Fuzzy logic-based approach for the uncertainty treatment in cementitious materials modelling

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Abstract

In the context of the Horizon 2020 project ReSHEALience, the concept of Ultra High Durability Concrete (UHDC) is introduced to refer to those materials belonging to the wide family of cementitious materials, whose mixture recipe is tailored to enhance the performance in terms of durability compared to ordinary concretes [1]. The target is achieved through the full exploitation of the inherent capacity of autonomously repairing the cracks which characterises the cement-based composites. For this reason, supplementary cementitious materials, such as slag and crystalline admixtures, are included into the mixture [2]. The UHDC concept is validated by means of either extensive and complex experimental programmes in the laboratory, and monitoring campaigns on structures in real service scenarios. However, the disruptive impact of such advanced materials on the construction market can be materialised only by modelling their behaviour accurately, in order to reliably predict the performance in different scenarios.

The behaviour of UHDC is well-captured by physics-based models, of which the Lattice Discrete Particle Model (LDPM) [3], for the mechanical problems, and the Hygro-Thermo-Chemical (HTC) model [4], for the simulation of moisture, heat and chemical phenomena, are two worthy examples. Recently, these models were extended for the autogenous and stimulated healing in ordinary and fibre-reinforced concretes at the Politecnico di Milano [5, 6]. However, the afore-mentioned models present a significant number of parameters that need to be calibrated against experimental measurements, which are almost always unavailable. This represents the most relevant issue to tackle for their use. In addition, accurate small-scale models, such as LDPM and HTC, are particularly suitable for the modelling at the material level. The upscaling to structural members, or even entire structures, requires the identification of *bridging* parameters, in charge of bringing the small-scale models' accuracy into the engineering models adopted for the long-term prediction at the structural level.

Among other methods for mathematically describing and quantifying uncertainty, the probability theory and fuzzy set theory could be used [7]. The probability theory is a mathematical theory of chance, stating the likelihood that an event will occur, by quantifying it with a number between zero and one. On the other hand, the logic of fuzzy set theory allows the quantification of degrees of truth or membership to a set [8]. Therefore, the latter is used to describe epistemic uncertainty, in particular the uncertainty resulting from insufficient information or lack of (experimental) data to deal with in complex systems, such as the cross-influence between the material composition, the chemistry, and environmental conditions on the material response. The fuzzy-set theory enables a flexible assessment of the possibility, which is necessary to deal with complex governing parameter systems and limited experimental databases.

The content of this paper focuses on the uncertainty featuring the models' calibration in case of limited experimental data on modelling material properties at microscopic and mesoscopic scales. To the purpose, a fuzzy logic-based approach is presented and tested for one of the UHDC mixtures identified within the activity of the project ReSHEALience. The accuracy of the fuzzy logic-based predictions is compared to the values of the models' parameters, gained through the calibration against experimental data. In particular, the proposed approach consists of five steps (see Fig 1).

1. Collection of the expert knowledge on the material itself and on the relationships between peculiar aspects, such as material composition, environmental conditions, loading regimes, and the models governing parameters.
2. Definition of a fuzzy cognitive map, namely a fuzzy graph for representing causal reasoning [9], which allows the extraction, analysis, and visualisation of the knowledge based on hard evidence as well as subjective expert judgement.
3. Implementation of a fuzzy rule base with if-then conditions. This fuzzy rule base is serving as the main combination between the membership functions, the causal relations, as it is stated in the cognitive map, and the expert knowledge provided by surveys or literature of similar materials.

4. Fuzzification of the parameters, which govern the models adopted, by associating a membership function to each of them. This operation is carried-out for those parameters whose value is affected by a scenario-related uncertainty.
5. De-fuzzification process: the membership functions, interval limitations and expert knowledge are combined into an inference system to identify a crisp value for each models governing parameter.

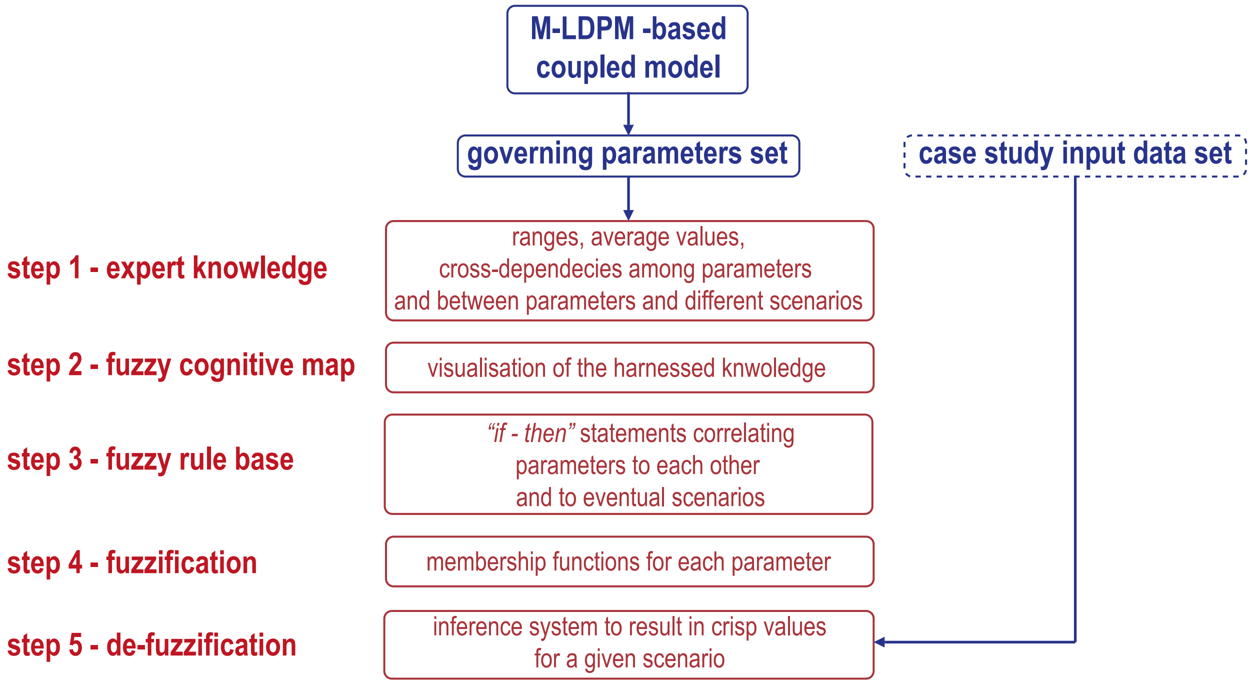

Fig. 1. Fuzzy logic and set theory-based approach for the calibration of the governing parameters in five steps.

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