

THE LOW- CARBON CONCRETE GUIDE: **MATERIALS**

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The Low-Carbon Concrete Guide: Materials

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First Edition, First Printing November 2025
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ISBN: 979-8-218-85914-5

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The author thanks Dr. Andrea Schokker, PE, LEED AP, and Dr. Charles Nmai, PE, M. ASCE, FACI, NEU Board of Directors president, for their thoughtful review and valuable feedback, which helped refine and improve the manuscript. All drawings were conceptualized by the author and produced by Kate McCabe, whose skill and creativity brought the ideas to life. Additional thanks are extended to everyone who generously contributed photographs and visual materials used throughout the book.

Author's note: The development of low-carbon concrete materials and technologies is advancing rapidly, with new products and approaches emerging across research and practice. This guide provides a snapshot of the field based on the best information currently available. Every effort has been made to capture the range of materials, technologies, and perspectives shaping low-carbon concrete and to present them as clearly and accurately as possible.

Variations in data availability and maturity across different technologies can make direct comparisons difficult, but the principles and context presented here are intended to serve as a foundation for interpreting and applying concepts in low-carbon concrete. This work is a living document and will be updated as new information and technologies emerge.

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LIST OF ABBREVIATIONS

IL	Portland-limestone cement	DOE	Department of Energy
IP	Portland-pozzolan cement	DOT	Department of Transportation
IS	Portland-slag cement	DRI-EAF	Direct reduced iron – electric arc furnace
IT	Portland-ternary cement	EAF	Electric arc furnace
AAC	Alkali-activated cement	ECC	Engineered cementitious composites
AACC	Alkali-activated calcined clay	EN	European Norm (European Standard)
AAFA	Alkali-activated fly ash	EP	Eutrophication potential
AAS	Alkali-activated slag	EPA	Environmental Protection Agency
AASHTO	American Association of State Highway and Transportation Officials	EPD	Environmental product declaration
AC	Alternative cement	f'c	Specified compressive strength of concrete, psi
ACA	American Cement Association	FA	Fly ash
ACAA	American Coal Ash Association	FAO	Food and Agriculture Organization
ACBFS	Air-cooled blast furnace slag	FBE	Fusion-bonded epoxy
ACC	Accelerated carbon curing	FFI	Fossil fuel industry
ACI	American Concrete Institute	FGD	Flue gas desulfurization
ADP	Adiabatic depletion potential	FHWA	Federal Highway Administration
AEA	Air-entraining agent	FRC	Fiber-reinforced concrete
AHJ	Authority having jurisdiction	FRGA	Fine recycled glass aggregate
AI	Artificial intelligence	FRP	Fiber-reinforced polymer
AMF	Aggregate mineral filler	GCC	Ground calcium carbonate
AP	Acidification potential	GCCA	Global Cement and Concrete Association
APC	Advanced process control	GE	E-glass ground glass pozzolan
APC	Air pollution control	GFRP	Glass fiber reinforced polymer
ASR	Alkali-silica reaction	GGBFS	Ground granulated blast furnace slag
ASTM	ASTM International	GGP	Ground glass pozzolan
BCSA	Belitic calcium sulfoaluminate	GHG	Greenhouse emission
BET	Brunauer-Emmett-Teller	GPS	Global positioning system
BF-BOF	Blast furnace – basic oxygen furnace	GS	Soda-lime ground glass pozzolan
BFRP	Basalt fiber reinforced polymer	GU	General use
BFSA	Blast furnace slag aggregate	GWP	Global warming potential
BOF	Basic oxygen furnace	GWP100	Global warming potential over 100 years
BSE	Backscattered electrons	HCFC	Hydrochlorofluorocarbon
BYF	Belite-ye'elimite-ferrite	HDPE	High-density polyethylene
CAC	Calcium aluminate cement	HE	High early strength
CBA	Coal bottom ash	HFC	Hydrofluorocarbon
CC	Carbonated cement	HPC	High-performance concrete
CCR	Coal combustion residue	HPGR	High-pressure grinding roll
CCS	Carbon capture and storage	HRWR	High-range water reducer
CCU	Carbon capture and utilization	HS	High sulfate resistance
CCUS	Carbon capture, utilization, and storage	HSC	High-strength concrete
CEN	European Committee for Standardization	HVFA	High-volume fly ash
CFA	Coal fly ash	IBC	International building code
CFC	Chlorofluorocarbon	IEA	International Energy Association
CFRP	Carbon fiber reinforced polymer	IPCC	Intergovernmental Panel on Climate Change
CIS	Commonwealth of Independent States	ISO	International Organization for Standardization
CKD	Cement kiln dust	ITZ	Interfacial transition zone
CLSM	Controlled Low-Strength Material	LA	Los Angeles
COP	Conference of the parties	LCA	Life cycle assessment
CRGA	Coarse recycled glass aggregate	LCC	Low-carbon concrete
CSA	Calcium sulfoaluminate cement	LCCA	Life cycle cost analysis
CSA	Copper slag aggregate	LC ³	Limestone calcined clay cement
DAC	Direct air capture		
DE	Diatomaceous Earth		

