EFFECT OF CELLULOSE FIBER ON PROPERTIES OF 
SELF-COMPACTING CONCRETE WITH HIGH-VOLUME MINERAL 
ADMIIXTURES

Zhengwu Jianga*, Nemkumar Banthia⁵ and Sarah Delbarc

a. Key Laboratory of Advanced Civil Engineering Materials of Ministry of Education, Tongji University, Shanghai, China 200092;
b. Department of Civil Engineering, University of British Columbia, 2024-6250 Applied Science Lane, Vancouver, BC, Canada V6T 1Z4
c. Department of Civil Engineering, Ecole des Mines de Douai, 941 rue Charles Bourseul, 59508 Douai, France

Abstract:
In this paper, effects of cellulose fiber in different dosages on fresh and mechanical properties of self-compacting concrete with high-volume mineral admixtures (HMSCC) were investigated. 35% Class F fly ash and 5% silica fume in substitution for cement by weight was added in concrete mixtures. Slump, slump flow and flow time of inverted slump cone were conducted to assess the fresh properties of HMSCC. Compressive strength, impact resistance and abrasion resistance of the concrete were determined for the hardened properties in accordance with ASTM standards. The results indicate that cellulose fiber improves fresh properties of HMSCC in appropriate dosage, and improves impact resistance of HMSCC gradually with the increase of cellulose fiber dosage, but plays little contribution to compressive strength. It also improves abrasion resistance of HMSCC through improving its surface mechanical properties.

Keywords: cellulose fiber; self-compacting concrete; impact; high volume; mineral admixture

1 INTRODUCTION

Due to its excellent workability, mechanical properties and durability, self-compacting concrete is applied extensively in concreting projects recently. Meanwhile, self-compacting concrete has become an important research and application aspect of high-performance concrete[1-3]. In recent years, a number of research and application on self-compacting concrete have been carried out [1-5]. In addition, chemical admixtures, mineral admixtures, such as fly ash, slag powder and silica fume or inert materials have become indispensable
components for preparing self-compacting concrete to improve fresh properties of self-compacting as well as its mechanical properties and durability[6-8]. Among these mineral admixtures, fly ash, a by-product of thermal power plants, is one of most popular supplementary cementitious materials due to its positive effect on concrete. Concrete incorporating with high-volume fly ash has been applied in many concrete projects worldwide due to its low hydration heat, good durability and mechanical properties [8-13].

Meanwhile, reinforcement of concrete with short randomly distributed fibers can improve some of the concerns related to concrete brittleness and poor resistance to crack growth. Fibers, used as reinforcement, can be effective in preventing cracks at both micro- and macro-levels. The character and performance of fiber reinforced concrete change depending on the properties of concrete and the fibers [14-15]. The properties of fibers that are usually concerned are fiber concentration, fiber geometry, fiber orientation, and fiber distribution. Many types of fibers used commonly in fiber reinforced concrete (FRC) are organic fiber (such as polypropylene, nylon), inorganic fiber (glass, asbestos and carbon) and steel fiber. Cellulose fiber is one of popular natural fibers are used in concrete to reduce plastic shrinkage and shrinkage cracking of concrete as well as enhancing tensile and flexural strengths, toughness, impact resistance, and fracture energy of concrete in recent years [16-19]. Cellulose fiber will also modify workability and surface condition of concrete. However, little research is focused on properties of cellulose fiber reinforced self-compacting concrete without or with high-volume fly ash. It is necessary to evaluate how cellulose fiber influences fresh properties and mechanical properties of HMSCC.

Therefore, the objective of this study is to evaluate the effect of cellulose fiber in different dosages on fresh properties and mechanical characteristics such as compressive strength, impact resistance and abrasion resistance of HMSCC. In HMSCC mixtures, total mass of cementitious materials is 550 kg/m³, in which 40% of cement is replaced by 35% fly ash and 5% silica fume, and necessary commercially available chemical admixtures such as a polycarboxylate-based superplasticizer (SP), a viscosity modifying admixture (VMA) and an air-entraining admixture (AEA) were used.

