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A Review of Interface Bonding Testing Techniques

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ABSTRACT

Interface bonding between asphalt layers has been a topic of international investigation over the last three decades. In this condition, many researchers created their techniques and used them to examine the characteristics of pavement interfaces. Test findings won't always be comparable to the lack of a globally standard methodology for interface bonding. Also, several kinds of research have shown that factors like temperature, the condition of the applied load, constructing material, and others impact surface qualities. The study intends to solve this problem by thoroughly investigating interface bond testing that might serve as a basis for a uniform strategy. First, a general explanation of how the bonding strength function works and how it affects the pavement is given. The construction of various setups is then examined, and their functions are contrasted, followed by an explanation of different interface bond test procedures according to loading situations. Based on previous findings, a concept for a systematic approach to a standard assessment of asphalt interface is proposed.

Keywords: Flexible pavement, Interface bond strength, Destructive tests, Non-Destructive tests.

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مراجعة لتقنيات اختبار الربط بين الواجهات

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الخلاصة

كان الترابط بين طبقات الأسفلت موضوع بحث دولي على مدار الثلاثين عامًا الماضية. في هذه الحالة، قام عدد من الباحثين بصنع تقنياتهم الخاصة واستخدموها لفحص خصائص واجهات الرصيف. من الواضح أن نتائج الاختبار لن تكون قابلة للمقارنة دائمًا مع الافتقار إلى منهجية قياسية عالمية لربط الواجهة. أيضًا، أظهرت عدة أنواع من الأبحاث أن عوامل مثل درجة الحرارة وظروف التحميل والمواد وغيرها لها تأثير على جودة السطح. تهدف هذه الدراسة إلى حل هذه المشكلة من خلال التحقيق الشامل في اختبار روابط الواجهة التي قد تكون بمثابة أساس لاستراتيجية موحدة. أولاً، يتم تقديم شرح عام لكيفية عمل وظيفة قوة الترابط وكيفية تأثيرها على الرصيف. يتم بعد ذلك فحص إنشاء الإعدادات المختلفة، ويتم تباين وظائفها، متبوعًا بشرح لإجراءات اختبار روابط الواجهة المختلفة وفقًا لحالات التحميل. تم اقتراح مفهوم لنهج منهجي لتقييم قياسي لواجهة الإسفلت، بناءً على النتائج السابقة.

الكلمات المفتاحية: الرصف المرن، قوة ربط الواجهة، فحوصات إتلافيه، فحوصات لا إتلافيه

1. INTRODUCTION

Pavement is a multilayered construction made up of various pavement materials for each layer. Pavement lifts must be connected so that the asphalt pavement acts as a monolithic structure; thus, vehicular and climatic loads are effectively transferred to the whole pavement **(Abbas and Al Mosawe, 2021)**. In flexible pavement distressing areas that need guidance, Performance loss may be caused by fatigue cracking, heat cracking, rutting, slippage, and moisture damage **(Abd and Qassim, 2017)**.
Sufficient bonding between asphalt layers reduces shear distortion, increases the elastic recovery performance, and reduces structural failure **(Boulangé and Sterczynskia, 2012)**; hence, a durable, flexible pavement may be anticipated. Pavement construction with multi-layers, particularly asphalt pavements, creates weak zones at the layer interfaces, resulting in a lower shear strength in these zones relative to the asphalt concrete mixture **(Alnuami and Sarsam, 2020)**. Due to construction issues, it is impossible to achieve complete bonding between parallel layers in real-world settings; as a result, the assumption of the full bond between the asphalt layers to analyze and design pavement is no longer invalid **(Diakhate et al., 2007)**. Previous research indicates that a poor link at one interface may result in an anticipated loss of 40-80% and as little as 15% of the pavement's life **(Albayati, 2018)**. Inadequate Interface Bond Strength **(IBS)** may also increase the asphalt pavement deformation, driving conditions are affected, the road surface maintenance expenses rise, early distress like slippage is eventually brought on, and surface cracking on the top and bottom. **(Mohammad et al., 2009; Vaitkus et al., 2011)**. Bond failure along pavement layers appears to be influenced by certain contributing elements **(Canestrari et al., 2013)**: low compaction of the layers, including the subgrade layer, subbase layer, or base layer, base layer segregation, the type of the bitumen used for the surface layer, the weather at

construction, contamination of the subsurface, moisture presence between the layers, and an insufficient tack coat application are all factors that can affect a base course.

