Performance Review of the Light-coloured Pavement of the 2009 Front Street Project in Dawson City Yukon

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ABSTRACT

In 2009, Yukon Highways and Public Works, the Yukon Cold Climate Innovation Centre, and Skookum Asphalt (division of Terus Construction Ltd.) partnered to install a light-coloured surface paving system on Front Street in Dawson City, Yukon. The light colour was required to provide a high albedo to minimize solar heat absorption and degradation of the underlying permafrost and to match the colour of gravel streets to maintain the frontier town aspect of Dawson City.

A specific petroleum-based synthetic binder was developed to meet the performance requirements of Dawson City. Specific construction procedures were developed and implemented for the installation of this unique pavement in an isolated location. The performance of the pavement and the permafrost impacts are being monitored in order to evaluate the potential benefits of the light-coloured pavements in permafrost environments. A five-year performance review is presented in this paper.

The adaptation of the synthetic binder to meet the requirements of a conventional bituminous binder performance grade for Northern Canada led to further study of this product for other Canadian applications. Further developments have shown that a wide range of synthetic binders having equivalent rheological properties to conventional performance graded binders may be produced in Canada.

RÉSUMÉ

En 2009, le ministère de la Voirie et des Travaux publics du Yukon, le Centre d'innovation en climat froid du Yukon, et Skookum Asphalt (division de Terus Construction Ltd.) se sont associés pour installer une couche de surface de couleur claire sur la rue Front, à Dawson, au Yukon. La couleur claire a été retenue pour fournir un albédo élevé afin de minimiser l'absorption de la chaleur solaire et la dégradation du pergélisol sous-jacent et pour correspondre à la couleur des rues de gravier pour maintenir l'aspect de la ville frontalière de Dawson.

Un bitume synthétique spécifique à base de pétrole a été développé pour répondre aux exigences de performance de la ville de Dawson. Des procédures de construction particulières ont été développées et mises en œuvre pour l'installation de cette chaussée unique dans un endroit isolé. La performance de la chaussée et les impacts sur le pergélisol sont surveillés afin d'évaluer les avantages potentiels des enrobés de couleur claire dans les régions où existe le pergélisol. Le présent document fournit une revue de performance du projet après cinq ans.

L'adaptation du bitume synthétique pour répondre aux exigences d'une classe de bitume conventionnelle pour le Nord du Canada, a mené à une étude plus approfondie de ce produit pour d'autres régions canadiennes. D'autres développements ont montré qu'une large gamme de liants synthétiques ayant des propriétés rhéologiques équivalentes aux classes de bitume conventionnelles peut être produite au Canada.

1.0 INTRODUCTION

The Yukon Department of Highways and Public Works maintains Front Street (km 713.9-716.0 of the Klondike Highway #2), which is the main thoroughfare leading highway and local traffic to the Yukon Ferry crossing in Dawson City. Dawson City is world renown for the 1898 Klondike Gold Rush and is considered as a highly valued part of Canada's heritage. At its peak in 1898, Dawson City claimed to have 30,000 residents and was the largest city in Canada west of Winnipeg. Today Dawson City has approximately 1,200 permanent residents and many visitors during the summer months. Parks Canada and the local community have taken great strides to maintain the buildings and streetscapes from the past. Dawson City is inscribed as the Dawson Historical Complex National Historic Site by the Heritage Sites and Monuments Board of Canada. The character-defining elements of Dawson City are protected by development controls to ensure the important heritage value of the tourism site is maintained.

Front Street is the only hard-surfaced road in Dawson City having had a Bituminous Surface Treatment (BST) installed in the 1980s. As for any other type of thin surfacing system, the BST needed maintenance and repairs and after nearly 30 years of service, the Yukon Government decided to renew the pavement section within the urban section of Dawson City. The renewal of the pavement with another BST was not considered as an option as the previous BST became a source of many complaints from the community due to dust and bitumen tracking. In 2008, the Yukon Department of Highways and Public Works initially opted to renew Front Street pavement surface with a traditional asphalt concrete pavement.

While this decision was applauded by the business community, it was strongly opposed by the Dawson Historical Society and the municipal planning board as being a solution incompatible with the community's heritage. Accordingly, it became imperative that the paving solution for the project needed to satisfy the historical requirements of the community. Furthermore, ice-rich permafrost underlies a large portion of Front Street and, in the event of permafrost degradation, potential for infrastructure damage is significant. As such, it also became necessary to consider the usage of a pavement system that would not change the thermal regime of the underlying permafrost material. The environmental significance of both the heritage value of Dawson City and the requirement to protect the permafrost from a projected surface temperature increase led to the need to develop an engineering solution using a light-coloured surfacing system [1].