2 EXPERIMENTAL

2.1 Raw materials

ASTM Type I Portland cement was used in all concrete mixes. A Class F type CI fly ash produced by HeidelbergCement Group in accordance with ASTM C 618 and a densified silica fume produced by Norchem Company were employed. Chemical components of cement and mineral admixtures is shown in table 1.

The Canadian local natural river sand with fineness modulus of 3.4 and specific gravity of 2.60×10³ kg/m³, and gravel coarse aggregate with the maximum size of 9.5 mm and specific gravity of 2.60×10³ kg/m³ was used.
Table 1 Chemical components of cement and mineral admixtures

<table>
<thead>
<tr>
<th></th>
<th>Na₂O</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>SO₃</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>TiO₂</th>
<th>MnO</th>
<th>Fe₂O₃</th>
<th>PbO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>0.31</td>
<td>0.85</td>
<td>4.45</td>
<td>18.5</td>
<td>2.9</td>
<td>-</td>
<td>-</td>
<td>0.35</td>
<td>67.2</td>
<td>0.26</td>
<td>0.07</td>
<td>2.92</td>
</tr>
<tr>
<td>Fly ash</td>
<td>4.67</td>
<td>1.56</td>
<td>22.6</td>
<td>45.8</td>
<td>0.55</td>
<td>0.95</td>
<td>0.57</td>
<td>8.62</td>
<td>3.80</td>
<td>0.03</td>
<td>7.08</td>
<td>-</td>
</tr>
<tr>
<td>Silica fume</td>
<td>-</td>
<td>11.4</td>
<td>0.92</td>
<td>70.1</td>
<td>0.33</td>
<td>-</td>
<td>1.14</td>
<td>1.05</td>
<td>-</td>
<td>-</td>
<td>2.63</td>
<td>0.39</td>
</tr>
</tbody>
</table>

The Glenium 3400 NV polycarboxylate-based superplasticizer (PC) with the solid content of 40% from BASF and the Darex II air-entraining admixture (AEA) from Grace were used. A methylcellulose base powder product was also used in HMSCC mixtures as a viscosity-modifying admixture (VMA).

A cellulose sheeted fiber in white square dice is investigated and its geometry with the diameter in 0.02 mm and length in 6 mm is shown in Fig.1. It can be dispensed in concrete mixture with agitating action easily and evenly.

Fig.1 Geometry of cellulose fiber

2.2 Mix proportion, making and curing of concrete specimens

The mix proportion of HMSCC reinforced with or without cellulose fiber used in the program is shown in table 2. Four concrete mixtures are prepared and one is the control mixture without cellulose fiber. The water to binder ratio is 0.3. The dosage of cellulose fiber ranges from 0 to 3.6kg/m³ in four concrete mixtures.

The mixing, making and demoulding and curing of concrete specimens were conducted in accordance with the standard ASTM C192. The concrete was mixed with a conventional rotary drum concrete mixer. Gravel, sand, cement, fly ash and silica fume were first put into the mixer. After about 30 seconds mix, the water was added slowly with PC, AEA and VMA which had been dissolved before in the water. The cellulose fiber was added slowly to the...
running mixer in order to avoid clumping. The materials were mixed for exactly five minutes. For each mixture, the fresh properties such as slump, slump flow and flow time of inverted slump cone of concrete were tested. Then, six cylinders for compressive strength test (Φ100×200 mm), five cylinders for impact resistance test (Φ153×63.5 mm) and three cylinders for abrasion resistance test (Φ300×100 mm) were cast. The moulds for abrasion test and impact test were not vibrated whereas the moulds for compressive strength test were put on a vibrating table and vibrated for one minute. After 48 hours, the specimens were demoulded and cured for 7 or 28 days.

