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Original Research Article

PERFORMANCE OF CONCRETE CONTAINING PARTIAL GRANITE AND TILING WASTES AS FINE AGGREGATE

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Abstract

The objective of this paper is to study the properties of different compositions of concrete made by substituting sand made of crushed limestone, which is over-exploited in Algeria, by two types of sands produced by the recycling of double-layer tiling and granite waste, respectively, with different mass percentages of 0, 10, 20 and 30%. The physical, mechanical and some aspects of the durability properties of six concretes were evaluated and compared to those of a reference concrete. The results obtained show that the incorporation of granite sand up to a rate of 20% improves the compressive strength and the resistance to acid CH_3COOH. For concretes made with tiling sand, the best compressive strength was observed in concrete with an addition rate of 10%. Furthermore, good tensile strength by splitting is obtained with rates of up to 30% of the two recycled sands.

Keywords: Tiling sand, granite sand, concrete, mechanical performance, durability

1. INTRODUCTION

The production of waste in recent years has been continuing to increase in quantity due to ever greater and more diversified consumption all over the world. As a result, landfill capacity has been increasingly depleted, especially around large cities. Thus, reducing the volume of waste by reusing it is a major challenge for governments because these substances pose enormous risks to the environment and to the health of populations.

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Across various regions of the globe, the unavailability of enough cement and aggregates to make cement concrete has led researchers and practitioners in the construction industries to exploit certain types of waste. They have extensively studied the impact of these recycled materials, with different percentages of substitution, whether cement, sand or even gravel, on the mechanical performance of recycled concrete and its implementation, and they have identified some alternatives that have positive effects on the mechanical, fresh and durability properties of the cement matrix.

This present research work is part of a sustainable development perspective and aims to recover the waste from granite transformed into countertops and the manufacturing debris of the floor covering known as double-layer tiles. These two materials are produced in Algeria in huge quantities and their waste is dumped in the open without any recycling. This practice, on the one hand, is detrimental to the environment, and on the other hand, involves additional transport costs for the producing factories. So, by introducing these wastes into concrete production, the objective of reducing building costs can be met and it will also help to overcome the problems related to land disposal.

In the granite stone industry, granite waste is generated as a by-product of the cutting and grinding of granite as reported by [1]. It is mostly composed of quartz and feldspar, but may also contain mica, amphiboles and other minerals. It can be used as a substitute for aggregate materials in concrete bulk production. A number of researchers have investigated the impact of replacing aggregates with granite wast on the properties of the concrete. However, each study provided a different optimal replacement percentage based on the experimental results obtained. The results shown in the literature depend on the design of the mixture, the nature of the materials, as well as the additions and the additives used. For example, Tangaramvong et al. 2021 [2] assessed the effects of recycled granite aggregate on the properties of two classes of concrete: one with 20 MPa and the latter with 50 MPa strength for various sand replacement ratios with granite particles. The results showed that the compressive strength of the concrete was not affected, the concrete’s flexural strength reduced with 50% of granite waste incorporated, and the effects were more pronounced in concrete with a lower strength. The presence of granite particles in the mixes also reduced the workability of the fresh concrete. Images of themicrostructure of granite waste concrete show a weakening of the interfacialtransition zone between the cement paste matrix and the aggregate. Patil et al. 2021 [3] evaluated the hardened properties of concrete made with copper slag (CS) and granite dust(GD) as partial replacements for sand at 7, 28, 56 and 112 days. The results show that, with increasing CS and GD content, the strength of the concrete containing CS and GD increases. Jain et al. 2020 [4] investigated the possibility of using granite powder(GP) and soda–lime glass powder (GrP) from waste glass bottles in concrete as a partial replacement for cement or sand, respectively. A significant improvement in durability properties was observed for concrete containing 15% GP and 30 % GrP. Binici et al. 2018 [5] showed that concrete formulas with granite, silica sand, and marble and basalt powder waste as fine aggregates were more durable than the control concrete. Singh et al. 2016 [6] studied the use of granite cutting waste (GCW) as a partial substitute for river sand in high-strength concrete. Eighteen concrete mixes were made at 0.30, 0.35, and 0.40 water cement ratios by replacing 0%, 10%, 25%, 40%, 55% and 70% of river sand by GCW. The test results suggest that the substitution of 25% and 40% of river sand by GCW has a favourable influence on the studied parameters: compressive, flexural strength, abrasive resistance, permeability, water absorption, carbonation, corrosion and microstructure, morphological and hydrating changes.

Granite waste is used today in landscaping, for embankment consolidation and for other non-structural applications. However, it should be noted that polished granite waste has so far been land filled, and little research has focused on the study of the performance of concrete made with polished granite aggregates despite the benefits that this will bring for all the related actors. It will allow manufacturing units to liquidate their waste stocks and facilitate the management of space for handling these products. Also, the elimination of waste will greatly contribute to the preservation of natural resources and the protection of the environment. Referring to the existing literature, a number of research works were carried out aiming at the recovery of this waste. Abisha et al. 2022 [7] tried using granite powder, which is obtained in the granite industry from the cutting and polishing of granite, as a partial replacement for manufactured sand in amounts of 0, 10, 20, 30, 40 and 50%. The findings obtained suggested that up to 10% substitution of fine aggregate with granite powder demonstrated strong strength and durability parameters. Chen et al. 2021 [8] tested the effects of replacing sand and/or cement in mortar mixes with granite polishing waste (GPW). The results indicated that adding GPW to replace sand increased the strength and durability, while adding GPW as an alternative to cement increased fluidity, but decreased the strength and durability. The mortar mixtures with GPW added to replace 10% sand and 5% cement have better overall performance and lower sand and cement contents than the control mortar mix containing no GPW. Also, Chen et al. 2020 [9] tested the possibility of using GPW to replace sand. They found that adding an appropriate amount of GPW as a substitute for sand reduces the quantity of waste disposed of and the consumption of sand, and enhances the mortar performance by filling the voids between sand particles to decrease the voids ratio and porosity and increase the packing density and water film thickness. Overall, within the ranges of the mix parameters covered in this study, the addition of GPW to replace 15% to 20% sand by volume would enhance the strength from 31.2% to 70.9% and improve the rheology and impermeability. Sharma et al. 2017 [10] demonstrated that the use of polished granite waste from discarded tiles to partially replace coarse aggregates in cement concrete decreases the compressive strength, flexural tensile strength, and tensile strength, while good results have been achieved on water absorption, abrasion and permeability. The concrete containing polished granite waste, substituting up to 20% of natural coarse aggregate, might be recommended for any application. However, the replacement of 20 to 40% may be recommended further for non-structural applications, pavements, etc.

