IOP Conference Series: Materials Science and Engineering

New perspectives for the green economy in Sicily

To cite this article: F Parisi *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **777** 012006

IOP Conf. Series: Materials Science and Engineering **777** (2020) 012006 doi:10.1088/1757-899X/777/1/012006

New perspectives for the green economy in Sicily

F Parisi[1,*], G Sabatino[1], G Marcianò[1], A Mottese[1], G Nania[2], F Leonetti[2], S Sfameni[3], M Di Bella[4], P Mazzoleni[5], G Barone[5], A Tripodo[1], D Drommi[6] and S Magazù[1]

[1] Department of Mathematical and Computational Sciences, Physical Science and Earth Science, University of Messina, Viale Ferdinando Stagno d'Alcontres 31, 98166 Messina, Italy.
[2] Edil Ponti SCARL, Contrada Giardina Km 98 300 snc, Gela (Caltanissetta), Italy.
[3] Department of Engineering, University of Messina, C.da Di Dio, Vill. S. Agata, 98166 Messina, Italy.
[4] Istituto Nazionale di Geofisica e Vulcanologia (INGV), Sezione di Palermo, Via Ugo la Malfa 153, 90146 Palermo, Italy.
[5] Department of Biological, Geological and Environmental Sciences, University of Catania, Corso Italia 57, 95129 Catania, Italy.
[6] Department of ChiBioFarAm, University of Messina, Viale Ferdinando Stagno d'Alcontres 31, 98166 Messina, Italy.

* E-mail: ing.parisifrancesco@gmail.com

Abstract. Geopolymers are synthetic materials, which attract increasing interest because they represent a supplementary cementitious material as an alternative to Portland cement. Geopolymers are considered as environmentally friendly materials, due to the low processing temperature and the absence of CO_2 gas emissions. These ecological features, linked to their technical properties, such as high strength, high acid resistance, and/or high-temperature resistance, make them very innovative technological materials. In addition, geopolymers show good performance if realized by the utilization of secondary raw materials (industrial wastes like fly ash or slag), thus improving strong interest in such technology from countries with growing industrialization. Here, in order to reduce global impacts and to stimulate the Sicilian green economy, we provide the evaluation of the Life Cycle Assessment (LCA) through the employ of local raw materials to produce geopolymers in Sicily. To reach this aim, geopolymers have been produced in collaboration with a Sicilian cement industry, through the use of local raw materials (furnace blast slag from Sicilian steelworks and Calabrian kaolinite) and the construction of a pilot plant. The obtained results show, for different scenarios, a considerable reduction of both CO_2 emissions and energy consumption, but also a general improvement of the environmental indicators.

1. Introduction

"Geopolymers" are synthetic materials obtained from alkaline activation of natural raw materials (e.g. clay as kaolin/metakaolin) or secondary raw materials (industrial wastes like fly ash or blast furnace slag) used to make binder systems as an alternative to Portland cement, besides restoration applications in the field of cultural heritage [1].The production process of Portland cement is well acknowledged as having a significant impact on the environment, for the high amount of CO_2 emissions (5-8% of global anthropic emissions) and the substantial energy consumption (mainly from fossil fuels) [2].

This study aims to analyze environmental and energetic impacts for the production of 1 kg of Geopolymers based concrete in two different formulations in a cement industry (Edil Ponti SCARL) in Sicily, Italy. The goal is to provide local raw materials (a furnace blast slag from Sicilian steelworks and a Calabrian kaolinite clay) to reduce global impacts and to stimulate the Sicilian green economy.

The most usable and complete technique to evaluate the potential impact on the environment during the Geopolymers production is named as Life Cycle Assessment (LCA) [3]. LCAs can help avoid a narrow outlook on environmental concerns by: 1) definition of goals; 2) compiling an inventory of relevant energy and material inputs and environmental releases; 3) evaluating the potential impacts associated with identified inputs and releases; 4) interpreting the results to help make a more informed decision.

The method used for LCA in this study is “from cradle to gate” which means that are evaluated environmental impacts associated with all the stages of the product life, from raw material extraction and distribution, through materials processing and manufacturing to the industry gate.

2. Local raw materials and analytical techniques

2.1. Sicilian furnace blast slag

To boost the Sicilian green economy, it is vital to choose local raw materials supplying. The furnace blast slag comes from a Sicilian steelworks (Acciaierie di Sicilia Spa, Catania) through a furnace blast (bow model). The geopolymerization reaction of the slag is highlighted by the different pattern resulting from the XRD characterizations (Figure 1) of the material before and after alkaline activation.

