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**Research Article**

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# Quantitative evaluation and enhancement of adhesion between bitumen and aggregates

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**ABSTRACT**

*Stripping of asphalt-binder (bitumen) from the aggregate surface can undesirably contribute to various distresses in hot-mix asphalt (HMA) pavements such as ravelling (aggregate loss), cracking, pot-holing, etc. As a means to minimize this phenomenon, a quantitative adhesion test and evaluation method (QATE) was proposed and investigated in this study to characterize the bitumen-aggregate bond strength and adhesion properties. Concurrently, an innovative anti-stripping additive was developed in the laboratory through appropriate combination of the following chemical agents: Polyamide (PA), anti-moisture polymer (AMP), epoxy resin (EP), and dioctyl phthalate (DOP). The optimum anti-stripping mix proportions were determined and proved effective with an adherence percentage of 97.3% after 10 minutes boiling in water.*

**Key words**: Adherence rate; bitumen; aggregate; cohesiveness; quantitative evaluation; anti-stripping agent

## INTRODUCTION

The bonding between asphalt-binder (bitumen) and aggregate plays an important role in governing the performance of hot-mix asphalt (HMA) pavements. Various reports about asphalt-aggregate interaction can be found elsewhere[1-5]. Inadequate bitumen-aggregate bonding can undesirably contribute to various distresses such as ravelling, stripping, cracking, pot-holing, rutting, etc.[6-10]. Thus, appropriate test methods for characterizing the bitumen-aggregate bond strength and adhesion properties to mitigate stripping are imperative. The ASTM D 3625 laboratory test method presents a generalized level of bitumen-aggregate adhesion/bonding based on the average stripping area of five bitumen-wrapped aggregates after sustaining 3 minutes exposure to boiling water as a measure of characterizing bonding and stripping potential in HMA mixes [11]. With this test method, however, it is often difficult (even for experienced researchers and technicians) to readily and effectively differentiate between Level II and III stripping, i.e., stripping area threshold greater or lower than 30%, respectively.

In this study, an innovative laboratory test method with an extended boiling time of 3-10 minutes was investigated to quantitatively characterize the adhesion between bitumen and aggregates. Additionally, an anti-stripping additive was also developed to aid in improving the HMA's resistance to stripping propensity. Polyamide (PA) and epoxy resin (EP), being some of the commonly used chemical agents[12], were the baseline ingredients for the developed anti-stripping additive.

## EXPERIMENTAL SECTION

### 1. Materials and test methods

A performance-graded (PG) bitumen, PG76-22[13] (Asphalt Institute 1996), which was commonly involved in the asphalt pavement construction in the South of China, was used in this study. Polyamide (PA), commercial anti-moisture polymer (AMP), epoxy resin (EP), and dioctyl phthalate (DOP) were utilized as ingredients for the anti-stripping additive to improve the stripping resistance potential of the resultant mix[7]. A commonly used aggregate type in China, granite, with a nominal maximum size of 31.5 mm was used. To obtain the optimum combination of various additives, i.e., the optimum mix proportions of the anti-stripping additives, an orthogonal ($L_9$ ($3^4$)) experimental plan as shown in Tables 1 and 2 was devised and executed accordingly.

**Table 1 Levels and factors in the orthogonal experiment**

| Item | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| Factor | AMP/PA | EP/PA | DOP/PA | Dosage (%) |
| Level 1 | 1/5 | 1/2 | 1/5 | 1 |
| Level 2 | 1/4 | 1 | 1/4 | 2 |
| Level 3 | 1/3 | 3/2 | 1/3 | 3 |

**Table 2 Orthogonal experimental arrangement**

| Item | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| Factors | AMP/PA | EP/PA | DOP/PA | Dosage (%) |
| # 1 | 1/5 | 1/2 | 1/5 | 1 |
| # 2 | 1/5 | 1 | 1/4 | 2 |
| # 3 | 1/5 | 3/2 | 1/3 | 3 |
| # 4 | 1/4 | 1/2 | 1/4 | 3 |
| # 5 | 1/4 | 1 | 1/3 | 1 |
| # 6 | 1/4 | 3/2 | 1/5 | 2 |
| # 7 | 1/3 | 1/2 | 1/3 | 2 |
| # 8 | 1/3 | 1 | 1/5 | 3 |
| # 9 | 1/3 | 3/2 | 1/4 | 1 |

The granite aggregates were then processed, cut, and reshaped into roughly cubic particles of approximately 15 mm in length. The anti-stripping additive was accordingly mixed with the original bitumen using a high speed shearing machine to produce the modified bitumen. The processed granite aggregates were then covered in a thin film of the original or modified bitumen as specified in the ASTM D 3625 test procedure[11]. After cooling, the granite aggregates were subjected to heating in water at 80 °C for 3-10 minutes as designed in this study.

