



## THE EFFECTS OF FREEZE-THAW CYCLES AND DEICER SALT BRINE ON THE TENSILE STRENGTH OF RECYCLED ASPHALT MIXTURES

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**Abstract:** In places of the world with severe seasonal variations, such as the province of New Brunswick, asphalt concrete mixtures are subjected to cyclic freezing and thawing during the cold months. Moreover, different types of deicers are frequently used to mitigate the effects of snow, ice, and freezing rain on the pavements to increase the levels of service of roadways. Despite having many safety advantages, the use of deicers has raised concerns over the effects on pavement materials. Salt is the most commonly used deicing product in New Brunswick and understanding its effect on the durability of asphalt concrete would help pavement managers to improve the determination of maintenance, preservation, rehabilitation, and the estimation of the life-cycle costs of pavement assets. This study investigated the effects of Freeze-Thaw Cycles (FTCs) and Deicer Salt Brine (DSB) on the tensile strength of recycled asphalt mixtures and conventional Hot Mix Asphalt (HMA). In partnership with the New Brunswick Department of Transportation and Infrastructure (NB DTI), five different mix designs of plant-produced asphalt mixtures, including recycled hot mixture and conventional HMA were collected from different projects in New Brunswick. These samples were subjected to different conditions simulating extreme weather in New Brunswick, including rain, freeze-thaw cycles, and the use of deicers over the pavement. The Tensile Strength Ratio (TSR) was determined to estimate the stripping susceptibility for each source material. The results from each source were then compared to evaluate the general performance differences between recycled and conventional HMA in New Brunswick, and this characterization is applicable to the development of new cost-effective pavements in the province.

### 1 INTRODUCTION

Many efforts have been made to address the issues of air pollution, global warming, and emissions of greenhouse gasses. It cannot be ignored that recycling is one of the best ways to a sustainable future. There are some methods of recycling in the asphalt paving industry, including hot mix asphalt recycling, hot in-place recycling, cold in-place recycling, and full depth recycling (Plescan and Plescan 2015). Recycling hot mix asphalt (HMA) material results in a reusable mixture of aggregate and asphalt binder known as reclaimed asphalt pavement (RAP) (Al-Qadi et al. 2007). According to the definition of the Federal Highway Administration (FHWA 2001), reclaimed asphalt pavement (RAP) is material containing asphalt and aggregates removed from a pavement and can be applied to any project which requires rehabilitation or major reconstruction. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. At the end of the service life of hot mix asphalt pavement, milled materials (RAP) still maintain considerable value, which can be reused in virgin HMA to reduce the amount of new material needed. The design of HMA with RAP is based on a three-tier

system (Al-Qadi et al. 2007). Less than 15% of RAP can be used without changing the virgin binder grade. When RAP content is between 15% and 25%, the high and low-temperature grades of the virgin binder are both reduced by one grade. Finally, if HMA has more than 25% RAP, blending charts are used to determine the grade of the binder.

Recycling has numerous advantages compared to conventional HMA, including economic, environmental, and social benefits (Hoppe et al. 2015). This study evaluated the tensile strength of recycled asphalt pavement including RAP after exposure to freeze-thaw cycles and brine in the province of New Brunswick.

## 2 FREEZE-THAW CYCLES AND ICE CONTROL METHODS IN NEW BRUNSWICK

Several studies have determined the effects of freeze/thaw cycles on flexible and rigid pavements. The annual average daily minimum and maximum temperatures in Fredericton, New Brunswick are  $-15^{\circ}\text{C}$  and  $+25^{\circ}\text{C}$  respectively (Living in Canada 2018). In addition, the precipitation of snow in New Brunswick generally occurs over a period of 6 months from November to April (Avirneni et al. 2016). Lamothe et al. (2017) revealed that freeze-thaw cycles damage the materials of asphalt mixtures dramatically. They found that this effect is more pronounced after the 30<sup>th</sup> cycle.

