Electric arc furnace steel slag as a raw material towards the production of "green" cements

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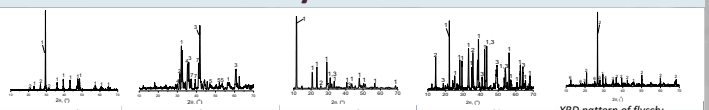
Abstract

Two types of "green" cements, a belite (BC) and a ferroalumino-belite (FABC) one were produced, using 10wt.% electric arc furnace steel slag (EAFS) as a raw material. Raw materials, produced clinkers and hydrated products of the cement pastes were characterized by XRF, XRD, TG, SEM-EDS techniques and the physical and mechanical properties of the produced cements were measured.

Introduction

Nowadays, more than 40% of the global steel production takes place in EAF. It is associated with the generation of 20 million tones EAFS. In Europe only 16.7% is used for cement production. Belite and FAB cements can be characterized as "green" ones as they require lower firing temperatures and the CO_2 emission is reduced. Utilization of EAFS in belite cements will reduce their environmental impact.

Raw materials analysis



XRD pattern of limestone: 1-calcite, 2 – quartz

XRD pattern of EAFS: 1 – larnite, 2 – gehlenite, 3 – wüstite, 4 – magnetite, 5 – brownmillerite

XRD pattern of gypsum: 1 –gypsum, 2 – quartz, 3 – dolomite

XRD pattern of bauxite: 1 – diaspore, 2 – boehmite, 3 – hematite

XRD pattern of flysch: 1 – calcite, 2 – quartz, 3 – illite, 4 – dolomite , 5 – albite, 6 – clinochlore

Chemical composition of the raw materials, XRF analysis (wt.%)

Raw materials	CaO	Fe_2O_3	SiO_2	Al_2O_3	MnO	MgO	Cr_2O_3	P_2O_5	TiO_2	SO_3	Cl	BaO	Na_2O	K_2O	V_2O_5	LOI	Total
EAFS	32.5	26.3*	18.1	13.3	3.94	2.53	1.38	0.48	0.47	0.44	0.14	0.14	0.13	n.d.	0.06	0.00	99.91
Limestone	48.9	1.00	9.00	1.36	n.d.	0.65	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.10	0.15	n.d.	38.00	97.16
Flysch	5.55	5.90	58.25	13.75	n.d.	2.86	n.d.	n.d.	n.d.	0.05	n.d.	n.d.	1.10	2.50	n.d.	9.80	99.76
Bauxite	3.62	23.00	14.30	49.20	n.d.	n.d.	n.d.	n.d.	n.d.	0.23	n.d.	n.d.	n.d.	n.d.	n.d.	13.89	104.24
Gypsum	24.73	0.04	12.76	0.18	n.d.	n.d.	n.d.	n.d.	n.d.	39.30	n.d.	n.d.	n.d.	n.d.	n.d.	23.14	102.00

*LOI: loss on ignitions, n.d.: not determined, * - FeO, Fe_2O_3*

Clinker production

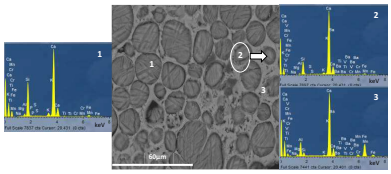
Raw materials content in the raw meal, quality indexes and estimated mineralogical phases

Clinker types	Raw material proportions					Quality indexes			Mineralogical phases						
	EAFS	Limestone	Flysch	Bauxite	Gypsum	LSF	AM	SM	C_3S	C_3A	C_2S	C_4AF	$C_4A_3\bar{S}$	$C\bar{S}$	C
BC	10	77.00	13.0	-	-	78.10	1.00	1.96	17.59	6.01	57.32	19.13	-	-	0
FABC	10	64.50	-	18.70	6.8	70.45	1.51	0.59	-	-	45.70	32.88	18.65	2.6	0.21

