An ACI Technical Publication

SYMPOSIUM VOLUME

Concrete and Cement-Based Composites for Sustainable Built Environments

SP-361

Editors:
Kimberly Waggle Kramer, Milena Rangelov,
and Hessam Azarijafari

American Concrete Institute
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Sponsored by
ACI Committees 130 and E702

ACI Concrete Convention
October 23-27, 2022
Dallas, Texas

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First printing, March 2024

Discussion is welcomed for all materials published in this issue and will appear ten months from this journal's date if the discussion is received within four months of the paper's print publication. Discussion of material received after specified dates will be considered individually for publication or private response. ACI Standards published in ACI Journals for public comment have discussion due dates printed with the Standard.

The papers in this volume have been reviewed under Institute publication procedures by individuals expert in the subject areas of the papers.

Printed in the United States of America

Editorial production: Gail L. Tatum

ISBN-13: 978-1-64195-245-3

Concrete and Cement-Based Composites for Sustainable Built Environments

Concrete has played a pivotal role in shaping the modern world's infrastructure and the built environment. Its unparalleled versatility, durability, and structural integrity have made it indispensable in the construction industry. From skyscrapers to long-span bridges, water reservoirs, dams, and highways, the ubiquitous presence of concrete in modern society underscores its significance in global development. As we stand at the crossroads of environmental awareness and the imperative to advance our societies, the sustainability of concrete production and utilization is becoming a new engineering paradigm.

The immense demand for concrete, driven by urbanization and infrastructure development, has prompted a critical examination of its environmental impact. One of the most pressing concerns is the substantial carbon footprint associated with traditional concrete production. The production of cement, a key ingredient in concrete, is a notably energy-intensive process that releases a significant amount of carbon dioxide (CO2) into the atmosphere. As concrete remains unparalleled in its ability to provide structural functionality, disaster resilience, and containment of hazardous materials, the demand for concrete production is increasing, while at the same time, the industry is facing the urgency to mitigate its ecological consequences.

This special publication investigates the multi-faceted realm of concrete sustainability, exploring the interplay between its engineering properties, environmental implications, and novel solutions, striving to provide an innovative and holistic perspective.

In recent years, the concrete industry has witnessed a surge of innovation and research aimed at revolutionizing its sustainability. An array of cutting-edge technologies and methodologies has emerged, each offering promise in mitigating the environmental footprint of concrete. Notably, the integration of supplementary cementitious materials, such as calcined clays and other industrial byproducts, has gained traction to reduce cement content while enhancing concrete performance. Mix design optimization, coupled with advanced admixtures, further elevates the potential for creating durable, strong, and eco-friendly concrete mixtures.

Concrete practitioners will gain an advanced understanding of a wide variety of strategies that are readily implementable and oftentimes associated with economic savings and durability enhancement from reading these manuscripts. The incorporation of recycled materials, such as crushed concrete and reclaimed aggregates, not only reduces waste but also lessens the demand for virgin resources. Furthermore, the adoption of efficient production techniques, along with the exploration of carbon capture and utilization technologies, presents an optimistic path forward for the industry.

This special publication aspires to contribute to the ongoing discourse on concrete sustainability, offering insights, perspectives, and actionable pathways toward a more environmentally conscious future.

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Functional Equivalency in the Comparative Life Cycle Assessment of Solid Waste Concrete: Implication of Mechanical Performance and Durability

Alireza Haji Hossein, Hessam AzariJafari, Rahil Khoshnazar

Synopsis: Portland cement concrete has shown great potential for recycling different waste materials. Solid waste incorporated concrete (SWC) is considered to have positive environmental advantages. However, the utilization of solid wastes may negatively impact the mechanical performance and durability of concrete. Therefore, any change in the performance metrics of SWC should be accounted for in the comparative life cycle assessment (LCA). This article will review the functional equivalency with respect to the mechanical performance and durability metrics for SWC incorporating four main streams of solid wastes; recycled concrete aggregate, municipal solid waste incineration ashes, scrap tire rubber, and polyethylene terephthalate. It will be shown that while in most cases, SWC may have an inferior compressive strength and/or durability pre-treatment, sorting, and appropriate replacement rate of the solid wastes may solve the problem and make SWC functionally equal to the conventional concrete. Moreover, some types of SWC such as those incorporating scrap tire rubber and polyethylene terephthalate may be more advantageous if used in specific applications where dynamic loads are prevalent given their superior impact resistance. Finally, the article will discuss new insights into defining the functional unit based on the performance and application of SWC to conduct a reliable LCA.

