Proceedings of the 10th International Conference On Civil Structural and Transportation Engineering (ICCSTE 2025)
July, 2025 | Imperial College London Conference Center, London, United Kingdom
Paper No. 238
DOI: 10.11159/iccste25.238

Advanced Fibre Modelling for Accurate Prediction of Splitting Tensile Strength and Failure Behaviour in Self-Compacting Concrete

Abdullah Alshahrani
Department of Civil Engineering, College of Engineering, Najran University
Najran, Saudi Arabia
aaalshahranie@nu.edu.sa

Extended Abstract

Developing Steel Fibre-Reinforced Self-Compacting Concrete (SFR-SCC) requires a precise balance of fibre properties and content to optimise rheological and mechanical performance while maintaining cost efficiency [1]. However, variations in mix constituents raise concerns regarding mechanical behaviour, particularly in strength, durability, and failure mechanisms. The lack of well-defined mix design procedures further complicates achieving consistent and reliable mechanical properties, necessitating advanced predictive tools for mix optimisation and structural performance evaluation[2]. Finite element modelling (FEM) offers an efficient solution for predicting mechanical properties and analysing the structural response of SFR-SCC, reducing reliance on costly and time-consuming experimental testing [3].

This study presents an automated fibre modelling approach to evaluate the splitting tensile strength and failure patterns of SFR-SCC using FEM and experimental validation. Unlike conventional methods that rely on idealised or manually defined fibre arrangements, this research integrates a Python-based algorithm within ABAQUS to generate realistic, non-intersecting, and randomised fibre distributions in the concrete matrix. In addition, to account for the fibre pull-out response, equivalent stress-strain relationships, derived from an analytical load-slip model, are assigned to steel fibres based on their orientation angles, improving the accuracy of fibre-matrix interaction predictions.

To validate the numerical model, experiments were conducted using hooked-end steel fibres at 0%, 0.25%, and 0.5% volume fractions. Slump flow and J-ring tests confirmed excellent flowability, while compressive and splitting tensile strength tests assessed hardened properties. The results showed that splitting tensile strength increased with fibre content, with failure transitioning from brittle fracture to distributed cracking, indicating enhanced ductility. Finite element simulations based on the Concrete Damage Plasticity (CDP) model captured the splitting tensile response, with deviations of up to 2.75% from experimental results, demonstrating the accuracy and efficiency of the proposed modelling framework.

The Python-based FEM framework successfully modelled random fibre distribution, while the embedded element approach simulated bond-slip interactions between fibres and the matrix. Numerical results closely aligned with experimental findings, confirming the model's predictive capability. These results highlight how computational modelling can refine mix design parameters, optimising the balance between workability, mechanical performance, and material efficiency.

Increasing the fibre volume fraction led to a progressive improvement in splitting tensile strength, demonstrating the positive correlation between fibre content and mechanical performance. The shift from brittle fracture to distributed micro-cracking confirmed enhanced energy absorption and ductility due to fibre reinforcement. The automated Python-based modelling approach significantly reduced manual pre-processing time, enhanced simulation reproducibility, and facilitated parametric studies on fibre orientation, volume fractions, and bond interactions. These improvements position FEM as a powerful tool for optimising SFR-SCC mix designs, minimising trial-and-error in material testing.

References

[1] A. Alshahrani, S. Kulasegaram, Effect of fibre diameter and tensile strength on the mechanical , fracture , and fibre distribution properties of eco-friendly high-strength self-compacting concrete, Constr Build Mater 403 (2023) 133161. https://doi.org/10.1016/j.conbuildmat.2023.133161.
[2] A. Alshahrani, S. Kulasegaram, A. Kundu, Elastic modulus of self-compacting fibre reinforced concrete : Experimental approach and multi-scale simulation, Case Studies in Construction Materials 18 (2023). https://doi.org/10.1016/j.cscm.2022.e01723.

[3] A. Alshahrani, S. Kulasegaram, A. Kundu, Utilisation of simulation-driven fibre orientation for effective modelling of flexural strength and toughness in self-compacting concrete, Constr Build Mater 459 (2025) 139767. https://doi.org/10.1016/j.conbuildmat.2024.139767.