To assess the status of IBS, several organizations and institutes have created their test techniques and technology **(Raab and Partl, 2004a)**. Notwithstanding these attempts, no standard test technique or process has been established. In this manner, though, rudimentary efforts have been made **(Raab, 2011)**.

This effort aims to provide a standardized method for IBS testing. First, existing test approaches and techniques are described to evaluate IBS. Second, each test method's key component will be explained, followed by a demonstration of several settings created for each method. Following that, a discussion is accomplished about IBS testing equipment with various operations and their benefits and drawbacks. Also, the outcomes of certain of these testing equipment are compared in accordance with earlier research.

2. EVALUATION TECHNIQUE FOR INTERFACE BONDING TESTS

In this part, we'll discuss the many testing methods and procedures that may be used to evaluate interface bonding. **Fig. 1** shows the typical loading conditions that pavement layer interfaces experience in real-world situations: pure shear, pure tension, shear compression, and shear tension **(Rahman et al., 2017).**

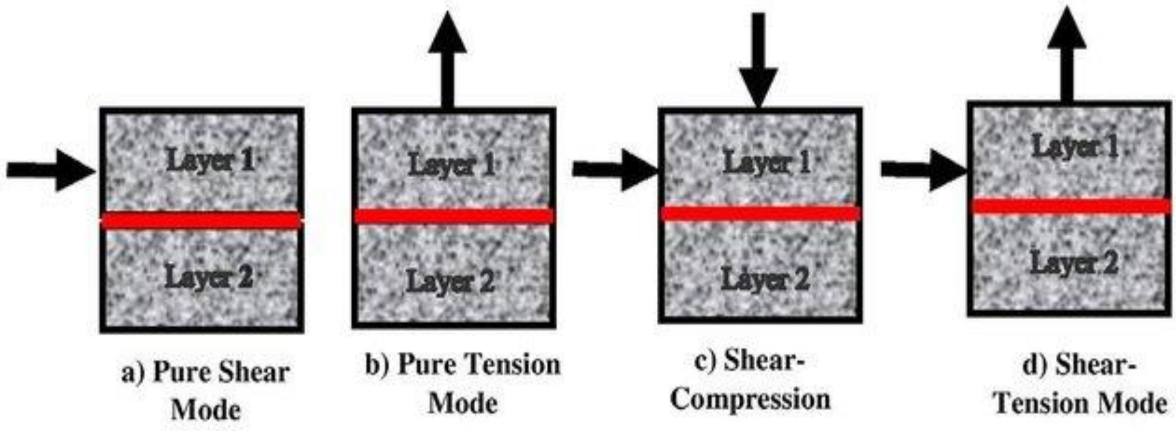

Figure 1. Variations in loading type at the pavement layers **(Rahman et al., 2017)**

Pure shear mode is commonly produced at interfaces without joints by temperature- and/or traffic-induced shear stresses transversely or longitudinally. Pavement with Portland cement concrete with an overlay layer of a hot mix asphalt, type 2 loading may be seen. Finally, the interface below a surface layer, where the IBS is relatively simple, may experience the shear-tension mode. The second circumstance, meanwhile, is uncommon in true pavement construction **(Sutanto, 2009; Al-Qadi et al., 2009)**. Using the previous discussion, many categories may be formed for the present test methodologies, as shown in **Fig. 2**. A certain type of test process is chosen based on the

The problem is how it is expected to be loaded and how accurate and repeatable it is **(Raab, 2011)**. The next sections will provide a detailed explanation of each testing technique category along with the pertinent most popular instruments. Notice that the following categories might be used to group all authorized test methods:

• The Destructive tests

• The non-destructive tests (NDT) on constructed roads which include some tests like the Falling Weight Deflectometer (FWD) test, Ground-Penetrating Radar (GPR), and infrared thermography.
Fig. 3 shows a schematic representation of a destructive interface bond testing equipment.

