

Advances in Development of Novel Ultra-High Performance Concrete

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ABSTRACT

The rising of terrorism activities has promoted fast development of new construction materials to enhance the resistance and resilience of buildings and infrastructure against blast loads. As a notable representative, ultra-high performance concrete (UHPC) has now been widely investigated by government agencies and universities. UHPC inherits positive aspects of ultra-high strength concrete (UHSC) and it is equipped with improved ductility as a result of fibre addition. These features make it an ideal construction material for bridge decks, storage halls, thin-wall shell structures, and other infrastructure against seismic, impact and blast loads.

In the thesis, development of novel UHPC material is presented. The new concrete material is distinguished from previous development by the inclusion of the nanoparticles. It was noticed that addition of nanoscale size particles results in significantly improved material properties without much change of the material composition. The present study focuses on influence of fibre material addition and nanomaterial addition on mechanical properties of UHPC material. In total, three kinds of steel fibre material with varying volume fraction are considered in the material design, in combination with four different nano materials at varying weight dosages. Discussion is carried out on fibre material geometry and fraction as well as nano particle effect.

Static material tests are carried out to understand material strength and ductility. Uniaxial compressive tests and flexural tensile tests reveal the exceptional material strength, ductility as well as energy absorption capability. Since the material aims at improving the structural performance under extreme loading conditions, dynamic material properties are also of significant importance. Split Hopkinson Pressure Bar (SHPB) tests are conducted on UHPC samples, dynamic compression tests and split tensile tests are studied and compared with static material strength to obtain the dynamic increase factor which is critical in the design of material and structures against dynamic loads.

All the above tests can be used to qualitatively and quantitatively examine the material performance with nano material and steel fibre material addition at macroscale. To further study the influence of these materials, microscopy analysis was conducted to provide explanation of macroscopic failure phenomenon at micro-scale. Morphology of the samples was observed by Scanning Electron Microscopy (SEM). X-Ray Diffraction (XRD) instrument was used for phase analysis and semi-quantitative analysis. Elemental analysis

was conducted by X-Ray Fluorescence (XRF). In SEM tests on post-damage UHPC samples, different damage modes at ITZ are identified, XRD and XRF analysis confirmed the filling and pozzolanic effect of nano particles addition.

In most cases, UHPC material can be treated as homogeneous at macroscopic scale, when observed at a smaller length scale, UHPC is heterogeneous and consists of constituents including aggregate, CH crystals, C-S-H gel, water and fibre material. It is impractical to consider all the phases in the microstructure of SFRC. In general, to investigate the interfacial transition zone (ITZ) effect on the fibre bonding properties, UHPC is described as multi-phase material consisting of the cement paste, aggregates, fibres and ITZs among them. The existence of ITZs weakens the bonding between the fibres and concrete matrix. The bonding performance of UHPC is influenced by the fibre geometry, fibre orientation, and also the strength of the matrix, it is therefore critical to consider the ITZ effect in the performance of UHPC. In the current study, the bonding effect between the fibre material and matrix is investigated firstly by single fibre pull-out tests in which different fibre embedding depths are considered. The experimental results are then used to establish the bond-slip relationship in the numerical model. Three dimensional mesoscale model with consideration of both the concrete matrix and fibre phase is established. Model calibration is conducted with comparison to static material tests, further validation is obtained through SHPB split tensile test simulation. The proposed 3D mesoscale model can effectively model the material behaviour especially the post yielding ductility.

With the understanding of the new material, field blast tests are carried out on concrete components constructed with this UHPC. Comparison is made against conventional concrete component and high strength concrete components, and the exceptional performance reveals its potentiality in the protective structural design.

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LIST OF PUBLICATIONS

1. Su, Y., Li, J., Wu, C.Q., Wu, P.T. and Li, Z.X. 2016. Influences of nano-particles on dynamic strength of ultra-high performance concrete. *Composites Part B: Engineering*, 91, pp.595-609.

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