THE WATER FOOTPRINT OF CEMENTITIOUS MATERIALS: A CASE STUDY ON HIGH FILLER MORTARS PRODUCTION

Tema: Sustentabilidade, vida útil e meio ambiente.
Grupo[1]

YAZMIN L. MACK V.[1], DANIELE PESSUTTO[2], VANDERLEY M. JOHN[3]
[1]Dr Sc Candidate at Polytechnic School of the University of São Paulo/USP, Researcher at Universidad Tecnológica de Panamá/UTP, yazmin.mack@lme.pcc.usp.br
[2]M Sc Candidate, at Polytechnic School of the University of São Paulo/USP, daniele.pessutto@lme.pcc.usp.br
[3]Prof Dr, at Polytechnic School of the University of São Paulo/USP, vanderley.john@lme.pcc.usp.br

ABSTRACT
Due to high consumption of construction materials and their environmental impacts, our group is dedicated to materials use efficiency. This case study uses a simplified method to estimate the water footprint of mortar production which represent ~40% of the cement use in Brazil. The results show ranges of 341-577 l/m^3 for direct water use, 698-4128 l/m^3 for indirect water use and -8-22996 l/m^3 for energy production -the most water intensive activity. This study represents a major contribution to the industry, academia and society since measuring is fundamental for water efficiency.

Key-words: water consumption, life cycle assessment, sustainable construction.

A PEGADA HÍDRICA DE MATERIAIS CIMENTÍCIOS: UM ESTUDO DE CASO SOBRE PRODUÇÃO DE ARGAMASSA COM ALTO TEOR DE FILLER

RESUMO
Devido ao alto consumo de materiais de construção e seus impactos ambientais, nosso grupo se dedica à eficiência no uso destes materiais. Este estudo de caso usa um método simplificado para estimar a pegada hídrica da produção de argamassa, que representa ~40% do uso de cimento no Brasil. Os resultados mostram faixas de 341-577 l/m^3 para uso direto, 698-4128 l/m^3 para uso indireto e -8-229996 l/m^3 para produção de energia -a atividade mais intensiva em água. O estudo representa uma importante contribuição para a indústria, o meio acadêmico e a sociedade, já que a medição é fundamental para a eficiência hídrica.

Palavras-chave: consumo de água, avaliação do ciclo de vida, construção sustentável.

Grupo 1: Oriundos de teses, dissertações e relatórios finais de projetos de pesquisa; ou **Grupo 2:** oriundos de disciplinas de pós graduação, iniciação científica, trabalhos de conclusão de curso (TCC), pesquisas aplicadas e outros.

1. Introduction

Access to fresh water is limited to less than 1 % of the water in the world and varies on the time of the year and location [1]. Water has become a scarce resource in many regions in the world already, and climate change may make it worst. Nevertheless, the demand for water is expected to increase in 50% between 2010-2050 [2]. Reasons for the increase of water demand include urban population growth, industrialization, and climate change [3].

In 2015, the total cement production was 4,6 billion tonnes and is expected to increase to 6 billion tonnes in 2050 [4,5]. From the huge cement production, approximately 40% goes to mortars [5]. The mortar demand is also influenced by population growth, better housing and infrastructure needs. The production of mortars requires large amounts of water in addition to mixing water which is usually the only water figure known.

The water footprint is a tool within life cycle thinking that allows to estimate potential environmental impacts related to water use and water consumption in the life cycle of a product [6]. While life cycle assessment has been widely used in construction and other materials, the water impacts are usually neglected or not consider to a complete extent [7,8]. Furthermore, the impacts related to water use and consumption are local, different from impacts due to CO_2 emissions which have global consequences independently of where the emissions happened [9,10]. This means that the consumption of the same amount of water will have different impact in different regions.

For efficient water use, measuring is fundamental [6]. Life cycle assessment and water footprint are tools that allow measuring water consumption, including consumption from the raw materials extraction and production [11,12]. However, existing water footprint methodologies are quite complex, and companies are struggling to use them [13]. We have been working on a simplified water footprint methodology for cementitious materials that will allow companies to estimate their water consumption and footprint since only a few studies have been done regarding water consumption and water footprint in cementitious materials -mostly focused in cement production itself [7,13–17].

As our group seeks for lowering potential environmental impacts in construction materials, a high filler mortar is under study to determine its capacity to absorb CO_2 while using less cement at the same time, which also reduces CO_2 footprint from the material. In this paper, the water footprint of this material is studied to complement its environmental profile.

This paper presents a case study on the water footprint of high filler mortar production. The study of a simplified water footprint methodology for cementitious materials represents a major contribution to the industry, academia and society since water impacts in this area have been little studied and due to current and future water scarcity problems. Furthermore, this study demonstrates the importance of collaboration between researchers.

Both studies -cementitious materials water footprint and the development of low carbon cementitious materials- are the result of academic work in partnership with the industry.

2. METHODOLOGY

The water-intensive activities within the mortar life cycle from cradle to gate for 1 m^3 of mortar are explored and presented with their corresponding water inventory figures. Since there are different technological routes and different water footprint characterization factors, the resulting variability is considered and presented.

