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Improving the Behaviour of Roads underlays by the Use of Industrial waste (Blast furnace slag)

H. Hadidane [1], H. Oucief [2], M. Merzoud [2*]

[1,2]*Laboratory Materials Geomaterials and Environment, Badji Mokhtar University, Annaba,(LMGE, UBMA) BP 12, Annaba 23000, Algeria*

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hocinehadidane@gmail.com
Phone: (+213) 664641856

Abstract
The accumulation of industrial wastes stemming from the iron and steel industry has had a negative influence on the environment. The adopted procedure aimed to eliminate these undesirable wastes through recycling them by utilizing them in appropriate areas. The objective of this work is to study the mechanical behaviour of a gravel–slag mixture based on crystallized and granulated slag activated by lime. The resistance to punching and the bearing ratio of this slag are studied through Proctor, California Bearing Ratio CBR, compression, and tensile tests for use in the layers of pavement (foundation and base layers). The obtained results of the gravel–slag mixture show very good performances compared with natural aggregates with regard to the resistance and thickness of the layers. The mixture's utilization in the road area has therefore allowed the recycling these industrial wastes, decreasing pollution, and using a minimum product requiring important energy and an economy on layers of surface realized with costly materials (bituminous concrete).

1. Introduction
In recent years studies concerning the environmental quality have shown that the steel industry is one of the industries whose activity involves significant consumption of natural resources and energy, is also generating waste that due to the valorization potential can be transformed into byproducts [1].
Blast furnace slag is an example of this waste since it comprises co-products of the manufacture of cast iron that come in two forms: granulated and crystallized slag. These products are available in large quantity in heaps that have altered the landscape and thus disturb the environment. In Algeria, the annual production of Blast furnace slag is estimated at 500.000 tons per year and finds only a few applications in cement. These slags can be used in the field of public works, in this sector, slag products are an alternative to natural alluvial resources.
According to the Technical and Promotion Center for Steel slag, the production of crude steel reached 200 million tons in 2015, five million tons of slag were produced in France [7]. These figures represent 16% of world output and make EU the second biggest producer behind China.
The total amount of Steel Furnace Slag (SFS) that is produced annually in Europe is around 30 million of tons (15% of steel production).
Around 75% of this SFS is black slag. All this black slag could be used as a new recycled aggregate for the construction and renewal of railways lines [2].
The recovery of blast furnace slag is not currently subjected to national rules regarding the use and protection of the environment. Moreover, the public works management is implementing a national action plan to encourage research in this direction [3].
The main objectives of this study are to characterize the materials used in the manufacture of gravel slag and to study the mechanical properties of mixtures to deduce the best formulation that presents a reasonable balance between the strength and the percentage of blast furnace slag.
The results are important, not only economically but also environmentally, by paving the way for the use of large quantities of Industrial waste (Blast furnace slag) Stored in nature.

2. **Materials**

2.1. *Gravel–Slag*

Gravel–slag is a mixture made by mixing in a Central continues: natural reconstituted gravel 0/20, crushed slag, granulated slag 0/5, and an activating agent (lime) with optimum water content [2][10].

2.2. *Crushed Gravel*

Crushed gravel 0/20 comes from the career of Guelma (Algeria). The mode of operation used is the slaughter of massive laminated using explosives. Laboratory results have shown that the aggregates have average resistance values. So these are good materials for use in road building [4].

2.3. *Crushed Slag (Crystallized) 0/20*

The liquid slag at 1300 °C or 1500 °C is discharged immediately into slag pockets, directly from the blast furnace, to be poured into the pits, one cast after another. They cool slowly, turning into hard artificial rock. The crystallized slag, which is chemically stable, is intended to be crushed to obtain crystallized slag aggregates [4].

2.4. *Crushed Granulated Slag 0/5*

The fragmentation of liquid slag grains of granular glass structure 0/5 by sudden quenching in water is the process called "granulation". This product results from passage through a mill and is used to correct the lack of fine elements in the mixture, to better position its granulometry on the axis of reference, And for their hydraulic reactivity which activates granulated slag [2].

2.5. *Lime*

Quicklime has a density of about 0.9 t/m3 and particle sizes at the outlet of the oven of 0 to 50 mm and 2 to 50 mm, changing to 12.5 to 50 mm and 0 to 12 mm after screening.

- The CaO content is greater than 95%.
- The S content is less than 0.05%.
- Reactivity (ASTM) for 2 minutes [4].

3. Experimental Methodology

The study involves several steps. Physical and chemical characterization is performed. The components necessary for the formulation of a road are identified and then the performance of the mixtures is investigated through mechanical tests [5].

