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Investigation of the relationship between fluidity and adhesion strength of unmodified and modified bitumens using the pull-off test method

Hend Ali Omar [a], Nur Izzi Md. Yusoff [a,*], Halil Ceylan [b], Zainuddin Sajuri [c], Fauzan Mohd Jakarni [d], Amiruddin Ismail [a]

[a] Dept. of Civil and Structural Engineering, Universiti Kebangsaan Malaysia, Malaysia
[b] Dept. of Civil, Construction and Environmental Engineering, Iowa State University, USA
[c] Dept. of Mechanical and Materials Engineering, Universiti Kebangsaan Malaysia, Malaysia
[d] Dept. of Civil Engineering, Universiti Putra Malaysia, Malaysia

HIGHLIGHTS

- The pull-off test was used to evaluate fluidity and adhesion strength of binders.
- Cement, hydrated lime and nano-clay were added to bitumen at 2 and 4%.
- The presence of additives altered the adhesion strength of the binders.
- The steel substrate shows better results compared to the granite substrate.

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ABSTRACT

This study was conducted to investigate the relationship between fluidity and adhesion strength of unmodified and modified bitumens through the use of the consistency and pull-off tests. A universal testing machine (UTM) was used to quantify the adhesion strength of unmodified and modified bitumens where a specially designed mold was fabricated using stainless steel and granite as substrates. Powder cement, hydrated lime and nano-clay were added to bitumen in two different percentages, namely 2 and 4% by the weight of bitumen. The X-ray diffraction (XRD) was used to determine the effects of the additives on the structure of the binders. On the other hand, the scanning electron microscope (SEM) was used to gather surface topography information of the additives scattered within the binder bulk. It was found that the values for adhesion strength varied depending on the types and percentages of additive used, as well as the substrates and their thickness. The use of stainless steel substrate produced a good correlation between adhesion strength and the results of consistency test, although the results for viscosity test showed a weaker correlation in identifying the changes in adhesion strength that was caused by the addition of additives. It can be deduced that the pull-off test can be a useful tool to determine the effects of additives on fluidity and adhesion strength when stainless steel substrate was used.

1. Introduction

The adhesion strength (also known as adhesion force or tensile strength) of a material is its ability to withstand an applied load (shear or tension) stress without failure. The adhesion strength of a bitumen-aggregate system reflects the strength of the asphalt mixture where the binder is responsible for providing adhesion between aggregate particles in a mixture. This property is very important because it extends service life of pavement in terms of resistance towards various types of distress. The adhesion strength of bitumen has been evaluated since before 1932 [1]. Since then, many attempts have been made to investigate the adhesion strength of binders and aggregate types and various methods have been proposed to study this property [2,3]. However, the proposed methods depend on focused material properties such as fracture parameters, surface energy and diffusion coefficient [3]. For example, the adhesion strength of bitumens can be evaluated through the use of pull-off, tensile or adhesion apparatus/machine.

Among them, the pull-off test is a commonly conducted test to evaluate the adhesion strength of unmodified and modified

* Corresponding author.
E-mail addresses: alihend72@yahoo.com (H. Ali Omar), izzi@ukm.edu.my (N.I. Md. Yusoff), hceylan@iastate.edu (H. Ceylan), sajuri@eng.ukm.my (Z. Sajuri), fauzan@eng.upm.edu.my (F.M. Jakarni), aismail@ukm.edu.my (A. Ismail).

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bitumens. The Pneumatic Adhesion Tensile Testing Instrument (PATTI) is one of the most widely used devices [4], and it was firstly used by Youtcheff and Aurilio [5] to evaluate the adhesion strength of bitumen. The universal test machine (UTM) has been used to investigate the tensile properties of bitumen since 1963 [6,7]. Since the realization of the benefits of evaluating the adhesion strength of bitumen, many studies have been conducted with several combined variables, such as type of bitumen and aggregate, varying temperature and effect of water. The UTM machine has been effectively used to evaluate adhesion strength under various conditions [2,6,8]. However, in this method, some parameters have to be controlled, such as thickness of bitumen film, temperature and rate of deformation, as the test results are sensitive towards these parameters. In addition, adhesion strength varies with the bitumen and aggregate type. The chemical and physical properties of bitumen and aggregate have been shown to play an important role in the adhesion system [2,3,8].

