Algerian Journal of Environmental Science and Technology
December edition. Vol.8. Nº4. (2022)
ISSN : 2437-1114
www.aljest.org

Effect of the addition of colored and not-colored glass waste on the mechanical performance of concrete

T. Ben Chabane[1]*, O.Fedaoui-Akmoussi[1], F.Taouche-Kheloui[1], T.Djadoun[1], K. Ait tahar[2]

[1]University of Mouloud Mammeri, Laboratory LGEA,Tizi-Ouzou, Algeria.
[2]University of Akli Mohand Oulhadj, Laboratoiry LM2D, Bouira, Algeria.

*Corresponding author: t.benchabane@yahoo.fr ; Tel.: +2137 77 95 34 96

ARTICLE INFO

Article History:

Received **: 29/12/2019**
Accepted **: 08/02/2021**

Key Words:

Glass waste;
Colored and not colored; glass;
Valuation;
Mechanical Tests;
Analyzes.

ABSTRACT

Abstract: *Waste recycling contributes topreservation of conventional natural aggregates, reduces greenhouse gas emissions. The recovery of wasteglass reduces storage volumes and allows the conservation of landfill spaces. The use of waste glass in the form of powders and aggregates ensures the lightening of building elements, better economic development and the promotion of new field materials.*
The aim of this experimental study is to recover waste glass by incorporating them by partial substitution in concrete in order to reduce the cement and sandquantities. Two types of waste glass were used: colored and not-colored glass from the bottles which are widespread in nature. The rates of 0%; 5%; 10% and 15% were used to replace cement and sand. The mechanical strengths were performed at 28 and 365 days. The results obtained confirm that the use of this type of waste at precise rates increases the compressive strength of concrete. Indeed, the finely ground glass powder improves long-term mechanical behavior of concrete due to its interesting pozzolanic effect.

I. Introduction

Concrete is the most used material for the construction of structures in general, so the production of cement is very important and its production process generates a very large amount of CO_2. Reducing the amount of cement produced represents environmental protection.The partial substitution of a certain quantity of Portland cement by one or more mineral additions when they are available at competitive prices can be advantageous not only from the economic, ecological but also with regard to mechanical performance [1].
This approach is part of the contribution to recycling and recovery of glass waste. In addition to protecting the environment, this initiative ensures the save natural resources (sand and gravel). In the literature, several types of glass waste are proposed such as green glass, brown glass, white glass and mixed glass (several colors) with different shapes and percentages.
This study interested in colored (green) glass waste and uncolored (white) glass waste from bottles, collected in nature.Generally, the glass used for the manufacture of these bottles is not recycled and more often the industries use it as lost packaging. The revalorization of this material after several life cycles is very interesting.However, its use in a cementitious matrix causes two reactions(see equations 1 and 2): the alkali-silica reaction (presence of reactive silica) and the pozzolanic reaction (finely ground glass grains).
The pozzolanic reaction is as follows:

$$\mathrm{Ca(OH)_2} + \mathrm{S_iO_2} \longrightarrow \mathrm{C-S-H} \quad \textbf{(1)}$$

Portlandite + pozzolan⟶ Hydrated calcium silicate

$$\mathrm{Ca(OH)_2} + \mathrm{Al_2O_3} \longrightarrow \mathrm{C-A-H} \quad \textbf{(2)}$$

Portlandite + pozzolan⟶ Hydrated calcium aluminate

Hydrated calcium silicate (C-S-H) and hydrated calcium aluminate (C-A-H) are insoluble products, they have binding properties. They increase the mechanical resistance and durability of materials by filling their pores and this by transforming portlandite ($Ca(OH)_2$) in the form of large crystals into CSH and crystallized CAH [2 - 4].

Glass is used in concretes and mortars, either in large particles, which leads to bad behavior for concrete or in the form of powder with a beneficial behavior [2]. If the diameter of the grains is large, this would generate the alkali-silica reaction: a reaction harmful to the concrete which can cause swelling and cracking under certain storage conditions (high temperature, high humidity> 80%) [5-8].Flexural strength losses occur when the replacement rate exceeds 25%, in particular glass granules of 20 mm in size seem to affect the durability of concretes [3,4].

