.
- Compression strength at the age of 2, 7, 14, 28 and 90 days measured on cubic samples of 15x15x15cm^3 preserved in water in accordance with standard NF EN 12390-3.
- Capillary absorption measured on samples of 7x7x28cm^3 in accordance with standard NF EN 480-5.
- Immersion absorption measured on cubic samples of 15x15x15cm^3 in accordance with standard NBN B 15-215.
- Chloride penetration measured on samples of 7x7x28cm^3 kept for 28 days in water then in a solution containing 3% chloride (NaCl). The samples were cut and treated with a silver nitrate solution on the cut concrete surface according to NT BUILD 492-1.

4. RESULTS AND DISCUSSION

4.1. Workability

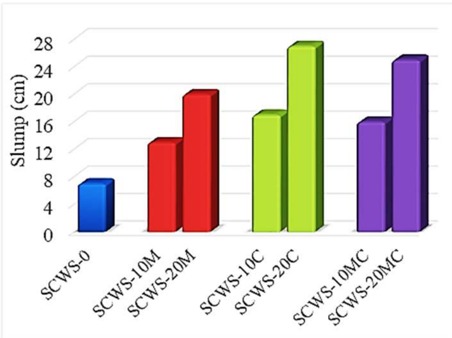


Fig. 5. Variation of workability as a function of the substitution rate

In general, the introduction of waste leads to an improvement in workability regardless of the substitution rate (Fig. 5). The introduction of the MS leads to an increase in workability relative to the reference concrete, whatever the degree of substitution, this increase is due to the fact that MS facilitates the dispersion of cement paste grains as a result of filling effect of concrete voids [30]. These results are consistent with those obtained by Baboo et al. (2011) [31], and unlike those obtained by Hebhoub et al. (2014) [14]. The introduction of ceramic sand leads to an improvement in workability regardless of the substitution rate with the maximum value of 20%, this is explained firstly by fineness modulus which is close to the optimal and the filling effect and the lowest absorption of CS on the other hand. These results are consistent with those obtained by López et al. (2007) [32] and unlike those obtained by Alves et al. (2014) [16].

4.2. Density

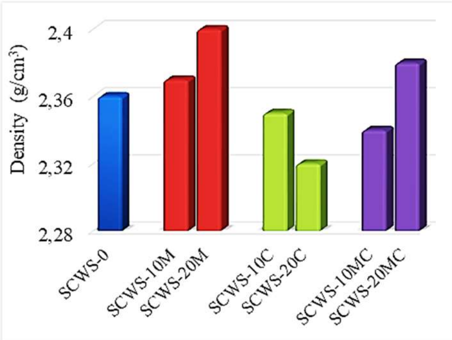


Fig. 6. Variation of density versus substitution rate

The introduction of MS as a partial substitution of DS increased the reference concrete density up to a maximum value of 2.40 g/cm^3 for concrete at a 20% substitution rate, this increase can be explained by high density of MS in comparison to DS (Djebien et al. 2015) [33]. For formulation SCWS-C, an increase in the CS substitution rate causes a decrease in density up to 2.32 g/cm^3 (Fig. 6) obtained at 20% rate. This can be explained by a lower density of CS, these results are consistent with those obtained by Vieira et al. (2016) [34]. The introduction of sand MC in the mixed formulation SCWS-MC results in an increase in density for a rate of 20%, the mixture of these two sands gives a balance between the densities of the latter.

4.3. Air content

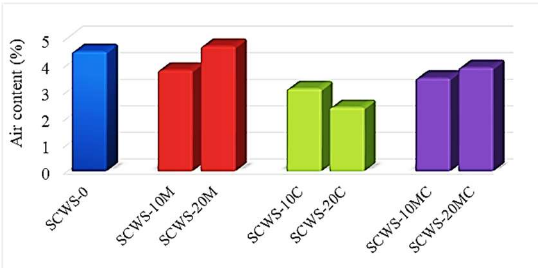


Fig. 7. Change in air content as a function of the substitution rate

The introduction of waste sands (Fig. 7) leads to a decrease in the air content regardless of the substitution rate except for formulation SCWS-20M where there is a slight increase, the latter is contrary to what has been found by Alyousef et al.

