Joint contribution of CEMBUREAU and EuCIA to the JRC "Recycling" definition project with regard to Co-processing of Composite End of Life/Use Material Specific to the Cement Industry

Summary

Composites are polymers that are reinforced with high strength and stiffness fibers, such as glass fibers and carbon fibers. Composites offer exceptional consumer properties and deliver significant material and energy savings helping thus to achieve today's energy and climate goals. They are used as durable and lightweight materials in for example wind turbine blades, cars and other transportation means and building and construction applications.
Composites can be formulated to withstand plenty of service environments (using different types of fibers and matrix materials), while satisfying many specific end-use requirements. However, the same material combination that determines the attractive properties of these materials, make them difficult to recycle.

Co-processing of End of Life/Use composites in cement manufacturing offers a unique waste management solution, where the material is simultaneously used as both a highly effective source of energy and of mineral raw material in a single process. Here, a joint document developed by CEMBUREAU and EuCia is augmented by applying the "R-index" to the compositional definition of the fiber glass reinforcement, a large and essential component that make composites work. **This study can be of help to clarify co-processing of composites in the cement process as a clear example of recycling under the Waste Framework Directive (WFD) EC/98/2008.**

1. Co-processing in Cement - General aspects

During co-processing the waste[1] is simultaneously used as both a source of energy and a source of mineral raw material in a single process. Additionally, co processing of composites in cement production is a zero-waste solution.[2]

Positive contribution to the environment:

- Circular economy: Co-processing allows material recycling in reducing the use of natural raw materials in cement manufacturing, while mitigating climate change contribution through replacement of fossil energy sources
- Climate change mitigation: Co-processing is a main pathway for reduction of CO_2 intensity in cement manufacturing and an essential element for the cement sector to reach the carbon neutrality vision of 2050. According to CEMBUREAU's Roadmap to Carbon Neutrality in 2050, the replacement of fossil fuels by non-recyclable and biomass waste, and the use of alternative raw materials, will deliver 15% of the CO2 emissions reduction in the cement industry in 2050. Considering the co-processing rate of 50% in 2019, the EU cement industry achieved to avoid the emission of 22.7 Mtonnes of CO2 which can be further increased every year, as the co-processing rate increases.

[1] This is a generalized term to include a wide variety of End of Life materials. Composites, although often not at the end of its useful life, can be considered part of that when its use is not needed anymore.
[2] It is claimed that some additions provide added value (catalytic, etc.) to the clinker production process, which is the energy intensive step of the cement production process

Difference between waste incineration and co-processing in a cement plant

- The fundamental difference lies in the fact that the main purpose of cement plants is to produce cement (i.e. create a value-added product) whilst incinerators are dedicated facilities for the disposal of waste that may or may not recover heat generated by combustion (i.e. "get rid" of a waste stream)
- Co-processing plants (such as cement or lime kilns, steel plants, etc.) whose main purpose is the production of material products and in which waste is used as a fuel and/or raw material that otherwise would be subject to disposal.

The cement manufacturing process is highly energy efficient.

- Energy efficiency in the cement kilns varies between 70% to 80% through re-use of flue gases for material pre-treatment.[3]
- Complete fuel burnout is ensured by the long residence time of combustion in the cement kiln as well as the high temperatures while complying with BAT and energy containment techniques, offering excellent conditions for complete valorization of alternative fuels.

