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# Fiber reinforcing effect on asphalt binder under low temperature

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## HIGHLIGHTS

- We investigate fiber reinforcing effect on asphalt binder under low temperature.
- Fiber pullout strength can exceed fiber strength due to asphalt coating effect.
- Aramid fiber needs longer embedment length to develop bond than polyester fiber.
- Addition of polyester fiber can greatly enhance failure tensile strain of asphalt.
- Fiber reinforced asphalt mains its tensile ductility with decreasing temperature.

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## ABSTRACT

This research examines reinforcing effect of different fibers on asphalt binder under low temperature. Laboratory test of multiple-fiber pullout (MFPT) from asphalt matrix was conducted to investigate the influence of fibers (fiber type and embedment length) and matrix (asphalt binder type) on the fiber pullout strength. Furthermore, the influence of fiber (with or without fiber, fiber length and dosage) and matrix (asphalt binder type and temperature) on the tensile properties of fiber reinforced asphalt (FRA) binder was investigated via direct tensile test (DTT). From the MFPT test it was found that fiber pullout strength can actually exceed the fiber strength provided by the manufacturer, presumably due to coating effect of the asphalt on the surface of fibers. Aramid fiber requires much longer embedment length to fully activate its bond with asphalt than the polyester fiber does. From the DTT test it was observed that addition of adequate polyester fiber can greatly enhance the tensile properties of the FRA, particularly in terms of failure tensile strain. While asphalt matrix becomes more brittle when temperature drops, FRA mains its tensile ductility with decreasing temperature, which deserves further investigation.



## 1. Introduction

While fibers are primarily used as reinforcements in cement concrete materials to enhance tensile properties and control cracks due to mechanical loads, temperature change and shrinkage [1,2], functions of fiber in asphalt mixture are much broader [3–5]. One of the most noted application of fiber in asphalt mixture is to act as stabilizer and prevent the drain-down of asphalt [6,7]. Furthermore, fiber changes the viscoelasticity of the modified asphalt [8], improves moisture susceptibility [9], creep compliance [10], resistance to rutting [11], wearing and freeze–thaw cycles [7,12], and also reduces reflective cracking of asphalt pavements [13,14]. In summary, the addition of fiber can greatly enhance the durability of asphalt concrete (AC) mixtures and pavements.

On the other hand, some researchers also have done numerous investigations to examine the reinforcing effect of fiber on the AC mixture. The fiber reinforcement was found to arrest the formation and propagation of cracks as well as carry the tensile loads once it cracks [15]. It is observed that adding carbon fibers to asphalt enhances material strength and fatigue behaviour while simultaneously increasing ductility [16]. Additionally, fiber also helps enhance the low-temperature anti-cracking property [17,18], improving the toughness, fracture energy and dynamic modulus of AC composite [19–21]. Aforementioned literatures suggest that fiber reinforcements improve mechanical properties of asphalt mixture significantly.

Compared with cement concrete pavement, AC pavement is very ductile due to its inherent viscoelastic behaviour under

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normal temperature. Nevertheless, AC pavement behaves the very same way as cement concrete pavement during winter as its deformation characteristics change from ductile to brittle. Therefore, it is essential to investigate the effect of fiber in reinforcing asphalt binder under sub-zero temperature, as a first step towards ductile AC pavement in winter. In particular, detailed examination is required to find out the effect of fiber type, fiber length, temperature and asphalt matrix on the fracture properties of FRA due to temperature loads.

To overcome the brittleness of cementitious materials, extensive studies have been conducted to enhance their tensile ductility though in-depth understanding of interactions between fiber, cement matrix and interface [1,2]. While some researchers studied the effects of fiber on anti-cracking properties of asphalt under low temperature [17,18], very few of them have investigated the interaction of fiber and asphalt matrix through experiments, e.g. fiber pullout test [20]. It is constantly noted that the fiber matrix interface governs the composite behaviour. Additionally, most current investigations examine fracture properties of asphalt by indirect methods, which may not necessarily reflect the fact that asphalt fractures due to low deformation capacity when temperature drops below zero. Therefore, as a starting point to develop a ductile asphalt concrete via holistic approach, this paper looks to understand better the interaction between fiber and asphalt matrix via multiple-fiber pullout test, as well as the tensile properties of asphalt via direct tensile test.

## 2. Experimental program

### 2.1. Materials

The matrix materials used in the experiments include Shell AH-70 asphalt (normal asphalt binder), TPS (Tafpack super) modified asphalt and asphalt mortar with powder binder ratio of 1:1.2.

The powder has a density of 2.641 g/cm$^3$ and hydrophilic coefficient 0.854. The size of powder is less than 0.075 mm. The physical properties of asphalt binder are shown in Table 1.

The basic physical properties of fibers for pullout test are shown in Table 2. Two fibers with large difference in tensile strength were chosen in the MFPT test, including aramid fiber and commonly used polyester fiber. The polyester fiber and aramid fiber (FORTA® AR) were provided by Xiamen Xinfurong fiber company and Beijing Texida Science and Technology Company, respectively.

