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The use of basalt aggregates in the production of concrete for the prefabrication industry: Environmental impact assessment, interpretation and improvement

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A R T I C L E I N F O

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A B S T R A C T

This study aims at environmentally assessing the most significant input and output flows related to the production of concrete using basalt aggregates. For this purpose, Life Cycle Assessment (LCA) was applied according to the ISO 14040:2006 and 14044:2006. All data used were collected on site based on observations during site visits, review of documents and interviews with technical personnel and management. They were processed by using SimaPro 7.3.3, accessing the Ecoinvent v.2.2 database and using the Impact 2002+ method. The LCIA results show that the most impacting phase is the production of the basalt aggregates, with "Human Health" being the most affected damage category because of the emissions to air, of 2.7 kg of particulates (grain size <2.5 μm). In addition to this, the concrete production causes, mainly, the emission, in air, of 465 kg of Carbon Dioxide and the consumption of 37.37 kg of crude oil, per cubic metre of concrete, affecting, the damage categories "Climate Change" and "Resources" also. Regarding "Ecosystem Quality", the occurred damage is due to the emission to air, of 29.6 g of Aluminium and of 251 mg of Zinc into the soil per cubic metre of concrete. Based on the obtained results, the increase of the amount of water used for particulates removal during the basalt extraction phase was assessed. Furthermore, the alternative use of limestone aggregates was assessed from both technical and environmental perspectives. The analysis developed highlighted a total damage decrease of 67%.

1. Introduction

Concrete is an artificial conglomerate consisting of a mixture of a binder, water and aggregates (sand and gravel) which, depending on the need, can be integrated with additives, in order to modify its physicochemical and mechanical properties. Nowadays, cement is the binder mainly used for the production of concrete even if, in the past, lime was sometimes used. Cement, when mixed with water, hydrates and hardens, giving to the mixture (concrete) hardness values as high as that for rocks. Concrete has good compressive resistance, while its behaviour to traction is considerably poor: for this reason, it is commonly reinforced by using steel strands. Steel reinforcement is, always, appropriately designed based on the traction effort magnitude and it is installed before concrete is cast.

According to Habert et al. (Habert et al., 2012), the building materials sector is one of the largest CO_2-emitting and resources consuming industrial sector in the world. Concrete is the single most world-widely used building material mainly because of its strength and durability, among other benefits. Concrete is used in nearly every type of construction, including homes, buildings, roads, bridges, airports and subways, just to name a few (Concrete CO2 F, 2008). To ensure the future competitiveness of concrete as a construction material, it is essential to improve the sustainability of concrete structures. For this purpose, environmental impact and resources consumption reduction-potentials can be found in the field of concrete construction, especially in raw-materials production and concrete manufacturing technology (Proske et al., 2013). In this context, Life Cycle Assessment (LCA) can be used as a design

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support-tool for assessing environmental impacts and improvement potentials in concrete production. In this way, it will be possible to make concrete more environmentally sustainable so that it can perform well compared to other construction materials. A literature review was developed for highlighting the most relevant research studies dealing with the environmental sustainability matter in the production of concretes. In particular, the following papers were found: Knoeri et al. (2013), regarding the application of LCA for comparing recycled and conventional concrete for structural applications; Cazacliu and Ventura (2010), in which LCA was applied for assessing technical and environmental effects of concrete production, comparing dry batch with central mixed plant; García-Rey and Yepes (2012), about the application of LCA on concrete structures for assessing and improving the environmental performance associated with the construction phase; Habert et al. (2012), where LCA was used for demonstrating that the use of high performance concrete for bridges construction causes less environmental impacts than the traditional one; Jonsson et al. (1998), dedicated to the application of LCA for assessing the environmental sustainability of both concrete and steel building frames; Zabalza Bribián et al. (2011), in which it was possible to prove that the use of the best available construction technique and of eco-innovation in the manufacturing plants can significantly allow the reduction of the damage due to the construction products from an LCA perspective; Nässén et al. (2012), where concrete and wood were compared considering the carbon dioxide emissions as well as the use of resources, materials and energy during the life cycle; López-Mesa et al. (2009), about the application of LCA for comparing, on equivalent building structures, the use of pre-cast and cast-in-situ concrete; Proske et al. (2013), presenting mix design principles and laboratory tests to show how concrete can be eco-friendly if produced with a reduced content of water and cement; Van den Heede and De Belie (2012) where a comparative assessment based on an LCA approach was carried out between traditional and "green" concretes; Valipour et al. (2014) where the environmental impact on the global warming potential of concrete containing zeolite was assessed compared to conventional one applying the life-cycle assessment method; Habert et al., 2011) where LCA was applied for environmentally assessing the geopolymer concrete production reviewing current research trends; Pelisser et al. (2012) dealing with the study of the utility of recycled tire rubber for lightweight concrete with added metakaolin, with the dual purpose of reducing cement consumption while achieving satisfactory strength; Blankendaal et al. (2014) reporting an LCA application example for assessing measures oriented to the environmental impact reduction of both concrete and asphalt; Mingnan et al. (2013) dedicated to the environmental assessment of ready-mixed concrete production in China; Yang et al. (2013) reporting an evaluation procedure for the CO_2 reduction of alkali-activated concrete. Furthermore, Ortiz et al. (2009) reviewed all the studies (from 2000 to 2007) about the application of LCA within the building sector.