2.0 THERMAL MODELLING

Dawson City is located in an area of discontinuous and warm permafrost, with temperatures ranging from -1.0 to -0.1°C and with high ice contents in its upper portion. These relatively warm temperatures make the permafrost vulnerable to thawing with an increase in the surface temperature.

The surface temperature is affected the amount of solar radiation absorbed at the surface, which is closely associated with the solar reflectance (i.e., colour) of the surface. Solar radiation absorbed at surface is converted into heat, which may potentially be transferred to the underlying permafrost. To determine whether or not the colour of the surface would cause the melting of the permafrost, the Yukon Government mandated Kryotek Arctic Innovation from Whitehorse to create a thermal model of Front Street to simulate and predict potential seasonal thawing depths and effect on the existing permafrost as a result of different surfacing materials [2].

Kryotek used a geothermal modeling program developed by the Alaska Department of Transportation to predict thaw depths for the 2009-2029 period. Without the inclusion climate warming prediction factors, the modeling results of the 20-year prediction period indicated no increase thaw depth for a gravel surface by 2029, 0.1 m for a white concrete surface, 0.6 m for a chip seal, and between 2.4 to 3.5 m by 2029 for a conventional black asphalt pavement surface. In consideration of the current maximum depth of seasonal thaw, which is only slightly above the existing ice-rich permanently frozen material surface for a significant section of Front Street, Kryotek recommended that a low solar radiation absorbing surfacing system equivalent to gravel or white concrete be selected.

3.0 PAVEMENT DESIGN

3.1 Pavement Options

Yukon Highways and Public Works considered the following options to construct a light colored surface.

Chip Seal/BST systems: Several Chip Seal/BST systems were considered utilizing various emulsified asphalts and aggregate gradations. A well-constructed Chip Seal/BST would essentially be the colour of the aggregate and could provide an effective light-coloured surface. The Yukon Highways Department has vast experience in constructing excellent performing BST surfaces throughout the Yukon but has traditionally not utilized this system in urban areas. Numerous intersections, parking lanes and the shear stress from numerous vehicle turning movements may lead to significant level of chip loss and maintenance costs. Furthermore, with the past experience with the BST on Front Street and the various complaints related to dust and potential tracking, Yukon Highways decided not to opt for this solution.

Sprinkle treatment: Embedding chips in the surface of freshly laid black asphalt concrete during the laydown operation has been used as a technique to increase road surface fiction. A similar process using light-coloured chips is used in road tunnels to achieve a light-coloured road surface and increase reflectivity. The potential for snow plows to remove the embedded chips weighed against pursuing this option.

Coloured paving material: Petroleum-based synthetic binders are available and may be utilized to produce different colours of surfacing systems in various forms. The coloured surfacing systems can be utilized to embellish architectural sites or provide clear marking of areas such as bus lanes, pedestrian crossings and bike paths to reduce traffic conflicts. Yukon Highways and Public Works Engineering staff opted for this solution as it would provide performance similar to traditional asphalt concrete pavement, a high surface albedo to reflect heat, and an ability to match the historical gravel streets in Dawson City.

3.2 Design of Pavement Materials

3.2.1 Background and Constraints

Dawson City was built rather hastily in 1898. The City itself is constructed on a flood plain of the Yukon River. A dyke was constructed to protect the city's infrastructure from regular flooding. A storm water system with catch basins was added at a later date at each intersection along Front Street. The system simply removes excess surface water from the catch basins to the river through a one-way valve on the river side of the dyke. The system is not ideal as there is virtually no natural drainage from the boardwalk along the building front to the dyke. In fact, the dyke is impeding the flow of water to the river in most instances if it does not make it to the catch basins in the rough storm water system. In addition, curb and gutter are not an option next to the historical boardwalk running along the buildings. The grading and drainage portion of the work was deemed vital toward protecting the permafrost as any ingression of water would further harm the permafrost condition. In addition, any disturbance of the in-situ soils or permafrost would lead to further deterioration of the permafrost and so existing drainage structures were used as much as possible.

The Yukon Government concluded that the grade could be raised a maximum of 100 mm along the entire length of the project. Because of the existing elevations of the buildings and the Dyke it was impossible to raise the road grade further. A 2 percent cross fall was built into the cross section to ensure drainage away from the buildings. Painstaking survey and grade control was undertaken to ensure all areas of the roadway were draining into existing catch basins utilizing primarily the existing granular structure with limited additional granular material. The control of surface water to ensure no infiltration to the permafrost was an essential part of the project.

