Computer simulation for optimizing mining waste recycling in cement raw meals

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Abstract: Cement production offers the opportunity to recycle and valorize certain mining wastes, containing the main cement oxides. This study presents a Python program for finding the optimum composition of a limestone-clay cementitious mixture in which we recycle mining waste (LCy%Wx%) to produce a Portland clinker as close as possible to a clinker taken as a reference (RR). The aim of this Python program is to determine the percentages of limestone, clay and waste in the LCW, by equating eleven of its characteristics to those of the reference raw meal; these characteristics encompass the four oxide compositions (CaO, SiO_2, Fe_2O_3, Al_2O_3), three moduli (LSF, SR, AF) and the proportions of the clinker's four main phases. This program allows the user to select limestone-clay-waste raw materials and a target reference with its eleven parameters. The script execution generates eleven solutions, stored in files as numerical tables and graphs. These results facilitate the selection of optimum percentages of cementitious raw materials. Ultimately, this recycling process offers both economic and ecological benefits.

Keywords: Cement raw, Mining waste, Recycling, Numerical simulation, Environmental impact.

محاكاة الكمبيوتر لتحسين إعادة تدوير نفايات التعدين في وجبات الأسمنت الخام

الملخص: يوفر إنتاج الأسمنت الفرصة لإعادة تدوير وتثمين بعض نفايات التعدين التي تحتوي على أكاسيد الأسمنت الرئيسية .
تقدم هذه الدراسة برنامج بايثون لإيجاد التركيب الأمثل لخليط أسمنتي من الحجر الجيري والصلصال حيث نقوم بإعادة تدوير مخلفات التعدين لإنتاج الكلنكر البورتلاندي أقرب ما يمكن إلى الكلنكر الذي يتم أخذه كمرجع.
الهدف من برنامج بايثون هذا هو تحديد نسب الحجر الجيري والصلصال والنفايات في الخليط المستهدف عن طريق مساواة إحدى عشرة من خصائصه بتلك الخاصة بالخليط المرجعي ؛ وتشمل هذه الخصائص تركيبات الأكسيد الأربعة، وثلاثة نسب الخليط الإسمنتي ونسب مكونات الإسمنت الأربع الرئيسية للكلنكر. يسمح هذا البرنامج للمستخدم باختيار المواد الخام من مخلفات الحجر الجيري والصلصال و المرجع المستهدف بخصائصه الإحدى عشرة. يؤدي تنفيذ البرنامج إلى ايجاد أحد عشر حلاً، يتم تخزينها في ملفات على شكل جداول رقمية ورسوم بيانية. هذه النتائج تسهل اختيار النسب المثلى للمواد الخام الأسمنتية. في نهاية المطاف، توفر عملية إعادة التدوير هذه فوائد اقتصادية وبيئية.
الكلمات المفتاحية: خام الأسمنت، مخلفات التعدين، إعادة التدوير، المحاكاة العددية، التأثير البيئي.

1. Introduction

Worldwide, mining activities generate enormous quantities of mining waste estimated, annually, at 65 billion tons [1]. These wastes affect the lives of humans, animals and plants because they pollute water, air and soil [2,3]. It is therefore necessary to recycle and possibly valorize mining waste [4-8], with economic and ecological benefits, and contribute to a more sustainable and circular economy [9,10]. However, beyond economic objectives, ecological considerations have become an imperative rather than a luxury for humanity. Generally, mining waste contains oxides like SiO_2, Fe_2O_3, Al_2O_3, CaO, SO_3, MgO, K_2O, Na_2O, etc. and the mined mineral; many of these oxides are found in cement. Furthermore, cement is a strategic and crucial material for human needs; in fact, according to Cembureau, global cement consumption reached 4.17 Gt in 2020 and the United Nations notes that concrete is the second most consumed product in the world, after water [11,12]. The enormous quantities of cement produced offer the possibility of recycling mining waste, and more generally industrial and construction waste. Usually cement is mainly formed by 80% limestone and 20% clay (weight), and the cement raw meal is heated to around 1450°-1500°C. There are more than ten different types of cement [13,14] and their composition of major oxides varies: calcium oxide 1 to 63%, silicon oxide 22 to 85%, aluminum oxides 7 to 23% and iron oxides 0 to 4%. Coal mining is one of the most important mining activities. Indeed, coal is a crucial strategic material for the world and constitutes 70% of fossil energy resources [15], but its extraction generates large quantities of waste of up to 15% by weight [16]. Several ways of recycling and valorizing coal gangue are exploited, particularly in the production of cement [17-20]. In our previous study by Belkheiri *et al.*[21], we studied the limestone-coal gangue cement mixture, because our characterizations had shown that the coal gangue is formed of quartz, clays and coal remains; and for this reason it plays the role of clay and source of energy. We carried out a computer simulation to determine the optimal percentages of limestone and gangue, and ultimately we had developed a good clinker limestone-gangue18.5% close to a clinker taken as a reference. More generally, in this study, we are interested in recycling certain mining waste from coal, phosphate and iron mines because, for logistical reasons, these mines are located near cement plants. The goal of the current work is to use a Python program to determine the optimal percentages of limestone, clay and mining waste to develop Portland clinkers as close as possible to a clinker taken as a reference. The choice of the Python programming language is due to its great popularity, as it is both powerful and easy to use; it is open-source and free. Python is also versatile and can be used to develop office software and web applications.

2. Materials and methods

2.1 Raw materials

Table 1: Notation of the cementitious compounds

Compound	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	Na_2O, K_2O	$3CaO.SiO_2$	$2Ca.SiO_2$	$3CaO.Al_2O_3$	$4CaO.Al_2O_3.Fe_2O_3$
Notation	C	S	A	F	$\underline{S}$	M	NK	C_3S	C_2S	C_3A	C_4AF

We consider cementitious materials used in two cement plants in the cities of Oujda and Marrakech; the mining waste that we wish to recycle comes from neighboring mines, for logistical reasons. These materials are listed in Table 2 with the following abbreviations:
LX: Limestone-Origin, X designates the origin:O for Oujda O, or M for Marrakech;
CX: Clay-Origin (or schist SX);
RX: Raw meal-Origin is a cement raw from a cement plant;
MW: MiningWaste. We consider the coal waste CW; the ZnO waste ZW(ZnO-PbO) and others [22]; the phosphate waste PW; the phosphate sludge SW [23]; the phosphogypse waste GW [24]; and from the iron-rich mine, we have the ferric waste FW [25];
MA: Mining-Ash. We consider fly ash from phosphate PA [26], and the pyrrhotite ash FA [27].
In Table 2, we indicate the raw feed, of cement plant, designated as the reference RO. Our objective is to produce a clinker that closely resembles this reference raw feed will be denoted with the index "ref" such as: C_{ref}, S_{ref}, …, LSF_{ref}, …, C_4AF_{ref}.