Snow and ice control methods are generally classified into three categories: mechanical, thermal and chemical (Hossain and Fu 2015). The most effective is the chemical method, which is subcategorized into deicing and anti-icing. Also, abrasives such as sand are deployed to improve traction. Different types of deicers are frequently used in cold regions including North America for the control of snow, ice and freezing rain to increase the levels of service and safety on winter roadways. The benefits of anti-icing are well documented in previous studies (TRS 2009; Hossain and Fu 2015). However, the use of these materials has raised concerns over their effects on pavements. Salt is one of the most common deicing products in New Brunswick and understanding the degree of deterioration caused by deicer treatments would help pavement managers to anticipate maintenance, rehabilitation, replacement actions and calculate life-cycle costs for the pavements more accurately.

Currently, research on the effects of deicers on the performance of flexible pavement is rare; however, there are numerous papers in relation to rigid pavements. The deicer salts accumulated on the surface of asphalt pavement can cause damage to asphalt material due to erosion and crystal formation after dehydration (Yu et al. 2013). Generally, deicing salt can be divided into three categories. The first category is chloride salt, such as calcium chloride, magnesium chloride, and sodium chloride. The second type is non-chloride salt such as calcium magnesium acetate (CMA), and potassium acetate. And, the third category is hybrid (Li et al. 2012).

In 2013, researchers from the Utah Department of Transportation Research Division published a literature review on the physical and chemical effects of deicers on concrete pavement (Sumsion and Guthrie 2013). They found that deicers can affect concrete both physically and chemically. Physical effects are typically manifested as cracking and salt scaling, while the chemical effects of deicers are often overshadowed by the physical effects. Sutter et al. (2006) revealed that exposure of various mortar specimens to calcium and magnesium chloride solutions at  $40^{\circ}\text{F}$  led to severe expansion, with deterioration first noticed at 56 days. Shi et al. (2011) soaked samples of rigid pavement in different types of deicer brine for around 340 days at room temperature. They found that continuous exposure to non-inhibited NaCl, inhibited NaCl and the inhibited  $\text{CaCl}_2$  deicer led to limited levels of strength gain of the concrete, whereas exposure to inhibited  $\text{MgCl}_2$  led to significant strength loss.

Moreover, some studies have been devoted to enhancing the performance of asphalt mixture through physical or chemical modifications. In 2010, research was done in the United States on the effect of different deicing solutions on the tensile strength of asphalt mixture (Goh et al. 2011), which demonstrated that weaker solutions of NaCl and stronger solutions of  $\text{MgCl}_2$  and  $\text{CaCl}_2$  are associated with higher tensile strengths of asphalt mixtures. Lamothe et al. (2017) published a journal paper about the degradation of hot mix asphalt samples subjected to freeze-thaw cycles and partially saturated with water or brine. A saturation process under vacuum was used and adapted from the test method on their research. Table 1 illustrates some details of the previous studies on the effects of deicers on the concrete and asphalt mixtures.

Table 1: Previous Studies on the Effects of Deicers on the Concrete and Asphalt Mixtures

Researcher/s and Year	Material Considering	Method	Period	Type of Salt	Dosage of Salt
Peterson 1995	Concrete	Soaking	22 months	CMA, NaCl	-----
Cody et al. 1996	Concrete	F/T, W/D, Soaking	222 Days	CaCl <sub>2</sub> , MgCl <sub>2</sub> , NaCl	-----
Sutter et al. 2006	Concrete	Soak@4°C	84 days	CaCl <sub>2</sub> , MgCl <sub>2</sub> , NaCl	3% by vol. of liquid chemicals, 3% by mass of solids
Shi et al. 2011	Concrete	Soak@25°C	330-347 days	CaCl <sub>2</sub> , MgCl <sub>2</sub> , NaCl	23-30% (by weight of solution)
Goh et al. 2010	Asphalt Mixture	-----	-----	CaCl <sub>2</sub> , MgCl <sub>2</sub> , NaCl	15% or less
Lamothe et al. 2017	Asphalt Mixture	Saturation	90min	-----	7,14,19%

### 3 RESEARCH GOAL AND OBJECTIVES

The main goal of this study is to evaluate the performance of conventional and recycled asphalt mixtures in New Brunswick in terms of tensile strength after exposure to water, freeze-thaw cycles and deicer salt brine. The main research objective which will be used to achieve this goal is measuring the effects of moisture on the recycled and conventional asphalt concrete mixtures using TSR.