(2018) [35]. The decrease in entrapped air content for formulation SCWS-10M is due to the improvement in segregation resistance capacity of marble waste sand [36, 33]. However, a decrease in the occluded air content as a function of the increase in CS waste rate can be explained by a higher fine content which contributes to reducing the porosity of concrete. Also, the weak movement of water molecules by means of capillary action can reduce the formation of air pores in concrete [37].

4.4. Compressive strength

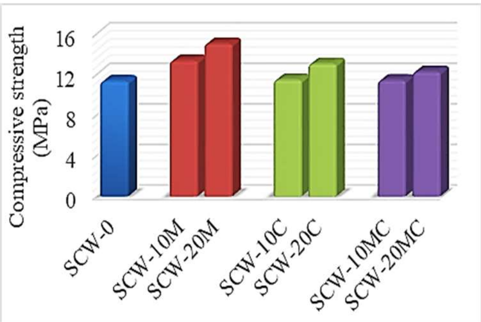
An increase in the substitution rate of waste sands (Figs. 8(a)-(b)) leads to an increase in compressive strength at early age (2 and 7 days) in the case of the reference concrete.

The strongest performances on 2 and 7 days are given by formulations SCWS-M, which are due to the chemical composition of MS which contains a lot of $CaCO_3$ which offers a lot of C_3S which is responsible for increasing the strength at early age [25 ,14, 28] on the one hand, and the filling effect of MS voids [38].

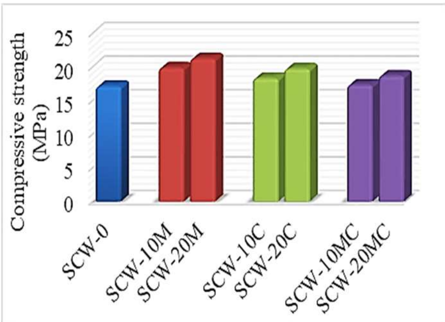
In the medium term of 14 days (Fig. 8(c)), the behaviour is not the same as in the short term where there is a slight increase in compressive strength and the best performance is given by the mixed formulation with a rate of 20%.

The best compressive strength at 28 days (Fig. 8(d)) is given by formulations SCWS-C as a function of the increase in the degree of substitution; the maximum value is recorded in SCWS with 20% CS content, this is explained by the chemical composition of CS which contains a very large amount of SiO_2 which gives a lot of C_2S and has a positive influence on the mechanical resistance at this age [26, 27].

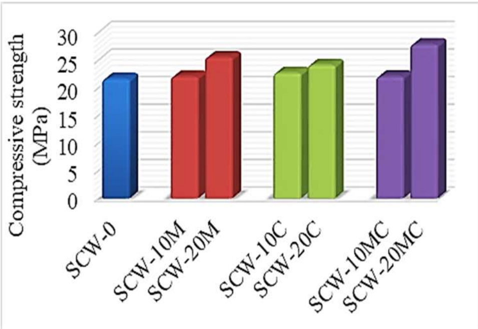
In the long term of 90 days (Fig. 8(e)), the behaviour is the same as at 28 days and the best performances are always given by formulations SCWS-C, this is due to a very high amount of C_2S which is responsible for long-term resistance, and these results are consistent with those obtained by Farinha et al. (2015).