Concrete modified with glass powders has been shown to have improved resistance to chloride permeability [5]. Accelerated mortar test results, ASTM C1260, indicated the effectiveness of glass powders at 10% and 20% replacement levels for suppressing the alkali-silica reaction in cementitious materials [6]. In order to limit the aggregate alkali reactions (RAG), the glass particle is reduced by crushing, studies showed that reducing the size of the particles considerably decreases the formation of RAG, and increases the mechanical resistance to compression as well as the maniability of concrete [7-9].The use of crushed glass waste as a cement substitute in the mortar gives improved resistance to alkali-silica reaction and chloride penetration and considerably improved sulfate resistance [10, 11].

In our case, we have studied the compressive strength evolution of concrete containing waste glass. Mass fractions ranging from 0% to 15% with a step of 5% have been used to replace cement and sand. The mechanical characterization is carried out after 28 days and 365 days on cylindrical specimens 16x32cm using a hydraulic press. The results obtained were compared with those of a controlconcrete without addition.

II. Materials and methods

II.1. Materials used

The materials used to producetheconcrete specimens are local materials from quarries such as washed sand (0-3), gravel (3-8), gravel (8-15)and CEM II /B-L 42.5 N cement. Two types of glasses are used, coloredand not-colored glass waste.

II.1.1.Cement

The binder used is a Portland cement compound CEM II / B-L 42.5 N. It chemical, Physical and mechanical characteristicsare reported in Tables 1 and 2 respectively:

Table 1.*Chemical composition of cement (%)*

S_iO_2	18.88
$Al_2\,O_3$	4.36
Fe_2O_3	3.10
CaO	62.23
MgO	1.43
SO_3	2.70
Na_2O	0.28
K_2O	0.58
Fire loss	6.50

Table 2. *Physical and mechanical characteristics of the cement used*

Physicalandmechanicalproperties	CEM II /B-L 42.5 N
Start of setting (min)	200
End of setting (min)	245
Compressive strengthR_{c28} (MPa)	≥42.5
Tensile strengthR_{t28} (MPa)	4.3

II.1.2. Aggregates

The aggregates used are quarry sand (Dedjel Sétif) and crushed gravel (3/8, 8/15). They are washed, dried in an oven at 105°C for 24 hours and then stored in bags inside the laboratory (dry and clean aggregates)see figure 1. The physical characteristics of aggregates are given in Table 3.

Figure 1.*The different aggregates used.*

Algerian Journal of Environmental Science and Technology
December edition. Vol.8. Nº4. (2022)
ISSN : 2437-1114
www.aljest.org

Table 3. *Apparent and absolute density of aggregates (NF P 18-554 and NF P 18-555)*

Aggregates	Sand 0 /3	Gravel 3/8	Gravel 8/15
Absolute density (g/cm^3)	2,63	2,6	2,72
Apparent density (g/cm^3)	1,485	1,46	1,42

The value of the fineness module (NF P 18-101) and the sand equivalent (NF P 18-598) are also measured and represented in table 4:

Table 4. *Equivalent sand value*

Component	Fineness module FM	Sand equivalent (%)	
		Visual (ESV)	Under piston (ES)
Sand (0/3)	2,87	86,14	85,15

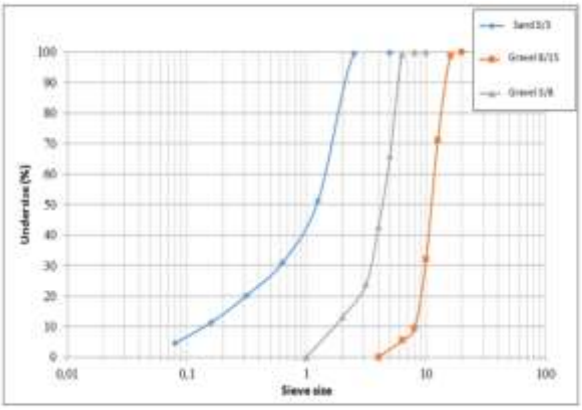

Figure 2.*Granulometric curve of aggregates*

The curve above represents the grain size curve of the various aggregates necessary for the confection of reference concrete.

II.1.3.Glasswaste

Bottles are collected either from illegal landfills in the middle of nature, or from road terminals. Once the bottles were reclaimed, they were cleaned to remove any impurities and the labels they contained. It is useful to point out that two types of bottles according to their color were recovered. These glass wastes were either crushed with a very precise particle size in order to have sand (colored and uncolored) and another finely ground to obtain a glass powder.