Laboratory scale clinker production procedure

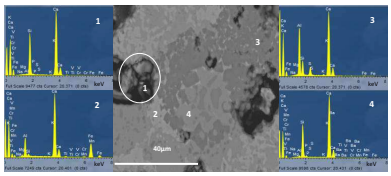
Milling of the raw materials at particles size < 90μm → mixed in resulted amounts from Bogue estimation → water addition → hand made pellets with diameter 15mm-20mm → pellets' dehydration at 110°C/24 hours → Firing temperature: *BC 1380°C, FABC 1320°C*, *soaking time 40min* → Fast cooling : hammer crushing + air blowing

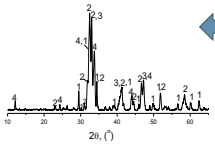
Clinker characterisation



SEM backscattered image with EDS spectra of BC clinker in polished section, nital 1% etched: 1-C_2S, 2-C_3S and 3-C_4AF

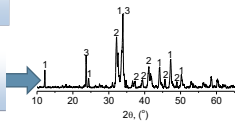
SEM backscattered image with EDS spectrua of FABC clinker, polished section: 1,4-C_2S, 2-C_4AF, 3-$C_4A_3\bar{S}$



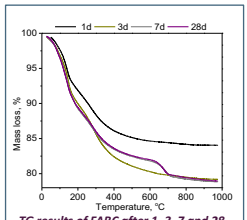


XRD pattern of BC: 1 - alite (C_3S), 2-belite (C_2S), 3 - calcium aluminate (C_3A) 4- brownmillerite (C_4AF)

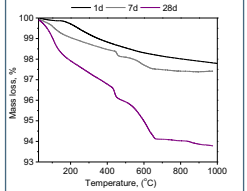
XRD pattern of FABC: 1 - brownmillerite (C_4AF), 2 - larnite (C_2S), 3 - yeelimite ($C_4A_3\bar{S}$)



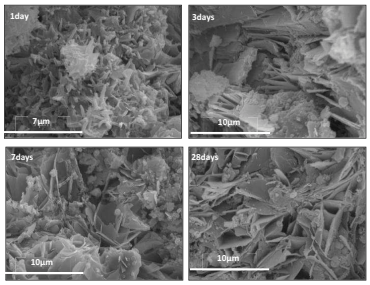
Hydration studies



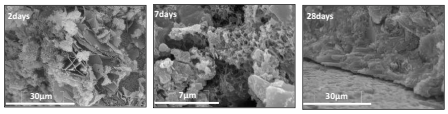
TG results of FABC after 1, 3, 7 and 28 days of hydration



TG results of BC after 2, 7 and 28 days of hydration



SEM, secondary micrographs of FABC after 1 day, 3 days , 7 days and 28 days of hydration



SEM, secondary micrographs of BC after 2 days, 7 days and 28 days of hydration

Physical and mechanical properties

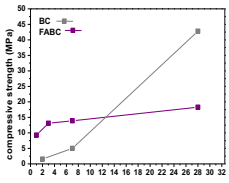
Milling time for 50g of clinker vs. particle size a) BC, b) FABC

a) BC	
milling time (sec)	particle size (mm)
97	1.25
103	1.25 - 1.8

b) FABC	
milling time (sec)	particle size (mm)
71	1.25
73	1.25 - 1.8

Physical properties of the cements and cements pastes, EN 196-3 and EN 196-6

Cement types	Specific surface (cm^2/g)	Initial setting time (min.)	Water demand (wt.%)	Soundness (mm)
BC	4057	20	27.6	1
FABC	4100	7	45	0.9



Compressive strength results of the cement paste after different curing time

Conclusions

- A BC and a FABC cement were produced with 10% EAFS addition.
- At 7 days, higher early strength was developed for the FABC (13,9MPa) than the BC (5MPa), due to the ettringite formation.
- At 28 days, BC (42,8MPa) develops higher compressive strength than FABC (18,3MPa) due to the late belite hydration.

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