

# Compilation of Pavement Interface Bond Strength Devices for Bond Strength Quantification

Fung-Lung Chang, Haryati Yaacob\*, Mohd. Rosli Hainin, Ahmad Safuan A. Rashid

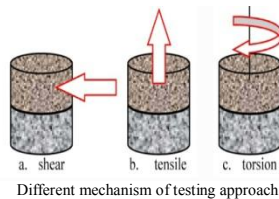
Faculty of Civil Engineering and Construction Research Alliance, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Malaysia

\*Corresponding author: haryatiyaacob@utm.my

## Article history

Received :5 June 2014  
Received in revised form :  
25 September 2014  
Accepted : 16 October 2014

## Graphical abstract



## Abstract

Flexible pavement is a multilayered structure constructed in layers. In order to ensure proper bonding such that a pavement behaved monolithically, tack coat is often applied. The developed pavement interface bond strength is therefore paramount in governing the overall performance of pavement serviceability. The present work reviews the current state of pavement interface bond strength quantification mechanisms, and the devices developed based on the mechanism. Related accessible literatures are collected and analyzed to compile the characteristics of each bond testing devices and evaluated for the capabilities and test performance. The investigation reveals 3 testing mechanisms incorporating shearing (pushing), tensile (pulling) and torsioning (twisting). However, shearing test seems to be the most popular device adopted to investigate the bond strength between two interfaces in contact, utterly due to the simplicity of the test setup. For tensile mechanism, the developed devices are generally portable and are mostly used to examine the tack coat quality. Finally, the device with torsional mechanism is not so popular as compared to the aforementioned mechanism. Nonetheless, it is developing steadily with the continuous research.

**Keywords:** bond strength, direct shear test, double-layered interface, pull-off test, torsional strength test

© 2014 Penerbit UTM Press. All rights reserved.

## 1.0 INTRODUCTION

Flexible pavement is a pavement structure consists of different layers of road materials. Being a layered structure, the bond between these pavement layers is of significant importance in enhancing the pavement performance and its service life. A pavement which behaved monolithically will be able to transfer traffic and environmental stress effectively from the contact surface to the base layer. Computer analysis using ALIZE program conducted by Roffe and Chaignon [1] concluded that pavement life was significantly reduced from 20 years to 7 or 8 years if the bonding capacity is insufficient. Over the years, pavement distress as a result of insufficient bond strength has been reported [2, 3]. Studies on interface bond characteristics are therefore getting more attention among the researchers [4-8].

In order to improve the bonding between the pavement layers, a thin layer of asphalt material normally refer to as tack coat is applied. The importance of applying tack coat has proved to increase the bonding performance between two interfaces. This is agreed by different researchers [9-13]. Besides, several specifications and guidelines also outlined the proper application of tack coat and the range of tack coat application rate in which the contractors are required to put them into implementation [14-20]. However, as the interface bond strength is a complex function of different factors like temperature, mixture types, tack coat types and application rates, just to name a few, the bonding

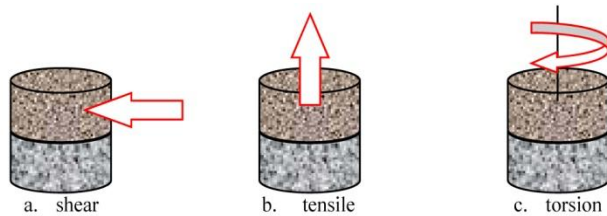
of a pavement interface remains a doubt although tack coat have been applied.

Due to that, different device is developed in the effort to quantify pavement interface bond strength. Most of the devices currently available performed the test in a destructive manner although there existed also devices to perform non-destructive testing. This paper however, focused on the destructive testing device only as these devices are much more developed and popular. The destructive test devices currently available adopted the mechanism of shearing (pushing), tensile (pulling) and torsioning (twisting) to perform the testing. All of the test mechanisms are graphically presented in Figure 1. Some of these devices, regardless of the testing mechanisms are able to perform the testing on double-layered asphalt specimen as well as to investigate the quality of tack coat used in construction. Most of the shearing devices performed the mechanical testing with double-layered specimen while the tensile pull-off devices performed the testing on the tack coats applied to determine the quality of the materials. The subsequent section will discuss in detailed on some of the devices used to quantify the bonding strength between pavement interfaces.

## 2.0 BOND STRENGTH DEVICE

There exists different mechanism of testing to quantify the degree

of adhesion between the pavement interfaces. These include direct shearing test (pushing), direct tensile test (pulling) and torque test (twisting). All the testing methods provide the information on the bonding of the pavement interface.



**Figure 1** Different mechanism of testing approach applied in various bond strength devices.

## 2.1 Direct Shear Test

Direct shear test can be considered as the most popular types of interface bond strength mechanism. The overall concept of the test is similar to that being used extensively in the research of soil mechanics. By adopting this testing mechanism, a shearing force will be applied parallel to the interface of a double layered specimen until separation occurs between the two layers. This test maybe performed under different testing configuration depending on the device capabilities and the research needs. The following subsection compiled several direct shear test devices available globally that is being used by different researchers in their effort to quantify pavement interface bond strength.