The literature review was useful in creating a better understanding of the state of the art of concrete production environmental assessment. Besides, it highlighted that a number of LCAs on different concrete-types have been conducted over the last few years from a technical and environmental perspective, but studies regarding the application of LCA to basalt aggregates based concrete were not found. From this point of view a gap in the literature was observed, thereby highlighting the need of LCAs on this topic. In this context, this paper deals with the environmental assessment of the input and output flows related to the production of concrete using basalt aggregates in Italy. For this purpose, LCA was considered a valid tool to be used because, as defined by the International Organization for Standardization in the ISO 14040:2006 (ISO 14040, 2006), it is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

2. The origin of concrete: a historical review

It is difficult to go back to the origins of the conglomerate building technique as it seems that, during the Assyrian and the Egyptian ages, buildings were constructed using fine materials. Greeks also, already, knew this technique, adopted for the construction of the Argos aqueduct, Sparta tank and for other buildings, traces of which still remain. The Romans gave a big boost to this technique, using it for different constructions (for example: roads, foundations and masonry buildings) which still survive in a good state of preservation. As far as the binder used is concerned, its invention is not of the Roman Age: it can be traced back to the third millennium BC when, in Egypt, gypsum mortar was used for the construction of masonry walls in blocks of stone. Until mortar was made using just lime, the hardening of the concrete was extremely slow, as the gradual consolidation of a lime mortar depends on the reaction between calcium hydroxide and carbon dioxide present in the air. The great revolution in this field occurred when lime was replaced by Pozzolan. Its chemical and physical characteristics were such that concrete hardened even in water, with no need for contact with the air. This allowed the production of high strength and fast hardening mortars. This finding, dating back to the first century BC, enabled the Romans building technique to be improved The decline of the Roman Empire, resulted in the inexorable decline in the quality of construction, especially in the suburbs of Rome. Pozzolan was no more used so that the way of producing concrete, and the technology was forgotten. Such decline continued throughout the Middle Ages. The discovery of the hydraulic lime (by the British Engineer John Smeaton) was a significant step forward in concrete production techniques. Such discovery marked the transition from the Roman concrete to the modern concrete. A synthesis process was developed for obtaining first hydraulic lime and then Portland cement. In 1860, based on the definition of the chemical composition of cement by M. Chatelier, industrial production of concrete was allowed and, since then, it has been under continuous development and innovation (Bostenaru-Dan et al., 2010; Palley, 2010).

3. Ready-mixed concrete: production data, main uses and mechanical properties

Ready-mixed concrete is produced in mixing plants located in buildings construction sites or in external appropriately equipped yards. According to the most recent statistics provided by the European Ready Mixed Concrete Organization (ERMCO), ready-mixed concrete market was heavily influenced by the economic dynamics which characterized the European Union in the last years. The crisis determined substantial changes in production levels: between 2009 and 2010, ready-mixed concrete production decreased by 4.3%: in 2011, there was a slight increase of 2.7% (ERMCO (European Ready Mixed Concrete Organization), June 2012). In this context, Italy, one of the leading countries in this sector, since 2008 has been recording decreased production. Concrete production decreased from 66 Mm^3 (2008) to 40 Mm^3 (2012) (AITEC (Associazione Tecnico Economica Cemento), 2012). Two different types of concrete can be identified: light and normal. Such a definition refers to its specific weight after drying, assuming values between 800 and 2000 kg/m^3, in the first case, while varying from 2000 to 2600 kg/m^3 in the second case. In particular, "light concrete" is mainly used, also in the form of blocks, for houses construction: such blocks are used for partitions and provide protection from noise and fire. "Normal concrete" is constantly used in the industrial and