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Tensile strength behavior of UHPC and UHPFRC

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Abstract

UHPC (Ultra High Performance Concrete) and UHPFRC (Ultra High Performance Fiber Reinforced Concrete) are remarkable materials which exhibit many enhancements when compared to the properties of conventional concrete. Besides having a very high compressive strength, this material possess a high tensile strength as well. The high value of tensile strength in UHPC and UHPFRC leads to more ductile behavior. A recent research at Kassel University, a fracture mechanics based study have been developed to determine the postcracking tensile behavior of UHPC and UHPFRC. The outcome indicates that despite the successful application studying the postcracking tensile behavior of mature conventional concrete, however, similar results of UHPC and UHPFRC specimens are still premature due to the limitation of related literatures. The tensile strength value is improved by the efficiency of fibers. This value is close to Japanese recommendation, namely 5 MPa (for UHPC). However, smaller than the proposed values by SETRA/AFGC guidelines of France namely 8 MPa (for UHPC) and 7-15 MPa (for UHPFRC). Investigating the tensile strength behaviors of UHPC and UHPFRC is significant to support the documentation writing of standard norms for structural design needs.

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1. Introduction

Between the years of 1990 and 1995, UHPC (Ultra High Performance Concrete) was first investigated by Bouygues in the name of RPC (Reactive Powder Concrete) [1]. Next, in 1997 the first world’s engineering structure made by RPC namely the Sherbrooke pedestrian bridge was built by Ductal® in Sherbrooke, Quebec, Canada [2]. UHPC is a natural extension of the conventional concrete (normal concrete, high strength concrete). This remarkable material exhibits enhancements for the concrete material properties. UHPC is called Ultra High Performance Fiber Reinforced Concrete (UHPFRC), when fiber is added in its composition. The additional of fiber is able to increase the UHPC strengths and durability.

UHPC, is a superplasticized and silica fume cement material, which also has an extremely low porosity. A very low water-cement ratio is needed to achieve possible densest material in a hardened concrete product of UHPC. In UHPC composition, the presence of very fine quartz sand instead of ordinary coarse aggregate is considered to be a key aspect for gaining better microstructure and performance. Therefore, reducing heterogeneity between cement matrices and aggregates [1, 3-5].

Besides having a very high of compressive strength value which is exceeding 150 MPa, current research show that UHPC is believed to have a high tensile strength value which may reach 15 MPa. This high value of tensile strength in UHPC, may lead for more ductility and for eliminating the need of reinforcements (i.e. bars, wire, mesh). Therefore, more flexibility for expanding the UHPC application in a more wide range of structural shapes and forms which is required by owners, architects and designers. The overall enhanced properties of UHPC contribute to the total performance of the structure, improve the construction safety. Thus, provide longer service life and lower the maintenance cost.

Despite the successful research and applications of UHPC and UHPFRC in the field, regards on the high tensile strength; however, current guidelines have not yet giving a standard norm, as the recommendations is still in premature due to limited literatures. As one of the superior property compare to conventional concrete, investigating the tensile strength of UHPC is significant for structural design needs. This study aims to investigate the postcracking tensile strength behavior of UHPC and UHPFRC. For clarifying the investigation results, current guidelines and previous research will be adapted.

2. Tensile strength behavior

In order to determine the tensile strength of UHPC and UHPFRC, a variety of specimens either with or without notches, can be used (see Table 1). In general, the experimental of direct tensile strength tests on UHPC (contains no fiber) result a mean of tensile strength values of 7-10 MPa. While, the Japan recommendation proposes a mean tensile strength value of 5 MPa [6], and the SETRA/ AFGC guidelines of France suggests mean direct and flexural tensile strength values of 8 and 8.1 MPa for design values, respectively. On the other hand, the tensile strength values of UHPFRC (contains fiber) tend to be higher, which is in the range of 7-15 MPa [7]. Fig. 1a illustrates a typical UHPC and UHPFRC tensile stress – crack opening diagram, wherein the slope of falling branch may be vary, depends on the fiber characteristics (i.e. amount and orientation). Fig. 1b illustrates a typical UHPC and UHPFRC bending tensile stress – crack opening diagram.
Table 1. Typical tensile strength test specimens of UHPC and UHPFRC [8]