The results of the water inventory are classified as direct water use- mixing the mortar and washing the yard, indirect water use for cement production, filler production and sand production. Finally, the water footprint for energy production -fuels and electricity- is included. For energy production, only cement and sand were included due to lack of water figures for the rest of the components and activities. However, cement and sand are known for being the most energy intensive activities.

A simplified water footprint methodology for cementitious materials is applied to a case study on high filler-low binder-low water mortar formulations. The water footprint (Equation 1) is the result of the impact assessment (characterization factors) applied to the water inventory (water consumption). The characterization factors used in this paper are presented in Table 1. This characterization factors were chosen for Brazil and represent and belong to three different water footprint methods in order to consider the variability. The water figures used in this paper are presented in Table 2.

$$Water\ Footprint = Water\ consumption * Characterization\ factor \quad (1)$$

Table 1 – Characterization factors from different water footprint methods for Brazil.

Water footprint method	Unit	CF	Reference
Hoekstra	m^3/m^3	0.05	(18)
ReCiPe 2016 H	m^3/m^3	1	(19)
AWARE	m^3/m^3	2.17	(10)

3. WATER USE IN MORTAR PRODUCTION

Mortar production consists of dust control during raw materials extraction, cement production and in the production of mortar. Only during mixing of the mortar, we estimate at least an approximate of 450 l/m^3 which depends on the formulation. Regarding sand extraction, there are many routes to obtain this material: hydraulic mining, pit sand, artificial sand and others are quite common in Brazil. An important activity within sand production is the washing of the sand due to impurities, clay or dust in the case of artificial sand. For hydraulic mining and washing of the sand, there is large amount of water that depending on the practices of the company could be reused but the water use is hardly controlled or not

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controlled at all. During cement production, depending on the type of kiln there could be at least four different processes that requires different amounts of water for cooling of the clinker. This water could also be reused. In this paper, we are considering mortar formulations with cement which consist mainly of clinker, gypsum and filler. However, for other types of cements that consist also of supplementary cementitious materials (SCM) which is usually the case, the treatment and production of these SCM should be consider within the life cycle of the mortar. On top of that, there is water for fuels and electricity production. All these activities consume water, i.e. water evaporates, integrates into the product, is discharged to a different water source than the original or its quality is decreased.

Table 2 – Water figure for the estimation of water consumption in different activities.

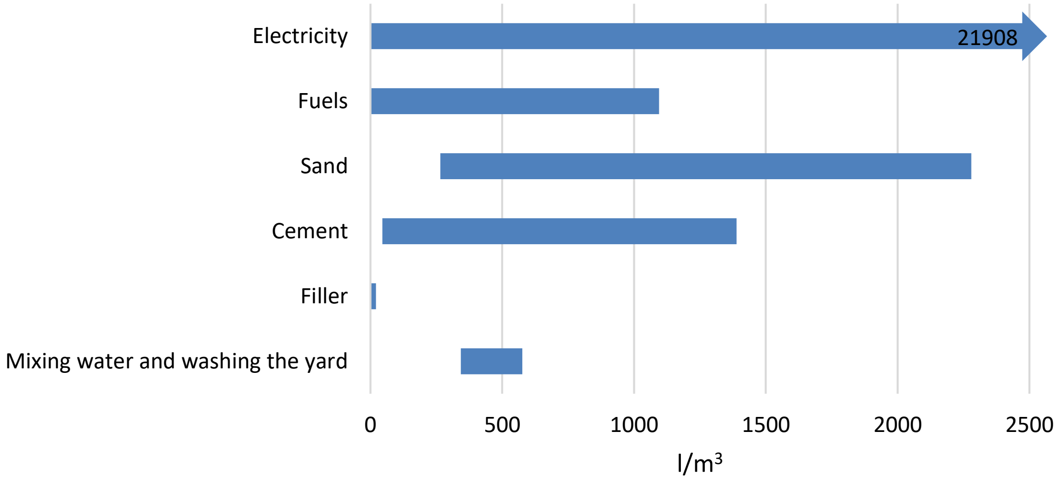
	Unit	Min	Max	Reference
Cement	Kg/kg	0.185	1.333	(7)
Filler	Kg/kg	0.023	0.08	
Sand	Kg/kg	0.116	1	
Washing the yard	Kg/m^3	1	3	
Formulation water	Kg/m^3	453	687	Mortar formulations
Fuels (cement)	Kg/kg	0	19.659	(20,21)
Fuels (sand)	Kg/kg	0	0.622	
Electricity (cement)	Kg/kg	0	1.0237	
Electricity (sand)	Kg/kg	-0.0025	0.0089	

4. CASE STUDY ON HIGH FILLER-LOW BINDER-LOW WATER MORTAR FORMULATIONS

The study on high filler mortar conducted in our lab -16 mortar formulations-, aims to quantify the CO_2 capture by the carbonation phenomenon for cement compositions with filler rate of: 0%, 30%, 50% and 70%. The quantities of raw material of the mortars were determined according to the water/solid ratio (w/s) and with the volume of paste of each composition. 5% of sand humidity was considered according to a 4% to 6% rate of sand humidity presented by Petrucci [22].

