Mitigating pavement shoulder cracking in northern, low volume highways by incorporating Tencate Mirafi® H_2R*i* wicking geotextile

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ABSTRACT
Edge cracking has been a challenge for the Yukon Government. In an effort to have an improved understanding of shoulder cracking and prevention methods, the Yukon Government partnered with FPInnovations and TenCate Geosynthetics to construct two, instrumented, thin pavement test sites on the Campbell Highway near Watson Lake, Yukon. Both test pavements were treated to mitigate edge cracking with Mirafi® H_2R*i*, a high strength-woven- geotextile with wicking properties. Project activities included site monitoring of moisture and temperature trends, crack mapping, differential compaction measurement, extended site observation and surveying. It has been concluded that Mirafi® H_2R*i* is draining moisture effectively. This helped improve the pavement materials' bearing capacity. Mirafi® H_2R*i* reduced shoulder cracking as well. Other factors (differential compaction and maintenance practices) contribute to edge cracking. This research will provide knowledge about solutions to mitigate pavement distress and reduce maintenance costs.

RÉSUMÉ
Les fissures d'épaulement représentent un défi pour le gouvernement du Yukon. Afin d'avoir une meilleure compréhension du mécanisme qui les régit et de les prévenir, deux sites d'essais ont été construits et instrumentés sur la route Campbell près de Watson Lake, au Yukon, en collaboration avec FPInnovations et TenCate Geosynthetics. Les deux sections d'essai de chaussées ont été renforcées avec Mirafi® H_2R*i*, un géotextile tissé à haute résistance, aux propriétés hygroscopiques. Les activités du projet comprenaient le traitement des données de teneurs en eau et de température, les mesures du compactage différentiel et l'observation du site. Il a été conclu que Mirafi® H_2R*i* drainait efficacement l'excès d'eau. Cela permet d'améliorer la capacité portante de la structure. Il semble que Mirafi® H_2R*i* ait réduit la fissuration. D'autres facteurs (compactage différentiel et les pratiques de maintenance) contribuent à la fissuration. Cette recherche fournira des solutions permettant d'atténuer l'endommagement de la chaussée et réduire les coûts d'entretien.

1 INTRODUCTION

According to the Yukon government, Department of Highways and Public Works (HPW), edge cracking in Yukon highways is caused by lateral and vertical displacement of the road shoulders and side slopes. This displacement results from differential frost heave of the side slope and concentration of moisture in the road edge materials due to road surface drainage penetrating downwards along the edge of the bituminous surface and moisture wicking upwards with capillary action. Edge cracking typically occurs within 2 years of road construction. Edge cracking has been observed in embankments, transition zones (cuts to fills, fills to cuts), through-cuts, realignments, and wet areas. Cracking commonly penetrates into the subbase; however, in some areas, cracking have reached the subgrade. Edge cracks may widen by the freezing and expansion of water accumulating in them. The Watson Lake area of the Yukon has been subject to climate changes in the last 15 years with warmer temperatures leading to more snow and freeze-thaw events, and potentially some permafrost melting. These climatic changes may promote edge cracking.

In 2015, a research contract was granted to FPInnovations by HPW to study the effectiveness of a wicking geotextile to mitigate edge cracking in the Yukon. This paper summarizes all the activities and results from the project, such as construction and instrumentation of two test sections, monitoring cracking and pavement distress at and near the test sections, performing field density testing, collecting and analyzing moisture and temperature from both test sections and gathering feedback from HPW staff regarding edge cracking causes and the ability of the wicking geotextile to mitigate edge cracking. Data was collected between September 2015 and January 2018, principally during the spring thaw and summer periods. The first objective of this project was to validate the potential causes and mechanisms of edge cracking. The second objective was to verify the ability of the wicking geotextile to drain water, increase road bearing capacity, and to prevent or reduce edge cracking.

2 SUMMARY OF LITERATURE REVIEW

The structural problems related to road construction in northern climates can be attributed to weak, uncompacted shoulder and side slope materials. Road shoulders and side slopes are difficult to compact and do not achieve the same density levels as materials under the running lanes. The under-compacted condition of these materials increases their hydraulic conductivity and causes them to intercept and retain road surface runoff. According to Lukas Arenson (2015), if the subgrade materials under the toe of the side slope are weak, or are weakened by high moisture levels, they will be inadequate to support the road edge which can lead to a rotation of the embankment.

