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# Investigation of the relative abrasion resistance of concrete pavement with chip-sprinkled surfaces

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ABSTRACT

Chip-sprinkling cement concrete (CSCC) pavement can provide satisfactory friction and has potential for noise attenuation due to its exposed surface texture, making abrasion resistance significant. The abrasion resistance of CSCC pavement was evaluated using the Cantabro test method, with smooth surface concrete as the control group. This method uses a Los Angeles Abrasion Machine without steel balls. Using the same method, the abrasion durability of CSCC was also assessed using different concentrations of sodium chloride solutions. The effects of different water/cement ratios and chip-sprinkling parameters were analyzed. The latter variables included aggregate particle size, aggregate spreading area ratio, and aggregate pressing depth ratio. Data indicate that the abrasion losses of CSCC specimens change quickly at first, but later they change more gradually. Aggregate particle sizes of 9.5–13.2 mm may be better when just considering the effect of aggregate particle size on the abrasion resistance. Abrasion losses of CSCC specimens multiply with increasing aggregate spreading area ratios and decrease with the rising aggregate pressing depth ratios. On the whole, abrasion resistance of CSCC is superior to the smooth surface concrete in the control group.

## 1. Introduction

Chip-sprinkling was developed in Belgium in the mid nineteen-seventies. Its surface is similar to exposed aggregate concrete. Sprinkling treatment consists of distributing polish-resistant stone chips on fresh concrete surfaces and techniques are utilized to partially embed the stones into the concrete at a certain depth. However, this treatment did not go further than the experimental stage due to difficulty with uniformly embedding chippings in the fresh concrete. After development and improvement, the technique was once applied on several motorway sections in France [1,2]. This technique was also used in the United States in the 1970s and 1980s with equipment rented from England [3]. It is difficult to find documents about it in the last two decades except for a brief introduction, which mentioned it with noise-reducing pavements. Although this sprinkling treatment may create a noisy surface, the use of high-quality aggregates can facilitate the associated noise attenuation while providing satisfactory surface friction [4].Thus, in recent years, it has caught the attention of researchers in the Xi'an Highway Research Institute and at Chang'an University. Aggregate spreading and embedding machine is under improvement [5]. This technique was also attempted to be used in composite pavement and bride deck pavement as interlaminar treatment [6]. Whereas, it is unknown whether the sprinkled aggregates perform well under external loads, especially under erosion of deicing salt. Abrasion resistance is a fundamental performance for concrete pavement. Chip-sprinkling cement concrete (CSCC) pavements require stricter abrasion resistance due to the special way that the exposed aggregate texture is formed. The abrasion resistance, to some extent, can also be a characterization of adhesion between aggregates and cement mortar.

There have been a great number of studies on abrasion resistance of concrete pavement. Previous research mostly focuses on abrasion resistance influencing variables and abrasion test methods. Abrasion resistance is influenced by variables such as compressive strength, aggregate properties, curing methods, test conditions (i.e. wet or dry), and surface finishing techniques [7–10]. Among the variables influencing abrasion resistance of pavement concrete, compressive strength is an important factor affecting abrasion resistance of concrete pavement and efforts have been made to find the relationship between compressive strength and abrasion resistance [10–12]. All the variables that have effects on abrasion resistance of common concrete may also affect CSCC pavement. The water/cement ratio is one of the key parameter in concrete parameter. Therefore, the water/cement ratio is taken into consideration. Chip–sprinkling is a surface finishing technique and its

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parameters affect the abrasion resistance of CSCC. Furthermore, deicing salt is often used in China. So chip-sprinkling parameters and deicing salt are considered in the research. However, previous studies are rarely found about this.

With regard to the abrasion test method, researchers from various countries, including America, India, Turkey, and China, have tried to characterize abrasion resistance of concrete pavement through different test methods [13–19]. The Chinese standard specification T0567-2005, American Society for Testing Materials (ASTM) C779, Turkish Standard Specifications (TS) 699–1987, ASTM C944, ASTM C1747, ASTM C131, and Indian Standard Specifications (IS) 1327–1980, etc. can be found in relevant documents. Previous research demonstrates that there exists little research on finding a method properly characterizing abrasion resistance of concrete pavement, especially for CSCC pavement. Most of the research is about ordinary concrete. These methods can be divided into two groups, surface rotary cutter method and Cantabro test method. Due to the exposed aggregates of CSCC pavements on the surface, the method of the rotating abrasion method T0567-2005 is not feasible. Using this method, the abrasion resistance of CSCC pavements cannot be well characterized in this way, so the Cantabro test method is considered.