| Test Specimens | Age | Axial tension | Bending Tension |
|----------------|-----|---------------|-----------------|
|                |     |               |                 |
| Concrete       |     |               |                 |
|                | Uniaxial Tension |          | Prism 160×40×40 |
|                | Notch specimen   | 160×40×40 | One point loading |
|                | Cylinder dog-bone specimen   | ϕ80 – base ϕ160 | Two point loading |
|                | 160×40×40 | One point loading | 700×150×150 |
|                | Beam            | Two point loading |
|                | 700×150×150         |                   |
| Curing         | M1Q | B3Q           | M1Q             |
|                | 90°C | 90°C          | 90°C            |
|                | 90°C | WL            | 90°C            |
|                | 90°C | WL            | 90°C            |
| Pouring Direction |     |               |                 |
|                | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical | Horizontal |
| Fracture energy | 7d  | 15757        | 9993           | -         | 20100     | 15097     | -         | 20355     | 14543     | -         | -         |
|                | 28d  | 14555        | -              | 12932     | 18052     | -         | -         | 19892     | -         | -         | -         |
|                | 28d+ | 17014        | -              | -         | 19820     | -         | -         | -         | -         | -         | -         |
| Tensile Strength | 7d  | 14.2         | 7.9            | -         | 34.0      | 22.5      | 11.1      | 22.1      | 17.6      | 18.3      | 18.0      |
|                | 28d  | 13.3         | -              | 7.0       | 35.7      | -         | 13.1      | 22.2      | -         | 20.4      | 17.9      |
|                | 56d  | 17.7         | -              | -         | 36.3      | -         | 16.2      | 22.1      | -         | 24.2      | 18.1      |

Fig. 1. Typical UHPC and UHPFRC: a) tensile stress-crack opening diagram, b) bending tensile stress – crack opening diagram [9]

3. Experimental investigation

A stress – crack opening behavior test of UHPC and UHPFRC, a type of M3Q_210, developed by and made in the Official Material Testing Institute for Construction Industry - AMPA (Amtliche Materialprüfanstalt für das Bauwesen) of Kassel University, have been conducted in Kassel University. In the UHPFRC, steel fiber having length of 9 mm and diameter of 0.10 mm, was added with a volume of 2 vol.-%. A series of prisms having a cross section of 40 x 40 mm² and were notched with a size of 5 mm x 5 mm, were used as specimens. The compressive strength of the UHPC and UHPFRC after 28 days was ± 180 MPa.

Prior to testing, the moulds of the specimens were removed one day after casting and the specimens were left to cure under room temperature. Towards the test, notched were applied on both top and bottom surfaces of specimens. The specimens were tested under an increasing deformation until failure by using RBO2000 Tension Testing Machine which has a maximum load of 1.6 MN. The loading was applied with a speed rate of 0.01 mm/ sec, however then was increased to 0.05 mm/ sec once the crack opening exceed 2 mm. Fig. 2 shows the set up and instrumentation of the test.
4. Test results and conclusion

A total of 2 series of M3Q_210 mixtures, each consists of UHPC and UHPFRC 2% (UHPC contains 2 vol.-% of fiber) were made and casted into prism specimens having a cross section of 40 x 40 mm². After the treatment days, the specimens were tested to investigate its tensile behavior.

Fig. 3 shows the typical types of failure as observed after the test was done. It can be seen from Fig. 3a that the experimental tensile strength tests of UHPC ended with sudden brittle failures and show no falling branch. On the other hand, the specimens made of UHPFRC containing 2 vol.-% of fibers (Fig. 3b); show ductile behaviors with a gradual falling branch in the stress versus crack opening diagram of fibers (pullout of the fiber). Next, after its onset cracking, specimens may show stress-crack opening behaviors.
Fig. 4 shows relationships between the tensile stress (strength) and crack opening diagram from the UHPC and UHPFRC investigated in this study. From Fig. 4, it can be identified that UHPC and UHPFRC used in the study have mean maximum tensile strengths of 4.0263 MPa (for UHPC) and 6.5851 MPa (for UHPFRC 2%); also having the correlation crack opening lengths of 0.0078 mm (for UHPC) and 0.0068 mm (for UHPFRC 2%). The increase of UHPFRC’s tensile strength is promoted by factors which influence fibers efficiency, such as: fibers’ geometric properties, volumetric ratio and bond characteristics. These tensile strength values are close to those suggested by Japanese recommendation, namely 5 MPa (for UHPC). However, the tensile strength values are smaller than the proposed values by SETRA/AFGC guidelines of France [AFG02] namely 8 MPa (for UHPC) and 7-15 MPa (for UHPFRC).

The different results may occur due to the treatment process chosen, wherein in this study specimens were treated in room temperature and without pressure process. These finding is interesting as it shows that different treatment and pressure processes being applied, a variety of fiber (in properties and volume) being added, and a variety type of mixture being used will definitely influence the tensile strength test results of UHPC and UHPFRC. This study may support the documentation writing of standard norms for structural design needs.

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