# THE COMPARISON OF MODIFIED IDOT & AASHTO T-283 TEST PROCEDURES ON TENSILE STRENGTH RATIO AND FRACTURE ENERGY OF MIXTURES

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## ABSTRACT

*The recognition of water as one of the main factors in deteriorating flexible pavements has resulted in the development of various moisture susceptibility test procedures. The evaluation of moisture damage can be performed using visual or retained strength tests. One of the most widely accepted methods to evaluate mixture stripping is the Modified Lottman (AASHTO T-283) test procedure. However, different highway agencies have their own modified test procedures according to their local requirements. In the current research, Modified IDOT and AASHTO T-283 conditioning methods were performed on a typical dense graded mixture that is used in the state of Illinois. The indirect tensile strength and fracture energy (Gf ) parameters, as the moisture damage severity indicators were determined for all the conditioned and dry samples. The tensile strength ratio (TSR) test results showed that IDOT modified test method, which does not consider the effect of freeze and thaw cycle, underestimates the water-induced damage in mixture. Moreover, it was observed that the fracture energy differs more significantly between dry and conditioned specimens using AASHTO T-283 method in comparison to Modified IDOT procedure. Therefore, it was concluded that freeze and thaw cycle should be included in the moisture damage test procedures as an important step to simulate the field winter conditions. Moreover, the fracture resistance of mixture can be considered as an indicator of the moisture susceptibility of the mixtures.*

**Keywords:** Mixture design, Freeze-Thaw, Fracture-toughness, Performance testing

## 1. INTRODUCTION

Since 1930s, the water at the aggregate-bitumen interface has been recognized as an important factor in deteriorating mixtures [1]. Basically, the main source of many critical types of distresses such as ravelling and fatigue cracking is the result of detrimental effect of moisture. The pavement community has recognized that moisture damage of mixtures has been a serious problem since the early 1960s [2]. It is important to address moisture damage and try to control its propagation because it reduces the performance as well as the service life of the flexible pavements.

Moisture damage is generally referred as stripping, which is the loss of adhesion between the bitumen and aggregate and/or loss of cohesion within the bitumen in the presence of moisture. Moisture damage is a sophisticated phenomenon, which is the result of thermodynamic, chemical, physical and mechanical processes [3]. Bitumen characteristics, aggregate characteristics, construction, weather and traffic are some of the main factors the can affect the level of moisture damage.

Almost 87% of the US transportation agencies are trying to limit the moisture damage on mixtures by establishing moisture susceptibility tests and minimum standards. The stripping potential evaluation can be generally performed using either visual tests like boiling test or retained strength tests such as indirect tensile test [4]. Table 1 shows some of the existing moisture damage laboratory test methods and their stripping indictor parameter.

**Table 1. Moisture damage laboratory testing methods**

| Moisture damage test name / Specification | Stripping indicator |
|---|---|
| Boiling test (ASTM 3625) | Visual measurement of the non-coated aggregate surface |
| Static immersion test (AASHTO T182) | Area of non-coated aggregate surface |
| Lottman test | A split indirect tensile test and determining TSR |
| Tunnicliff and Root conditioning | Determining TSR |
| Modified Lottman (AASHTO T 283) | Determining TSR |
| Immersion-compression (AASHTO T 165) | Unconfined compressive strength ratio |
| Hamburg wheel-tracking test | Rutting depth of the samples under water |

Measuring the fracture energy as a moisture sensitivity indicator is not commonly used in the previous studies. However, Birgisson et al. introduced a new parameter to evaluate moisture sensitivity, which is the energy ratio (ER). He used the Superpave indirect tension test fracture parameters and monitored creep properties, resilient modulus, tensile strength, fracture energy (FE) limit, and dissipated creep strain energy limit. From his study it was found that ER is capable of detecting the effects of moisture damage on the fracture resistance of mixtures, and also to detect the presence of antistripping agents in mixtures [5]. Later, Othman used the critical energy release rate obtained from the fracture resistance test. He concluded that the critical energy release rate concept is a successful tool to characterize the resistance of rubber-modified mixtures to moisture damage [6].

