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THE EFFECT OF REPLACEMENT OF NATURALS AGGREGATES BY SLAG PRODUCTS ON THE STRENGTH OF CONCRETE

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ABSTRACT

The aggregates (sand and gravel) form the skeleton of the concrete, they occupy approximately 75% of its volume, and intervene directly on the physical and mechanical properties of concrete.

The aim objective of this experimental work consists in:

- Substituting sand by granulated blast furnace slag.
- Substituting natural gravels by crystallized slag.

The use of the method of substitution permits to improve the strength of the concrete, to increase the production of building materials in Algeria and to protect the environment, it also gave an economic approach to the construction industry.

The experimental results obtained show that the partial substitution of ordinary sand by slag gives better results compared with the ordinary concrete, the total substitution of natural gravels by crystallized slag improves the strength, but the full replacement of fine and coarse aggregates by slag products affect negatively the strength of concrete.

Keywords: crystallized slag, granulated slag, gravel, sand, steam curing, strength, substitution

1. INTRODUCTION

The choice of aggregates is important, their quality plays a great role, they can not only limit the strength of concrete but owing to their characteristics, they affect the durability and performance of concrete. (Neville, 2000).

Generally, sands and natural gravels obtained by screening, or sometimes through crushing are satisfactory, as the igneous rocks or those sedimentary crushed ones.

The resort to artificial aggregates such as the granulated and crystallized slag allows us to extended construction material scale, to limit over use of natural resources and to value the slag products, that are piled up into blast furnace of El hadjar (Algeria) without being able to find valuable solutions.

The blast furnace slag is a by-product obtained in the manufacture of pig-iron in the blast furnace, and is formed by the combination of the earthly constituents of iron ore with the

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limestone flux (Lea, 1971).

Blast furnace slag issues from blast furnace as a molten stream at a temperature of 1400-1500°, it may be treated trough various methods following the desired type :

When the slag is allowed to cool slowly, it solidifies into a grey, crystalline, stony material, know as air cooled, or dense slag. This forms the material used as a concrete aggregates, it is a real silico calcareous rock, similar to the basalt, of angular aspect, rugous and of micro alveolar structure. (Venuat, 1989).

- When the molten slag is chilled very rapidly either by pouring into a large excess of water, or by subjecting the slag stream to jets of water. The quenching breaks up the material into small particles, solidifies as a glass. The product is called granulated slag and is used as cement, or as a sand for concrete. (Venuat, 1984).
- The granulated slag can replace the natural sand in concrete, the same can be said about the crystallized slag, which after crushing, constitutes an excellent normalized gravels (Zeghichi and Mezghiche, 2005a, 2005b).
- This article studies the effect of partial or total substitution of natural aggregates by slag products (granulated or crystallized one) on the mechanical behavior, following this plan:

Study of the effect of partial or full substitution of fine aggregate by granulated slag on the strength of concrete.

- Study of the effect of partial or full substitution of aggregate by crystallized slag on strength of concrete.
- Study of the effect of partial or total substitution of and fine coarse aggregates by slag products on strength of concrete.

2. EXPERIMENTATION

2.1 Materials

- Portland cement type CPJ CEM II/ A42,5 comes from Msila factory, the Blaine fineness is 3420cm^2/g and its compressive strength at 28 days is 45 MPa, its chemical composition is given in Table 1.

Table 1. Chemical composition of the constituents of concrete

Constituents	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O
CPJ 42,5	20.70	68.92	4.75	3.57	4.75	1.98	6.39	0.09
Sand	89.67	5.96	0.90	0.91	0.2	0.05	0.3	0.01
Coarse aggregate	40.65	40.56	8.87	3.25	3.65	0.79	0.65	0.01
Granulated slag	39.99	41.13	9.73	3.56	3.38	0.67	0.58	0.01
Crystallized slag	40.26	40.89	8.98	2.98	3.40	0.59	0.6	0.01

- Coarse aggregates (naturals aggregates): are a local one, obtained by crushing of the limestone rock, the aggregates has two fractions 3/8 (3 to 8mm) and 8/16 (8 to 16mm).
- The dune sand is a clean, siliceous and fine sand a fraction 0/3 taken from Msila region.
- The slag comes from the metallurgic unit of El hadjar (Annaba):
  - ➢ The granulated slag is obtained by rapid immersion in a cold water basin, its particle size from 0 to 5 mm.
  - ➢ The crystallized slag is obtained when slag cools slowly, it is crushed in tow sizes 3 to 8mm and 8 to 16mm (similar to naturals aggregates).
  - ➢ The chemical composition of naturals aggregates and artificial one given in (table1).

