FISSAC

FOSTERING INDUSTRIAL SYMBIOSIS FOR A SUSTAINABLE RESOURCE INTENSIVE INDUSTRY ACROSS THE EXTENDED CONSTRUCTION VALUE CHAIN

Characteristics of waste streams and requirements for recycling processes

Executive summary

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Deliverable 2.2, entitled "Characteristics of waste streams and requirements for recycling processes", was prepared as an outcome of the "Task 2.2: Waste characterization and requirements for recycling processes", included on the Work Package WP2 – "Closed loop recycling processes to transform waste into secondary raw materials". The submission of this report constitutes the successful achievement of the FISSAC Milestone 4: "Waste characterized and requirements established. Closed loop recycling processes designed and validated".

Based on requirements proposed in previous FISSAC tasks, this report deals with the characterisation of the industrial waste streams covered in FISSAC. The results of this task aim to identify potential technical barriers to be improved later on, through the implementation of enhanced recycled routes. In addition, this report also identifies potential lack of harmonized standards hampering full acceptance in construction applications to be developed in a later stage of the project.

Sectors and secondary raw materials (SRM) involved

This report covers up to 10 types of waste streams and by-products from six main industrial sectors, such as Steel Industry, Secondary Aluminium Industry, Ceramic Industry & Recycling Industry from C&DW and Recycling Industry from Quarry/Mining. Concerning the potential applications, four construction sub-sectors are considered, focusing on countries (Turkey, Italy, Spain, Sweden and UK), where a specific sector is of great relevance or the final applications are going to be demonstrated:

1. Eco-cement
2. Green Concrete & Autoclaved Aerated Concrete (AAC)
3. Ceramic products
4. Wood Plastic Composites (WPC)

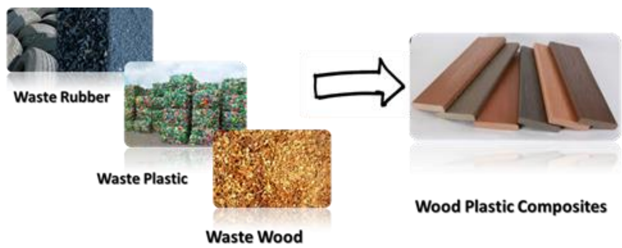
Characterization was performed in function of the target applications. Those are potential use as clinker raw meal and mineral additives, additions/aggregates, source of alumina, source of CaCO3. The construction sub- sectors and residues selected are as follows:

Waste materials for eco-cements

Construction sub-sector	SRM	Applications
Eco cement	Ladle furnace slag	Clinker raw meal
	Glass waste	Clinker raw meal & mineral additives
	Ceramic waste	Clinker raw meal & mineral additives
	Aluminium waste	Clinker raw meal
	Ladle furnace slag	Clinker raw meal
Green Concrete (ready mixed & AAC)	EAF slag	Aggregates
	LF slag	Aggregates
	Ceramic waste	Additions/aggregates
Ceramic products	Aluminium industry	Source of alumina
	Marble slurry	Source of $CaCO_3$
Wood plastic composites	Tyre rubber	SRM
	Plastic waste	SRM
	Wood waste	SRM

Waste materials for green-concrete

Waste materials for WPC

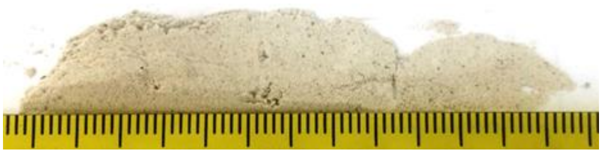


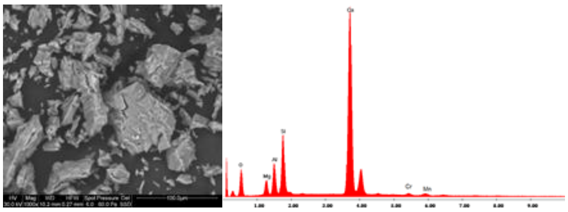
Characterization of raw waste materials

Waste characterization is exhaustively presented in Chapter 3 ("Results and conclusions") of the report, where physical, chemical, mineralogical, morphological and environmental properties of waste materials are covered. This characterization plan was designed specifically for each type of waste material according to the destine application.