Table 2 Mix proportion and compressive strength of HMSCC with or without cellulose fiber

<table>
<thead>
<tr>
<th>No.</th>
<th>Cellulose fiber</th>
<th>Mix proportion (kg/m³)</th>
<th>Compressive strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cement</td>
<td>FA</td>
</tr>
<tr>
<td>CSC1</td>
<td>0</td>
<td>330</td>
<td>192.5</td>
</tr>
<tr>
<td>CSC2</td>
<td>1.2</td>
<td>330</td>
<td>192.5</td>
</tr>
<tr>
<td>CSC3</td>
<td>2.4</td>
<td>330</td>
<td>192.5</td>
</tr>
<tr>
<td>CSC4</td>
<td>3.6</td>
<td>330</td>
<td>192.5</td>
</tr>
</tbody>
</table>

2.3 Testing method
2.3.1 Slump and slump flow
Flowability, segregation resistance, stability and viscosity of fresh properties of self-compacting concrete are evaluated through the measurement of slump, slump flow and flow time of inverted slump cone (FTIS), shown in Fig. 2.

Fig.2 Schematic diagram of testing method of fresh properties for self-compacting concrete

Slump test is one of the most common methods to evaluate flowability and segregation resistance of concrete and the slump flow test is used to assess the horizontal free flow (deformability) and segregation resistance of self-compacting concrete in the absence of obstructions. The procedure for the slump flow test and the commonly used slump test are almost identical. In the slump test, the change in height between the cone and the spread concrete is measured, whereas in the slump flow test the average final diameters of the spread concrete at two vertical directions in horizontal plane is determined as the slump flow.
diameter (D). According to Nagataki and Fujiwara [20], a slump flow diameter ranging from 500 to 700 mm is considered as the slump flow required for a concrete to be classified as SCC. According to Specification and Guidelines for SCC prepared by EFNARC [21] (European Federation of National Trade Associations), a slump flow diameter ranging from 650 to 800 mm can be accepted for SCC. In addition, any segregation border between the aggregates and mortar around the edge of spread is recorded.

2.3.2 Flow time of inverted slump cone (FTIS)

FTIS test is designed to viscosity, stability and flowability of fresh properties of SCC. The measurement procedure of FTIS is defined as follows: invert the slump cone on the supporter surface. Add fresh concrete into it fully. Then float it. Take the slump cone up and record the time in the same time. Allow fresh concrete to flow out from the bottom mouth of the slump cone. The flow time when all fresh concrete flows out is recorded using the stop watch (s). FTIS could indicate plastic viscosity and yield value of SCC mixture. DTIS testing method is practical, convenient and repeatable in labs and on site. Good flowable and stable concrete would consume short time to flow out. FTIS is recommended less than 35s for SCC [22].

2.3.3 Compressive strength

The compressive strength of FRC was tested at 7 days and 28 days as per ASTM C39 using a 2.8 MN load-controlled compression testing machine. Only the peak loads were recorded, and converted to compressive strengths by using an elastic analysis.

2.3.4 Impact resistance

The impact resistance of concrete was tested as per ICC-ES AC32 at 28 days [23]. The test method compares the impact resistance of concrete with and without synthetic fibers. Impact resistance is characterized by the measure of the energy consumed to fracture a specimen, the number of blows in a “repeated impact” test to achieve a prescribed level of distress and the extent of damage. The equipment for the drop weight impact test consists of a standard, manually operated 10-pound (4.54 kg) compaction hammer with an 18-inch (457 mm) drop, a 63.5 mm –diameter hardened steel ball and a flat base plate with four lugs welded to it, shown in Fig.3.
When tested, the drop hammer shall be placed with its base upon the steel ball and held there with enough down pressure to keep it from bouncing off the ball during the test. The hammer shall be repeatedly dropped 18 inches (457 mm), and the number of blows required to cause the first visible crack on the top and to cause ultimate failure are both recorded. Ultimate failure occurs when the test specimen comes in contact with three of the four lugs welded to the base plate. The results are evaluated on the basis of averaging the test results. Any individual peculiarities among test results are noted.