Pictures of the six surfaces of each cubical-shaped granite particle were taken using a normal digital camera. Contrast to the specified method analysed by two experienced technicians from the estimated stripping rates of five particles, the proposed quantitative adhesion testing and evaluation (QATE) method presents the adherence rate automatically from the software of Vision Builder. The parameters including Hue, Saturation and Intensity were kept constant as shown in Figure 1.

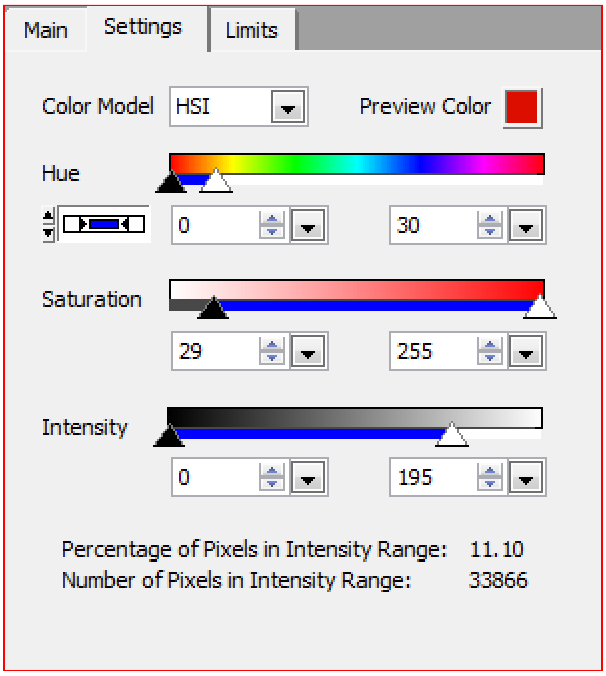


**Figure 1 Parameters specified in Vision Builder**

**Table 3 Adhesion test results for 10 minutes boiling**

| Item | Factors | Range | Level | | | Average Adherence Rate (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | Level 1 | Level 2 | Level 3 |
| A | AMP/PA | 3.723 | 1/5 | 1/4 | 1/3 | 93.357 | **95.153** | 91.43 |
| B | EP/PA | 3.66 | 1/2 | 1 | 3/2 | **95.6** | 91.94 | 92.4 |
| C | DOP/PA | 3.487 | 1/5 | 1/4 | 1/3 | 93.733 | 91.36 | **94.847** |
| D | Dosage | 0.543 | 1% | 2% | 3% | **93.65** | 93.183 | 93.107 |

## RESULTS AND DISCUSSION

The test results in Figure 2 show that there is an insignificant difference in the adherence rate among the groups boiling for 3 and 5 minutes. However, a significant difference in the adherence rate among the groups was observed when the boiling time was increased to 10 minutes. Consequently, the adherence test results for the 10 minutes boiling time were further analysed.