Double-layer tiling is a floor covering formed by two layers, prepared separately, which then become a single body by means of the pressure exerted on them by a hydraulic press. The first layer is formed by marble shot, marble powder or granite and cement. The second layer is composed of crushed sand and cement. Large amounts of tiles are thrown away either during production in tile factories because of poor and mediocre production practices or by citizens changing the flooring of their homes. Very little research has been conducted on the recycling of tile waste in the construction field, and a lack of reliable data must be underlined on the use of sand recycled from this waste in concrete, because the latter is mainly composed of old mortar and hardened cement paste. Tennich et al. [11-12-13] in years 2015, 2017 and 2018 studied the influence of marble and tile factory waste used as a mineral addition on the mechanical properties, on the hydration reaction in early age, on the resistance to cracking, sulphate attack and carbonation of self-compacting concrete (SCC). The results obtained demonstrate the good impact of all the additions both on the properties in the hardened state and on the durability of the SCCs. Kherraf et al. 2022 [14] studied the mechanical performance and durability of mortars made in part by sand extracted from marble, floor tiles and cinder blocks to replace silica sand. They conclude that the mortar based on 20% marble sand waste exhibits the best performance of all the mortars in terms of flowability, entrained air, flexural strength, water absorption, and resistance to attack by acetic acid solution. However, the mortar with 20% floor tile sand achieves the highest compressive strength. Furthermore, the mortar containing 15% of cinder block sand is more resistant to attack by sulphuric acid. Kechkar et al. 2022 [15] initiated a comparative study of the fresh and hardened properties of concrete manufactured from recycled sand from three types of waste: marble, tile and cinder block. The results of this study indicated that, the concretes containing the waste sands have satisfactory properties. However, the tiling sand is more effective than the other two recycled sands.

This research work aims to study the mechanical performances and some aspects of durability of the various compositions of superplasticized concrete made by substituting the limestone crushed sand that is currently over-exploited in Algeria by two types of waste sands, namely granite and double-layer tiling in mass percentages of 0, 10, 20 and 30%. The experimental program was divided into two parts. The first dealt with the impact of recycled sand on the concrete's freshness and mechanical properties. The second part addressed the durability behaviour of the concrete mixtures that achieved the best performance in both sets of concrete by conducting a mass loss test during a 180-day period of exposure to 5% NaCl and CH_3COOH by weight.

2. USED MATERIALS AND METHODS

2.1. Materials

The following materials were used to produce concrete mixtures:

• A composite Portland cement (C) of the CPJ-CEM II / A-M (S-L) /42.5N type, with an absolute density of 3.01 g/cm^3 and a specific surface area of 3180 cm^2/g. This cement was provided by the company GICA in Hadjar Essoud- Skikda, Algeria. The chemical composition of the cement is shown in Table 1.

• Two types of gravel were used in this study, G 4/8 and G 8/16. These are of the crushed type of limestone originating from LAGHEDIR quarry (Skikda-East of Algeria). Table 2 shows the physical properties of the gravels and Fig.2 presents their granulometric curves.

• Three types of sand were used as fine aggregate:

- Quarry sand (QS) class 0/4 (Fig.1a) from LAGHEDIR quarry (Skikda-East of Algeria);
- A granite waste sand (GWS) class 0/4 (Fig.1b) obtained from industrial residues resulting from the shaping of the black galaxy granite slabs utilised for the production of countertops. It is imported from INDIA. The origin stone has a dark black background with small flecks of gold and silver which gives it the appearance of stars in the sky. The polished surface countertops are not the result of a treatment. This finish is obtained by polishing the stone with diamond plates of 7 different grains. The finish is smooth and shiny. To obtain a grain of sand, the waste has undergone primary crushing with a hammer to reduce the size of black galaxy granite residue. Then, secondary crushing in a jaw crusher of the laboratory of the civil engineering department of the university 20 August 1955 Skikda, to obtain the dimensions of the desired grains. Finally, Screening to remove impurities and to obtain granular fractions;
- A tile waste sand (TWS) of class 0/4 (Fig.1c), obtained after crushing and sieving the tile waste at the manufacturing plant.

a) QS b) GWS c) TWS

Fig.1. The sands used

The chemical and physical properties of the different types of sand are grouped in Tables 1 and 2, respectively, and their particle size distribution is illustrated in Fig.2 above.

• A superplasticizer/high water reducer (Sika Viscocrete TEMPO 12) with a dosage range of 0.3 to 3.0% of the binder weight.

• Tap water (E) for mixing.

As illustrated in Table 1, chemical analysis of cement ,QS, GWS and TWS was evaluated using gravimetrical methods according to: IS :1727-1967.

Table 1. Chemical compositions of cement and fine aggregates

Oxide weight (%)	CEM II 42,5	QS 0/4	GWS 0/4	TWS 0/4
CaO	62.61	51.56	9.06	53.56
SiO_2	21.12	2.62	41.2	4.00
Al_2O_3	5.76	0.59	13.2	1.47
Fe_2O	3.52	0.75	9.59	0.63
K_2O	0.79	0.13	0.08	/
SO_3	2.06	0.30	0.31	/
NaO_2	0.17	0.03	2.5	/
MgO	1.34	1.52	4.99	1.58
Cl^-	0.003	/	0.01	/

According to the results illustrated in Table 1, it can be seen that the nature of the crushed sand and the tiling waste is essentially limestone, while the polished granite waste sand is composed of silica, iron, aluminium, calcium, sodium and manganese.

The physical characteristics are determined in accordance with the standards in force and the test results are presented in Table 2.

