Tensile constitutive model of reactive powder concrete based on flexural experiment

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Abstract. Reactive powder concrete (RPC) is a kind of ultra high performance concrete material, which has ultra high compressive strength and durability as well as good tensile property, elastic modulus, energy absorption and ductility. All these properties make it to be a better choice for the construction of bridges, buildings, military architectures, nuclear structures and the buildings bearing severe environment. The good tensile property, durability and ductility of RPC depend on the steel fibres mixed in the concrete. The bridge effect of steel fibres provides high tensile strength and crack resistant property. The tensile constitutive model of RPC differs from the normal concrete. This study tried to obtain the tensile constitutive model of RPC based on the flexural experiments of RPC prism. On the basis of test results, the tensile constitutive model of RPC is given in this study.

1. Introduction
Reactive powder concrete (RPC) is a kind of ultra high performance concrete. Since its appearance in the Bouyues’ laboratory in France[1-2], it has been explored and used for several decades. RPC has ultrahigh performance, including ultra high compressive strength, high tensile strength, high elastic modulus, high energy absorbing, high ductility and good durability. The cement matrix is enhanced by the steel fibres, which develops the high tensile properties and crack resistance of RPC.

These good mechanical properties of RPC make it to be a better choice in the construction of buildings. RPC has been applied in many structures worldwide[3-4]. The first application of RPC was the Sherbrooke Bridge in Canada. The single span this bridge is 60m with RPC truss. Then the Seonyu Bridge was designed and constructed in South Korea with a single span of 120m, in which the RPC slab was used to support the beam. The first application RPC in highway bridges is the Mars Hill Bridge in USA. This is a precast and prestressed high way bridge with a span of 33.5m, RPC was used to improve the durability of bridge structure. The first application of RPC in railway bridges is the RPC girder used in the Caoqian Railway line, which has a lower height of cross section than the normal concrete(NC) bridge for the application of RPC in China.

The RPC material has been widely applied in bridge structures due to its high mechanical properties and durability. RPC material has been explored by the researchers in many countries. The studies at first focus on the composition and preparation of RPC material[5-13]. These studies explored how to optimize the particle size distribution by changing the composition of RPC and how to improve the microstructure of matrix by changing the preparation procedures. These studies make a great contribution to RPC material for behaving ultra high mechanical performance and durability.
Then the studies of RPC focus the structural behaviours after the application of RPC[14-19]. The flexural properties of RPC girders were explored. The RPC girders have higher rigidity, cracking strength and ultimate strength than NC girder. The bridging effect of steel fibres in RPC can obviously improve the flexural properties of girders. Also the number of cracks on the surface of RPC girders is much higher than NC girders. The smeared cracks property of RPC is utilized when bearing bending moment, a large number of small cracks appeared instead of some large cracks. Then the durability of RPC structures was improved by the appearance of these small cracks. The shear properties of RPC girders were also studied by the explorers. The addition of RPC has a great effect on the shear failure mode and strength. RPC girders showed better shear behaviours than NC girders. But the studies in this scope are not sufficient to fully address the shear mechanism of RPC girders. All the test results show that RPC is a better material when applied in bridge girders compared with NC.

The higher tensile strength of RPC plays an important role in improving the mechanical properties of RPC structures. It is critical to consider the tensile strength of RPC in the calculation of RPC structures, and then the tensile constitutive model of RPC becomes important. However, the tensile constitutive model has not been fully explored, and only a few papers represented the explorations on tensile constitutive model of RPC. Most of these studies explored the tensile property of RPC structures bearing uniaxial tensile force, which react lower tensile strength when applied in RPC girders bearing moment. This study tries to explore the tensile constitutive model of RPC through flexural experiments of RPC prism.

2. Experimental programme

2.1. Mixture proportions of RPC

The mixture proportions of RPC are most important for achieving ultra high performance. The mix proportions of RPC explored in this study are given in Table 1. Silica fume and cement are used to improve the micro structure of RPC mixture. The fine aggregate added in the mixture proportions of RPC included course sand, medium sand and fine sand. The coarse aggregate added in the mixture proportions of RPC is gravel, in order to reduce the shrinkage effect. The steel fibres are added to increase the tensile properties and cracking resistance.

Table 1. Components of the RPC mixture designs(kg/m$^3$).

| Cement   | Silica fume | Gravel  | Coarse sand | Medium sand | Fine sand | Steel fibre | Water | Water-reducing agent |
|----------|-------------|---------|-------------|-------------|-----------|-------------|-------|----------------------|
| 624      | 178         | 547     | 225         | 448         | 112       | 120         | 150   | 18                   |

2.2. Fabrication and specimen dimensions

The fabrication procedure is also important to the mechanical properties of RPC. In order to achieve high performance, the fabrication procedure must include the steam curing process. The mixing and curing procedure of RPC is provided in Fig. 1. Then the mixtures are molded in to 100*100*400mm bars for the flexural tests, the specimens are presented in Fig. 2.
2.3. Test setup and instrumentation

The test setup is shown in Fig. 3. Each specimen was loaded in the compression testing machine, and the load and tensile strains were measured during the loading process. In order to get the accurate loading process, the load and tensile strains were measured by dynamic acquisition instrument (DH5923) with a sampling frequency of 500Hz.
3. Experimental results
The tensile strains at the bottom of the RPC specimen were measured as well as the load applied on the specimen. Then the stresses can be determined through the load. The stress and strain relations are presented in Fig. 4. The descending stage cannot be measured for the insufficient stiffness of testing machine.

The results show that the tensile stress-strain relationship of RPC can be divided into two stages: (1) the stage before cracking, in this stage, stresses increase linearly with strains until the appearance of cracking; (2) the stage after cracking, in this stage, the stresses increase linearly with strain until the broken of specimen. This stage is also called strain hardening.

4. Tensile constitutive model
Based on the experimental results, the average first cracking strength and the peak strength can be obtained. Also the tensile constitutive model of RPC contains two stages, including the first increasing stage and the second strain hardening stage, in which the first cracking point and the ultimate point are determined from the test results. The fitting curve of RPC tensile constitutive model are presented with the test curves in Fig. 5. The comparison between the fitting curve and the test results indicates that the fitting constitutive model can represent the tensile property of RPC. Then the calculation equations of RPC tensile constitutive model are given in Eq. (1).
5. Conclusions

(1) The specimens 100*100*400mm bars made of RPC were designed and fabricated in this study.

(2) The tensile stress-strain relationship of RPC were tested and measured by dynamic acquisition instrument with a sampling frequency of 500Hz.

(3) Based on the experimental results, the tensile constitutive model of RPC was obtained. This can be used in the calculation of flexural properties of RPC girders.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Project No. 51278040), the Major Project of China Railway (Project No. K2019G005), and the Science and Technology Projects of Hebei Transportation Department (No. C18L00580).

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