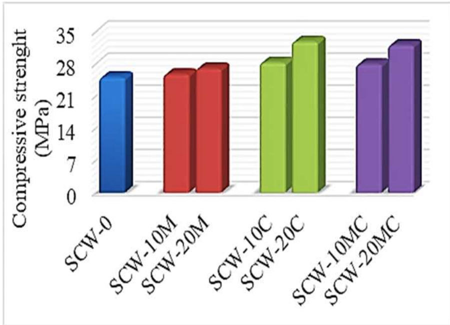
(a) At 2 days



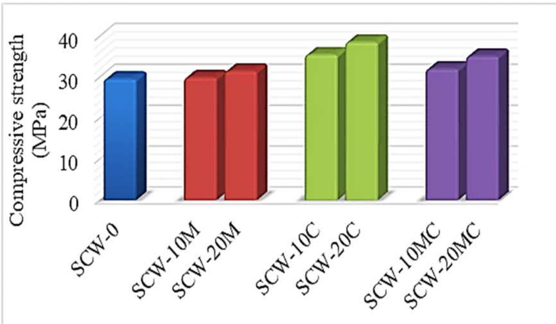
(b) At 7 days



(c) At 14 days



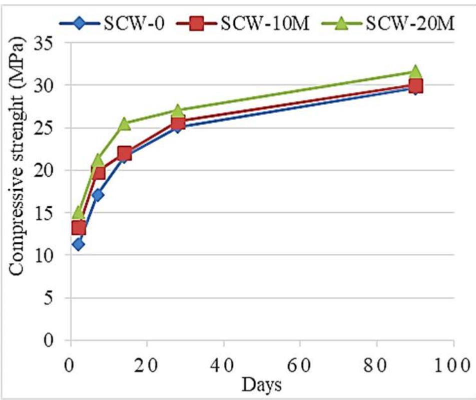
(d) At 28 days



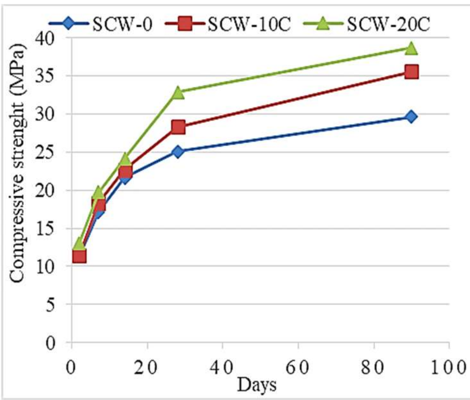
(e) At 90 days

Fig. 8. Compressive strength of the concretes studied

The effect of waste sand on increasing the compressive strength of concrete over time is clear for the substitution of CS versus mixed sand MC and MS (Fig. 9).



(a)



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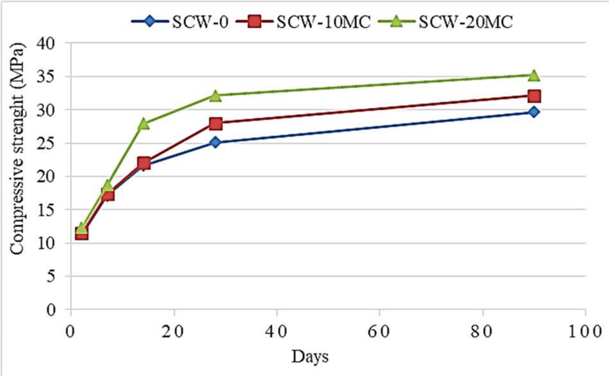
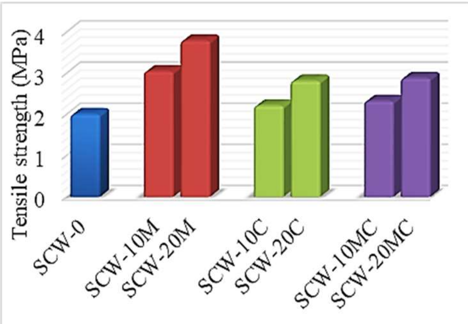


(e)

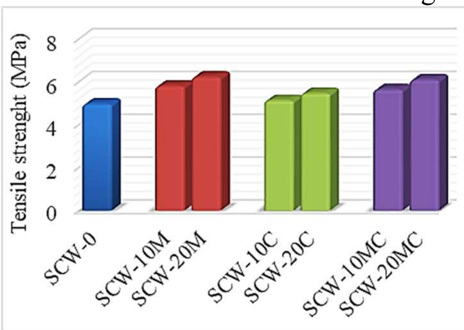
Fig. 9. Compressive strength of concretes studied as a function of time

4.5. Flexural tensile strength

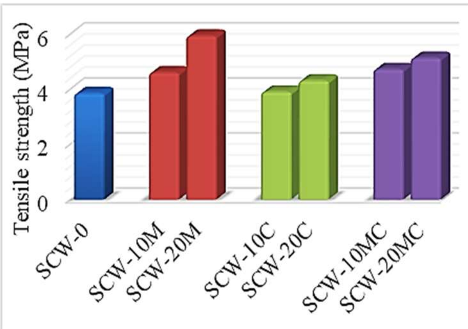
In general, the bending tensile behaviour is the same as in compression; an increase in the substitution rate causes an increase in these resistances in all ages.