Results have been classified into physical-mechanical (grading, expansion…), chemical (composition, reactivity) mineralogical (main minerals), morphological (shape) and environmental (potential leaching). Comparative charts have been included and materials suitability and critical aspects and technical constrains are evaluated according obtained results.

For each waste material and industrial application, in the Chapter 4 ("Conclusions"), a list of favourable characteristics, technical constraints, and potential treatments were identified aiming to set the basis for ulterior work.





SEM and EDAX characterization of Lf slag samples

Critical aspects in the use of SRMs

Concerning **Eco-cement production**, the following conclusions can be drawn:

Raw meal:

- To avoid undesirable oxidizing environment during clinker process due to the high amounts of FeO slag wastes.
- Slag waste magnetic separation before usage in cement process, separation of Fe^{+2}.
- To limit some undesired chemical compounds that may affect to the clinkerization.
- Comminution (crushing and grinding) is obligatory in order to feed to the system as a raw material for CSA cement clinker production.
- Moisture content should be max. 15% to inhibit prehydration of the cement particles.
- Cr (VI) content must be monitored according to REACH Regulation.
- Reduction in chlorides and fluorides for specific waste streams (SEROX)
- Further analysis on the effect of alkali on the CSA manufacturing stages

Mineral additives:

- Proper standardization is required for the conformity of usage of mineral additives for eco-cements.
- Waste materials, as mineral additive, should be as fine as cement and it should feed to the grinding equipment together with clinker, gypsum and other minor components.
- Decreasing in free MgO content is only required for the binary-cement production and aggregate.
- Moisture content should be max. 3% to inhibit prehydration of the cement particles.
- Cr (VI) content must be monitored according to REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) Regulation.

The following conclusions can be drawn for **Green Concrete production**:

When using **EAF slags**:

- EAF slags must be turn into aggregates through treatment processes including crushing, sieving and magnetic separators.
- High values of expansion attributed to free lime and free magnesia for the high alloy and stainless EAF steel slags require for a deeper study in later work. Accelerated ageing methods (e.g. accelerated carbonation or others), will be designed and validated aiming to reduce expansion values below 1%.
- The lack of fine fractions require the use of fine particles coming from other mineral sources, being coarse fractions more interesting for use in concrete manufacturing.

When using **LF slags**:

- Metallic traces contained in the LF slags must be removed through magnetic separators.
- LF steel slags can be used as fine fractions for the concrete manufacturing process, where potential hydraulic reactivity might induce gain in compressive strength at early curing days. A deeper analysis should be performed later.

When using **ceramic waste** streams:

- Ceramic waste materials must be granulated for use in concrete.
- The coarse fractions induce lack of mechanical resistance in concrete.
- It is recommendable the crushing, sieving and purification of fine fractions aiming to take advantage of the latent pozzolanic properties.

In addition, the main potential constraints hindering the use of EAF steel slags, LF steel slags and ceramic wastes in **Autoclaved Aerated Concrete (AAC)** are summarized as follows:

- All the waste materials must be granulated for use in AAC.
- In order to induce pozzolanic activity, the target waste materials must be crushed, sieved and separated from metallic traces.
- CaO and SiO_2 content of EAF samples are low, that may cause the reduction in thermal insulation properties of AAC due to their high density.

SRM from both the aluminium industry and the Marble slurry are adequate for **Ceramic Products** production with minor critical aspects:

Aluminium oxide based materials (SEROX):

- Sieving slurry to reject hard aggregated and large agglomerated particles.
- Reduction in metallic particles aiming to avoid defects in tiles.

Marble slurry:

- A filter press process and a partially drying is required to avoid the corrosive impact on slurry on containers, drastic modifications of material storage and changes in the dosage procedure of component for the ceramic formulation.