Table 2: %wt (XRF) of cement materials and mining waste

Material	Num	C	S	A	F	$\underline{S}$	M	NK	LOI	TOTAL	Component
RO	1	42.8	13.8	3.4	2.2	0.1	1.5	0.6	35.0	99.4	Raw reference
LO	2	50.2	4.8	1.4	0.6	0.1	1.5	0.5	40.6	99.8	Limestone
LM	3	47.2	4.9	1.0	0.5	0.0	0.9	0.2	45.4	100.0	Limestone
CO	4	10.3	48.4	13.8	6.8	0.0	2.6	2.9	15.0	99.9	Clay
CM	5	11.4	46.5	14.5	5.4	0.0	3.4	2.7	17.2	101.1	Clay
SM	6	12.1	50.3	13.6	2.4	0.0	0.9	7.9	12.8	100.0	Schist
CW	7	0.8	52.4	21.9	4.6	3.6	1.3	3.8	10.6	98.9	Coal waste
ZW	8	19.0	29.6	4.3	31.1	0.0	3.2	0.9	1.7	89.9	WasteZn-Pb
FW	9	0.6	52.5	1.8	10.2	22.3	0.6	0.3	11.2	99.5	Pyrhwaste
PW	10	43.0	11.6	0.9	0.4	0.8	3.3	0.6	39.5	100.0	Phos waste
SW	11	34.2	22.8	2.5	0.9	0.0	4.1	1.2	34.3	100.0	Phosludge
GW	12	31.5	0.5	0.1	0.1	46.9	1.6	0.0	16.0	96.7	Phosgypsum
FA	13	0.5	13.0	4.0	64.9	4.0	2.7	0.8	7.7	97.7	Pyrhwaste
PA	14	4.8	52	23	5.9	0.5	2	1.7	10	99.2	Phospho-ash
AA	15	2.7	32.3	13.3	35.4	2.2	2.5	1.3	8.9	98.4	FA50%-PA50%
None*	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	None

*The "None component" is a fictitious material, it is introduced for the purposes of the Python program; this program is designed for three materials limestone-clay-other, in the limestone-clay case the third material "None" has compositions of 0%. We can also consider a material which is a mixture of two, or more, materials among those available, for example a waste formed by mixing two mining waste like AA: FA50%PA50%.

2.2. Definitions and expressions

In the cement process, certain physicochemical properties of the cementitious mixture are given by the following three moduli:

- Lime saturation factor : $LSF = \frac{100C}{2.8S+1.65A+0.35F}$
- Silica ratio : $SR = \frac{S}{A+F}$
- Alumino-ferrate ratio : $AF = \frac{A}{F}$

The raw feed will be heated at 1450°C to obtain a clinker. The composition of the four main phases of clinker can be estimated by a suitable formula. This composition is usually given by the Bogue or Taylor methods [28,29], but we have used the proposal by Shim *et al* [30] given in Table 3; this system of equations is based on experimental data, and has good accuracy for cement mixtures with a C/S ratio of between 2.2 and 3.2. The choice of this Shim model is due to the fact that it comes from many practical experiments. However, it is possible to use other theoretical methods, by Bogue or Taylor, by changing the matrix k to kB (Bogue) presented in grey on lines 89-92 of the script, and thus, compare the results on the percentages of the clinker phases.

Table 3: Compositions in clinker's phases calculated by the model Shim *et al*

Phase	Usual range*	Notation	Calculation of the expected mass composition by Shim's model
C_3S	45-65	p_1	$= 4.088\ C - 7.212\ S - 6.745\ A - 1.436\ F - 2.863\ \underline{S}$
C_2S	10-30	p_2	$= -3.113\ C + 8.442\ S + 5.136\ A + 1.093\ F + 2.180\ \underline{S}$
C_3A	5-12	p_3	$= 0.028\ C - 0.153\ S + 2.604\ A - 1.702\ F - 0.020\ \underline{S}$
C_4AF	6-12	p_4	$= -0.01\ C - 0.058\ S + 0.016\ A + 3.047\ F + 0.007\ \underline{S}$

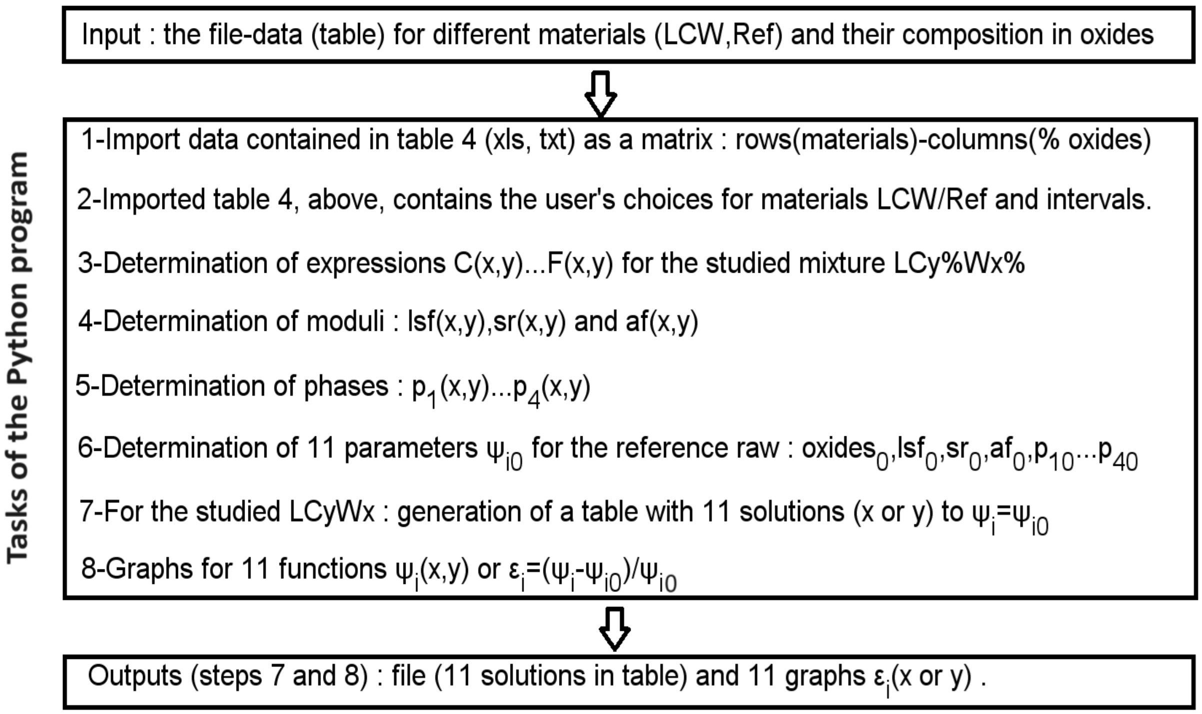
*in UK and Europe.

2.3. Methods

The user must have the Python software installed on his computer. The Python program named LCyWx.py is elaborated for raw feeds formed by Limestone (100-y-x %wt)+Clay (y %wt) + Waste (x%wt), where W is a mining waste or none. We will have to study eleven functions Ψ_i (x, y), where Ψ_i can be one of the oxides C (x, y), S (x, y), A (x, y), F (x, y); moduli LSF (x, y), SR (x, y), AF (x, y); and the compositions of clinker's phases denoted in Table 3: p_1(x, y), …, p_4(x, y).

The expressions of the Ψ_i (x, y) functions, vs x-y, are established by Python using the data of the Table 2. For mixtures LCyNone we have to study $\Psi_i(y)$ and for LCy0Wx, we have to study Ψ_i (x, y_0=cst), where $y_0=y_{op}-\alpha$, $\alpha>0$ and y_{op} is an optimal value chosen by the user after studying the LCyNone. The approach of the Python program is given by Figure1; the version used is 3.7.4 (Win,64 bits), with Pyzo interpreter.

Figure 1: Description of the steps of the python program



3. Results and discussion

3.1. Prelude

For the studied mixtures LCyWx, the composition in oxides constitutes the basis of calculations, and the compositions of oxides are calculated after considering losses on ignition; thus for C,

we have: $$C(x,y)=100.\frac{(100-y-x).C_L+y.C_C+x.C_W}{100-(100-y-x).LOI_L+y.LOI_C+x.LOI_W}$$

Where C_L, C_C, C_W are the percentages of C, respectively in limestone, in the clay and in the waste; LOI_L, LOI_C, LOI_W are the percentages of loss on ignition in these materials. For the raw feed reference, these 11 quantities are constant and noted $\Psi_{i,\,ref}$: C_{ref}, S_{ref}, …, p_{4ref}. It is possible to predict qualitatively the effect of the variation of y or x on the five characteristics C, S, A, F, AF, which are homographic functions in the form:

$$\Phi_j(x,y_1)=\frac{ax+b}{cx+d}\quad ;\frac{\partial\Phi_j}{\partial x}=\frac{ad-bc}{(cx+d)^2}$$

where y_1 is constant. The variations of this function are given by its derivative ; if the numerator a.d-b.c >0: Φ_j is increasing when the variable x increases, and if a.d-b.c< 0, Φ_j decreases when x increases; a, b, c and d are listed in Table 2.

