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Review

The past and future of sustainable concrete: A critical review and new strategies on cement-based materials

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ABSTRACT

The negative impacts of cement-based material (CBM) production are way bigger than ever expected. To illustrate the scale of this phenomenon, all the forests in the world, regardless of the fact that they are disappearing at an alarming rate, are not enough to offset even half the environmental impact (EI) of global aggregates and cement production. Thus, it is necessary to promote scientific research and guide more researchers and professionals in the construction industry to investigate the undiscovered sustainability paths, namely for concrete before and after end-of-life. For that purpose, a global and extensive review is made here to provide an overall view of concrete sustainability in all possible paths. Then, each path is organized as follows: (i) brief introduction, (ii) presentation of non-traditional materials and techniques that can be used for the selected strategy, (iii) their limitations and (iv) future trends. The study also identifies what is already known to avoid putting valuable research resources into redundant scientific studies. The following paths of concrete production sustainability were identified: mix composition (e.g. reduce the EI and resources use of binders, aggregates, water and reinforcement), materials manufacturing (e.g. new production techniques of cement, aggregates and steel bars), concrete mixing (e.g. mixer type and mixing method), on-site application (e.g. regular casting and digital concrete/3D printing), and in-service performance (e.g. increase the durability of reinforced concrete and carbon capture and thermal conductivity). On most of these paths, many studies have been made on the same non-traditional materials and techniques and similar outputs were obtained. Yet, many other non-traditional materials and techniques have not been explored before, or are incomplete in terms of the characteristics analysed. More than providing definite solutions, this contribution intends to open the minds of the readers to the vastly unexplored world of “green concrete”.

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Acronyms list

AAM	Alkali-activated material
ACR	alkali-carbonate reaction
ADP	abiotic depletion potential
AP	acidification potential
ASR	alkali-silica reaction
AWA	agricultural waste ash
AWAF	agricultural wastes and aquaculture farming
AWAFA	agricultural wastes and aquaculture farming ashes
BLA	bamboo leaf ash
BTQ	binary, ternary and quaternary
CBA	coal bottom ash
CBM	cement-based materials
CCA	corn cob ash
CDRA	mixed construction and demolition recycled aggregate
CDW	construction and demolition waste
CNT	carbon nanotubes
ECR	epoxy-coated rebar
EC	expanded clay
ECG	expanded cork granules
EGA	elephant grass ash
EI	environmental impacts
EP	Eutrophication potential
FA	coal fly ash
FBBA	forest biomass bottom ash
FRP	fibre reinforced-polymer
GGBS	ground granulated blast furnace slag
GR	galvanized rebars
GWP	Global warming potential
L	lime
LCA	Life Cycle Assessment
LOI	loss on ignition
LWA	light-weight aggregate
M	methylcellulose
MIBA	municipal solid waste incinerator bottom ash
MIFA	municipal solid waste incinerator fly ash
MRA	mixed recycled aggregate
MSA	mussel shell ash
NF	natural fibres
ODP	ozone depletion potential
OPC	Ordinary Portland cement
OWA	olive waste ash
PCM	Phase change materials
PE-NRe	non-renewable primary energy resources
PE-Re	renewable primary energy resources
POCP	photochemical ozone creation potential
POFA	palm oil fuel ash
RCA	recycled concrete aggregate
RH	rise husk
RHA	rise husk ash
RMA	recycled masonry aggregate
SAP	Super absorbent polymer
SA	silica aerogel
SBA	sugarcane bagasse ash
SCC	self-compacting concrete
SCM	supplementary cementitious material
SF	silica fume
SMM	Shape memory material
SP	Superplasticizer
SSA	sewage sludge ash
SSD	saturated surface-dry
SSR	stainless steel rebar
TWA	tire waste aggregate
TWA	tobacco waste ash
WA	wood ashes
w/b	water to binder ratio
WFA	wood fly ash
WSA	wheat straw ash

1. Introduction

Many studies have alerted us to the negative impacts of cement-based materials (CBM) production within the construction industry. These impacts may be way bigger than ever anticipated. Illustrating the concept, the total world production of aggregates and cement can be around 48.3 billion tonnes (IEA, 2019; USGS, 2019) and 4.1 billion tonnes (average - (PMR, 2017; Freedonia, 2016)) in 2018, respectively. Additionally, the average global warming potential (GWP) of 1 kg aggregate and cement is 0.0123 kg $CO_{2\ eq}$ (Marinković et al., 2010; Korre and Durucan, 2009; Tošić et al., 2015; Braga, 2015) and 981 kg $CO_{2\ eq}$ (Marinković et al., 2010; Braga, 2015; Teixeira et al., 2016; Blengini, 2006; ECRA, 2015; de Schepper et al., 2014a; Chen et al., 2010), respectively. Thus, the total GWP of aggregates and cement will be around 5.9409E+11 kg $CO_{2\ eq}$ and 4.0221E+15 kg $CO_{2\ eq}$, respectively. Contrary to a common statement, instead of concrete, aggregates are the most consumed material after water. Previous values shown in the previous sentences indicate that, although aggregates consumption is almost 12 times bigger than that of cement, their environmental impact (EI) is insignificant relatively to cement. If one considers only half of the produced aggregates and cement