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# Effects of anti-stripping agents on the microscopic strength of mineral aggregate contact surface

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## HIGHLIGHTS

- Anti-stripping agents may have influence on cohesive strength of the bitumen.
- Compatibility between anti-stripping agent and bitumen requires focused attention.
- Total strength is the effective index for evaluating anti-stripping agents.

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## ABSTRACT

This study investigated the effects of types I and II anti-stripping agents on the microscopic strength of the mineral aggregate contact surface of mixture. Panjin70# bitumen and SBS-modified bitumen were used as binders and granite acid stone was used as the aggregate. Microscopic strength covers the total strength of the contact surface, adhesion strength between the aggregate and bitumen, and the cohesive strength of the bitumen binder. Microscopic strengths were tested after short-term aging (RTFOT) and long-term aging (RTFOT + PAV). Results show that the enhancement effect of type I anti-stripping agents on adhesion was weakened after aging treatment, but anti-stripping agents exert no remarkable influence on cohesive strength under such treatment. Short-term aging treatment has slightly influence on enhancement effect of type II anti-stripping agents on adhesion, but the enhancement effect on adhesion was not obvious after long-term aging treatment and cohesive strength of bitumen significantly decreased at low temperature, thereby markedly diminishing total strength. Anti-stripping agents may influence adhesive and cohesive strengths of bitumen, choosing the anti-stripping agents should seriously considering the compatibility between anti-stripping materials and bitumen.



## 1. Introduction

Cracking and ravelling are two typical asphalt mixture defects that destroy the integrity of mixtures, shorten the service life of road structures, and seriously influence normal road use. Thus, improving the anti-cracking and anti-ravelling abilities of pavement is an important component of research on pavement performance [1–4]. Existing studies indicate that adhesive effects are critical to anti-cracking and anti-ravelling properties. Weak adhesion, such as that exhibited by granite acid stone, easily causes water damage [5–7]. To improve the adhesive strength and reasonable use of granite acid stone, researchers have proposed numerous technical measures, amongst which using anti-stripping agent is an important technique [8,9].

Lime is the first-generation representative of anti-stripping agents and is still used in many countries. It efficiently improves adhesive effects and the water stability of mixtures, as well as retards ravelling. When applied, it evenly covers contact surfaces, and the enhancement is achieved by surface modification, which forms many porous rough structures on mineral aggregate contact surfaces. But the use of lime necessitates metric and feeding equipment, which increases complexity [10–12].

Incorporating anti-stripping agents is a convenient and efficient way to improve the adhesive effects. Such agents reduce interfacial tension between aggregates and bitumen. Three types of anti-stripping materials are currently available: metal saponated substances, amines, and non-amines. Metal saponated substances are rarely used because they are easily separable from bitumen [13–15].

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In this study, prophase investigation was conducted to study the effects of bitumen on the microscopic strength of the aggregate contact surface of mixture. Microscopic strength covers the total strength of the contact surface, adhesive strength, and cohesive strength. Results show that cracking and ravelling occurred on the contact surface, and that these defects were converted into separate bonded aggregates during the final stage of defect formation. This result is attributed primarily to the failure of the mineral aggregate contact surface. To elucidate this failure, the failure mechanism of the mineral aggregate contact surface of AM-20 semi-open-graded bituminous-stabilized macadam was manually broken down. The results show that failure of adhesion between the aggregate and bitumen occurred, and that the bitumen binder exhibited cohesive failure. In the failure process, temperature and the oil film thickness of the contact surface also posed significant effects [16].

Given that bitumen mixtures are prepared under high temperatures, an effective anti-stripping agent should possess better temperature stability; that is, it should not decompose at high temperatures. At the same time, anti-stripping agent should ensure total strength on the premise of improving adhesive strength; that is, the cohesive strength of the bitumen binder should not be weakened.

## 2. Methods for testing microscopic strength

### 2.1. Traditional methods

Boiling water is the most direct way to examine adhesion and compare the adhesive effects of different anti-stripping agents. A mineral aggregate wrapped with oil film is immersed in slightly boiling water and removed after 3 min. Researchers then observe the degree of stripping of bitumen film, on whose basis adhesion levels are assessed [17,18]. Domestic and international scholars have developed methods for testing adhesion on the basis of the fundamental theory of adhesive work, which can be calculated by testing the surface tension and contact angle of bitumen. The adhesive effect is then determined on the basis of the numerical value of adhesive work [19,20].