Following specifications must be taken into account for each raw material for **Wood Plastic Composites (WPC)** industry:

Wood waste:

- Wood flakes maximum size is established at 800 µm to avoid some issues during production, such as line speed, moisture, appearance quality standards, etc.
- Moisture content analysis shall be performed on every delivery from the supplier to avoid humidity ranges below explosion hazard and over production and quality issues.
- To avoid yeasts and moulds in the final product.

Plastic waste:

- To control the pellet size required to be melted.
- Melt flow index. It must not be over 0.9 g/10min aiming to achieve a proper mix. In addition, this parameter is a proportional link to the rubber degradation due to the higher temperatures required for melting.

Rubber waste:

- Particle size. Rubber powder with particles over 667 µm are not acceptable due to this parameter affects a better final product will be produced. If the rubber particles are too large they can peel off the final product leaving voids that can be fill with water.

Conclusion

From the aforementioned results and discussions, following aspects were evaluated in the conclusions:

- Favourable characteristics;
- Technical constrains;
- Potential treatments to be studied and up scaled in T2.3;
- Considerations to be assessed in WP3 to 5.

In the following tables conclusions in relation to mentioned evaluation aspects are compiled.

This evaluation enabled identifying the potential technical barriers for each material and application. The use of the acquired knowledge during this task will be used to overcome such barriers and improve the implementation of enhanced recycled routes.

Conclusions for ECO-CEMENT application: CSA production

Waste material	Favourable characteristics	Technical constraints	Potential treatments to be studied and up scaled in T2.3	Considerations to be assessed in WP3-5
EAF slag	Source of CaO.	For the case of direct feeding to preheater, preliminary grinding needed	To preheater feeding grinding below about 90 microns	Effect of the MgO for high alloy and stainless EAF slags Content of V and Cr
		Separation and elimination of Fe^{2+} and Mn^{2+}	Magnetic separation processes (limit will be established with cement plant)	
LF slag	Ca content is >40% (min. content should be 30%) Source of CaO	For the case of direct feeding to preheater, preliminary grinding needed	To preheater feeding grinding below about 90 micron To grinding equipment feeding, no need for any preliminary treatment	Effect of the MgO for high alloy and stainless EAF slags. Effect of TOC
		Magnetic particles	Magnetic separation process (limit will be established with cement plant)	
		Reduction in Cl<0.1% and F<0.15%	Hydrometallurgical processes to reduce halogen content <0.15%	
Al oxide based materials	High Al_2O_3 (>60%) content	Presence of chlorides, fluorides, moisture	Hydrometallurgical processes to reduce halogen content <0.15%. Drying guaranteeing moisture content <15%. Removal of metallic impurities if necessary	Study on the MgO phases in the CSA manufacturing process
Ceramic waste	High SiO_2 content		To preheater feeding grinding below about 90 microns	Influence of the Na_2O during the clinkerization
Glass waste	High SiO_2 content	Size of the “Glass Sample E” is large	To preheater feeding grinding below about 90 microns	Influence of the Na_2O during the clinkerization
		Presence of plastic particles: could cause problems in kiln feed	Separation of plastic particles: proper Collection methodology /technology to be selected	Effect of TOC

Conclusions for ECO-CEMENT application: binary-cement production

Waste material	Favourable characteristics	Technical constraints	Potential treatments to be studied and up scaled in T2.3
EAF slag		Low pozzolanic property	Not feasible for binary cement production; laboratory trials will be made only to test their usage as mineral additive
		EAFCEM1-TCM: decreases initial setting time drastically. This may decrease workability of concrete	
		High MgO content may lead to swelling effects	
LF slag	Hydraulic activity	High MgO content may lead to swelling effects	Magnetic separation process (limit will be established with cement plant)
Ceramic waste	CERWCON2-TEC present reactive silica >30%; reactive SiO2 analysis needs to be done for CERWCEM1-KER		Grinding below 50 mm
Glass waste	Potential pozzolanic activity. Reactive silica around 50%	Presence of plastic particles: could lead to problems in grinding process and homogenization of cement bulk	Separation of plastic particles: proper collection methodology technology to be selected
		Size of the "Glass Sample E" is large	Grinding below 50 mm

