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THE COMPARATIVE STUDY OF THE PERFORMANCE OF CONCRETE MADE FROM RECYCLED SAND

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ABSTRACT

The main objective of this study of research is to initiate and develop a comparative study of fresh and hardened properties of concretes made from recycled sand from three types of waste: marble waste, tiling waste and cinder block waste. And this, in the intention of contributing to the world effort relating to the preserve of natural aggregate resources and limit landfill to the ultimate waste thresholds.

To do this, in the composition of a current concrete with a water / cement ratio equal to 0.55, an equivalent volume of sand from the three wastes respectively replaced a volume of 15% of the ordinary sand. The properties in the fresh state: workability, air content and density and in the hardened state: compressive strength, flexural tensile strength, compressive strength determined with non-destructive tests, water absorption by immersion, absorption by capillarity and chloride penetration of the various concretes produced are analyzed, and compared to those of the ordinary concrete.

The results obtained show that the concretes containing the waste sands have acceptable characteristics. However, tiling waste sand performs better than the other two recycled sands.

KEYWORDS

Sand, Marble, Tiling, Cinder block, Waste, Performance, Concrete

INTRODUCTION

The building materials industry is always a source of waste which is most often throw out in landfills or in the nature, which has negative effects on the environment. For this purpose, in Western countries, this type of rejection is strictly prohibited and the management of solid waste, whether by valorization or recycling, remains a major concern [1]. The objectives are reducing the volume of waste and preserving natural resources [2].

The domain of civil engineering, like other domains, are increasingly interested in the recovery of this type of waste, given the obligation to take charge of waste by the regulations in force, and the economic, environmental and technical importance that some waste can bring to the construction sector. Moreover, it is clear that current research carried out in the field focuses on the development of new composites and building materials incorporating additions and aggregates from waste, with the aim of improving the mechanical, physical and the durability of the materials produced [3].

It should be noted that in Algeria, 12 million tons of industrial waste are produced each year. However, the recycled quantity does not exceed in the best case 10%. Among this waste, we have the waste from the factories of tiles, marble and cinder blocks, which generate significant quantities of waste.

This study of research falls within this context and is concerned with the recovery of sands from this waste (marble waste, tiling waste and cinder block waste) in the manufacture of hydraulic concrete.

Several previous studies have been carried out on the recovery of marble waste as a substitute for fine aggregates in concrete, they have observed an improvement in mechanical characteristics [4], [5] and [6]; thus, improved properties when fresh [4]. Sudarshan and Vyas, 2015 [7] studied the behavior of concrete by substituting coarse aggregate with marble waste aggregate, they also observed that this waste improves the workability of concrete, their compressive strength and their resistance to attack of sulfuric acid. Chaid and al, 2011 [8] substituted a part of cement with marble powder; they observed an improvement in the physico-chemical properties of concrete. Djebien and al, 2015 [9], in the formulation of a self-compacting concrete, substituted the sand of dune by a sand of marble waste with variable percentages of 25%, 50%, 75% and 100% respectively and found that recycled sand reduces density, air content, flow in a confined environment as well as mechanical resistance. Benhalilou and al, 2020 [10] in their studies on sand concrete, substituted 5%, 10%, 15% and 20% of the volume of dune sand by a marble waste sand, they found acceptable results from the point of view of workability, mechanical strengths and durability. In a research on mortars established by Hebhoub and al, 2020 [11], in which they substituted 5%, 10%, 15% and 20% of the volume of natural sand by a marble waste sand, the results show that the introduction of Recycled sand in mortars gives good results and can be used as aggregate.

Concerning the tiling waste, there are very few studies on its effects on the properties of cement materials. Tennich and al, 2013 [12] studied the effect of adding tiling waste powder on the in the fresh state and in the hardened state properties of self-compacting concrete and showed that the addition of this waste gave satisfactory mechanical strengths and characteristics in the fresh state.

However, we note the absence of studies on the behavior of materials incorporating cinder block waste.

The research presented in this work consists of a comparative study between three types of concrete containing 15% of recycled sand (marble waste, tiling waste and cinder block waste) partially substituting in volume an ordinary sand in the composition of a hydraulic concrete of water/cement ratio equals 0.55. The experimental approach consists in observing the modifications induced by the recycled sands on the characteristics of the concretes studied in the fresh state, in the hardened state and on some aspects of durability, and to compare them with those of the ordinary concrete containing ordinary sand.

