DOI: 10.29202/nvngu/2018-1/22

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INDUSTRIAL APPLICATION OF BLAST FURNACE SLAG AS A SUBSTITUTE FOR SAND AT THE CEMENT PLANT OF HADJAR-SOUD (ALGERIA)

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ПРОМИСЛОВЕ ЗАСТОСУВАННЯ ДОМЕННОГО ШЛАКУ В ЯКОСТІ ЗАМІННИКА ПІСКУ НА ЦЕМЕНТНОМУ ЗАВОДІ ХАДЖАР-СУУД (АЛЖИР)

Purpose. This study is conducted on the use of industrial waste (blast furnace slag) from the El-Hadjar steel plant located in eastern Algeria. The research aims to understand the behaviour of the addition of Slag as raw material (replacing sand) in the preparation of the mixture before baking in the rotary kiln at the Hadjar-Soud cement plant in Skikda.

Methodology. The representative samples taken from the cement plant site are subjected to grinding of the mixture of limestone, slag, clay and iron ore, the material prepared at a grain size of less than 50 μ is subjected to a physicochemical characterization. The prepared sample is placed in a furnace with a temperature of up to 1450 °C.

Findings. The results obtained during the tests show that the addition of slag into the raw meal does not affect the chemical or mineralogical composition of the clinker. However, the clinker obtained reveals significant results and meets the Algerian standard NA 442 2000 (CPJ CEM II/A 42.5). The addition of slag to replace the sand has allowed us to reduce the annual CO_2 emission rate by about 17.5 %, and contributes to the reduction of pollution.

Originality. The originality of this work is the preparation of the raw cement meal, based on slag (already decarbonated material) instead of sand. As a rule, for the production of cement clinker, the proportion of the raw materials is: limestone (77–80 %), clay (16–18 %), iron ore (1.5–3 %) and sand (2–4 %). In the present work, the proportions for the production test of the slag-based clinker are respectively: limestone 70 %, slag 9 %, clay 19.2 % and iron ore 1.8 %. The estimate of the annual CO_2 emission rate in the cement plant was carried out by the Software (GEMIS 4.7).

Practical value. The process for obtaining slag-based clinker (steel waste) is probably of great importance for the production of cement for several reasons: the production of one tonne of Clinker at a minimum cost, along with management of non-renewable natural raw materials, such as sand and limestone deposits, and work towards sustainable development.

Keywords: *Algeria, Hadjar-Soud cement plant, slag, environment*

Introduction. Cement is an industrial material, produced from a mixture of raw materials including limestone, and clay. Several types of cements such as Portland cements, cements of blast furnaces, and others, are obtained by means of a baking process which combines these raw materials at 1450 °C in a rotary kiln.

In the case of Hadjar-Soud cement plant, located in the Wilaya of Skikda in the north-east of Algeria; the composition of the raw remains in defining proportions: limestone $CaCO_3$ (77 to 80 %); clay Al_2O_3 (16 to 18 %); SiO_2 sand (2–4 %); iron ore (1.5 to 3 %).

Cement that is mainly composed of blast furnace slag and Portland cement has been marketed in China for more than 20 years and makes about 40 % of the total production of steel slag; this type of cement has the advantages of higher cost of abrasion resistance, a decrease in the evolution of hydration heat and later development of strength, but the disadvantage is that with the longer setting time the initial resistance is lower, so the CaO content of steel slag can cause volume expansion problems.

In the blast furnace, in addition to the iron ore and the coke, a flux, generally based on lime, is introduced in order to lower the melting point of the gangue and thus allow the ore to be extracted at a temperature of 1400 at 1500 °C [1].

The oxides of the filler not transformed into metal constitute the slag; it is evacuated from a blast furnace in the liquid state to the melting temperature of the matrix separating the melt by difference in density. According to the corresponding cooling process, two types of slag are obtained; the granulated slag (vitrified) during sudden cooling (case studied) and the rock slag (crystallized) resulting from slow cooling.

So, slag is a by-product of the transformation of iron into steel, it has differences in chemical composition depending on raw materials and process. Fifty million tonnes/year of steel slag are produced as industrial waste in the world [2], at present; cement plants use slag as an addition to gypsum in cement after firing, in order to improve the cement characteristics and to increase the production of cement products.

According to the Global Carbon Project [3], 36 billion tonnes of CO_2 were emitted to the atmosphere in 2013 due to the burning of fossil resources (oil, gas, coal) and cement plants. For the cement production industry 0.7 Mt CO_2 year for a cement plant-type producing 1000000 t/year (0.7 t of CO_2 per tonne of cement), the assessment of the various environmental impacts reveals that the combustion of the natural gas (CH_4) contributes to the cooking of meal in the rotary kiln, so the decarbonation phase of limestone contributes greatly to global warming by formation of greenhouse gases (GHG).