### 2.1.1 Leutner Shear Test

Leutner shear test can be regarded as the earliest types of shear device designed by Leutner to investigate the pavement interlayer bond strength [21 after 22]. It was firstly developed in Germany and had already contributed significantly in the development of modern shearing devices. The operation of this device is similar to that of a Marshall flow and stability test device as described in ASTM D6927 [23]. A constant displacement rate of 50mm/min, in this case the shear displacement rate is applied to a double layered specimen where the interface bond strength is to be determined until the specimen eventually failed. The maximum shear strength was recorded and the shear stress is calculated by dividing the peak shear strength with the cross sectional area of the specimen. It is to be noted that the cross sectional area varies since the device is capable to investigate the bond strength for double layered specimen of 100mm and 150mm diameter, depending on the needs of the research. From this device, a graphical representation of shear loading and displacement can be plot. The Leutner shear test device is presented in Figure 2a.

### 2.1.2 Layer Parallel Direct Shear Tester

Layer Parallel Direct Shear (LPDS) Tester as shown in Figure 2b is a modified version of Leutner shear test device developed by the Swiss Federal Laboratories for Materials Science and Technology (EMPA) [24-26]. This particular device is very similar to the Leutner shear test devices, but still several differences can be identified. Besides measuring pavement interface bond strength, this device also measured the in-layer shear properties to define the quality of a particular mixture [27].

The LPDS tester consists of major components like pneumatic clamp, U-bearing and a yoke. The pneumatic clamp holds the bottom part of the double layered specimen that rest on the U-bearing up to the interface in contact, leaving the top part

suspended. The pneumatic clamp induced certain amount of pressure to hold the specimen firmly. The shearing process is done by the yoke of the device at a displacement rate of 50mm/min with a gap width of 2mm between the shearing platens until the specimen eventually fail. This device performed the shearing test for specimens with diameter of 150mm. The LPDS tester has been incorporated into the Swiss Standard SN 671961 at year 2000 and it is a provision for a double-layered specimen to be cured for 8 hours and tested at 20°C in order to comply with this standard [28 after 26].

### 2.1.3 FDOT Shear Tester

Florida Department of Transportation (FDOT) shear tester or better known as FDOT shear tester is another device which is in used to determine the bond strength of a pavement interface with the shearing mechanism. This device was developed in 2003 following the request of the FDOT engineers to investigate the performance of bond strength for paving works done on wetted tack coat due to the rain water. Several attempts were made by Sholar *et al.* [29] in order to produce the best shear tester which fulfilled the needs. In lieu of the initial shearing device produced which is the modified version of shear tester to measure the bond strength between bonded concrete [30], modification was done to produce the final version of shear tester. The reason in which further modification was needed is that the existing shear tester provides less flexibility apart from being cumbersome to work with.

The final version of FDOT shear tester is as shown in Figure 2c. It fits specimen of 152.4mm only where the gap of the shearing platen accommodating the double layered specimen was set to be 4.8mm. The loading mode was strain controlled instead of stress controlled, with a rate of 50.8mm/min. The testing is done at temperature of 25°C. All these features were selected after careful investigation on each of the parameters before the final decision was made. This device was always referred to whenever there raised concern over the level of bond in between two interfaces of a pavement due to effect of rain water.

### 2.1.4 LISST Device

Louisiana Interlayer Shear Strength Tester (LISST) is developed at Louisiana Transportation Research Centre to characterize the pavement interface properties [31]. It also contributed as a part of National Highway Research Program Project (NCHRP) 9-40. It is a custom fabricated mould inclusive of two shearing platens (in which one of it is stationary reaction frame and another one is the mobile shearing frame) with a gap width of 12.7mm in between.

Normal load can also be applied in addition of the shear stress by the normal load actuator attached to the mould. The mould fits 100mm and 150 mm diameter of double-layered specimen. To operate the shear test, the mould needs to attach to a Material Testing System (MTS) for the loading to initiates. Where the effect of temperature on the interface bond strength is needed, the temperature chamber of the MTS can be utilized to provide such feature. Under the NCHRP 9-40, Mohammad *et al.* [27] had also proposed a standard test method of determining the interlayer shear strength of asphalt pavement layers with the aid of LISST device. This drafted standard aims to submit to the American Association of State Highway and Transportation Officials (AASHTO). In this standard, it is specified that a double-layered specimen should be cured for 2 hours at the desired test temperature (4.4°C, 25.0°C and 60°C as per the specification) prior to testing at the constant displacement rate of 2.54mm/min. If normal load is required, a normal pressure up to 206.84kPa

should be applied on a 150mm diameter specimen. The illustration of LISST device is as in Figure 2d.

### 2.1.5 NCAT Bond Strength Device

National Centre for Asphalt Technology (NCAT) bond strength device also applies the shearing mechanism to determine the bond strength within pavement interfaces. Likewise, this device is attached to a universal testing machine or a Marshall press for the loading of specimens, just like how the specimens were loaded when dealing with FDOT shear tester.

The latest improvement made over the existing NCAT bond strength device is the capability of the device to apply confinement pressure to the double-layered specimen as presented in Figure 2e [32]. Previously, such feature was not available and the device is similar to the other devices described earlier. The NCAT bond strength device tested specimens of 150mm in diameter with the shearing rate of 50.8mm/min. In between the shearing platens, a gap width of  $6.35\text{mm} \pm 0.8\text{mm}$  should be provided. A 453.6kg (1000lb) load cell was attached to the body of the device to measure the amount of confinement force needed, which later may be converted into confinement pressure taking into consideration the surface area in contact. Since 2008, the Alabama Department of Transportation (ALDOT) had adopted this device to determine the bond strength between layers of an asphalt pavement as specified in ALDOT Procedures ALDOT-430 [33].