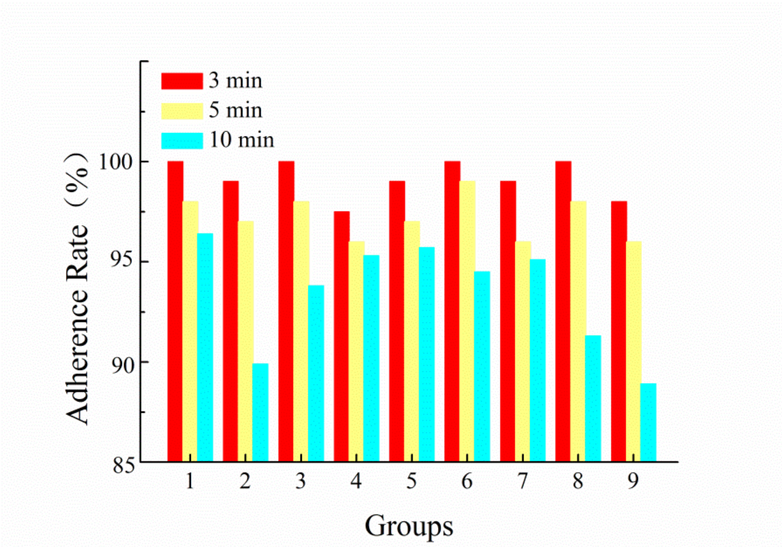


**Figure 2 Adherence rate of the nine groups of stones subjected to various boiling time**

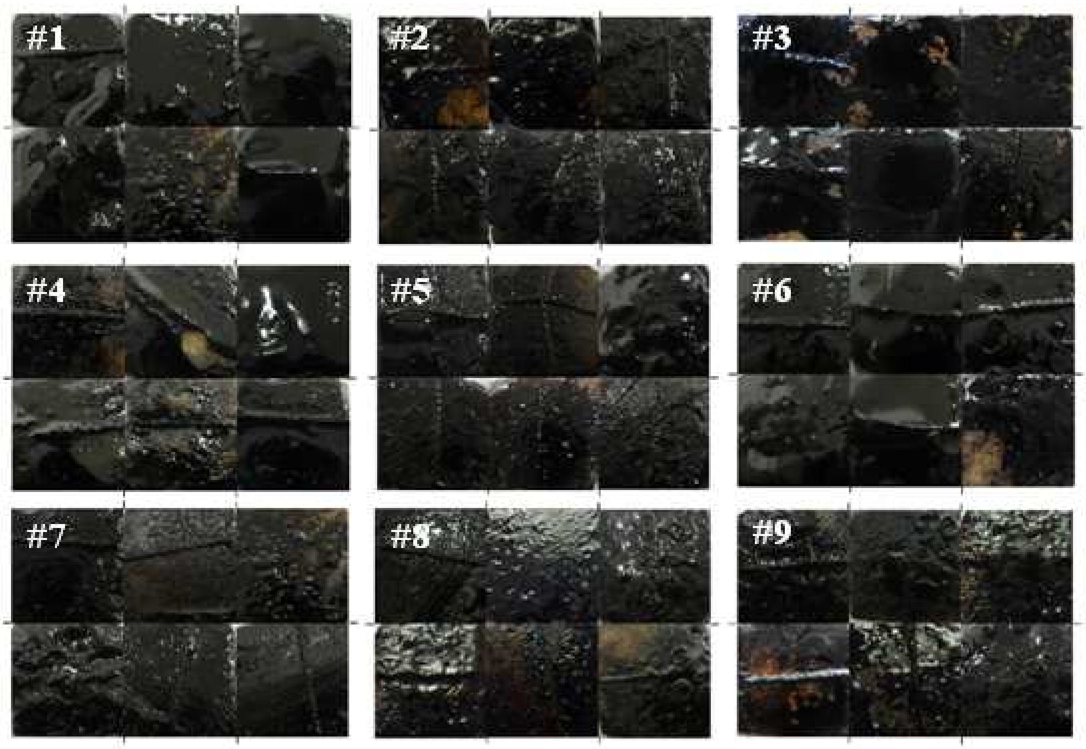


**Figure 3 Granite particles coated with a thin film of bitumen (10 minutes boiling)**

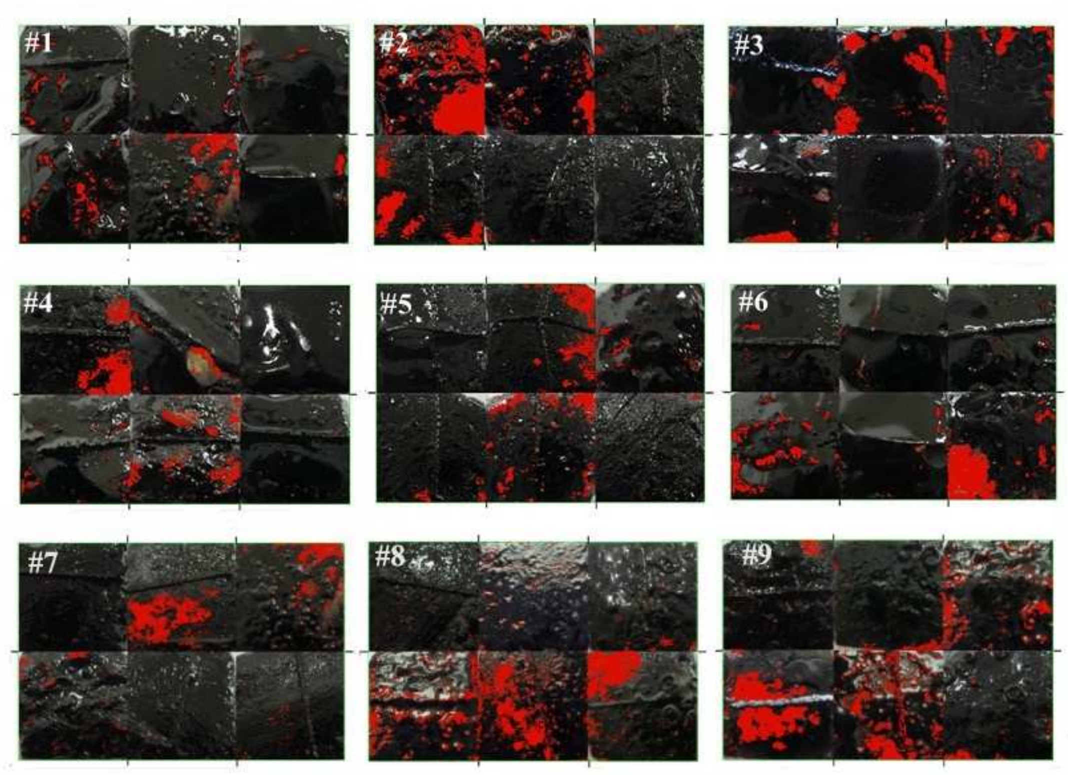


**Figure 4 Pictures processed by Vision Builder (10 minutes boiling)**

Pictures in Figure 3 show the nine groups of the stones exposed to 10 minutes boiling (note: each group contains six surfaces of the stone). All the pictures were analysed by Vision Builder, respectively. The stripping area was identified by red colour (Figure 4).

The adherence rate after 10 minutes boiling is illustrated in Figure 5. Group #1 demonstrates the highest adherence rate while group #2, group #8 and group #9 shows relatively low adherence rate. The intuitive analysis of the orthogonal results was listed in Table 3.