The physical properties are regrouped in (Table 2):

Table 2. The physical properties of materials

Materials	**Sand**	**Gravel 3/8**	**Gravel 8/16**	**Granulated slag**	**Crystallized slag 3/8**	**Crystallized slag 8/16**
Absolute density, kg/m^3	2540	2540	2560	1909	2550	2500
Bulk density, kg/m^3	1540	1340	1370	958	1270	1150
Porosity, %	39.37	46.96	46.00	-	46	46.80
Absorption, %	2.30	0.20	0.50	10	1.38	1.38
Fineness modules	1.55	-	-	3.54	-	-
Sand equivalent, %	75	-	-	80	-	-
Abrasion, %	-	20	22.87	-	-	28.55

The Figure 1 shows curves representing the particle size analysis of the different types of aggregates (fine and coarse) (natural and artificial)

The coarse aggregates (natural and artificial) have the similar curves.

2.2 Mixture proportions

The concrete mixtures proportions used, have been determined by ’’Dreux Gorisse’’ method (Daupain and all, 2000).

*. Concrete with natural aggregates:

cement : $350kg/m^3$, sand = 629 kg/m^2 , gravel = 1153 kg/m^3 , water : 197 L/m^3.

*. Concrete with artificial aggregates :

cement : $350kg/m^3$, granulated slag : 445,5 kg/m^3 , crystallized slag : 1154 kg/m^3, water:197 L/m^3.

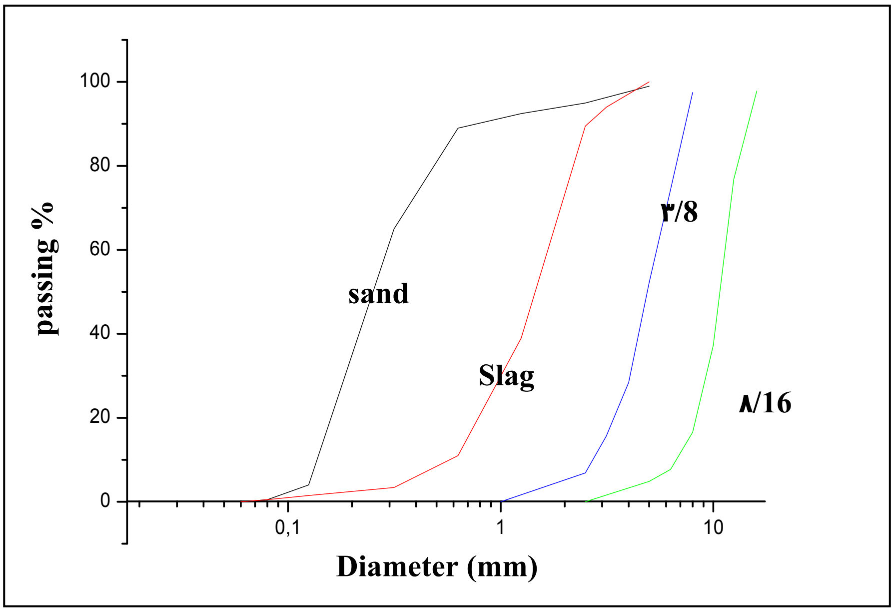

Figure 1. Gradation of aggregates used

2.3 Specimen preparation and conditioning

Compression tests were carried out on 10 x 10 x 10 cm cubes, for the different mixes of concrete.

The specimens were stored in water at 20°C.