Figure 3. *The appearance of glass waste according to the color of the bottles collected*

The chemical compositions as well as the analysis by laser particle size distribution of the colored and not-colored glass powder are indicated respectively in Table 5 and Figure 4.

Table 5.*Chemical composition of the colored and non-colored glass powder*

Content(%)	Glass	
	Colored glass (CG)	Not Colored glass (NCG)
SiO_2	73.53	73.74
Al_2O_3	1.64	1.14
Fe_2O_3	0.50	0.28
CaO	10.68	10.00
MgO	0.65	0.75
SO_3	0.09	0.35
K_2O	0.22	0.09
Na_2O	11.83	13.08
P_2O_5	0.09	0.01
TiO_2	0.15	0.05
Fire loss	0.63	0.51

The chemical composition of the glass powder shows that the material mainly contains silicon (73.53% for colored glass and 73.74% for non-colored glass), sodium oxide (11.83% for colored glass and 13.08% for not-colored glass) and lime (10.68% for colored glass and 10% for not-colored glass).

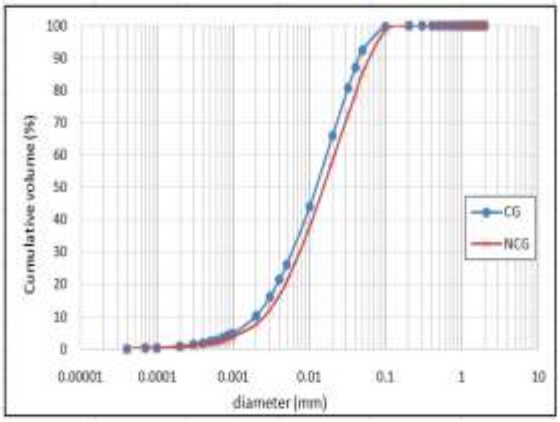

Figure 4.Granulometric analysis by laser diffraction of glasses.

Colored glass and not-colored glass have similar grain size curves. We note the presence of a fairly significant finesse. The curves show 50% of the particles characterized by a diameter of 12.11 µm for colored glass (CG) and 15.05 µm for non-colored glass (NCG). Also 90% of the particles are characterized by a diameter of 44.74 µm for colored glass and 59.34 µm for not-colored glass.

II.1.4. Micro structure of the glass powder

In order to have a fine powder, the glass is ground using a ball mill for an hour of time, this saves energy, facilitates the process of reuse and implementation. The following figures 5 and 6 showimages produced using a scanning electron microscope (SEM) of the powders studied.

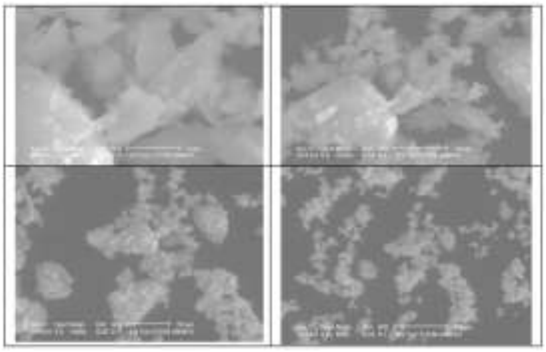

Figure 5. *SEM observations of colored glass*

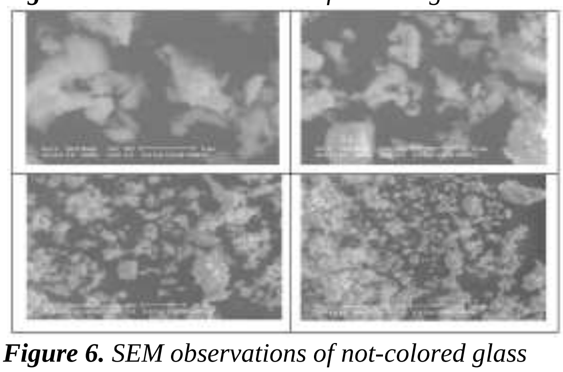

Figure 6. *SEM observations of not-colored glass*

From the images taken using a electronic scanning microscope on the colored and not colored glass powder, it can be seen that the grain size is uniform and no particular grainshape has been observed for both types of glass powder (colored and not colored).