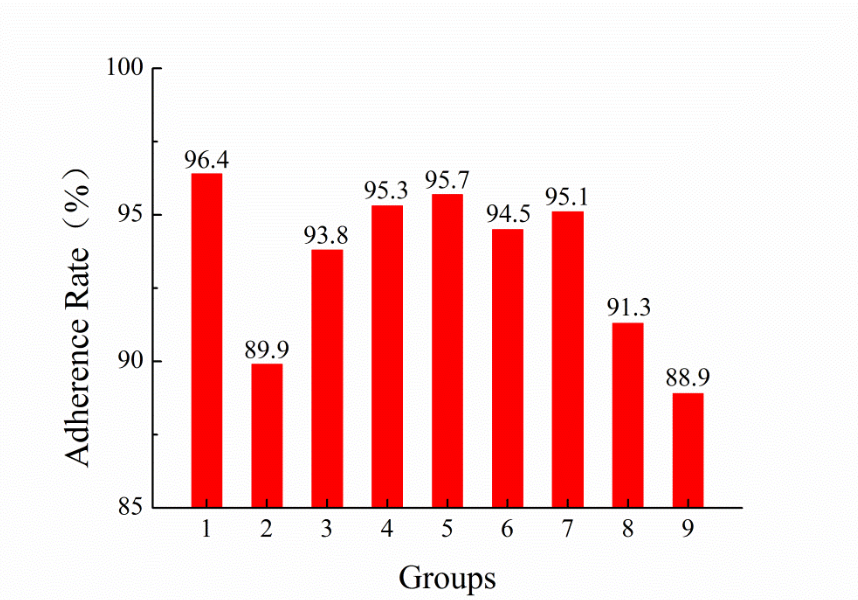


**Figure 5 Adherence rate of granite exposed to 10 minutes boiling**

From the result shown in Table 3, the critical factors influencing the material anti-stripping resistance in their rank order of significance are AMP/PA, EP/PA, DOP/PA and dosage. The optimum mix combination of the ingredients for the anti-stripping additive can then be $A_2B_1C_3D_1$, namely, AMP: EP: DOP: PA = 1/4:1/2:1/3:1, whereas the optimum dosage of the additive is 1%. As evident in the Table 3, higher dosage of the anti-stripping additive did not significantly influence the adherence coverage; however, such high dosages have the potential to raise the mix temperature susceptibility and the experiment costs. Thus, for practical purposes, the optimum dosage of the anti-stripping additive was recommended as 1% and added in the subsequent tests.

