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Definition, Focus Area and Key Topics



Guang Ye and Frank Dehn

Abstract This chapter serves as a concise introduction to the State-of-the-Art Report on the Mechanical Properties of Alkali-Activated Materials (AAMs) in construction. It emphasizes the important role of mechanical properties in shaping AAM research and highlights key areas of exploration, including the impact of raw materials on mixture design, fresh properties, and a broad range of mechanical characteristics. Additionally, it outlines the structure of the book, guiding readers through its extensive coverage of theoretical foundations, practical insights, and emerging standards for AAMs. Overall, it sets the stage for understanding how AAMs can significantly advance sustainable construction practices.

1 Overview of Alkali-Activated Materials (AAMs)

Alkali-activated materials (AAMs) have emerged as a promising alternative to Portland cement-based materials in the construction industry, driven by their potential to significantly reduce greenhouse gas emissions while maintaining or even surpassing the performance of conventional materials. AAMs are derived from industrial by-products such as blast furnace slag, fly ash, and other aluminosilicate precursors, activated by alkaline solutions to form a hardened binder. This innovative approach not only reduces the carbon footprint of construction but also utilizes industrial waste, aligning with the principles of a circular economy.

Despite their environmental and technical advantages, AAMs face several challenges, particularly regarding their mechanical properties and long-term performance. These challenges include variability in formulations, the influence of curing conditions, and uncertainties about their behavior under long-term loads. This book,

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"*Mechanical Properties of Alkali-Activated Materials—State-of-the-Art Report*," addresses these issues comprehensively, offering insights from the RILEM Technical Committee TC 294 MPA. Authored by leading experts, this volume provides a critical review of the mechanical properties of AAMs, serving as a bridge between theoretical advancements and practical applications.

Mechanical properties form the backbone of material selection and design in construction. For AAMs, these properties include compressive strength, tensile behavior, flexural performance, elastic modulus, creep, shrinkage, and bond behavior. While the short-term performance of AAMs often matches or exceeds that of Portland cement concrete (PCC), long-term behavior remains less predictable. This unpredictability stems from the unique chemical compositions of AAMs, which vary widely depending on the precursors and activators used.

One critical question in AAM research is whether existing design codes for PCC can be directly applied to AAMs. The chemical composition and reaction mechanisms of AAMs differ significantly from those of traditional concrete, leading to variations in strength development, bond behavior and time-dependent properties such as creep and shrinkage. While the 28-day compressive strength of AAMs may be comparable to PCC, their long-term mechanical behavior could diverge significantly. This raises questions about the applicability of traditional constitutive laws used for concrete. Should these laws be modified to account for the unique properties of AAMs? These are some of the fundamental issues explored in this report.

The application of existing structural design codes to AAMs poses several challenges. Design codes for concrete structures are based on decades of research on PCC, which exhibits relatively uniform behavior across different mixtures. In contrast, the behavior of AAMs can vary significantly depending on the precursor and activator used, as well as the curing conditions. For example:

Bond Behavior: The bond between AAM and reinforcement steel may differ due to variations in the chemical composition and microstructure of the binder.

Strength Development: While AAMs may achieve rapid strength gain, their long-term strength behavior could be influenced by factors such as curing temperature and the presence of residual unreacted material.

Creep and Shrinkage: AAMs exhibit distinct creep and shrinkage characteristics compared to PCC. For instance, slag-based AAMs may show higher shrinkage, increasing the risk of early-age cracking.

Cracking and service life: the higher susceptibility to cracking of slag-based AAMs for example, reduces its long-term mechanical and durability performance and increases its susceptibility to corrosion, reducing the overall service life of the concrete structure.

Mechanical and durability performance at serviceability limit state (SLS) and, in particularly, at ultimate limit state (ULS): fly ash-based AAMs exhibit higher resistance to chloride- and carbonation-induced corrosion and limited performance loss after exposure to aggressive environments.

The lack of standardized guidelines for addressing these differences complicates the integration of AAMs into mainstream construction practices. This book provides

a detailed exploration of these issues, offering recommendations for future research and practical implementation.