MATERIALS AND EXPERIMENTAL PROCEDURES

Materials

For our work, we used a CPJ-CEM II 42.5 (S-L) cement from the cement factory of Hdjar Soud- Skikda (East of Algeria). Two crushed gravel of class 3/8 and 8/15, and 04 types of sand:

- Ordinary sand (OS) of class 0/2,
- Marble waste sand (MWS) of class 0/2 of crushed nature, comes from quarry: derivatives of marble of Fil-fila (Skikda-East of Algeria);
- tiling waste sand (TWS) of class 0/2 obtained by crashing and sieving on a sieve of size 2 mm the falls of tiling;
- Cinder block waste sand (CWS) of class 0/2 obtained by crashing and sieving on a sieve of size 2mm the falls of cinder block.

Their particle size analyzes of sands used are presented in Figure 2, and their physical characteristics are given in Table 1.

(a) (b) (c)

Fig. 1 – Waste of marble (a), waste of tiling (b) and waste of cinder block (c).

Tab. 1: Physical characteristics of the 04 sands used.

	Sand (OS)	Sand (MWS)	Sand (TWS)	Sand (CWS)
Apparent density (g/cm^3)	1,510	1,660	1,590	1,520
Absolute density (g/cm^3)	2,590	2,750	2,620	2,610
Value of blue methylene (%)	1,10	0,50	0,50	1,00
Sand equivalent (%)	84	67	61	78
Water absorption (%)	1,12	2,37	3,50	3,33
Fineness modulus	1,88	1,87	2,36	2,64
Fines content (%)	1	12	8	6

From these results, we can say that:

- Marble waste sand (MWS) is the densest in comparison with tiling waste sand (TWS), cinder block waste sand (CWS) and ordinary sand (OS) respectively.
- Ordinary sand (OS) is cleaner than other sands.
- Tiling waste sand (TWS) and cinder block waste sand (CWS) have the highest absorption coefficients.
- The cinder block waste sand (CWS) gives the highest fineness modulus, which indicates that concrete made with this type of sand gives good resistance to the detriment of workability.

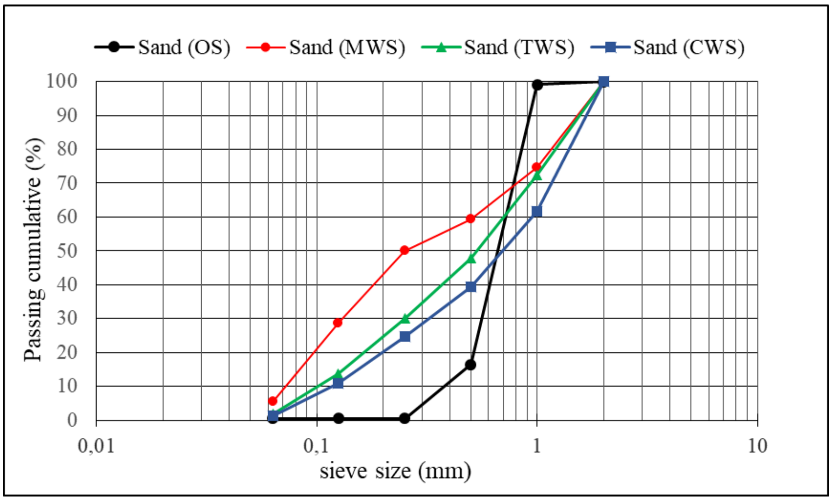

Fig. 2 – Sieve analysis for the 04 sands used.

According to the results of the particle size analyzes carried out on the study sands, it can be seen that:

- The three types of sands have a continuous granulometry and fall within the granular spindle.
- (MWS) sand is a finer compared to other sands used. While the (OS) and is very poor in fines elements.

The chemical characteristics of the different sands are given in Table 2.

Tab. 2: Chemical characteristics of the 04 sands used.