Edge cracking also can occur if road edge materials are too weak to support heavy vehicles driving along the road shoulder.

The maintenance practice of plowing snow from the running surface into the shoulder can have a significant impact on edge cracking (Bradley et al. 2016). With spring thawing, the accumulation of snow on the shoulder creates differential thawing which is a significant contributor to edge cracking.

Bringing these concepts together, edge cracking occurs when loosely compacted road shoulders and side slopes rotate and spread outward. Rotation and spreading may result from weak materials under the side slope toe, differential frost heave and thawing, over-steepened side slopes, and concentration of moisture in the road edge materials. Differential thawing at the road edge is promoted by prolonged exposure to snow, and to a heightened moisture content in the materials; and, soil displacement is exacerbated by a loosely compacted condition and over-steepened geometry of the side slope. Also, according to Christine Lepage (2015), edge cracking is common in northern areas and can be caused by some or all of the following: overstep sideslopes, lack of stability and lateral support on the shoulders, differential compaction between the road and the shoulder, differential thawing of shoulder materials, and traffic operating close to the shoulder.

3 SITE CONSTRUCTION

In October 2015, FPInnovations, HPW, and TenCate established two instrumented sites with which to test the effectiveness of a new geotextile product to mitigate edge cracking and control roadbed moisture in a northern highway. The two test sites are located approximately 40 km north of Watson Lake, along the Campbell Highway (Figure 1). The two test sites are referred to as “site 4” and “site 6”. Site 4 is located on a tangent near KM 40.5. Site 6 is located on a tangent near KM 40.9. Prior to study, edge cracking extended for the entire 43-m length of site 4 along the eastern shoulder, and two parallel 15-m-long cracks were in the western shoulder. In site 6, edge cracking extended for the entire 43-m length of the eastern shoulder, and one 9-m-long crack was along the western shoulder.

Figure 1. Looking south from site 6 towards site 4 (from Bradley et al. 2016)

Dimensions and structure of the Campbell Highway test sites are presented in table 1.

Table 1. Road structure

	Thickness (mm)	Description
BST[1] mat	20-25	Granular A-type gravel in emulsified asphalt (HF, 250S)
Base	150	Granular A (20-mm crush)
Subbase	600	Granular E (200-mm pit run)
Subgrade	Ripped weathered rock	
Original Ground	(USCS classification SM) Silty gravelly sand (site 4); silty sand and gravelly silty sand (site 6)	
Road Prism	5.25 m lane width; 4% cross slope (treated as a low volume road); 3:1 side slopes for fills under 2 m high	

[1]Bituminous Surface Treatment

TenCate provided Mirafi® H_2R*i* for the test. This type of wicking geotextile was selected on the basis of its separation, filtration, soil reinforcement, soil confinement, and drainage properties. The geotextile‘s wicking ability is promoted by proprietary hydrophilic and hygroscopic yarns. Also, the wicking geotextile offers soil and base course reinforcement and confinement resulting in greater load distribution, and robust damage resistance for moderate to severe stress installations.

As for test site instrumentation, moisture was monitored using 6 GS-1 moisture sensors with an array of 10 epoxy 44007 NTC thermistors. The tenth thermistor was located in a radiation shield assembly installed at roadside on the datalogger housing to measure air temperature. Lakewood Systems Ltd.’s Ultralogger datalogger was used to manually download data from the 16 site sensors (6 moisture sensors ad 10 thermistors) at approximately 1 month intervals. The installation of the instrumentation at site 4 is summarized in table 2 below, as an example.

Table 2. Summary of instrumentation at site 4
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Site 4	centreline	road shoulder	road shoulder - control section (no geotextile)
Thermistors	above geotextile (15, 30, 45cm) 4 below geotextile (70, 100, 130, 160cm)	1 below geotextile (70cm)	1 at 70 cm
Moisture sensors	1 above geotextile (30 cm) 1 below geotextile (70 cm)	1 above geotextile (40 cm) 1 below geotextile (70 cm)	1 at 40 cm 1 at 70 cm

The wicking geotextile at both sites was installed within the subbase (69 cm and 79 cm down from the road surface at site 4 and site 6, respectively) as shown in figure 2.