2.3.5 Abrasion resistance

The abrasion resistance of concrete was tested at 28 days as per ASTM C1138. It is determined the relative resistance of concrete to abrasion under water. This test method provides a relative evaluation of the resistance of concrete to the simulating behavior of swirling water containing suspended and transported solid objects that produce abrasion of concrete. Determine and record the mass of the specimen in air and in water during abrasion every 24-hour interval. It consists of three 24-h periods for a total of 72 h. The volume of concrete lost and average depth of wear at the end of any time increment of testing is calculated.

3 RESULTS AND DISCUSSION

3.1 Effect of cellulose fiber on fresh properties of HMSCC

![Fig.4 Effect of cellulose fiber on fresh properties of HMSCC](image)

The results of fresh properties such as slump, slump flow and FTIC of HMSCC are shown in Fig.4. As seen in the table and the figure clearly, with the increase of cellulose fiber dosage, concrete slump decrease a little, whereas their slump flow first decreases slightly and then drops greatly, and the FTIC change is the same to slump flow. The slump flow of all mixtures was in the range of 550-750 mm and the FTIS was less than 35 s except of the mixture with the cellulose fiber dosage of 3.6 kg/m³. Therefore, all concrete mixtures were considered as SCC except CSC4.

In addition, for control concrete mixtures, there was a little segregation and bleeding near the edges of the spread-out concrete as observed from the slump flow test, which was also verified in harden concrete. With the addition of cellulose fiber, there was little segregation at the cellulose fiber dosage of 1.2 kg/m³ and no segregation for concrete mixtures with the
cellulose fiber dosage above 1.2 kg/m³. This could be explained that due to fly ash’s characteristics of smooth surface and spherical shape, fly ash will improve fresh properties of concrete mixtures, but fly ash concrete exhibits a tendency to bleeding and segregation, especially for high volume fly ash concrete, and cellulose fiber reduces bleeding and segregation of HMSCC mixtures. It also indicates that cellulose fiber improves fresh properties of HMSCC in appropriate dosage, especially for high volume fly ash concrete, and reduces flowability of HMSCC when its dosage exceeds a certain amount.

3.2 Effect of cellulose fiber on compressive strength of HMSCC

The compressive strength of HMSCC with different dosage of cellulose fibers at 7 and 28 days was shown in Table 1. Seen from it, compressive strength of concrete of each group increases as curing age increases, but the compressive strength of all mixtures is only about 40MPa and the growth rate is a little low from 7 days to 28 days compared to the other high-volume fly ash concrete investigated [10, 11]. It maybe lies in high-volume fly ash content and the poor pozzolanic effect of fly ash due to its low fineness and quality, and so it reduces the hydration degree of cementitious materials in HMSCC at 28 days compared to control concrete.

At the same age, compressive strength of all concrete with or without cellulose fiber varies a little in the range of error. With the increase of the dosage of cellulose fiber, the compressive strength of concrete has no manifest trend to decrease or increase. It also indicates that cellulose fiber didn’t increase the compressive strength, the same as to the other results [24, 25].

3.3 Effect of cellulose fiber on impact resistance of HMSCC

In the impact test, blow number of first crack and blow number of failure are used to reflect the cracking resistance and crack propagation resistance of fiber reinforced concrete respectively. The blow number to first crack and blow number to failure of concrete with different dosage of cellulose fiber at 28 days were shown in Fig.5. From Fig.5, blow number to first crack and blow number to failure of HMSCC increases with the increase of cellulose fiber dosage obviously. Compared with control concrete, the blow number to first crack of HMSCC increases by 62.5%, 81.3% and 112.5%, and the blow number to failure of HMSCC increases by 31.4%, 60.0% and 112.5% when the dosage of cellulose fiber reaches 1.2, 2.4 and 3.6 kg/m³ respectively.