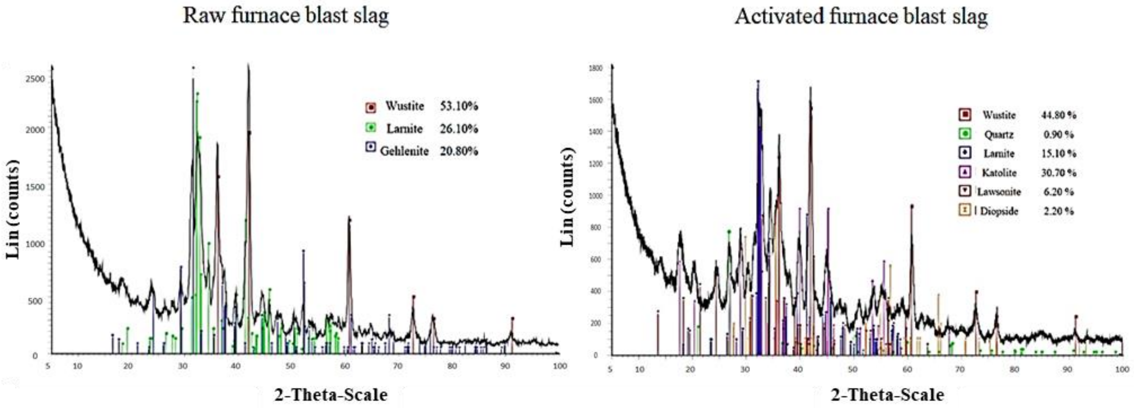

Figure 1. XRD patterns of the raw furnace blast slag (left) and of activated furnace blast slag (right).

2.2. Calabrian kaolinite

In Calabria there are several sites where kaolin is extracted. Two quarries in which mining activities are still active are in Acri (Cs), named “Colle Costantino” and “Colle Costantino Ampliata”.The site under study falls within the area of Longobucco, where mainly terrigenous lithotypes are present. The succession is represented by the formation of Torrente Duno (conglomerates, sands and clays), and at the bottom the Hercynian crystalline basement. In the past, some studies have been conducted [4] focused on 18 samples cataloged as follows: the sediments of the Torrente Duno formation (LB1 – LB8 samples), the sediments of the Fosso Petrone formation (sample LB9 – LB11) and Fiume Trionto (sample LB12 – LB18). Table 1 shows major elements and Chemical Index of Alteration (CIA) ratio of Calabrian kaolinite samples: LB1 – LB8 samples have content of SiO_2, Al_2O_3, TiO_2, Fe_2O_3, and K_2Osimilar to PAAS (Post-Archean Australian Shale) [5] and a lower MnO, MgO, CaO,Na_2O, and P_2O_5 content; the sediments of the Fosso Petrone formation (sample LB9 – LB11) and Fiume Trionto (sample LB12 – LB18) result rich of CaO and poor of SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO, Na_2O, K_2O andP_2O_5 related to the PAAS.

Table 1. XRF data of major elements (wt %) and Chemical Index of Alteration (CIA) ratio of the analyzed calabrian kaolinite.

Formations	Torrente Duno							
Sample	**LB1**	**LB2**	**LB3**	**LB4**	**LB5**	**LB6**	**LB7**	**LB8**
SiO_2	55.16	71.27	65.92	59.38	58.81	59.23	63.32	71.18
TiO_2	0.90	1.10	1.03	1.30	1.35	1.20	0.93	0.95
Al_2O_8	22.08	16.15	19.20	20.05	20.73	19.49	19.52	13.94
Fe_2O_8	6.04	2.35	2.49	6.79	1.01	4.03	5.01	3.35
MnO	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
MgO	1.60	1.11	1.51	1.43	1.48	1.00	1.28	1.44
CaO	0.30	0.14	0.51	0.18	0.19	1.06	0.22	0.81
Na_2O	0.16	0.14	0.31	0.17	0.18	0.32	0.16	0.47
K_2O	4.72	3.51	3.70	4.44	4.66	3.72	4.44	3.53
P_2O_5	0.03	0.02	0.02	0.04	0.04	0.03	0.02	0.01
L.O.I.	9.01	4.19	5.59	6.22	5.65	9.92	5.08	4.31
C.I.A.	73.40	73.30	73.50	73.00	72.70	71.70	73.30	65.70