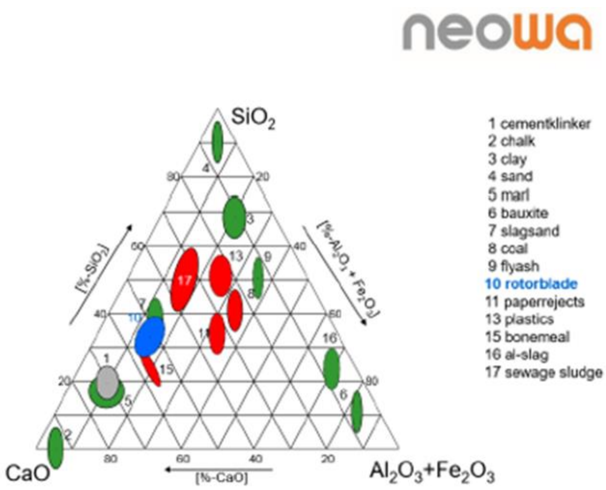
Waste used as an alternative fuel or/and wastes used as raw materials require both consistency in calorific content as well as consistency in composition. This can be guaranteed by adequate processing of End of Life/Use composites.

2. End of Life or Use composite materials used for clinker production

In a recent study, methods for identifying the material-recyclable share of solid recovered fuel during co-processing in the cement industry have been developed.[4] In addition, based on the above methods, the material-recyclable share of Solid Recovered Fuel (SRF) during co-processing in the cement industry has been calculated.[5]

Clinker production requires a high amount of thermal energy. It is therefore attractive to replace traditional (fossil) by alternative fuels such as Refuse Derived Fuels (RDF), which is a collection of waste materials with a residual intrinsic calorific value. Solid Recovered Fuel (SRF) is a subgroup of RDF composed of sorted solid waste or End of Use materials. SRF consists of a variety of materials with different calorific value and with different chemical/ physical constituency. The use of waste as substitute raw material or SRF is subject to specific EU quality requirements as defined under BAT (Best available Technologies).

End of Life or Use **composite materials** used for clinker production are especially suitable because of their high content of useful solid material (fiber glass, about 50% m/m) that is compositionally akin to the clinker composition (see figure) and thus a highly attractive mineral raw material source. In addition, the resin part of the composites will be a very effective alternative fuel as it is intimately distributed around the fiber, which is right at the spot of the chemical conversion.



[3] The use of composites waste will likely complement this efficiency as the material and thus initrinsic fuel is initimately mixed with the other raw materials.

[4] https://www.sciencedirect.com/science/article/pii/S2215016120300571?via%3Dihub

[5] https://www.sciencedirect.com/science/article/abs/pii/S0921344920300185

For the determination of the recyclable fraction in SRF an R-index is proposed:

$$R - Index = \frac{AC}{100} \cdot (w_1 + w_2 + \ldots + w_n) \qquad (1)$$

With

R-Index Recycling-Index (recyclable fraction in SRF; the reference value is the dried sample) [$\%_{DM}$]

AC Ash content [$wt\%_{DM}$]

$w_{1,2,\ldots,n}$ Mass fractions of elementary oxides that can be attributed to recycling [$wt\%_{DM}$]

A thorough assessment will demonstrate that it is clear that the R-index is very close to the content of solid material i.e. about 50% m/m glass fiber content in the composites stream as virtually all components of the ash content represent essential elements for Portland cement. This can be derived from the general composition of glass fiber products as presented in ASTM D578, where the general purpose fibers in table 1. are the relevant compositions for recycling. This will be also the case for mineral fillers, often used in composites for functional reasons. It is important to realize that all constituents of the glass network are in their oxide form, which will in addition to avoidance of natural raw materials also reduce CO2 emissions as such, as well as through a lower energy need for fusion in the clinker network.