	Sand (OS)	Sand (MWS)	Sand (TWS)	Sand (CWS)
$CaCO_3$	--	98.67	--	--
CaO	0.80	55.29	53.53	47.49
Al_2O_3	2.36	0.14	1.47	1.28
FeO_3	1.5	0.09	0.63	0.72
SiO_2	94.09	0.53	4.00	2.20
MgO	0.14	0.2	1.58	1.83
Na_2O	0.20	0.00	--	--
K_2O	0.58	0.01	--	--
Cl^-	0.00	0.025	--	--
SO_3	0.01	0.04	--	--
PF	--	43.40	41.70	43.60
R. Insoluble	--	0.035	--	--

Referring on chemical analyzes, it can be seen that the recycled sands: MWS, TWS and CWS are calcareous in nature. In contrast, ordinary sand (OS) is siliceous in nature.

Experimental program

Mix design

In this experimental investigation, a volume of ordinary sand equal to 15% was substituted in the composition of a control ordinary concrete (OC) formulated using the Dreux Gorisse method and whose Water / cement ratio was set at 0.55, by three recycled sands: marble waste sand, tiling waste sand and cinder block waste sand.

Therefore, the other three formulations obtained are: concrete (MWC) based on marble waste sand, concrete (TWC) based on tiling waste sand and concrete (CWC) based on cinder block waste sand.

The different compositions of the concrete are grouped together in Table 3.

Tab. 3: Concrete mix constituents.

	OC (0%)	MWC 15%)	TWC 15%)	CWC (15%)
Cement (Kg)	350.00	350.00	350.00	350.00
Water (L)	192.50	192.50	192.50	192.50
OS (Kg)	711.75	605.00	605.00	605.00
MWS (Kg)	--	113.00	--	--
TWS (Kg)	--	--	108.00	--
CWS (Kg)	--	--	--	107.5
G 3/8 (Kg)	511.75	511.75	511.75	511.75
G 8/15 (Kg)	587.00	587.00	587.00	587.00

Testing methods

The tests carried out on the different formulations are:

- Characterization tests in the fresh state: slump test, density and air content were carried out according to the standards: Standard NA 431, Standard NA 436 and Standard NA 434 successively.
- Destructive tests: compressive strength on specimens of size (150x150x150) mm3 in accordance with standard NA 427 and flexural tensile strength on specimens of size (7x7x28) mm3 according to standard NA 428. These tests were studied at age 7, 28 and 90 days.
- Non-destructive tests: ultrasound test and sclerometer test were carried out on specimens of dimension (200x200x200) mm^3 according to standards NA 5027 and NF EN 12504-2 respectively.
- Capillary water absorption test and water absorption test by total immersion were carried out on prismatic specimens of (70x70x280) mm3 in accordance with standard NA 255, and on cubic specimens of (150x150x150) mm^3 in accordance with the standard NBN B 15-215 respectively.
- chloride Penetration, the test was carried out on specimens of dimension (70x70x280) mm^3 according to UNI 7928 and JIS A 1171 standards.

RESULTS AND DISCUSSIONS

Workability (slump)

According to the results shown in Figure 3, the workability of the concretes studied varies between 5 and 9 cm. Therefore, the range of concretes thus produced is plastic.

In addition, the substitution of ordinary sand by recycled sands (marble waste, tiling waste and cinder block waste) respectively decreased the subsidence by 22%, 33% and 44%.

This result is expected from the fact that:

- Recycled sands have higher absorption coefficients than ordinary sand,
- Their fines content is greater than that of ordinary sand,
- The fineness and the angular shape of the grains of recycled sands inducing a relatively high friction between the constituents of the cement matrix [13].

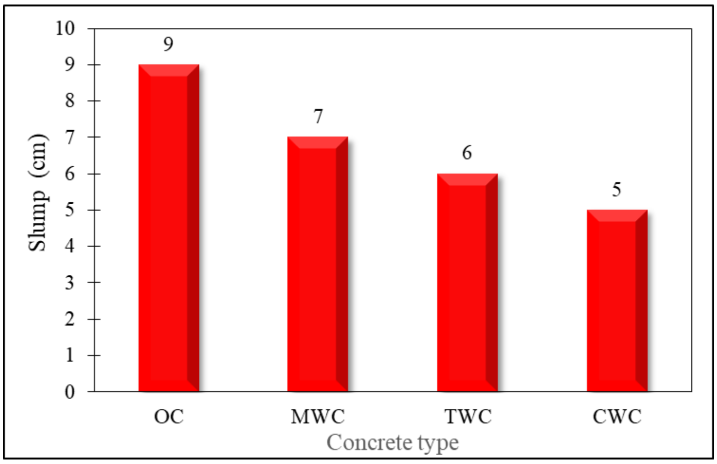

Fig. 3 – Variation of slump as a function as type of waste sand.

