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Simulation of self-compacting concrete flow in the J-ring test using smoothed particle hydrodynamics (SPH)

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ABSTRACT

A range of SCC mixes with 28-day cube compressive strength between 30 and 80 MPa has been prepared in the laboratory, and the time t_{500J} (the time when the mix spread reaches 500 mm) and diameter of the flow spread of each mix were recorded in the J-ring test. The entire test was then simulated from the moment the cone was lifted until the mix stopped flowing. An incompressible mesh-less smoothed particle hydrodynamics (SPH) methodology has been implemented in this simulation and a suitable Bingham-type constitutive model has been coupled with the Lagrangian momentum and continuity equations to simulate the flow. The aim of this numerical simulation was to investigate the capabilities of the SPH methodology to predict the flow of SCC mixes through gaps in reinforcing bars. To confirm that the mix flows homogeneously, the distribution of large coarse aggregates in the mixes has been simulated and examined along several cut sections of the flow pancake. It is revealed that all the simulated mixes meet the passing ability criterion with no blockage as in the laboratory J-ring test with respect to t_{500J}, the flow spread, and aggregate homogeneity.

1. Introduction

With the recent tendency towards the use of computer modelling in solving complex engineering problems, its application in concrete technology is in demand and increasingly becoming an accepted tool. Owing to the requirement for highly durable concrete structures, self-compacting concrete (SCC) with its unique characteristics (flow-ability, passing ability and stability) has been developed, and is increasingly replacing vibrated concrete (VC) in different structural applications. SCC, which is characterised in its fresh state by high flow-ability and rheological stability, has excellent applicability for elements with complicated shapes and congested reinforcement. It has rationalised the construction process by offering several economic and technical advantages over VC.

Since the main characteristic of SCC is its flow-ability, its fresh property cannot be thoroughly comprehended without understanding its rheology. The quality control and accurate prediction of the SCC rheology are crucial for the success of its production. The accurate prediction of the SCC flowing behaviour is not a simple task, particularly in the presence of heavy reinforcement, complex formwork shapes and large size of aggregate. In this regard, the indispensable and inexpensive approach offering considerable potential is the numerical simulation of SCC flow. This approach will deepen the understanding of the SCC mix flow behaviour and evaluate its ability to meet the necessary self-compacting criteria of passing ability and segregation resistance (i.e. homogeneous distribution of coarse particles in the matrix).

From a computational point of view, choosing the right strategy for the simulation is an important issue, and several approaches have been tried to simulate the flow [1–3]. Of these approaches, the one offering considerable potential is the smoothed particle hydrodynamics (SPH). Identifying SCC as a homogeneous fluid that consists of particles of different sizes and shapes, SPH (as a mesh-free particle method) is an ideal computational method to represent its rheological behaviour with an acceptable level of accuracy. This methodology can also assist in proportioning SCC mixes, thus improving on the traditional trial and error SCC mix design [4–6]. It has also been used and proved to be efficient and accurate in modelling the flow and monitoring the movement of large aggregates and/or short steel fibres of SCC in the cone slump flow and L-box tests [7–9]. The SPH simulation methodology also provides a useful tool for predicting the yield stress (τ_y) of SCC mixes accurately in an inverse manner from the flow spread [10]. This is particularly relevant to the characterisation of an SCC mix because the measurement of τ_y by rheometers is inconsistent and fraught with inaccuracies.

The aim of this paper is to extend the SPH approach to simulating the flow of SCC in the J-ring test. This methodology will provide a thorough understanding of whether or not an SCC mix can satisfy the self-compatibility criterion of passing ability through narrow gaps in reinforcement besides the flowability criterion. The capabilities of the SPH methodology will be validated, in terms of flow pattern, time to reach

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