3.1. *Physical Properties of Materials Used*

The physical properties are shown in Table 1 according to the standards EN 1097-6 and EN 933-8 [6,7].

Table 1: Physical Properties

	Density Bulk [g/Cm3]	Absolute Density [g/Cm3]	Sand Equivalent (%)	Impact Resistance
Crushed Slag 0/20	1.539	2.686	79.757	28.58
Gravel Crushed 0/20	1.812	2.549	78.183	21.44
Granulated Slag 0/5	0.733	2.712	97.907	----------
Crushed Granulated Slag	1.317	2.941	98.902	----------

According the table1 we note that absolute density of crushed granulated slag is superior than other materials, because is ground and contains fine elements of the order of 0.8μ. This fineness make the apparent mass of the latter, increase than other materials this can increase its absolute density.

3.2. *Chemical Composition of Materials Used (NF EN 1744-1 + A1) [8]*

The chemical composition of the slag depends on the iron blast furnace charge. It is adjusted to allow the removal of harmful components in the operation of the blast furnace and the quality of melting. The basicity index values of both slags are greater than unity, which shows that they are basic in nature. The one used in our study is of the order of 1.12 (Table 2).

Table 2: Chemical Composition of the Materials Used

Oxide (%)	CaO	SO3	SiO_2	Al_2O_3	MgO	$CaCO_3$	Mn_2O_3	KO	PO_5	TiO_2
GC	42.10	–	4.62	1.68	–	51.69	–	–	–	–
LG	45.88	0.48	34.99	9.79	3.92	–	2.67	0.96	0.01	0.34
LC	46.6	5.1	–	3.85	40.53	–	2.59	0.07	0.23	0.05

3.3. *Mechanical Tests*

The mechanical tests were carried out on samples, according to the standards NF EN 1097-2 §5 and EN 1097-1 [9,10].

Table 3: Los Angeles, Dynamic Fragmentation, and Micro-Deval Tests

Material	Los Angeles (LA) (%)	Dynamic Fragmentation (DF) (%)	Micro-Deval Dry (%)	Micro-Deval Damp (%)	Specifications
Crushed Gravel 0/20	23	25	5	17	LA ≤ 25% DF ≤ 25% MDE ≤ 20%
Crushed Slag 0/20	24	22	4.4	20	

The laboratory results showed that the aggregates have mean resistance values of 23–24% (Los Angeles) and 17–20% (damp Micro-Deval). So they are good materials that are acceptable for use in road building.

4. Composition of the gravel–slag

4.1. *Composition*

The mixtures used in this study include three formulations of various percentages. These formulas require a catalyst of ground granulated slag with lime to correct and improve the performance of the mixture, which is composed of crushed gravel (natural) 0/20, crushed slag 0/20, granulated slag 0/5, comminuted granulated slag, and lime.

The choice of these formulations has been prepared so as to be in the axis of reference in accordance with CTTP (Guide for the Rehabilitation of Roads: 2nd edition) [11].

4.2. *Selection of the Formulation*

In the study of the formulation of gravel slag, it is necessary to develop sufficiently efficient gravel slag formulas to be used in road foundations. Thus to an economy on natural products used. To this end, the particle size has a significant effect on the mechanical properties of the materials. The gravel–slag proposed in this study must have a continuous granularity characterized by two factors:

-The maximum size of the elements of D = 20 mm results in a homogeneous mixture, which facilitates mixing and reduces segregation [11].

-The axis of reference of the gravel–slag 0/20 [11], defines the area in what must be the axis of the mixture, whose average size curves appear in figure 1. [12-14]

4.3. *Determination of Formulations*

The solutions adopted for the crushed gravel and slag are as follows:

