RECYCLABILITY OF RECYCLED CONCRETE PRODUCTS IN CEMENTS

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Abstract This research addresses the recycling possibilities of a concrete product that contains coarse concrete aggregate as recycled material. The use of this finely milled product is proposed as an active addition to cement that already includes by-products in their composition. The partial substitution of cement by secondary raw materials contributes positively to the reduction of waste dumping and to the reduction of greenhouse gas emissions. However, the substitution rates of secondary raw materials are higher in concrete aggregates (20%) than in cements. The dosage of a concrete includes approximately three times more coarse aggregate than cement. This means that the amount of waste that can be incorporated into recycled concrete is greater if it is done as coarse aggregate than if it is added to cement. The main advantage of the partial substitution of cement lies in the reduction of CO_2 derived from the decarbonization process of the cement raw materials.

Keywords: circular economy, cement, concrete, recycling, secondary raw material

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1 Introduction

The use of concrete wastes in new building products in the Circular Economy framework currently has a medium scope. On one hand, there are already industrial applications of recycled concrete aggregates to be used in new concretes. But on the other hand, the researches about how to use this waste as fine aggregate in mortar or concrete or finely milled as cement addition is still under development.

It is needed to focus on recycled concrete because now the standard (AEN/CTN 146) allows to include until a 20 % of coarse aggregate from recycled aggregates. However, the Circular Economy concept requires to consider the recyclability of these new products one they are at the end of their live and when they are considered as wastes.

One recycling way of these wastes is the treatment in order to manufacture again recycled aggregates to be added to new concrete mixes. On this way, the new concrete will include a 20 % of recycled concrete. But this already included a 20 % of recycled concrete. So, it means, in total a 24 % of recycled material so in according to that standard, the proportion of recycled material will increase in each step. Although it will be limited due to the technical characteristics.

The second recycling way is the use in cement. If it is considered the Portland Cement production in Europe in the last years has passed 100 million tons per year, even short addition may have a huge impact. In fact, the waste additions to cement is already a common practice but to add other options may be of great interest because now some of these wastes are sold as raw materials with a high dependence and a high availability risk. In addition, it is necessary to consider that the cement industry is responsible of the 5 of the greenhouse gases produced every year (Benhelal, Shamsaei et al. 2021) and the 5-8 % of the CO_2 emissions (Sousa, Bogas 2021). Therefore, to include low proportions of secondary raw materials as cement additions will positively contribute to decrease these emissions. It is due to the main chemical process associated to the cement manufacturing: the decarbonization. Calcium carbonate present in the cement is transformed into calcium oxide with the emission of CO_2. So, if other compounds different than the calcium carbonate are used in cements, the emissions will decrease.

The possibility to use concrete waste as cement addition depend on the state of the waste in terms of particle size. It is important to use the reactivity of the dust (<0,063 mm) which is obtained by a milling of the concrete, in order to perform partial substitutions of the cement (Xiao, Ma et al. 2018). However, it seems difficult to perform cements additions higher than 10 % due to the strength decrease of the final products. In addition, it must be considered that these additions should be combined with those commonly used now such as fly ashes or silica fumes which have already high performance.

This work aims to analyse the possibility of use waste from recycled concrete as active addition to an industrial cement in order to evaluate the potential advantages and the limits of use. The plan is to evaluate short additions of milled concrete in cements: 5, 7 and 10 %. Although the potential reduction of the CO_2 is about 38-76 kg per ton of produced cement, the final strength of the cement should be tested.

2 Materials

The concrete waste used in this study comes from the manufacturing of concrete probes with a 20 % of recycled concrete aggregate. The wastes of the compressive strength tests from a previous research which included a new concrete with recycled material are studied in the present work. The compressive strength of this old concrete at 28 days was 34,3 Mpa and it was manufactured with:

- CEM II/A-M 42,5 R.
- Coarse aggregate 6/20 mainly composed by silica.
- A substitution of 20 % of the coarse aggregate by recycled concrete aggregate from a CDW manager located in Madrid
- Fine aggregate 0/6 mainly composed by silica.
- Superplasticiser
- Water

The cement used in the present research is the same than the used in the previous one: CEM II/A-M 42,5 R. A Portland Cement with the addition of fly ashes and limestone (12-20 %) and with a compressive strength at 28 days of 42,5 Mpa.