II.2. Concrete formulation

In this study, we used a concrete composition according to the Dreux-Gorisse method. The proportions of the different constituentsare presented in Table 6.

Table 6. *Concrete composition*

Components (Kg/m^3)	Quantity (Kg)
Cement	400
Sand 0/3	586
Gravel 3/8	272
Gravel 8/15	1003
Water	200
Water/cement ratio (W/C)	0.5

Figure 7. *Appearance of concrete specimens*.

Cylindrical specimens measuring 16x32 cm were made (Figure 8). The samples were kept immersed in a water basin according to standard NF P 18-404. The introduction by substitution of the glass powder as an addition or the crushed glass as aggregate (sand) as well as the different combinations used to make the samples are presented in table 7.

Table 7.The different rates used.

Concrete	Percentage of glass powder substituted for cement (%)	Percentage of crushed glass substituted for sand (%)	
Reference Concrete (RC)	0	0	
Colored Glass (CG)	5	0	C5P0S
		5	C5P5S
		10	C5P10S
		15	C5P15S
	10	0	C10P0S
		5	C10P5S
		10	C10P10S
		15	C10P15S
	15	0	C15P0S
		5	C15P5S
		10	C15P10S
		15	C15P15S
Not colored Glass (NCG)	5	0	NC5P0S
		5	NC5P5S
		10	NC5P10S
		15	NC5P15S
	10	0	NC10P0S
		5	NC10P5S
		10	NC10P10S
		15	NC10P15S
	15	0	NC15P0S
		5	NC15P5S
		10	NC15P10S
		15	NC15P15S

III. Results and discussion

The compressive strength of the samples at 28 days is obtained using a hydraulic press with a load speed of 0.5 kN/s, figure 8.

Figure 8. *Mechanical resistance device*

The average mechanical strengths at 28 and 365 days for each composition are shown in Figures 9, 10 and 11 below:

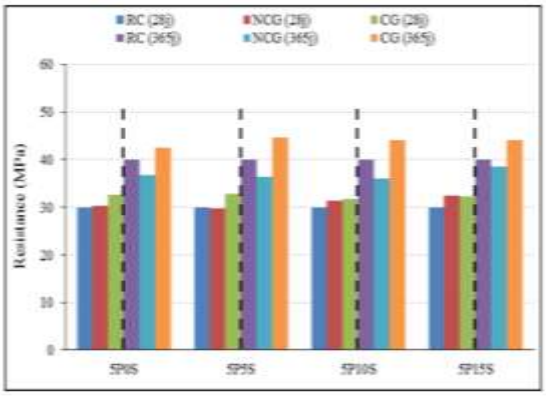

Figure 9.*Compressive strength of concrete containing 5% glass powder*

At 28 days, all variants of colored and not-colored glass specimens developed a slight increase in strength over that of the reference specimen apart from a few exceptions. These results are explained by the fact that in a short term, the hydration reactions of the components of the mixture (cement +glass) are not complete. Indeed, the kinetic reaction is delayed according to the rate of glass waste added. These results are similar to those found [12 -14].
By comparing the resistance of samples containing 5% not-colored glass waste, dosed with different levels of crushed glass (0%, 5%, 10% and 15%) as sand (aggregate) figure 9, it can be seen that these resistances are practically similar to that of reference concrete.The variant (5P5S) record the lowest resistance with a value of 29.81MPa.
On the other hand, an increase in compressive strengths was recorded for the specimens formulated with colored glass waste. Indeed, the highest resistance is recorded by the variant (5P5S)

with a value of 32.85MPa against a value of 29.98 MPa of the reference concrete.

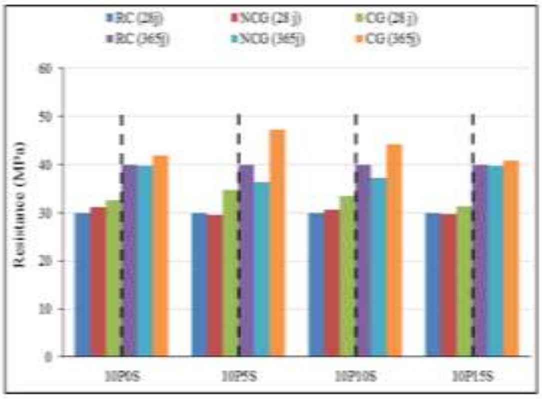

Figure 10. *Compressive strength of concrete containing10% glass powder*

In figure 10, with a partial substitution of 10%, it's also noted that for all the variants, the resistances of the samples containingwaste colored glass are greater than those of concretes of dosed with waste not-colored glass and that of the reference concrete. For colored glass the best variant is (10P0S) which has a resistance of 34.78MPa. The lowest resistance recorded for colored glass is variant (10P5S) with 29.53MPa.