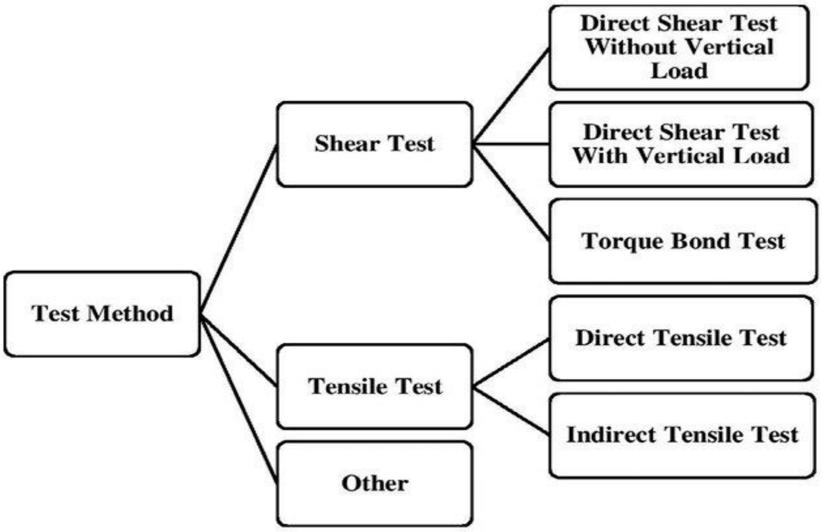

Figure 2. Techniques of testing interface bonding **(Rahman et al., 2017)**

2.1. The Shear Test

The shear test can be subdivided into two categories:

2.1.1. Direct Shear Test (including or not including normal load)

Due to its easy operation and adaptability, the direct shear test is considered the main method for evaluating the IBS. Shear testing in soil mechanics is where the creation of shear testing equipment began, and throughout time, several nations and labs designed and constructed their machines **(Raab et al., 2009)**. Al-Qadi developed the Direct Shear Test Fixture, which seems useful in determining the IBS. The test calculates the values of a direct shear load and their subsequent displacement. The IBS values are computed by fracturing the average shear stress by the bonded cross-sectional area.
The start of using a standard shear test machine was from the Karlsruhe University in Germany. They made a shear system that could be attached to a universal test machine. Even though this system could only be used for static testing and it wasn't possible to apply a normal force, it was updated and used by many other countries. It was still one of the best ways to test the bonds between layers.
Measuring the maximum shear load and corresponding displacement is necessary to evaluate interfacial bonding properties. These are useful in determining how appropriate a given material is to be used in tack coating. Specimens of (6 in) diameter were cored from a laboratory compacted composite (12in × 12in width, 2.8in height). Shear loads are added vertically to a specimen of two layers using a controlled strain mode with a set rate of 2 in/min at 21.1°C temperature till damage is observed **(Al-Qadi et al., 2009)**.