The Python program generates a second file containing graphs of the relevant functions of the form, $\varepsilon_i(x,y)=\frac{\Psi_i-\Psi_{i,ref}}{\Psi_{i,ref}}$, which must not deviate too much from zero and this allows to assess the similarity of the studied mixture with the targeted reference.

3.2. Choices of the user added to Table 2 transformed into Table 4

After the "None" line in Table 2, the user adds additional lines : Choices1(line 20 in python program) or 2 or 3 where he specify four lines (in table cemat.xls) : limestone-clay-waste-reference by giving their respective four numbers given in the 2d column of Table 4 ;

For the two mixtures LCyNone or LCy0Wx, the user gives bounds of the intervals for graphs εi (x, y): (y_1, y_2), (x_1, x_2), and the value y_0 used for LCy0Wx. The Python program uses data of table 4 to conduct calculations and simulations for mixtures LCyNone or LCy0Wx ; this program is given in appendix. Table 4 is a file (cemat.xls for example) containing the material compositions obtained by XRF and completed with the user's nine choices : four materials, four bounds and y_0.

The user have to place the two files, namely "cemat.xls" containing Table 4 and the Python program "LCyWx.py" (lines 1-296), in the same folder (cempy for example), and it must modify line 9 to indicate the path to this folder (for example : path = 'C:/Users/Desktop/cempy) ; the program "LCyWx.py" can be copied (without the first column containing numbers of instruction’s lines) into the script part of the Python software, saved and, then, executed via the RUN menu. Upon execution, two output files are produced: one table file containing the eleven solutions and a file with the eleven graphs εi (x, y); both output files will be stored in the same folder as the "LCW.py" program. The analysis of these results allows the user to make a compromise and choose the optimal cementitious mixture for the targeted Clinker. The program "LCyWx.py" contains explanatory texts written after a hash (#), which are ignored by Python but helpful for user s' understanding. If the user wants to calculate the percentages of the phases using the Bogue model, he must change the elements of matrix k from lines between lines 81-85. However, the program uses calculations presented in Table 3, which attenuates the influence of the adopted model when working with relative deviations ε_{ph} (x, y) between the studied raw feed and the reference.

Table 4: XRF Composition of limestones, clays and mining waste; with user's choices

Material	Number	C	S	A	F	S	M	NK*	LOI	TOTAL	Component
RO_1	1	42,8	13,8	3,4	2,2	0,1	1,5	0,6	35,0	99,4	raw-r-other
RO_2	2	42,8	12,3	3,7	1,7	0,3	2,0	0,9	36,3	99,9	rawreference
LO	3	50,2	4,8	1,4	0,6	0,1	1,5	0,5	40,6	99,8	limestone
LO_2	4	48,2	5,7	2,0	0,7	0,2	1,2	0,6	40,6	99,2	limestone2
LM	5	47,2	4,9	1,0	0,5	0,0	0,9	0,2	45,4	100,0	limestone
CO	6	10,3	48,4	13,8	6,8	0,0	2,6	2,9	15,0	99,9	clay
CM	7	11,4	46,5	14,5	5,4	0,0	3,4	2,7	17,2	101,1	clay
SM	8	12,1	50,3	13,6	2,4	0,0	0,9	7,9	12,8	100,0	schist
CW_1	9	0,7	52,4	21,9	4,6	3,5	1,3	3,8	10,6	98,68	coalwaste
CW_2	10	0,6	52,2	21,6	4,7	1,0	1,0	3,0	14,2	98,1	coalwaste
CW_3	11	1,0	54,2	17,7	8,9	0,0	1,3	3,3	12,5	98,1	coalwaste
ZW	12	19,0	29,6	4,3	31,1	0,0	3,2	0,9	1,7	89,9	wasteZn-Pb
FW	13	0,6	52,5	1,8	10,2	22,3	0,6	0,3	11,2	99,5	pyrhwaste
PW	14	43,0	11,6	0,9	0,4	0,8	3,3	0,6	39,5	100,0	phoswaste
SW	15	34,2	22,8	2,5	0,9	0,0	4,1	1,2	34,3	100,0	phosludge
GW	16	31,5	0,5	0,1	0,1	46,9	1,6	0,0	16,0	96,7	phosgypsum
FA	17	0,5	13,0	4,0	64,9	4,0	2,7	0,8	7,7	97,7	pyrhwaste
PA	18	4,8	51,5	22,6	5,9	0,5	2,2	1,7	10	99,2	phospho-ash
AA	19	2,7	32,3	13,3	35,4	2,2	2,5	1,3	8,9	98,4	FA-PA
None	20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	none

Mat/choices	choice1	choice2	choice3	etc.
limestone	3	3	3	
clay	6	9	9	
waste or none	20	20	12	
referenceraw	2	2	2	

IntervalsGraphs	Min($y_1$or x_1)	Max($y_2$orx_2)	y_c
LCyNone : graph $\varepsilon_i(x=0,y)$	15	25	variable
LCycWx : graph $\varepsilon_i(x,y_c)$	0	10	17

Put this file cemat.xls with LCW.py in your (same) folder cempy. Path 'C:/Users/belkh/Desktop/cempy/'

3.3. Application for a usual raw meal Limestone-Clay-None

Among the different cases treated LCyNone with the two main materials, limestone-clay, of a cement raw meal, we present, for example, the results for the LOCOy mixture and RO as a reference; all materials limestone-Clay-Reference are from Oujda plant. The program produces the two files : Table 5 gives 11 mixtures corresponding to the 11 solutions, and Figure 2 shows the graphs of the 11 functions ε_i relative to the four oxides, three modules, and four phases respectively; the dashed line corresponds to the reference with ε_{i0} =0. The deviation of a graph from this line reflects the divergence of the studied mixture from the reference.