Due to relatively light traffic volumes the Yukon Government selected a road structure of 100 mm of paving materials overlying the existing re-graded granular structure. To mitigate additional costs of the light-coloured surface paving material it was decided to utilize a 75 mm base layer typical of a Yukon Government Asphalt Concrete Pavement with traditional asphalt cement. A surfacing paving material with a small top size aggregate was selected to be placed at a thickness of 25 mm to mitigate additional cost of the proposed light-coloured paving material and to provide the albedo required for historical and environmental considerations.

3.2.2 Binder Selection and Development for Dawson City

Traditional asphalt binders and organic pigments have been utilized in North America in the past to create coloured pavements. The experience has usually led to the asphalt concrete pavement darkening over time towards the normal black colour. Accordingly, a petroleum-based synthetic binder primarily used in Europe was selected to produce coloured pavements. Skookum Asphalt decided to use Bituclair® which is one of the synthetic binders available. Bituclair® is translucent in thin films and does not containing any asphaltene molecules which are responsible for the black colour of conventional binders [3].

The first challenge was to develop a binder that could withstand the severe temperature range prevalent in Dawson City. The original target was to design a binder to meet the Performance Grade of PG 52-40 with an emphasis on the low temperature performance. Although important, the relatively low traffic volumes did not make the high temperature PG as critical as the requirement of the low temperature to meet the extremely harsh winters of Dawson City. The binder was formulated starting from an existing Bituclair® ES formulation. Three binders were studied including a 94, 123, and 163 dm penetration grade binders. The high PG 58 grade was never achieved for any of the tested binders. Two binders provided a high temperature PG of 52 and the other graded to a high temperature PG of 46. The low temperature PG value of the 123 dm penetration graded as -39. It was also noted that the 123 penetration binder retained the penetration value after the Rolling Thin Film Oven Test (RTFOT), which simulates the ageing during the mixing of paving material and Pressure Aging Vessel (PAV) testing, which simulates ageing after 5 to 10 years. Many formulations were tested with the final result being a PG 52 for the high temperature and PG -39 for the low temperature.

The binder was manufactured at the Colas Midi-Mediterranean binder manufacturing facility LMS located in Vitrolles in the south of France. To ensure the binder was not contaminated during shipment, Skookum commissioned the manufacturing of new 20 tonne “bitutainers,” which could be shipped like conventional containers. The bitutainers were shipped from Europe through the Panama Canal to Vancouver, BC and then trucked 2,500 kilometres to Dawson City. Bitutainers were designed to reheat the product upon arrival at the plant site so that the binder could be brought to the mixing temperature and blended with aggregate in the paving material plant.

3.2.3 Aggregate Selection and Production

As no previous asphalt concrete pavement has been produced in Dawson City, the aggregate sources needed to be analyzed for suitability for asphalt pavement production. The existing aggregate sources available were at Yukon Government maintenance yards and consisted of rock tailings left behind from the early 1900s Gold dredges. In the 1900s, the gravel was thawed, dredged, processed, the gold mined and remaining tailings deposited in such a way that all of the natural sands were buried by a coarse gravel to cobble material ranging in size from 12.5 to 300 mm. The aggregate selected came from the Grader Station located at km 706 on the Klondike Highway. The petrographic analysis identified the aggregate was a basalt and suitable for asphalt production. Aggregate property testing was conducted and the test results are provided in Table 1.

Table 1. Aggregate Properties

Test	ASTM Procedure	Yukon Government Specification	Test Results
Petrographic Analysis		---	111
Los Angeles Abrasion, Gradation B Max % loss	ASTM C 131	Coarse Agg. < 25 Fine Agg. - n/a	18.6
Magnesium Sulphate Soundness Max % loss	ASTM C88	Coarse Agg. < 12 Fine Agg. <16	8 10
Sand Equivalent Minimum	ASTM D2419	Coarse Agg. - n/a Fine Agg. > 35	 60
Light Weight Particles (specific gravity less than 1.95) Max % mass	ASTM C123	Coarse Agg. < 1.5 Fine Agg. - n/a	0
Flat & Elongated Particles ratio Greater than 5:1 Max % by Mass		Coarse Agg. < 15 Fine Agg. - n/a	4
Plasticity Index Maximum	ASTM D424	Coarse Agg. - n/a Fine Agg. < 4	Non plastic