2 Focus Areas of the RILEM Technical Committee TC 294 MPA

The RILEM Technical Committee TC 294 MPA has played an important role in advancing the understanding of the mechanical properties of AAMs. The committee has gathered extensive data on various aspects of AAM behavior, including:

- Early age fresh properties: determining setting time and flowability, affected by chemistry and mixture of AAMs.
- Compressive Strength: Exploring the factors influencing the compressive strength of AAMs, including mix design and curing conditions.
- Tensile and Flexural Strength: Investigating the tensile properties and flexural performance of AAMs, which are critical for structural applications.
- Shrinkage and Creep: Examining issues such as autogenous shrinkage, drying shrinkage, and restrained shrinkage, which affect the volume stability of AAMs. Analyzing the time-dependent deformation of AAMs and their susceptibility to shrinkage-induced cracking.
- Bond Behavior: Assessing the bond between AAMs and reinforcement, which is crucial for structural integrity.

These investigations have revealed that the composition of AAMs varies significantly across regions, influenced by the availability of precursors and the choice of activators. Additionally, curing conditions play a critical role in determining the mechanical properties of AAMs. By addressing these variables, the committee has provided a comprehensive understanding of AAM behavior, which is reflected in this book.

3 Key Topics Covered in This Book and Target Audience

This book is structured into five parts, each addressing a critical aspect of AAMs:

Part I: Introduction. This section introduces the fundamental concepts of AAMs, introduces the classification of AAMs, the terminology, and abbreviations used in this book.

Part II: Chemistry and Mix Design. Chapters on conventional and novel precursors and activators provide insights into the chemical and mineralogical properties of AAMs. A detailed discussion on nano- and micro-scale modeling highlights the potential for optimizing AAM formulations.

Part III: Fresh and Hardened Properties. These chapters examine the behavior of AAMs in both fresh and hardened states, including the influence of reaction kinetics, precursors, activators, admixtures, and mixing conditions on the fresh properties of AAMs, as well as recent progress in AAC mix design and its mechanical properties.

Part IV: Volume Stability and Cracking Potential. The issues of shrinkage, creep, and cracking are explored in depth. The potential for early-age cracking in slag-based AAMs and strategies to mitigate these effects are discussed extensively.

Part V: Standards and Applications. This section reviews existing standards and norms for AAM production and highlights successful applications, demonstrating the potential for AAMs to replace PCC in various construction scenarios.

A critical focus of this book is bridging the gap between research and practice. By compiling data from literature studies, this volume provides a solid foundation for developing new standards and guidelines tailored to AAMs. Key findings include:

- The necessity to adapt existing constitutive laws for AAMs, accounting for their unique mechanical behavior.
- The need to evaluate experimentally and numerically the elasto-plastic behavior of reinforced concrete structures to guarantee the safety of the end users at both serviceability and ultimate limit states by implementing the currently available design and dimensioning tools.
- The importance of addressing early-age cracking risks through improved mix designs and curing methods.
- The potential for developing standardized testing methods to evaluate the long-term mechanical performance of AAMs.
- The urgency to bridge the gap between research and practice by fully characterizing the short- and long-term mechanical performance of AAMs in natural conditions to compare its performance with PCC-based structures and finally develop design codes and standards to promote their use in the construction industry as structural materials.

This book is intended for a wide audience, including:

- Researchers: Seeking insights into the latest advancements in AAM research.
- Engineers: Looking for practical guidance on implementing AAMs in construction projects.
- Policymakers: Interested in developing standards and norms for sustainable construction materials.

By addressing the challenges and opportunities associated with AAMs, this book aims to accelerate their adoption and promote their use as a sustainable alternative to PCC.

4 Conclusion

Mechanical Properties of Alkali-Activated Materials—State-of-the-Art Report serves as a definitive reference for advancing the understanding and application of AAMs. By addressing critical questions about their mechanical properties, design codes, and long-term mechanical behavior, this book provides the knowledge needed to unlock the potential of AAMs in sustainable construction. Whether you are a researcher, engineer, or policymaker, this volume offers valuable insights and practical solutions to drive the future of construction.