First Formula

10% crushed gravel 0/20
75% crushed slag 0/20
15% granulated slag 0/5

Second Formula

20% crushed gravel 0/20
70% crushed slag 0/20
10% granulated slag 0/5

Third Formula

40% crushed gravel 0/20
55% crushed slag 0/20
05% granulated slag 0/5

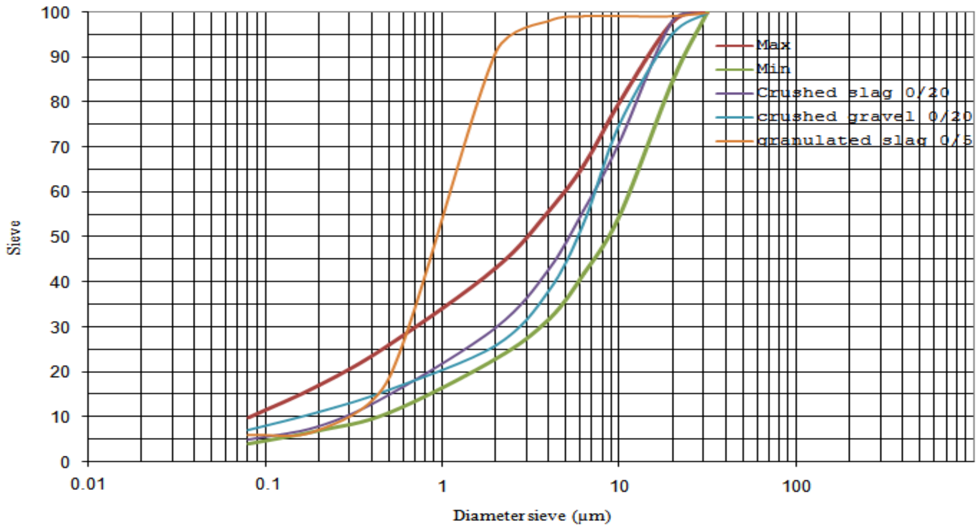

Figure 1: Axis Regularity of the Mixture

5. **Mechanical behaviour of selected formulation**

5.1. *Proctor test (NF P 94-093)*

The purpose of the test is to determine the optimum water content for compaction of the selected formulations. The tests were performed using a California Bearing Ratio (CBR) mold and the mass of the modified Proctor test, in order to find the optimum water content and maximum dry density. [15]

The results of the proctor test on the reference material (crushed gravel 0/20) give a dry density 2.10 kg/cm^3 for an optimum proctor w% = 7.5%. Figure 2 shows the variation in dry density as a function of the water content.

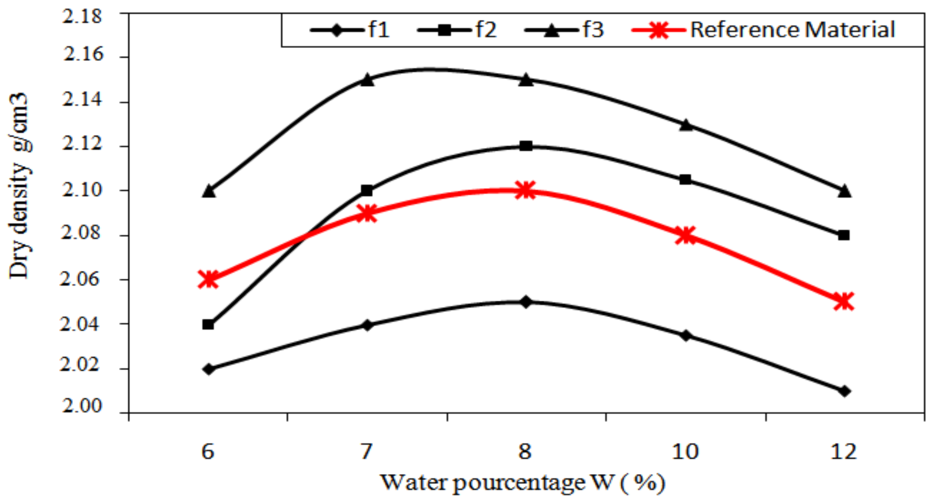

Figure 2: Proctor Curves F1. F2 and F3

On reviewing the results of the modified Proctor test, it is found that the dry density of the three mixtures varied from 2.05 to 2.15 g/cm3 for an optimum Proctor varied between 7 and 8% (See Fig 2). We also note that the last two formulations have a dry density greater than that of the reference material.

Compared with the reference material, The first formulation has a lower dry density, Which requires to improve its dry density by the compaction in order to enhance the compactness of the material.

5.2. *California Bearing Ratio (CBR) test (NFP 94-078)*

The CBR index is the result of a mechanical test for characterizing the load-bearing capacity of soil. It is determined from the extent of depression of a standard peak in a specimen compacted by mass of the modified Proctor The higher this index, the better the behavior of the soil. [15]. Figures 3, 4 and 5 show the evolution of the pressure of three formulations by different compaction energy (10. 25 and 56 shots) depending on the depression of the tip. From the figure 3, we can see that for the first formulation, when the compaction energy varies between 10 and 25 shots, the pressure changes from 110 to 180 kgf/cm^2, showing the importance of compaction for good punching resistance.