Density in the fresh state

It is clear from Figure 4 that the density in the fresh state of ordinary concrete is lower than that of concrete with recycled sands. This is logically explained by the fact that the substitute products (marble waste, tiling and cinder blocks waste) have a greater density than that of ordinary sand.

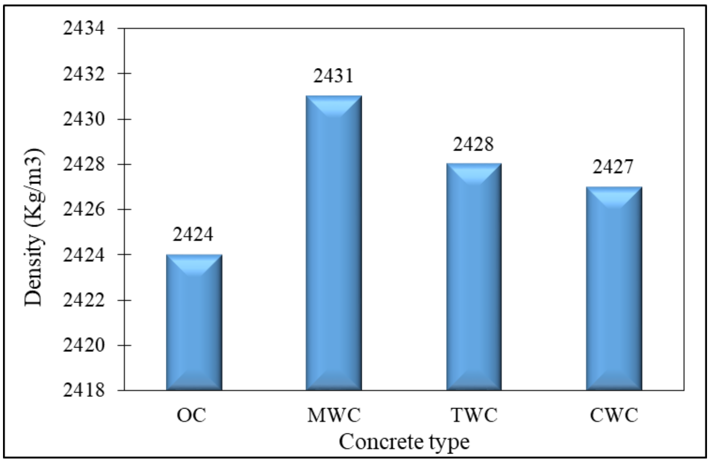

Fig. 4 – Density variation depending on the type of waste sand.

Air content

From Figure 5, it can be seen that the air content of the four formulations studied varies between 4 and 9%.

Substitution of ordinary sand by 15% marble and tiling waste sand reduced the entrained air content of the concrete by 9% and 5% respectively. This reduction is due to the high fines content of this waste compared to ordinary sand, which leads to good compactness. This result agrees with what was found by Hebhoub et al. 2011 [14]. On the other hand, the waste sand from cinder blocks increased the air content by 4% compared to ordinary concrete. This can be attributed to a poor spatial arrangement of the grains of sand of irregular angular shape resulting from the presence of an old mortar matrix attached to the grain of sand.

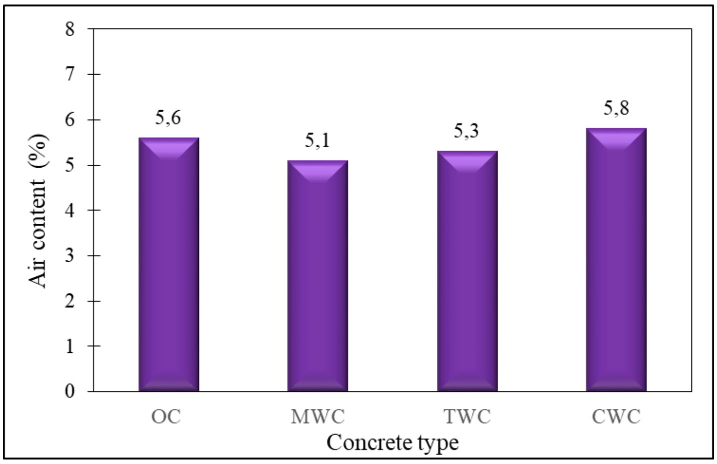

Fig. 5 – Variation of air content as a function as type of waste sand.

Compressive strength

The results, shown in Figure 6, indicate that the compressive strength increases as time passes regardless of the type of concrete tested. This can be explained by the development of the cement hydration phenomenon as a function of time in the presence of sufficient humidity.

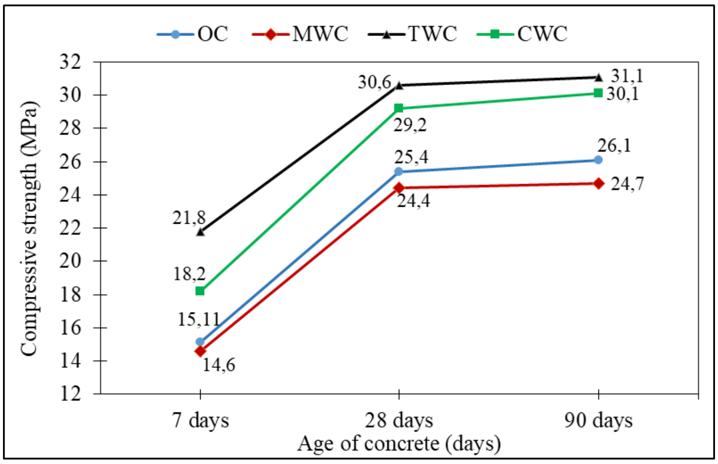

Fig. 6 – Evolution of compressive strength as a function of age and type of waste sand.