Table 2. Physical characteristics of sands and gravels

Aggregate	QS	TWS	GWS	G 4/8	G 8/16
Apparent volumetric mass (g/cm^3)	1,45	1,12	1,50	1.57	1,44
Absolute volumetric mass (g/cm^3)	2,65	2.62	2,7	2,72	2,75
Blue mythelene value %	0.43	0.5	0,43	/	/

Sand equivalent (%)	73	71	77	/	/
Water absorption after 24 h (%)	1.81	3.91	0,36	1,18	0,61
Fineness modulus	3.22	3.8	2,49	/	/
Fines content (%)	7.56	2.25	7.86	/	/
Los Angeles testing (%)	/	/	/	30,44	23
Micro-Deval testing (%)	/	/	/	13	15

These can be interpreted as follows:

- The three sands are clean and have different absolute volumetric mass. TWS has a density close to that of QS, while the GWS sand has the highest density;
- The water absorption of TWS is significant, ten times higher than that of GWS sand. This value is also high compared to that recorded for QS. This can be explained by the high porosity of the existing residual cement paste in the tile waste sand. On the other hand, the absorption capacity of GWS is low due to the intrinsic characteristics of original stone.
- The TWS waste sand has fewer fine particles than the QS and the GWS sand used contains a quantity of fine particles equivalent to that contained in the QS;
- GWS sand has a lower fineness modulus than that QS sand, while TWS has the highest fineness modulus. In fact, the GWS is a medium sand and the QS and TWS are a little coarse;

The granulometric analyses of the sands are carried out according to standard NF EN 933-1.

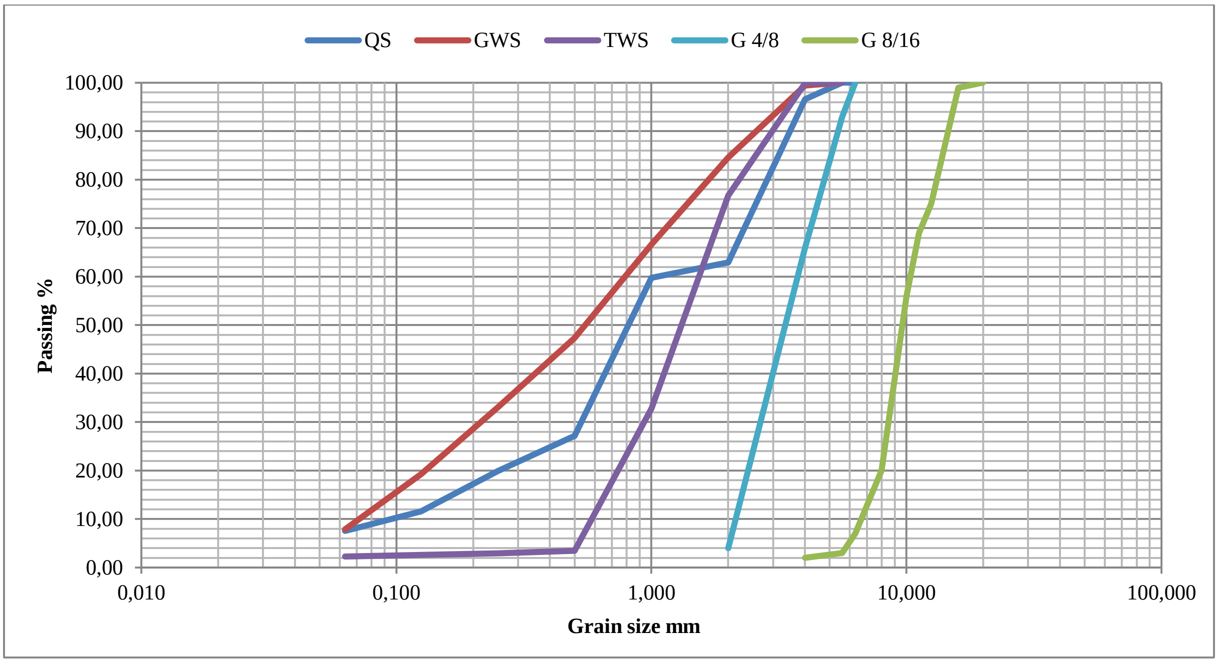

Fig. 2. Particle size distribution of the aggregates

From Fig.2, it can be seen that the grain size of QS and GS sands is uniform, while it is tight for TS sand.

2.1 Methods and formulation

The concretes were made in accordance with the Dreux–Gorisse method. The water/cement ratio is kept constant (W/C=0.45). For the choice of this value, we carried out workability tests of fresh concrete between 18cm±1. The nature and dosage of gravel are kept constant. The composition of the sand is variable depending on the rate of substitution of QS by TWS and GWS : 0, 10, 20 and 30% by mass. The notations used are as follows:
RC: Concrete made with crushed limestone sand only;
CTS_{10}, CTS_{20},CTS_{30}: Concretes made with partial replacement of QS by 10, 20 and 30% of TWS, respectively;
CGS_{10},CGS_{20}, CGS_{30}: Concretes made with partial replacement of QS by 10, 20 and 30% of GWS, respectively.

Detailed mix proportions of different mixes cast are shown in Table 3.

Table 3. Mix proportions of concretes (kg/m^3)

Notation	C	E	QS	TWS	GWS	G 4/8	G8/16	Plasticizer (%)
RC	370	166	899	00	00	345	660	2,78
CTS10	370	166	809	90	00	345	660	2,78
CTS20	370	166	719	180	00	345	660	2,78
CTS30	370	166	629	270	00	345	660	2,78
CGS10	370	166	809	00	90	345	660	2,78
CGS20	370	166	719	00	180	345	660	2,78
CGS30	370	166	629	00	270	345	660	2,78

Mixes were cast in a pan mixer of 60 litres capacity. After introducing the materials in the pan mixer, dry mixing was carried out for 1 minute to ensure homogeneity among the dry concrete materials. The water was then added and mixing was carried out for another 4 minutes. Just after mixing, the fresh concrete mixes were put to the slump test. Fully compacted by using a vibrating table, the specimens were left in a casting room at a temperature of about 20 °C. They were taken out from the moulds after 24 h and put into a water-curing tank until the time of testing.

3. RESULTS AND DISCUSSIONS

3.1 Fresh state properties

3.1.1 Density

The bulk densities of the fresh concrete mixes were determined as per NF EN 12350-6 from 150 mm concrete specimens. The result shown in Fig.3 was determined by dividing the average weight of three cubes by the volume of the concrete cubes.
Fig.3 shows that the density increases with the increase in the rate of recycled sand in the concrete. In fact, with a rate of 30% of GWS, the maximum density is observed. This value exceeds that of the control by 8% and that of the concrete based on 30% TWS by 6.1%.