Some specimens were heat treated with steam [T° = 60°, H = 95%] (the steam curing cycle was 16 hours). The temperature was then raised from +20°C to 60°C in 2 hours and was kept constant for 12 hours before it was reduced to 20°C in 2 hours.

The mixtures of concrete prepared are presented in (Table 3).

Table 3. Proportions of aggregate fractions in concrete mixtures:

Mixtures	Sand	Granulated slag	Gravel	Crystallized slag
Mixture I	100%	0%	100%	0%
Mixture II	70%	30%	100%	0%
Mixture III	50%	50%	100%	0%
Mixture IV	0%	100%	100%	0%
Mixture V	100%	0%	50%	50%
Mixture VI	100%	0%	0%	100%
Mixture VII	50%	50%	50%	50%

Mixture VIII	0%	100%	0%	100%

3. RESULTS AND DISCUSSION

3.1 The effect of replacement of sand by granulated slag on compressive strength of concrete

Tests carried out on cubes of concrete show the effect of the substituting part of sand by granulated slag (30%, 50%) and the total substitution on the development of compressive strength.

Compressive strength test result at 3days, 7days, 28days, 60days and 5months of hardening are presented in Figure 2.

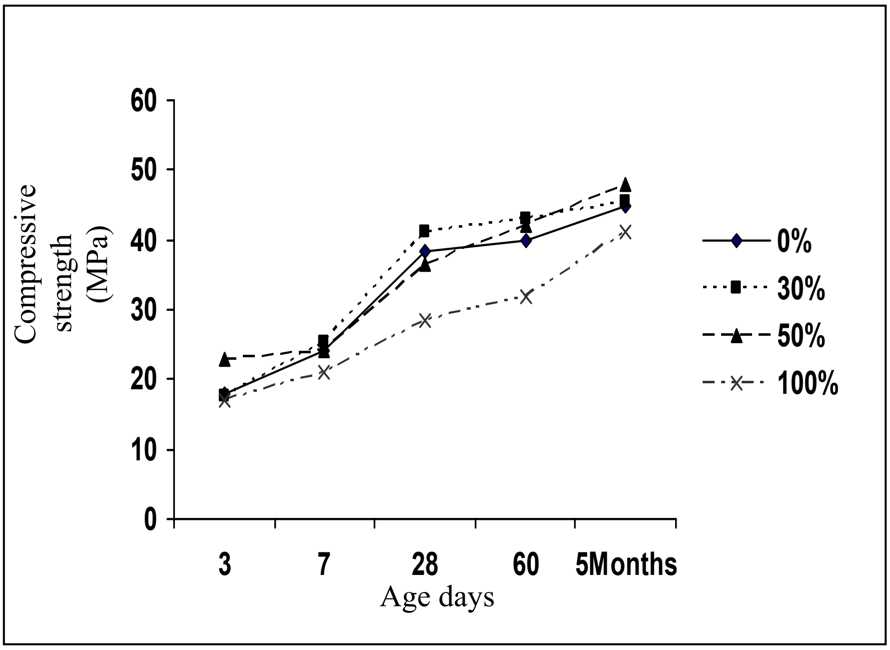

Figure 2. Compressive strength as a function of granulated slag (fine aggregate) percentage

It was noticed that, the compressive strength increases with the age of sample.

We noticed the improvement of strength for the mix with presents 30% of granulated slag, over the reference concrete at all ages.

We noticed an increase in strength at an early age (3 days) for the 50% granulated slag mix and similar strength to the control of at all other ages. The total substitution of sand by granulated slag caused a decrease in strength at early ages out was almost reaching the control at 5 months.

The improvement of compressive strength in mixtures of 30% and 50% of granulated slag is linked to two factors:

- Adjusting of the size particle of the mix (sand and granulated slag) whose fineness modulus is acceptable (≈2,5).

- Finely, slag is a real binder, during the hydration of portland cement the $Ca(OH)_2$ enters in reaction with slag components, forming the CSH, which playing the role of filling empty spaces in binding medium thus reinforcing the concrete structure. (Mezghiche and all, 1999)

3.1.1 The steam curing effect on the strength evolution

The temperature elevation leads to a more active early hydration and promotes the formation of hydrates.