To this end, the aim of this study is to investigate the behaviour of blast furnace slag as a substitute for sand in the natural raw material mixture. It is, thus, part of the concept of sustainable development applied to blast furnace slag; this concept leads us to favour a mode of production and management that reserves for non-renewable natural resources for future generations, and, in addition, it also participates in the reduction of greenhouse gas emissions in the environment, including CO_2.

Methods and Materials. ***Preparation of raw meal.*** The representative samples of the tests for the production of slag-based cement clinker are provided by the Hadjar-Soud Cement plant, (Skikda, Algeria). The chemical composition of the raw materials is presented in Table 1.

To realize the essay of preparation of the raw meal, a mixture of four samples (limestone, clay, slag and iron) is carefully weighed with an electronic balance, then pulverized by a disk crusher to (Retesch RS200 type), the disk crusher plays the role of a perfect Homogenizer of four elements, the size grading must be lower than 50 μm and the rate of humidity does not exceed 5 %.

Afterward, the obtained mixture undergoes an analysis by X-ray fluorescence (XFR) of Bruker AXS S8 LION type. The operation of dosage must be repeated until obtaining values limiting the percentage of certain elements in the raw mixture (CaO, Al_2O_3, Fe_2O_3, and SiO_2).

The chemical composition of raw meals, prepared according to the optimal proportions of raw materials, is recapitulated in Tables 2 and 3. To determine the performances of cement, a calculation of modules of raw meals was realised.

Production of clinker. For the production of the clinker with and without slag [4], two samples of the raw meal were prepared according to the percentage indicated in Table 2, the applied process of baking is the same for the production of both types of clinker, the time of staying of meal inside the kiln is 60 min.

After drying in an oven at 110 °C, the samples were placed inside the oven at 500 °C (type carbolite RHF 16/8, temperature max 1600 °C), the temperature was increased

Table 1

Results of chemical analyses of raw materials

Element	Limestone	Clay	Slag	Iron
CaO	54	5.44	34.04	15.36
Al_2O_3	0.32	17.94	6.61	4.11
Fe_2O_3	0.29	7.57	4.46	40.26
SiO_2	0.61	53.80	32.89	19
MgO	0.36	2.01	8.08	2.07
Na_2O	0.07	0.89	0.42	-
K_2O	0.03	1.75	0.67	0.9
Cl^-	-	0.013	-	-
SO_3	-	0.02	0.42	0.4

Table 2

Proportion limits of the elements and dosage of the raw material

Designation	Limestone	Clay	Iron-ore	Slag	Sand	
Limits of raw material values (slag-based meal), %	68–72	18.9–19.4	1.6–2	8.5–9.5	-	Total
Limits of raw material values (meal without slag or ordinary), %	77–83	13–14	1.5–3	-	2–4	
The quantity taken for the test						
Proportion of elements of raw material taken for tests (with slag), %	70	19.2	1.8	9	-	100
Proportion of elements of raw material taken from test (without slag), %	81.5	13.5	2	-	3	100

to 1000 °C. The samples were left for 30 min inside, and finally, the temperature was again increased to 1450 °C, while the samples remained again for another 30 min. In order to avoid transforming C_3S to C_2S, the samples were rapidly cooled down at the end of the process.

The clinkers produced were analysed by chemical analysis, X-ray diffraction and optical microscopy. Furthermore, the clinkers obtained were analysed by XFR, XRD and optical microscopy. The results of the analyses are presented in Table 4. The mineralogical phases of the clinkers and of the slag used are determined by the XRD, type PANalyticale (X'Pert PRO) and the results are illustrated in Figs. 1 and 2. The microscopic observation of polished sections of clinkers, is realized by means of a computer-assisted optical microscope, type LEICA DMLM, the results of the observation are shown in Fig. 3.