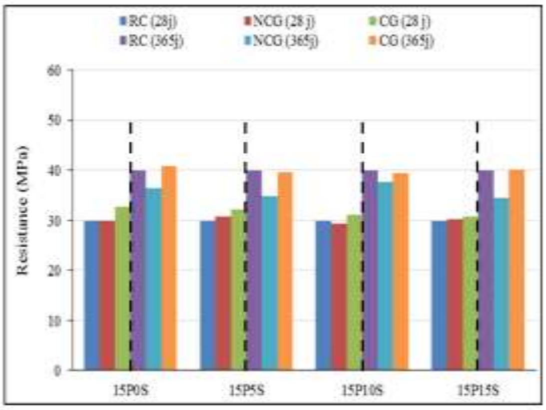

Figure 11. *Compressive strength of concrete containing 15% glass powder*

As in the previous cases, it can be seenin figure 11 that the concrete of waste colored glass has better strengths than those containing waste of non-colored glass. The highest resistance is recorded for the variant (15P5S) with 32.66 MPa for colored glass against the smallest resistance for the variant (15P10S) with a value of 30.74 MPa for not colored glass.

On the other hand, we noted, for the two types of glass waste, that compared to the 5% and 10% percentage of glass powder, all the resistances from the 15% dosage of glass powder, show a slight drop in resistance and this for all combinations of glass sand.

At 365 days, series of test specimens realized with the same variants as at 28 days presented very interesting mechanical behavior.

For certain variants, the figures above show a clear increase in compressive strengths compared to the reference concrete. As can be seen, the resistances depend on the fineness, the content and the color of the glass.A tendency to strength increase was observed with 5% and 10% of glass powder with the different percentages of glass sand; it's of the order of 11% and 16% respectively compared to reference concrete. When the level of cement replacement has been increased beyond 15%, this resistance decreases. If we compare this variation to the strength reference concrete at 28 days it becomes of the order of 32.88% and 57.90% for respectively 5% and 10% substitution.

This gain in resistance can be attributed to the pozzolanic activity of the glass powder which generates a filler effect in the cement matrix due to their fineness.An interaction between the portlandite released by the cement hydration and the reactive silica of the glass powder allows the latter to fix the lime. This result is confirmed by several studies [7, 9, 10, 21, 22].

The difference in resistance observed between colored glass and non-colored glass results from the fineness effect.Colored glass has a finer particle size distribution than non-colored glass. In fact, more than 90% of colored glass particles are characterized by a diameter of the order to 45 µm against 60 µm for non-colored glass as indicated in the particle size analysis. The finer grains effectively fill voids and result a dense microstructure in concrete.Shao et al.[15] have shown that more the diameter is smaller, more the favorable development of pozzolanic reaction.

A study [16] has shown that the color of the waste glass is a parameter to be taken into account. Indeed, the chemical composition of this material has an important role in the evolution of compressive strengths of concrete. This research has shown that green glass is the most pozzolanic material, followed by clear and brown glass, which gives it better mechanical performance. The results of the present experimental study agree favorably with the results of the literature. The best performance recorded for colored glass is 47.34 MPa against the greatest strength of 39.76 MPa for not-colored glass concrete.

III.2. Activity Index

The NF P18 513 standard prescribes the activity index (I_a) as an effective parameter for the pozzolanic activity evaluation. This index is the ratio between the compressive strength (f_{ci}) concrete with waste glass addition and the compressive strength (f_{cref}) reference concrete

Algerian Journal of Environmental Science and Technology
December edition. Vol.8. Nº4. (2022)
ISSN : 2437-1114
www.aljest.org

[4,17] according to equation (3). The activity indices values of two types of glass concrete are presented in Figures 12 and 13.