### 2.1.6 Ancona Shear Testing Research and Analysis (ASTRA)

The Ancona Shear Testing Research and Analysis (ASTRA) device is designed by a group of researchers analysing the slippage characteristics at the asphalt pavement interfaces and investigating the shear behavior of an emulsified asphalt [34]. ASTRA was developed in the Università Politecnica delle Marche in Italy. It is a direct shear box type of device, complying with the Italian Standard UNI/TS 11214, which can be normally encountered especially in the study of soil mechanics [35].

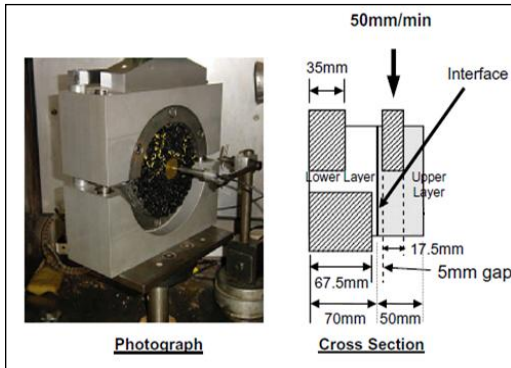
Like NCAT bond strength device, the special feature possess by ASTRA is the capability to provide the double-layered specimen to be tested with normal stress apart from the shear stress. But, the normal stress is applied with a lever and weight system, which is like applying dead load to the specimen. ASTRA accommodates cylindrical specimen whereby the diameter of the specimen varies from 94mm to 100mm and also prismatic specimen with maximum cross sectional area of  $100 \times 100\text{mm}^2$ . The rate of shearing for ASTRA ranges from 0.0008mm/min to 9.5mm/min. This indicates that the rate of the shearing may be adjusted accordingly to the researchers' and the research needs.

Likewise, the double layered specimen was fixed in the shear box frame for the shearing to initiates. In between the shear frame there is a small gap in which the gap width is not mentioned from the publication. Another special feature of this device is the presence of the climatic chamber to carry out the shear test. This enabled the effect of temperature on the pavement interface bonding to be studied in a more systematic manner since the concern over heat loss during testing is solved. The output of the device which shown in Figure 2f is the data file with shear load and horizontal and vertical displacement in related with time.

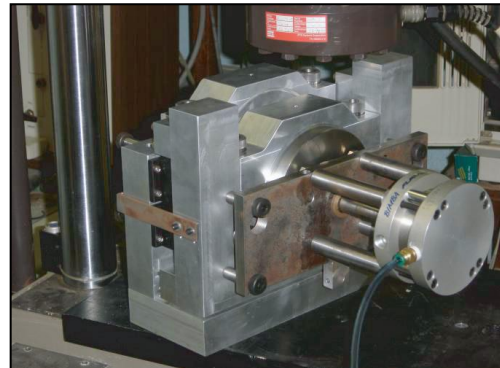
### 2.1.7 Discussion

The popularity of direct shear test used to investigate the shearing resistance between two interfaces should not be questioned further

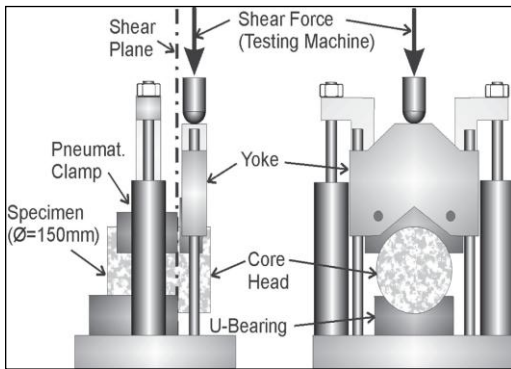
when this testing mechanism is used in pavement engineering. The best supporting fact is the presence of a variety of shear device currently available worldwide as discussed in the previous section. In fact, there are still numerous pavement interface shear tester existed. However, only selected shear tester which provides sufficient information from the accessible literature are discussed herein. The major advantage of the device performing shearing mechanism is the simplicity feature of the overall system, especially in fitting the double-layered specimen to the clamp or the shearing platens. From the discussed shear testing devices, there are some similarities which can be observed. Most of the devices accept specimen with 150mm diameter. Also, the rate of shearing is strain controlled, whereby most devices experienced shearing rate up to 50mm/min. The reasons for these parameters are well discussed in [29]. According to them, larger specimen diameter of 150mm compared to 100mm produced less variable results, especially for mixture containing large nominal maximum aggregates size. As for the loading rate, most devices favor 50mm/min as this rate is very common in asphalt testing. Also, higher rate of shearing will returns in higher failure stress compared to lower rate of shearing, which later ease the discernment of good and poor bonding. In between the two shearing platens also, certain amount of gap width is provided. This applicable to all shear test device herein except Leutner shear test device. The importance of gap width in governing the interface bond strength is discovered by Collop et al. due to the large variability observed from the testing results [22]. Modification was hence done to Leutner shear test device by introducing a gap width of 5mm, aiming to compensate the skewed interface between double-layered specimens and to minimize crushing of the aggregates at the edge of the specimen. This later raised the interest among other researchers to investigate further on the effect of gap width between shearing platens where several other conclusions were made [36]. Despite similarities, differences may also be observed. The most obvious being the capabilities of LISST, NCAT bond strength device and ASTRA device to provide with the testing specimen with confinement pressure. Such function would better reflect the real pavement condition which generally exposed to the shear stress and normal stress at the same time. Confinement pressure of ASTRA device is provided using dead load through the lever and weight system but not LISST and NCAT bond strength device. Such system maintained the magnitude of the normal stress exerted following the possibilities of normal stress increment due to specimen tilting upon subjected to shearing process. The absence of normal stress hinders the investigation of frictional properties and aggregate interlocking between two pavement interfaces, which is generally agreed as important properties that contributed to the bonding characteristics apart from the applied tack coat. Such statement agrees to the findings of different researchers who conducted their research using a device capable to provide confinement pressure [12, 32, 39]. Another specialty provided by the ASTRA device is the presence of temperature chamber. The presence of the chamber will certainly be beneficial in the investigation of temperature-shear strength relationship of two interfaces. Such feature maintained the test temperature throughout the testing and minimizing heat loss, especially for low shearing rate device like LISST and ASTRA. Finally, if the research using ASTRA device is extended to be carried out at different vertical stress, a Mohr Coulomb failure envelope could be obtained. This will help further to understand the relationships between stress and frictional characteristics to predict the interface behavior [39].