Figure 2. Wicking geotextile installation (Bradley et al. 2016)

After installing the Wicking geotextile and instrumentation, the road was reconstructed by placing and compacting in-place lifts of “Granular E” specification subbase material. Over this, a base layer of 150 mm of “Granular A”-specification base material was placed, shaped to a 4% crown, and watered and compacted in-place (see table 2). BST was applied to gravel surfaces in June 2016.

4 RESULTS ANALYSIS

4.1 Site monitoring and general observations

General observations from site monitoring between September 2015 and January 2017 showed minor edge cracking at sites 4 and 6 in May 2016. Severe edge cracking (up to 10 cm wide) was found approximately 40 m north of site 6. Some of the edge cracking noticed outside of sites 4 and 6 was deep enough to have reached the subbase layer (i.e., 15+ cm deep). Figure 3 illustrates edge cracking on sites 4 and 6, as well as edge cracking north of site 6. The edge cracks on treated sites 4 and 6 appear less severe than the edge cracks north of site 6, outside of the test area.

Figure 3. Edge cracking at sites 4 and 6 (left), and outside of site 6 (right) (from Bradley et al. 2017)

The observations from the site monitoring during summer 2016 triggered a field density study with a nuclear density gauge to document roadbed density differences between the road running surface and the road shoulder and have a better understanding of the observations presented in figure 3.

Two trends were observed from the density study:

- Materials outside of the edge crack were less dense than inside (i.e., closer to the road centre). Base materials were as much as 8% less dense outside of edge cracks, whereas the uppermost 150 mm of subbase material was as much as 45% less dense outside of edge cracks.
- The level of compaction in the road increased from the surface downwards.

The most advanced state of edge cracking was noticed on the fill slope side of the road section located at KM 66.275 (outside of test sites). This area had dramatically reduced soil density (55%-59%) outside of edge cracks in the top of the subbase. The road had steeper sideslope than at KM 40 where the test sections are located.

It is possible to correlate the differential in compaction with the severity of edge cracking. Also, there is strong evidence of a relationship between a roadbed’s level of compaction and its porosity and ability to soak up water from precipitation. Less dense roadbed materials have a more open structure that will soak up more surface runoff and may, depending on the gradation and pore sizes, promote capillary rise of ground water.

Monitoring, conducted by HPW and FPInnovations, continued during spring and summer 2017. Similar to the observations from 2016, more minor edge cracking was observed at sites 4 and 6 in spring and summer 2017. Those cracks were less significant than the ones observed outside of the test sites. The edge cracks observed in 2016 at sites 4 and 6 did not appear to increase in size in 2017, however, cracks observed outside of sites 4 and 6 increased in size in 2017 as a comparison to 2016. Figure 4 illustrates the progression of edge cracking at sections outside of the test sites, at KM 66.275, which is untreated, has steeper slopes and differential compaction at the edges.

Figure 4. Pronounced edge cracking at KM 66.275 in spring 2017 (right), as a comparison to spring 2016 (left)

4.2 General trends from temperature and moisture data analysis

The following observations from temperature and moisture data collected at sites 4 and 6 apply to the period between September 2015 and mid-January 2018. The data acquisition systems were programmed to record data hourly from the sensors.

4.2.1 General temperature trends

The maximum and minimum temperature profiles (Figure 5) show a wide range of temperatures at the test sites during the entire study period. The ‘trumpet’-shaped curve shows that, for the entire period of this study, the test site ambient temperature ranged widely, from 38°C to -30°C. Temperatures recorded for 2017 were colder than in 2016. Minor variation between sites was noted at depth, and neither site was underlain by permafrost (indicated by the soil temperatures at a depth of 1.6 m being well above 0° C).

For simplicity, since the temperature and moisture trends are similar between sites 4 and 6, only results from site 4 are presented.