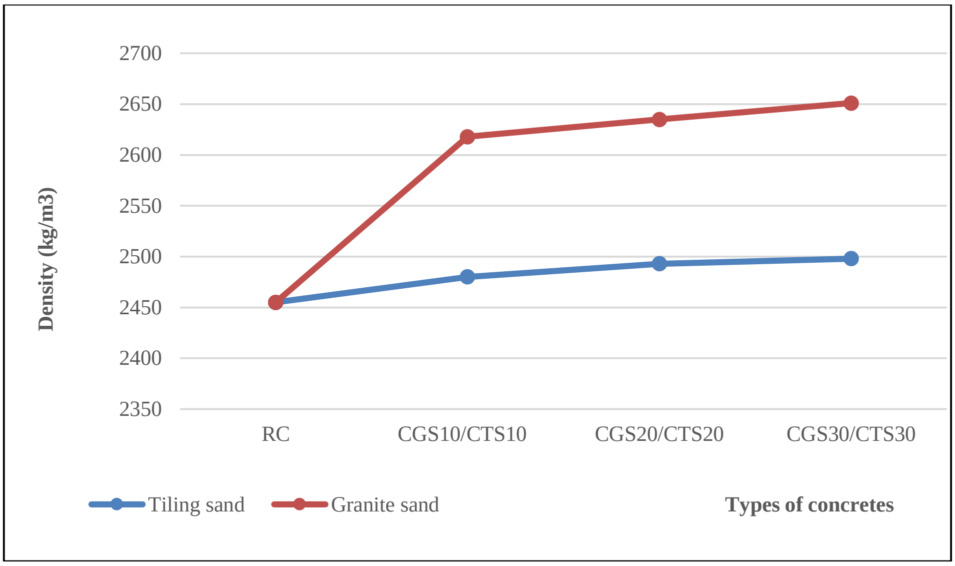

Fig. 3. Variation of the density in the fresh state

These results can be explained by the fact that the density and hardness of GWS are higher than those of QS and TWS. Also, the grains that make it up are finer, which allows them to easily penetrate between the coarse aggregates and make the concrete denser. In addition, the increase in the density of the concretes based on TWS compared to that of the control concrete is attributable to the increase in the water content generated by the absorption of water by the grains of the sand, consisting mainly of an old mortar and a very porous cement paste.

3.1.2 Slump test

The measurements of the slump height of the fresh concrete were carried out using the Abrams cone, according to standard NF EN 12350-2.

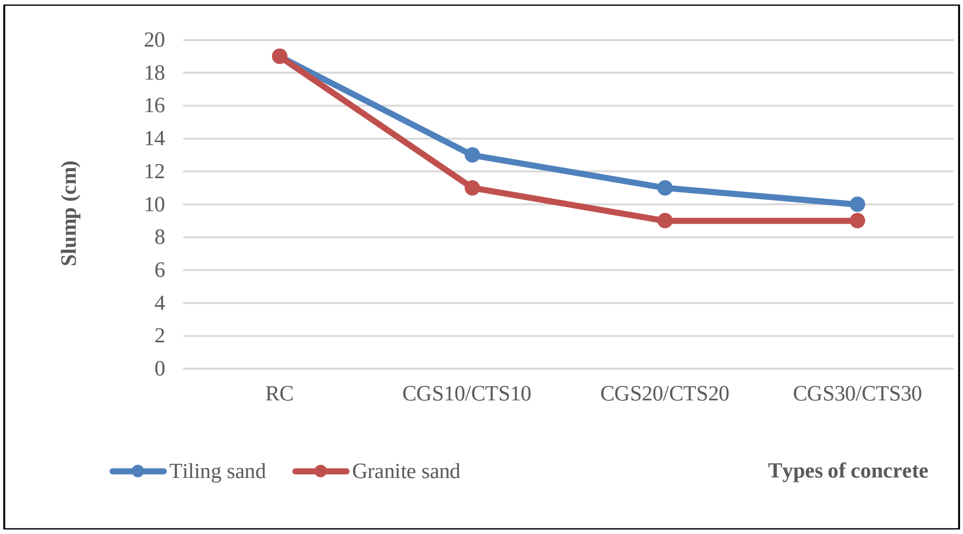

Fig. 4. Slump test results

By analysing the results illustrated in Fig.4, it is noted that the incorporation of increasing rates of TWS and GWS in the reference formulation generates workability losses of all the concretes under study. The range of concretes incorporating TWS is that of very plastic concretes, while the range of concretes based on 20 and 30% GWS is plastic. These findings are mainly due to the high friction induced by the rough surface and the angular shape of the grains of granite [16] and tile sands compared to those of crushed limestone sand. This result agrees well with Vijayalakshmi et al. 2013 [17], who found that concrete containing granite dust is less workable than reference concrete.

The variations in values between the two series of recycled concretes are due to differences in the grain size, the amount of fines and the absorption coefficient.

In order to obtain the targeted slump, two types of modifications can be considered, either by increasing the quantity of cement or by applying plasticizers (with the same amount of water); the latter represents a safe and less expensive solution

3.1.3 Content of air incorporated

The air content was measured according to the standard NF EN 12350-7. Fig.5 illustrates the results of the air content measurements carried out on the different concrete compositions. The results shown represent the average of three measurements.