Table 1 Compositions of commercial glass fibers

		Composition, wt%												
Fiber	Ref	SiO_2	B_2O_3	Al_2O_3	CaO	MgO	ZnO	TiO_2	Zr_2O_3	Na_2O	K_2O	Li_2O	Fe_2O_3	F_2
General-purpose fibers														
Boron-containing E-glass	1, 2	52–56	4–6	12–15	21–23	0.4–4	...	0.2–0.5	...	0–1	Trace	...	0.2–0.4	0.2–0.7
Boron-free E-glass	7	59.0	...	12.1	22.6	3.4	...	1.5	...	0.9	...	...	0.2	...
	8	60.1	...	13.2	22.1	3.1	...	0.5	...	0.6	0.2	...	0.2	0.1
Special-purpose fibers														
ECR-glass	1, 2	58.2	...	11.6	21.7	2.0	2.9	2.5	...	1.0	0.2	...	0.1	Trace
D-glass	1, 2	74.5	22.0	0.3	0.5	...	...	...	...	1.0	<1.3	...	...	...
	2	55.7	26.5	13.7	2.8	1.0	...	...	...	0.1	0.1	0.1	...	...
S-, R-, and Te-glass	1, 2	60–65.5	...	23–25	0–9	6–11	...	...	0–1	0–0.1	...	...	0–0.1	...
Silica/quartz	1, 2	99.9999	...	...	...	...	...	...	...	...	...	...	...	...

As the resin is intimately dispersed in the clinker batch the intrinsic caloric value will be used at a 100% efficiency. This represents not only avoidance of fossil fuel, but also contributes, at an overall estimated efficiency of say 80%, to a reduction of more than 100% in fuel need, adding further to a significant CO2 emission reduction. [6] This is in sharp contrast to energy recovery, generating electricity, where efficiency of energy return can be as low as 15%.[7]

[6] https://www.researchgate.net/figure/Calorific-values-of-plastics-compared-with-conventional-fuels_tbl1_293156565

[7] https://ec.europa.eu/environment/pdf/waste/framework/guidance.pdf

3. Co-processing of composites in cement kilns is recycling

The Directive WFD EC/98/2008 lays down measures to protect the environment and human health by preventing or reducing the generation of waste, the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use, which are crucial for the transition to a circular economy and for guaranteeing the Union's long-term competitiveness. This is defined in a hierarchy to apply as a priority order in waste prevention and management legislation and policy through
(a) prevention;
(b) preparing for re-use;
(c) recycling;
(d) other recovery, e.g., energy recovery; and
(e) disposal

This hierarchy is widely recognized and should be implemented by member states to meet the objectives of the generally agreed WFD EC/98/2008.

The use of waste in cement kilns is a combination of energy recovery and material recycling. Where waste materials cannot be managed technically or economically by prevention and reduction, reuse and recycling, the cement manufacturing process provides a more environmentally sustainable solution compared to landfill or incineration, thanks to the full energy and material recovery in the process. It is therefore believed that co-processing should be recognized higher up in the waste hierarchy as recycling over recovery. In addition, co-processing is recognized as one of the most energy-efficient waste-to energy techniques in the Communication from the EC in 26.01.20217, superior to incineration with heat recovery. In an earlier document the positive LCA effect of use of End of Life/Use composites in cement production is stressed. [8]

Differences between the emissions from an incineration plant and a cement plant

For a cement plant there are only emissions to air and no waste products and the emissions are regulated under the Industrial Emissions Directive (IED – Directive 2010/75EU). Water is in cement plants mainly used for cooling purposes and therefore their waste water is normally not contaminated. For an incinerator or energy recovery there are typically in addition to emissions to air also solid and waste water releases to the environment, which require further treatment before they can be released. With air emissions both an incinerator and a cement plant have equipment to pre-treat the final emissions following BAT.

Material use, the mineral and organic fraction

During the mineral recycling of End of Life/Use composites in co-processing the energy and the material part are fully recovered in the clinker production, which is the intermediate product of cement. The R-index is almost equal to the composites ash content and on average will be 50%, which is a very welcome contribution. The organic component is a highly effective fuel providing very local heat to the clinker process supporting in close contact the fusion of the minerals into becoming the cement clinker. As argued above the presence of organic, polymeric matter is therefore a component that by enhancing process quality and efficiency is also reducing fossil fuel use at a 100+% level.
Further, co-processing results in no residue materials, like ash, and, where cement is used for the production of concrete, this constitutes a material that is again 100% recyclable at the end of its life. This process is fundamentally different from the recycling of the bottom ashes of the incineration or energy recovery plants. The polluted and variable quality of the bottom ashes makes them a waste

[8] https://www.avk-tv.de/files/20130212_recycling_made_easy.pdf

quite difficult to handle, less suitable for cement production and only occasionally used as a filling material in the road construction works.