Experts agree that the best methods among the different laboratory testing procedures are those, which are capable of simulating moisture damage mechanism as closely as possible to the field conditions. Coplantz et al. found that stripping did not occur in specimens subjected to vacuum saturation only, and that the freeze-thaw cycles will affect the laboratory performance of the mixture significantly [7]. Moreover, Gilmore et al. reported progressive changes in tensile strength when specimens were repeatedly exposed to freeze-thaw cycles [8].

The Illinois department of transportation (IDOT) has modified the AASHTO T-283 test procedure to evaluate the stripping potential of the mixtures [9]. The major differences that IDOT introduced to AASHTO T-283 test method are eliminating the 16 hours curing of the mixture during mixing, as well as the 16 hours of freezing at -18$^o$C. In this research, these two different moisture test methods were performed to determine the stripping resistance of a typical 19.0 mm mixture, which is used in the state of Illinois. Following each test method, the 150 mm diameter by 95 mm height cylindrical laboratory specimens in 7 $\pm$ 0.5% air-void content were prepared, and tested to determine the Tensile Strength Ratios (TSR) values between conditioned and dry status. In addition, the fracture energy test was performed on the dry and conditioned disk shaped compacted specimens (DCT) to clarify the effect of the two different conditioning procedures on the fracture resistance of the mixture. All the laboratory tastings were conducted in Advanced Transportation Research Engineering Laboratory (ATREL) at the University of Illinois.

## 2. EXPERIMENTAL TESTING SETUP AND PROCEDURE

Three limestone aggregate stockpiles were used in this research including CM11, CM16, and FM20. Table 2 displays all the data about the utilized control mix design. The first step in the procedure was to fractionate each aggregate type over its proper sieves to make the necessary batches for the mixture samples for both the Indirect Tensile Test (IDT) and Fracture Energy (FE) test. Number of batches for the IDT and the FE tests were 12 and 4 respectively. Bitumen PG 58-22 was utilized for mixing. It was taken into consideration that the aggregate blend percentages along with the bitumen content percentage added by the weight of the aggregate would result in samples with 7 $\pm$ 0.5% air voids.

**Table 2. Control mix design details**

| **Aggregate batching** | | **Final aggregate blend gradation** | | **Optimum design data** | |
|---|---|---|---|---|---|
| Aggregate stockpile | Blend (%) | Sieve size (mm) | Passing (%) | Number of gyrations | 90.00 |
| CM11 | 43.2 | 25.00 | 100.0 | PG 58-22 (%) | 4.9 |
| CM16 | 27.1 | 19.00 | 96.1 | *Bulk specific gravity ($G_{mb}$) | 2.456 |
| FM20 | 28.5 | 12.50 | 75.6 | *Maximum specific gravity ($G_{mm}$) | 2.558 |
| MF | 1.2 | 9.50 | 64.5 | Target air void (%) | 4.00 |
| ***Related ASTM Specifications** | | 4.75 | 39.5 | VMA (%) | 13.7 |
| C 127: Aggregate bulk specific gravity<br>C 128: Aggregate apparent specific gravity<br>D 2041: Maximum specific gravity ($G_{mm}$)<br>D 2726: Bulk specific gravity ($G_{mb}$) | | 2.36 | 27.5 | VFA (%) | 73.0 |
| | | 1.18 | 17.8 | Dust proportion ratio | 1.01 |
| | | #30 | 12.3 | *Aggregate bulk specific gravity | 2.695 |
| | | #100 | 6.2 | Aggregate effective specific gravity | 2.958 |
| | | #200 | 4.6 | *Aggregate apparent specific gravity | 3.021 |

According to the research hypotheses, two conditioning processes were adopted in this research; the AASHTO T-283 and the IDOT modified conditioning processes. Total number of batches was divided into half for each conditioning process. In other words, 6 and 2 batches from IDT and FE respectively conditioned according to AASHTO T-283 test, and same number conditioned according to IDOT modified process. The two processes share that all the batches were to be heated along with the bitumen at the mixing temperature, which was in this case 155ºC for 2 hours. After that, the batches were mixed with 4.9% bitumen by the weight of the aggregate. In AASHTO T-283 condition process, the mixed batches of the tensile strength and fracture energy tests were kept to cool at room temperature for 2 hours, then they were placed in the oven at a temperature of 60ºC for 16 hours.