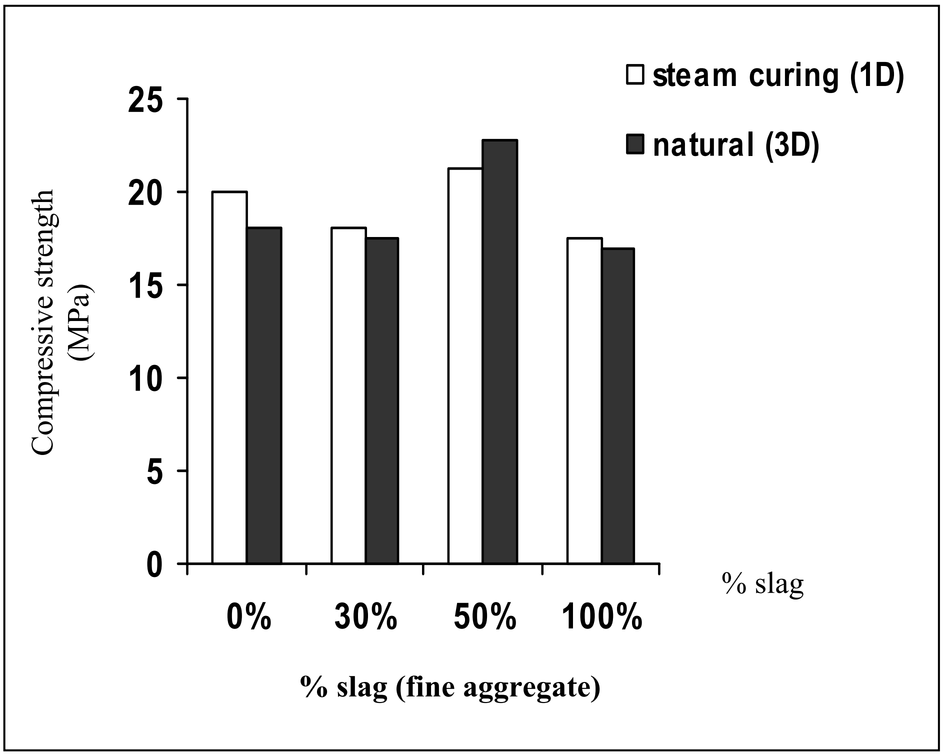

Figure 3. The effect of steam curing on the compressive strength (after 1 day)

In Figure 3 we present the strength at one day on different mixes of concrete cured with steam and compare them with standard curing at 3 days.

The results are almost at the same level, the steam curing used has positive effect on the early development of strength.

3.2 The effect of replacement of coarse aggregate by crystallized slag on compressive strength of concrete

In this part, the substitution of coarse aggregate by crystallized slag is of 50% and 100%.

The compressive strengths are evaluated at 28 days, 60 days and 5 months of age, the obtained results are shown in Figure 4.