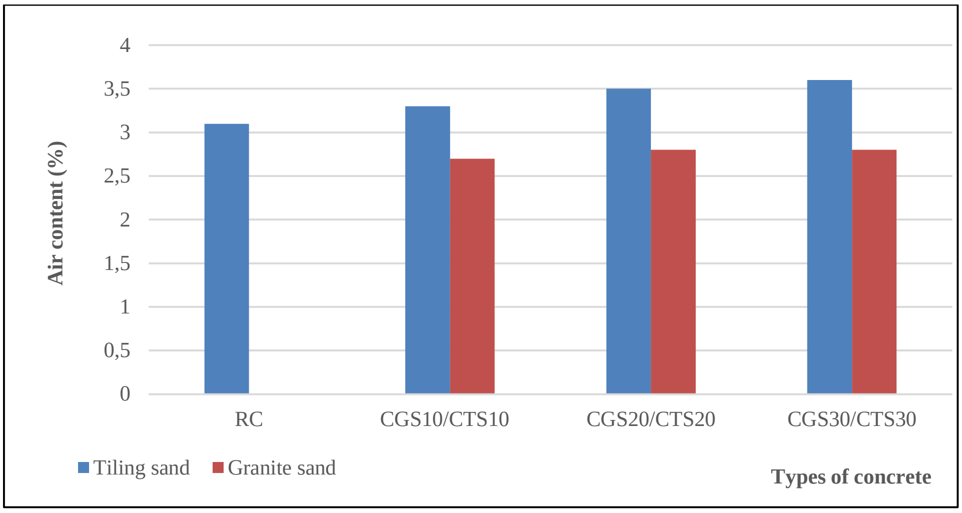

Fig.5. Variation of air incorporated in concretes

The values of the air content in all the concretes prepared fall within an interval ranging from 2.7 in the CGS10 to 3.6% in the concrete containing CTS30. There is a proportionality between the increase in the rate of substitution of crushed sand by waste tile sand and the growth in the values of entrained air. On the other hand, the quantities of air trapped in the concretes incorporating the GWS are lower than those shown by the control concrete and the concretes based on TWS, and decrease inversely with the increase in the rates of substitution. This is undoubtedly linked to the morphology of the sand grains of porous tiling, which traps air bubbles in the cementitious matrix of the concretes during the vibration phase and which does not favour a correct arrangement of the constituents in the mixtures compared to the reference concrete, which increases the volume of air. Furthermore, the fine grains of granite sand occupy the space between the aggregates and consequently reduce the volume of entrained air. In addition, granite is porous to a minimal degree due to the intrinsic characteristics of original stone.

3.2 Hardened state properties

3.2.1 Compressive strength

Compressive strengths of samples were determined in compliance with Standard NF EN 12390-3. Eighty four samples of 150 × 150 × 150 mm size including three for each of the age groups, 7, 14, 28 and 90 days, were produced to determine the compressive strengths.

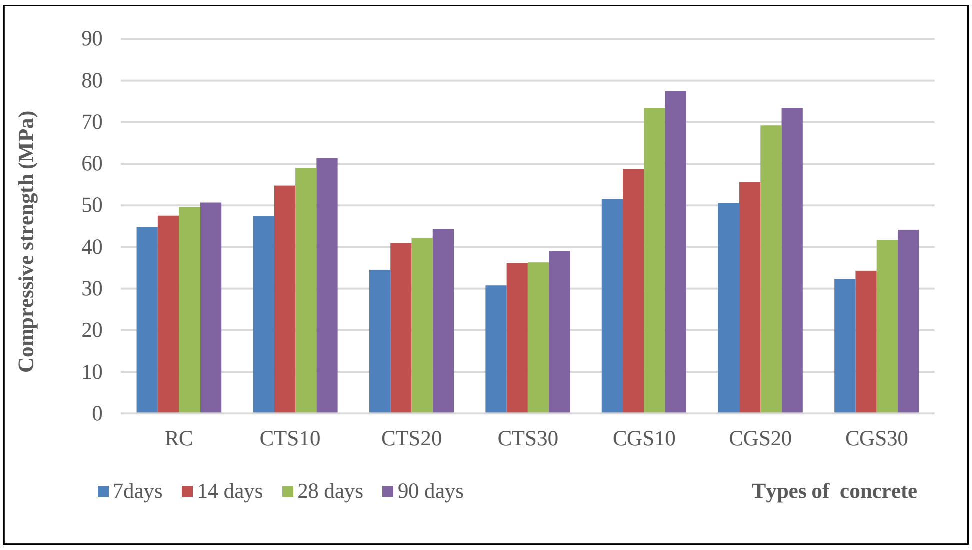

Fig.6. Variation of compressive strength of concrete

Fig.6 shows that, for all the concretes, the compressive strength increases progressively with the duration of storage in water, which can be explained by the development of the cement hydration phenomenon as a function of time.

The introduction of a rate of 20% of GWS sand considerably improves the compressive strength of the control concrete at the four times of 7, 14, 28 and 90 days. At 7 days, the increase is around 14.82% and it rises to 48% and 52% at 28 and 90 days, respectively. This can be explained by the increase in the compactness of the mixtures based on granite sand, because the grains of this waste are harder than the grains of QS, where granite has a hardness of 6–8 on the Mohs scale compared to the limestone, which has a hardness between 1 and 5. Also,the rough texture and angular shape of granite lead to the formation of stronger bonds and better interlocking strength between the coarse aggregate phase and cement–mortar paste, which decreases the amount of air incorporated [18]. Furthermore, the fine particles of granite sand might have filled the concrete pores and densified the concrete matrix. In addition, Amani et al. 2021 [19] demonstrated that the granite powder accelerates the compressive strength growth rate in early ages, mainly due to the faster hydration reaction and greater C_3S content. Also, all the mix designs containing granite powder have some pozzolanic reactions, which helps them to have more efficient gel, resulting in higher compressive strength [20].

For the concretes based on TWS, the compressive strength increases increased when substituting a mass of 10% QS by the TWS at all ages. At the age of 7 days, the increase is around 5.5%. Moreover, at 14 days, it is improved by 15.2%. At 28 days, the progression becomes more significant, amounting to 18.8%. Finally, the rate of increase reaches 21% at 90 days.

In fact, the compressive strength increases for this rate of 10% due to the decrease in the W/C ratio, a consequence of the absorption of the mixing water by the old mortar and the old hardened cement paste making up the waste. In addition, the angular aggregatesprovide a better interlocking effect in the concrete and show better bonds [21-22]. Beyond that, the compressive strength drops due to the increase in the quantities of air included in concrete containing 20 and 30% recycled sand due to their poor microstructure. Once the optimum substitution level is reached, any higher amount of TWS sand might increase the surface area of the aggregate particles instead of filling up the voids.

3.2.2 Flexural strength

The flexural strength of the concrete was determined by the third-point loading method as described inNF EN 12390-6: 2012. Fig.7 presents the flexural strength test results for the various mixtures of recycled concrete. The results obtained correspond to an average of the values obtained for three tests.