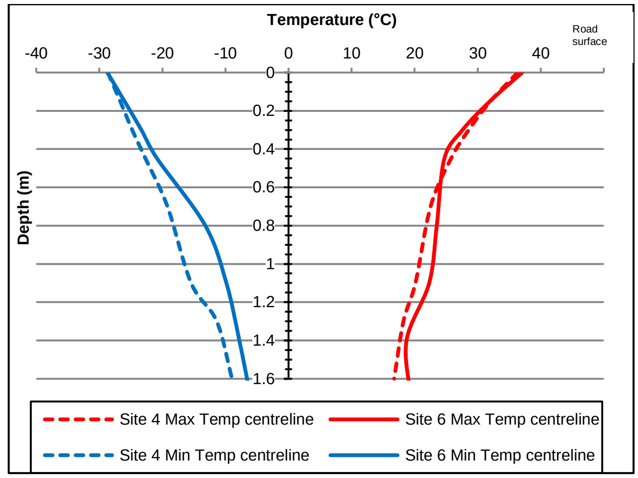

Figure 5. Centreline and shoulder temperature ranges with depth, sites 4 and 6 in, 2016 to 2018

Figure 6 compares temperature trends during fall 2015, 2016 and 2017. Similarly, Figure 7 compares temperature trends during spring 2016 and 2017. As anticipated, there was greater temperature variation at shallow roadbed depths where there are greater responses to diurnal temperature fluctuation. The road shoulder had consistently cooler temperatures than at centreline for the same 70 cm depth during fall and spring for the entire period of the study. This is attributed to the road shoulder having lower soil densities, and hence, lower levels of compaction and wetter soil conditions. Besides illustrating that shallow roadbed depths have higher sensitivity to air temperature variation, these charts also show top-down freezing and thawing events.

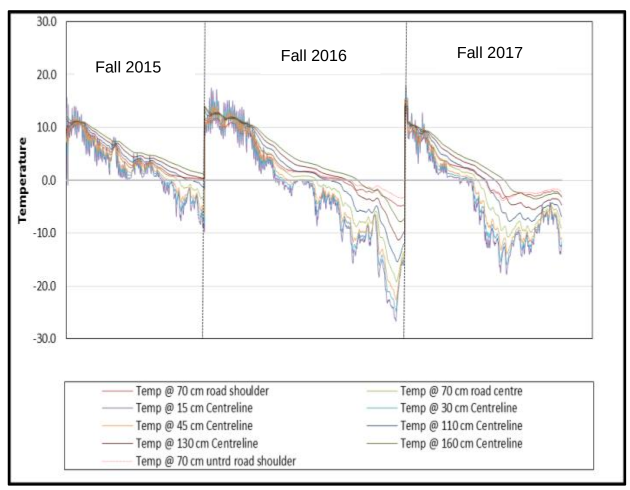

Figure 6. Comparison of temperature data, site 4, fall 2015, Fall 2016 and Fall 2017

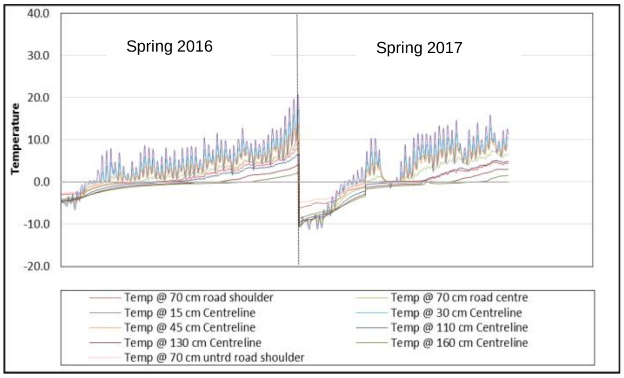

Figure 7. Comparison of temperature data, site 4, Spring 2016 and Spring 2017

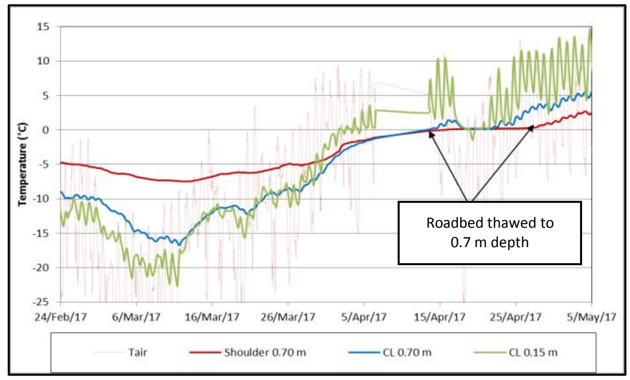

Figure 9. Temperature at shoulder and centreline, site 4, late winter- early spring 2017