Then, oven temperature was increased to the compaction temperature, which was 137ºC, and the mixture pans were left for additional two hours. The mixtures were then compacted using the Superpave Gyratory Compactor (SGC) to a height of 95mm for the tensile strength samples and 170mm for the fracture test samples. The compacted samples were left to cool at room temperature for 24 hours.

Regarding the IDOT modified conditioning process, the mixed batches were returned immediately to the oven, and left there for 2 hours at a temperature of 137ºC. Then, the mixtures were compacted using the SGC. The compacted samples were left for 24 hours to cool at room temperature. Both FE samples of the AASHTO T-283 and IDOT modified were then sawed to produce three DCT specimens from each sample. The DCT specimens were then left to dry for 24 hours at room temperature**.**

## 2.1 Indirect tensile strength test (IDT)

Twelve samples were compacted for the IDT test, six of them were conditioned using the AASHTO method (referred to as AASHTO IDT samples) and the other six were conditioned following the IDOT modified method (referred to as IDOT IDT samples). The AASHTO IDT samples were divided into two sets; 3 samples for dry set and 3 samples for wet set. The dry set samples - according to AASHTO conditioning process – were wrapped in a plastic bag and placed in a 25ºC water bath for 2 hours, see Figure 1.

**Figure 1. Wrapped AASHTO dry samples in 25ºC water bath**

Regarding the AASHTO IDT wet set; the samples were first saturated in such a way that (70 to 80)% of the air void volume of each sample was filled with water. After saturation, each sample was sealed and placed in a plastic bag that contained 10ml of water. The samples were then placed in the freezer at a temperature of -18ºC for 16 hours. After unwrapping the plastic bags, the samples were removed from the freezer and immediately placed in a 60ºC water bath for 24 hours, see Figure 2. After this step, the samples were placed in a 25ºC water bath - same that was used for AASHTO dry set – for 2 hours, see Figure 1, then they were ready to be tested.

**Figure 2. Submerged wet set samples in 60ºC water bath**

The IDOT IDT samples were also divided into two sets; 3 samples as a dry set and 3 samples as a wet set. The dry set samples were just submerged in a 25ºC water bath for 2 hours and they were ready to be tested. Regarding the wet set samples; they were saturated until their air void volume was (70 – 80)% filled with water. Then, the samples were placed in a 60ºC water bath for 24 hours. Afterwards, the samples were placed in the 25ºC water bath for 2 hours and then they were ready to be tested. Table 3 shows a general comparison between the two procedures, which followed for conditioning the samples.

**Table 3. Comparison between AASHTO T-283 and IDOT Modified AASHTO T-283 specifications**

| Conditioning Specification | Mixing Procedure | Dry Set Conditioning | Wet Set Conditioning |
|---|---|---|---|
| **AASHTO T-283** | • Heating aggregate and binder at mixing temperature.<br>• Mixing aggregate and binder.<br>• Cool mixture at room temperature for 2 hours.<br>• Put mixture in oven for 16 hours at 60°C.<br>• Increase oven temperature to compaction temperature for 2 hours.<br>• Compact the mixture | Wrap in a plastic bag and place in 25°C water bath for 2 hours | • Saturate each sample in the range of (70-80)%.<br>• Wrap sample in saran paper.<br>• Place wrapped sample in plastic bag containing 10ml of water.<br>• Place sample in freezer for at least 16 hours at -18°C.<br>• Unwrap the sample and place in 60°C water bath for 24 hours.<br>• Place sample in 25°C water bath for 2 hours. |
| **IDOT Modified AASHTO T-283** | • Heating aggregate and binder at mixing temperature.<br>• Mixing aggregate and binder.<br>• Put mixture in the oven for 2 hours at compaction temperature.<br>• Compact the mixture | Place samples in 25°C water bath for 2 hours without wrapping | • Saturate each sample in the range of (70-80)%.<br>• Place sample in 60°C water bath for 24 hours.<br>• Place sample in 25°C water bath for 2 hours. |