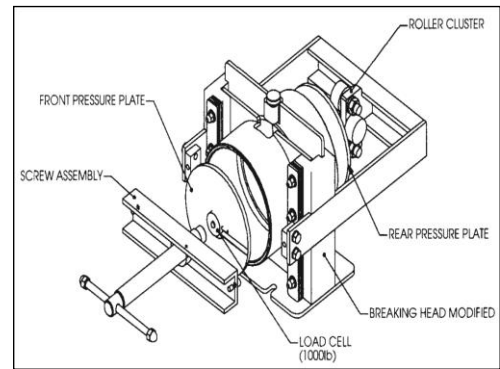
2a. Leutner shear device [37].



2d. LISST device [38].



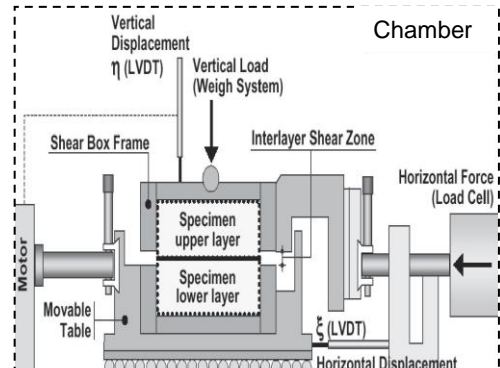
2b. LPDS test device [26].



2e. NCAT shear device [32].



2c. FDOT shear tester [29].



2f. ASTRA device [39].

Figure 2 Various types of interface bond strength device adopting the shearing mechanism.

2.2 Tensile Strength Test

Besides shearing, tensile strength test which adopting the pulling mechanism is another common testing adopted to quantify pavement interface bond strength. In a simpler explanation, tensile test, or sometimes known as pull-off test is a pulling test whereby a pulling force is applied to pull apart a double-layered specimen until the specimen is separated into two pieces (i.e. the specimen failed in tension). In addition to that, this pulling mechanism was also applied to evaluate the material properties of a tack coat material. Existing literature reveals that there are several pull-off devices that are currently being used to investigate the degree of adhesion between pavement layers as well as the quality of tack coat. However, some of these devices have limited information from the accessible literature. The following section

presents some of the tensile strength test device which performs the pull-off test.

2.2.1 Japan Pull-Off Test And KDOT Pull-Off Test Device

Due to the high level of similarities, these two devices were grouped and discussed in this section. Investigation on airport pavement bond strength with the aid of the Japan Pull-off test device had been conducted by Hachiya and Sato [40]. However, no illustration of the test device is provided. It was their effort to overcome poor bond between airport pavement following the report of surface course breaking at the location where the aircrafts decelerates or turns. However, there is no schematic diagram presented and therefore very limited information on the pull-off test device that can be extracted from their publication. Only the dimension of the prismatic double-layered specimen,

which is 50mm width, 100mm long (50mm for each layer) and 50mm height as well as the pulling rate of 1mm/min and 100mm.min is being mentioned.

Rahman *et al.* investigated the effect of tack coat application rate for 4.75mm nominal maximum aggregate size superpave overlay mix on two rehabilitation project in Kansas, United States of America [41]. Pull-off test was conducted for cored double-layered specimen with the Kansas Department of Transportation (KDOT) pull-off device as shown in Figure 3a. This device has partially adopted the procedure as stated in ASTM D4541 [42] during the operation of specimen pulling. The rate for which the pulling strain is applied is set at 25mm/min. Coring specimens of approximately 50mm diameter was used in this test.

### 2.2.2 Switzerland Pull-Off Test Device

As early as 1999, the pull-off test device has been used by the Swiss Federal Laboratories for Materials Testing and Research (EMPA) in-situ in their effort to obtain the tensile bond strength between an asphalt surfacing and a concrete layer underneath [43] after [8]. Later in 2004, the pull-off test used complies with the German testing specification ZTV-SIB 90 was used to evaluate the interlayer shear performance of a pavement [44]. The device consists of a 100mm diameter disc which is glued to the upper layer of the specimen while the bottom layer is fixed to a concrete plate. A tensile rate of 100N/s is then applied gradually until the specimen fail. The device is presented in Figure 3b.

### 2.2.3 UTEP Pull-Off Test

The device is developed at University of Texas at El Paso (UTEP) thus it is known as the UTEP Pull-off test [45]. The device is as illustrated in Figure 3c. The development of this device aims to inspect and quantify the bonding characteristics of the tack coat material applied on site since the existing method used to determine the quality of a particular tack coat is very subjective. Thus, this device is used to measure the quality of the tack coat applied on a pavement but not to focus on the double layered specimen. The measured tensile strength of a tack material reflects the suitability of the particular material to be applied as tack coat in construction.