Aggregate production proceeded with the bottom lift paving aggregate being produced to a typical Yukon Government 12.5 mm minus material. The approach for the top lift paving material was to produce the paving mixture with a specific aggregate gradation that would facilitate placement at a thickness of 25 mm. The paving material was to be produced using “2.5/5 mm” coarse aggregate and “0/2.5 mm” Manufactured Fine (MF). As indicated in the National Asphalt Pavement Association (NAPA) Information Series on Thin Asphalt Overlays for Pavement Preservation [4] a small Nominal Maximum Aggregate Size (NMAS) of 4.75 mm was preferred to ensure ease of placement and compaction. In addition, the smaller NMAS would yield a mixture with less permeability, which experience has indicated would produce a pavement which is less susceptible to moisture damage in relatively light traffic volumes in the Yukon. Superpave 4.75 and MTQ standard for ESG-5 gradations specifications [5] provided in Table 2 served as baseline for the final selection of the gradation for the surface mixture.

Table 2. Superpave 4.75 and Ministry of Transportation, Quebec (MTQ) ESG-5 Gradation Specifications

Sieve Size	Superpave 4.75	MTQ ESG-5
	Percent Passing by Mass	
12.5 mm	100	--
10 mm	--	100
9.5 mm	95-100	--
5 mm	--	85-100
4.75 mm	90-100	--
2.5 mm	--	50-70
1.18 mm	30-60	
80 um	--	4-12
75 um	6-12	--

The production of any type of aggregate in the Yukon is a challenge. The mobile equipment available in the Yukon used was well-suited for a typical crusher run type production operation. The requirement for the production of paving material aggregate is seldom required outside of Whitehorse. Accordingly, the production of 2.5/5 mm coarse aggregate and the 0/2.5 mm MF for the production of the light-coloured paving material was difficult, particularly to obtain efficiently screening at the 2.5 mm sieve size opening. Despite the screening difficulties, the aggregate gradations remained consistent, which would allow for good production control during paving material production. The gradations for each of the three aggregates used for the top lift paving material are provided in Table 3.

Table 3. Gradations of Aggregate used for the Production of the Light-coloured Paving Material

Sieve Size	2.5-5.0 mm	< 2.0 mm	Natural Sand	Mix-Design Gradation	Ministry of Transportation, Quebec ESG-5
	Percent Passing by Mass				
Blend	45	40	15	-	-
10 mm	100	100	100	100	100
5 mm	80.6	99.5	100	95.0	85-100
2.5 mm	33.5	88.2	100	54.5	50-70
80 um	4.9	14.3	3.7	7.5	4-12

3.2.4 Mix Designs

The base lift was a Marshall mix design constructed to meet the Yukon Government Specification utilized on relatively low volume roads in the Yukon. Natural sand was added to meet the relatively fine-grained nature of the specification.

The design of the light-coloured pavement involved two main considerations; the required performance of the mix, and to achieve a high albedo or reflectivity. The preliminary trial mixes indicated that the natural colour of the aggregate when mixed with the translucent binder generated a relatively dark green tone. The binder supplier confirmed from their past experience that the aggregate colour had a major role in the overall colour of the final pavement. The natural colour of the aggregate led Skookum to introduce a white natural fine grained clean sand material to help lighten the aggregate skeleton and improve overall volumetric properties of the mix. The sand was sourced in Mayo, Yukon located 250 kilometres from Dawson City.

A mineral pigment is typically used to adjust the colour of the mix. Mineral pigments, added in a powder form, are generally preferred for convenience of blending and more importantly heat resistance during mixing. The amount of pigment added is a function of desired colour. The pigment used for the production of the Dawson City mixture was introduced in the mixing cycle of paving material production plant.

A titanium dioxide pigment was chosen and mixed at varying percentages in the laboratory to lighten the colour of the aggregates/Bituclair® blend. The colour tones of the cut specimens of the various blends (see Figure 1) did not show significant difference in colour tones between 1.0 and 2.0 percent titanium dioxide. Accordingly, a rate of introduction of titanium dioxide pigment of 1.5 percent was selected to account for possible field production variability and to produce a stable colour that was acceptable in terms of both the historical colour of the gravel roads and to obtain a high albedo for solar reflectance.

The mix design for the light-coloured paving material was developed using the guidelines provided in the Asphalt Institute MS-2 Manual [6]. Mix properties are provided in Table 4.

