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Impact of Blast Furnace Slags as a Substitute Aggregate on the Strength of Hydraulic Concretes

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Abstract: The blast furnace slag comes out of the blast furnace in liquid form at 1500°C. When cooled slowly, in the open air, the crystallized blast furnace slag is obtained. Its uses are generally the same as those of natural rocks. The purpose of this article is to measure the influence of the substitution of Diack basalt aggregates by blast furnace slags (FABRIMETAL slags) on the compressive strength of hydraulic concretes. For this two reference concrete mixtures were used. The first concrete mixture (concrete 1) is mixed with basalt of Diack only, and the second concrete mixture (concrete 5) is mixed with FABRIMETAL slags only. Then basalt substitutions by slags were performed on the concrete 1 at 10%, 25% and 50%. The results obtained showed that slags influence the strength of hydraulic concretes formulated with basalt of Diack by decreasing it. The 28-days compressive strength of concrete 1 drops from 28.8 MPa to 24.8 MPa for 10% substitution, 24.4 MPa for 25% substitution and 21.8 MPa for 50% substitution. However, given the low dispersion of the results obtained (Standard Deviation = 2.28), the substitution of basalt by slag is still possible provided that hydraulic concrete is optimized with additives or a slight cement overdose.

Keywords: Slag, Basalt, Hydraulic Concrete

1. Introduction

From the projects of the National Agency of the Organization of the Islamic Conference (NAOIC), to the current plan of emerging Senegal (ESP), Senegal is experiencing real estate development. This requires a high demand for building materials such as aggregates. With the ban on exploiting the basalts of Dakar and the drying up of Diack's quarries, sources of aggregate are becoming increasingly rare and remote. The use of artificial aggregates is a solution that cannot completely replace aggregate sources, but remains a solution to preserve them. These artificial aggregates include slag aggregates from blast furnaces. The uses of crystallized slag are generally those of natural rocks of the same physico-chemical characteristics: aggregates for concrete, for bituminous asphalt, for severe treated with hydraulic binder, ballast, etc. They are covered by the same standards. The purpose of this article is to measure the influence of the substitution of basalt aggregates by blast furnace slag aggregates on the compressive strength of hydraulic concretes. Several studies have been conducted on the impact of slags on the strength of hydraulic concrete. Indeed, the work of Chaïd et al. [1] showed that the use of 0/3 mm blast furnace slag sand increased the compressive strength (100 MPa) of high-performance concrete as a function of shelf life in selenite water (365 days). The work of Tahar et al. [2] also showed that the use of blast furnace slag powder increased compressive strength. The work of Sadok et al. [3] showed that the compressive strength of cement-based mortars with El Hadjar crushed slag remains low at age fasting, but comparable in the long term compared to a mortar with CEM I. However, It should be noted that for all these studies the slags used are ground. In our study the slag will be used as is without modification. This article will begin with the presentation of the materials used as aggregates, followed by the experimental mix design procedure and compression tests, and finally the analysis and interpretation of the results obtained.

2. Materials Specifications

2.1. Diack's Basalt

The Diack Basalt Quarry is located 37 km southeast of the city of Thies, in the rural community of Ngoundiane, and 80 km east of Dakar. It is a volcanic rock of dark color, with a density close to 3 [4].

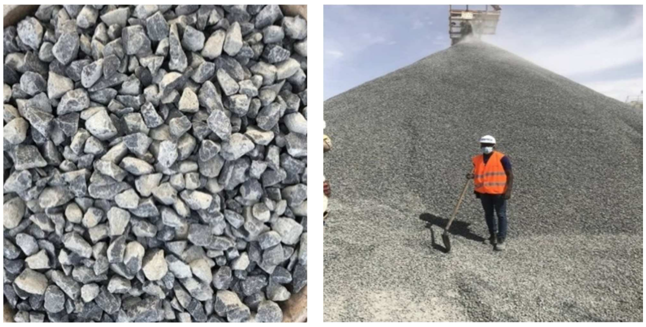

Figure 1. *Diack basalt aggregate.*

The rock is composed mainly of plagioclases and pyroxenes with sometimes other accessory minerals such as olivine. Three types of facies can be distinguished at Diack [4, 5]:

1) a predominantly fine-grained face, mainly represented by basanites (Figure 1);
2) a medium-grained face less abundant than the preceding face;
3) and a coarse-grained face, represented by fully crystallized grained rocks.

