ASSESSING THE ECO-EFFICIENCY OF RECYCLING WASTE IN CONCRETE

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ABSTRACT

The most used material in the world – the concrete – is also a big contributor to global warming due to the use of cement in compositions. Production of 1 ton of clinker emits around 1 ton of CO₂; 5 to 7% of total global CO₂ emissions are from cement production. So, concrete eco-efficiency is linked to optimization of cement content. But concrete chain had being also other sustainable demands, such as the use of wastes in mixtures.

This paper discusses the influence of waste use in concrete mixtures on cement and total binder content of these mixtures, in order to assess how first action, even with sustainable purposes, can change the concrete total CO₂ emissions.

It was created two indexes to evaluate concrete efficiency in terms of binder content and CO₂ emissions. It was analyzed some Brazilian papers by new index, and it was concluded that use of wastes in concrete mixtures need to be reviewed and accurately evaluated, because sometimes this action increase concrete binder consumption and CO₂ emissions, with bigger global warming impact than ordinary concretes.

Keywords: waste, aggregate, binder, cement, concrete, sustainability, eco-efficiency.

1. INTRODUCTION

Inside a concrete mixture, the cement is not so much important in terms of mass – it is approximately 8 to 15% of total weight. However, it is very important in terms of sustainability, specifically to global warming: more than 80% of concrete CO₂ emissions take place in cement production (Vares; Hakkinen, 1998). This data shows that the heaviest and more voluminous concrete components – the aggregates – can have a significant impact in terms of raw material consumption, but their contribution to some other important impacts are comparatively low.

Despite of this, a lot of papers show a big concern in reuse or recycling a big range of different sorted wastes as concrete aggregates. This concern is valid, because waste reuse or recycling is an action in the way of sustainability, important to decrease landfill disposals and save raw materials. However these good sides are not the only one inserted in a sustainable
evaluation. All impacts need to be assessed in a more accurate way: only measure if waste can substitute raw aggregates and deliver adequate compressive strength to concrete are not enough. It is necessary to evaluate all sides of the problem, as, for example, if the mechanical performance indicators are being achieved by some high environmental costs, such as the increase of cement consumption – and respectively CO2 emissions increase.

Thus, the purpose of this paper is to analyze and discuss results from Brazilian literature papers that use different waste types in concrete and in an increasing scale of replacement by natural components, in order to compare how the increase of recycled materials replacement in concrete can influence its embedded CO2 emissions.

2. METHODOLOGY

2.1 Bibliographical research – Brazilian literature

It was collected data from some Brazilian papers. All papers studied must have some common and unambiguous characteristics and information, such as; a) specimens 28-day mechanical strength, in MPa; b) aggregates and waste consumption, in kg·m⁻³; c) increasing replacement rates of natural aggregates by wastes; and d) binder consumption, in kg/m³. In Brazil, commercial cements are frequently composed by clinker and some other binders, as, for example, fly ash (FA) or blast-furnace slag (BFS), in wide range. When only cement type was available, it was divided in individual binder consumptions in accordance with average rate of clinker replacement.

2.2 Assessment tools: two new environmental indexes

In order to make possible an objective and precise comparison of environmental performance between different concrete mixtures, it was created two new indexes that analyzes a relationship between environmental impact – measured by CO2 emissions and total binder consumption – and the function of the concrete – the resistance. They are called Binder Intensity \( (bi) \) and CO2 Intensity \( (ci) \), which measure, respectively, the total amount of binder necessary to deliver 1 MPa of strength resistance; and the total amount of CO2 emitted by each 1 MPa. Their calculations are presented, respectively, in Equations 1 and 2.

\[
bi = \frac{b}{s} \quad (1),
\]

where \( b \) is the total consumption of binder materials (kg·m⁻³) and \( s \) is the mechanical compressive strength of concrete at a given age. In this study \( s \) will be the compressive strength (MPa) at 28 days.

\[
ci = \frac{c}{s} \quad (2),
\]

where \( c \) is the total CO2 emission (kg·m⁻³) to produce and transport all concrete materials and \( s \) is the mechanical strength at 28 days.

2.3 CO2 emissions estimative by type of binder

In order to estimate the total amount of CO2 emitted by m³ of concrete produced, it was used medium emission values per unit of binder. These values were results of bibliographical research of more than 5 references to clinker emissions (Yamamoto et al, 1997; Gartner, 2004; Josa et al, 2004; USGS, 2005; IEA, 2006; Damtoft et al, 2008). Silica fume (SF), fly
ash (FA) and blast-furnace slag (BFS) are waste of other industrial processes, so their emission was allocated as zero. Values used to $ci$ calculus are presented in Table 1.