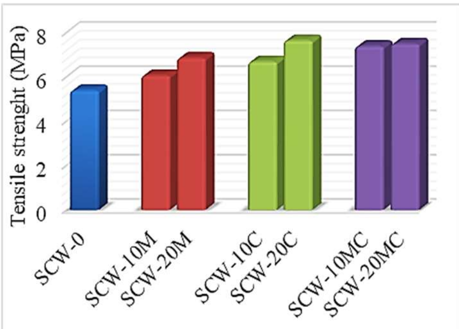
(a) At 2 days



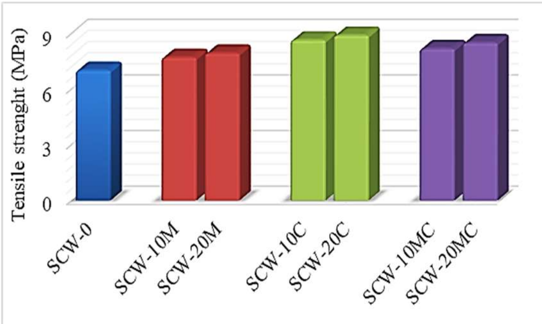
(b) At 7 days



(c) At 14 days



(d) At 28 days



(e) At 90 days

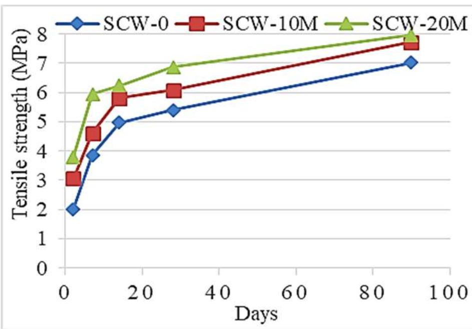
Fig. 10. Tensile strength of the concretes studied

At 2, 7 and 14 days, the best tensile strength is given by SCWS-M (Fig. 10 (a)-(b)-(c)), this is explained by the presence of $CaCO_3$ in MS which increases the cohesion [26,27] on the one hand and which accelerates strength at early age on the other hand [28]. The lowest performances at the same ages are given by SCWS-C.

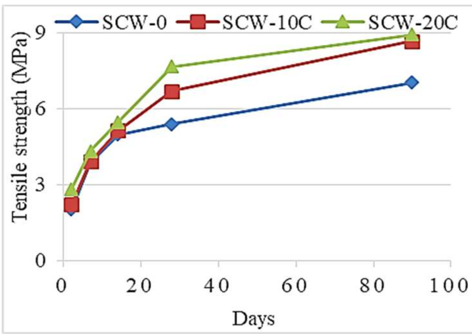
At 28 and 90 days, there is an increase in tensile strength in SCWS-C and SCWS-MC; this is due to the pozzolanic reaction of CS which increases the long-term strength; these results are consistent with those obtained by Farinha et al. (2015), Silva et al. (2009).

With regard to increasing the tensile strength of concrete as a function of time (Fig. 11), the effect of MS is evident in the early days and the reverse for CS, the effect of which is clearer with the weather. Simultaneously, sand MC gives us a consensual solution to increase the resistance whatever the time.

It can be said that the partial substitution of the ordinary sand with marble waste sand, ceramic or both sets, improves tensile strength by bending sand concrete lightened by straw fibres.



(a)



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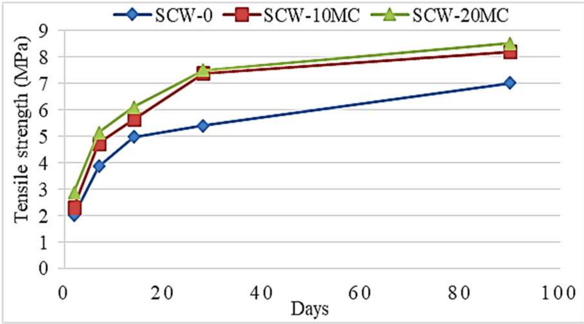


(e)

Fig. 9. Compressive strength of the concretes studied

4.6. Capillary absorption

The results (Fig. 12) show that the introduction of waste sand at a substitution rate of 10% decreases water capillary absorption in comparison to that of the reference concrete, with a minimal absorption recorded in SCWS-10C, these results are consistent with those obtained by Farinha et al. (2015), this is because CS grains fill the pores of concrete which provide thinner capillaries and a weaker water flow on the one hand, and the pozzolanic activity probably due to the reaction between SiO_2 and Al_2O_3 with $Ca(OH)_2$, which produces additional phases of CSH (foreignity) and mono-sulfate and others (Farhina et al. 2015, Silva et al. 2009, Vieira et al. 2016).