2.2. Blast Furnace Slags

The blast furnace slags (Figure 2) used in this study were supplied by FABRIMETAL located in Sébikhotane, Dakar, Senegal. In metallurgy, slags are solid by-products of the melting, refining, processing or shaping of high temperature metals. They are mixtures of various oxides which float over the molten metal, or detach from it when they are applied at high temperatures. In the particular case of iron metallurgy, iron-poor slags are called «slags», iron-free slags in iron metallurgy and ferroalloys. They are by far the most common type of slag [6, 7].

Figure 2. *Blast furnace slags (FABRIMETAL slags).*

The most common modern slags come from the manufacture of steel from non-phosphorous iron ore (blast furnace or converter slags), or from the smelting of scrap in electric arc furnaces. Excluding the production of stainless steels, these steel slags generally have the following composition (Table 1) [8].

Table 1. *Typical compositions of steel slag (as a% of weight) in comparison with Diack basalt [5].*

Slag type	FeO/Fe_2O_3	MnO	SiO_2	Al_2O_3	CaO	MgO	P_2O_5	CrO_3	S
Blast furnace	-	0,1-0,5	33-39	9-13	39-42	6-9	-	-	1,2-1,4
Electric arc furnace	15 - 35	<10	10-20	<10	30-40	<10	<2	<2	<0,25
LD Converter	15 - 35	3-10	9-13	0,5-3	42-52	1-8	1,5-4	~ 2	~ 0,25
Diack basalt type	12,04	0	49,33	13,48	9,69	8,64			0,24 (SO_3)

2.3. The Sand of Beer

Figure 3. *Beer sand.*

The Beer Sand Pit is located in the small town of Cayar, 14°55'35' North and 17°07'23' West. The city is next to the Atlantic Ocean at the junction of the Cape Verde peninsula and the African continent. It is an administrative part of the Thies region, but sixty (60) km from Dakar [9]. It is one of the yellow dunes (semi-fixed dunes), which occupy the background of the white dunes (Figure 3). They extend from Dakar to Saint-Louis, they were set up in the upper quaternary (holocene), precisely in Tafolian by coastal drift phenomena, through the wind and coastal currents allowing the accumulation of sand on the beaches, and pioneer plants, which play a fundamental role, ensuring the fixation and stability of sand that would otherwise be dispersed. These dunes are characterized by their yellow colors (Figure 2), their small size of sand grains and their more or less fixed appearance [10, 11].

2.4. Geotechnical Properties of Materials of Mix Design

For Diack basalt, the fraction of aggregate used are 0/3 mm, 3/8 mm and 8/16 mm. The identification tests covered the sieve analysis [12], the flattening coefficient [13], the absolute density [14], the apparent density [15], the wear resistance MDE [16], the resistance to fragmentation by impact LA [17], the porosity and the absorption coefficient. For Beer sand, identification tests were carried out on the determination of the fineness module from the results of the sieve analysis, the equivalent test [18], the apparent density and the specific weight. Since the fineness module of the Beer sand was weak, a mixture of 50% of basaltic sand and 50% of Beer sand was made. The results of the identification tests on the samples are recorded in Table 2.