3 Method

The CO_2 emissions have been estimated in a theoretical way. Assuming a minimum proportion of calcium oxide present in the cement. And considering that all this oxide comes from calcium carbonate after a decarbonisation treatment in a specific proportion which depends of the stoichiometric ratio.

$$CaCO_3 \rightarrow CaO + CO_2$$

In the behaviour of the additions has been considered the main composition of them:

- Fly ashes: no calcium carbonate
- Milled concrete: no calcium carbonate
- Limestone: a 100 % of calcium carbonate.

4 Discussion

The main source of CO_2 pollution by the cement production process comes from the decarbonisation of the lime in (calcium carbonate) into calcium oxide by the thermal treatment of the raw materials:

$$CaCO_3 \rightarrow CaO + CO_2$$

It is possible to consider a typical minimum content of CaO in cement of 60 % which means a theoretical emission of 765 kg of CO_2 per ton of produced cement. Although this value may change with the temperature of the process and the energetic consumption of fuel has been not considered. A substitution of 5-10 % of cement per milled concrete (already decarbonized) may reduce about 38-76 kg of CO_2 per ton of produced cement.

There is a natural carbonisation of the concrete during their live so in real terms there will be a small amount of calcium carbonate in the concrete wastes. However, it is not easy to measure this parameter in concrete wastes since it depends on the type of original concrete, its age and weather conditions, among others. For this research, no natural carbonisation of the concrete has been considered.

The cement of this study contains about 12-20 % of fly ashes and limestone so its emissions may be partially reduced if this proportion are completely fly ashes (which do not include carbonate) but in the case of a predominance of limestone as active addition the emissions will be higher than a cement without this kind of addition.

Although the current trend is the addition of limestone after the thermal process (and therefore without the emission of CO_2), there is a greater tendency towards the calcination of secondary raw materials in order to achieve their activation. Because the second recycling of the products will not only contain cement, but also other waste such as ceramic or concrete, the calcination of this cement will emit CO_2 from both cement and the limestone. Therefore, all additions before the thermal process have been considered.

It is possible to consider six different scenarios where the addition is minimum (12%) and with three different ratios fly ashes / limestone:

- 100 % limestone / 0% fly ashes
- 50 % limestone / 50 % fly ashes
- 0 % limestone / 100 % fly ashes

And the same three scenarios assuming the highest addition (20%).

- 100 % limestone / 0% fly ashes
- 50 % limestone / 50 % fly ashes
- 0 % limestone / 100 % fly ashes

The next table summarise this situation and shows the theoretical emissions in kg per ton of produced cement.

Table 1: Theoretical CO_2 emissions (kg) per ton of produced cement (CEM II).

	Clinker (%)	Fly ashes (%)	Limestone (%)	Clinker emissions (kg/t)	Limestone emissions (kg/t)	Cement emissions (kg/t)
	100	0	0	765	0	765
1	88	0	12	672,8	152,9	825,7
2	88	6	6	672,8	76,5	749,2
3	88	12	0	672,8	0,0	672,8
4	80	0	20	611,6	254,8	866,5
5	80	10	10	611,6	127,4	739,0
6	80	20	0	611,6	0,0	611,6

As it was expected, the limestone addition have a worse effect in terms of emissions than the original cement without addition (equivalent to CEM I). But the addition of fly ashes is very positive even in the case of use the same proportion of fly ashes than limestone.

These results can be optimized with the addition of milled concrete waste in a proportion of 5, 7 or 10 % of the total cement. They are small quantities that will not negatively affect to the final strength of the products or even can improve it. The next table shows a theoretical estimation of those additions.