Figure 2: Graphs for the cementitious mixture LOCOyNone

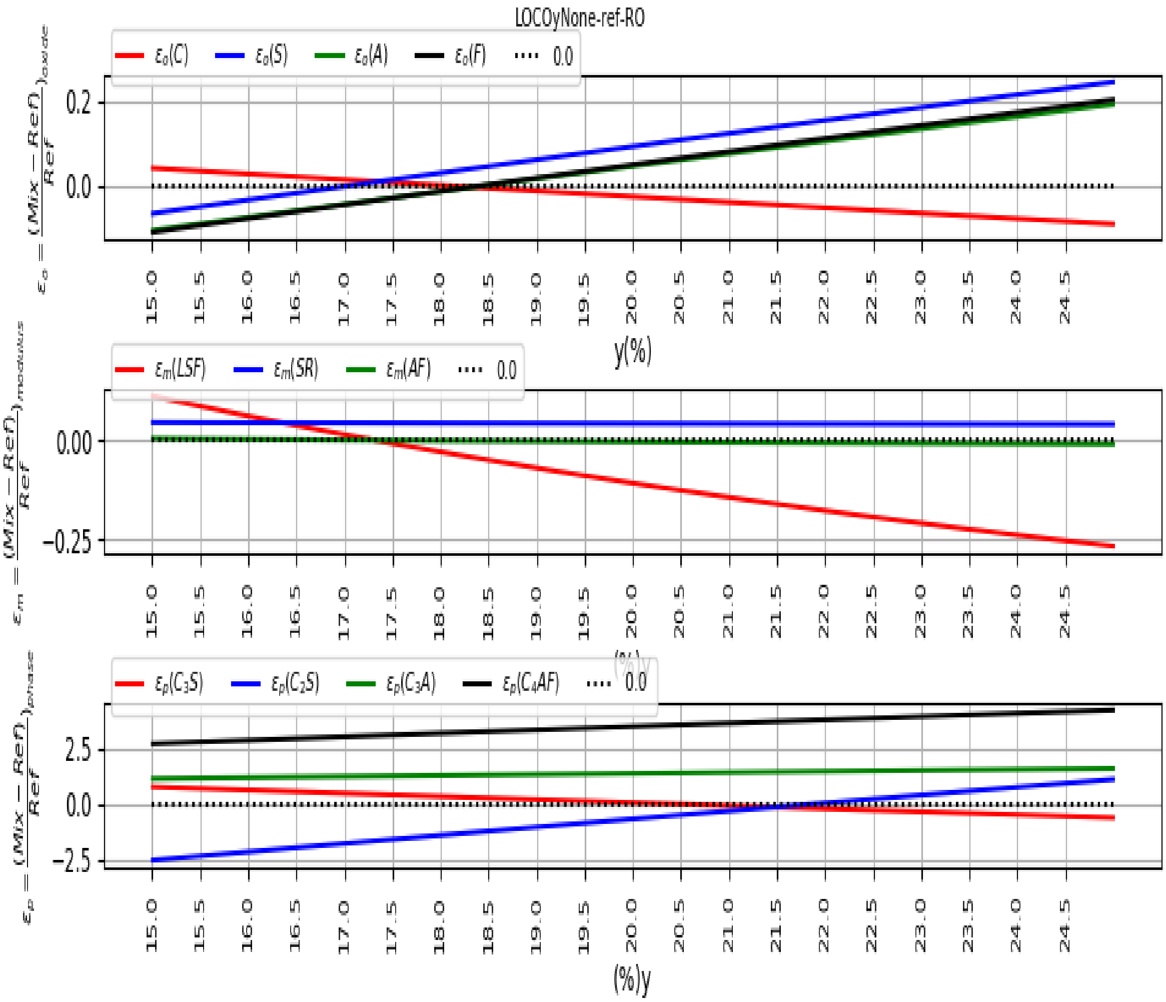


Table 5: Values for eleven parameters for the raw feed LOCOyNone using Shim proposition (rejected value if C/S out of interval 2.2-3.2)

02/01/24, 15:32 RO-vs-MIX:LOCONone Calculations using Shim –proposition (from experiments)

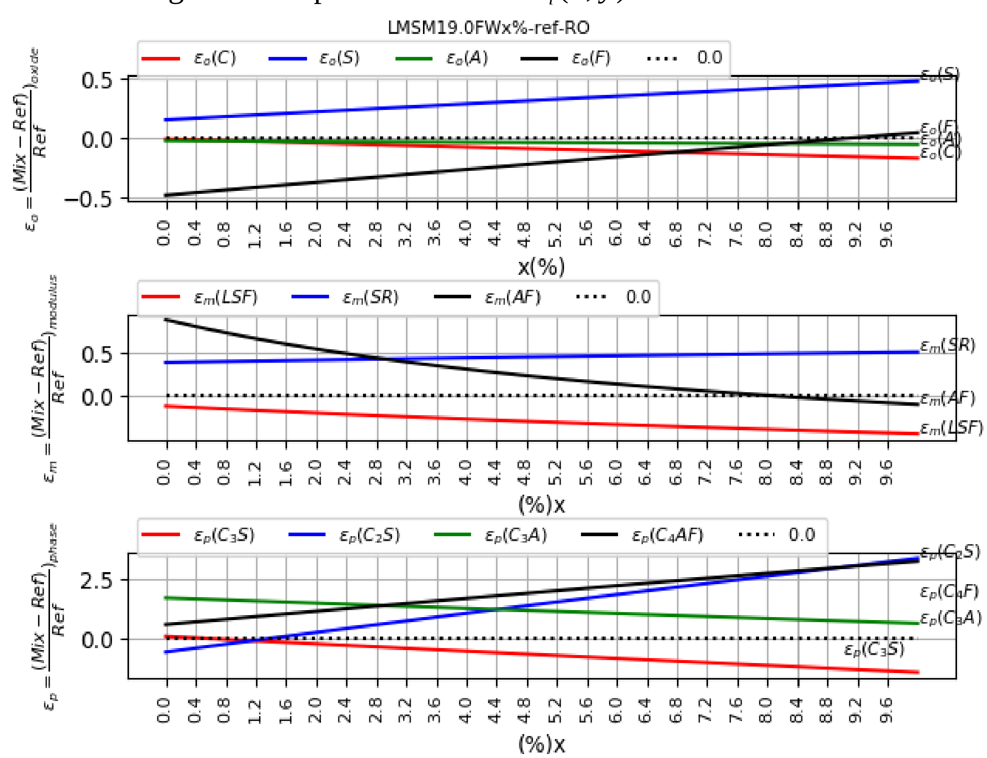
Solution	Ref:RO	%LO	%CO	%None	C: 60-69	S: 18-24	A: 4-8	F: 1-8	LSF: 92-102	SR: 1.8-2.7	AF: 1-1.5	C_3S: 50-70	C_2S: 15-30	C_3A: 5-10	C_4AF: 5-10	C/S 2.2-3.2
C=	67,1	81,9	18,1	0	67,13	19,89	5,67	2,7	100,36	2,38	HV:2.1	HV:88.31	RV	8,99	6,51	3,38
S=	19,2	82,97	17,03	0	68,08	19,25	5,48	2,61	HV:105.22	2,38	HV:2.1	HV:98.25	RV	8,8	6,25	3,54
A=	5,7	81,57	18,43	0	66,83	20,09	5,73	2,73	98,94	2,38	HV:2.1	HV:85.26	RV	9,05	6,58	3,33
F=	2,7	81,6	18,4	0	66,86	20,07	5,72	2,73	99,07	2,38	HV:2.1	HV:85.54	RV	9,05	6,58	3,33
LSF=	103,8	82,67	17,33	0	67,81	19,43	5,54	2,64	HV:103.82	2,38	HV:2.1	HV:95.46	RV	8,85	6,32	3,49
SR=	2,3	RV	RV	0	R.V	R.V	R.V	R.V	LV:-292.55	2,28	HV:1.84	RV	RV	RV	RV	RV
AF=	2,1	82,22	17,78	0	67,41	19,7	5,61	2,68	101,78	2,38	HV:2.1	HV:91.27	RV	8,93	6,43	3,42
C_3S=	65,8	79,44	20,56	0	64,95	21,36	6,09	2,91	LV:90.45	2,37	HV:2.09	65,77	LV:12.92	9,44	7,09	3,04
C_2S=	23,9	78,17	21,83	0	63,85	22,1	6,3	3,02	LV:85.91	2,37	HV:2.09	54,31	23,85	9,66	7,38	2,89
C_3A=	3,9	RV	RV	0	91,89	3,18	0,91	0,32	HV:864.85	2,59	HV:2.86	RV	RV	LV:3.91	RV	28,9
C_4AF=	1,5	RV	RV	0	85,67	7,37	2,1	0,92	HV:346.28	2,44	HV:2.29	RV	RV	5,18	LV:1.54	11,62
Remarks:		RV:	RejectedValue		LV:	LowValue		HV:	HighValue		Shim	proposition	:	2.22	<C/S<	3.21

Fort he Shim's model, the criterion C_3S=C_3S_{ref} =65.8 respects the ratio C/S=3.04 between 2.2 and 3.2; the correspondant mixture is LOCO20.5%None. If we use Bogue's model, and for the optimal solution C_3S_B= $C_3S_{ref,B}$ =66.9 (B means Bogue's model), we obtain the mixture LOCO19.5%NoneB and the values of oxides-modulis-phases are respectivly: 65.7, 20.7, 5.91, 2.82, 94.5, 2.37, 2.09, 66.8, 8.96, 10.88, 8.59.