## 2.2 Fracture Energy Test (FE)

The specification of this test can be found under ASTM D 7313 – 07 [10]. The main purpose of this test is to assess the resistance of HMA to fracture due to low temperature. Many factors affect fracture energy of mixtures including mainly bitumen and aggregate type. It should be noted that DCT samples were tested at -12ºC. The load versus deflection curve is the main output for each sample. Finally, fracture energy is obtained by calculating the area under the curve divided by the ligament area according to the equation 1:

$$G_f = \frac{AREA}{B.(W-a)} \quad (1)$$

Where $G_f$: fracture energy (J/m$^2$), *AREA*: area under load-deflection curve (mm-kN), *B*: specimen thickness (m), and *(W-a)*: Initial ligament length (m)

Twelve DCT samples were prepared, six conditioned following the AASHTO method (referred to as AASHTO FE samples), and six conditioned following the IDOT modified AASHTO (referred to as IDOT FE samples). The AASHTO FE samples were divided into two sets; 3 samples in dry set and the other three in wet set. Preparation of the dry and wet set of AASHTO FE was similar to that followed for the AASHTO IDT dry and wet sets. The IDOT FE samples were also divided into two sets dry and wet each with 3 samples. Preparation of both set samples were similar to that mentioned for the preparation of IDOT IDT dry and wet set samples. The FE samples were then placed in a -12ºC chamber for 2 hours before testing.

## 3. TEST RESULTS & DISCUSSIONS

### 3.1 Indirect tensile strength test (IDT)

Following the conditioning and the preparation of the IDT samples, they were immediately tested using the IDT apparatus in ATREL; see Figure 3. The IDT test results have been summarized in Table 4. Moreover, the TSR values have been plotted in Figure 4.

**Figure 3. IDT apparatus at ATREL**

**Table 4. IDT results for the AASHTO and IDOT samples**

| Conditioning Method Sample No | Indirect Tensile Strength (kPa) | Average Tensile Strength (kPa) | Tensile Strength Ratio |
|---|---|---|---|
| **AASHTO-D1** | 759.14 | 671.14 | 0.78 |
| **AASHTO-D2** | 624.66 | | |
| **AASHTO-D3** | 629.63 | | |
| **AASHTO-W1** | 513.29 | 521.39 | |
| **AASHTO-W2** | 467.96 | | |
| **AASHTO-W3** | 582.91 | | |
| **IDOT-Dry-1** | 556.49 | 572.24 | 0.88 |
| **IDOT-Dry-2** | 580.50 | | |
| **IDOT-Dry-3** | 579.74 | | |
| **IDOT-Wet-1** | 531.99 | 505.75 | |
| **IDOT-Wet-2** | 516.67 | | |
| **IDOT-Wet-3** | 468.58 | | |

It can be seen that TSR value in AASHTO method is almost 13% less than IDOT Modified procedure. Therefore, it is clear that eliminating the freeze-thaw cycle in sample conditioning will lead to underestimating the moisture damage on the mixture.

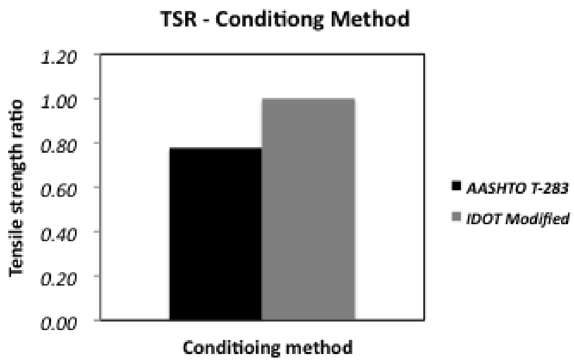


**Figure 4. TSR for different conditioning method**

Figure 5 shows the comparison of IDT results for dry and wet samples in different conditioning methods. Comparing the IDT results for dry conditioned samples in AASHTO and IDOT modified procedure show that the long-term aging of the bitumen during mixing will lead to higher values of indirect tensile strength. The increase in resilient modulus and indirect tensile test parameters due to bitumen aging has been studied well in the literature [11]. However, comparing the IDT results for wet conditioned samples in AASHTO and IDOT Modified procedure shows clearly the detrimental effect of freeze-thaw cycle on overcoming the long-term aging effect and decreasing tensile strength values.