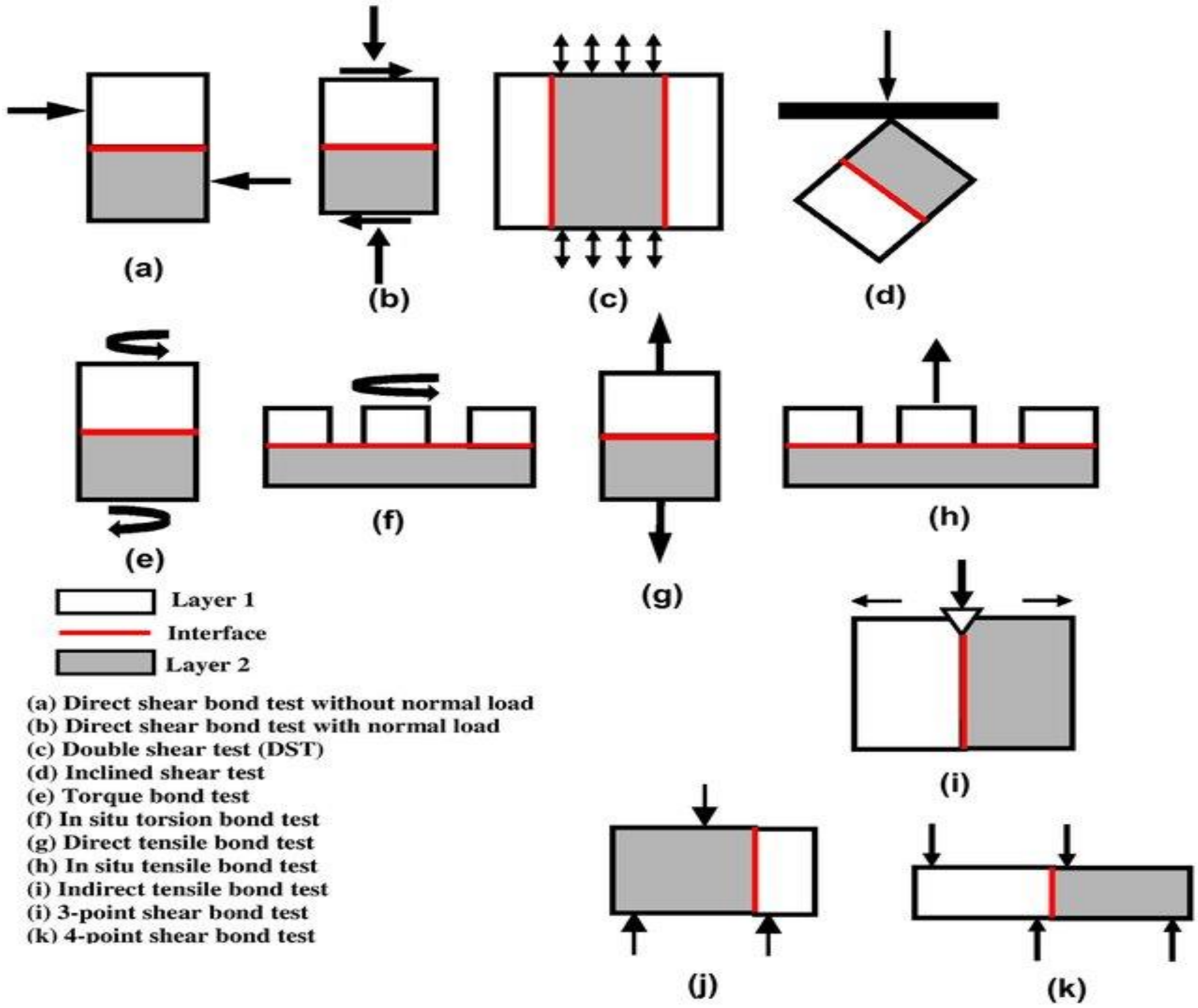

Figure 3. Graphical depiction of several contact bonding test procedures **(Rahman et al., 2017)**

The layered Parallel Shear test (LPDS) devise illustrated in **Fig. 4 (Raab et al., 2009)**. The measurement of the nominal average shear stresses and maximal shear stiffness is needed in determining the inlayer and interlayer shear characteristics of asphalt concrete. The former is useful in evaluating the quality of the mixture, whereas the latter is required to assess tack coat features. A shear load is added vertically upon composite specimens with strain control mode at a fixed speed. The cylinder-formed composite specimen has a 3.94 in diameter and could be either lab-fabricated or pavement-cored and requires to be glued.

The Florida Department of Transportation (FDOT) suggested a simpler and directly applicable shear device for measuring the IBS to evaluate tack coat performances. The application of shear load vertically on the double-layered asphalt concrete samples continues with controlled strain mode, with a steady rate of 2.0 in/min at 25°C until specimen failure is achieved. The cylindrical samples have a diameter of 6-in and may be either lab-fabricated or excerpted from roads with no need for trimming to suit the device itself. The gap of 0.19-inch width between shear plates is shear strength at the moment of failure, as shown in **Fig. 5 (Sholar et al., 2004)**. **Table 1.** Lists a few well-known direct shear testing apparatuses without applying typical stress.

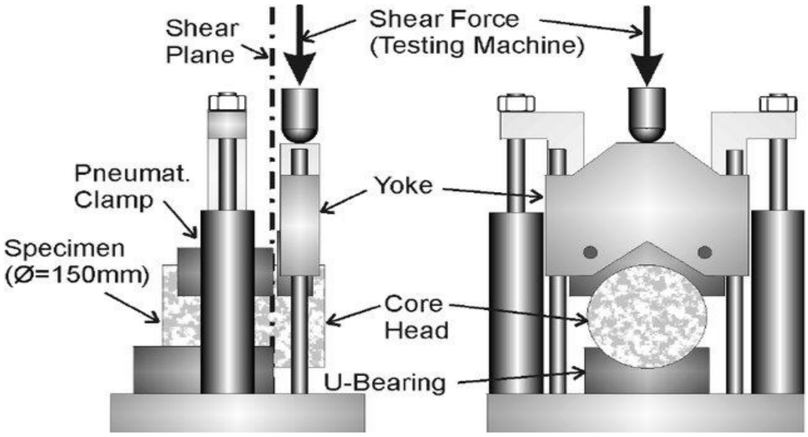

Figure 4. LPDS Apparatus **(Raab et al., 2009)**

Figure 5. FDOT bond strength device **(Sholar et al., 2004)**

Table 1. Devices for Direct shear test without vertical load

Device name	Reference
The modified letter	**(Vaitkus et al., 2011)**
Layer-parallel direct shear (LPDS)	**(Raab and Partl, 2004a)**
Superpave shear tester (SST)	**(Mohammad et al., 2002)**
Louisiana interface shear strength tester (LISST)	**(Mohammad et al., 2009)**
Florida department of transportation (FDOT) shearing test	**(Sholar et al., 2004)**
Direct shear testing	**(Yildirim et al., 2005)**
Modified compact shearing (MCS)	**(Diakhate et al., 2006)**
Double shear test (DST)	**(Diakhaté et al., 2011)**
The shear test mold	**(Uzan et al., 1978)**
Virginia shear fatigue test	**(Donovan et al., 2000)**
Laboratory bond interface strength device (LBISD)	**(Woods, 2004)**
The shear strength test	**(Vacin et al., 2005)**