3.4. Application for raw meal Limestone-Clay-Waste

The simulation shows that the limestone-shale mixture LMSMy% approaches the cru-reference for y in the interval 19.7-20.5%, but the AF modulus, AF= 3.9, is higher than 1.5. Therefore, we propose using the FW waste or FA waste as a third material to optimize the mixture LMSM19None, and we have selected y_0=19 as the optimal value. Figure 3 illustrates the graphs of functions ε_i(x or y) and ε_{i0}=0 related to this analysis. We were content to reason on graphs and omitted to give the table containing the 11 solutions, for this cement mix, with the chosen reference RO. Figure 3, below, illustrates the graphs of functions related to this analysis. The results reveal that despite incorporating mining waste as a corrective material, achieving a perfect match for all 11 parameters is not feasible, necessitating a compromis. In the LMSM19FWx case study, x needs to be between 0.6% and 1.4% to achieve the desired balance; we can choose the optimal composition is LM:80.4%, SM:19%, FW:0.6%, which gives 65.7%C_3S, 16.7%C_2S, 10.4%C_3A and 2.7%C_4AF ; if y_0 decrease from 19% to 18%, the modulus AF decreases from 3.4 to 3.1 for this clinker 's composition.

Figure 3 :Graphs of functions $\varepsilon_i(x,y)$ for LMSM19FWx



3.5. Summary of optimised cement mixtures LCyWx

Depending on the materials available, it is possible to prepare cement mix scenarios. In our previous study, we used coal gangue mining waste itself as clay, hence the LOCWyNone mixture, and which gave a good LOCW18.5%None clinker; we can then add a corrective material ZW. Likewise, we can consider incorporating into the LMSM limestone-shale mixture, the PW waste or even a mixture of two AA wastes. In Table 6, examples of optimal LCyNone or LCy0Wx cement mixtures are given.

Table 6: some examples of optimized raw feeds for clinker elaboration

Mix(LCyWx)	**Solution**	**%L**	**%C**	**%W**	**C**	**S**	**A**	**F**	**LSF**	**SR**	**AF**	**C_3S**	**C_2S**	**C_3A**	**C_4AF**
LOCWyNone	**$C_3S=C_3S_{ref}$**	**83,23**	**16,77**	**0,00**	**65,01**	**19,90**	**7,49**	**1,97**	**92,68**	**2,10**	**3,79**	**65,76**	**8,63**	**14,89**	**4,34**
LOCWy0ZWx	**$C_2S=C_2S_{ref}$**	**80,60**	**17,00**	**2,40**	**62,70**	**20,67**	**7,55**	**3,08**	**85,69**	**1,95**	**2,45**	**48,75**	**23,85**	**13,00**	**7,67**
LMSM19FAx	**$C_3S=C_3S_{ref}$**	**79.99**	**19**	**1.01**	**65.50**	**22.20**	**5.62**	**2.48**	**89.6**	**2.74**	**2.27**	**65.7**	**15.4**	**8.90**	**2.27**
LMSM19PW	**$C_3S=C_3S_{ref}$**	**75,30**	**19,00**	**5,70**	**65,89**	**22,72**	**5,57**	**1,40**	**89,36**	**3,26**	**3,97**	**65,75**	**16,95**	**10,47**	**2,39**
LMSM19AA*	**$C_3S=C_3S_{ref}$**	**80,26**	**19,00**	**0,74**	**65,81**	**22,45**	**5,73**	**1,84**	**89,55**	**2,96**	**3,12**	**65,76**	**16,15**	**10,21**	**3,73**

*****AA=50%ashFA+50%ashPA

For cement mixtures to be suitable, the oxides provided by the raw materials must respect given limitations and proportions [31, 32, 33, 34]; in general the compositions (by wt) are in intervals :C between 60-69% , S between 8-24%, A between 4-8%, F between 1-8%, M less than 5%, N-K less than 2 %, $\underline{S}$ less than 3%, and in clinker free lime less than 2% . The lime saturation factor LSF represents the ratio between the available amount of C and the amount required to react with S, A and F to form the clinker phases. When the LSF is high, the clinker is rich in C_3S indicating good quality. Although, these reactions, between oxides, are not entirely complete, resulting in the presence of unreacted free lime CaO, which must be kept below 2% to prevent mortar expansion. The amount of free lime in the mixes after burning at 1400 °C for 30 min is given by Fundal's empirical equation [35]: $\% CaO_{(free)} = 0.31 (LSF-100) + 2.18 (SR- 1.8) + 0.73 Q_{45} + 0.33 C_{125} + 0.34 A$,where Q_{45} is the fraction by weight of quartz particles >45 µm, C_{125} the fraction by weight of limestone particles >125 µm and A the fraction of clay materials >45µm. In practical applications, the LSF typically varies between 92 to 98%. Alternative formulations for LSF may also be used, reflecting the presence of anhydrite, where CaO is combined with SO_3 ($-0.7.SO_3$), however, it could also reflecting the possibility of replacement of CaO by MgO (+0.75MgO). The silica modulus (SR) represents the ratio of the oxides S / (A+F), it controls the burnability [36]. Higher SR values can slow down the formation of C_3S , and when the SR decreases, the amount of molten material in the burning zone is large. Regarding the AF modulus (A/F) a higher value can be can be disadvantageous in certain cement applications resulting in reduced setting time. In such cases, additional gypsum may be required to delay the setting time.

Often, high values have been observed for ε_{AF}, and therefore it is necessary to use corrective materials, to decrease this parameter. For an LCNone mixture (or LCN, simply), we look for a condition on a third material W to correct its alumina-ferric oxide ratio AF, and we note by a/f the ratio of W and by x' its percentage in LCW ; we show that we must choose W having a ratio smaller than that of the LCN mixture :

$$AF_{LCW} = \frac{A + x'a}{F + x'f} = \frac{A(1 + x'\frac{a}{A})}{F(1 + x'\frac{f}{F})} = AF_{LCN}\frac{1 + x'\frac{a}{A}}{1 + x'\frac{f}{F}} \text{ : so } AF_{LCW} < AF_{LCN} \text{ if } AF_W < AF_{LCN}$$

In our example, the AF ratio for waste materials FA and ZW are respectively 0.06 and 0.14. It is not possible to obtain equalization of the 11 parameters between the LCW mixture and the reference, but this is not very restrictive. In general, depending on the desired performance, it is possible to develop a material composed of several mining wastes among those available. Ultimately, the mining wastes considered can be recycled into clinkers, and this program would provide the optimal compositions. In the case of phosphate wastes, the influence of P_2O_5 and PG compounds on special belt clinkers [37] and the potential to lower clinking temperature have been reported in the literature [38]. While recycling existing mine waste is possible, it is crucial to reassess current production processes to minimize waste generation and promote environmentally friendly practices [39].