The testing begins by placing the UTEP pull-off device on the tacked surface with the contact plate is in contact with the tack coat material after the applied tack coat has set. A dead load of 18.1kg (40lb) is applied for 10 minutes as confinement to ensure that the contact plate is firmly contact to the tacked surface. The dead load is removed once 10 minutes approaches and the contact plate is detached by the mean of pulling as a result of torque applying to the device. The maximum torque required to detach the contact plate is later convert to tensile strength using the calibration factor. An acceptance criterion for tack coat applied on field was later proposed from the laboratory and field test conducted with this device [46].

### 2.2.4 LTCQT Device

Louisiana Tack Coat Quality Tester (LTCQT) device, which is graphically presented in Figure 3d is a tack coat quality testing using the pulling-off mechanism. It is developed under the collaboration of Louisiana Transportation Research Centre and Instrotek Inc. for the NCHRP 9-40. The final LTCQT device is after several modifications made on the first and second generation of the device itself [27, 47]. A software named LTCQT Tack Coat Measurement System is also incorporated to this device which ease the data management.

To examine qualitatively on the tack coat materials using this device, several parameters are needed to be fulfilled. The loading rate is fixed at 0.2mm/s until maximum tensile load is achieved. Also, the contact plate of the device should be kept in contact with the tack surface for 3 minutes, with a contact pressure of 10.8kPa. In the case that the tack coat used is in the emulsified form, curing time of 1 hour should be provided with the aid of the infrared reflective heating (IRH) lamp. The IRH lamp provide uniform heat distribution which speed up the water evaporation process. A standard method of test to determine the quality of tack coat on site or in laboratory was also proposed to AASHTO as published in NCHRP 7-12 [27].

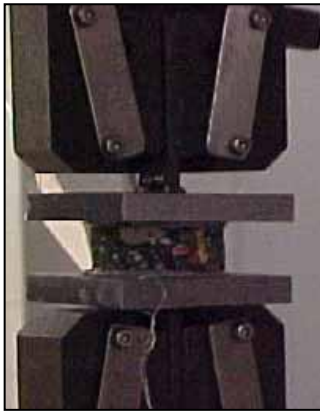
### 2.2.5 Discussion

The pull-off test is the popular types of test to determine the tensile bond for two interfaces in contact. Such statement is made taking into consideration that the pull-off test not only applicable in flexible pavement of multiple layers structures, but also being used in concrete structures interfaces as well as rigid pavement [48]. The pull-off test for concrete pavement has been specified in the British Standard BS EN 13863-2 [49]. In the construction of concrete block pavement also, the pull-off test is conducted to determine the shear strength between the block interfaces [50].

Even more interesting, there also exists a standard specification on the measurement of pull-off strength between two flat interfaces as specified in ASTM D4541 [42]. Also specified in Austria is the Austrian pull-off test that was strictly enforced in enforced in Austrian Standard in which the minimum tensile strength of the double-layered specimen need to be fulfilled [51]. The tensile strength tested must be greater than 1.5N/mm<sup>2</sup> when using modified binders and 1.0N/mm<sup>2</sup> with the application of unmodified binders.

A major advantage of the pull-off test device is the mobility of the device itself to be applied in-situ or in the laboratory. The working mechanism of the test regardless of on site or laboratory remains the same. As mentioned by Tschegg *et al.* [52], partial coring of pavement up to a certain depth just after the interface should be performed prior to the installing of the pull-off device. The contact plate of the device is later glued to the surface of the coring using epoxy, hence the pull-off commenced until maximum tensile stress is achieved and recorded.

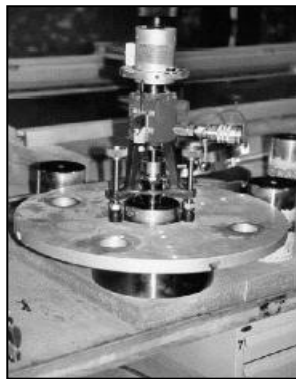
However, there are numeral drawbacks which cannot be ignored. The pull-off test responds in a wide scattering plot of results, which is believed to be the effect of eccentricity of pulling load from the plunger as discussed by Tschegg *et al.* [52]. Such statement is further supported by Canestrari *et al.* [53] who mentioned that the eccentricity is the result of possibly inclined piston head. At the same time, for testing the double-layered asphalt specimen, the process is time consuming especially for the application of epoxy. This is important to ensure that the steel plate and the specimen are properly bonded since there is tendency for the failure to occur at the steel plate-asphalt specimen interface rather than the double-layered asphalt specimen interface itself. Even if the degree of adhesiveness at both interfaces is good enough, another concern when conducting the pull-off test is the failure in tensile of the inlayer material within a single layer of specimen. Such failure might be more pronounce in the presence of higher testing temperature. To counter these problems, it is suggested that a clamping system is used instead of the existing steel plate adhering method. Proper clamping just at the interfaces will definitely produce the intended failure mode. Finally, the mechanism of pulling



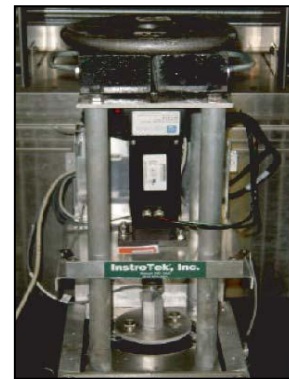
3a. KDOT pull-off device [41].



3c. UTEP pull-off test device [45].



3b. Switzerland pull-off test device [44].



3d. Louisiana Tack Coat Quality Tester (LTCQT) device [47].