Formations	Fosso Petrone			Fiume Trionto						
Sample	**LB9**	**LB10**	**LB11**	**LB12**	**LB13**	**LB14**	**LB15**	**LB16**	**LB17**	**LB18**
SiO_2	54.15	64.83	64.32	57.13	47.91	46.98	60.99	39.60	37.32	30.45
TiO_2	0.75	0.61	0.56	0.69	0.68	0.68	0.53	0.42	0.41	0.40
Al_2O_8	16.85	10.14	9.19	12.23	13.15	13.62	9.33	8.48	7.19	8.90
Fe_2O_8	3.83	3.52	3.06	3.50	3.33	3.24	2.82	2.56	2.72	2.78
MnO	0.02	0.03	0.03	0.01	0.02	0.02	0.03	0.03	0.04	0.04
MgO	2.26	2.05	1.98	2.19	2.53	2.47	1.99	1.72	1.70	2.12
CaO	5.03	6.23	7.77	8.62	12.95	12.71	9.79	21.47	24.23	25.00
Na_2O	0.30	0.42	0.43	0.35	0.35	0.34	0.36	0.27	0.35	0.19
K_2O	3.70	2.74	2.45	2.76	2.76	2.80	2.59	2.01	1.49	2.15
P_2O_5	0.06	0.08	0.07	0.04	0.04	0.05	0.08	0.08	0.09	0.09
L.O.I.	13.04	9.36	10.14	16.27	16.27	17.09	11.50	23.36	24.47	27.89
C.I.A.	-	-	-	-	-	-	-	-	-	-

3. Life Cycle Analysis

3.1. Production process description

The preparation of geopolymeric concrete is made up of three principal steps: raw materials supplying, distribution to the industry and preparation process.

To realize the final product, the first step is to grind the raw materials through an electronic mill Elite MGS Italy (1 kW) model with four independent grinding unit of 1800 cc for 30 min. After grinding, the raw materials have the eligible granulometry to be mixed by a cement mixer Syntesi 190 IMER (1 kW) for 30 min. Then, the mixture is placed manually on formworks and put in an electric oven (3 kW) at 80°C for 72 h. Table 2 shows the compositions of the two samples analyzed for 1 kg of final product(declared unit of LCA):

Table 2. Compositions of geopolymeric concretes for LCA.

Furnace blast slag concrete 1 kg		**Calabrian Clay concrete 1 kg**	
Furnace blast slag	225 g	Calabrian clay	225 g
Sand	770 g	Sand	770 g
Sodium silicate (37%) (dry)	0,72 g	Sodium silicate (37%) (dry)	9,25 g
Sodium hydroxide 9 M (dry)	16,20 g	Sodium hydroxide 12,5 M (dry)	5 g
Water	40 ml	Water	100 ml

3.2. LCI Life Cycle Inventory

Through the Life Cycle Inventory are evaluated input and output data for all the stages of the product's life. Table 3 shows the global impacts for 1 kg of raw material supplying (S) and distribution (D):

Table 3. CO_2 emissions and Energy demand for raw materials supplying (S) and transport (D).

Raw materials (1 kg)	**Emission (Kg CO_2/kg)**		**Energy demand (MJ/kg)**	
	S	D [6]	S	D [6]
Furnace blast slag [7]	0,551	0,0085 (100 km)	18,7	1687,5
Calabrian clay [8]	0,424	0,036 (420 km)	4	6930
Sodium silicate (37%) (dry) [9]	0,424	0,65(1350 km)	13,14	4050
Sodium hydroxide (dry) [10]	1,100	0,024 (310 km)	8,35	5759
Sand (extraction) [8]	0,424	-	4	-

The production process, for both samples, is influenced by thermal curing at low temperatures (80°C for 72 h) as results from the Table 4:

Table 4. CO_2 emissions and energy demand for production process.

Production process (1 kg)	**Emission (Kg CO_2/kg)**	**Energy demand (MJ/kg)**
Grinding (30 min)	0,025	0,180
Mixing (30 min)	0,025	0,180
Thermal curing (80°C,72 h)	0,480	3,450
TOT.	0,530	3,810

3.3. Calculation of geopolymer concrete impacts

To evaluate environmental and energetic impacts of the final product (Global Warming Potential – GWP, and Cumulative Energy Demand - CED), the input data for each raw material are calculated according to the relative presence in the compositions of the two samples:

Table 5. GWP and CED indicators for the two geopolymeric concretes.

