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PREDICTING SELF-COMPACTING CONCRETE SHRINKAGE BASED ON A MODIFIED FUZZY LOGIC MODEL

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Abstract: *The occurrence of shrinkage in concrete leads to development of internal tension stresses which can result in concrete cracking. The presence of cracks in concrete creates pathways that ease the access of aggressive agents reducing concrete structure durability and service life. Consequently, the correct reduction of shrinkage strain during the designing process is important to assure the structure's durability and long time serviceability. In light of this, the objective of this research was to develop an experimental based fuzzy logic model to predicting self-compacting concrete shrinkage. The fuzzy logic model decision-making is optimized though an evolutionary computing method, therefore enhancing computational effectiveness. The obtained results are compared to the B3 shrinkage prediction model and statistical analysis, indicating the reliability of the proposed model, are presented.*

Keywords: ***Fuzzy logics, shrinkage, self-compacting concrete, evolutionary computing***

1. Introduction

Concrete shrinkage is defined as decrease in concrete volume with time. This volume decrease does not depend on external stress and it is not completely reversible. The occurrence of shrinkage in concrete leads to development of internal tension stresses, thus resulting in concrete cracking, creating pathways that ease the access of aggressive agents into concrete and contributing to reduction in concrete structure durability. Therefore, a trustworthy definition of concrete shrinkage strain is a key factor in the structure's design, since it helps reducing maintenance costs, and ensures that the specifications of expected service life and durability requirements will be fulfilled.

The use of high-performance concretes, more specifically *SCCs*, is rapidly developing in the construction industry, probably because of the production process costs and the advantageous organizational nature of this material. When compared to conventional concrete, *SCC* requires, for instance, a higher volume of cement paste in the composition to achieve excellent deformability and high formwork filling capacity. This way, considering that shrinkage is a results of hydration reaction in the cement paste, *SCC* are likely to present higher values of shrinkage strain. Hence, measuring shrinkage strain in *SCC* mixtures arises as a relevant issue. However, measurement of shrinkage strain is laborious, time consuming and expensive, so construction designers tend to use shrinkage prediction models. The prediction models aim to determine concrete shrinkage strain in a faster and less expensive way when compared to experimental measurements. Amongst several existing models, the *B3* model has been widely used for predicting concrete shrinkage. Despite its convenience, shrinkage strains obtained from this prediction model, among others, do not necessarily match experimental measurements. In light of this, the present work aimed to develop a methodology for defining a prediction model for *SCC*. The proposed methodology is based on the combination of Soft-computing techniques, particularly fuzzy logic systems and genetic algorithm, to build a prediction model.

2. Proposed methodology

Fuzzy theory correspond to a natural way of thinking where verbally expressed rules are applied to deal with vagueness, imprecision, and ill-defined data. The key factors to achieve an acceptable

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performance in a fuzzy logic system are connected to the definition of the number of fuzzy sets, as well as the shape of the membership functions. Generally, the number of fuzzy rules is defined by the user's experience and the shape of membership functions is set as linear, this corresponds to the classical fuzzy logic approach. Nevertheless, when this approach is implemented to non-linear materials, the final results are a rather rough shaped piecewise curves. To avoid that, and aiming to improve the entire modelling process, a modified approach is proposed in this research.

In the proposed methodology, the user's task is to define the number of representative intervals for experimental shrinkage strain curves obtained from concrete mixtures with different volumes of cement paste. Once this value has been defined, the automatic process of generating a population and evaluating the best fit, which is the genetic part of the algorithm, is repeated until convergence occurs. The genetic algorithm task is to minimize the mean square error between experimental and predicted data, thus leading to a group of optimized fuzzy sets. The optimization of the membership functions' shape allows reducing the data collection time and computational cost.

3. Results and discussion

The obtained fuzzy logic model, named *FL-I*, is composed by five groups of fuzzy sets: two connected to the shrinkage strain, two connected to concrete age, and one connected to the volume of cement paste. The results from this model were compared with other experimental data, in addition to the *B3* model. Altogether, the verification data is composed by five different shrinkage strain curves that were considered in this part of the analysis.

For the tested input data, the mean square error resultant from *FL-I* model was lower than *B3* in all cases. The overall mean square error of *FL-I* model was equal to *23.7%*, against *28.1%* for the *B3* model, indicating that *FL-I* allows a better strain prediction for the investigated experimental data. Although the overall mean square error presented by the *FL-I* model was lower than *B3*, its value is still considered high, around *20%.* The reason for that is likely because only two experimental curves were used as training data, which constrained the shape of fuzzy sets group connected to the cement paste volume to be linear. The final result would possibly be different if an intermediary curve was included as training data, since this would allow the optimization of the fuzzy sets connected to the volume of cement paste, leading to a lower overall error in the prediction values.

To verify this assumption, one of the experimental curves from the verification data was included as training data, and the optimization process was performed again. Hence, a new prediction model, named the *FL-II* model, was obtained. This model was then compared with other experimental data and the *B3* model. The final results indicate that the overall mean square error from *FL-II* is considerably lower than the *FL-I* model. In this case, a reduction from *23.7%* to *7.6%* in the mean square error was achieved, indicating that the use of a larger number of experimental data likely to reduce errors.

4. Final considerations

The use of the proposed methodology, which combines fuzzy logics with genetic algorithm, has shown satisfactory results. The optimized group of fuzzy sets allowed a proper prediction of the shrinkage curves with a reduced number of rules, making the modelling process more effective. Finally, the statistical analysis show that the overall mean square error of the *FL-I* is lower than the *B3* model for the investigated data, indicating that *FL-I* model better represents the materials behavior and can be used to predict *SCC* shrinkage once the limits of the model are attended. The further inclusion of additional training data in the optimization methodology contributed to reducing the overall error of the model from *~20%* to *~7%,* demonstrating the flexibility of the model in self-adjusting according to the training data. Such flexibility provides a great advantage of the optimized fuzzy logic-based model in comparison with prediction models based on equations and its constants.

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