Albedo of Pavement Surfacing Materials: In Situ Measurements

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Abstract: In order to limit heat intake in the ground underneath pavements, high albedo surfaces can be used in cold regions to mitigate permafrost degradation. In this study, experimental sections at Site Experimental Routier de l'Université Laval (Québec, 2014), on the Alaska Highway (Beaver Creek, Yukon, 2012 and 2014 and at km post 1786, Yukon, 2014), and in Tasiujaq (Nunavik, Québec, 2015) were used to document the effectiveness and durability of high albedo surfacing materials. The test sections were equipped with thermistors and data loggers recording surface temperatures. Albedo and skid resistance were also monitored at these sections. In addition to the experimental sites, several albedo measurements were made on asphalt surfaces to develop a relationship between albedo and pavement age.

Keywords: Albedo; Pavement; Permafrost; Solar reflectance.

1 INTRODUCTION

Due to global warming in northern regions, the consequences of thermal degradation of thaw sensitive permafrost have been observed and documented in the last few decades. The increase of air temperature affects surface temperature of pavements and will eventually induce thaw settlements of the ground. In ice-rich permafrost conditions, this will cause distortions as well as longitudinal cracking of the pavement, which can significantly affect road serviceability and performance. In addition, the construction or rehabilitation of a pavement structure makes it more vulnerable to heat intake due to the darkness of the new asphalt, which increases absorption of solar radiation (Doré and Zubeck 2009).

One of the main factors governing heat intake from solar radiation is the albedo of surfacing materials. Albedo (or solar reflectivity) is defined as the ratio between reflected and incident solar radiation and is a dimensionless number, defined in equation 1.

$$a = \frac{I_R}{I_I} \quad [1]$$

where a is the albedo, I_R is the reflected solar radiation and I_I the incident solar radiation. Albedo is presented in decimals and ranges from 0 for a black body that absorbs all solar radiations, to 1 for a surface reflecting all radiations. As solar reflectivity is acknowledged to have a major influence on thermal performance of pavement structures (Akbari et al. 2012), high albedo surfaces were previously considered as an alternative to protect transportation infrastructures built on frozen ground. In the summer, for peak solar exposition and under low wind conditions, the surface temperature of a new asphalt pavement with an albedo of 0.05, which means it reflects 5% and absorbs 95% of the solar radiation, can reach 50°C higher than air temperature (Synnefa et al. 2008).

High albedo materials have been used to protect paved road and airfield pavements built on thaw sensitive permafrost. However, this technology has encountered problems such as slipperiness and localized icing (ADOTPF 1985) and it has been reported that those products can cause glare and reduce visibility (Karlessi et al. 2013). Moreover, the cost of maintenance can be important for frequent repainting. Some high albedo materials are selective. They reflect more effectively certain wavelengths, usually near infrared (700-2500nm), than visible light (400-700nm). These materials can thus be dark coloured and still have high albedo characteristics. This technology is already used to mitigate urban heat islands, referring to temperature increase in urban areas compared to surrounding rural areas.

The goal of the study is to develop a thermal stabilization method for pavements built on thaw sensitive permafrost based on the use of high albedo surfacing materials. The specific objectives are to quantify the benefits of high albedo surfacing materials, to document the effect of time on albedo, and to assess its potential for permafrost regions. The performance of high albedo surfacing materials used on pavements and the effects of time influencing albedo are documented in this paper.

2 METHODOLOGY

In this study, high albedo product (HAP) was tested on asphalt concrete and bituminous surface treatment (BST) in different site locations. Albedo measurements were performed with a Kipp and Zonen pyranometer (3cm diameter, measuring spectral scale from 300 to 2800nm). Those measurements require a sunny clear sky, because clouds cover, haze and shade can significantly affect the amount of incident solar radiation. The zenith, angle of the sun depending on its elevation, must be less than 45° according to ASTM standard (ASTM E1918-06). The latitude and time of the year can also affect albedo and solar zenith, introducing some errors in the measurements. The albedo is a parameter changing with time, it typically decreases due to weathering and abrasion for high albedo surfacing materials (Yu and Lu 2013), while asphalt concrete albedo increases with time due to the oxidization of the bitumen. In order to study the effects of the pavement age mentioned, several albedo measurements were taken.