Assuming that edge cracking develops between March and May, a correlation was sought between roadbed temperature and time. Figures 8 and 9 compare centreline and shoulder temperatures at site 4 during late winter to spring 2016 and 2017, respectively. In 2016/17 and winter 2017/18, road centreline was as much as 5°–6° C colder than the shoulder. These two figures show that the main reason for the differences between centreline and shoulder temperatures is the insulating effect of snow and ice accumulated on the road shoulders by winter maintenance. In fact, the presence of snow on the road shoulders both created a temperature differential between centreline and shoulder, and eliminated diurnal temperature fluctuation at the road shoulder. The shoulder temperatures fluctuated slowly during the winter and appear as very smooth lines. In contrast, the centreline temperature appears as a very jagged line indicating rapid, diurnal, variation in the absence of snow on the road surface.

The lines for centreline and shoulder temperature at 0.7 m display diurnal temperature variation on April 8 and April 16, respectively, for 2016 and on April 13 and April 26, respectively, for 2017, when they thawed. The trends observed at site 4 were observed at site 6.

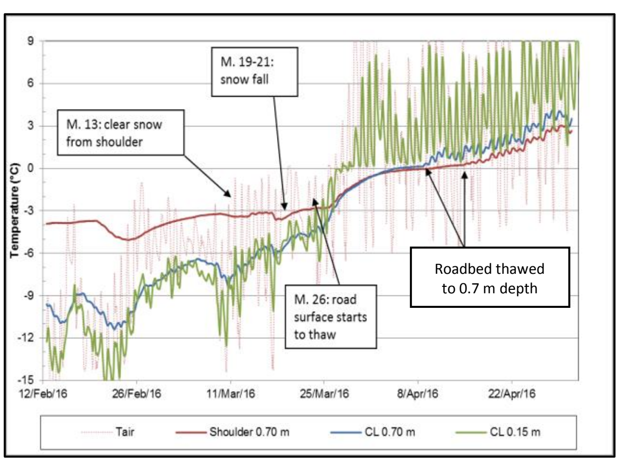

Figure 8. Temperature at shoulder and centreline, site 4, late winter- early spring 2016

4.2.2 General moisture trends

Figures 10 and 11 present moisture data from site 4 during spring 2016 and 2017, respectively, and compare road centreline to road shoulder at two different depths. Both in 2016 and 2017, the centreline thawed several days before the road shoulder, and the untreated shoulder thawed slightly slower than did the shoulder with the wicking geotextile. Under the wicking geotextile at site 4 (at a depth of 0.7 m), the roadbed thawed nine to ten days earlier at centreline than at the road shoulder, in 2016. In 2017, under the wicking geotextile at site 4, the roadbed thawed fifteen days earlier at centreline than at the road shoulder. Since temperatures were colder in 2017, thawing at centreline and at shoulders occurred 5 to 10 days later. Both in 2016 and 2017, higher moisture levels were recorded at 0.7 m than at 0.3 m and 0.4 m. An analysis of temperature data (Figures 8 and 9) for the same spring 2016 and 2017 periods showed that the centreline thawed faster than the shoulders. This statement is substantiated by the thawing patterns illustrated in figures 10 and 11.