At all deadlines, concrete based on Waste Tile Sand (TWC) and concrete based on cinder block waste sand (CWC) exhibit higher strengths than ordinary concrete. After 90 days of storage, the strengths recorded exceed 30MPa and differ from that of the control concrete by 19% and 15% respectively. This can be attributed to the water absorption capacity of the tiling, cinder block waste which reduces the water / cement ratio [15], and to the role of the fines, which fill the granular interstices and make the mixture more compact.

The lowest compressive strength values are recorded by the concrete (MWC) with a decrease of around 5.6% compared to that of the control concrete. This reduction can be justified by a separation effect of the aggregates exerted by the cement paste incorporating the marble fines [16]. These results remain acceptable for ordinary concrete.

Flexural tensile strength

In Figure 7, we note that the introduction of recycled sands in the formulation of ordinary concrete leads to an improvement in Flexural tensile strength at all times.

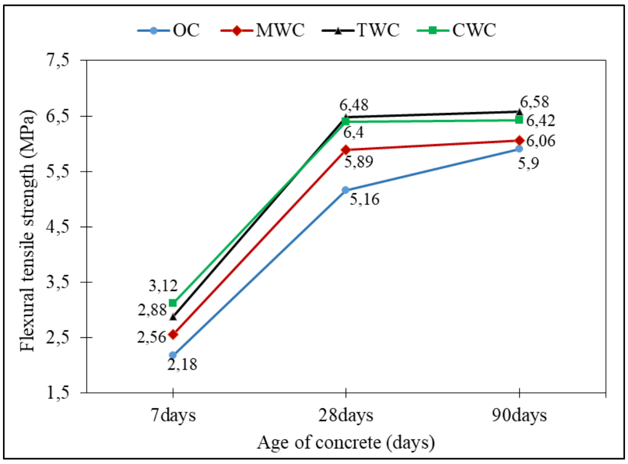

Fig. 7 – Evolution of flexural tensile strength as a function of age and type of waste sand.

At 7 days of age, the concrete made from cinder block waste sand (CWC) gave the best resistance, showing a value that exceeded that of the ordinary concrete by 21%. At 28 day, the resistance shown by the concrete with the waste tiling sand (TWC) deviates from that of the ordinary concrete (OC) by 25.5%.

At 90 days, the best resistance is obtained by (TWC) by exceeding the value of the ordinary concrete by 11%.

In the case of both tiling and cinder block waste sands, the growth of strengths is likely the result of the bond that developed as time elapsed between the hydrated cement paste and the grains of crushed sand having a rough and porous surface.

The increase in the tensile strength of the concrete containing the marble waste sand is justified by the plasticizing capacity of the marble.

Non-destructive testing

The results of non-destructive tests: the sclerometer test and ultrasound test for the four concretes studied at 28 days are shown in Figure 8.

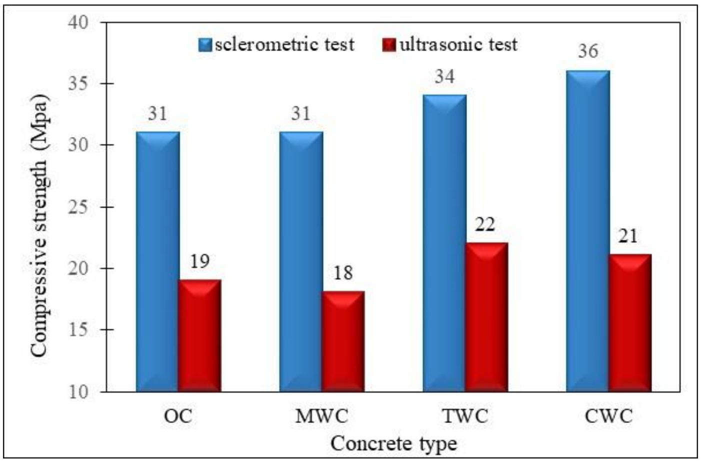

Fig. 8 – Evolution of compressive strength by non-destructive testing of the 04 concretes studied.