LCA for 1 kg of furnace blast slag concrete			
		GWP ($kgCO_{2eq}$)	**CED (MJ)**
Raw materials supplying		0,15	4,45
Distribution		0,04	865,60
Production process		0,53	3,81
	TOT.	**0,72**	**873,86**

LCA for 1 kg of calabrian clay concrete			
		GWP ($kgCO_{2eq}$)	**CED (MJ)**
Raw materials supplying		0,06	0,16
Distribution		0,02	658,30
Production process		0,53	3,81
	TOT.	**0,61**	**662,27**

4. Results and discussion

In this study are analyzed the environmental impacts of the production of two geopolymeric concretes through the Life Cycle Analysis.

In terms of CO_2emissions, for both samples, the thermal curing, in the production process, is the principal source. Thanks to the low temperature (80 °C), GWP of both geopolymeric concretes is 40%-50% lower than Portland concrete manufacturing (1 $kgCO_2eq/kg$), on average. Both samples have shown the possibility of room temperature curing so it is possible to break down the value of GWP and CED indicators.

The furnace blast slag is an ideal raw material for the production of a geopolymeric binder by alkaline activation. In Sicily, it is easily available and its production is steady throughout the year. The goal is to make it a secondary raw material otherwise it would be destined for landfill disposal.

The result of LCA shows that the cumulative energy demand of the entire life cycle depends mostly on distribution. For distances over 500 km the impacts are remarkable. To minimize the environmental impacts and to boost the sicilian green economy, it is vital to choose local raw materials (overall for chemicals supplying). Further studies are needed to extend laboratory results to an industrial upscaling.

5. Conclusions

The aim of this work is to value the production of two geopolymeric concretes in Sicily (Italy). Local raw materials like calabrian kaolin or sicilian furnace blast slags are used to realize two different types of concrete. Analytic characterizations show the eligible properties of raw materials for the geopolymerization process.

Geopolymeric concretes have mechanical performances comparable to ordinary Portland concrete and are used to make binder systems in the constructions or for restoration applications in the field of cultural heritage.

A Life Cycle Assessment (LCA) "from cradle to gate" is drafted for the realization of each samples and two global indicators are evaluated (GWP, CED). Results show that each sample produces a GWP indicator 40% lower than Portland concrete manufacturing (1 kg CO_2eq/kg) on average. Geopolymer production represents a smart and eco-friendly alternative to Portland cement, which allow the production of a green material and also improving the sicilian local economy.

Acknowledgments

The research is supported by the AGM for CuHe project. PNR 2015-2020. Area di Specializzazione "CULTURAL HERITAGE". CUP E66C18000380005. CNR and Noxorsokem Group S.r.l. are gratefully acknowledged for S. Sfameni Industrial PhD funding.

References

[1] Provis J L and van Deventer J S J 2009 *Geopolymers Structures, Processing, Properties and Industrial Applications* (Woodhead Publishing Limited and CRC Press LLC) pp 2-6
[2] Provis J L and van Deventer J S J 2009 *Geopolymers Structures, Processing, Properties and Industrial Applications* (Woodhead Publishing Limited and CRC Press LLC) pp 379-380
[3] Provis J L and van Deventer J S J 2009 *Geopolymers Structures, Processing, Properties and Industrial Applications* (Woodhead Publishing Limited and CRC Press LLC) pp 194-209
[4] Perri F, Cirrincione R, Critelli S, Mazzoleni P and Pappalardo A 2008 Clay Mineral Assemblages and Sandstone Compositions of the Mesozoic Longobucco Group, Northeastern Calabria: Implications for Burial History and Diagenetic Evolution, *Int Geol Rev* **50** 1116–1131
[5] Taylor S R and McLennan S M 1985 The continental crust: Its composition and evolution, United States
[6] Bernetti A, Contaldi M and Sestili P 2017 ISPRA Istituto superiore per la protezione e la ricerca ambientale *Transport Rep 2017*
[7] Buttiens K, Leroy J, Negro P, Thomas J S, Edwards K and De Lassat Y 2016 The Carbon Cost of Slag Production in the Blast Furnace *J Sustain Metall* **2** 65-66
[8] Lavagna M, Mondini D and Paleari M 2011 Murature ad alte prestazioni. Valutazioni termiche, acustiche, ambientali ed economiche di soluzioni di involucro in laterizio (Maggioli Editore) pp 89-90
[9] Fawer M, Concannon M, and Rieber W 1999 Life Cycle Inventories for the Production of Sodium Silicates *Int. J. LCA* **4** 210-212
[10] Bousted I 2005 Eco-profiles of the European Plastic Industry: Sodium Hydroxide, A report for Plastic Europe Association, pp 1-18.