LH	Low heat of hydration	SCC	Self-consolidated concrete
LOI	Loss on ignition	SCM	Supplementary cementitious material
LULUCF	Land use, land-use change, and forestry	SEM	Scanning electron microscope
LWA	Lightweight aggregate	SE	Secondary electron
MCP	Manual of Concrete Practice	SF	Silica fume
MEA	Monoethanolamine	SFA	Silica Fume Association
MH	Moderate heat of hydration	SFRC	Steel fiber-reinforced concrete
MICP	Microbiologically induced calcium carbonate precipitation	SSA	Specific surface area
MK	Metakaolin	SSC	Super-sulfated cement
MOC	Magnesium oxychloride cement	TGA	Thermogravimetric analysis
MOS	Magnesium oxy-sulfate cement	UFS	Used foundry sand
MPC	Magnesium phosphate cement	UHPC	Ultra-high performance concrete
MS	Moderate sulfate resistance	UNFCCC	United Nations UN Framework Convention on Climate Change
MSW	Municipal solid waste	VOC	Volatile organic compound
NGO	Non-governmental organization	WAP	Water absorbing polymer
NIST	National Institute of Standards and Technology	WBCSD	World Business Council for Sustainable Development
NMIC	National Minerals Information Center	WHR	Waste heat recovery
NP	Natural pozzolan	XRD	X-ray diffraction
NR	Not reported	XRF	X-ray fluorescence
NREL	National Renewable Energy Lab		
NRMCA	National Ready-Mixed Concrete Association		
NEU	An ACI Center of Excellence for Carbon Neutral Concrete		
ODP	Ozone depletion potential		
PC	Portland cement		
PCA	Portland Cement Association		
PCC	Portland cement concrete		
PCE	Polycarboxylate ether		
PCR	Product category rule		
PE	Polyethylene		
PET	Polyethylene terephthalate		
PLC	Portland limestone cement		
PM	Particulate matter		
POCP	Photochemical ozone creation potential		
POFA	Palm oil fuel ash		
PP	Polypropylene		
PRC	Polymer reinforced concrete		
PSD	Particle size distribution		
psi	Pounds per square inch		
PV	Photo-voltaic		
PVA	Polyvinyl alcohol		
QA	Quality assurance		
QC	Quality control		
RCA	Recycled concrete aggregates		
RDF	Refuse-derived fuel		
RHA	Rice husk ash		
RMI	Rocky Mountain Institute		
S-LCA	Social life cycle assessment		
SAI	Strength activity index		
SAP	Superabsorbent polymer		
SCA	Slag Cement Association		
SCBA	Sugarcane bagasse ash		

LIST OF CHEMICAL FORMULAS

Oxides

Al_2O_3	Alumina, aluminum oxide
CaCO_3	Calcium carbonate, calcite
CaO	Calcia, calcium oxide, lime
Fe_2O_3	Iron oxide
H_2O	Water
K_2O	Potassium oxide
MgO	Magnesium oxide, magnesia, periclase
Na_2O	Sodium oxide
$\text{Na}_2\text{O}_{\text{eq}}$	Sodium oxide equivalent
SiO_2	Silica, silicon dioxide
SO_3	Sulfate

Major Portland Cement Phases and Gypsum (Cement Chemist Notation)

C_3A	Aluminate, tricalcium aluminate, $3\text{CaO}\cdot\text{Al}_2\text{O}_3$
C_2S	Belite, dicalcium silicate, $2\text{CaO}\cdot\text{SiO}_2$
C_3S	Alite, tricalcium silicate, $3\text{CaO}\cdot\text{SiO}_2$
C_4AF	Ferrite, tetracalcium aluminoferrite, $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$
CH_2	Calcium sulfate, gypsum, $\text{CaSO}_4\cdot 2\text{H}_2\text{O}$ (set regulator)

Portland Cement Hydrates

AFm	Monosulfate, C_4AH_{12} , $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{SO}_3\cdot 12\text{H}_2\text{O}$
AFt	Ettringite, $\text{C}_6\text{A}_3\text{H}_{32}$, $6\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{SO}_3\cdot 32\text{H}_2\text{O}$
C_3AH_6	Hydrogarnet, $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 6\text{H}_2\text{O}$
$\text{C}_6\text{AFH}_{12}$	Aluminoferrite hydrate, $6\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3\cdot 12\text{H}_2\text{O}$

CH	Calcium hydroxide, portlandite, $\text{Ca}(\text{OH})_2$	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$	Serpentine
C-S-H	Calcium silicate hydrate, $3\text{CaO} \cdot \text{SiO}_2 \cdot 8\text{H}_2\text{O}$ (variable stoichiometry)	M-S-H	Magnesium silicate hydrate
		Na_2CO_3	Sodium carbonate
		Na_2SiO_3	Sodium silicate
		NaOH	Sodium hydroxide
		N-A-S-H	Sodium aluminate silicate hydrate

Alternative Cements

C_4A_3	Ye'elimite, $4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot \text{SO}_3$
CA	Monocalcium aluminate
CAH	Calcium aluminate hydrate
$\text{CaMg}(\text{CO}_3)_2$	Dolomite
C-A-S-H	Calcium aluminate silicate hydrate
KOH	Potassium hydroxide
K_2SiO_3	Potassium silicate
MgCO_3	Magnesite
$\text{Mg}(\text{OH})_2$	Magnesium hydroxide, brucite
Mg_2SiO_4	Olivine

Environmental/Emissions-Related Compounds

CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
SF_6	Sulfur hexafluoride
SO_x	Sulfur oxides



Figure 1 Concrete arches along the Almería seawall in Spain. Like passing through successive arches, reducing the carbon footprint of concrete requires many coordinated steps over time. *Photo courtesy of Najeeb Jindeel.*