The performance of pavement materials must be improved to minimize the effects of the environment and the increase in traffic load, which lead to various types of problems that shorten the service life of pavements. One way to improve pavement performance is through the modification of binders and/or aggregates [9]. Various additives such as polymer, rubber, cement and recently, nanomaterials thus far have shown good results in delaying some of the problems on pavements [10–12]. The presence of those additives changes the fluidity of bitumen [13]. Consistency tests such as the penetration and softening point tests are usually used to evaluate the effect of additives on bitumen properties. These tests have been proven to be effective in evaluating the effect of additives on bitumen properties [13]. In addition to these commonly used tests, it is also possible to use another test such as the pull-off test, to assess the effect of adding additives to bitumen. Some studies have found good correlation between viscosity and the pull-off strength of bitumen [6,14,15]. A similar result was obtained for the softening point test where it correlates well with the adhesion strength of bitumen [15,16]. The correlation between pull-off test and consistency test highlights the ability of the pull-off test to evaluate very thin bitumen film.

Most earlier studies confirmed that adhesion strength of bitumen increases with the increase of viscosity [6,17]. In the effort to investigate this fact, cement, hydrated lime and nano-clay were added to binders and their effects were investigated using the consistency tests and pull-off test. It is a known fact that hydrated lime and cement are used as filler, but the main reason for using these powder materials in this study was to change the viscosity of the binder and subsequently, evaluate the change in viscosity through the consistency and pull-off tests. The first hypothesis is that the addition of additives would alter the fluidity and adhesion strength of a binder. The second hypothesis is that there exist a relationship between the consistency properties and the adhesion strength of bitumen. Therefore, the first objective of this study is to explore the effect of additives on consistency properties and adhesion strength of both unmodified and modified bitumens. The second objective is to observe if there exist any correlations between the results of consistency test and adhesion strength. The correlation between consistency tests and pull-off tests highlights the capability of this method to evaluate the fluidity of bitumen. Finally, the effect of water on adhesion strength of the unmodified and modified bitumens was investigated. The flow chart in Fig. 1 shows the sequence of this study.

2. Experimental design

2.1. Materials and sample preparation

This study used a 60/70 penetration grade bitumen as the control sample. The physical properties of the control sample were determined through the penetration, softening point and viscosity tests. Details of their physical properties are given in Table 1. The additives namely cement, hydrated lime, and nano-clay were added to the 60/70 penetration grade bitumen. All materials were supplied by the Cenco Sains Company in Malaysia. All modified samples were prepared by adding 2 and 4% additives by the weight of bitumen. The preparation procedure was based on the results of a previous investigation which showed that variation in the mixing process has different effects on the properties of modified binder [15]. The bitumen

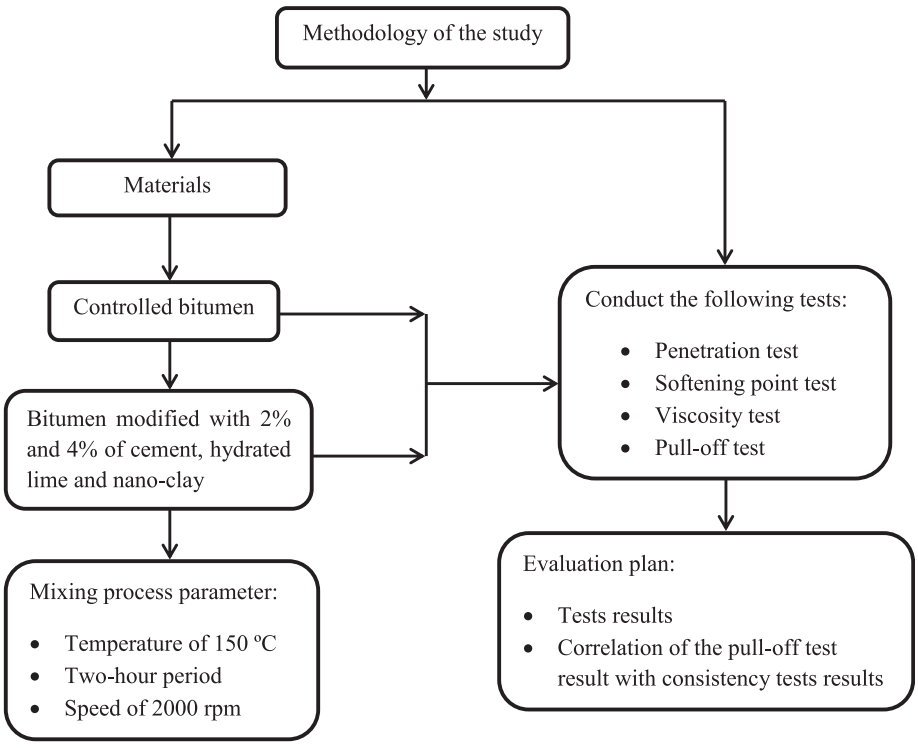

Fig. 1. Flow chart of the experiment.