2.1 Test Sites

In order to test and quantify the performance of high albedo surfaces, three experimental sites, located in the Province of Quebec (Forêt Montmorency) and in the Yukon Territory (Alaska Highway: Beaver Creek and at km post 1786) were selected and prepared for this project. The sites are equipped with thermistors and data loggers in order to monitor surface temperatures. A pyranometer was used to measure surface reflectivity in accordance with ASTM standard (ASTM E1918-06).

A total of five different high albedo surfacing materials were provided by two industrial partners (company 1 and company 2), for the experiments on the test. Company 1 provided a resin based acrylic products (1a) and an acrylate based polyester product (1b) in two different colours (smoke gray and cool gray). Company 2 provided a bitumen based product labelled 2a white. Since light coloured products can cause visibility issues for drivers or pilots, selective high albedo coatings presenting a darker colour were developed for road exposed to the reflected radiation for extended periods of time.

2.1.1 SERUL

Laval University (UL) has an experimental road site located at Forêt Montmorency (N 47°19', W 71°8') called SERUL, *Site Experimental Routier de l'Université Laval*. The five different products were installed at this test section. The application of the products and the instrumentation at the SERUL test site were performed early September 2014. While only two products were applied on a BST, as shown in figure 1, the rest were applied on the asphalt concrete surface.

(a) (b)

Figure 1. Site located at SERUL, Québec, (a) on BST, (b) on asphalt pavement.

The dimensions of each of the test surfaces were 2.5m x 3.5m. To install the sensors and connect the cables to the data logger, a superficial saw cut was made and the temperature probe was inserted in a tiny hole drilled in the cut. Both hole and saw cut were filled with epoxy. For product 1, the paint was applied with a broom in three layers on top of the dry epoxy in order to obtain a uniform colour. This product was prepared by mixing the paint with silica sand with a mass ratio of 1 to 2. Application of product 2 was made in one layer using a squeegee and silica sand was also mixed with the product. The average surface temperature was calculated daily for each tested surface. Air temperature reported at a meteorological weather station near the site (Environment Canada 2014) provided air temperature data for the analysis but solar radiation was not available.

2.1.2 Alaska Highway

In addition, two other sites on the Alaska Highway were used to complete this first part of the study. The first one is the test section near Beaver Creek (N 62°23', W 140°52') and the second site is located at kilometer post 1786 of the Alaska Highway, between Destruction Bay and Beaver Creek (N 61°36', W 139°35').

In 2008, 12 experimental sections were built in Beaver Creek to analyze the thermal performance of several permafrost protection techniques. One of the sections was built to assess the effectiveness of high albedo pavement using bituminous surface treatment with light-coloured aggregates (L-BST). A temperature probe monitoring surface temperatures was used on a 50m x 10m section. At this test site, the reference section, also built in 2008, is a conventional BST. In 2011, product 1b smoke gray and a different product provided by company 2 labelled as 2b white was installed on cold mix with a squeegee. A control section made using conventional cold mix was installed as well. The dimensions of the experimental tested surfaces were 4.1m x 4.3m for product 1, 3m x 2.9m for product 2 and 3m x 3m for the control section, as shown in figure 2.

Albedo and surface temperatures were measured at Beaver Creek site from summer 2012 till rehabilitation in summer 2014. Albedo was annually measured in May, allowing monitoring of the reflectivity of applied surface coatings with time. Those measurements were obtained for product 1b smoke gray, product 2b white and the cold mix and were

Figure 2. Site located on Alaska Highway near Beaver Creek.

also collected for sections constructed in 2008, which are characterized by L-BST and control BST.

The second site (at km post 1786) was prepared in August 2014. The product 1a smoke gray and 1b cool gray were tested and the dimensions were 10m x 20m, as presented in figure 3. The same application procedure previously described for SERUL was used.

(a) (b)

Figure 3. Site located on Alaska Highway at km post 1786 on BST, product 1a smoke gray (a), product 1b cool gray (b).

2.2 Quantification of the Evolution of Albedo with Time

In order to develop a relationship between the age of the asphalt pavement and the albedo, measurements were taken with a pyranometer in the summer of 2014 on parking lots of UL and at the experimental sites of SERUL and Beaver Creek. Pavement age varies from 0 to 31 years old. Albedo measurements of HAP from SERUL and Beaver Creek are also presented in the results section in function of age.