4. Conclusions

This study has two main objectives: (i) investigating the recycling or potential recovery of mining waste, leading to economic and ecological benefits, and (ii) providing a simulation tool to closely match a target cement raw meal with a cementitious mixture. the python program is easy to use because it imports the oxide composition information (XRF) and the 9 user choices entered in the cemat table file; it generates 11 solutions and 11 graphs of the parameters retained for the cement mixture LCyWx and the target raw reference. It efficiently determines the x% and y% percentages, achieving the desired values for the four oxides, three moduli, and the percentages of the four clinker phases. The outcomes of this paper can be summarised as follows:

- Mining waste can be effectively recycled and even recovered in cement production. This approach offers ecological benefits as the waste materials become immobilized within the cement structures. In contrast, leaving these waste materials in nature could lead to their mobility, causing potential environmental issues in water, soil, and air.
- The python program gives the variations of the relative deviations, with respect to the reference, of the 11 characteristics ε_i (x, y), as well as the speed of these variations. In general, according to each of the 11 ε_i (x, y) parameters, the user chooses a maximum aceptable value

- This program can be extended by adding other parameters; this involves, for example, taking into account other oxides, like free lime and MgO, minors components, etc; or the unit prices of LCW materials to assess the unit cost of the clinker studied. The program does not need to be modified, if the user adds or subtracts materials in the material part of the data table.
- The third material can also be a corrective material, or a mixture formed from different materials. The program can be applied to other waste, such as construction waste, etc.
- The type and quantity of mining waste used can influence the burnability, grindability, but also the quality of the clinker and, consequently, the resulting concrete. The Python program can be extended to determine the composition of minor compounds. Thus some heavy metals (Cu, Zn) have a good influence on the burnability of clinker; but some compounds must not exceed certain limits: chloride ions can contribute to the corrosion of iron in concrete, P_2O_5 can reduce C_3S content, ZnO can cause delay in the setting of cement, etc. In addition, during the production of clinker, atmospheric emissions must comply with environmental standards.

All the results and simulations obtained through the Python program can help in decision-making by optimizing the choice selection of the composition of the mixture studied. However, the mathematical aspect should not overshadow other physico-chemical considerations in real-world industrial and manufacturing processes.

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Appendix : the used Python rogram LCW.py (instructions lines 1-296)

(modify path in line 9, #ignored instruction or text)