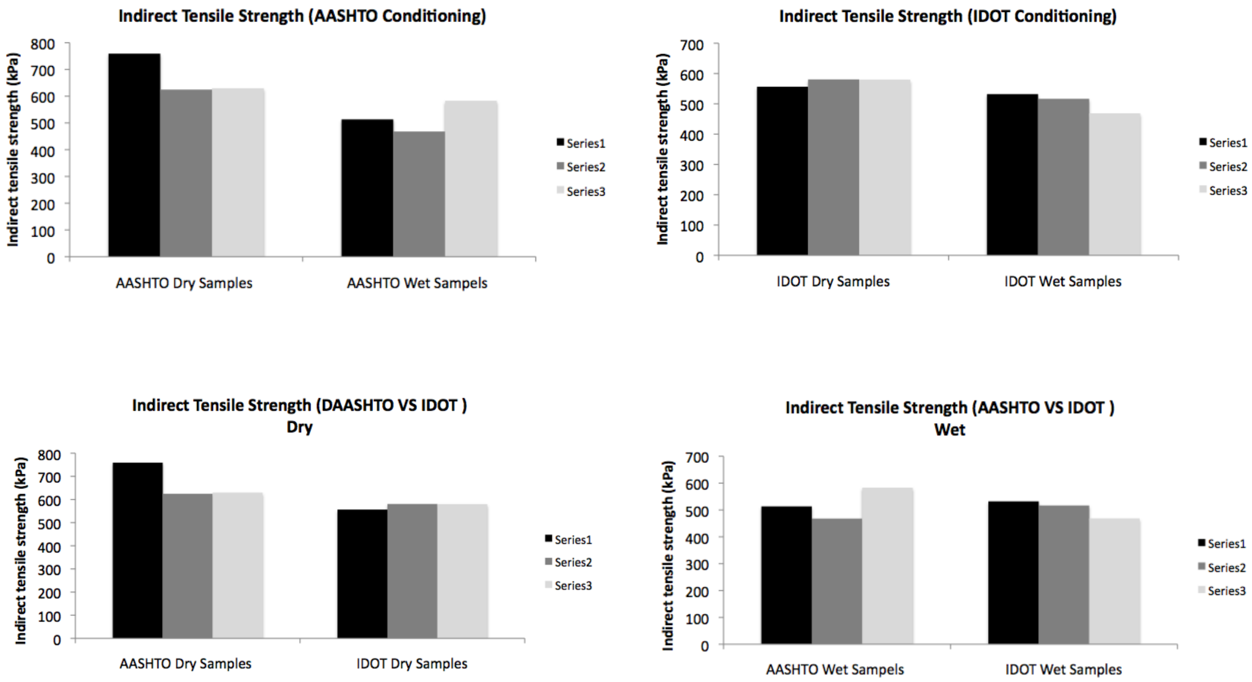


**Figure 5. Comparison of IDT values in AASHTO & IDOT Modified procedure**

### 3.2 Fracture energy test (FE)

FE samples were placed and tested in ATREL also utilizing the fracture energy apparatus, see Figure 6. The fracture energy test results have been summarized in Table 5. It has to be noted that second specimen of the AASHTO Dry set failed during the test. Therefore, the result from this sample was not considered in the analysis. Moreover, 3 extra control samples (with 2 hours conditioning during mixing) and without any climate conditioning method were prepared and tested to provide the information as a reference point of the fracture energy of unconditioned mixture with 58-22 bitumen.

Figure 7 shows the comparison of the fracture energy test results. Comparing all the results with the fracture energy of the control samples shows that aging and conditioning will harden the bitumen and decrease the fracture energy. The effect of long-term aging on decreasing facture energy can be seen by comparing AASHTO and IDOT modified dry samples. Surprisingly, Figure 7 shows that the AASHTO wet conditioned samples with 1 freeze and thaw cycle had the closet fracture energy to control samples.