Table 2. *Summary table of geotechnical characterizations of aggregates (basalt and sand).*

intrinsic and manufacturing properties	**Aggregates**					**Normative specifications of aggregates**	**Compliance**
	Gravels		**sands**				
	Basalt 8/16 mm	**Basalt 3/8 mm**	**Basalt 0/3 mm**	**Beer sand**	**Basalt 0/3 mm+Beer Sand 50%**		
Flattening coefficient (%)	- 15.86	- 17.07	- -	- -	- -	< 25	Non-compliant Compliant
fineness modulus M*f*	- -	- -	- 2.77	1.036 -	- 1.96	1.8 < MF <2.8	Non-compliant Compliant
Sand equivalent test (Es)	- -	- -	- 65	84	- 71	60 ≤ ES< 80	Non-compliant Compliant
Gravel surface cleanliness. P (%)	- 0.080	-	- -	- -	- -	≤ 5	Non-compliant Compliant
Micro-Deval coefficient (MDE)	- 15.5	- 15.7	- -	- -	- -	< 20	Non-compliant Compliant
Los Angeles coefficient (LA)	- 10.7	- 17.06	- -	- -	- -	< 25	Non-compliant Compliant
Water absorption coefficient WA24 (%)	- 0.28	- 0.82	- -	- -	- -	≤ 2.5	Non-compliant Compliant
Bulk volumetric mass (kg/l)	1.670	1.562	1.701	1.520	1.762	-	-
Intergranular porosity	0.422	0.449	0.391	0.394	0.317	-	-
Specific volumetric mass (kg/l)	2.894	2.836	2.793	2.427	2.583	-	-

For FABRIMETAL slags the granular classes used are 0/3 mm. 8/16 mm and a mixture of 50% of slags (0/3 mm fraction) and 50% of Beer sand. The identification tests were based on the same tests as Beer's basalt and sand. The results of the identification tests on the samples are recorded in Table 3.

Table 3. *Summary table of geotechnical characterizations of slags and mixing with Beer sand.*

Intrinsic and manufacturing properties	**Aggregates**			**Normative specification of aggregates**	**Compliance**
	Gravel	**Sand**			
	Slag 8/16 mm	**Slag 0/3 mm**	**50% Slag 0/3 mm 50% Sand of Beer**		
Flattening coefficient (%)	6.40	-	-	< 25	Compliant
Fineness modulus M*f*	-	3.828	- 2.308	1.8 < MF < 2.8	Non-compliant Compliant
Sand equivalent test (Es)	- -	87 -	- 75	60 ≤ ES< 80	Non-compliant Compliant
Micro-Deval coefficient (MDE)	- 7.7	- -	- -	< 20	Non-compliant Compliant
Los Angeles coefficient (LA)	30.68 -	- -	- -	< 25	Non-compliant Compliant
Water absorption coefficient WA24 (%)	- 1.88	- -	- -	≤ 2.5	Non-compliant Compliant
Bulk density (kg/l)	1.597	1.77	1.84	-	-
Intergranular porosity	0.436	0.428	0.305	-	-
Specific density (kg))	2.836	3.076	2.65	-	-

Based on the results of the geotechnical characterization tests of the aggregates. we noted that the sands we had collected do not comply with the specifications in terms of fineness module (M*f*) and sand equivalent (ES). This is the reason why we try to mix each of them with the fraction 0/3 mm of basalt (basalt sand). The mixture was made to proportions of 50% basaltic sand and 50% dune sand in order to make adjustments on the fineness module and the sand equivalent to have values that fall within the range of the normative specifications. Thus. we find that the mixture of 50% of Beer sand with 50% of basaltic sand gives values of ES and M*f* according to specifications. For this reason. in the mix design studies of hydraulic concrete. Beer sand was used (improved with 50% of basalt sand). And it is in this same logic that the fraction of 0/3 mm of slag was used to make an improvement of Beer's sand when formulating with slag and sand. For slag the special features that are to be noted on the results are:

1) absorbs more water than basalt (1.88% versus 0.08% for basalt);
2) its resistance to dynamic fragmentation is low compared to basalt (LA=30.68 versus LA=10.7);
3) its sand equivalent is not compliant but in the right because it is cleaner than basalt (ES=87 against ES=84 for Beer sand).

Thus. with slag concretes we will not necessarily expect better resistance results than basalt. However. the contribution on physicochemical performance is not to be neglected. The following mix design studies will help us understand the impact of slag.