$$I_a = \frac{f_{cj}}{f_{cref}} \times 100 \quad \textbf{(3)}$$

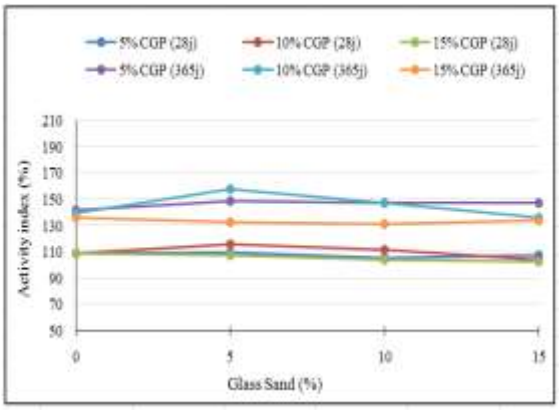

Figure 12. *Evolution of the colored glass activity index.*

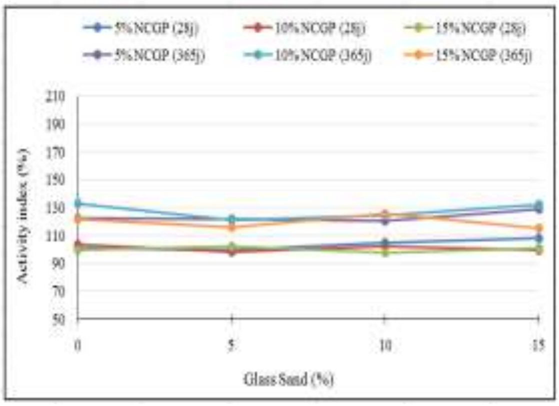

Figure 13. *Evolution of the not-colored glass activity index.*

By comparing the two glasses pozzolanic activity indices, it sees that the colored glass presented a better activity index which is between 130% and 160%. This is due to the glass grains size which has a major role in the pozzolanic activity: more the grains are finer, better its pozzolanic activity. The best value is obtained for 5% and 10% glass powder addition with all glass sand percentages studied. For not-colored glass, the activity index is between 115% and 130% at 365 days. The pozzolanic activity is more developed in the case of colored glass unlike not-colored glass.

IV. Conclusion

In this study, we investigated the influence of using waste glass powder at different rates in concrete to replace cement and crushed waste glass to replace sand. The mechanical characterization carried out on the different specimens made it possible to draw the following conclusions:

- The waste glass addition significantly improves the concrete properties. The waste glass concrete strength gradually increases until it exceeds that a reference concrete. At young age (28 days) this variation isn't important because of pozzolanic reaction slowness. At 365 days, it sees that the strengths register an improvement for colored glass concrete unlike not-colored glass concrete. In fact the concrete based on colored glass waste generates an increase of approximately 16% against a decrease for concretes based on not-colored glass waste with a value of 10%. The development of weak resistance at a young age is observed. This increased significant in long term which emerges from the various results of this study is also observed [18-20].

- In the case of concrete dosed with colored glass waste, the variant (10P5S) registers the highest resistance 47.34MPa, against a lower resistance value recorded for variant (15P10S) 39.40MPa. Similar results have already been found in the literature [3, 4]. Beyond a certain rate of glass waste (around 25%), the concrete samples undergo a drop in mechanical resistance. The excess of the waste glass causes the dispersion of cement grains and therefore makes less resistant the cementitious matrix.

- For concrete blended with not-colored glass waste, the concretes strengths studied have decreased compared to that for reference concrete and this for all the variants (5%, 10% and 15%) of glass powder with (0%, 5%, 10%, 15%) glass sand.

- The reclaimed glass waste can be used either as a mineral addition (substitution of cement) or as aggregates in concrete. Indeed, aggregates based on crushed glass waste don't improve mechanical resistance. However, finely ground, this material contributes significantly to increasing the mechanical performance of concrete.

-In the long term, the pozzolanic effect of colored glass powder gives better compressive strength of concrete.

-Beyond a certain threshold, the increase in the content of glass waste in the concrete leads to a decrease in the compressive strength.

-The recovery of waste glass recovery presents promising way for manufacture of new concretes.