The Cantabro test is widely used. While the adhesion between the aggregate and asphalt binder is poor, aggregates tend to break down easily. Cantabro Test (T0733-2011) is used in Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) to evaluate aggregate breakdown on road surfaces by the index of raveling loss after the Los Angeles Abrasion Machine has rotated for 300 revolutions without steel balls [20]. Similar methods have been extended to evaluate moisture-induced damage, and durability of porous asphalt mixtures, etc. [21–23]. Yang [24] referred to the Cantabro Test and fabricated cylinder porous cement concrete specimen with 100 mm in diameter and 70 mm in height, to conduct abrasion resistance test. Wu et al. [25] compared ASTM C131 Cantabro Test using the Los Angeles Abrasion Machine, with Loaded Wheel Abrasion Test using the Asphalt Pavement Analyzer (APA) [26], and his research results indicated that the Cantabro test and the APA abrasion tests were both effective in evaluating abrasion resistance of pervious concrete. Bing [27] adopted the Cantabro test to evaluate abrasion resistance of hot rolled asphalt (HRA).

On the whole, the chip-sprinkling technique is lacking in previous research. Documents related to CSCC are rarely found, especially for abrasion resistance, whereas, abrasion resistance of the CSCC pavement is closely related to its other performances. These performances include noise attenuation, and surface friction, etc. Taking into consideration aforementioned methods and the fact that CSCC pavement has similar texture to HRA, this research tries to adopt the Cantabro Test method to evaluate abrasion resistance of CSCC.

## 2. Research objective

The overall objectives of this research are as follows:

1) Evaluate abrasion resistance characteristics of CSCC using the Cantabro test method.
2) Characterize the effects of the water/cement ratios and chip-sprinkling parameters on abrasion resistance. The latter variables include aggregate particle size, aggregate spreading area ratio and aggregate pressing depth ratio.
3) Evaluate abrasion durability by immersing specimens into sodium chloride solutions with concentration of 5%, 10% and 20% respectively, to simulate effects of deicing salt on abrasion resistance.

**Table 1**
Chip-sprinkling parameters.

| Parameter levels | Aggregate parameters | | |
|---|---|---|---|
| | Aggregate particle size (mm) | Aggregate spreading area ratio (%) | Aggregate pressing depth ratio (%) |
| 1 | 4.75–9.5 | 50 | 20 |
| 2 | 9.5–13.2 | 60 | 40 |
| 3 | 13.2–16.0 | 70 | 60 |
| 4 | 16.0–19.0 | 80 | 80 |

*Notes:* Spreading area ratio means percentage between the aggregate spreading area and the pavement surface area; Aggregate pressing depth ratio is the percentage between aggregate pressing depth and the original depth.

## 3. Materials and experimental program

### 3.1. Materials

The ordinary Portland cement (PO. 42.5) conforming to Chinese Standard Specifications JTG/T F-30 2014 was used. It was supplied by Jidong Limited Liability Company. Aggregates were selected based on their ability to meet the Chinese Standard Specifications JTG/T F30-2014. The graded gravel and river sand were selected as coarse aggregate and fine aggregate respectively. Water used in this research was potable water. The water did not need to be treated and therefore it could be directly used in the mixture. The aggregates that were sprinkled on the concrete pavement surface were diabase. In this research, chip-sprinkling parameters, such as aggregate particle sizes, aggregate spreading area ratios and aggregate pressing depth ratios, are shown in Table 1. Each parameter has four levels. When analyzing the effect of one parameter on abrasion resistance characteristic of CSCC specimens, the other two parameters were kept fixed.

### 3.2. Mixture proportion

The water/cement ratio is a parameter determined by water usage per unit volume and cement usage per unit volume. There are two common ways of obtaining the target water/cement ratio. One is to change the water usage per unit volume while keeping cement usage per unit volume fixed, and the other is to change the cement usage per unit volume while keeping water usage per unit volume fixed. Xiong et al. [28] proposed that the abrasion resistance of concrete pavement, by reducing water usage per unit volume, is better than that by increasing cement usage per unit volume in adjusting water/cement ratio process. Therefore, in this research, mixture proportions with different water/cement ratios were accomplished by keeping cement usage per unit volume fixed and changing water usage per unit volume at the same time. A total of three mixtures with water/cement ratios 0.37, 0.47 and 0.57 respectively were proportioned. The mixture proportions are shown in Table 2.

### 3.3. Specimen fabrication

#### 3.3.1. Chip-sprinkling technique

Chip-sprinkling is a surface texture treatment technique. After a

**Table 2**
Mixture proportions with different water/cement ratios.

| Water/cement ratio | Water(kg/m$^3$) | Cement(kg/m$^3$) | Sand(kg/m$^3$) | Aggregate(kg/m$^3$) |
|---|---|---|---|---|
| 0.37 | 156 | 422 | 615 | 1191 |
| 0.47 | 198 | 422 | 615 | 1191 |
| 0.57 | 241 | 422 | 615 | 1191 |