Table 3

Chemical analysis results obtained for raw meal

Element	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	Na_2O	K_2O	Cl^-	SO_3
meal with slag	42.56	4.09	2.48	13.78	1.36	0.14	0.36	0.005	0.13
meal without slag	43.97	3.65	2.34	12.39	1.19	0.12	0.32	0.006	0.14

Table 4

Chemical and mineral analyses of clinker with and without slag

Element	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	Na_2O	K_2O	Cl^-	SO_3	C_3S	C_2S	C_3A	C_4AF
Clinker-based slag	65.98	6.34	3.84	21.36	2.11	0.22	0.56	0.007	0.2	57.61	17.80	10.30	11.69
Ordinary clinker without slag	66.16	5.64	3.78	22.08	1.01	0.22	0.43	0.017	0.10	57.30	20.10	8.35	11.5

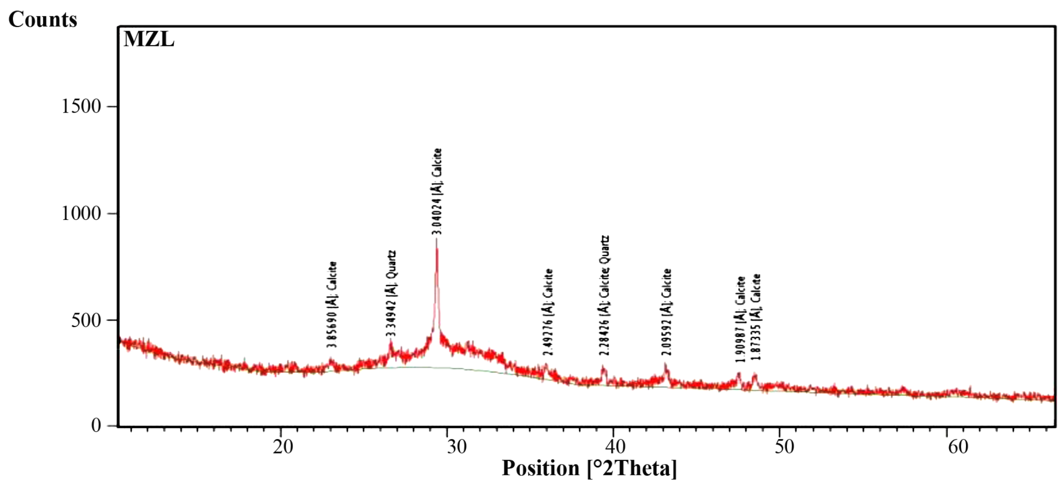


Fig. 1. XRD result of slag used

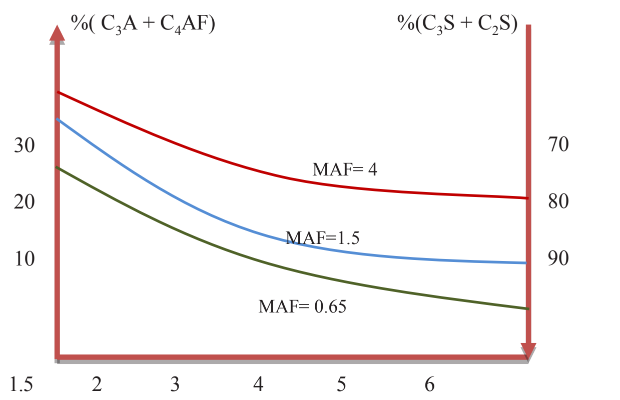


Fig. 2. Influence of silicic module on the mineralogical composition of clinker [8]

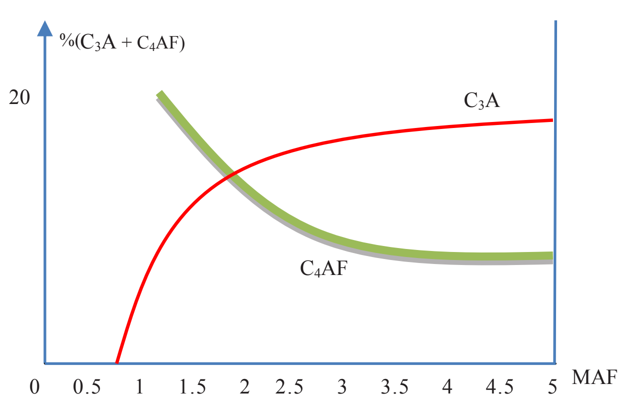


Fig. 3. Influence of the MAF on the correlation between C_4AF and C_3A [8]

The assessment of CO_2 emissions. The assessment of the CO_2 emissions during the production of both clinkers is done by the means of Global Emissions Model for Integrated Systems (GEMIS) 4.7, 2011. This software is a database program for Life Cycle Assessment (LCA), designed as a tool for the comparative assessment of the environmental effects of energy, by Öko-Institut and Gesamthochschule Kassel (GhK) [5]. The software contains an impact analysis system and a database of materials used, processes, means of transport and energy allowing modelling of the product.