Fig.5 Effect of cellulose fiber on blow number to first crack and failure of HMSCC at 28 days
Although the coefficient of variation of the blow number to first crack and blow number to failure in the experiment are 33.1% and 25.4% respectively due to the limitations of this impact resistance method [26], as shown in Fig.4. It still proves that cellulose fiber improves impact resistance greatly with the increase of cellulose fiber dosage, especially for first cracking due to impact, which means it is effective to inhibit cracking and crack propagation resulting from dry shrinkage and plastic shrinkage etc.

From the typical failure pattern and damage extent of HMSCC without and with cellulose fiber due to impact shown in Fig.6, HMSCCs without and with cellulose fiber normally were split into two pieces due to hammer impacts from the first crack to extreme failure. It also indicates that cellular fiber only improves the toughness of HMSCC to some extent.
3.4 Effect of cellulose fiber on abrasion resistance of HMSCC

Fig. 7 Abrasion depth of HMSCC without or with cellulose fiber at 28 days

![Graph showing abrasion depth vs. cellulose fiber dosage](image)

The curves of abrasion depth of HMSCC incorporated with different dosage of cellulose fiber tested 28 days are shown in Fig. 7. It can be found that, in general, abrasion depth of HMSCC decreases with the increase of the dosage of cellulose fiber, and the abrasion depth of HMSCC with cellulose fiber dosage of 1.2 kg/m³ is the lowest, which is not the same to ordinary concrete that abrasion depth of fiber reinforced concrete decreases gradually with the increase of the dosage of fiber. It seems a little strange. However, this can be explained that segregation in the surface of HMSCC specimens due to high volume of fly ash results in the phenomena of abrasion test, which is proved by the typical surface characteristics of HMSCC shown in Fig. 8.

As well known, abrasion resistance of concrete is governed by its bulk mechanical properties as well as surface mechanical properties. The factors which affect bulk mechanical properties or surface mechanical properties of concrete will also have critical influences on abrasion resistance of concrete, including the amount and type of cement, w/c ratio, aggregate...
property and dosage, concrete strength, the use of supplementary cementitious materials, fiber addition, curing conditions and surface finishing, and testing method [27-29]. As observed from fig.7, the surface of CSC1 specimens after 3 days’ abrasion still shows rich in cement paste due to segregation and bleeding, and the surface of CSC2 specimens after 3 days’ abrasion still shows rich in mortar, the surface of CSC3 and CSC4 specimens after 3 days’ abrasion shows normal concrete condition. Since there exists “pulling out” effect of coarse aggregate in low-strength concrete that coarse aggregate will be easily pulled out of the surface due to abrasion action, mortar with cellulose fiber shows higher abrasion resistance and concrete with high dosage of cellulose fiber show low abrasion resistance because of low bulk compressive strength of HMSCC. Therefore, cellulose fiber has double effects on abrasion resistance. In one hand, it increases abrasion resistance through improving workability of HMSCC, and in the other hand, it reduces the abrasion resistance of low-strength HMSCC because of “pulling out” effect. So, the abrasion depth of CSC2 HMSCC gets the lowest though double effects of cellulose fiber. It also indicates that surface mechanical property of HMSCC is one of the main factors that govern its abrasion resistance. Cellulose fiber improves abrasion resistance of HMSCC through the improvement of its surface properties. More rules about effect of cellulose fiber on abrasion resistance of concrete shall be studied further in the future.

4 CONCLUSIONS
1. Cellulose fiber improves fresh properties such as segregation and bleeding of HMSCC mixtures in appropriate dosage, and reduces flowability of HMSCC when its dosage exceeds a certain amount.
2. Cellulose fiber improves impact resistance of HMSCC gradually with the increase of cellulose fiber dosage, especially for first cracking due to impact, but plays little contribution to compressive strength.
3. Cellulose fiber improves abrasion resistance of HMSCC through the improvement of its surface mechanical properties.

REFERENCES