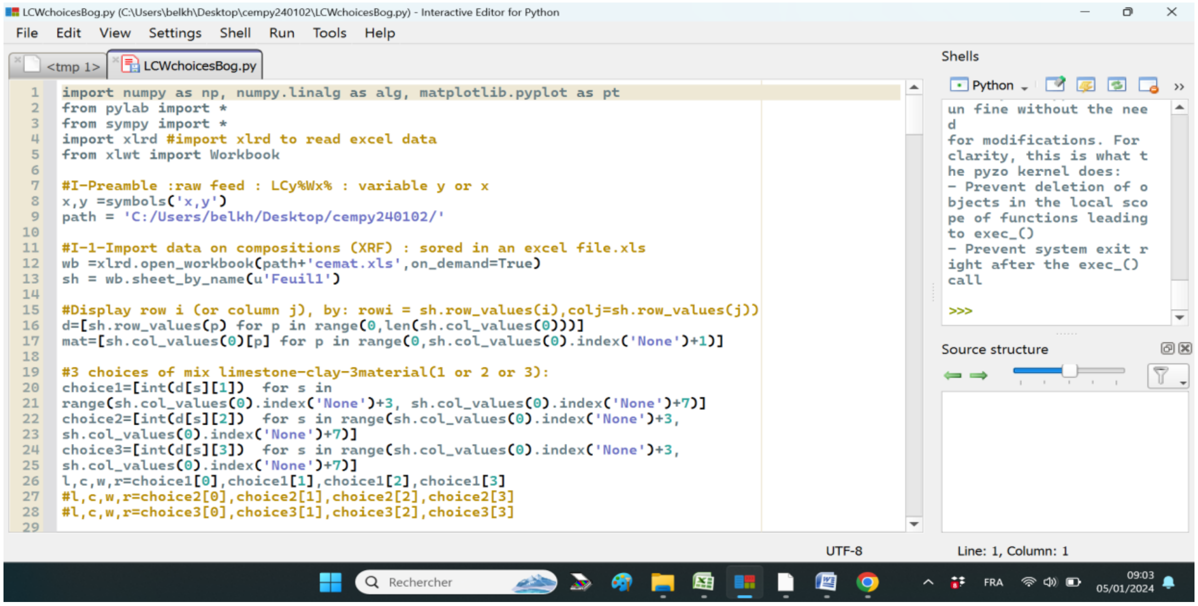
```
import numpy as np, numpy.linalg as alg, matplotlib.pyplot as pt
from pylab import *
from sympy import *
import xlrd #import xlrd to read excel data
from xlwt import Workbook

#I-Preamble :raw feed : LCy%Wx% : variable y or x
x,y =symbols('x,y')
path = 'C:/Users/belkh/Desktop/cempy240102/'

#I-1-Import data on compositions (XRF) : sored in an excel file.xls
wb =xlrd.open_workbook(path+'cemat.xls',on_demand=True)
sh = wb.sheet_by_name(u'Feuil1')

#Display row i (or column j), by: rowi = sh.row_values(i),colj=sh.row_values(j))
d=[sh.row_values(p) for p in range(0,len(sh.col_values(0)))]
mat=[sh.col_values(0)[p] for p in range(0,sh.col_values(0).index('None')+1)]

#3 choices of mix limestone-clay-3material(1 or 2 or 3):
choice1=[int(d[s][1])  for s in
range(sh.col_values(0).index('None')+3, sh.col_values(0).index('None')+7)]
choice2=[int(d[s][2])  for s in range(sh.col_values(0).index('None')+3,
sh.col_values(0).index('None')+7)]
choice3=[int(d[s][3])  for s in range(sh.col_values(0).index('None')+3,
sh.col_values(0).index('None')+7)]
l,c,w,r=choice1[0],choice1[1],choice1[2],choice1[3]
#l,c,w,r=choice2[0],choice2[1],choice2[2],choice2[3]
#l,c,w,r=choice3[0],choice3[1],choice3[2],choice3[3]

#4+1 choices:bonds intervals and y0
y1,y2,x1,x2,yc=d[len(mat)+8][1],d[len(mat)+8][2],d[len(mat)+9][1],
d[len(mat)+9][2],d[len(mat)+9][3]
print('intervaly1-y2=',y1,y2,'--intervalx1-x2=',x1,x2,'--yc=' ,yc)
for p in range(0,6):
   print(d[0][p],' ',d[l][p],' ',d[c][p],'',d[w][p])
if w==sh.col_values(0).index('None'):
   x=0
   name=d[l][0]+d[c][0]+str(y)+d[w][0]+'-ref-'+d[r][0]
else:
   x!=0
   y=yc
   name=d[l][0]+d[c][0]+str(y)+d[w][0]+str(x)+'%'+'-ref-'+d[r][0]
print('The mixture studied is :',name)

#II-Compositions of oxides  after loss of ignition(lists: o and o0=refernce
#Mass of raw feed mr=100 kg, after LOI, we get mk mass of clinker

mk=0.01*((100-x-y)*(100-d[l][9])+y*(100-d[c][9])+x*(100-d[w][9]))
o=np.array([((((100-x-y)*d[l][q]+y*d[c][q]+x*d[w][q]))/(mk)) for q in
range(2,7)])
o0=np.array( [(100*(d[r][q]))/(100-d[r][9])  for q in range(2,7)])

#solutions x or y for equation OXi=OXi0:
ox=[(solve(o[q]-o0[q]))[0] for q in  range(0,4)]

#III-Determination of the 3 modulus (list:m) with hypothesis for
#LSF(A/F><0.64),-0.7*so3 gypsum),SR,AF

if (d[l][4]/d[l][5]<0.64 or d[c][4]/d[c][5]<0.64
or d[r][4]/d[r][5]<0.64):
         lsf=100*(o[0]-0.7*o[4])/   (2.8*o[1]+1.18*o[2]+0.65*o[3])
         lsf0=100*(o0[0]-0.7*o0[4])/(2.8*o0[1]+1.18*o0[2]+0.65*o0[3])
         print('Modify LSF denominator expr to: 2.8S+1.1A+0.65F,in line...')
else:
   lsf=100*(o[0]-0.7*o[4])/(2.8*o[1]+1.65*o[2]+0.63*o[3])
   lsf0=100*(o0[0]-0.7*o0[4])/(2.8*o0[1]+1.65*o0[2]+0.35*o0[3])
   print('keep LSF denominator expr (2.8S+1.65A+0.35F):see line...)')

#Verification 0.71<AF<2.27 :LSF ok!n LSF substract gypsum

sr=o[1]/(o[2]+o[3])
af=o[2]/o[3]
m=[lsf,sr,af]

sr0=o0[1]/(o0[2]+o0[3])
```

```
af0=o0[2]/o0[3]
m0=[lsf0,sr0,af0]

#solutions of mod i=mod i,0 :[14.68, 3.835, -0.82]
md=[(solve(m[q]-m0[q]))[0] for q in range(0,3)]

#IV-Determination of % phases in clinker (after LOI);phases noted p1=C3S,p2=C2S,
#p3=C3A,p4=C4AF
#Phases determinated by Shiu (or Bogue orTaylor)model : matrix =k
k=np.array([[4.088,-7.212,-6.745,-1.436,-2.863],[-3.113,8.442,5.136,1.093,2.18],
[0.028,-0.153,2.604,-1.702,-0.020],[-0.01,-0.058,0.016,3.047,0.007   ],
[ 0.006,-0.02,-0.011,-0.002,1.696  ]])
p0 = np.linalg.solve(k, o0)
p = np.dot(k,o)
#kB=np.array([ [4.071,-7.600,-6.718,-1.430  ],[ -3.072,8.600,5.068,1.079   ],
#[0,0,2.650,-1.692     ],[0,0,0,3.043]])
#p0 = np.linalg.solve(kB, o0[:4])
#p = np.dot(kB,o[:4])
#ph : solutions for equations ph i=phi,0
ph=[(solve(p[q]-p0[q]))[0] for q in range(0,4)]

#V-Results :
#11 solutions for 11 criterions are stored in sol

sol=[float("%.2f" % x) for x in (ox+md+ph)]

#cr=o[:4]+m+p #expressions of 11 parameters vs x or y
cr=[o[0],o[1],o[2],o[3],m[0],m[1],m[2],p[0],p[1],p[2],p[3]]

#st matrix where we replace x or y by its solution  from 11 values of
#sol:11 lists, each list have 11elmnts
s0=[['R.V' if (v<0) or (v>100) else v for v in sol]]

if w==sh.col_values(0).index('None'):
    st=[[float("%.2f" % cr[q].subs(y,sol[v])) for v in range (0,11)] for q
    in range(0,11)]
    solz=[['RV' if (v<0) or (v>100) else 100-v for v in sol]]
    solx=[(0*np.ones(len(sol))).tolist()]
    soly=[['RV' if (v<0) or (v>100) else v for v in sol]]
else :
    st=[[float("%.2f" % cr[q].subs(x,sol[v]))  for v in range (0,11)] for q
    in range(0,11)]
    solz=[['RV' if (v<0) or (v>100) else 100-y-v for v in sol]]
    soly=[(y*np.ones(len(sol))).tolist()]
    solx=[['RV' if (v<0) or (v>100) else v for v in sol]]
#st[0]: values of C for each solution yi,xi

s1=[['RV' if (h<0) or (h>100) else h for h in st[u]] for u in range(0,4)]
#4 oxides in 4 col and 11 raws ; r.v: rejected value

s2 = [[ 'LV:'+str(t) if (t < 92 and t>0) else 'HV:'+str(t) if t>102 else 'RV'
if (t<0) else t for t in st[4]]]

s3 = [[ 'LV:'+str(t) if (t < 1.8 and t>0) else 'HV:'+str(t) if t>2.7 else 'RV'
if (t<0) else t for t in st[5]]]

s4 = [[ 'LV:'+str(t) if (t < 1  and t>0) else 'HV:'+str(t) if t>1.5 else 'RV'
if (t<0) else t for t in st[6]]]

s5=[['LV:'+str(t) if (t<45 and t>0) else 'RV' if (t>100 or t<0)  else
'HV:'+str(t) if (t>65 and t<100) else t for t in st[7] ]]

s6=[['LV:'+str(t) if (t<10 and t>0) else 'RV' if (t>100 or t<0)  else
'HV:'+str(t) if (t>30 and t<100) else t for t in st[8] ]]

s7=[['LV:'+str(t) if (t<5 and t>0) else 'RV' if (t>100 or t<0)  else
'HV:'+str(t) if (t>12 and t<100) else t for t in st[9]]]

s8=[['LV:'+str(t) if (t<6 and t>0) else 'RV' if (t>100 or t<0)  else
'HV:'+str(t) if (t>12 and t<100) else t for t in st[10] ]]

s9=[[   st[0][i]/st[1][i]  for i in range(0,11) ]]

s10=[ [   float("%.2f" % x) for x in s9[0]]]

s11=[[ 'RV' if s10[0][i]<0 else s10[0][i] for i in range(0,11)       ]]

he=[[ 'C=', 'S=', 'A=', 'F=', 'LSF=', 'SR=',
'AF=', 'C3S=', 'C2S=', 'C3A=', 'C4AF=']]
```

```
rr=[[]+[float("%.1f" % x) for x in o0[:4]      ]+[float("%.1f" % x) for x in m0]
+[float("%.1f" % x) for x in p0[:4]] ]

#sp=[['p','h','a','s','e', 'c','l','i','n','k','e','r']]
sp=[   ['|','|','|','|','|','|','|','|','|','|','|','|']]
tot=he+rr+solz+soly+solx+s1+s2+s3+s4+s5+s6+s7+s8+s11#+sp

r1=['Solution','Ref:'+d[r][0],'%'+d[l][0],'%'+d[c][0],'%'+d[w][0],
'C:','S:','A:','F:', 'LSF:', 'SR:','AF:', 'C3S:','C2S:', 'C3A:', 'C4AF:','C/S']
r2=['','','','','',
'60-69','18-24','4-8','1-8', '92-102', '1.8-2.7','1-1.5'
, '45-65','10-30', '5-12', '6-12','2.2-3.2']

r14=[ 'Remarks:','','RV:' ,'RejectedValue','','LV:','LowValue','', 'HV:',
'HighValue' ,'','     '+'Shim', 'proposition',':','2.22','<C/S<','3.21' ]

[tot[q].insert(0,r1[q]) for q in range(0,len(r1))]
[tot[q].insert(1,r2[q]) for q in range(0,len(r2))]
[tot[q].insert(14,r14[q]) for q in range(0,len(r14))]


#VI-File (xls or txt) with numerics values

import xlsxwriter
from datetime import datetime

workbook =xlsxwriter.Workbook(path+name+'Bogjan4.xlsx')
worksheet = workbook.add_worksheet(name)

date_time = datetime.now()
worksheet.write_datetime(0, 0, date_time)
date_format = workbook.add_format({'num_format': 'dd/mm/yy,  hh:mm'})
worksheet.write_datetime(0, 0, date_time, date_format)
worksheet.write(0,1,'RR:'+d[r][0]+'-vs-')
#worksheet.write(0,1,)
worksheet.write(0,2,d[l][0])
worksheet.write(0,3,d[c][0])
worksheet.write(0,4,d[w][0])
worksheet.write(0,7,'Calculations')
worksheet.write(0,9,'using')
worksheet.write(0,10,'Shim'+ ' '+'-')
worksheet.write(0,11,'proposition')
worksheet.write(0,13,'  '+'(from ')
worksheet.write(0,14,' experiments)')
row = 2

for col, data in enumerate(tot):
    worksheet.write_column(row, col, data)

#worksheet.write(row+len(tot[0]),1,'r.v: rejected value')

workbook.close()

#VII-Graphs for functions
#Intervals :without waste y1,y2=15,25;in presence of waste x1,x2=0,10
#Graphs for Shim model, modify to get graph3phases for Bogue model,etc...

if w==sh.col_values(0).index('None'):
    #x1,x2=15,25
    t=np.linspace(y1,y2,20)
    g=np.array([[cr[i].subs({y:q}) for q in t] for i in range(0,11)])
    variable=y
else :
    #x1,x2=0,10
    t=np.linspace(x1,x2,20)
    g=np.array([[cr[i].subs({x:q}) for q in t] for i in range(0,11)])
    variable=x

one=np.ones(len(t))

dc=(g[0])/(o0[0]*one)-one
ds=(g[1])/(o0[1]*one)-one
da=(g[2])/(o0[2]*one)-one
df=(g[3])/(o0[3]*one)-one
mi=min([ min(dc),min(ds),min(ds),min(df)])#min value
ma=max([ max(dc),max(ds),max(ds),max(df)])#max value
#sq=(float(ma)-float(mi))/4
```

```
pt.subplots_adjust(hspace = 0.9,left=0.135, bottom=0.15, right=0.97, top=0.91,
wspace=None)
pt.clf()
pt.subplot(3,1,1)
pt.plot(t,dc,'r',t,ds,'b',t,da,'g',t,df,'k',t,0*one,'k:')
pt.grid()
pt.suptitle(name,fontsize=8)
pt.xlabel('{}'.format(variable)+'(%)')
pt.xticks(np.arange(t.min(),t.max(), step=0.4), fontsize=8,rotation=90)
#pt.yticks(np.arange(y1,y2, step=sp), fontsize=8)
pt.ylabel(r"$\epsilon_{o}=\dfrac{(Mix-Ref)}{Ref})_{oxide}$", fontsize=8)
pt.text(x2,dc[len(t)-1],r"$\epsilon_{o}(C)$", fontsize=8)
pt.text(x2,ds[len(t)-1],r"$\epsilon_{o}(S)$", fontsize=8)
pt.text(x2,da[len(t)-1],r"$\epsilon_{o}(A)$", fontsize=8)
pt.text(x2,df[len(t)-1],r"$\epsilon_{o}(F)$", fontsize=8)
pt.text(x1-0.5,0,'  ', fontsize=6)
pt.legend([r"$\epsilon_{o}(C$)",r"$\epsilon_{o}(S)$",r"$\epsilon_{o}(A)$",
r"$\epsilon_{o}(F)$","0.0"],ncol=5,loc="upper left",bbox_to_anchor=(0,1.35),
fontsize=8)
pt.show()

dlsf=(g[4])/(m0[0]*one)-one
dsr=(g[5])/(m0[1]*one)-one
daf=(g[6])/(m0[2]*one)-one

pt.subplot(3,1,2)
pt.plot(t,dlsf,'r',t,dsr,'b',t,daf,'k',t,0*one,'k:')
pt.grid()
pt.suptitle(name,fontsize=8)
pt.xticks(np.arange(t.min(),t.max(), step=0.4), fontsize=8,rotation=90)
pt.xlabel('(%){}'.format(variable))
pt.ylabel(r"$\epsilon_{m}=\dfrac{(Mix-Ref)}{Ref})_{modulus}$", fontsize=8)
pt.text(x2,dlsf[len(t)-1],r"$\epsilon_{m}(LSF)$", fontsize=8)
pt.text(x2,dsr[len(t)-1],r"$\epsilon_{m}(SR)$", fontsize=8)
pt.text(x2,daf[len(t)-1],r"$\epsilon_{m}(AF)$", fontsize=8)
pt.text(x1-0.5,0,'  ', fontsize=6)
pt.legend([r"$\epsilon_{m}(LSF)$",r"$\epsilon_{m}(SR)$",r"$\epsilon_{m}(AF)$",
"0.0"  ],ncol=4, loc="upper left",bbox_to_anchor=(0, 1.35), fontsize=8)
pt.show()

dp1=(g[7])/(p0[0]*one)-one
dp2=(g[8])/(p0[1]*one)-one
dp3=(g[9])/(p0[2]*one)-one
dp4=(g[10])/(p0[3]*one)-one

pt.subplot(3,1,3)
pt.plot(t,dp1,'r',t,dp2,'b',t,dp3,'g',t,dp4,'k',t,0*one,'k:')
pt.grid()
pt.suptitle(name,fontsize=8)
pt.xticks(np.arange(t.min(),t.max(), step=0.4), fontsize=8,rotation=90)
pt.xlabel('(%){}'.format(variable))
pt.ylabel(r"$\epsilon_{p}=\dfrac{(Mix-Ref)}{Ref})_{phase}$", fontsize=8)
pt.text(x2-1,dp1[len(t)-1]+0.7,r"$\epsilon_{p}(C_{3}S)$", fontsize=8)
pt.text(x2,dp2[len(t)-1],r"$\epsilon_{p}(C_{2}S)$", fontsize=8)
pt.text(x2,dp3[len(t)-1],r"$\epsilon_{p}(C_{3}A)$", fontsize=8)
pt.text(x2,dp4[len(t)-1]-1.5,r"$\epsilon_{p}(C_{4}F)$", fontsize=8)
*pt.legend([r"$\epsilon_{p}(C_{3}S)$",r"$\epsilon_{p}(C_{2}S)$",
r"$\epsilon_{p}(C_{3}A)$",r"$\epsilon_{p}(C_{4}AF)$" ,"0.0 "  ],ncol=5,
loc="upper left", bbox_to_anchor=(0, 1.35), fontsize=8)
pt.show()
savefig(path+name+'.png')
```