Table 2 illustrates the materials used in this study which have been collected by NBDTI from different paving projects in New Brunswick in the summer and fall 2017.

Table 2: Description of Samples Collected

Source Code	Date, receiving Materials	Mix Type	AC Type	AC %	Antistrip
1 R	Jun. 23/2017	HRD	PG 58-28	6.05	Adhere 6500
1 C	July. 31/2017	D	PG 58-28	5.80	Adhere 6500
2 R	July. 31/2017	HRD	PG 58-28	6.30	No
3 R	July. 31/2017	HRD	PG 58-28	6.40	No
4 R	Sep. 25/2017	HRD	PG 58-28	6.00	Adhere 6500

### 4 METHODOLOGY

In this study, five different samples of recycled asphalt mixture and HMA from different asphalt plants in New Brunswick were collected. The Marshall compaction method was used for preparing the specimens. These samples were then subjected to different simulated weather conditions. Finally, samples were subjected to a TSR test to determine the effects of those conditions on the asphalt mixtures.

The following are the laboratory stages of this research:

1. Determination of theoretical maximum specific gravity ( $G_{mm}$ ) of uncompacted mixtures (ASTM-D2041 2011).
2. Preparation and compaction of 4 inches diameter cylindrical asphalt mixtures specimens using Marshall apparatus (ASTM-D6926 2017).
3. Determination of bulk specific gravity of compacted asphalt mixtures (ASTM-D2726 2017).
4. Sorting the specimens into 5 subsets and measuring their heights.
5. Determining the degree of saturation (DoS) and Volume of the specimens after partially saturating them. The following equation has been used to find the DoS (ASTM-D4867 2014):

$$[1] \text{DoS} = \text{Vol.}_{aw} / \text{Vol.}_{va}$$

where, DoS: Degree of Saturation

Vol.<sub>aw</sub>: Volume of the absorbed water, cc

Vol.<sub>va</sub>: Volume of the air voids, cc

6. Conditioning the specimens by simulating extreme weather in New Brunswick
7. Measuring the heights of specimens
8. Determining water absorption and DoS of the specimens after conditioning
9. Calculate the tensile strength ratio based on the following equation: (ASTM-D4867 2014)

$$[2] S_t = 2000 P / \pi t D \text{ (kPa)}$$

where,  $S_t$ : Tensile strength, kPa

P: Maximum load, N

t: Specimen height immediately before tensile test, mm

D: Specimen diameter, mm

## 5 SIMULATION OF EXTREME WEATHER

Based on the extreme weather in New Brunswick, four different conditions including moisture, single freeze-thaw cycle (FT), multiple freeze-thaw cycles (FTCs), and brine saturation were simulated in this research. (Table 3)

### 5.1 Moisture

According to ASTM-D4867 (2014), the moisture-conditioned specimens were soaked in distilled water at +60°C for 24 hours. After that, all the specimens, unconditioned and moisture-conditioned were soaked in the water bath at +25°C for 1 hour.

### 5.2 Freeze-Thaw Cycle (FT)

Based on ASTM-D4867 (2014), each specimen was wrapped tightly with two plastic layers. Each of them was then placed into a leak-proof plastic bag containing 3 mL of water and sealed with a tie. Next, they were placed into a freezer at -18°C for 15 hours, before placing into a water bath at +60°C for 24 hours. The bag and wrapping plastic were then removed, and the temperature of the specimens was adjusted by soaking in a water bath for an hour at 25°C.