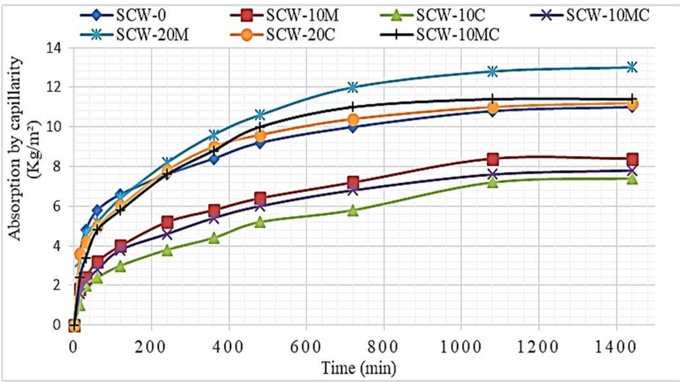


Fig. 12. Capillary absorption of water as a function of time

The same behaviour is found in SCWS-10M, where MS improves the bond between cement paste and fine aggregates due to their angular and elongated geometry [39], which is reflected in the reduction of the water capillary penetration capacity, these results are confirmed by Topçu et al. (2009) [40]. At 20% substitution, the increase in waste sand leads to an increase in water absorption for all formulations after time of 200 min, up to a maximum value recorded in SCWS-20M, this is due to the fact that the average size of concrete capillary pores become larger [39], knowing that the highest absorption coefficient is given by MS.

4.7. Immersion absorption

Immersion absorption of water is a property related to the durability of concrete, it allows estimating the volume of open pores of concrete by the penetration of water through the structure of these pores.
The results obtained from the immersion absorption test (Fig. 13) indicate that the substitution of the ordinary sand with waste sand at a rate of 10% leads to a decrease in absorption compared to the reference concrete. The lowest absorption is recorded by formulation SCWS-10C, this is explained by the effect of fillers and the pozzolanic reaction of ceramic waste sand with calcium hydroxide ($Ca(OH)_2$) which leads to a less porous and more impervious concrete (Sampaio et al. 2017), knowing that the CS absorption coefficient is lower than that of DS and MS.

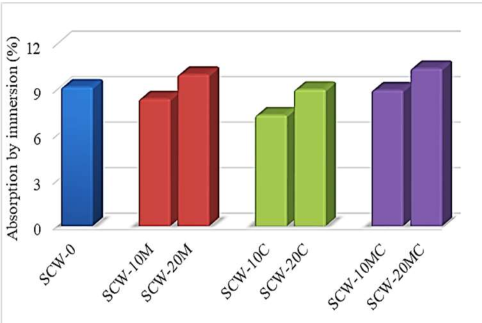
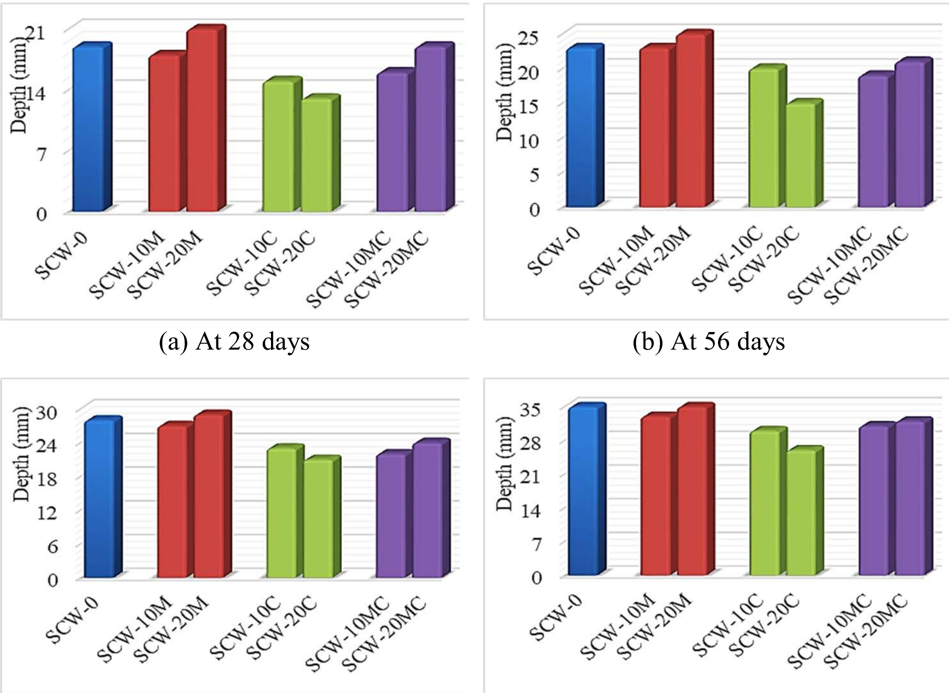