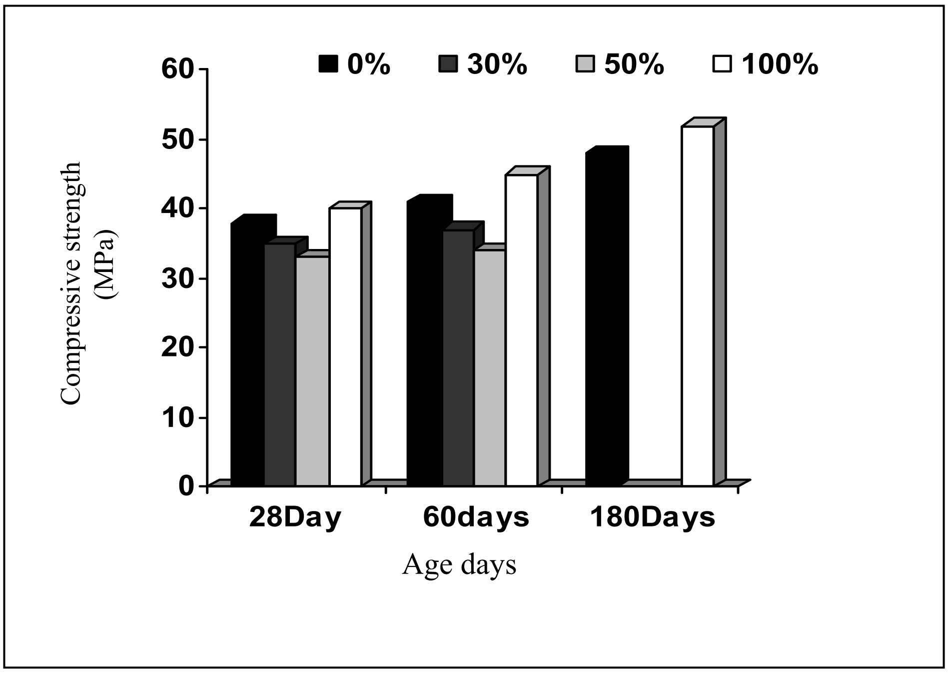

Figure 4. Compressive strength as function a percentage of crystallized slag (coarse aggregate)

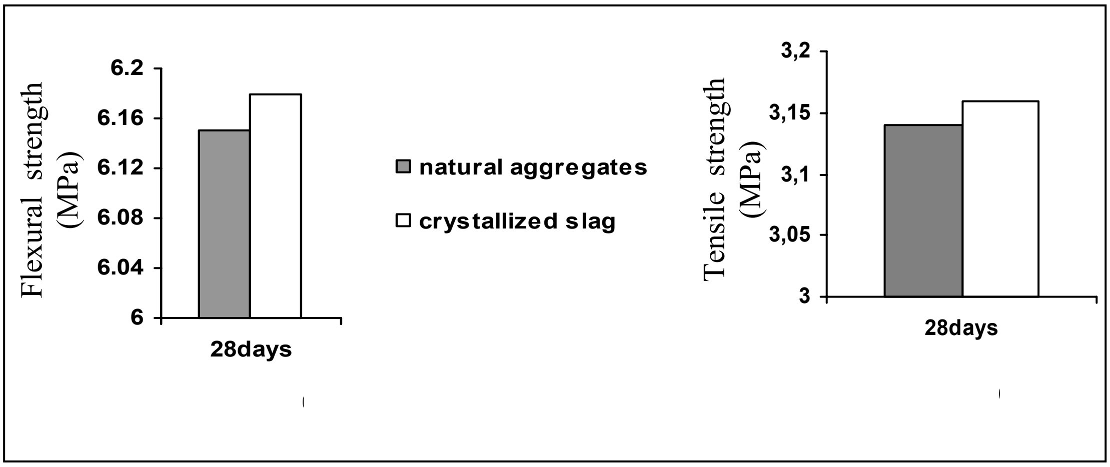

Figure 5. The flexural strength (a) and the tensile strength (b) at 28 days

The partial substitution of natural coarse aggregate with crystallized slag affect compressive strength particularly for a substitution of 50% either at 28 days of hardening or 60days.

This phenomenon can be explained by the non-compatibility of natural and artificial gravels due to their chemical compositions, their physical characteristics are different (elasticity modulus).

The strength improvement is notably observed when concrete is constituted with just crystallized slag at different ages of hardening (which has been already proven by other researchers) (Aitcin, 1966). This improvement is due to good adhesion between the aggregate of the crystallized slag and hydrated paste.

This phenomenon can be explained by:

- The superficial rugosity of slag aggregates.
- Water, witch is absorbed by slag aggregates, at the mixing moment becomes avaible within time to hydrate the grains of anydre cement.

We have to evaluate also the tensile strength and the flexural one for the same type of concrete (100% crystallized slag).

The obtained results are represented in Figure 5.

Owing to its physico-chemical characteristics, its angularity and its cleanliness, the aggregates of crystallized slag ensures to concrete strong bonding between the aggregates and cement .

The obtained results affirm the better adhesion between aggregates of crystallized slag and the paste of cement.