CO2 reduction

As both the mineral raw material will reduce CO2 emissions as it is already de-carbonized requiring also therefore less fuel and the organic polymeric moieties are locally 100+% effective to allow fusion of the batch components, an overall significant reduction of CO2 emissions is achieved.

In conclusion:

Co-processing of composites into cement clinker is a clear example of recycling according EC/98/2008, where both its mineral and polymeric part have a critical role. The mineral raw material as well as the organic polymeric part are in synergy highly effective for clinker manufacturing and have no resemblance to any extent to “energy-recovery” and/or “backfilling”. Composites recycling in co-processing contributes to a circular economy by effectively reducing overall CO2 emissions. An analysis of the abovementioned contributions is planned following an LCA to be used for comparison and to allow a full life cycle analysis.

CEMBUREAU The European Cement Association

EuCIA European Composites Industry Association

ANNEX I

DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)
https://ec.europa.eu/environment/topics/waste-and-recycling/waste-framework-directive_en
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008L0098-20180705&from=EN

CHAPTER I SUBJECT MATTER, SCOPE AND DEFINITIONS
Subject matter and scope

This Directive lays down measures to protect the environment and human health by preventing or reducing the generation of waste, the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use, which are crucial for the transition to a circular economy and for guaranteeing the Union's long-term competitiveness

Waste hierarchy
The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:
(a) prevention;
(b) preparing for re-use;
(c) recycling;
(d) other recovery, e.g., energy recovery; and
(e) disposal

'**re-use'** means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived
'preparing for re-use' means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing;
'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations;
'recovery' means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfill a particular function, or waste being prepared to fulfill that function, in the plant or in the wider economy.
Annex II sets out a non-exhaustive list of recovery operations
'**material recovery'** means any recovery operation, other than energy recovery and the reprocessing into materials that are to be used as fuels or other means to generate energy. It includes, inter alia, preparing for re-use, recycling and backfilling;
'backfilling' means any recovery operation where suitable non-hazardous waste is used for purposes of reclamation in excavated areas or for engineering purposes in landscaping. Waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purpose
'disposal' means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Annex I sets out a non-exhaustive list of disposal operations

ANNEX II

RECOVERY OPERATIONS
R 1 Use principally as a fuel or other means to generate energy (*)
R 2 Solvent reclamation/regeneration
R 3 Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes) (**)
R 4 Recycling/reclamation of metals and metal compounds (***)
R 5 Recycling/reclamation of other inorganic materials (****)
R 6 Regeneration of acids or bases
R 7 Recovery of components used for pollution abatement
R 8 Recovery of components from catalysts
R 9 Oil re-refining or other reuses of oil
R 10 Land treatment resulting in benefit to agriculture or ecological improvement
R 11 Use of waste obtained from any of the operations numbered R 1 to R 10
R 12 Exchange of waste for submission to any of the operations numbered R 1 to R 11 (*)
R 13 Storage of waste pending any of the operations numbered R 1 to R 12 (excluding temporary storage, pending collection, on the site where the waste is produced)

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32018L0851
DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 30 May 2018 amending Directive 2008/98/EC on waste

Subject matter and scope
This Directive lays down measures to protect the environment and human health by preventing or reducing the generation of waste, the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use, which are crucial for the transition to a circular economy and for guaranteeing the Union's long-term competitiveness.'

15a. **"material recovery"** means any recovery operation, other than energy recovery and the reprocessing into materials that are to be used as fuels or other means to generate energy. It includes, inter alia, preparing for re-use, recycling and backfilling;';
17a**. "backfilling"** means any recovery operation where suitable non-hazardous waste is used for purposes of reclamation in excavated areas or for engineering purposes in landscaping. Waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purposes;';