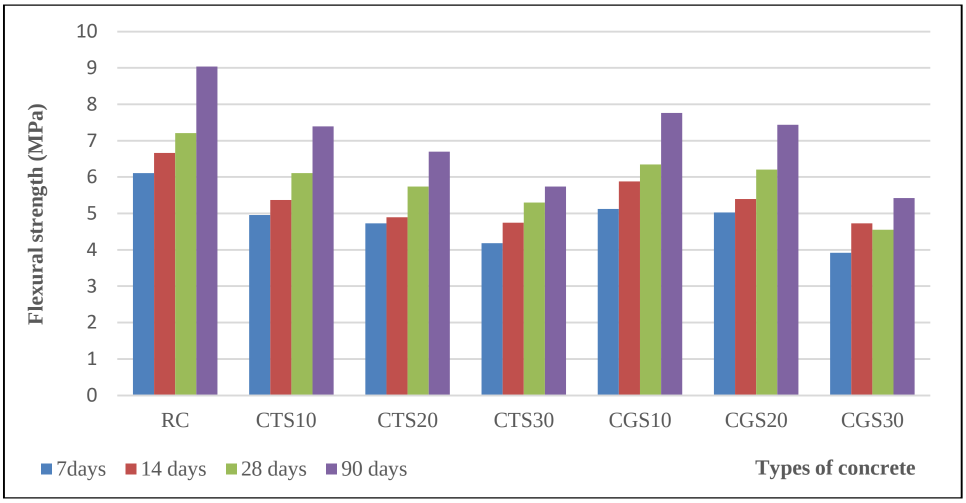

Fig.7. Variation of flexural strength of concretes

It is clear that the flexural strengths of the recycled concretes are directly influenced by the introduction of waste sands, and are lower than that of the reference concrete made with limestone sand only. The loss of strength increases as the quantity of recycled sand increases, and decreasesof the order of 16.5 and 22% for the CGS10 and CTS10 concretes compared to the control concrete are recorded at the age of 90 days. This is due to reduced bonding performance because the bond between the surface of the granite sand and the cement matrix will not be as strong as that of the bonding with the natural aggregates having a rough surface knowing that some grains of the Black Galaxy Granite contains small flecks of gold and silver and one face polished. Besides, the voids present in the mixes when the percentage of TWS increases and the presence of old mortar in the composition of the TWS constitutes an additional zone of weakness for the new concrete because the cement guangue foundalone or surrounding the initial grain is known to have a high porosity which can be accentuated by the crushing phase, due to the creation of internal cracks [23]. This reduction can be also explained by the fact that there is more demand for cement paste after the interlocking between the grains of recycled sand and the cement paste.

It can be concluded that the substitution of limestone sand by TWS and GWS sands had a negative impact on the flexural strength. Therefore, the surface condition of the grains and the quantities of fines and cement present have a primary role in improving the adhesion of the aggregate paste and consequently the resistance to bending.

3.2.3 Splitting tensile strength

The splitting tensile strength was determined according to EN 12390-6:2011. The results obtained are shown in Fig.8.

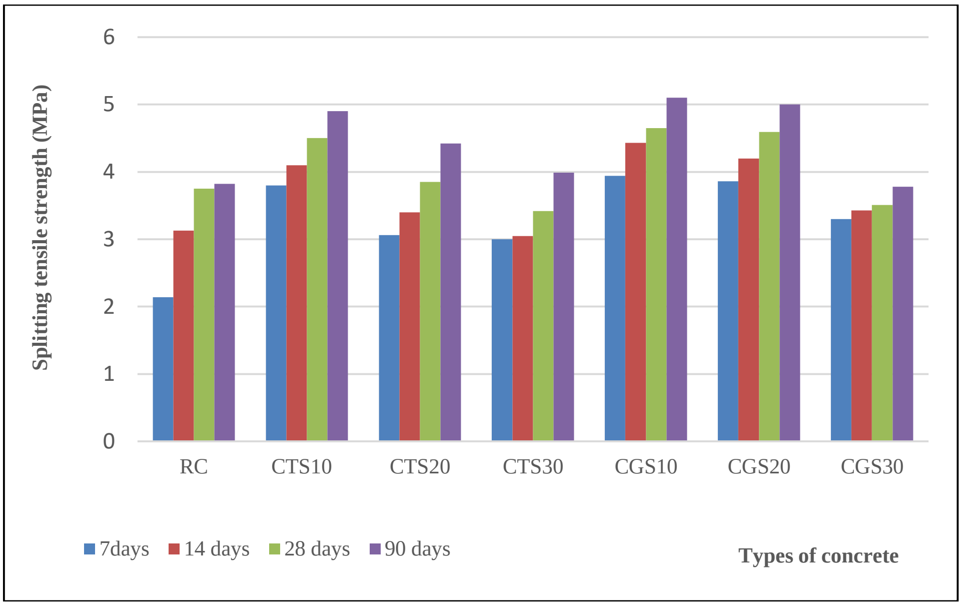

Fig.8. Change of tensile splitting strength of concretes

The splitting tensile strength, like the compressive strength, is affected by the content, size, type, and quality of the recycled sand. The incorporation of sand, whether GWS or TWS, results in an increase in the splitting tensile strength.The factor responsible for the observed trend with the compressive strength is also responsible for the observed trend with the splitting tensile strength.
So, the introduction of rates of up to 30% of TWS or GWS sand as a replacement for limestone sand leads to an improvement in the splitting tensile strength of the concrete.

3.2.4 Compressive strength obtained by the sclerometer test

The compressive strengths by sclerometric testing of the cubic specimens were determined after 28 days in accordance with standard NF EN 12504-2. The results obtained are illustrated in Fig.9, which shows that the surface hardness of the concretes formulated from GWS is higher than that of the concretes incorporating TWS sand. However, the CGS_{10}concrete has strength comparable to that of the control.
This is mainly due to the intrinsic characteristics of the grains of granite sand, which are hard, and their rough and irregular morphology offer better adhesion to the paste for a substitution rate of 10%.