3. Mix Design Method

The mix design method used is Dreux-Gorisse method [10]. Tables 4. 5. 6. 7 and 8 present the proposed mixtures including:

1) Concrete 1: table 4 the reference mixture with basalt (fraction 3/8 mm and 8/16 mm) and sand mixture (50% of Beer sand and 50% of fraction 0/3mm of basalt sand);
2) Concrete 2: table 5. 10% substitution;
3) Concrete 3: table 6. 25% substitution;
4) Concrete 4: table 7. 50% substitution;
5) Concrete 5: table 8 the slag formula (8/16 mm) and sand mixture (50% of Beer sand mixed with 50% of fraction 0/3 mm of slag).

Table 4. *Concrete 1: Reference mixture with basalt (fraction 3/8 mm and 8/16 mm) and sand mixture (50% of Beer sand and 50% of fraction 0/3 mm of basalt sand).*

Reference mixture with basalt (fraction 3/8 mm and 8/16 mm) and sand mixture (50% of Beer sand and 50% of fraction 0/3 mm of basalt sand)					
Components	**Mass/ m³**	**Mass for six test pieces (kg)**	**Required collapse of concrete (cm)**	**Collapse obtained from concrete (cm)**	**Water used (liter)**
Basalt 8/16 mm	814.0	38.269			
Basalt 3/8 mm	447.2	21.024			
Basalt 0/3 mm (50%) + sand (50%)	635.9	29.896	6	6	7.9
Cement	375.0	17.6			
Water	166.0	7.8			

Table 5. *Concrete 2: Mixture with a substitution of 10% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3mm).*

Mixture with a substitution of 10% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3mm)						
Components	**Mass/ m³**		**Mass for six test pieces (kg)**	**Required collapse of concrete (cm)**	**Collapse obtained from concrete (cm)**	**Water used (liter)**
Basalt 8/16 mm	Basalt 90%	732.6	34.44			
	Slag 10%	81.4	3.826			
Basalt 3/8 mm	447.2		21.024			
Sand	317.95		14.948	6	6	8.8
Basalt 0/3 mm	Basalt (90%)	286.15	13.453			
	Slag (10%)	31.795	1.494			
Cement	375		17.6			
Water	166		7.8			

Table 6. *Concrete 3: Mixture with a substitution of 25% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3mm).*

Mixture with a substitution of 25% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3mm)						
Components	**Mass/ m³**		**Mass for six test pieces (kg)**	**Required collapse of concrete (cm)**	**Collapse obtained from concrete (cm)**	**Water used (Liter)**
Basalt 8/16 mm	Basalt (75%)	610.5	28.7			
	Slag 8/16 (25%)	203.5	9.567			
Basalt 3/8 mm	447.2		21.024			
Sand	317.95		14.948	6	6	9
Basalt 0/3 mm	Basalt (75%)	238.463	11.21			
	Slag (25%)	79.487	3.74			
Cement	375		17.6			
Water	166		7.8			

Table 7. *Concrete 4: Mixture with a substitution of 50% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3 mm).*

Mixture with a substitution of 50% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3mm)						
Components	**Mass/ m³**		**Mass for six test pieces (kg)**	**Required collapse of concrete (cm)**	**Collapse obtained from concrete (cm)**	**Water used (liter)**
Basalt 8/16 mm	Basalt (50%)	407	19.135			
	Slag (50%)	407	19.135			
Basalt 3/8 mm	447.2		21.024	6	6	9.2
Sand	317.95		14.948			
Basalt 0/3 mm	Basalt (50%)	158.975	7.474			

Mixture with a substitution of 50% of basalt (fraction 8/16mm and 0/3 mm) by slag (fraction 8/16 mm and 0/3mm)						
Components	**Mass/ m³**		**Mass for six test pieces (kg)**	**Required collapse of concrete (cm)**	**Collapse obtained from concrete (cm)**	**Water used (liter)**
	Slag (50%)	158.975	7.474			
Cement	375		17.6			
Water	166		7.8			