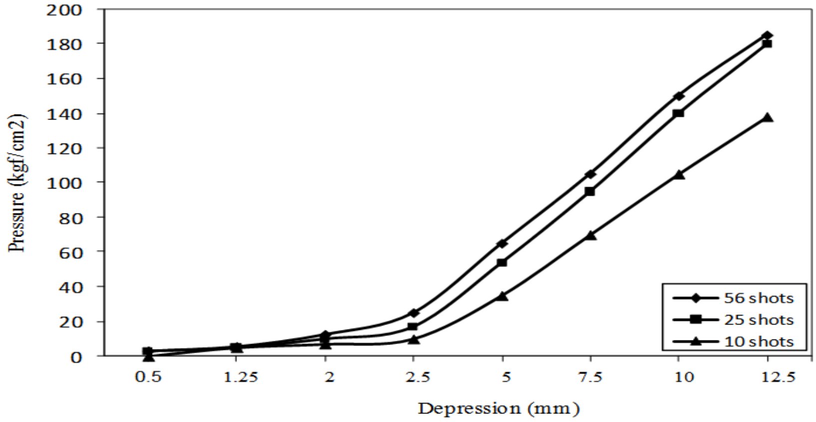

Figure 3: CBR curve of formulation 1 measurements

For the second formulation, the compaction energy remains significant because of its slag content.
For the third formulation, which has a low percentage of slag, we note that for a compaction energy varying from 10 to 56 shots, the pressure is low compared to the first two formulations. Note that the more the percentage of slag increases, the more important the punching force becomes. This explains the role of slag in improving the behaviour of the gravel slag with regard to deformation.

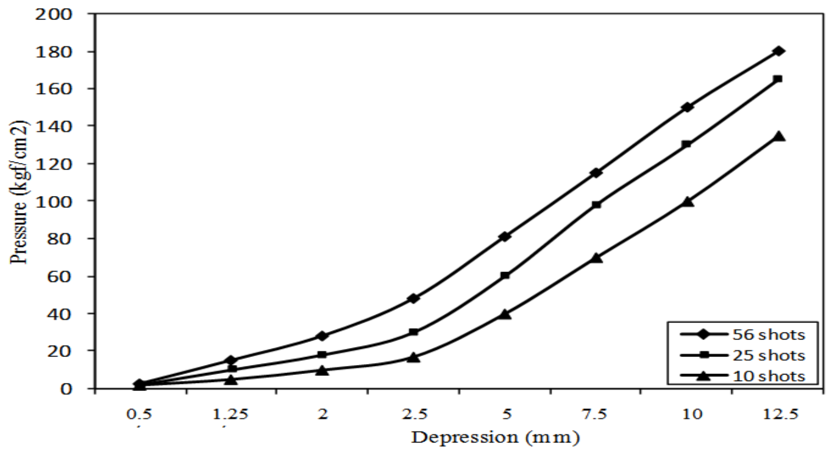

Figure 4: CBR curve of formulation 2

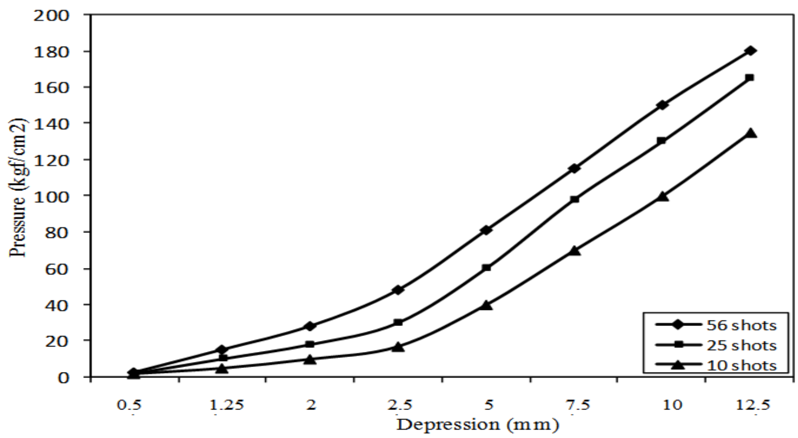

Figure 5: CBR curve of formulation 3

5.3. *Making of Test Specimen (NF EN 12390-2)*

Preparing the material has optimum water content obtained by the modified Proctor (MP) each corresponds to a given formula (to study) [16]:

• The first mixed formulation has a water content of W1 = 8%.
• The second mixed formulation has a water content of W2 = 7.75%.
• The third mixed formulation has a water content of W3 = 7.2%.

The specimens were made with the CBR mold. The material is compacted into five layers, each receiving 56 blows by the mass of the modified Proctor test. The manufactured specimens are kept in their molds for 24 hours so that the catch occurs, allowing the removal of the specimen for preservation.