The impact and application of normal stress, which simulates an actual wheel load, on interlayer bond strength have been hotly debated in the literature up to this point **(Tozzo et al., 2014)**. As a result, several researchers created direct shear test equipment that included normal load application. **Table 2** provides a number of direct shear test equipment with potential normal load applications.

Table 2. Devices for Direct shear test with vertical load

Device name	Reference
Sapienza inclined shear test machine (SISTM)	**(Tozzo et al., 2014)**
Sapienza horizontal shear test machine (SHSTM)	**(D'Andrea et al., 2013)**
Sapienza direct shear testing machine (SDSTM)	**(Tozzo et al., 2014)**
Louisiana interface shear strength tester (LISST)	**(Mohammad et al., 2009)**
Ancona shear testing research and analysis (ASTRA)	**(Santagata and Canestrari, 1994)**
Direct shear device	**(Chen and Huang, 2010)**
Shear fatigue test	**(Romanoschi, 1999)**
National Center for Asphalt Technology (NCAT) bond strength device	**(West, 2005)**
Superpave shear tester (SST)	**(Bognacki et al.,2007)**
Interface shear testing device (ISTD)	**(Al-Qadi et al., 2012)**

Using IBS data without ordinary restriction results in an overdesigned layer of pavement, which might be relevant only for tack coat QC/QA considerations, according to an investigation by **(Karshenas et al., 2014)** on the significance of normal confinement to shear bond failure; other research works in a related field of study have been found **(Santagata and Canestrari, 1994; Mohammad et al., 2009; Piber et al., 2009)**.
However, owing to their straightforward operation, versatility, and straightforward procedure for producing specimens, direct shear tests without a normal load are extensively utilized across the globe **(Collop et al., 2003; Sholar et al., 2004)**.

2.1.2. The Torque Bond Test

Torque bond tests may also be used in the evaluation of the IBS. The method development was in Sweden. Later, the British Board of Agreement (BBA) accepted it as an approved methodology for thin surfacing systems **(BBA, 2013)**. This methodology is applied for assessing the IBS between two layers: the surface layer, which must be thin, and the binder layer, which is a normal asphalt layer in the field or the lab, by determining the maximum shearing torque at any temperature. Using a portable torque wrench, tension is subjected to a plate that is adhered to the core surface until the bond experiences a twisting shear failure or a torque of (300 N.m) is reached **(BBA, 2013)**.
The results of experimental experiments demonstrate that the traditional torque bond test has a number of drawbacks:
1. Constant specimen size,
2. The topmost pavement contact is the only place where it is often relevant in the field,
3. Due to manual operation, the torque rate is inadequate,

4. Abnormal axial bending,
5. Applying pressure to twist off the surface **(Collop et al., 2011; Sutanto, 2011)**.

As a result, some researchers have created their apparatus. In the literature, several utilized torque bond test devices are listed in **Table 3**.

Table 3. Devices for torque bond test

Device name	Reference
Manual torque bond test	**(BBA, 2013)**
Laboratory-based manual torque bond test	**(Diakhate et al., 2007)**
Automatic torque bond test	**(Sutanto, 2009)**
Tack coat evaluation device (TCED)	**(Woods, 2004)**
In Situ torsion shear test	**(Diakhate et al., 2007)**
Monotonic torque test	**(Diakhaté et al., 2011)**

(Choi et al., 2005) modified a manual torque bond test in a lab, which allows testing at different temperatures in addition to the shear strength of any contact of interest. Yet, there were unresolved restrictions with the newly built technology. Researchers at the University of Nottingham **(Collop et al., 2011)** created an automated, regulated torque bond apparatus to address the existing problem and undertake semi and repetitive load interface testing. The device transfers the vertically subjected stress or displacement and turns it into torque, depending on the rack and pinion mechanism.

Several studies were conducted **(Sutanto, 2011)** to compare the automated torque bond test findings with the manual torque bond test. The results show that the manual torque bond test has a greater Coefficient of Variability (COVs) than the automated torque bond test. Moreover, the automated bond test yield findings showed an increment of 20–30% compared to the manual test, maybe because of the manual device's shortcomings.