### 5.3 Freeze-Thaw Cycles (FTCs)

The specimens were wrapped and then placed into a plastic bag, in the same way as the FT conditioning. For the minimum and maximum cyclic temperature, due to the lack of a standard test method for exposing asphalt mixtures to rapid freezing and thawing, the standard test method for concrete has been used in this study. According to this standard (ASTM-C666 2015), the nominal FTCs are lowering the temperature from +4°C to -18°C and raising it from -18°C to +4°C in a cabinet (Figure 1). For the Number of FTCs, some studies revealed that in the province of Quebec, the number of cycles is between 40 and 51 annually (Lamothe et al. 2017). So, 50 cycles of freezing and thawing has been chosen in this study as the assumed number of FTCs in the province of New Brunswick per year. The variation of FTCs cabinet temperature in 1 cycle can be found in Figure 1.

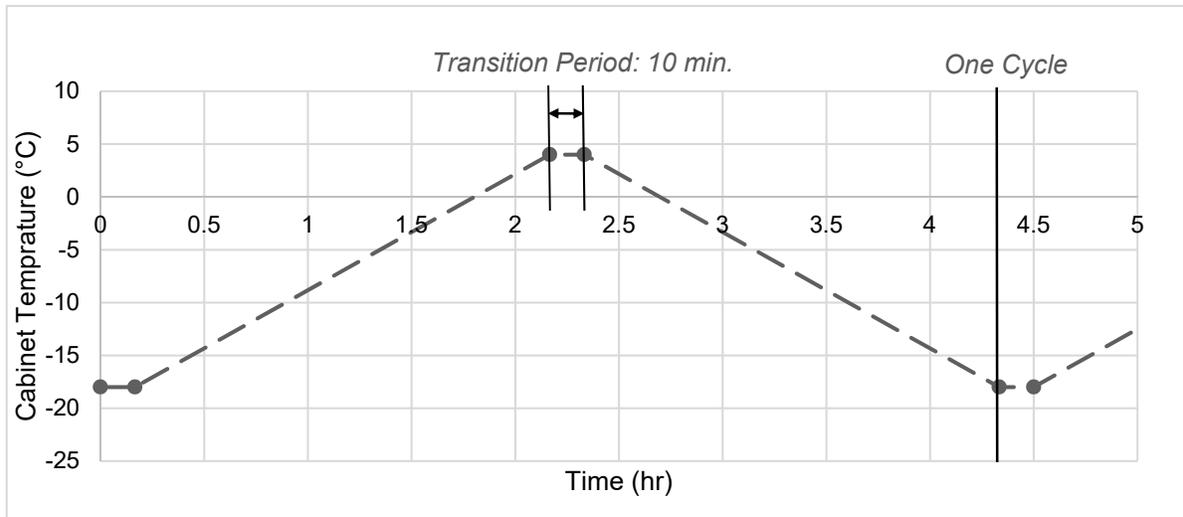


Figure 1: FTCs cabinet temperature in 1 cycle

### 5.4 Partial Saturation with Brine

Considering Lomothe *et al.* (2017), the specimens were placed into the flask of rice test filled with brine (15% salt by weight of solution) at the vacuum pressure of 30 mmHg for 90 minutes.

Table 3: Summary of different simulations of extreme weather considered in this study

Conditions	Summary of Procedure
Moisture conditioning	24 hours at 60±1°C
FT	15 hours at -18±2°C, then 24 hours at 60±1°C
FTCs	50 cycles between -18°C and +4°C
Saturation with brine	1.5 hrs at 30 mmHg, 15% salt by weight of solution

## 6 ANALYSIS AND RESULTS

### 6.1 Effect of Extreme Weather Conditions on the Asphalt Mixtures

Various tensile strengths of asphalt mixtures were derived for the different samples (Figure 2). Sample 4R has the highest and sample 1R has the lowest tensile strength among the other samples. It is obvious that effect of multiple freeze-thaw cycles is more than the other conditions, especially in the sample 4R. In addition, tensile strength of 2R and 3R dropped more than the other samples, which probably is because of the lack of antistrip in the mix. Moreover, the tensile strength of the sample 2R after FT was apparently higher than the moisture conditioned samples; however, subsequent analysis demonstrated that the difference is

not statistically significant. To better understand, the effects of different conditions on the tensile strength of asphalt mixtures is plotted on figure 3.