5.4. *Evolution of Compressive Strength as a Function of Time*

From figure 6, it can be seen that the slag hydration indicated a good evolution of the three formulations from 7 to 14 days. Beyond 14 days, there was a second smaller hydration, and after 28 days the development of resistance was considerable in the first formulation and modest for the other two. The first composition allowed proper hydration in the long run with a jump of resistance very clear increment of resistance, whereas hardening remains slow for the second and third formulation beyond 90 days.

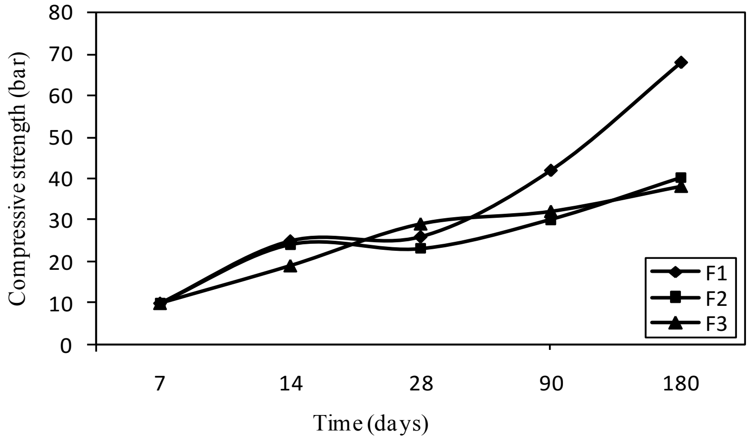

Figure 6: Compressive strength as a function of time

5.5. *Evolution of Tensile Strength as a Function of Time* [*17, 18*]

From Fig 7, it can be seen that the tensile strength of crushed samples after 90 days is similar to those of the first and second formulations. This step is very important and characterized with good stabilization of the hydration of slag for a curing time of 7 to 180 days. The graph shows a low strength of the third formulation compared to the other two. It is important to note that the best behaviour the second formula in 7 to 90 days and the evolution of Tensile strength of the first formula near the second, for a curing time varies between 90 and 180 days.

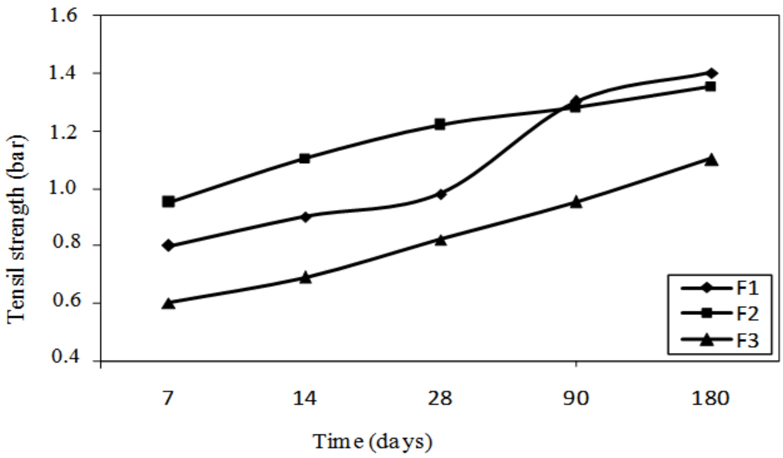

Figure 7: Tensile strength as a function of time

Conclusion

Based on the results of the laboratory tests, the following conclusions were made:

-Treatment with granulated slag is technically very interesting for the development of local materials and construction of the bases layers of roads.

- Improving the CBR bearing layers of processed slag is caused by an improvement in puncture resistance that allows them to better withstand loads induced by traffic.

-These results confirm the physical role of granulated slag, which consists in filling the voids between the grains of the mixtures tested. This filling increases the compactness of these mixtures and therefore their mechanical strength.
-Slags studied possess physical and mechanical properties which are comparable with the characteristics of natural aggregates usually used in the Road infrastructure;
-The success of techniques for gravel slag is related to its hydraulicity and the curing time according to the percentage of crushed and granulated slag;
-According to the formulations obtained, it allows a good long-term catch, which facilitates curing and setting of the mixture used in layers of road by compaction under traffic and immediate exploitation, which is favourable in relation to the cracking that can occur with abrupt exothermic reactions;
-The results are decidedly satisfactory for all the mix with the slag, with good values of Mechanical behaviour , without penalisation in terms of densification and workability of the mixes;
-The mixes with slag have been characterised by a low water damage so demonstrating a good durability;
In conclusion, the experiments have verified that the use of waste material from steel production (Blast furnace slag) in the layers of pavement is a technically satisfactory option that fulfils the spirit of the ‘‘Zero Waste’’ target, that the iron and steel industry has been aiming for in the last decade.

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