Another Important observation was that at centreline, both under and over the fabric, moisture levels were higher in 2016 than in 2017. This variation in moisture levels at road centreline during spring 2016 and 2017 can be explained by the impact of Bituminous Surface Treatment (BST) application in summer 2016. In fact, after installing the wicking geotextile and instrumentation in September 2015, BST was applied to sites 4 and 6 only on June 2016. It was anticipated that a difference in solar gain on the road surface would be noticed after BST application. After the BST application, it was noticed that centreline materials stopped experiencing wetting from rain events and slowly dried. This occurred because, after BST application, the soil at 30 cm on centreline was sealed between two relatively impervious layers. The BST retains more solar energy and increase roadbed temperature.

The ability of the geotextile to drain the roadbed was illustrated by Figures 10 and 11 as well. At both centreline (0.3 m) and shoulder (0.4 m) of the treated sites, after the release of water by thawing, the moisture contents decreased by 1% to 1.5% in 2016 and by 1% in 2017. In contrast to this, after thawing of the untreated shoulder, the excess water did not drain away. Also, field density tests show evidence of the shoulders being less compacted and, therefore, hold a higher void index.

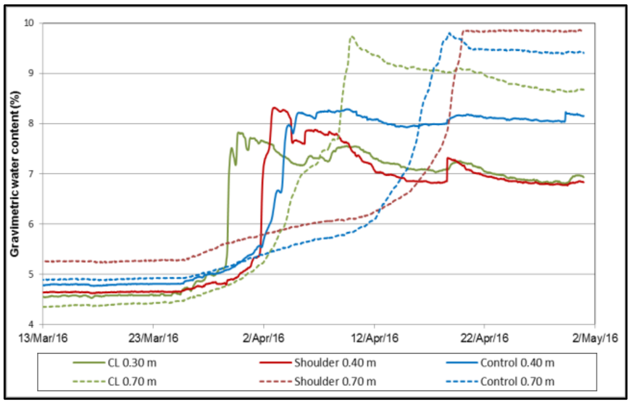

Figure 10. Moisture data, site 4, spring 2016

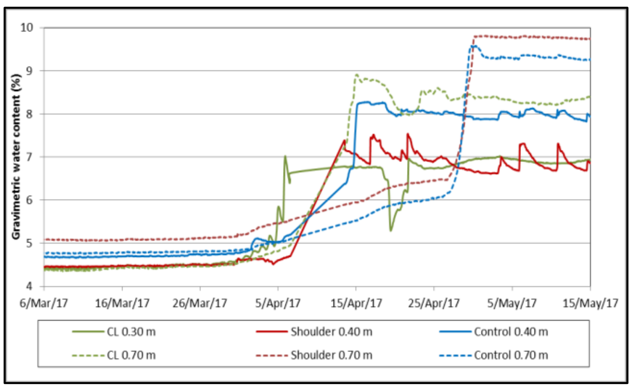

Figure 11. Moisture data, site 4, spring 2017

5 DISCUSSION

5.1 Validation of the Causes of Edge Cracking on Northern Roads

Many scientists in northern environments have attempted to quantify the causes of edge cracking, as stated in the literature review. In this study, it was possible to validate some of the potential causes of edge cracking.

5.1.1 Difference in compaction between road shoulders and running surface

One cause of differential compaction is that heavy vibrating drum compactors cannot safely compact along the outside edges of lifts when side slopes are steep. Efforts to do this may result in heavily overcompacted materials just inside the edge and undercompacted materials immediately outside of this. As an example, the field density study showed that the most advanced state of edge cracking was noticed at KM 66.275 which had steep side slopes of 2:1 and had dramatically reduced soil densities (55%-59%).

5.1.2 Combination of maintenance practices and differential winter freezing and spring thawing

Temperature and moisture data analysis during the spring period found that the road centre thawed faster than the shoulders which were still covered in snow. This may have caused further decompaction and edge cracking. Maintenance practices can accentuate this mechanism if plowed snow is allowed to accumulate on the road shoulders and sideslope.

5.1.3 Road prism side slope

Observations from site monitoring, validated by site survey and crack mapping using Lidar suggested that steeper slopes increase edge cracking susceptibility. Yukon highway construction specifications require secondary highway sideslopes over 2 m high to be constructed at 2:1 and sideslopes under 2 m high to be constructed at 3:1. In contrast, primary highway sideslopes are constructed at 4:1. Severe cracking occurred at KM 66.275 of the Campbell Highway where a high 2:1 sideslope is present. Sites 4 and 6 were built with a 3:1 side slope. Steeper side slopes promote edge cracking by reducing the stability of sideslope and shoulder materials.