3 RESULTS AND ANALYSIS

3.1 Test Sites

3.1.1 SERUL

Albedo measurements made at the SERUL test site in October 2014, are presented in table 1. The solar reflectivity of all products was found to be higher than the reflectance of the control. Depending on the specific colour of product 1 on asphalt pavement, smoke gray presents an average albedo of 0.33, while cool gray presents an average albedo 14% higher (0.375). The highest solar reflectance measured was 0.49 with product 2a white, which is 0.36 higher than the control section. The control surfaces are 7 years old and showed an albedo of 0.13 for asphalt pavement and 0.11 for BST, respectively. Albedo of

Table 1. Albedo Measurements at Forêt Montmorency on October 2nd

Product	Color	Albedo on asphalt	Albedo on BST	Age
1a	smoke gray	0.34	-	0
1b	smoke gray	0.32	-	0
1a	cool gray	0.36	0.34	0
1b	cool gray	0.39	-	0
2a	white	0.49	0.48	0
Control	-	0.13	0.11	7

the tested products on BST are 0.34 for product 1a cool gray and 0.48 for product 2a, which are very similar to the data obtained for asphalt concrete.

The n-factor was calculated from the average daily temperature measured during the two weeks following the installation and is shown in figure 4. The n-factor is used to relate air temperature to surface temperature. The n-factor is defined in equation 2 as:

$$n - factor = \frac{T_{product}\,(°C)}{T_{air}\,(°C)} \quad [2]$$

where $T_{product}$ is the surface temperature of the product (°C) and T_{air} is the air temperature (°C). This factor is used particularly for engineering purposes in order to determine the surface temperature from readily available air temperature data. The n-factor is an approximation since many factors may significantly influence how the surface responds to air temperature variations. According to Doré and Zubeck (2009), the thawing n-factor for asphalt concrete has a range of 1.6 to 3.0. Figure 4 presents the evolution, with respect to time, of n-factor, calculated from the average daily temperature, and the difference of surface temperature between high albedo surface and control (ΔT). The ΔT is defined in equation 3 as:

$$\Delta T(°C) = T_{product} - T_{control} \quad [3]$$

where $T_{product}$ is the surface temperature of the product (°C) and $T_{control}$ is the surface temperature of the control (°C).

Similar tendencies are noted for the n-factor of every product and the highest values were always obtained for the control section. The pavement surface is usually warmer than air temperature during sunny days due to absorbed solar radiation. On September 18th, the n-factor of product 1b smoke gray reached a maximum value of 4.7 while average daily air temperature was the coldest during the month at 2.1°C. It was previously reported by Dumais (2014) that when air temperatures decrease, pavement surface temperatures decrease with a time lag due to the effect of surfacing materials thermal capacity, which causes some thermal inertia. The monthly average n-factor for surfacing materials on asphalt pavement was 1.76 for all products provided by company 1 and 1.49 for product 2, while n-factor of the control is 2.29. Regarding surface temperature, the difference between the control and the high albedo surfacing materials, for an average air