The inventories of inputs provided by the Hadjar-Soud cement plant [6], in the form of data (for the production of one tonne of clinker), are as follows:

1. Production of clinker in 2015 is 814,000 t of clinker.
2. Natural gas CH_4: to produce 1 kg of the clinker, the consumption of natural gas (CH_4) reaches 0.1 Nm^3, or 0.09 kg of fuel.
3. Raw material (meal): 1 kg of the clinker requires 1.89 kg of raw meal.
4. Electricity: electricity consumption is 120 kw/h to produce 1 tonne of cement.
5. The plant works at 100 % of its capacities.
6. Proportions of the raw materials used to prepare 1 tonne of slag-based clinker are: 700 kg of limestone, 192 kg of clay (marl), 18 kg of iron and 90 kg of the slag.
7. Proportions of raw materials to prepare 1 tonne of sand-based clinker are: 815 kg of lime, 135 kg of clay (marl), 20 kg of iron and 30 kg of sand.

We noticed that, inventories of inputs are identical for both types of clinker, unless a change in the proportions of raw materials (limestone, slag, clay, sand and iron) occurs, see Table 2. The results of evaluation are recapitulated in Tables 5, 6 and 7.

The tests of preparation and dosage for the production of the clinker are realized in the following laboratories:

1. Laboratory of the chemical and mechanical analyses of the cement plant Hadjar-Soud.
2. Laboratory of mineral resources and environment, USCR "X-rays diffraction" at the University of El-Manar, Tunisia.
3. Laboratory of valorisation of mineral resources and environment of the mining department.
4. Metallurgy and Materials Engineering Laboratory, University of Annaba.

Results and discussion. ***Chemical and mineralogical characterization of the slag used.*** The results of the chemical analysis presented in Table 1, show that the slag is constituted from 95 to 98 % of a mixture of four oxides: the silica SiO_2, the lime CaO, the alumina Al_2O_3 and the magnesia MgO. The additive consists of secondary oxides such as FeO, MnO and sulfur compounds. The mineralogical composition is determined by XRD, the results obtained are illustrated in Fig. 1, and they are crystallized constituents, essentially silicates or silico-aluminates of lime. Among others, we also meet oxides, sulphides, and, exceptionally, nitrides.

Determination of cement performance. ***Optimization of raw material proportions.*** The proportions of raw materials for the preparation of ordinary raw meals (sand-based) are well known, while the slag-based meal requires prior optimization. To determine the optimum quantity of raw materials, different dosing tests are performed. The results show that 9 % of slag addition in the raw meal can reduce the amount of limestone down to 70 % (Table 2).

It is evident that 9 % of slag replaced partially by the rate of CaO and the SiO_2 is, respectively, in the limestone and the sand. The chemical analysis of both raw meals made by XRF, presents a difference in chemical composition, although the contents always stay within the standard proportions (Table 3).

Table 5

Clinker CO_2 EQ/T GHG emission results in tonne

Element	Quantity (t)	Factor	CO_2 equivalent 10^{-3}	Part (%)
CO_2	$802.29\cdot10^{-3}$	1.00	802.29	98.34
CH_4	$410.77\cdot10^{-6}$	25.00	10.27	1.26
N_2O	$10.76\cdot10^{-6}$	298.00	3.21	0.39
Somme			815.79	100

Table 6

Results per tonne CO_2/t of clinker

Process	Quantity (t)·10^{-3}	Part (%)
Non-metallic minerals/cement clinker-DZ-2015	545.00	67.93
heat-process-CaO-gas-DZ-2010 (end-energy)	192.51	23.99
gas-CC-DZ-2010-1	48.45	06.04
diesel motor-DE-2010	7.63	$951.36\cdot10^{-3}$
compressor-GT-DZ-2010-1	4.76	$593.61\cdot10^{-3}$
gas-boiler-DZ-2010-1	0.96	$119.16\cdot10^{-3}$

Table 7

Comparison of CO_2 emission results

	Decarbonation t CO_2/ t clinker	Combustion t CO_2/ t clinker	CO_2 t/year
Sand-based clinker	0.663	0.231	727716
Sand-based clinker	0.545	0.192	599918
Difference CO_2/t clinker	0.118	0.039	127798
Annual Difference, t/year	96052	31746	

Computation and discussion of the obtained modules and indices. Since the time of "*Le Chatelier*" (1850–1936) almost all researchers who have studied the Portland cement worked to search the relationship between the four fundamental oxides CaO, SiO_2, Al_2O_3 and Fe_2O_3, which constitute the different Portland cement [7]. The relationships between these oxides are named modules. In practice, the proportion of the principal constituents of clinker is calculated in the form of rates, modules or chemical indices, results of studies of many scientists about the mechanisms of formation and reactions of Portland clinker.