5.1.4 Trafficking the shoulder

Edge cracking may also be promoted by heavy traffic driving on the shoulder and shearing the loosely compacted material. This was not studied in the study.

5.2 Analysis of the impact of the wicking geotextile on road performance

5.2.1 Validation of geotextile wicking and draining properties

Figures 10 and 11 illustrated moisture levels above and under the wicking geotextile both at the road centreline and the road shoulder (on the treated and untreated sections). Starting on March 25 in 2016 and April 02 in 2017, frozen water in the roadbed started melting and being released at the thawing front as top-down thawing began. In 2016, moisture contents reached 7.8% and 8.2%, respectively, at the road centreline (0.3 m) and the treated shoulder (0.4 m). Approximately 10 days later, a percentage of the moisture had dissipated and moisture contents were down to 6.8%, both at road centreline and treated shoulder. On the untreated shoulder, however, moisture content at 0.4 m depth increased to 8.2% after thawing but remained at this high level of moisture throughout the spring period. In 2017, moisture contents reached 7% and 7.5%, respectively, at the road centreline (0.3 m) and the treated shoulder (0.4 m). On the untreated shoulder, however, moisture content at 0.4 m depth increased to 8.3% after thawing. Under the wicking geotextile, however, spring thaw moisture levels at centreline at Site 4 peaked to 9.6% and then dropped to 8.6% in two weeks in 2016. In 2017, it peaked at 9% then dropped to 8.5% 3 weeks later. At both sites, moisture levels in the road shoulder, with or without wicking geotextile, showed little to no drainage for the same time period.

Spring moisture levels showed the ability of the wicking action of the wicking geotextile to drain excess water that accumulates at the thawing front during top-down thawing in the spring.

During spring and summer, as a comparison to the control sections, the test site treated shoulders above the wicking geotextile experienced recurrent, rapid increases and decreases in moisture content. To better understand these events, a comparison with precipitation data was made. Precipitation data for the summer period were from Environment Canada's weather station located at Watson Lake airport (closest weather station to sites 4 and 6). Figures 12 and 13 compare summer moisture contents at site 4 with summer precipitation events for 2016 and 2017, respectively. There was strong agreement between the precipitation events and increases in moisture above the wicking geotextile. This is another indication of the fabric's ability to drain excess moisture from the road shoulders.

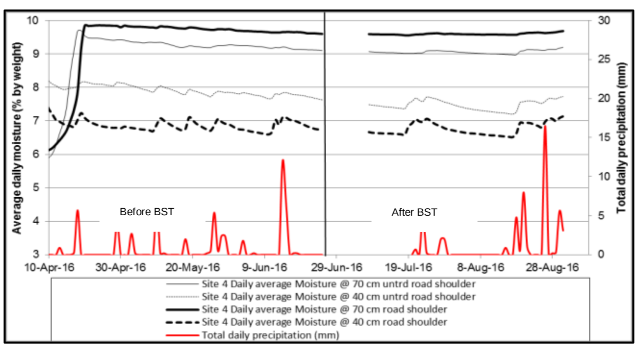

Figure 12. Comparison of precipitation and road moisture, site 4, spring and summer 2016

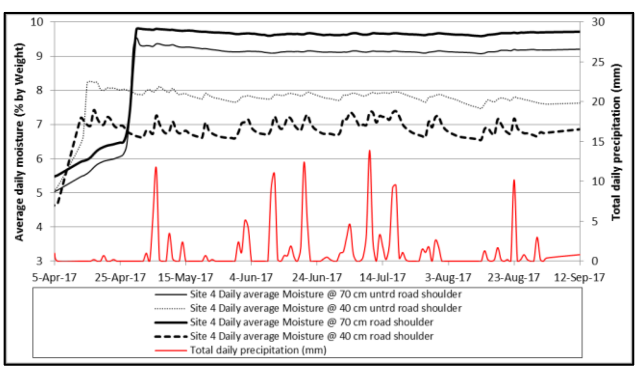

Figure 13. Comparison of precipitation and road moisture, site 4, spring and summer 2017