Figure 4: opening and running the program LCW.py


LCWchoicesBog.py (C:\Users\belkh\Desktop\cempy240102\LCWchoicesBog.py) - Interactive Editor for Python
File Edit View Settings Shell Run Tools Help
<tmp 1>
LCWchoicesBog.py
import numpy as np, numpy.linalg as alg, matplotlib.pyplot as pt
from pylab import *
from sympy import *
import xlrd #import xlrd to read excel data
from xlwt import Workbook
#I-Preamble :raw feed : LCy%Wx% : variable y or x
x,y =symbols('x,y')
path = 'C:/Users/belkh/Desktop/cempy240102/'
#I-1-Import data on compositions (XRF) : sored in an excel file.xls
wb =xlrd.open_workbook(path+'cemat.xls',on_demand=True)
sh = wb.sheet_by_name(u'Feuil1')
#Display row i (or column j), by: rowi = sh.row_values(i),colj=sh.row_values(j))
d=[sh.row_values(p) for p in range(0,len(sh.col_values(0)))]
mat=[sh.col_values(0)[p] for p in range(0,sh.col_values(0).index('None')+1)]
#3 choices of mix limestone-clay-3material(1 or 2 or 3):
choice1=[int(d[s][1]) for s in
range(sh.col_values(0).index('None')+3, sh.col_values(0).index('None')+7)]
choice2=[int(d[s][2]) for s in range(sh.col_values(0).index('None')+3,
sh.col_values(0).index('None')+7)]
choice3=[int(d[s][3]) for s in range(sh.col_values(0).index('None')+3,
sh.col_values(0).index('None')+7)]
l,c,w,r=choice1[0],choice1[1],choice1[2],choice1[3]
#l,c,w,r=choice2[0],choice2[1],choice2[2],choice2[3]
#l,c,w,r=choice3[0],choice3[1],choice3[2],choice3[3]
Shells
Python
un fine without the nee
d
for modifications. For
clarity, this is what t
he pyzo kernel does:
- Prevent deletion of o
bjects in the local sco
pe of functions leading
to exec_()
- Prevent system exit r
ight after the exec_()
call
>>>
Source structure
UTF-8
Line: 1, Column: 1
Rechercher
FRA
09:03
05/01/2024