3.3 The effect of substitution of natural aggregates (fine and coarse aggregate) with those of slag

The substitution of the natural aggregates with granulated and crystallized slag is done partially at 50% and totally at 100%.

Compressive strengths at 28 and 60days of natural hardening are presented in Figure 6.

According to these results, we note that partial substitution of natural granular skeleton with an artificial one influences positively the compressive strength whilst on the other hand the total substitution drastically diminishes the strength.

This can be explained by the poor quality of granulated slag as sand (a very coarse sand, and a high degree of absorption).

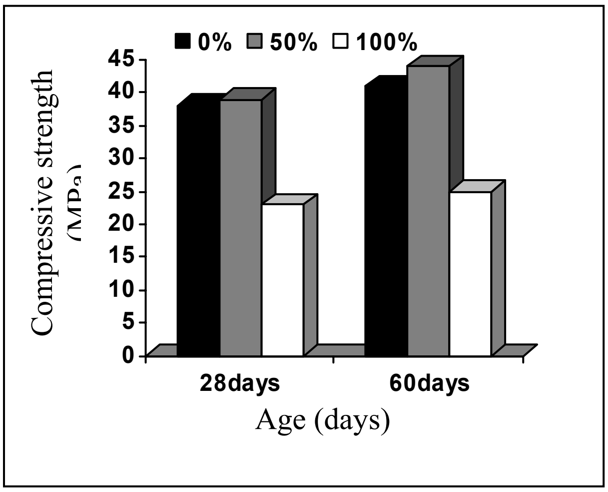

Figure 6. Compressive strength as a function of percentage of slag (fine and coarse) aggregates

4. CONCLUSIONS

This work relates to the usage of the blast furnace slag, a waste cheap material used as fine and coarse aggregates in the concrete mixtures we recommend the approval of the industrial by-product in the following uses in concrete:

- The partial substitution of sand with granulated slag presents a double interest, it results in the improvement of compressive strength at different ages and, at the same time the reduction of stocks of the granulated slag one can correct the very fine sand with the coarser granulated slag material.
- The Algerian crystallized slag is considered better than the average level of natural aggregates concerning its chemical characteristics the state of its surface and its angularity.
- The total substitution of natural coarse aggregate with crystallized slag affects positively the tensile, flexural and compressive strength.
- The partial substitution of natural aggregate with slag aggregates permits a gain of strength at long term.
- The entire substitution of natural aggregates with slag aggregates should be avoided, it affects negatively the strength (a loss in strength of 38%) .

REFERENCES

1. Aïtcin, P.C. Sur les propriétés minéralogiques et l'utilisation dans les mortiers et bétons de laitiers de hauts fourneaux de fonte, Thomas". Publication Technique No. 174, No. 608 et 609, Mai et Juin,1966.
2. Daupain, R. Lanchon, R., and Saint-Arroman, J.C. Granulats, Sols, Ciments et Bétons. Edition Casteilla, Paris, 2000.
3. Lea, F.M. The chemistry of cement and concrete. Chemical Publishing Co., Inc. New York, 1971.
4. Mezghiche, B. Guettela, A. Chebili, R. and Zeghichi, L. Study of the effect of alkalis on the slag cement systems, Proceedings of International Conferences on Modern Concrete Materials, Binders, Additions and Admixtures, Dundee. Scotland. 1999, pp.287-293.
5. Neville, M.A. Propriétés des bétons. Edition Eyrolles, Paris, 2000.
6. Venuat, M. La pratique des ciments, mortiers et bétons. Paris, 1989.
7. Venuat, M. Adjuvants et traitements. Paris, 1984.
8. Zeghichi, L. and Mezghiche, B. L'effet du remplacement de sable par du laitier sur la résistance du béton, *Al Azhar University Engineering Journal*, AUEJ, No. 1 **8**(2005a), January.
9. Zeghichi, L. and Mezghiche, B. Etude des propriétés d'un béton à base des granulats du laitier d'El Hadjar. Congrès International, Réhabilitation Des Constructions et Développement Durable, Alger, 3-4 Mai, 2005b.