5.2.2 Ability of the wicking geotextile to increase pavement bearing capacity

The ability of the wicking geotextile to drain moisture has a direct impact on the increase of bearing capacity of the road matrix. It has been proven in this study that the wicking geotextile decreased roadbed base material moisture by 1% to 1.5% on average. This allows road materials, which are at a partially saturated state right after spring thaw or right after an episode of summer precipitation, to get back to their natural in-situ state, which is closer to the optimum moisture content. Lin (2018) study has shown that the ability of the wicking geotextile to drain water allows the granular material's resilient modulus to be close its optimum, hence increase the overall bearing capacity of the structure, using matrix suction mechanism. Also according to Lin (2018), by implementing the wicking geotextile, the resilient modulus can be theoretically increased by 3 times and the permanent deformation can be reduced to half. The structural benefits can be further enlarged to 4-6 times if the water content can be further reduced by 2%.

5.2.3 Ability of the wicking geotextile to prevent or reduce edge cracking

The main finding of this project was that a difference in moisture level between the road running surface and the road shoulder is potentially not the main reason for edge cracking. Various results detailed in this paper demonstrated that the geotextile wicking and draining properties are working well. Roadbed moisture was well controlled through these actions of the geotextile. Although it reduced roadbed moisture levels, some minor edge cracking was observed on the treated shoulders. However, there is strong evidence that the wicking geotextile reduces edge cracking as more severe edge cracking was found in nearby untreated road sections. HPW noted that edge cracking may take as long as five years to manifest after road construction.

It was also shown in this study that the areas with the most severe edge cracking were untreated and were constructed with high fine content materials, steep slopes, differential compaction, etc. In other words, although the sections treated with the wicking geotextile performed much better than any other section studied during this project, the wicking geotextile did not completely prevent edge cracking although it reduced it. In addition to the wicking geotextile, having the proper construction materials, uniform compaction, proper slopes, good winter maintenance practices, etc could have helped completely prevent edge cracking.

5.3 Potential recommendations to prevent or reduce edge cracking

The combination of the following recommendations should allow preventing edge cracking:

- The wicking geotextile is recommended for low volume pavements in northern environment;
- Side slopes should not be steeper than 3:1 to avoid difficulty during compaction;

- Compaction needs to be performed accordingly to allow uniformity between road shoulder and running surface;
- Roads should be built using well graded granular materials with low fine content;
- Maintenance practices should be conducted to avoid accumulation of snow on shoulders;
- The wicking geotextile should be placed closer to surface. Alternatively, two layers of wicking geotextiles, one at the top of subgrade and one in the base could be considered.

These recommendations will allow moisture regulation in road structure and avoid differential in thawing, moisture level, compaction, which all contribute to edge cracking.

6 CONCLUSION

This paper summarises results from the study of edge cracking on northern highways, and their control with the wicking geotextile. Test sites construction was documented and detailed analyses of moisture and temperature data from two instrumented test sites were conducted, in conjunction with monitoring of distress at these sites. The objective was to use information gathered from the data analyses, and extended with site observations, to evaluate the wicking geotextile's ability to drain the road and to prevent edge cracking.

The first finding from this study was that the wicking geotextile is draining road shoulder's excess in water content (%). The sections with the wicking geotextile showed less edge cracking as well. It can be concluded that the wicking geotextile helped reduce edge cracking. The wicking geotextile, as installed, did not however prevent edge cracking.

Other factors such as the differential in compaction between the road running surface and shoulder, the side slopes and the location of the wicking fabric inside the road matrix, the materials type and the winter maintenance practices, play a major role in accelerating the mechanism that cause edge cracking. The combination of site monitoring from 2016 and 2017 allowed concluding that there is a correlation between edge cracking with those factors which might decrease the wicking geotextile's effectiveness in preventing edge cracking.

The findings and information from this innovative research will provide knowledge to owners, designers, maintainers of low volume northern roads and local communities about road construction solutions to mitigate pavement distress, improve safety, and decrease maintenance costs.

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