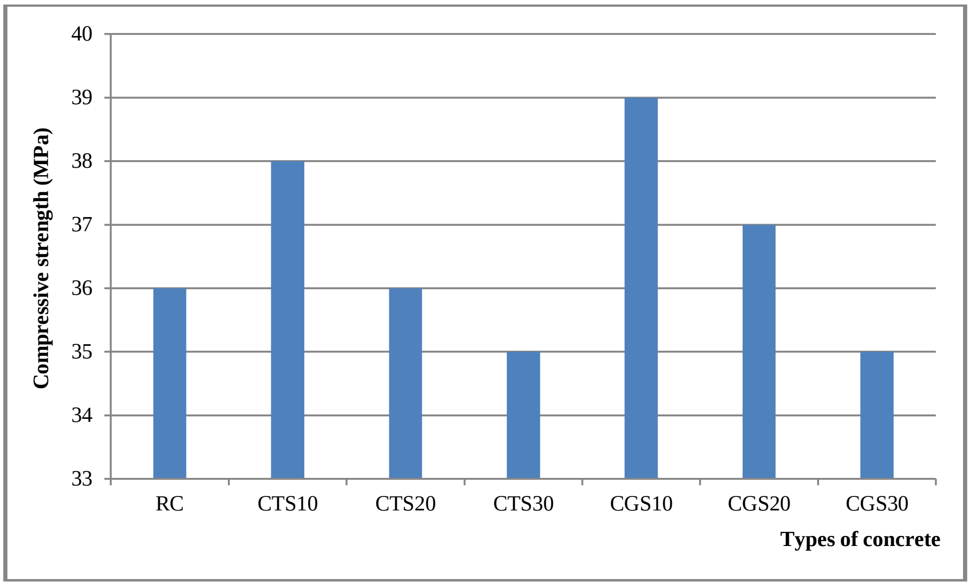

Fig.9. Compressive strength obtained by sclerometer

3.2.5 Ultrasound speed test

Ultrasonic sound velocity tests of the samples made with TWS and GWS was conducted after 28 days and the results are given in Fig.10. The penetration speed is calculated by measuring the time it takes the ultrasound waves to travel from the source point on one face to the receiver on the other face, taking into consideration the distance travelled, according to NF EN 12504-4.

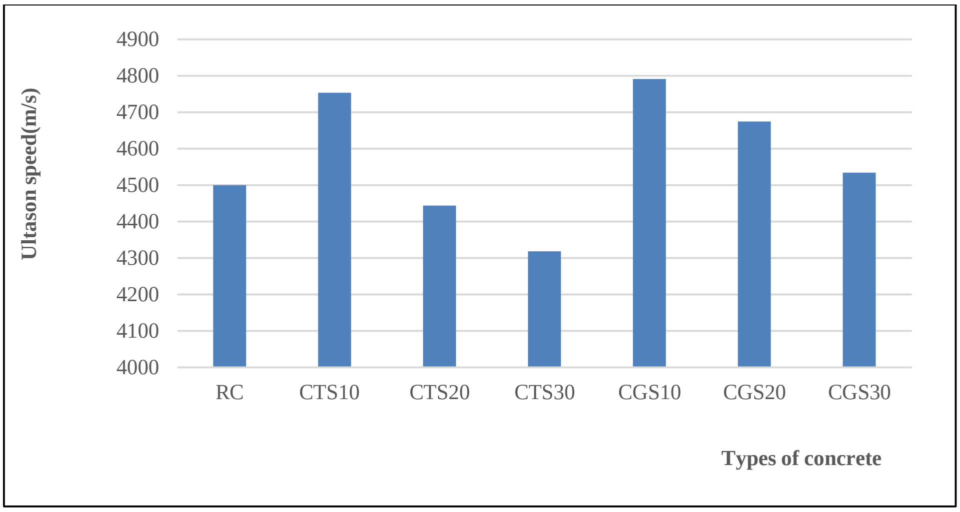

Fig.10. Variation of ultrasonic pulse velocity

The results shown in Fig.10 indicate that the velocity of the ultrasonic waves increases inversely with the increase in the rate of replacement of QS with GWS. In addition, the introduction of up to 30% granite sand leads to higher velocities than that illustrated by the control concrete. On the other hand, during the incorporation of TWS, the wave speeds become lower than that of the control concrete when

rates of 20 and 30% are used. The 10% TWS mix is the only one in the series that exhibits a higher wave velocity than the control.
This means that the introduction of up 30% of GWS and 10% of TWS improves the homogeneity of the concrete.
This result is in agreement with the literature, which indicates that the ultrasonic sound penetration velocity coefficient decreases when the amount of voids inside the material increases. The void ratio is one of the most important factors that affects the mechanical properties of hardened concrete [24].

3.3 Durability

At the end of the first part, we can say that a rate of 20% of GWS sand and a rate of 10% of TWS present the maximum mass proportions for their use as partial substitutes for QS. For this purpose, the durability was evaluated after immersion of the CGS_{20} and CTS_{10} samples in 5% CH_3COOH and NaCl solutions for periods of up to 180 days. The resistance of the blended concrete mixes against acid attack was studied following ASTM C 267-01.

3.3.1 Attack by acetic acid CH3COOH

The changes in weight of the concrete specimens when exposed to CH_3COOH solution for a period of 180 days are shown in Fig.11.

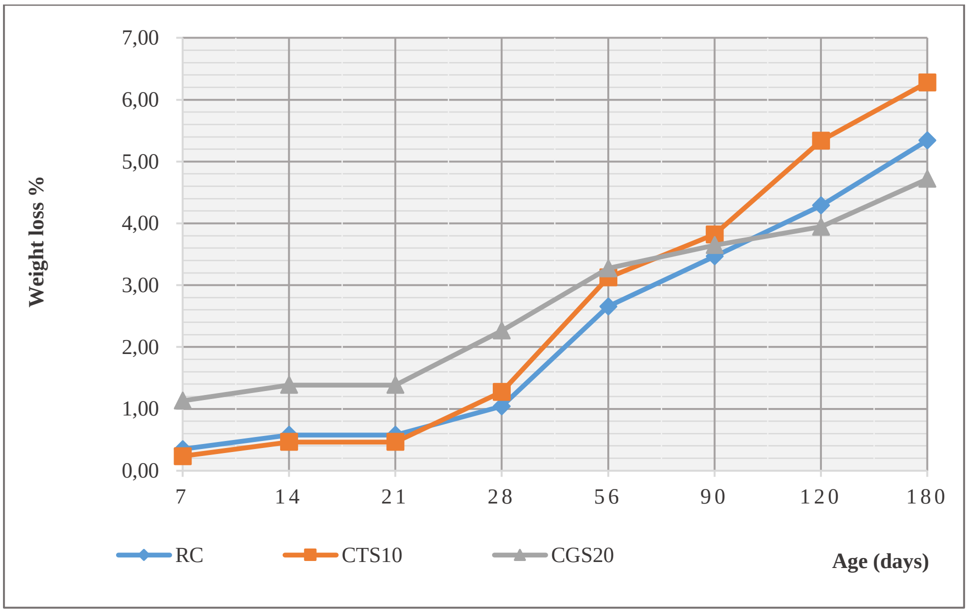

Fig.11. Percentage of change in weight of concrete mix specimens when exposed to CH3COOH solution