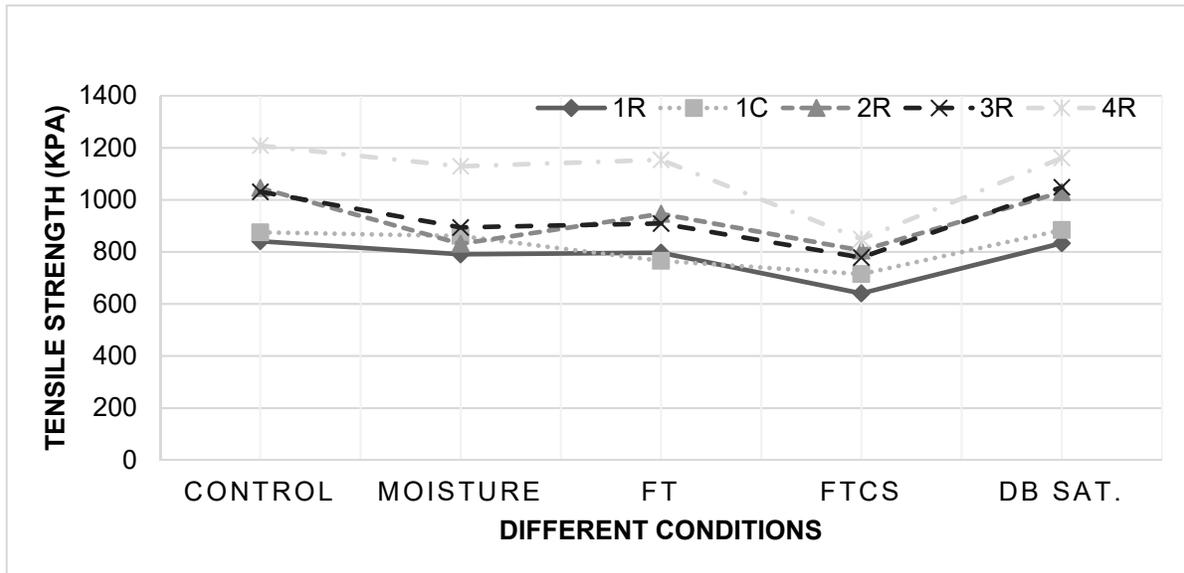


Figure 2: Tensile Strength of Asphalt Mixtures for Different Samples

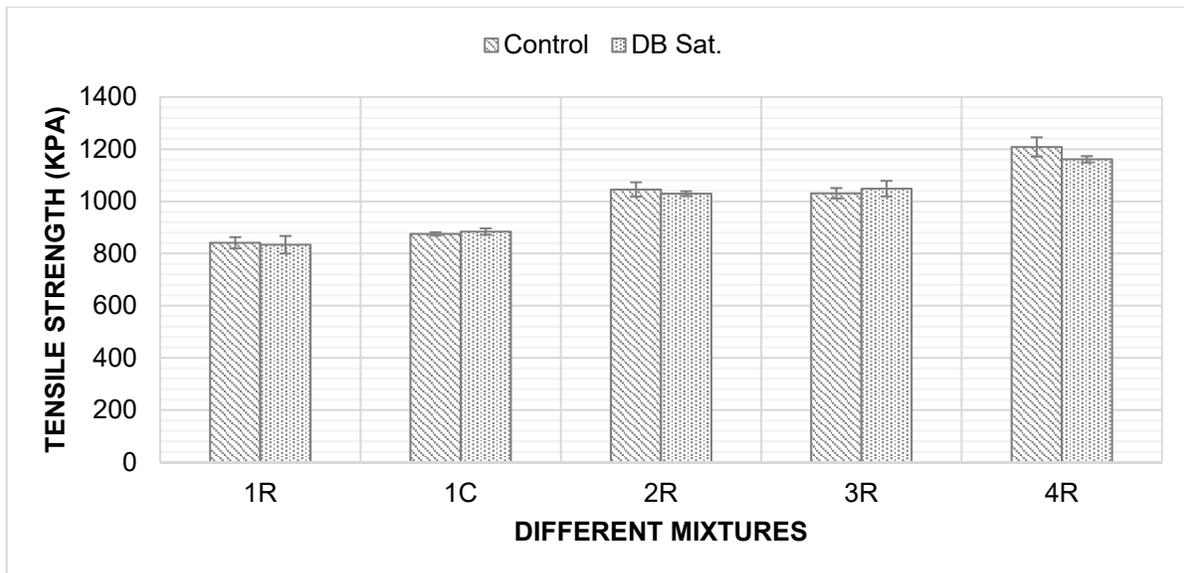


Figure 3: Tensile Strength of Five Samples Considered in This Research

The statistical analysis (t-Test) were done to identify significance of the effects of DSB saturation on different samples. It can be seen that the effects of DSB saturation on the mixtures is not significant (Table 4).

Table 4: t-Test, Paired Two Sample for Means

	1R		1C		2R		3R		4R	
	Con.	DSB	Con.	DSB	Con.	DSB	Con.	DSB	Con.	DSB
Mean	841	834	875	884	1046	1030	1031	1049	1208	1161
Variance	2092	5087	188	659	3424	383	1772	3990	6124	673
Observations	3	3	3	3	3	3	3	3	3	3

t Stat	0.16	-0.5	0.35	-0.3	0.79
P(T<=t) one-tail	0.44	0.33	0.38	0.38	0.26
t Critical one-tail	2.92	2.92	2.92	2.92	2.92
P(T<=t) two-tail	0.89	0.66	0.76	0.76	0.51
t Critical two-tail	4.3	4.3	4.3	4.3	4.3

## 6.2 Comparison between Recycled and Conventional Mixtures

A comparison of tensile strength between conventional asphalt mixture (1C) and Recycled asphalt mixture (1R) coming from the same source is plotted in figure 4. It can be seen that the control mixture type D has the higher tensile strength compared to the control HRD.