The values of the modules and indices calculated on the basis of the results of the chemical analyses of raw meal based on slag obtained previously; are presented in Table 8. According to the calculation results, the following points can be mentioned:

1. Michaelis hydraulic module MH, generally we work between 2 and 2.1.

If MH < 1.7, strength cement is low, dehydration is difficult to adjust. If MH > 2.3, it results in hard baking, high initial resistance, increasing the volume of cement following the free lime [8].

2. The Kühl Silicic Module (Ms) of ordinary cements is between 2.2 and 2.6. The high silica cements have a very high silica modulus (Ms > 5).These types of cement contain a less durable vitreous phase which makes the cooking of its clinker difficult; otherwise, we noticed a reduction of dehydrations and hardening in time. Clinkers with a small silicic module are easily cooked because of a longer vitreous phase. The latter constitutes a coating for the rotary kiln.

Within certain limits, the higher the Ms content is, the higher the ($C_3S + C_2S$) content is and the lower the ($C_3A + C_4AF$) content is.

If Ms > 3, the cooking ability of the raw mixture decreases due to the percentage reduction of the liquid phase. The clinker is normally pulverulent; the crusting becomes unstable due to its low thermal shock resistance. The cement will have a longer hold.

When Ms < 2, the baking ability of the raw mixture increases, as well as the percentage of the liquid phase in the cooking zone, the strength of the cement decreases and the hardening time is shortened. Fig. 2 shows the correlation between mineral silicates and fondants, for a given value of Ms.

3. MAF (Kühl Alumino-Ferric Module) is between 1.5 and 2.5.

If MAF < 1.5, the clinker does not contain C_3A, it contains only C_4AF during the formation of clinker minerals (MAF < 0.64). C_3A will form when C_4AF is saturated. In this case, the cement has a low hydration heat and a resistance against the attacks of ions rich in sulphate.

MAF > 2.5: the clinker contains a high content of alumina, and C_3A will be very important in the cement. The viscosity of the liquid phase increases considerably, which makes it difficult to form C_3S, the initial strength of the cement increases, the heat of hydration of the cement increases and the setting time becomes faster. The strength of cement in aggressive locality decreases [9].

MAF determines the duration of the liquid phase during the clinker burning process and the properties of the liquid phase (viscosity and surface tension) [10]. An increase in the MAF causes increasing in C_3A content and reduces C_4AF (Fig. 3).

4. The Lea and Parker saturation factor (LSF) is between 85 and 100 [8]. This module represents the ratio of the lime present in the mixture and the amount of lime that can be bound in the clinker lime standard allows us to know the behaviour of the mixture during cooking and to provide the quality of cement. The higher is lime standard, the higher the resistance of cement will be, too, and cooking will be difficult and will require an increase in calorie consumption for firing. Moreover, a high lime standard has a negative influence on the volume stability of the hydrated cement (free lime content)

According to the results, it is obvious that they meet the standards; the slag-based meal is adequately acceptable for the production of cement clinker.

Mineralo-chemical characterization of the two types of clinker. The main minerals composing the clinker are:

- (CaO) $3SiO_2$ or C_3S (Tricalcium silicate) or Alite;
- (CaO) $2SiO_2$ or C_2S (Dicalcium silicate) or (Belite);
- (CaO) $3Al_2O_3$ or C_3A (Tricalcium aluminate);
- (CaO) $4Al_2O_3Fe_2O_3$ or C_4AF (Tetracalcium alumino-ferrite).

The contents of these mineral species and the chemical composition of the two types of clinker were defined by the XRF. The results obtained are summarized in Table 4.

In both types of clinker, the main phases, C_3S, C_2S, C_3A and C_4AF, were well formed (Figs. 4, 5). The clinker with slag contained more C_4AF and less C_2S, a dif-

Table 8

Modules and indices obtained for raw cement

Modules and indices	Formals	Values	Limits
Michaelis hydraulic module (MH)	$\frac{CaO}{SiO_2 + Al_2O_3 + Fe_2O_3}$	2.09	2–2.1
Kühl Silicic Module (Ms)	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	2.10	2.2–2.6
Kühl Alumino-Ferric Module (MAF)	$\frac{Al_2O_3}{Fe_2O_3}$	1.65	1.5–2.5
Lea and Parker saturation factor (LSF)	$\frac{CaO}{2.8\ SiO_2 + 1.18\ Al_2O_3 + 0.65\ Fe_2O_3}$	90	90–100

ference was attributed to the partial replacement of limestone and sand with slag, which is higher in iron than in other mixtures. As for the distribution in most clinkers, the phases were developed moderately and distributed in an inhomogeneous way. The clinker phases were well developed and the grains of the *Alite* and de *Belite* were also observed, which coincides with the results of P. E. Tsakiridis [4].