**Figure 6. DCT samples placed inside fracture energy apparatus**

**Table 5. Fracture Energy test results for the AASHTO and IDOT samples**

| Conditioning method Sample No. | Peak load (kN) | Fracture Energy (J/m$^2$) | Average Fracture Energy (J/m$^2$) |
|---|---|---|---|
| AASHTO-D1 | 2.841 | 391 | 426 |
| AASHTO-D2 | 3.037 | 461 | |
| AASHTO-D3 | 3.379 | --- | |
| AASHTO-W1 | 2.903 | 604 | 606 |
| AASHTO-W2 | 3.095 | 627 | |
| AASHTO-W3 | 2.975 | 587 | |
| IDOT-Dry-1 | 3.248 | 604 | 582 |
| IDOT-Dry-2 | 3.092 | 565 | |
| IDOT-Dry-3 | 3.065 | 576 | |
| IDOT-Wet-1 | 2.629 | 479 | 539 |
| IDOT-Wet-2 | 3.162 | 574 | |
| IDOT-Wet-3 | 3.011 | 563 | |
| Control-1 | 2.901 | 674 | 711 |
| Control-2 | 3.760 | 728 | |
| Control-3 | 3.178 | 731 | |

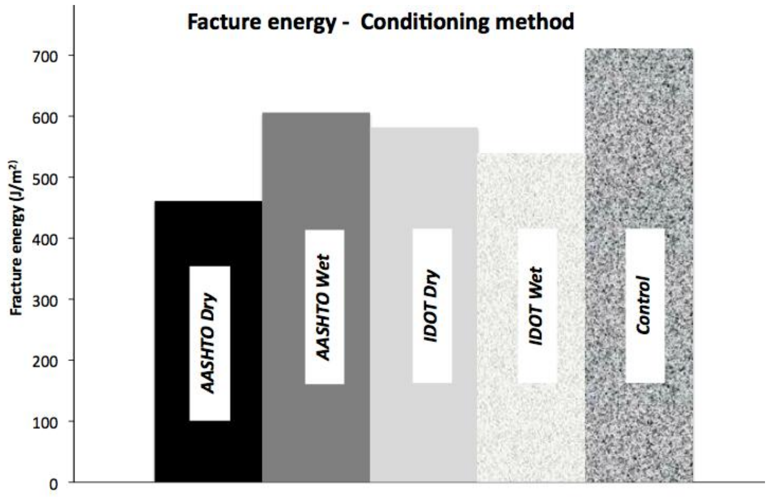


**Figure 7. Comparison of FE values in AASHTO & IDOT Modified procedure**

Therefore, it can be concluded that 1 freeze and thaw cycle softens the bitumen by even overcoming the effect of long-term aging in hardening the bitumen. It has to be mentioned that the fracture energy tests were performed at -12$^{o}$C while it took two hours for the samples to reach to the test temperature. Comparing IDOT Modified wet and dry samples shows the effect of water conditioning on decreasing the fracture energy.

## 4. CONCLUSIONS & RECOMMENDATIONS

This study showed that IDOT modified test method overestimates the mixture TSR values by not properly considering the detrimental effect of real winter climate conditions. In addition, it was observed that long-term bitumen aging will increase the indirect tensile strength. The freeze-thaw cycle was found as an important factor in decreasing the indirect tensile strength.

The fracture energy test results showed that aging and conditioning of the samples would lead to decrease in fracture energy. Moreover, in equal level of bitumen aging, freeze-thaw cycle was found as a factor in softening the bitumen and increasing the fracture energy. However, water conditioning of the samples decreased the mixture fracture resistance.

Therefore, it was confirmed that at least one freezing and thawing cycle is to be introduced in the moisture damage test procedures for better simulation especially in the wet-freeze regions. Moreover, it can be concluded the fracture resistance of mixture can be considered as an indicator of the moisture susceptibility of the mixture; however, more lab testing on various types of mixture using different methods of conditioning are recommended to better clarify the effect of sample conditioning on mixture fracture energy. Designing a complete test matrix is recommended to provide the data to compare the effect of one conditioning factor independent from other factors, on the striping properties of each mixture.

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