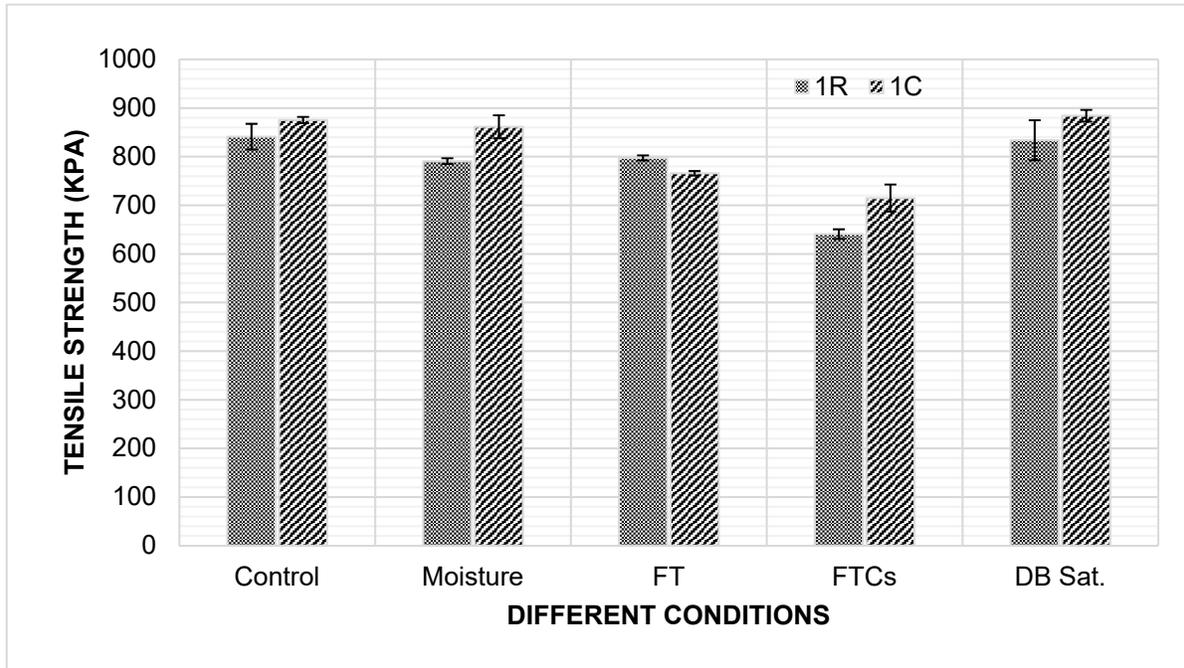


Figure 4: Comparison of Tensile Strength between Conventional Mixture and Recycled Mixture

t-Test analyses show that the difference between tensile strength of conventional and recycled mix is not significant, for all the conditions except for FT where the analysis indicated that the tensile strength of the conventional mix is significantly different (lower) than the strength of the recycled hot mix (Table 5).

Table 5: t-Test for Comparison of Conventional (D) and Recycled (HRD) Mixtures

	Control		Moisture		FT		FTCs		DSB	
	D	HRD	D	HRD	D	HRD	D	HRD	D	HRD
Mean	875	841	861	791	766	797	715	641	884	834
Variance	188	2092	2514	103	98.6	83.4	3470	296	659	5087
Observations	3	3	3	3	3	3	3	3	3	3
t Stat	1.84		2.31		-9.6		1.83		0.9	
P(T<=t) one-tail	0.10		0.07		0.01		0.1		0.23	
t Critical one-tail	2.92		2.92		2.92		2.92		2.92	
P(T<=t) two-tail	0.21		0.15		0.01		0.21		0.46	
t Critical two-tail	4.30		4.30		4.3		4.3		4.3	

## 7 CONCLUSIONS

Indirect tensile strength tests were subjected to four recycled and one conventional asphalt mixtures. All five materials were then conditioned, exposed to moisture, freeze-thaw, freeze-thaw cycles, and saturation in salt brine. The following conclusions are drawn from this research:

6. After moistening, the reduction of tensile strength of mixture for the samples 2R and 3R without antistrip in the mix were 20% and 13% respectively, while the tensile strength of the other samples containing antistrip was 5% approximately.
7. One Freeze-thaw cycle reduced the tensile strength of asphalt mixtures by approximately 10%.
8. The highest reduction in tensile strength of the asphalt mixtures happened after 50 FTCs conditioning by the range of 18% to 30%.
9. DSB saturation did not have a significant effect on the tensile strength of the asphalt mixtures.
10. In a comparison of two types of mixtures (HRD and D), conventional asphalt mixture apparently had a slightly higher tensile strength than the recycled mixture, however the difference was not statistically significant.

## 8 RECOMMENDATIONS

This paper is based on the preliminary results of an ongoing study at the University of New Brunswick, aimed at evaluating the effects of freeze/thaw cycles and deicer salt brine on the durability of plant produced recycled asphalt mixtures. This research concentrated on the tensile strength of asphalt mixtures. Four sources in the province of New Brunswick were considered in this study. It is recommended that more sources of recycled and conventional asphalt mixtures be tested to fully understand the effects of the extreme weather on the material.

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