The crystals of Belite were uniformly distributed with respect to Alite, indicating that the clinkerization reaction occurred in the direction of the Alite and that the raw meal mixture was homogeneous.

The mineralogical and chemical composition of the clinker is suitable for the preparation of composite cements (CPJ CEM II/A 42.5) which meets the requirements of the Algerian standard NA 442: 2000 [11].

The assessment of CO_2 emissions by GEMIS 4.7 software. ***Impact indicators.*** The Global Warming Potential (GWP), expressed in carbon dioxide, is the contribution to atmospheric absorption of infrared radiation by anthropogenic derived gases such as CH_4, CO_2 and N_2O, which contribute to an increase in global warming [12]. The results given by the simulation are mentioned in the tables below, the three main greenhouse gases are: CO_2, CH_4 and N_2O, but what we are more interested in is the emission of CO_2.

According to Tables 5 and 6, the processes result in the following:

1. Non-metallic mineral-clinker: decarbonation.
2. Heat-process-CaO-gas-DZ-2010: combustion of natural gas (Algeria).
3. Gas-CC-DZ-2010-1: electricity used.

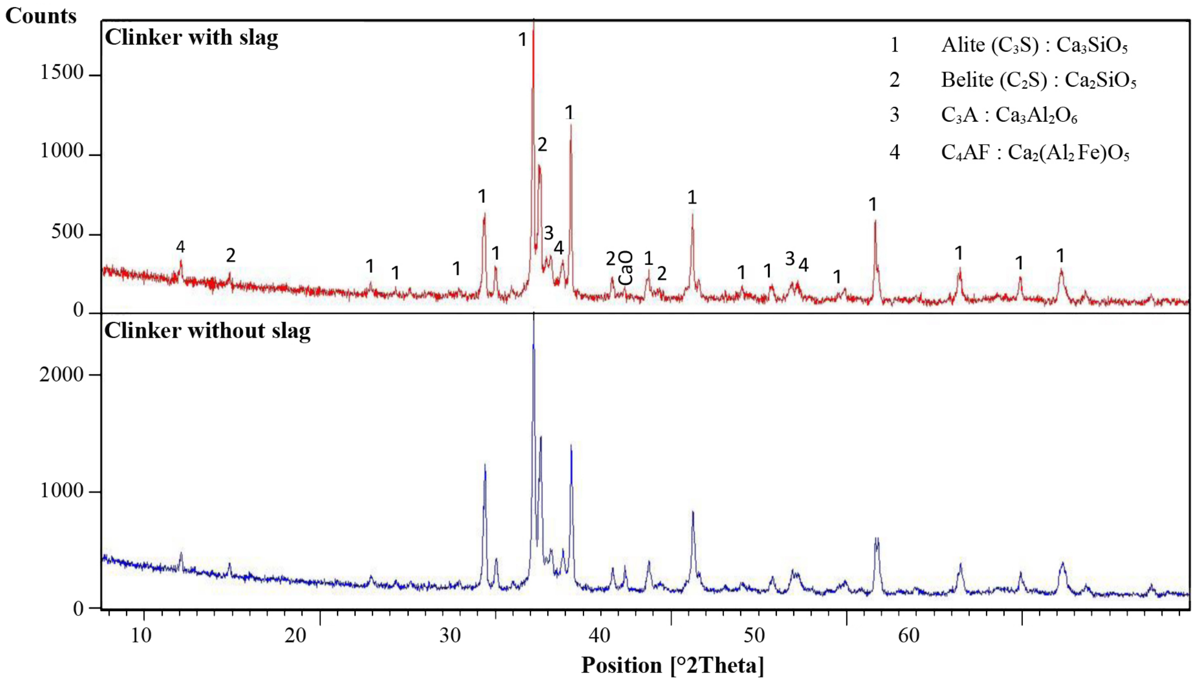
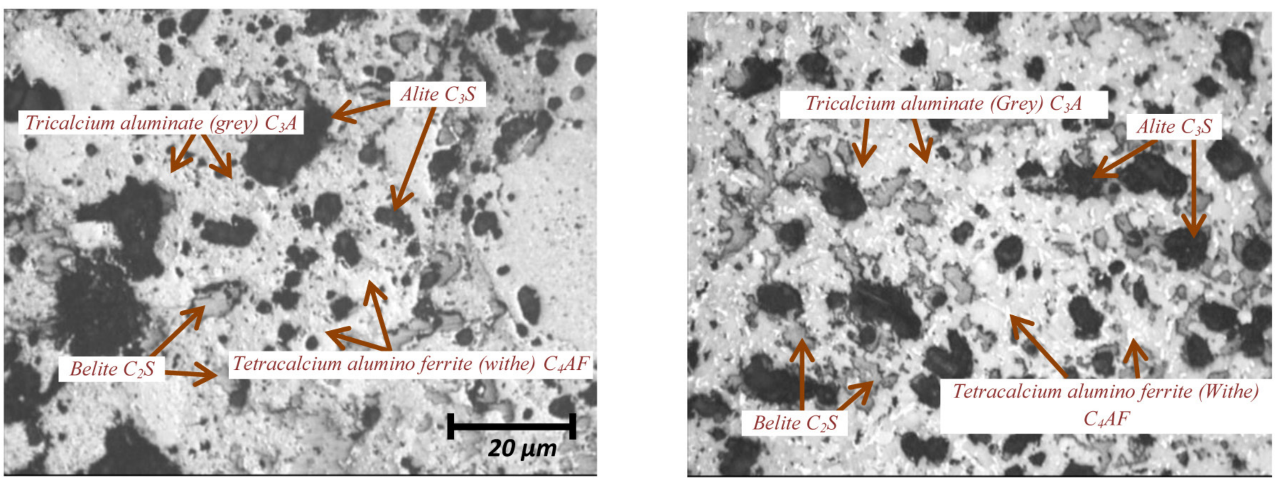