Conclusions for GREEN CONCRETE application

Waste material	Favourable characteristics	Technical constraints	Potential treatments to be studied and up scaled in T2.3
EAF slag			Must be granulated through crushing, sieving and magnetic separation
		High values of expansion for the high alloy and stainless EAF steel slags. Mainly attributed to the presence of free lime or magnesia (deeper analyses needed)	Accelerated aging methods (accelerated carbonation or others) to be designed and validated to reduce expansion values below 1%
		Lack of fine fractions	Use of fine fractions from other mineral sources
	Coarse fractions seem to be more feasible for use in concrete manufacturing		
LF slag		Can contain metallic traces	Magnetic separators
	Can be used as fine fractions for concrete manufacturing process		
Ceramic waste		Coarse fractions induce lack of mechanical resistance in concrete	Not a feasible use
	Fine fractions can induce pozzolanic activity		Grinding, sieving and purification to take advantage of those fractions

Conclusions for GREEN CONCRETE application – AAC production

Waste material	Favourable characteristics	Technical constraints	Potential treatments to be studied and up scaled in T2.3
EAF slag		Crushing & grinding needed to 90 µm	Crushing & grinding to 90 µm
		High grinding energy demand due to high resistance to fragmentation	
		Low pozzolanic properties	
		This kind of materials may increase density and thermal conductivity coefficient of AAC	Not feasible for AAC production
		Cannot be used as mineral additive	Only EAFCON2-TEC B may be valorised in AAC
LF slag	High amount of CaO and SiO_2		
	Hydraulic activity		
		Crushing & grinding needed to 90 µm	Crushing & grinding to 90 µm
Ceramic waste	High SiO2 content		
		Crushing & grinding needed to 90 µm	Crushing & grinding to 90 µm

Conclusions for CERAMIC PRODUCTS application

Waste material	Favourable characteristics	Technical constraints	Potential treatments to be studied and up scaled in T2.3
Al oxide based materials		Presence of hard aggregated size particles	Sieving slurry to reject these particles
		Presence of large agglomerated particles not removed during milling, possible damage on milling elements	
		Presence of metallic particles: • Provoke appearance of defects in tiles • Consider final impact in ceramic	Magnetic separation systems seem not to be able to eliminate metallic particles due to non-magnetic response of Al Other treatments?
Ceramic waste		Humidity exceeds required <15%	
		Semiliquid behaviour: raw materials for tiles are required to be solid, not slurry. Corrosive impact of slurry on containers	Drastic modifications of material storage and changes in dosage procedure of component for the ceramic formulation. Partially dry slurry i.e. through filter press process

Conclusions for WOOD-PLASTIC COMPOSITES application

Waste material	Favourable characteristics	Technical constraints	Potential treatments to be studied and up scaled in T2.3
Wood		Particle size: wood flakes >800µm would lead to issues (line speed, moisture, etc.). Large flakes would not give final acceptable appearance to the final product.	
		Moisture content <3% can be an explosion risk; above 9% higher end of processing capability to obtain a good quality product	MW technology: first, reduction of moisture content up to 1% on SRM; second, improve process efficiency (process speed), reducing drying time and energy consumption
	Biocide content: helps to avoid yeasts and moulds		
Plastic		Pellet size: the bigger the pellet, the higher the melting temp; this could lead to rubber degradation	
		Melt flow index (MFI): must not be over 0.9g/10min to achieve a proper mix. MFI <0.1g/10min could lead to rubber degradation due to higher temperatures required for melting the plastic	
		Particle size: rubber powder with particles >667µm not acceptable. Large particles can peel off final product leaving voids that can be filled with water and therefore reduce dramatically product life expectancy	
Rubber		Particle size: wood flakes >800µm would lead to issues such as line speed, moisture, etc. Large flakes would not give final acceptable appearance to the final product	