Keywords: Solid waste concrete, Life cycle assessment (LCA), Recycled concrete aggregate (RCA), Municipal solid waste incineration (MSWI), Scrap tire rubber (STR), Polyethylene terephthalate (PET)

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INTRODUCTION

Portland cement (PC) concrete is the second most used material on the earth, only after water. In 2017, the worldwide concrete production summed up to roughly 20 billion metric tonnes [1, 2]. Large volumes of cement and concrete production are responsible for nearly 8% of anthropogenic greenhouse gas (GHG) emissions. In addition, natural coarse and fine aggregates comprise about 75 vol.% of the concrete, requiring a significant amount of materials extraction and hauling. Therefore, it is essential to find suitable replacements for the PC and natural aggregates to meet the net-zero emission goals that the UN has set for 2050 [3], and preserve the natural resources on the earth.

Every year, a large amount of solid wastes from different sources is generated around the world [4]. Construction and demolition waste (CDW), fly ash (MSWFA) and bottom ash (MSWBA) from municipal solid waste incineration (MSWI), scrap tire rubber (STR), and polyethylene terephthalate (PET) form a large portion of the total solid wastes [5–7]. Therefore, it is imperative to practice different recycling methods to overcome the environmental problems associated with solid waste production.

In order to reduce the environmental impacts (EI) associated with cement and concrete production and solve the natural aggregate depletion problem, concrete has been extensively used as a medium for recycling different types of solid wastes. Recycled concrete aggregate (RCA) with more than 90 wt.% concrete has been used as alternative aggregate in the production of recycled aggregate concrete [8–10]. MSWFA and MSWBA, based on their physico-chemical properties, can be used as replacement for either PC or natural aggregates. Pieces of STR and PET can be used as recycled aggregate or reinforcing fibers in concrete. While solid wastes such as RCA, MSWFA and MSWBA, STR, and PET are widely available, and can decrease the PC and natural aggregate content of the concrete, they may be detrimental to the mechanical performance and durability of the concrete. It is worth mentioning that industrial by-products such as coal fly ash and ground granulated blast-furnace slag have been successfully used in concrete as supplementary cementitious materials with a notable performance enhancing effect. Therefore, the effect of such industrial by-products on the performance metrics of the concrete is beyond the scope of this review article.

Compressive strength and durability parameters such as resistance to freeze-thaw (F-T) cycles, chemical attacks, carbonation, and alkali-silica reaction play an important role in the life cycle cost and EI of the concrete. Compressive strength that is widely used as a parameter in designing reinforced concrete structures is dependent on the mix design of the concrete (such as PC and aggregate content, water to binder (w/b) ratio, and type and amount of different admixtures) and can affect the dimensions of the structural members such as girders and columns. Durability, as defined by the American concrete institute (ACI), is the ability of concrete to resist the service and deteriorating conditions such as weathering and chemical attacks for which the concrete is designed, while maintaining its form, quality, and serviceability [11]. Durable concrete significantly reduces the costs and EI associated with repair, maintenance, and reconstruction. On the other hand, reports show that poor durability of concrete has been the major cause for destruction of some infrastructures [12, 13]. Therefore, solid waste incorporated concrete (SWC) with different compressive strength and durability compared to those of conventional concrete should be considered functionally inequivalent. Consequently, it is important to include the changes in the compressive strength and durability in the EI calculations.

Life cycle assessment (LCA) is a quantitative tool to assess the EI of different products and services. Data acquisition and calculation methods in the LCA research articles and case studies have been developed and presented based on ISO 14040 [14] and ISO 14044 [15] framework. Accordingly, the four main steps in conducting a comprehensive LCA are goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and data interpretation.