Fig. 4. XRD results of clinker with and without slag



a *b*

Fig. 5. Optical microscope observation of the polished clinker section:
a – clinker with slag; b – clinker without slag (with sand)

4. Diesel motor-DE-2010: trucks used in the iron mines, limestone and marl.

5. Compressor-GT-DZ-2010-1: compressors used in the transport of natural gas.

6. Gas-boiler-DZ-2010-1: gas consumed in boiler annexes processes.

The natural gas (CH_4) used in the clinker production, contributes to 23.99 % (0.192 tonne of CO_2) of the total emission balance GHG ($802.29x10^{-3}$ tonne of CO_2 EQ/T of clinker). The main source of CO_2 emission is the decarbonation phase, mainly due to the transformation of limestone into lime and CO_2, based on the following chemical reaction: $CaCO_3 \rightarrow CaO + CO_2$.

The decarbonation phase contributes to 67.93 % of CO_2 emissions (e.g. 0.545 t CO_2/tonne of clinker produced).

If we repeat the modelling of CO_2 emissions by the program (GEMIS 4.7) for the sand-based clinker, we keep the same input data used for slag-based meal; except for the proportion of raw materials: limestone 78 %, clay 18 %, iron 2 % and sand 3 %. The results obtained are given in the Table 7.

The simulation results by the software GEMIS 4.7, shows that the substitution of sand by the slag in raw materials at the Hadjar-Soud cement plant, has led to a decrease in the annual CO_2 emission from both processes, decarbonation and combustion, down to 17.56 % (127798 tonne).

The main cause of CO_2 reduction is mainly due to the partial replacement of limestone ($CaCO_3$) in the raw material, by an already decarbonated products (slag), knowing that over 60 % of CO_2 emissions in cement manufacturing come from the decarbonisation process (in our case study, the emission rate due to decarbonation is 67 %).

Conclusion. The present study is based on the addition of slag issue from the blast furnace as a substitute of sand in the natural raw material of limestone, iron ore and clay. The conclusions we have drawn from these research studies are as follows:

1. The steel complex of El-Hadjar is located about 50 km from the cement plant, while the natural sand comes from the Tebessa region, located about 300 km southeast of the cement plant.

2. The addition of 9 % of slag in the raw material did not affect the chemical or mineralogical composition of the clinker obtained. On the contrary, a reduction in the use of limestone in raw material down to 10 % has been noticed. The chemical composition of the meal is maintained within the standard values, the quality of the meal is checked by the modules and the control indices.

3. The crystals of Belite are uniformly distributed with respect to the Alite, which shows that the clinker reaction was in the direction of the Alite and that the mixture of the raw meal has a homogeneous granulometric and chemical composition.

4. Laboratory tests on representative samples show that the clinker obtained with the slag, widely meets the Algerian strict standards (NA 442-2000).

5. The production of clinker based on the blast furnaces slag shows a significant decrease in the annual CO_2 rate, around 18 %, which represent 128000 t/year, which is explained by the use of industrial material environmental friendly, having interesting properties with respect to its porosity, a light density and homogeneous and stable granular-chemical distribution; furthermore, a tonne of slag is about 6 times less expensive than a tonne of sand.

Acknowledgement. This research work was carried out at Annaba University, Algeria, under the sponsorship of the Mineral Processing and Environmental Research Laboratory, whose financial and technical assistance is gratefully acknowledged.