It can be seen that the weight loss of the concretes increases continuously with the exposure time. It reaches 3.94 and 4.72% at 120 and 180 days, respectively, for the CGS_{20} concrete. These results are lower than those of the control concrete, which displays mass losses of the order of 4.29 and 5.34% at the two above-mentioned ages; there is therefore an improvement in the resistance to CH_3COOH attack. These findings prove the positive effect of the fine particles present in the granite sand on the evolution of resistance to acid attack; this is because of the pozzolanic reaction that induces the production of C-S-H, the occupation of voids, and consequently reduces the pore size. This is in agreement with the results reported in several studies [25-26-27]. The loss in mass of the concrete based on TWS is greater than that of the reference concrete and of the CTS_{10} from the age of 90 days. It reaches 6.28% at 180 days. This is due to the progressive decalcification of C-S-H and, in other proportions, ettringite and monosulfoaluminate [28]. This may be due in part to the inferior microstructure of the concrete.

3.3.2 Weight loss after exposure to NaCl solution

The results of the weight loss of the specimens exposed to the 5% NaCl solution, for a duration of 180 days, are shown in Fig.12.

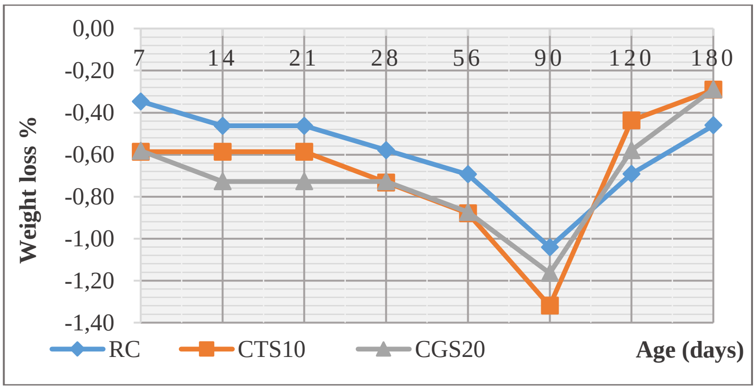

Fig.12. Percentage of change in weight of concrete mix specimens when exposed to NaCl solution

In Fig.12, it can be seen, in general, that all the concretes showed increasing weight gains from the first week of storage until the age of 90 days. The maximum value was obtained by concrete containing 10% TWS, followed by concrete containing 20% GWS. Beyond that, the curves change in temper; certainly very low mass loss readings were identified for the three types of concrete. At 180 days, the two recycled concretes show equivalent mass gains that are lower than that of the control concrete.
This phenomenon is explained by the fact that Cl^- ions form chloroaluminates (Friedel's salt). The latter is transformed into ettringite (Candlot salt). The ettringite formed by Cl^-, once dissolved, participates in the loss of mass of the concretes [29]. Therefore, it can be concluded that the chloride attack, unlike the acid attack, is not aggressive and does not cause deterioration of the concrete.

4. CONCLUSIONS

The study presented in this work concerns the evaluation of the behaviour of two groups of concrete made partially with recycled sands; the first group of concrete was made with GWS and the second was formulated with TWS. The results achieved showed that:
- The TWS and GWS have heterogeneous properties distinct from those of crushed limestone sand. These characteristics are closely linked to three main factors: the type of original waste, the production process and the size obtained by the crushing process of the recycled grains.
- The replacement of QS by recycled sands of GWS and TWS generally leads to an increase in the unit weight of the resulting concrete. Certainly, the intrinsic characteristics of the waste sands are the main parameters that govern this drop.
- With the increment in the GWS and TWS percentages, the concretes showed a lower slump, which indicates a loss of workability. This can be developed by plasticizers or superplasticizers improving their workability and increasing the amount of fines in the tile sand by improving the grinding process.

▪ The entrained air content decreases linearly with increasing GWS content; however, it increases continuously when increasing the rate of substitution of QS by TWS.
▪ The compressive strengths, at all ages, of concretes formulated from 10, 20% of GWS sand and 10% TWS are better than those of the control concrete. The best performing mix is the one containing 10% of GWS.
▪ The bending tensile stresses decrease linearly with the substitution of QS sand by recycled sand, and more particularly with that of TWS sand.
▪ In tension by splitting, the strengths of the recycled concretes are greater than or equivalent to that of the control. The substitution rates can reach 30%.
▪ For the sclerometer test, concrete with 10% of granite sand showed strength comparable to that of the control, but the rest of the mixtures displayed lower values.
▪ GWS based concrete indicates excellent quality concrete, but the introduction of tile sand affects the homogeneity of the recycled concrete.
▪ For durability, the concrete containing 10% of TWS has better chemical resistance to CH_3COOH organic acid attack than the control and the concrete containing the GWS, and the reduction in weight is due to the dissolution hydrates produced, which lead to porous concretes.
▪ The immersion of concrete specimens in NaCl solution does not have a harmful effect on the weight loss.

Finally, the incorporation of 20% of GWS sand into the concrete improved the compressive strength and resistance to CH_3COOH acid attack. Similarly, the use of rates up to 30% of this sand contributed to increase the splitting tensile strength. On the other hand, the introduction of up to 30% of the TWS made it possible to achieve better splitting resistances than that obtained by the control concrete, but which were generally lower than those illustrated by the concretes formulated from GWS. Furthermore, its use is limited to 10% to achieve a compressive strength greater than that of the reference composition.

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