In general, there is an improvement in resistance for concrete based on recycled sands compared to ordinary concrete.

For the sclerometer test, it is noted that concrete with cinder block waste sand (CWC) gave the highest resistance compared to study concretes. This is due to the morphology of the cinder block waste aggregates, which offers better adhesion to the cement paste than ordinary aggregates due to the presence of an old cement matrix attached to the grain of sand.

On the other hand, for the ultrasound test, it was the concrete with tiling waste, which gave the best resistance. This means that the introduction of sand from waste tiling improves the homogeneity of the concrete.

Concrete with marble waste gave the lowest strengths compared to study concretes. This leads us to say that the rate of 15% of marble sand gives the lower adhesion to the paste than the other two mixtures.

Immersion absorption.

We can notice (Figure 9) that the water absorption by total immersion of ordinary concrete is greater than that of concrete based on recycled sand, and concrete (MWC) has the lowest water absorption by compared to other concretes.

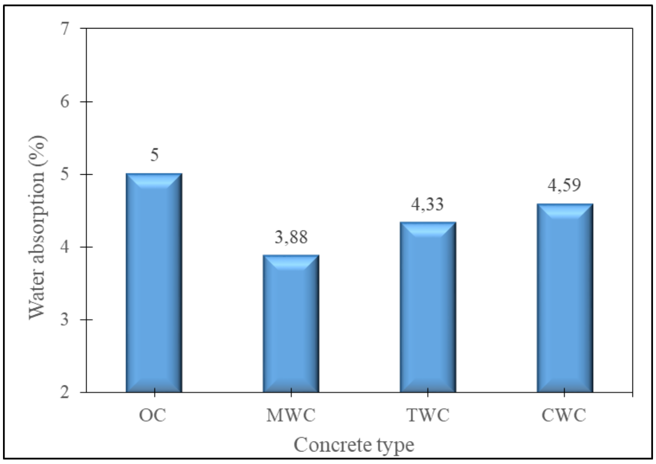

Fig. 9 – Evolution of water absorption of the 04 concretes studied.

Compared to ordinary concrete (OC), there is a decrease in water absorption of 8.2%, 13.4% and 22.4% for concretes (CWC), (TWC) (MWC) respectively. This result can be linked to the presence of the amounts of fine in the recycled sands, which are relatively high compared to ordinary sand, which leads to the decrease in porosity and to have concretes of good compactness.

Absorption by capillarity

Capillary porosity is a micro-structural characteristic that influences transfer properties [17]. The values of the capillary water absorption test for the different compositions are shown in Figure 10.

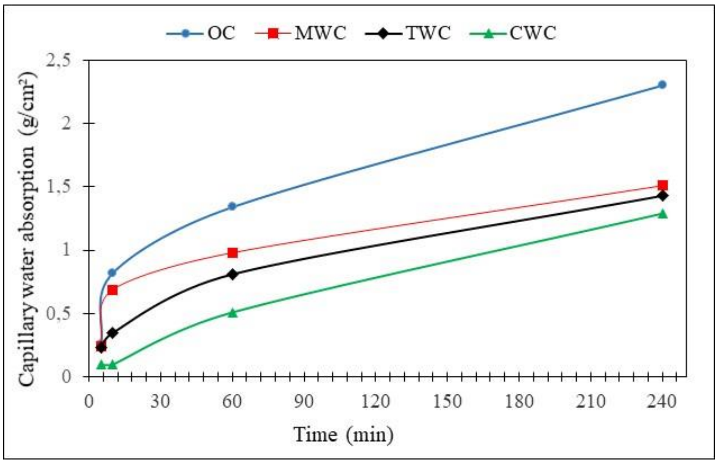

Fig. 10 – Evolution of capillary water absorption of the 04 concretes studied.

It can be seen that, compared to ordinary concrete (OC), the use of waste has reduced the amount of water absorbed. Concrete with cinder blocks waste gave the lowest values of capillary absorption.

After 24 minutes, the amount of water absorbed by the concretes (MWC), (TWC), and (CWC) decreased by 34.4%; 37.8% and 43.9% respectively compared to that of the ordinary concrete (OC). The incorporation of 15% of these wastes in the concrete tends to limit the water absorption of the composite.