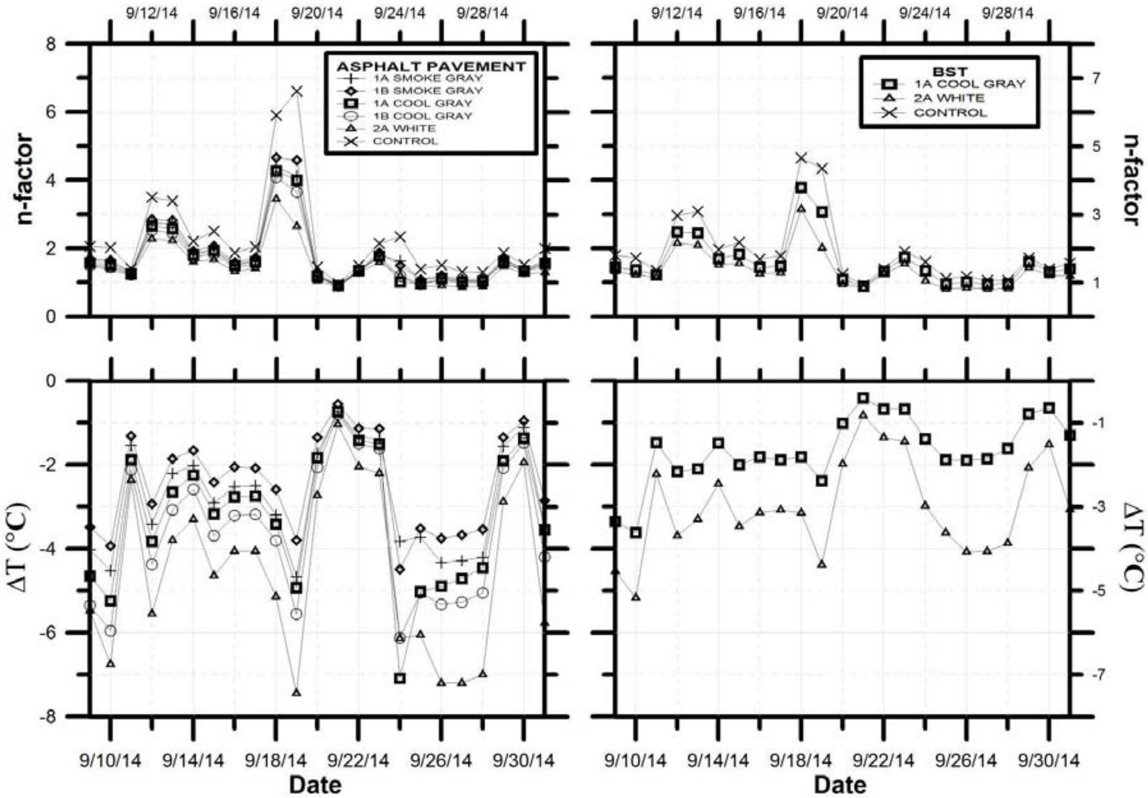

Figure 4. n-factor and ΔT for the products applied on asphalt pavement and BST (SERUL).

temperature of 8.1°C recorded in September, is -4.4°C for product 1 and -6.6°C for product 2. Average n-factor for products applied on BST was 1.60 for product 1a cool gray, 1.37 for product 2 and 1.90 for the control leading to a difference between the surface temperature between the control and product 1 of -2.4°C and -4.3°C for product 2.

Regarding the ΔT parameter values, presented in equation 3 and in figure 4, from September 9th to October 1st, average surface temperature of products provided by company 1 ranged from 6.7°C to 17.4°C, from 5.0°C to 14.7°C for product 2, while the corresponding temperature for the control was 8.7°C to 21.7°C. The average difference between the control and high albedo coating is -3.1°C for the product provided by company 1 and -4.6°C for the product provided by company 2. The greatest ΔT is -7.5°C, measured for product 2 on September 19th when air temperature was 1.9°C. The ΔT parameter values are lower for products installed on BST, the average difference between control and product surface temperature is -1.7°C for product 1 and -3.0°C for product 2.

The average n-factor obtained from September 9th to October 1st is presented as a function of the albedo in figure 5. A linear relationship is observed between both parameters and as albedo increases, n-factor decreases. The average n-factor for the control on asphalt pavement is 2.29 meaning its surface temperature is 2.29 times higher than air temperature is on average.

In order to evaluate surface friction of the pavement surfaces where the products were applied, a British pendulum test was performed on SERUL's test sections according to the ASTM standard (ASTM E 303) on November 13th, which allowed obtaining a British Pendulum Number (BPN). Average air temperature was -6.0°C and might have led to some imprecision affecting the rubber slider of the pendulum. Threshold values of BPN are required specifically for road markings (Australia BPN=45, New-Zealand BPN=50) (Harlow 2005), for highways (BPN=55) and for curves (BPN=65) (Road Research 1969). All the products provided by company 1 on asphalt pavement showed BPN values higher than 55, which means they meet the minimum criteria to be used on highways but not in curves, except for product 1b smoke gray. Silica sand added to the product helped increase skid resistance. The product provided by company 2 presents a low BPN, (25) and the explanation might be related to the high application rate, and to the installation performed with a squeegee, causing an increase of the product thickness and filling of the macro-texture of the pavement. Products installed on BST test sections did not meet the minimum values specified. However, product 1a cool gray has a BNP value higher than the control.

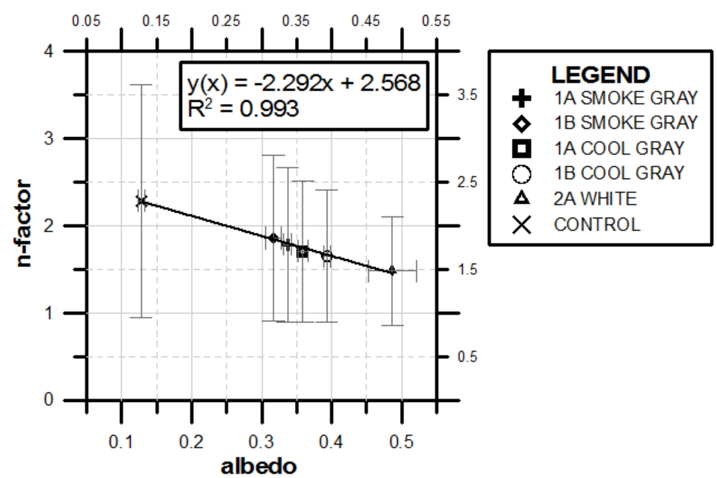

Figure 5. n-factor as a function of albedo.