To check the effect of the anti-stripping additive on the bitumen-aggregate bonding (i.e., PG 76-22 plus granite), adhesion tests were carried out without (Figure 6a) and with the additive (Figure 6b). After 10 minutes of boiling in water, the photos taken indicated favourable anti-stripping improvement as illustrated in Figure 6. The bitumen film (PG 76-22) was almost entirely striped off from the granite aggregate surfaces while the average adherence percentage of the granite surfaces with the anti-stripping additive was maintained at 97.3%.

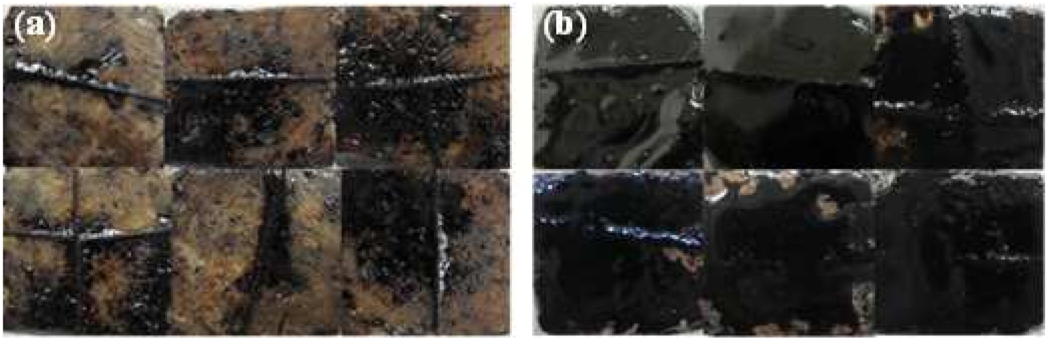


**Figure 6 After 10 minutes boiling - (a) without and (b) with anti-stripping additive**

Due to the potential evaporation of the constituent compounds such as the fatty amine groups during construction and in-service, durability and temperature stability are pertinent issues associated with most commercial anti-stripping additives[14,15]. To assess the temperature stability of the anti-stripping agent developed in this study, adherence rate was measured using the same aforementioned methods after rolling thin-film oven (RTFO) aging[16]. The results in Figure 7 shows that the adherence coverage was higher than 90% even after 10 minutes of boiling; indicating favourable heat and water resistance of the developed anti-stripped agent.

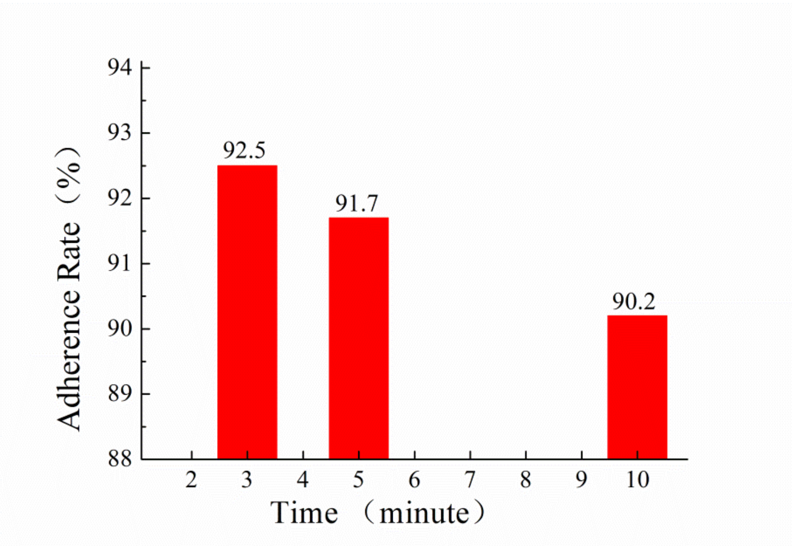


**Figure 7 Adherence rate after RTFO aging**

## CONCLUSION

As a supplement to the traditional ASTM D 3625 method for adhesion evaluation of bitumen and aggregate, an innovative adhesion test method, with an extended 10 minutes boiling time at 80 °C, was proposed and proved efficient in quantitatively evaluating the anti-stripping effect. In addition, an innovative anti-stripping agent was developed combining four ingredients of PA, AMP, EP and DOP. The adherence percentage test results indicated a significant improvement in the stripping resistance of the HMA by blending with 1% of the developed anti-stripping agent. Temperature stability was also satisfactory; with higher than 90% adhesion coverage after 10 minutes boiling time.

**Acknowledgement and Disclaimer**

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