**Figure 3** Various types of interface bond strength device performing the testing with the tensile pull-off mechanism.

off prohibits the application of confinement pressure. This eventually results in the impossibility to investigate on the friction properties provided by the interlocking of the aggregates between the specimen interfaces.

### 2.3 Torsional Strength Test

Torsional mechanism is another mechanism used to evaluate the adhesion of two interfaces apart from shearing and tensioning. It might not be as popular as the other two mechanisms described earlier, but still there existed devices which are able to perform the torsional mechanism to quantify two interfaces in contact. Torsion is an act of twisting, which involved fixing one end or both ends of an object then to perform the twisting in an opposite directions. Similar to tensile mechanism, the torsional strength test can be used to determine the bond strength of a flexible pavement layers as well as the quality of tack coat. The subsequent section will discussed some of the devices that adopted the torsional mechanism during the interface testing.

#### 2.3.1 Torque Bond Test

The torque bond test was originally developed in Sweden for the in-situ assessment of bond conditions and has been adopted in the UK as-part-of the approval system for thin surfacing systems [54 after 55]. This particular device can perform the torque test either for field specimens or specimens fabricated in the laboratory. The specimens can be 100mm in diameter or 150mm in diameter depending on the core.

The test is conducted by conglutinating the surface of the core to the metal plate of the device. For testing in-situ, partial coring up to at least 20mm below the interface of interested need to be done while testing at laboratory, the specimen is clamped to the device. Once the adhesion between the specimen surface and the metal plates developed such that no failure is expected to occur between this interface, torque is applied manually at a steady rate to the specimen. The application of torque stress stopped once maximum torque achieved or when the recorded torque exceeds 300Nm. If the tested specimen is laboratory fabricated, it should be tested at 20°C unless otherwise stated. A more complete procedure may be obtained from [56].

#### 2.3.2 ATacker™

The ATacker™ is a special device such that it can either performed a torque test or tensile test (Figure 4). In the effort of the Mississippi Transportation Research Centre to evaluate the torsional shear strength and the tensile strength of different tack coating materials, it was proposed that a device should be developed. The ATacker™ device is the research output capable of performing the intended features [57]. The major components of the device developed by Instrotek Inc. include a smooth, circular aluminium contact plate, torque and force gauge and the force driven lever.

The sizes of the contact plates used differ accordingly to the types of tack coat materials. For tack material of PG binders,



4a. Torque bond test device [55].



4b. ATacker™ test device [47].

Figure 4 Devices with torsional testing mechanism.

contact plate of diameter size 12.7mm and 25.4mm was used. Meanwhile, the quality testing of emulsified tack coat materials used contact plates of 50.8mm diameter and 127.0mm diameter. Once the tack coat material at desired amount is applied on the plate breaks and sets, a standard normal force of 178N was applied for 60 seconds to maximize the contact surface area of the contact plate. Depending on the types of test needed, torsional or tensile force is applied until the tack coat materials failed.

### 2.3.3 Discussion

The existing literature results in limited types of torsional strength test device. But this mechanism of testing is definitely developing following more and more research works that are conducted in the recent years [8, 58, 59]. It is capable to perform both testing in-situ or in the laboratory whereby comparison of the results can be made. Similar to tensile test, the quality of the adhesive between the contact plate and the specimen surface need to be ensured in order to obtain the bond strength between two interfaces in contact. An important limitation to this mechanism is the unfeasibility of the test if the bonding at the interface is higher than the torsional resistance of the material within a single lift. At the same time, Canestrari *et al.* [53] also highlighted the non-uniform stress distribution which varies from zero at the center to the maximum at the outside of the core when testing is done with this mechanism.

The initial torque bond test is manually operated which the application limited at in-situ for thin surfacing only. Due to that, Choi [60] after Sutanto [8, 58] developed a laboratory based manual torque test in which the test can be carried out in a controlled environment. The further drawbacks were later overcome by following the development of mechanically controlled automated torque bond test in the research by Sutanto [8, 58]. According to him, the automated torque bond test resulted in higher bond strength value compared to manual torque bond test when operated at a contact rate of 600Nm/min.

### 3.0 CONCLUSION

In conclusion, shear types testing is still the most popular mechanism adopted to conduct the interface bond strength testing among the discussed mechanism. The test is generally rapid, easier to set up and results in reliable output with the extensive research carried out worldwide with different shear tester. The

development of tensile test and torsional test however, could not be ignored as the devices with this mechanism normally are portable and can be applied in-situ. This is especially useful when to test the quality of tack coat before paving works begin. It will certainly ensure the adhesiveness of the tack coat materials and to prevent further losses like the premature failure of a pavement due to insufficient interface bonding.

Continuous research also ended up with different types of devices being developed at different countries. While some parties might claimed that there is no standardization for all of these devices which often end up with incomparable research results, it should be understood that the pavement conditions varies from one location to another. The differences may range from the seasonal effects, construction technique as well as the traffic intensity. A universal bond strength testing device should therefore be developed incorporating different conditions which may be experienced by the pavement.

### Acknowledgement

The authors are grateful to Ministry of Higher Education (MOHE) for the Fundamental Research Grant Scheme (Vote 4F201) and the Universiti Teknologi Malaysia Research grants (GUP Tier 2 Vote 06J52) for the financial support in this research project.