V. References

1. Safer, O.; Belas, N.; Belguesmia, K.; Belaribi, O.; Mebrouki, A.; Bouhamou, N. Influence de l'incorporation de la vase du barrage Chorfa sur les performances mécaniques des bétons ordinaires. *Algerian Journal of Environnement Science and Technology* 3:3-A (2017) 478-484.
2. Midgle, H.G.; Illston, J.M. The penetration of chlorides in to hardened cements pastes. *Cement and Concrete Research* 14 (1984) 546–558.
3. Dreux G.; Jean festa. Nouveau guide du béton et de ses constituants. *Édition Eyrolles* (1998).
4. Shi, C.; Wu, Y.; Rieflerb, C.; Wang, H. Characteristics and pozzolanic reactivity of glass powders. *Cement and Concrete Research* (2005) 987–993.
5. Garcia-diaz, E.; Riche, J.; Bulteel, D.; Vernet, C. Mechanism of damage for silica reaction. *Cement and Concrete Research* 36 (2006) 395–400.
6. Shi, C.; Wu, Y.; Shao, Y.; Riefler, C. Alkali-aggregate reaction of concrete containing ground glass powder. *Proceedings of the 12th International Conference on AAR in Concrete* (2004) 789–95.
7. Tagnit-Hamou, A.; Nkinamubanzi, P-C. Les ajouts cimentaires et le développement durable. *Note trimestrielle d'information du Centre d'Études et de Services Technologiques de l'Industrie des Matériaux de Construction* 08 (2002) 9–11.
8. Kojima, T.; Tagagi, N.; Haruta, K. Expanding characteristics of mortar in glass powder produced from waste bottles. *11 th International conference on Alkali Aggregate Reaction, Quebec* (2000).
9. Mafalda Matos, A.; Sousa-Coutinho, J. Durability of mortar using waste glass powder as cement replacement. *Construction and Building Materials* 36 (2012) 205–215.
10. Idir, R. Mécanisme d'action des fines et des granulats de verre sur la réaction alcali-silice et la réaction pouzzolanique. *Thèse de doctorat INSA Toulouse* (2009).
11. Chen, C.H.; Huang, R.; Wu, J.K.; Yang, C. Waste E-glass particles used in cementitious mixtures. *Cement and Concrete Research* 36 (2006) 449-456.
12. Shayan, A.; Xu, A. Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs. *Cement and Concrete Research* 36 (2006) 457-468.
13. Taha, B.; Nounu, G. Properties of concrete contain mixed color waste recycled glass as sand and cement replacement. *Construction and Building Materials* 22 (2008) 713-720.
14. Taha, B.; Nounu, G. Using lithium nitrate and pozzolanic glass powder in concrete as ASR suppressors. *Cement and Concrete Composites* 30 (2008) 497-505.
15. Shao, Y.; Lefort, T.; Moras, S.; Rodriguez, D. Studies on Concrete Containing Ground Waste Glass. *Cement and Concrete Research* 30 (2000) 91-100.
16. Karamberi, A.; Moutsatsou, A. Participation of Colored Glass Cullet in Cementitious Materials. *Cement and Concrete Composites* 27 (2005) 319-327.
17. Idir, R.; Cyr, M.; Tagnit-Hamou, A. Use of waste glass in cement-based materials. *Déchets sciences et techniques*, 57, (2010) 10.
18. Lker, I.; Topc, B.; Canbaz, M. Properties of concrete containing waste glass. *Cement and Concrete Research* 34 (2004) 267-274.
19. Chen, G.; Lee, H.; Lun Young, K.; Yu, P.; Wong, A.; Tao, T.; Cho, KK. Glass recycling in cement production – an innovative approach, *Waste Manage* 22 (2002) 747 – 753.
20. Schwarz, N.; Dubois, M.; Neithalath, N. Electrical conductivity based characterization of plan and coarse glass powder modified cement pastes. *Cement and concrete composites* 29 (2007) 656 – 666.
21. Kamali, M.; Ghahremaninezhad, A. Effect of glass powders on the mechanical and durability properties of cementitious materials. *Construction and building materials, – Elsevier* 98 (2015) 407-416.
22. Soliman, N.A.; Tagnit-Hamou, A. Development of ultra-high-performance concrete using glass powder towards ecofriendly concrete. *Construction and Building Materials* 125 (2016) 600–612.

Please cite this Article as:

Ben Chabane T., Fedaoui-Akmoussi O., Taouche-Kheloui F., Djadoun T., Ait tahar K., *Effect of the addition of colored and not-colored glass waste on the mechanical performance of concrete,* ***Algerian J. Env. Sc. Technology**, **8:4 (2022)*** **2720-2727**