Table 2: Theoretical CO_2 emissions (kg) per ton of CEM II with milled concrete produced cement (CEM II with commercial additions and milled concrete)

	Clinker (%)	Fly ashes (%)	Limestone (%)	Clinker emissions (kg/t)	Limestone emissions (kg/t)	Cement emissions (kg/t)	Cement emissions (kg/t)-Concrete (5%)	Cement emissions (kg/t)-Concrete (7%)	Cement emissions (kg/t)-Concrete (10%)
	100	0	0	765	0	765			
1	88	0	12	672,8	152,9	825,7	784,4	767,9	743,1
2	88	6	6	672,8	76,5	749,2	711,8	696,8	674,3
3	88	12	0	672,8	0,0	672,8	639,1	625,7	605,5
4	80	0	20	611,6	254,8	866,5	823,1	805,8	779,8
5	80	10	10	611,6	127,4	739,0	702,1	687,3	665,1
6	80	20	0	611,6	0,0	611,6	581,0	568,8	550,5

In the best scenario (6), a substitution of 10 % of milled concrete by cement with a 20 % of fly ashes can reduce the emission above 30 %. In the most common cases (scenario 5) where a mix of lime and fly ashes are used, the reduction may be about 7-13 % depending the quantity of milled concrete added.

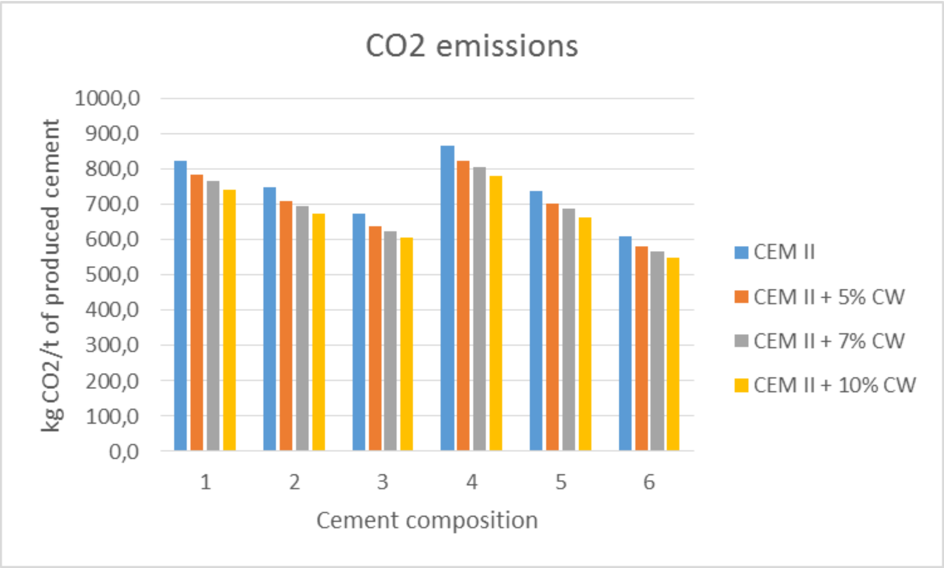

Figure 1: CO_2 emissions by every kind of addition.
Source: own.

The highest reduction of the CO_2 emissions are according to the highest additions of the milled concrete. The main issue to be solved is the mechanical performance of these kind of cement additions. Probably the limit proportion is 10 %. Additions higher than this may cause a decrease of the strength. But lower proportions such as 7 % may develop a high strength, even improving the strength of the original cement. But it depends of the quality of the concrete waste. In general terms, if the presence of sulphates is low, the quantities of silica and calcium oxide are high, the final strength may be optimum. But in any case, to perform a detailed strength study is required.

5 Conclusions

In a theoretical framework, the milled concrete addition to commercial cements in low proportions (5, 7 and 10 %) may considerably improve the CO_2 emissions due to the decarbonisation of calcium carbonate into calcium oxide. In addition, if the cement to be used already includes other additions such as fly ashes or limestone, the potential reduction of those emissions is interesting (7-13 %).

With this forecast of emissions saving, it is suggested to continue the research with a practical study whose main goal should be to define the maximum proportion of milled concrete which is possible to use in this kind of cement. A simple test plan should include a reference sample without additions and mixes with additions of 5, 7 and 10 % of milled concrete in order to study the final strength at 7, 28 and 90 days. On this way, the potential pozzolanic activity of the materials (fly ashes are considered as pozzolanic material) will be also studied.

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