2.2. Tensile Test

2.2.1. The Direct Tensile Test

Tensile and shear failure between two bonded layers may occur due to vehicular or environmental factors, as was previously discussed. Thus, it is crucial to measure the tensile IBS. Tensile tests are test techniques that can measure failure by highlighting the weakest point in the testing system and assessing the tensile bond between a couple of adherent layers of asphalt at the site or in the laboratory **(Xiao et al., 2015)**. **Table 4**. lists several frequently used direct tensile test equipment.

Pull-off tests can be considered prevalent tensile tests since they are simple to conduct in the field. The pull-off test is typically performed by physically applying a torque or tensile force on tack-coated surfaces via a shaft or nut and computing the tensile strength. The American Society for Testing and Materials (ASTM) (ASTM, 2014) devised a recommended test methodology to measure the tension necessary to separate two bonded layers.

Conventional direct tensile testing equipment, such as the ATacker and UPOD devices, is controlled manually. This might cause the plate to be pulled off at a non-uniform rate and have eccentric loading effects, making the results unreliable. To deal with this problem, the Louisiana Tack Coat Quality Tester (LTCQT) was created through the study of **(Mohammad**

et al., 2012) as a way to test the quality of a tack coat that has been applied in the field and to compare how different tack coat materials react.

Table 4. Devices for direct tensile test

Device name	Reference
Tack coat evaluation device (TCED)	**(Woods, 2004)**
UTEP pull-off device (UPOD)	**(Eedula, 2007)**
Interface bond test (IBT)	**(Hakimzadeh et al., 2012)**
Modified pull test	**(Xiao et al., 2015)**
Pull-off test device	**(Raab and Partl, 2004b)**
Schenck-Trebel test	**(Litzka et al., 1994)**
Tensile test	**(Santagata and Canestrari, 1994)**

As shown in **Fig. 6 (Ghabchi et al., 2018)**, the LISST system assessed the ISS of test specimens made at different application levels, both with and without tack coats. The calculated ISS values were evaluated for the optimal application rate for different surface types of tack coats and for testing the tack coat resistance to varying conditions at the site. The LISST system consisted of two attachments, as one of these fixtures can move parallel, whereas the other stationary jaw moves up and down (moving jack). After setting the double-layered asphalt sample in the LISST device, the moving jaw was loaded vertically, parallel to the interface of the asphalt layers, to establish shear stresses in the preexisting interlayer. The load application was increased until interlayer failure was observed. A loading frame developed by materials testing systems (MTS) was used in this research by applying load within the LISST device to the sample. Additionally, the prototype was used to record the axial forces at displacement. IBS values were calculated by dividing the maximum axial load at fault by the sample cross-sectional area.

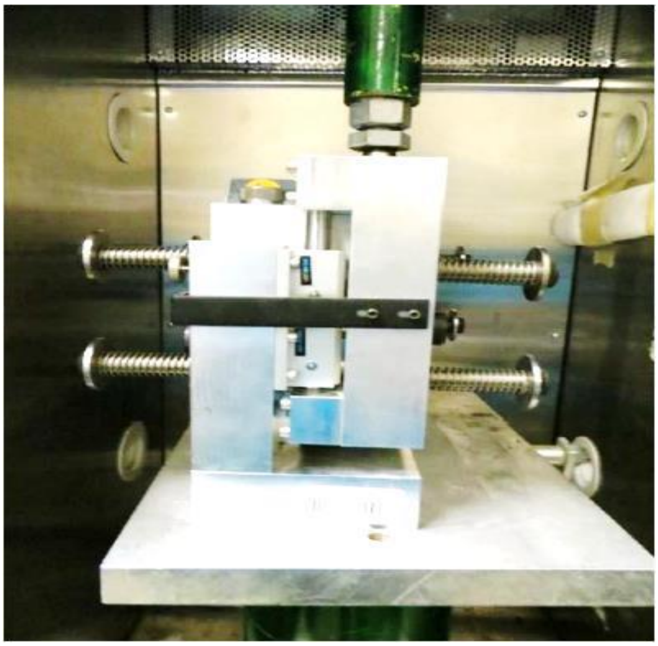

Figure 6. LISST interlayer shear strength **(Ghabchi et al., 2018)**

2.2.2. Indirect Tensile Test

Despite its popularity and simplicity, the pull-off test technique has a variety of drawbacks. For example, a single measurement shows a disability to characterize the bond dissociation of materials represented as flexible or fragile attitude, and the findings are highly dispersed due to human operation. The wedge splitting test is a modern indirect tensile test technique that **(Tschegg et al., 1995)** developed to overcome these problems. A thin wedge is subjected to the interface of a double-layer sample under the condition that the horizontal element of the applied force keeps layers apart.