### 2.2. Multiple-fiber pullout experiment

It is well know that the fiber plays an important role in fiber reforced composite material in the post-cracking stage, where fibers bridge cracks and delay the opening of crack into major fracture. The bridging effect of fibers to transfer load from one crack face to another can be represented by fiber pullout test, in which single fiber is typically pulled out of asphalt matrix. In this study, however, a multiple fiber pullout test (MFPT) was adopted to enhance the robustness of experiment as opposed to single fiber pullout test.

The MFPT test was conducted on AsphaltPro™ direct tension tester by Instron company in accordance with ASTM D6723 standard. The testing was controlled by displacement, with testing rate adjusted according to embedment length of individual samples to ensure quasi-static loading condition. The test temperature was set to −18 °C, while the temperature range of the tester is +6 °C to −36 °C. The displacement and loading data was continuously recorded by data acquisition system.

As shown in Fig. 1, the fibers were first evenly glued on one end form before assembling of the formwork. Once the glue dried and hardened, the mould was then assembled completely with the fibers away for pouring of asphalt/asphalt mortar on the bottom of the mould. Asphalt mortar was prepared in advance which is mixed by asphalt and powder at 180 °C. The powder binder ratio was 1:1.2. Once the asphalt/asphalt mortar reached 150 °C, it was poured to form the bottom side of the sample. Afterwards, the fibers were carefully laid out straightly on the poured asphalt/asphalt mortar. Finally the rest of the asphalt/asphalt mortar was placed on the top of the fibers to make the whole MFPT specimen. In the casting process, care was taken to make sure there was no large air void in the specimens. Once the temperature of the samples reduced to about 20 °C, they were levelled by hot scraper to ensure the surface was horizontal. After finishing of the specimens, they were stored in the refrigerator together with the mould at −18 °C. When the whole specimen was cooled to −18 °C it was ready for MFPT test. The whole process was repeated for samples with different embedment length, fiber type and asphalt binder type as they were three major variables on the behaviour of fiber pullout strength.

### 2.3. Direct tensile test

In previous studies of asphalt behaviour under low temperature, fracture properties were typically examined via indirect test method, such as splitting tensile test and flexural test. While these tests are relatively easy to conduct, they may not represent the actual loading condition and failure mode of asphalt pavement under decreasing temperature. The loading condition of splitting tensile test and flexural test differs from direct tensile test in that the tensile stress field is more or less disturbed by the compressive stress field in the first two cases, while it is uniaxial tensile stress field in the third case. Research has shown that the structural ductility revealed in flexural test of fiber reinforced cement concrete (FRCC) cannot guarantee the tensile ductility of FRCC under direct tensile test as the propagation of its crack tip was arrested by the compressive field [22]. Under subzero temperature, behaviour of asphalt matrix is also very brittle, similar to that of cement concrete material, therefore it is very likely the same conclusion holds true for FRA.

DTT test was again conducted on AsphaltPro™ direct tension tester in accordance with ASTM D6723 standard. Two asphalt types were adopted, including Shell AH-70 asphalt (normal asphalt binder) and TPS modified asphalt. Considering processibility of fiber in asphalt, only polyester fiber was adopted in the test. Asphalt was heated to 180 °C, and mixed with fiber. And the mixture was poured in the mould with the size of 100*90*15 mm. The test was controlled at displacement rate of 1 mm/min. The test temperature was set at −18 °C, which is in consistence with that of the MFPT test. The displacement and loading data was continuously recorded by data acquisition system. Furthermore, fiber dosage, fiber length and test temperature were varied to examine their influence on the fracture properties of FRA. The maximum tensile stress, failure tensile stress and failure tensile strain was derived from the experimental data for further discussion.

## 3. Results and discussion

### 3.1. Multiple-fiber pullout experiment

The test results from fiber pullout experiment are shown in Table 3, where the fiber pullout strength is obtained from specimens with different asphalt type, fiber type and embedment length. As shown in Fig. 2, the fiber pullout strength first increases with embedment length and then stabilizes at around 700 MPa for polyester fiber. In the case of aramid fiber, it shows similar trend as that of the polyester fiber initially, but declines rapidly after the peak of 3700 MPa. It should be noted that the relations between polyester fiber pullout strength and embedment length are almost identical for both normal and TPS modified asphalt matrix.

From Tables 2 and 3, it should be reminded that pullout strengths of both fibers are larger compared with the tensile strength provided by manufacturers. One hypothesis for this discrepancy may be that fibers were artificially "coated" with a layer of asphalt during pouring process of sample preparation, therefore resulting in increased apparent pullout strength. The drop in pullout strength of aramid fiber after peak load may be due to its relative smaller tensile ductility (i.e. more brittle) as compared with that of the polyester fiber, as shown in Table 2.

**Table 1**
Physical properties of asphalt binder.

| Asphalt type | Penetration (25 °C, 0.1 mm) | Softening point (°C) | Ductility at 15 °C (cm) | Density (g/cm$^3$) | Thin film oven aged (165 °C, 5 h) | |
|---|---|---|---|---|---|---|
| | | | | | Mass loss (%) | Penetration ratio (%) |
| Normal asphalt binder | 67 | 48.5 | >100 | 1.037 | 0.28 | 86.6 |
| TPS modified asphalt | 53 | 84 | 66.5 | – | 0.03 | 83 |