<table>
<thead>
<tr>
<th>Binder</th>
<th>Emissions, kg CO$_2$ / kg binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinker</td>
<td>1</td>
</tr>
<tr>
<td>Blast-furnace slag</td>
<td>0</td>
</tr>
<tr>
<td>Fly ash</td>
<td>0</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>0</td>
</tr>
</tbody>
</table>

2.4 Analysis of highest $bi$ and $ci$ results

In order to investigate how wastes could decrease concrete eco-efficient – determined by higher $bi$ and $ci$ values –, data collected were analyzed by crossing wastes replacement with $bi$ and $ci$ indexes, generating interesting graphs that can help to understand $bi$ and $ci$ trends according waste replacement increase or decrease.

3. RESULTS AND DISCUSSION

First paper analyzed was Reschke et al (2005). Data is presented in Figure 1. It can be seen that the higher the foundry slag content in concrete, the higher is the $bi$ indicator. The data with $bi$ above 20 kg·m$^{-3}$·MPa were achieved by more than 45% of foundry slag substitution in relation to clinker.

But it is also possible to note that the increase of granulated foundry slag content and of the $bi$ are not followed by an increase in $ci$ data, which remains the same by different slag contents. This fact shows that, in this case, the clinker content (main responsible by $ci$, as can be perceived in Table 1) stands unchanged for different concretes, and only the granulated foundry slag is increased, causing a $bi$ increase. So it is possible to conclude that, if $bi$ performance is decreased and $ci$ stands unchanged, the granulated foundry slag addition do not have positive impacts on concrete environmental performance. The strength is not increased. The use of this type of slag only helped to decrease this waste volume, which is not a real good environmental action. Waste is being used with no gains, only adding binder to concrete.
The second and third paper analyzed were Mosca; Lintz; Carnio (2005) and Penha et al (2006), which studied concretes produced with different contents and types of fiber rubber from tires wastes. Data are presented in Figure 2. The tendency observed was the increase of bi caused by increase of rubber content, and the higher bi values (above 20 kg·m⁻³·MPa) was achieved by concretes that used the higher rubber contents, in both cases. Bi results increased in a straight way in accordance with rubber content increase. Same trends are found for ci.

Almeida et al (2004), the fourth paper with high bi values, replaced natural sand by PET sand as fine aggregates, resultant from the recycling process of PET. Again is noticed, in Figure 3, that the increase of PET sand content in concrete increase bi and ci values. The higher bi and ci values were done with more that 50% of replacement.
An interesting case for discussing wastes influences on $bi$ and $ci$ indexes was the paper from Isaia; Gastaldini; Moraes (2003), whose results are displaced in Figure 4. In comparison with reference concrete with no additions, the increase of fly ash replacement resulted in higher $bi$. Same trend was found for limestone filler. For rice husk ash $bi$ decreased for low replacement contents (12.5 and 25%) but increased for higher ones (50%). Comparing these three fillers separately, limestone filler replacement generated higher $bi$ results. But the most curious fact is that the use conjugated of fly ash and rice husk ash generated higher $bi$ in comparison with the use of the same fillers separately for lower replacement contents, but a lower $bi$ for higher replacement contents. The fact proves the importance of some other influences in concrete performance that are not very known or controlled yet, such as particles packing or fillers dispersion.

In all articles listed, higher values of $bi$ were achieved in higher raw materials (clinker or aggregates) replacement by waste or recycled materials.
Moreover, Brazilian concretes can achieve ci values under 2 kg·m⁻³·MPa, which is directly related to clinker replacement by some mineral admixtures such as, more than 50% of blast-furnace slag and up to 10% of silica fume. This shows that mineral admixtures, which are waste, increase concrete environmental performance by avoiding CO₂ clinker production emissions.

4. CONCLUSIONS

The use of recycled waste in concrete mixtures is becoming a current practice, mainly due to wastes related environmental aspects that are causing problems to world sustainability, such as the volumes of waste for disposing to landfills. The most common are wastes recycled as aggregates and mineral admixtures generated as by-products from other industries, such as fly ashes, blast-furnace slag and silica fume.

Despite of the importance of recycling for sustainability, its assessment cannot to be done in only one way; it needs to include different environmental impacts. In concrete mixtures containing recycled wastes, the assessment through bi and ci indicators showed that the use of some wastes as recycled aggregates decreased the concrete eco-efficiency in terms of global warming. On the other hand, it was also noted that most eco-efficient concretes in terms of CO₂ emissions also use recycled materials such as silica fume and blast-furnace slag.

So recycling is an action that needs to be used carefully but have potential to consolidate benefits. It is not necessary to choose between recycling or global warming: with a complete assessment both can be taken into account. The global warming load decrease, which is certainly the worse impact of concrete chain, depends on a correct concrete mixture process and a more accurate analysis of waste used versus clinker consumption. It is suggested a detailed and critical analysis of waste to use in concrete before trying to implement it on market, because a more sustainable solution in one aspect – reuse of waste – can be less sustainable in others.

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REFERENCES