Table 4. Light-coloured Paving Material Mix Design Properties

50 Blow Marshall	Mix Design	Specification
Binder Specific Gravity	1.000	--
Binder absorption combined aggregate	1.16	--
Bulk Specific Gravity of combined aggregate	2.629	--
Binder content	6.4% by dry agg.	--
Percent air voids	3.2	3.0 – 5.0
Percent Voids in Mineral Aggregate (VMA)	14.9	Min 14.0
Percent Voids Filled with Asphalt (VFA)	78.3	65-78
Percent effective asphalt content	4.9	--
Binder film thickness	6.6	--
Dust to binder ratio	1.5	0.9-2.0

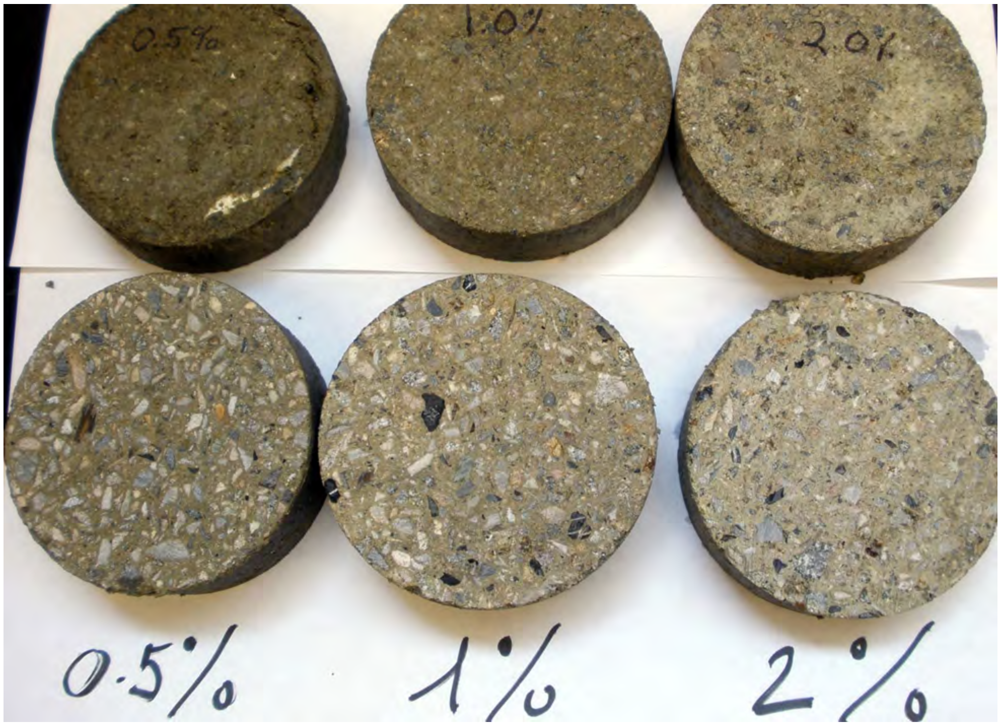

Figure 1. Colour Tones Resulting from Various Percentages of Titanium Dioxide Addition

4.0 PAVEMENT CONSTRUCTION

4.1 Equipment Preparation

The quality plan for the project went beyond the typical best practices for paving and took into consideration the unique nature of the manufacturing and placement of a light-coloured paving material. While best practices for manufacturing at the plant and during placement remained strong considerations, additional steps were taken to identify other potential difficulties.

The cleaning of all equipment was deemed necessary due to the light-coloured binder. The cleaning of the plant presented a unique challenge, light-coloured paving materials are usually produced in batch plants and the cleaning is relatively easy. In this particular case the only plant available was a parallel flow drum mixer plant and accordingly, all blackened components of the plant needed to be cleaned. The plant also needed to have an injection system for the titanium dioxide to be installed. Again, for a conventional batch plant the addition of a pigment is relatively easy but in this case it needed to be done in a continuous flow.

As previously indicated, the binder was delivered in 20-tonne bitutainers specifically made for the light-coloured binder, which simplified the storage of the binder on site. Nevertheless, a new piping system was installed to bring the binder from bitutainers to the mixing chamber of the plant. The cleaning of the plant also included the dry mixing of aggregates at elevated temperatures. The burner at the plant was adjusted to ensure good fuel combustion to ensure no contamination that could affect the colour and to ensure that elevated mixing temperature could be achieved. Propane was utilized for the burner.

All pavers, compactors, steel rollers were cleaned as well. Rust was removed as the ferric oxide is a pigment on its own that may have affected the colour of the mat. Water tanks on the rollers were flushed and thoroughly cleaned for that reason. All hand work tools were purchased new for the project as well as new boots for the entire crew.