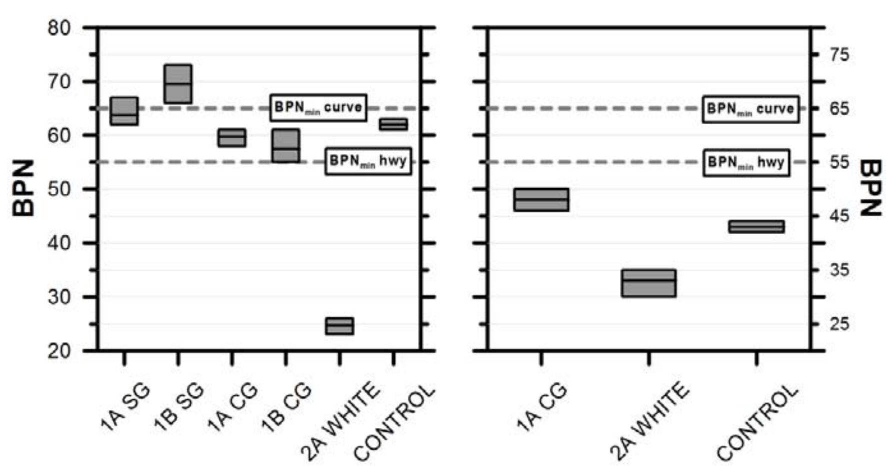

Figure 6. British Pendulum Number of the products, SERUL.

3.1.2 Alaska Highway

Only albedo values are presented for the Yukon test sites. Table 2 summarizes all the test results from Beaver Creek site. It can be noticed that the albedo of the applied products decreases with time. Product 1b smoke gray lost 35% of its solar reflectivity after 1 year and the value remained stable the following year. Product 2b white lost approximately 8% of its solar reflectivity after 1 year and 5% the second year. The albedo of the L-BST stayed the same during 2 years in service, which means that weathering or oxidation do not have a significant influence on the reflectance of this material. Also, the cold mix presented an albedo of 0.04 the first year but the reflectance increased by a factor 3.5 after only one year and remained somewhat stable afterward.

Albedo measurements at kilometer post 1786 of the Alaska Highway are shown in table 3. The two products were applied on BST and present albedo higher than the control. As a matter of fact, the application of high albedo surfacing materials leads to an increase of the albedo up to 3 to 4 times the value measured on the control surface. Product 1a smoke gray presents an albedo of 0.28 on BST and product 1b cool gray has an albedo of 0.36, a difference of 29% between the different products. Surface temperatures are not yet available for this site.

Table 2. Albedo Measurements of the Test Sections in Beaver Creek, May

Product	Color	Installation	Albedo 2012	Age	Albedo 2013	Age	Albedo 2014	Age
1b	smoke gray	2012	0.40	0	0.26	1	0.26	2
2b	white	2012	0.60	0	0.55	1	0.52	2
L-BST		2008	0.23	4	0.23	5	0.23	6
Cold mix		2012	0.04	0	0.14	1	0.13	2
Control		2008	-	-	0.14	5	-	-

Table 3. Albedo Measurements at 1786 km, September 16th

Product	Color	Albedo	Age
1b	smoke gray	0.28	0
1b	cool gray	0.36	0
Control		0.09	-

3.2 Quantification of the Evolution of Albedo with Time

In order to support the development of a thermal stabilization approach based on the use of high albedo surfacing materials, the evolution of the albedo of unprotected and protected surfaces need to be documented in order to be able to assess the benefit of the thermal protection. The relationship between albedo and age for different surfacing materials is presented in figure 7.

According to *American Concrete Pavement Association* (ACPA 2002), albedo of a new asphalt pavement is between 0.05 and 0.10 demonstrating low solar reflectance values, while the albedo of a weathered and oxidized asphalt pavement is typically between 0.10 and 0.15. In this study, albedo of a new pavement was between 0.04 and 0.11 and the albedo of a weathered pavement was between 0.11 and 0.16, which is in good agreement with the literature available. As shown in figure 7, a logarithmic relationship between albedo of asphalt pavement with respect to pavement age is proposed using different measurements gathered in this project. As expected, bitumen oxidation and surface weathering, which characterize pavement aging, seem to be closely related to an increase of the albedo.