### References

- [1] Roffe, J.C. and F. Chaignon. 2002. Characterization tests on bond coats: Worldwide study, impact, tests and recommendations, *3rd International Conference Bituminous Mixtures and Pavements Thessaloniki*. November 21 –22, 2002. 12 -19.
- [2] Santucci, L. 2009. *Recent Findings on The Use Of Tack Coat Between Pavement Layers*. Pavement Technology Update, University of California Pavement Research Center.
- [3] Chen, D. 2010. Slippage failure of a new hot-mix asphalt overlay. *J. Perform. Constr. Fac.* 24(3): 258 -264.
- [4] Romanoschi, S. 1999. *Characterization of Pavement Layer Interfaces*. PhD Thesis. Department of Civil Engineering, Louisiana State University.
- [5] Kruncheva, Mariana R., Andrew C. Collop, and Nicholas H. Thom 2005. Effect of bond condition on flexible pavement performance, *J. Transp. Eng-ASCE*. 131(11): 880 -888.
- [6] Kruncheva, Mariana R., Andrew C. Collop, and Nicholas H. Thom 2006. Properties of asphalt concrete layer Interfaces. *J. Mater. Civil Eng.*, 18(3): 467 -471.
- [7] Wheat, M. 2007. *Evaluation of bond strength at asphalt interfaces*. Master's Thesis. Department of Civil Engineering, Kansas State University.
- [8] Sutanto, M.H. 2009. *Assessment of Bond Between Asphalt Layers*. Ph.D Thesis. Department of Civil Engineering, Nottingham Transportation Engineering Centre, University of Nottingham.