The water boiling method presents two core limitations. First, it requires expert test skills, which are difficult to master because accurately determining water boiling conditions vary depending on individual. Second, the stripping area of bitumen is determined through visual measurement, making for inconvenient estimation and subjective experimental results. The test method based on adhesive work has a clear theoretical basis, but the surface tension of bitumen at thermal melting conditions is difficult to determine during the actual test process and the approach is also constrained by the performance of the instruments used to measure surface tension.

### 2.2. New testing technology for adhesive and cohesive strengths

Fig. 1 shows that the contact surface of the mineral aggregate suffers from damage under tensile load. $S_t$ denotes the contact surface area, and $S_a$, and $S_c$ respectively represent the adhesive and cohesive failures that occur after damage. At an $S_a$ and $S_c$ of 0, cohesive and adhesive failures occur, respectively. Adhesive and cohesive failures co-exist when $S_a$ and $S_c$ are not 0. The total tensile strength is $R_t$; the adhesive strength of bitumen and the aggregate is $R_a$; and the cohesive strength of the bitumen binder is $R_c$. The relationship between tensile failure load $F$ and total tensile strength $R_t$ is expressed by Eq. (1), and that amongst tensile failure load $F$, adhesive strength $R_a$, adhesive failure area $S_a$, cohesive strength $R_c$, and cohesive failure area $S_c$ is expressed by Eq. (2).

$$R_t \times S_t = F \tag{1}$$

$$R_a \times S_a + R_c \times S_c = F \tag{2}$$

Tensile failure load $F$ can be directly measured by a hydraulic force measurement device. As indicated by the statistical results on the failure forms on the mineral aggregate contact surface, complete cohesive failure occurs under a thick oil film (i.e., $S_a = 0$ and $S_c = S_t$). Thus, Eq. (2) can be rewritten as

$$R_c \times S_t = F \tag{3}$$

Under a thick oil film, cohesive strength $R_c$ can be obtained from tensile failure load $F$ and contact surface area $S_t$. After determining cohesive strength $R_c$, cohesive failure area $S_c$, adhesive failure area $S_a$, and the microscopic strength parameters of the mineral aggregate contact surface at different states can be calculated using Eqs. (1) and (2). These equations include total tensile strength $R_t$, adhesive strength $R_a$, and cohesive strength $R_c$. The loading equipment is shown in Fig. 2, and the failure form of the contact surface is shown in Fig. 3.

The best advantage of this test method is that it presents a quantitative measure of adhesive, cohesive, and total strength under different conditions, such as the material (e.g. bitumen), temperature, and oil film thickness applied to a contact surface. It also facilitates the analysis of the influencing factors for microscopic strength, the quantitative determination of the reinforcing effect of many anti-stripping agents, and the establishment of a foundation for correlation studies on improving the microscopic strength of mineral aggregate contact surfaces.

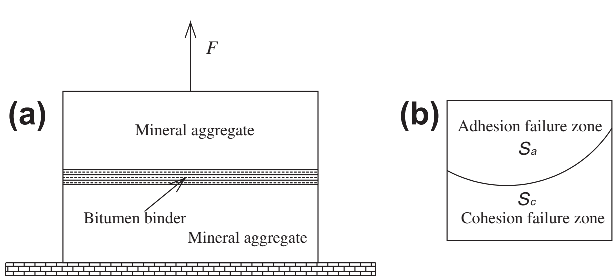


**Fig. 1.** Schematic of the tension failure test on the mineral aggregate contact surface:(a) schematic of load applied; and (b) schematic of contact surface failure.

## 3. Test material

Panjin70# bitumen and SBS-modified bitumen were selected for this study. Their technical parameters are listed in Table 1. Granite acid stone was chosen as the aggregate. The asphalt anti-stripping agents were types I and II anti-stripping agents. The type I agent is composed of higher fatty acids and organic amines, which are used to produce an amine anti-stripping agent by condensation/dehydration, the final product presents as solid sheet particles. The type II agent consists primarily of phosphorus-hydroxyl organic compounds and presents as dark liquid.

## 4. Test scheme

The rotating film aging test is applied to the thermal aging of bitumen mixed with the anti-stripping agents. This procedure stimulates the short-term aging of bitumen, as well as long-term aging when pressure aging is carried out.

The composition of the anti-stripping agent is 0.5% of bitumen. The materials were adequately mixed and modified bitumen was prepared using a shearing machine.

The aggregate contact surface had dimensions of 2.0 cm × 1.8 cm. Oil film thickness was controlled at 0.25 mm by tube titration, and the aggregate and bottom plate were fastened. Before the test, relevant technical methods were used to eliminate the influence of gravity caused by the mold.

**Fig. 2.** Loading method for the contact surface.