Table 8. *Concrete 5: Reference mixture composed of 50% of fraction 8/16 mm of slag and sand mixture (50% of Beer sand and 50% of fraction 0/3mm of slag).*

Reference mixture composed of 50% of fraction 8/16 mm of slag and sand mixture (50% of Beer sand and 50% of fraction 0/3 mm of slag)					
Components	**Mass/ m³**	**Mass for six test pieces (kg)**	**Required collapse of concrete (cm)**	**Collapse obtained from concrete (cm)**	**Water used (liter)**
Slag 8/16	1216.3	57.183	6	6	10
Slag 0/3 (50%) + Sand (50%)	609.0	28.631			
Cement	375.0	17.6			
Water	229.8	10.8			

4. Analysis and Interpretation of Results

Figure 4 shows the results of compression tests on cylindrical test pieces [19] of the different concretes studied at 7 days and 28 days. Based on the analysis of the results of the various concrete tests studied (Mix design and compression tests on cylindrical test pieces). we can say that the reference mixture of basalt and Beer sand (concrete 1), gives satisfactory results for concrete C25/30 [11, 19]. This concrete 1 will be used in this research as a comparison since most concrete structures in Senegal use basalt as aggregate. Following the substitutions carried out. it was observed that the results of the 7-day and 28-day compression strength tests of 16 x 32 cylindrical test pieces decreased with the increase in the percentages of substitutions (Figure 4).

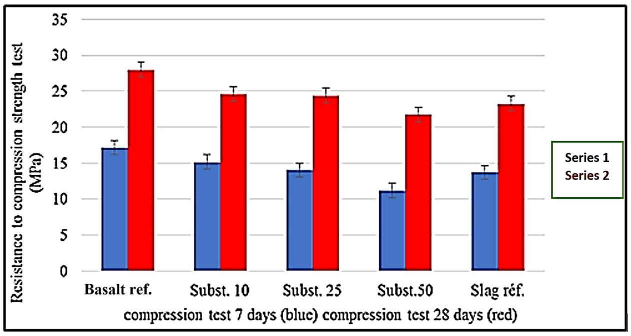

Figure 4. *Evolution of resistance as a function of the rate of substitution of basalt by slag.*

For concrete 5 representing the reference slag mixture. the results are superior to those of the 50% substitution. which may be explained by the fact that the slag has a defect of adhesion in relation to basalt aggregates. However. the explanation may be sought in further studies on adhesion to the scale of mineralogical composition or surface properties. Table 1 showed that Diack basalt and slags have the same chemical compositions except for MnO. P_2O_5 and CrO_3. On the other hand. slags are less resistant to shocks and absorb more water. However. the binding properties of chemical compounds may be different within each material (basalt. slag). Depending on the physical and chemical properties of the slag. it is similar to slag or pumice. hence its name metallic slag. The material is smooth. light and vacuolar (cavity presence). So, the mortar can incorporate cavities. This explains that with concrete 5. the results are more satisfactory than with 50% substitution. It is also important to note that slags which are more porous than other materials. will require greater amounts of mixing water in their formulation depending on the percentages of substitutions (from 50% substitution. about 28% water). This increase in water quantity can be elucidated by the water absorption test (Tables 2 and 3). It is also important to note that slags which are more porous than other materials. Will require greater amounts of mixing water in their formulation depending on the percentages of substitutions (from 50% substitution. about 28% water). This increase in water quantity can be elucidated by the water absorption test (Tables 2 and 3).

5. Conclusion

The objective of this study was to investigate the influence of slag on concrete. but also and above all to have an idea of the geotechnical characteristics of the material in order to be able to correlate with the results found for interpretation. Thus in conclusion we can say that the slags. slightly decrease the strength of the hydraulic concrete according to the results obtained. However. the exact explanation of the cause of this decrease seems to require further study. However. we must not lose sight of the fact that this material (slag) does not have satisfactory results in terms of resistance to fragmentation. but its use in hydraulic concrete formulations is appreciable for certain structures.

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