- [9] Louw K. 2006. *Bond and tack coats to improve total structural integrity*. DIGEST 2006. Southern African Bitumen Association (Sabita).
- [10] Tashman L., K. Nam, Papagiannakis T., Willoughby K., Pierc L., and Baker, T. 2008. Evaluation of construction practices that influence the bond strength at the interface between pavement layers. *J. Perform. Constr. Fac.* 22(3): 154-161.
- [11] Plug C.P., A.H.D. Bondt, Hydra, R. 2010. Optimum bonding of thin asphalt overlays on porous asphalt. *5th World Congress on Emulsions*. Lyon, France, October, 2010.
- [12] Chen J.S. and C.C. Huang. 2010. Effect of surface characteristics on bonding properties of bituminous tack coat. *Transport. Res. Rec.* 2180: 142-149.
- [13] Cortina, A.S. 2012. *Optimization of In-Situ Tack Coat Application Rate And Installation*. Master's Thesis. University of Illinois.
- [14] OHIO. 2001. *Proper Tack Coat Application*.
- [15] WSDoT. 2003. *Tack Coat*, Tech Notes.
- [16] Blades, C. and E. Kearney. 2004. *Asphalt paving principles*. Cornell Local Roads Program.
- [17] Cross S.A. and P.P. Shrestha. 2005. *Guidelines for Using Prime And Tack Coats*. Report No. FHWA-CFL/TD-05-002. United States of America.
- [18] Hanson K. 2008. Avoid slippage by using good tack coat practices, Idaho *Technology Assistance Newsletter*. Idaho. Vol. 4.
- [19] JKR. 2008. *Standard specifications for road works*. Section 4: Flexible pavement. Kuala Lumpur, Malaysia.
- [20] Caltrans. 2009. *Tack coat guidelines*. State of California, Department of Transportation.
- [21] Leutner R. 1979. *Untersuchung Des Schichtenverbundes Beim Bituminösen Oberbau (In German)*. Bitumen 3.
- [22] Collop A.C., N.H. Thom, Sangiorgi, C. 2003. Assessment of bond condition using the Leutner shear test, *Proceedings Of The ICE-Transport*.156(4): 211-217.
- [23] ASTM. 2006. D6927- *Standard Test Method For Marshall Stability And Flow Of Bituminous Mixtures*. American Society for Testing and Materials. United States of America.
- [24] Partl M.N. and C. Raab. 1999. Shear adhesion between top layers of fresh asphalt pavements in Switzerland. *Proceedings of 7th Conference on Asphalt Pavements*. South Africa.
- [25] Raab C. and M.N. Partl. 2006. Adhesion testing on rehabilitated concrete pavements. *10th International Conference on Asphalt Pavements*. Quebec City, Canada.
- [26] Raab C. and M.N. Partl. 2009. Influence of tack coats on the adhesion properties of asphalt pavements. *Efficient Transportation and Pavement Systems*. 517-527.
- [27] Mohammad L.N., M.A. Elseifi, Bae A., Patel N., Button J. and Scherocman J.A. 2012. *Optimization of Tack Coat For HMA Placement*. Transportation Research Board of the National Academies, NCHRP Report 712.
- [28] Swiss Standard. 2000. *SN671931-Bituminöses Mischgut, Bestimmung des Schichtenverbunds (nach Leutner)* (in German and French).
- [29] Sholar G.A., G.C. Page, Musseleman J. A., Upshaw P.B. and Moseley H.L. 2003. Preliminary investigation of a test method to evaluate bond strength of bituminous tack coats. *Journal of Association of Asphalt Paving Technologists*. 73: 771-806.
- [30] IOWA. 2000. Method of test for determining the shearing strength of bonded concrete. Test Method No. IOWA 406-C.
- [31] Mohammad L.N., A. Bae, Elseifi, M.A., Button, J. and Scheroman, J.A. 2009a. Interface shear strength characteristics of emulsified tack coats. *Journal of Association of Asphalt Paving Technologists*. 78: 249-278.
- [32] West R. C., J. Zhang, Moore, J. 2005. *Evaluation of Bond Strength Between Pavement Layers*. NCAT Report 05-08.
- [33] ALDOT. 2008. Standard test method for determining the bond strength between layers of an asphalt pavement. *ALDOT Procedures*. ALDOT-430.
- [34] Santagata E., F. Canestrari, and Santagata, F.A. 1993. Laboratory shear testing of tack coat emulsion. *First World Congress on Emulsion*. Paris, France, October, 19-22, 1993.
- [35] Canestrari F., E. Pasquini, and Belogi, L. 2012. Optimization of geocomposites for double-layered bituminous systems. *7th RILEM International Conference on Cracking in Pavements*.
- [36] Raab C., M.N. Partl El Halim, A. O. 2009. Effect of gap width on interlayer shear bond Results, *International Journal of Pavement Research Technology*. 3(2).
- [37] Collop A.C., M.H. Sutanto, Airey G.D. and Elliot R.C. 2009. Shear bond strength between asphalt layers for laboratory prepared samples and field cores. *Constr. Build. Mater.* 23(6): 2251-2258.
- [38] Mohammad L.N., M. Hassan, Patel N. 2011. Effects of shear bond characteristics of tack coats on pavement performance at the interface. *Transport. Res. Rec.* 2209: 1-8.
- [39] Canestrari F., G. Ferrotti, Partl M.N., and Santagata, E. 2005. Advanced testing and characterization of interlayer shear resistance. *Transport. Res. Rec.* 1929: 69-78.
- [40] Hachiya Y. and K. Sato. 1997. Effect of tack coat on bonding characteristics at interface between asphalt concrete layers. *Proceedings of the 8th International Conference on Asphalt Pavements*.
- [41] Rahman F., M. Hossain Hossain, M. 2009. Measurement and evaluation of tack coat application rate for 4.75 mm NMAS superpave overlay mix. *2009 Mid-Continent Transportation Research Symposium*. Ames, Iowa.
- [42] ASTM. 2009. *D4541-Standard test method for pull-off strength of coatings using portable adhesion testers*. American Society for Testing and Materials, United States of America.
- [43] Raab C. and M.N. Partl. 1999. *Methoden zur beurteilung des schichtenverbunds von asphaltbelägen*. Zurich, Switzerland, Eidgenössisches departement für Umwelt, Verkehr, Energie und Kommunikation/Bundesamt für Strassen. (In German)
- [44] Raab C. and M.N. Partl. 2004. Interlayer shear performance: Experience with different pavement structures. *3rd Euraspalt & Eurobitume Congress*. Vienna, Austria.
- [45] Deysarkar I. 2004. *Test Set-Up To Determine Quality Of Tack Coat*. Master's Thesis, University of Texas at El Paso.
- [46] Eedula S.R. and V. Tandon. 2006. *Field Tack Coat Acceptance Criterion*. Texas Department of Transportation.
- [47] Mohammad L.N., A. Bae, Elseifi M.A., Button, J. and Scheroman J.A. 2009b. Evaluation of bond strength of tack coat materials in field: Development of pull-off test device and methodology. *Transport. Res. Rec.* 2126: 1-11.
- [48] Bakhsh K.N. 2010. *Evaluation of Bond Strength Between Overlay And Substrate In Concrete Repairs*. Master's Thesis. School of Architecture and the Built Environment, Royal Institute of Technology.
- [49] British Standard 2003. BS EN13863, Concrete pavements - Part 2: Test method for the determination of the bond between two layers, British Standard Institution, United Kingdom.
- [50] Ling T.C., H.M. Nor, Hainin M.R. and Chik A.A. 2009. Laboratory performance of crumb rubber concrete block pavement. *Int. J. Pavement Eng.*, 10(5): 361-374.
- [51] Chaignon F. and J.C. Roffe. 2008. Characterisation on bond coats: Worldwide study, impact, tests, recommendations (Presentation Slides). *International Symposium on Asphalt Emulsion Technology*.
- [52] Tschegg E.K., G. Kroyer, Tan D.M., Stanzl-Tschegg S.E. and Litzka, J. 1995. Investigation of bonding between asphalt layers on road construction. *J. Transp Eng-ASCE*. 121(4): 309-316.
- [53] Canestrari F., G. Ferrotti, Lu X., Millie, A. Partl M.N., Petit C., Phelipot-Mardel A., Piber H. and Raab C. 2013. *Mechanical Testing Of Interlayer Bonding In Asphalt Pavements*. Springer Netherlands.9: 303-360.
- [54] Walsh I.D. and J.T. Williams. 2001. *HAPAS Certificates For Procurement Of Thin Surfacing*. Highways Authority Product Approval Scheme.
- [55] Tashman L., K. Nam, and Papagiannakis A.T. 2006. *Evaluation Of The Influence Of Tack Coat Construction Factors On The Bond Strength Between Pavement Layers*. Washington State Department of Transportation.
- [56] BBA. 2011. *Guideline Document for The Assessment And Certification Of Thin Surfacing Systems For Highways*. British Board of Agrément.
- [57] Buchanan M.S. and M.E. Woods. 2004. *Field tack coat evaluator (ATACKer™)*. Mississippi Transportation Research Centre.
- [58] Sutanto M. H. 2011. Development of automatic torque bond test. *Jurnal Transportas*. 11(3): 191-200.
- [59] Hakimzadeh S., N. Kebede, and Buttlar, W.G. 2012. Comparison between optimum tack coat application rates as obtained from tension and torsional shear type tests, *7th RILEM International Conference on Cracking in Pavements*. Springer Netherlands. 4: 287-297.
- [60] Choi Y.K., M.H. Sutanto, and Airey G. D. 2005. *Bond Between Asphalt Layers*. Nottingham, UK Highways Agency, Scott Wilson Pavement Engineering Ltd.