Fig. 7 (Tschegg et al., 1986) illustrated the maximal horizontal stress **(F_m)** and specific fracture energy **(GF),** whose determination is significant in characterizing the fracture mechanical behavior of layer bonding. This factor is essential in determining how appropriate the material will be used in tack coating. Using a wedge, the load is applied vertically to the two-layer sample with a groove and starter notch along with the interface at a steady rate until the sample is separated. The samples take the form of a cube or cylinder, with the start notch in the middle interface, and may be either produced in a laboratory or taken from the field.

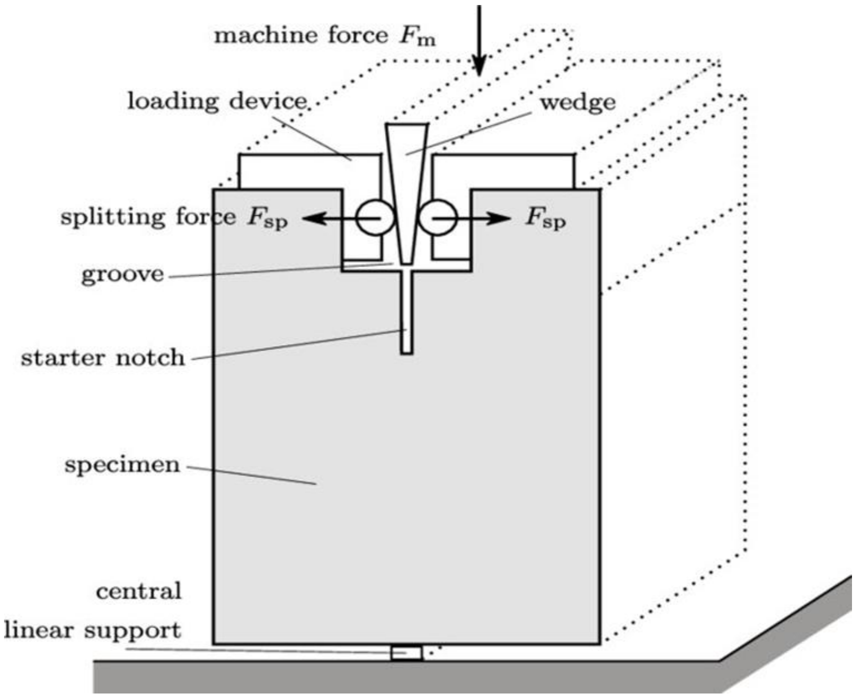

Figure 7. Wedge Splitting test **(Tschegg et al., 1986)**

3. DISCUSSION ON IBS TESTING EQUIPMENT

Many academics have conducted in-depth studies over the last several decades due to the importance of interface bond assessment. While examining interface qualities, one should remember that Raab and Partl claimed that surface layer adhesion under operational circumstances is susceptible to tensile and shear modes.

Several European nations, the US, Canada, and others have created and implemented their interface bond testing techniques and tools in recent years **(Raab and Partl, 2004b)**.

The ASTRA component conformed with European and Italian standards **(Pasquini et al., 2014)**, the BBA suggested the torque bond test, the pull-off test was confirmed in the ASTM,