These results can be justified by the plasticizing capacity of the marble waste sand, which closes the capillary pores. And the heterogeneity of the tiling and cinder block waste sand used given the presence of a residual mortar surrounding the particle of the waste sand, which reduces the interconnection of the pores of the capillary network.

Chloride penetration

We note that among the four concretes studied (Figure 11); concrete with marble waste (MWC) gave the greatest penetration depth (20.8 mm), with an increase of 7.2% compared to ordinary concrete.

For the other two concretes (TWC) and (CWC), the chloride penetration depth is lower than that of ordinary concrete. It goes from 19.3 mm for ordinary concrete to 17.2 mm; 16.2 mm for concrete TWC) and (CWC), therefore a decrease of 11.3% and 16.5% respectively. These results lead us to say that the chloride penetration rate depends on the porosity of the concretes and the size of the pores as well as the mobility of the chlorides inside the pores following their distribution in the cement matrix.

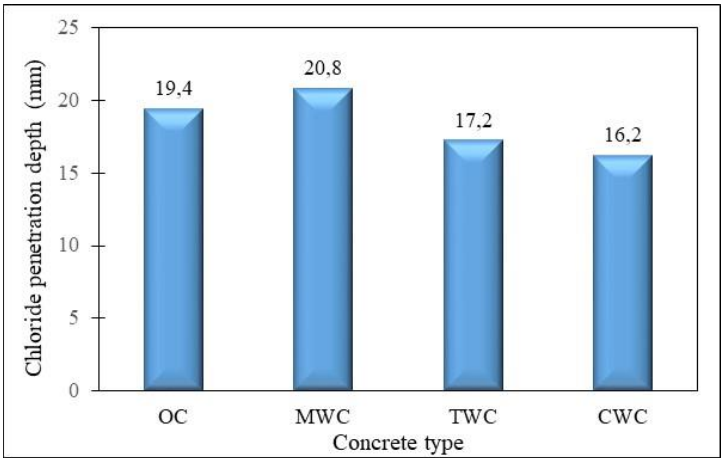

Fig. 11 – Chloride penetration depth of the 04 concretes studied.

CONCLUSION

This work presents an experimental study carried out with the aim of evaluating and comparing the performance of concrete made from recycled aggregates. The concretes studied are obtained by substituting a volume of 15% of ordinary sand by three different waste sands: marble waste, tiling waste and cinder block waste.

From the results obtained, the following main conclusions can be drawn:

- The substitution of ordinary sand by recycled sands increases the density and decreases the workability of the concrete.
- The substitution of ordinary sand by recycled sands decreases the entrained air content of the concrete except for concrete made from cinder block waste sand
- The volume substitution of 15% of ordinary sand by an equivalent volume of recycled sand improves mechanical properties. Concrete incorporating tiling waste sand gave the best mechanical resistance compared to other concretes.
- Recycled sands reduce the quantity of water absorbed by total immersion of concrete made from recycled sands. Concrete made from marble waste sand gave the lowest absorption.
- The introduction of recycled sands decreases the amount of water absorbed by capillary action of concrete made from recycled sands compared to ordinary concrete. The lowest capillary absorption value is recorded for concrete with cinder block waste sand.
- The use of recycled sands in concrete decreases the chloride penetration depth compared to ordinary concrete. Concrete with cinder block waste gave the lowest penetration depth.

The results obtained show a favorable effect of all the substituents both on the mechanical properties and on the durability of the concretes. However, the best results of the tests on the concretes are with cinder block waste sand and tiling waste sand.

Finally, the use of a percentage of 15% of cinder block and tiling waste sands in the manufacture of concrete seems a promising way to valorize these two types of waste.

REFERENCES

[1] Nadjoua B., 2017. Granulats recycles de substitution pour bétons hydrauliques : béton de démolition - déchets de briques - déchets de verre (Substitute recycled aggregates for hydraulic concrete: demolition concrete - waste bricks - waste glass). PhD Thesis, University of Constantine, Algeria.

[2] Lilia B., Dyhia B., 2017. Recyclage des déchets inertes de marbre et de granite de la marbrerie YAHIAOUI-DBK dans la fabrication des dallages de sol (Recycling of inert waste of marble and of granite from the YAHIAOUI-DBK marble factory in the manufacture of floor tiles). Master Thesis, University of Mouloud Mammeri Tizi-Ouzou, Algeria.