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Мета. Дане дослідження проведене стосовно використання промислових відходів (доменного шлаку) сталеливарного заводу Ель-Хаджар, розташованого у східному Алжирі. Метою дослідження є розуміння особливостей додавання шлаку в якості сировини (що заміщує пісок) при підготовці розчину перед обпаленням в обертовій обпалювальній печі в умовах цементного заводу Хаджар-Сууд у Скікде.

Методика. Запропоновані проби, що взяті на цементному заводі, піддаються подрібненню в суміші з вапняком, шлаком, глиною й залізною рудою; далі

здійснюється фізико-хімічна діагностика готового матеріалу у вигляді часток розміром не більше 50 μ. Готовий зразок розміщують у печі при температурі до 1450 °С. Оцінка показника річного викиду CO_2 на цементному заводі здійснювалася за допомогою Software (GEMIS 4.7).

Результати. Результати, отримані під час тестування, показують, що додавання шлаку до сировинної суміші не впливає на хімічний чи мінералогічний склад клінкера. Тим не менш, отриманий клінкер демонструє значні результати й відповідає стандартам Алжиру NA 442 2000 (CPJ CEM II/A 42,5). Додавання шлаку замість піску дозволило скоротити річні викиди CO_2 на 17,5 % і сприяти зменшенню забруднення.

Наукова новизна. Полягає у підготовці сировинної цементної суміші, що ґрунтується на шлаку (уже декарбонізований матеріал) замість піску. Зазвичай для виробництва цементного клінкера застосовуються наступні пропорції сировини: вапняк 77–80 %, глина 16–18 %, залізна руда 1,5–3 % та пісок 2–4 %. У наданій роботі пропорції для виробництва зразка клінкера, в основі якого шлак, наступні: вапняк 70 %, шлак 9 %, глина 19,2 % та залізна руда 1,8 %.

Практична значимість. Процес отримання клінкера на основі шлаку (відходів виробництва сталі) має велике значення для виробництва цементу за кількома причинами: виробництво однієї тони клінкера за мінімальної вартості, а також використання й відтворення невідновлюваної натуральної сировини, такої як пісок і вапняк, і робота в напрямі стійкого екологобезпечного розвитку.

Ключеві слова: *Алжир, цементний завод Хаджар-Сууд, шлак, навколишнє середовище*

Цель. Данное исследование проведено касательно использования промышленных отходов (доменного шлака) сталелитейного завода Эль-Хаджар, расположенного в восточном Алжире. Целью исследования является понимание особенностей добавления шлака в качестве сырья (замещающего песок) при подготовке раствора перед обжигом во вращающейся обжигательной печи в условиях цементного завода Хаджар-Сууд в Скикде.

Методика. Представительные пробы, взятые на цементном заводе, подвергаются измельчению в смеси с известняком, шлаком, глиной и железной рудой; далее осуществляется физико-химическая диагностика готового материала в виде частиц размером не более 50 μ. Готовый образец помещают в печь при температуре до 1450 °С. Оценка показателя годового выброса CO_2 на цементном заводе производилась с помощью Software (GEMIS 4.7).

Результаты. Результаты, полученные во время тестирования, показывают, что добавление шлака в сырьевую смесь не влияет на химический или минералогический состав клинкера. Тем не менее, полученный клинкер демонстрирует значительные результаты и соответствует стандартам Алжира NA 442 2000 (CPJ CEM II/A 42,5). Добавление шлака вместо песка позволило сократить годовые выбросы CO_2 на 17,5 % и способствовать уменьшению загрязнения.

Научная новизна. Состоит в подготовке сырьевой цементной смеси, основанной на шлаке (уже декарбонизированный материал) вместо песка. Обычно для производства цементного клинкера применяются следующие пропорции сырья: известняк 77–80 %, глина 16–18 %, железная руда 1,5–3 % и песок 2–4 %. В представленной работе пропорции для производства образца клинкера, в основе которого шлак, следующие: известняк 70 %, шлак 9 %, глина 19,2 % и железная руда 1,8 %.

Практическая значимость. Процесс получения клинкера на основе шлака (отходов производства стали) имеет большое значение для производства цемента по нескольким причинам: производство одной тонны клинкера по минимальной стоимости, а также использование и воспроизводство невозобновляемого натурального сырья, такого как песок и известняк, и работа в направлении устойчивого экологобезопасного развития.

Ключевые слова: *Алжир, цементный завод Хаджар-Сууд, шлак, окружающая среда*

Рекомендовано до публікації Abdelaziz Idres. Дата надходження рукопису 11.12.16.