and recently, the LISST technique was authorized as a standard evaluation for assessing the IBS by AASHTO.
Yet, the results of the experiments show that each of these test methods and equipment has advantages and disadvantages, which are discussed below. The introduction of the Leutner device was made in subsection 2.1.1. Study shows that the device has several flaws, including non-uniform IBS stresses, no normal stress being supplied to the surface layer, and no space between the shearing rings. Furthermore, **(Collop et al., 2003)** noted that the test findings are rather unpredictable.
The lack of space between the shear platens in the classic Leutner shear test caused the interface to be misaligned with the shear plane, particularly for specimens containing inconsistent interfaces. To find solutions, (**Choi et al., 2005)** originally implemented a 5 mm gap in the UK and said the tests would benefit from it. The supplementary investigation also showed that the findings' degree of variability was reduced when a 5 mm gap was included in the shear plane **(Collop et al., 2009)**. Moreover, **(Raab et al., 2010)** ran an experimental attempt to understand the function of the gap more fully. The study's findings indicated that the gap width affected the interface shear outcomes, and other research with comparable designs supports these findings **(Sholar et al., 2004).** Generally, a gap width only slightly wider than 0 mm would be sufficient to streamline and improve the testing.
The LPDS test created by the EMPA is considered an improved edition of the Leutner test, and its most benefits found are as follows **(Raab and Partl, 2009; Kim et al., 2011)**: higher flexibility in geometry, the distribution of stress that may be uniform, and an easy-to-use instrument for quality assurance testing and post-construction surface evaluation. In addition, LPDS has several disadvantages, such as neglecting the overall effect of horizontal and vertical stresses as well as dilatancy and eccentricity effects, the limited temperature at testing and the thickness of specimen due to the effect of the "snow plow", and producing inconsistent results at extremely high temperatures.
Researchers often employ shear box-type experiments as shear and normal loads occur at the interface. Nevertheless, there are a few flaws in this test methodology. The lack of complementing shear stresses causes the shear stress distribution on the interface to be non-uniform, according to **(Kruntcheva et al., 2006). (de Bondt, 1999)** later introduced a four-point shear test configuration to address the issue. In addition, it is important to examine the experimental complexity linked to applying normal and shear stresses. In conclusion, the gadget may be useful, especially for research reasons, but a more straightforward method is required for actual field assessments of interface qualities.
Even though experimental results for both devices were comparable in an investigation made by **(Kim et al., 2011)**, a comparison in testing methodology between shear box and LPDS showed that the shear stress-deformation curve for both tests was completely different because of the varied shear scheme and stress conditions imposed during testing. Identical results have also been achieved elsewhere **(Tozzo et al., 2014)**.
Many theoretical and experimental studies have been conducted to date in the research to assess the outcomes of various interface bonding devices while considering variations in testing parameters, including failure mode, setup configuration, geometry, and other factors. Several of these researches are emphasized in the sentences that follow. **(Deysarkar, 2004)** performed research utilizing many instruments, including the ATAKER (shear and tension-type), the UTEP torque test, the KMC shearing device, and the UTEP pull-off device (UPOD). The findings showed that tension mode setups, regardless of the surface studied, could more accurately detect the quality of one tack coat. In an experimental study, **(Tashman et al.,**

2008) investigated the impact of construction parameters on the bond strength at the interface between pavement layers. The three test methods are the UTEP pull-off test, the torque bond test, and the FDOT shear tester. The results showed that debonding at the interface brought on by stress conditions seemed better simulated by the FDOT shear tester. The findings of the UTEP pull-off test were usually dissimilar from those of the other two tests, whereas the results of the torque bond test were congruent with those of the FDOT shear tester.

4. CONCLUSIONS

This work discussed and reviewed IBS testing in pavement layers to develop a widely used standard approach for an in-depth comprehension of interface characterization and assessment. The following conclusions might be made in this regard:

- The absence of worldwide consensus about test methodologies, protocols, and assessment standards has led to substantial diversity and sometimes contradictory results in the literature.
- Any effort to standardize the bonding assessment of pavement layers should consider the competing interests of researchers and highway builders. Researchers need an accurate and efficient technique, while road contractors and agencies need it quick and easy to use.
- Under in-service circumstances, it is possible for the bonding between neighboring layers to break in both shear and tension modes, which should be considered.
- The validity of the results collected via a standardized test procedure is primarily determined by its repeatability and reproducibility.
- To standardize a test technique, it is essential to consider how various test parameters and situations affect interface bonding qualities and how these numerous significant aspects interact.

NOMENCLATURE

AST	Advanced Shear Tester	LISST	Louisiana Interface Shear Strength Tester
ASTM	American Society for Testing and Materials	LPDS	Layered Parallel Shear Test
ASTRA	Ancona Shear Testing Research and Analysis	LTCQT	Louisiana Tack Coat Quality Tester
BBA	British Board of Agreement	MCS	Modified Compact Shearing
COVs	Coefficient Of Variability	MTS	Materials Testing Systems
DST	Double Shear Test	NCAT	National Center for Asphalt Technology
FDOT	The Florida Department of Transportation	NDT	Non-Destructive Tests
FWD	Falling Weight Deflectometer	SDSTM	Sapienza Direct Shear Testing Machine
GF	Specific Fracture Energy	SHSTM	Sapienza Horizontal Shear Test Machine
GPR	Ground-Penetrating Radar	SISTM	Sapienza Inclined Shear Test Machine
IBS	Interface Bond Strength	SST	Superpave Shear Tester
IBT	Interface Bond Test	TCED	Tack Coat Evaluation Device
ISTD	Interface Shear Testing Device	UPOD	UTEP Pull-Off Device
LBISD	Laboratory Bond Interface Strength Device		

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