

Steel Fiber-Reinforced Concrete in Mesoscale through a Combined DEM-FEM Approach

**Riccardo Lando^{†1*}, Beatrice Pomaro^{†1}, Gabriel B. Barbat^{†2},
Valentina Salomoni^{†1} and Gianluca Mazzucco^{†1}**

^{†1}Department of Civil, Environmental and Architectural Engineering (DICEA),
University of Padova, Via F. Marzolo 9, 35131 Padova, Italy

^{†2}International Center for Numerical Methods in Engineering (CIMNE), Technical University of
Catalonia – BarcelonaTECH, Edificio C1, Campus Norte, Jordi Girona 1-3, 08034 Barcelona, Spain

* e-mail: riccardo.lando.1@phd.unipd.it, <https://orcid.org/0009-0000-0808-8738>
beatrice.pomaro@unipd.it, gabriel.barbat@upc.edu, valentina.salomoni@unipd.it,
gianluca.mazzucco@unipd.it

ABSTRACT

Over the past decades, several approaches have been developed to enhance the mechanical strength of concrete, among which the incorporation of metallic fibres into the cementitious matrix represents an effective solution. The resulting strength increase can be investigated through mesoscale analyses based on the Finite Element Method (FEM). Nevertheless, the generation of realistic sample geometries of aggregates and fibres remains a challenging task.

In this work, an in-house polyhedral Discrete Element Method (DEM) code [1] is employed to simulate large assemblies of interacting particulate bodies, a task that is generally well suited for rounded particles of comparable size. However, the highly slender, needle-like geometry of steel fibres introduces significant numerical instabilities, mainly due to ill-conditioning and edge cases in contact detection algorithms. In addition, particular attention is required in the integration of finite rotations and in the calibration of rotational damping parameters in order to avoid non-physical behaviour.

These issues are addressed by adopting a Minkowski-differences-based contact algorithm as a complementary tool to the primary contact detection scheme. Moreover, the use of a quaternion-based explicit integration of the angular momentum equation [2] ensures a consistent update of finite rotations without inducing numerical distortion in the rigid bodies. Finally, a careful calibration of the rotational damping coefficients is performed to achieve a more realistic interaction between steel fibres and stone aggregates.

The final particle configurations obtained from the DEM simulations are subsequently discretised to perform FEM analyses. The non-linear visco-elasto-plastic behaviour of concrete is modelled using an in-house constitutive model [3]. The ultimate objective of the study is to quantify the strength enhancement provided by steel fibres by comparing the numerical results with experimental data and with previous coupled DEM–FEM simulations performed on concrete without fibre reinforcement.

REFERENCES

- [1] R. Lando, B. Pomaro and G. Mazzucco, Systematic Generation of Mesoscale Concrete Mix-Designs with the Discrete Element Method [Conference Presentation], XVIII International Conference on Computational Plasticity, Barcelona, Spain, 2025.
- [2] L. J. H. Seelen, J. T. Padding and J. A. M. Kuipers, Improved quaternion-based integration scheme for rigid body motion, *Acta Mech.* 227, 3381–3389, 2016. <https://doi.org/10.1007/s00707-016-1670-x>
- [3] G. Mazzucco, B.F. Dongmo, B. Pomaro, J. Zhang, V. Salomoni, C. Majorana, A 3D visco-elasto-plastic damage constitutive model of concrete under long-term loads. *European Journal of Mechanics - A/Solids* 112, 105646. 2025 <https://doi.org/10.1016/j.euromechsol.2025.105646>