Figure **1** presents the water consumption of mortar production, its different components and energy production in ranges of minimum-maximum values. Direct water use for mixing and washing the yard ranges from 341 to 577 l/m^3. Indirect water use for filler, cement and sand, ranges from 698 to 4128 l/m^3. Water use for energy production including fuels and electricity ranges from -8 to 22996 l/m^3. It is observed that energy production is the most water intensive activity. Within water use for the mortar components -sand, cement and filler- it is observed that sand and cement represent the highest water consumption. Direct water use for mortar mixing and for washing of the yard, represents a small amount compared to the other water uses.

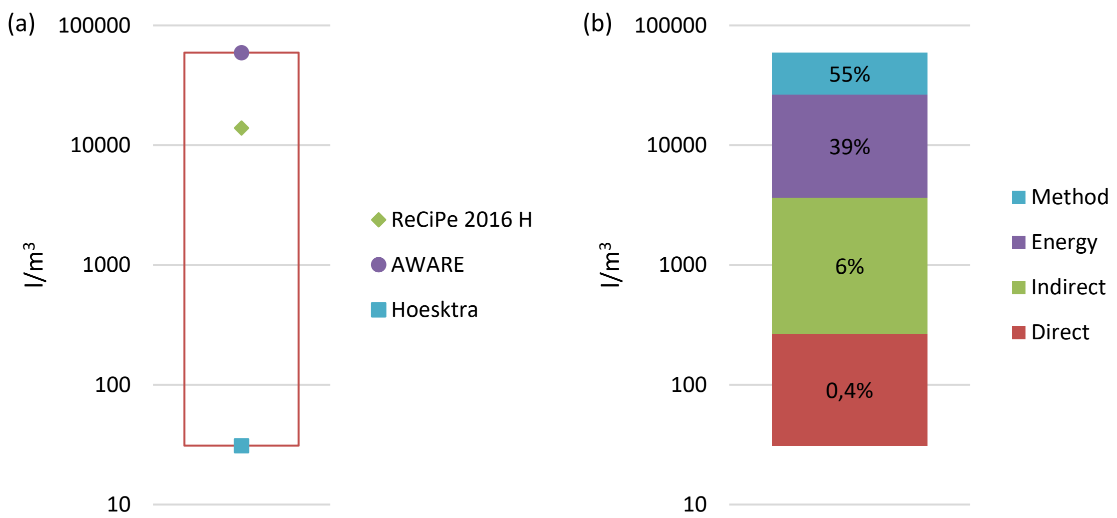
Figure 1 – Variability in water consumption for different activities within the mortar production life cycle.



Source: the authors

Figure **2** presents the variability due to the characterization factor of the impact assessment method. It is observed that more than half of the variability comes from the choice of method. After that, 39% of the variability comes from the energy production. Direct and indirect water use makes up for 1% and 6% respectively.

Figure 2 – (a) Variability in water footprint of mortar production from cradle to gate and (b) sources of variability.



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5. DISCUSSION

The direct water use -mixing and washing the yard could vary due to the formulation, strength requirements and efficiency in on site water use respectively. Weather also plays an important role in water consumption, for instance, for washing the yard. Practices such as water reuse could lower water consumption but are not so common in the job site and should be encouraged. Regarding indirect water use for cement, filler and sand production, there are different production routes for each of these materials which will result in variability in water consumption of mortar production. This variability should be considered instead of choosing one value to represent a product's water consumption and footprint.

Water consumption for energy production -fuels and electricity- is quite high. These activities are considered background activities in the life cycle of mortar production since the mortar producer cannot control or influence them. In this case, an energy efficiency approach should be considered in order to reduced water consumption, CO_2 emissions and energy consumption itself. Apart from energy production, mortar consumes high quantities of water for cement and sand production.

The reference mortar formulations -no filler- are the ones that uses more water since they require more mixing water and more water for cement production. The use of filler is beneficial since it helps to reduce cement consumption which results in less CO_2 emissions, less water for cement production and less water demand for mixing the mortar.

More than 50% of the variability comes from the choice of method (characterization factors) which means we must understand the method and characterization factors when performing water footprint analysis and for interpretation of results. Furthermore, it is necessary to detail the method and characterization factors when reporting water footprint results. In this study, the chosen characterization factor corresponds to Brazil. We strongly argue that characterization factors for water footprint analysis should be done at a basin level and not at a country level even more if the country is continental size as Brazil is. This is due to the local and seasonal characteristics of potential water impacts.

6. CONCLUSIONS

The water footprint of high filler mortar production was estimated through a simplified water footprint methodology. The results demonstrate a high water consumption and variability. This result is important to identify where is needed and possible to work on water reduction. The most intensive activities -energy production- are background activities, therefore an energy efficiency approach is needed. After energy, cement and sand production contribute the most. Thus, these activities should be carefully performed, and the water use should be controlled and reduced. Reuse and recycling practices are highly recommended. This paper also demonstrates the relevance of collaboration in research.

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