[3] Hamza C., Zahir T., 2017. Amélioration des propriétés mécaniques du plâtre de construction avec des déchets plastiques et verre," (Improvement of the mechanical properties of building plaster with plastic and glass waste). Master Thesis, University Akli Mohand Oulhadj, Bouira, Algeria.

[4] Hebhoub H., Belachia M., 2011. Introduction de sable de déchet de marbre dans le béton hydraulique (Introduction of marble waste sand into hydraulic concrete). Nature et Technologie, p. 6,

[5] Tugrul Tunc E., 2019. Recycling of marble waste: A review based on strength of concrete containing marble waste," Journal of Environmental Management, vol. 231, pp. 86-97. https://doi.org/10.1016/j.jenvman.2018.10.034

[6] Omar O. M., Abd Elhameed G. D., Sherif M. A., Mohamadien H. A., 2012. Influence of limestone waste as partial replacement material for sand and marble powder in concrete properties. Housing and Building National Research Center Journal, vol. 8, pp. 193-203. http://dx.doi.org/10.1016/j.hbrcj.2012.10.005

[7] Kore S., Vyas A., 2015. Behavior of Concrete Using Marble Waste as Coarse Aggregate. UKIERI Concrete Congress –Concrete Research Driving Profit And Sustainability. India.

[8] Chaid R., Jauberthie R., Abadlia M. T., Talah A., 2011. Effet des déchets de marbre sur la durabilité des bétons en milieu marin (Effect of marble waste on the durability of concrete in the marine environment). The XXIXe Rencontres Universitaires de Génie Civil. Tlemcen, Algeria.

[9] Djebien R., Hebhoub H., Belachia M., Berdoudi S., Kherraf L., 2018. Incorporation of marble waste as sand in formulation of self-compacting concrete. Structural engineering and mechanics: An international journal, vol. 67, pp. 87-91. DOI: https://doi.org/10.12989/sem.2018.67.1.087

[10] Benhalilou M. I., Belachia M., Houari H., Abdelouahed A., 2020. The Study of the Characteristics of Sand Concrete Based on Marble Waste Sand. Civil And Environmental Engineering Reports, vol. 30, No.1, pp 130-144. DOI: 10.2478/ceer-2020-0010.

[11] Hebhoub H., Kherraf L., Abdelouahed A., Belachia M., 2020. Introduction of Marble Waste Sand in the Composition of Mortar. In book: Use of Sandy Materials in Civil Engineering, Publisher: Intechopen. DOI: 10.5772/intechopen.91254

[12] Tennich M., Ben Ouezdou M., Kallel A., 2013. Béton autoplaçant à base de déchets de marbres et de carrelage (Self-compacting concrete made from waste of marble and of tiles). Journées nationales de béton : JNB'13. Tunisia.

[13] Djebien R., Belachia M., Hebhoub H., 2015. Effect of marble waste fines on rheological and hardened properties of sand concrete. Structural Engineering and Mechanics, vol. 53, pp. 1241-1251. DOI: 10.12989/sem.2015.53.6.1241.

[14] Hebhoub H., Aoun H., Belachia M., Houari H., Ghorbel E., 2011. Use of waste marble aggregates in concrete. Construction and Building Materials, vol. 25, pp. 1167-1171. https://doi.org/10.1016/j.conbuildmat.2010.09.037.

[15] Sancheti G., Bhargava S., Jain K., 2020. Mechanical and Durability Performance of Concrete Made with Waste Marble and Fly Ash. Jordan Journal of Civil Engineering, vol. 14, pp. 305-318.

[16] De Larrard F., Tondat P., 1993. Sur la contribution de la topologie du squelette granulaire à la résistance en compression du béton (On the contribution of the topology of the granular skeleton to the compressive strength of concrete). Materials and Structures, vol. 26, pp. 505-516.

[17] Belkadi A. A., 2018. Contribution à l'étude de la durabilité et les performances des bétons autoplaçants (fibres végétales, milieu agressif, formulation, modélisation) (Contribution to the study of the durability and performance of self-compacting concretes (vegetable fibers, aggressive environment, formulation, modelization)). PHD thesis, Mohamed Khider university – Biskra- Algeria.