Data taken at SERUL were used to verify the proposed model. In figure 7, it can be noticed that most of the changes to surface albedo are likely to occur between 0 and 5 years, a period during which a variation of 8% of the albedo is observed. Afterwards, according to the proposed model, albedo should gradually stabilize or show slight changes between 5 and 30 years, with a maximum variation of the albedo of 1.7%.

The albedo measurements of HAP, also presented in figure 7, vary from 0.28 to 0.60 depending on the product. Data from 0 to 2 years old are presented and changes of albedo were observed over time due to traffic and passages of the snow plough. The changes of albedo are mostly observed during the first year and tend to stabilize in the second year. It is not possible at this time to propose a relationship between time and albedo for the HAP due to the lack of data. Albedo measurements will be taken on a yearly basis in the next few years.

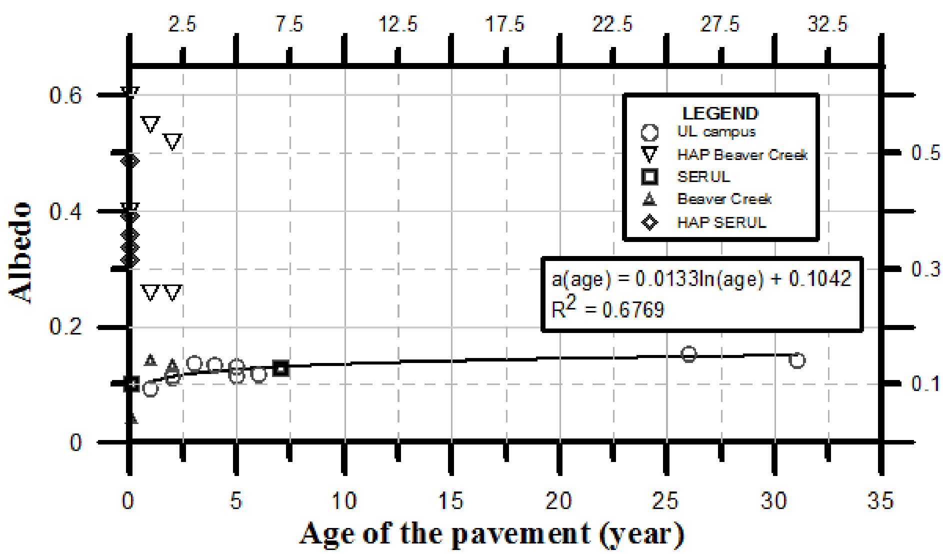

Figure 7. Albedo depending on the age of the pavement.

4 CONCLUSION

This paper presents the properties of high albedo surfacing materials through field experiments. Because cool paving material technology is still in development, no official standard exists for their application on civil infrastructure. In this study, a British pendulum number allows estimating the impact of such materials on pavement functional performance. With respect to skid resistance, product 1 met the standard for a use on highways according to the *Road Research Laboratory* within the first year of application. The following are the primary conclusions of this research:

1. Surface temperature decreases with increasing albedo;
2. Pavement treated using products provided by company 1 had about the same skid resistance as the control for asphalt pavement and provided 11% higher skid resistance for BST. High albedo product provided by company 2 provided 60% less skid resistance for asphalt pavement and 25% less for BST. The application method seems to be an important factor in the poor performance of product 2;
3. The n-factor decreased with higher albedo. For a one-month observation period on asphalt pavement, the average albedo measurements of the product provided by company 1 (0.35) had a n-factor of 1.76, which means a surface temperature of 14°C for an average air temperature obtained in September of 8.1°C. For product 2, the albedo was 0.49, the n-factor was 1.48, and the surface temperature was 12°C. For example, with a new pavement having an albedo of 0.05, surface temperature would be 20°C, making a difference of 7°C compared to surface temperature of HAP.

Laboratory protocols for measuring albedo, skid resistance, stripping resistance, and durability will be developed in laboratory, in order to develop a set of technical specifications to support the implementation of high albedo surfacing strategies in permafrost environments. Furthermore, a new experimental site, planned for construction in summer 2015 on the access road of Tasiujaq airport (northern Québec), will also increase the database of thermal behaviour of surfacing materials and develop a thermal stabilization procedure to prescribe an albedo value depending on properties of the site in permafrost regions.

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