Fig. 13. Change in the immersion absorption coefficient
as a function of the substitution rate

The substitution with 20% waste sand results in a slight increase in water absorption compared to that of the reference concrete for formulations SCWS-20M and SCWS-20MC, due to the higher absorption coefficient of MS on the one hand and that the increase in the occluded air content of SCWS-20M is related with immersion absorption on the other hand, which affects the compactness of concrete due to the roughness of MS aggregates [39]. Low absorption concrete is more compact, impervious and can retain its long-term properties [41].

4.8. Chloride penetration

From the results obtained (Fig. 14), it is found that the lowest depth of chloride penetration is given by formulation SCWS-C as a function of the increase in the CS substitution rate in comparison to that of the reference concrete at all ages, up to a maximum value of 20%, this decrease is due to the filling effect which reduces the volume of the internal pores of concrete [17] on the one hand, and on the other hand, ceramic sand contains a quantity of alumina (Al_2O_3), the latter promotes the formation of C_3A which fixes the chloride ions [42], it also contains SiO_2 which contributes to the formation of C_2S, the latter gives great durability to the aggressive environment [26].



(a) At 28 days (b) At 56 days

(c) At 90 days (d) At 120 days

Fig. 14. Depth of chloride penetration

The same behaviour is recorded by formulation SCWS-MC, a slight decrease in penetration depth was observed as a function of the MC substitution rate at 10% and 20% relative to the reference concrete. With respect to formulation SCWS-M, the introduction of 10% MS results in a slight decrease in penetration depth for all ages; these results are similar to those obtained by Rana et al. (2015) due to the reduction of capillary passages which leads to a decrease in chloride ion migration [43, 38]. At a 20% substitution rate, the penetration depth of chloride increases compared to the control concrete at 28 days, this increase is achieved over time to reach a value almost similar to that of the reference concrete at 120 days.

5. CONCLUSIONS

Based on the results of this study, we can draw the following conclusions:

- The introduction of waste as sands leads to an improvement in the workability of SCWS.
- The use of waste as sand in sand concrete lightened by straw fibres reduces the occluded air content, except for marble waste sand added at a rate of 20%.
- The substitution of the ordinary sand with marble waste sand increases the compressive and tensile strength at early age.
- The best performances in medium-term compression and in long-term traction are given by formulation SCWS-20MC.
- Formulation SCWS-20C gives the best compressive and tensile strengths in the long term.
- The introduction of waste sands at a rate of 10% leads to a decrease in capillary absorption with a better behaviour observed on ceramic concrete. The higher the rate, the absorption is more important. The same trend was observed for immersion absorption at a rate of 10%, while the effect is reversed for a 20% rate of marble waste sand and mixed waste sand.
- The substitution of the ordinary sand with ceramic waste sand and mixed waste sand reduces the depth of chloride penetration; the best results were achieved by SCWS with a 20% content of ceramics.
- Marble waste sand has a negative effect on the durability of SCWS at a substitution rate of 20%. It can be concluded that marble and ceramic waste can be used as fine aggregates in the composition of sand concrete lightened by plant fibres.

Despite these results, further tests are recommended in order to fully evaluate the performance of lightweight sand concrete and to know the effect of the introduction of marble waste sand and ceramic waste sand as the substitute of the ordinary sand on concrete properties. These tests and their results will be available in later articles.

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