4.2 Paving

The critical final grade preparation was completed and the 75 mm conventional base lift asphalt material was placed in a single lift. A bond coat was applied upon completion of the base pavement layer. The bond coat was seen as essential due to the thin surface lift. Typically, a SS-1 is utilized in the Yukon for overlays. However, due to the thin lift and fear of delamination from the base layer, as well as the issue of slow setting material tracking on the light-coloured pavement it was decided to utilize a CRS-1P sourced form Emulsion Products Co. out of North Pole, Alaska. The haul distance of 700 km was a major concern as it would require a stable product to be transferred over the rough Top of the World Highway into Dawson City. The bond coat was applied at an application rate of 300 g/m^2 residual binder. The fast setting nature of the emulsion alleviated the concerns with pickup and tracking onto the light-coloured pavement and facilitated the placement of the light-coloured paving material in a thin 25 mm lift.

A test strip was placed at the Yukon Government maintenance yard with the intention of using this material for maintenance purposes in the future. The test strip allowed for calibration of the plant and crew to understand the procedures required to place the light-coloured paving material. A rolling pattern was established and the crew become aware of potential workability issues. Compaction was achieved with the use of a double vibratory steel roller set at low amplitude and frequency to achieve 14 impacts per 0.3 m. No pickup of the light-coloured mixture was encountered and paving of the light-coloured material was completed over a period of 5 days. Figures 2 through 4 display images of the paving process and final pavement surface.

Figure 2. Paving Operation, Dawson City, Yukon, September 2009

Figure 3. Ground View of Front Street, Dawson City, Yukon, September 2009

Figure 4. Aerial View of Front Street, Dawson City, Yukon, September 2009

5.0 MONITORING AND EVALUATION

5.1 Pavement Condition

An annual inspection has been conducted on km 713.9 to km 716 on the Klondike Highway #2 since the completion of paving in September 2009. Low traffic volumes in Dawson City did not warrant the study of projected rut depth for this pavement. A visual pavement condition record has been established to monitor the performance of the pavement surface condition, subsurface condition, drainage, deterioration, distortion and riding comfort. A Pavement Rating System for Low-Volume Asphalt Roads as outlined in Asphalt Institute Information Series No. 169 [7] was considered adequate for the pavement performance evaluation for this project and the scope of this paper. The results of the visual inspection conducted in May 27, 2015 are presented in Table 5 and a representative photo of the project is shown in Figure 5.

Table 5. Visual Inspection May 2015

Asphalt Pavement Rating Form		
Street or Route - Klondike Hwy #2	City - Dawson City, Yukon	
Length of Project -Km 713.9 to km 716.0		
Pavement Type – Light-coloured Surfacing System	Date –May 27, 2015	
(Note: A rating of "0" indicates defect does not occur)		
Defects		Rating
Transverse Cracks	0-5	2
Longitudinal Cracks	0-5	0
Alligator Cracks	0-10	0
Shrinkage Cracks	0-5	0
Rutting	0-10	0
Corrugations	0-5	0
Raveling	0-5	0
Shoving or Pushing	0-10	0
Pot Holes	0-10	0
Excess Asphalt	0-10	0
Polished Aggregate	0-5	0
Deficient Drainage	0-10	1
Overall Riding Quality (0 is excellent;10 is very poor)	0	0
	Sum of Defects	3
Condition rating = 100 – Sum of Defects		
Condition Rating		**97**

Figure 5. Front Street Pavement Conditions as of May 2015

5.2 Geothermal Modeling and Surface Albedo

The geothermal modeling used to predict the impact of the surfacing materials on the underlying permafrost uses various parameters as input to simulate thaw and freezing depth [2]. One of those parameters is the Mean Annual Surface Temperature (MAST) and the direct effect of modifying the surface albedo[1] can change the MAST and the quantity of heat transferred to deeper soil strata [8]. Accordingly, the result obtained from the geothermal modeling indicated that a low solar radiation absorbing surfacing system (i.e., an albedo equivalent to the existing gravel) would not change the MAST and that the usage of a conventional asphalt pavement with an albedo of 0.05 at year one would increase the MAST by 3.0°C over a period of 10 years.

The albedo of the existing gravel was not available in the planning phase of the project; accordingly, there was not a set albedo value specified by Yukon Highways and Public Works Engineering Department. The acceptance of the mixture colour was based on a visual evaluation of the mixture's colour and comparing it to the existing gravel. In a subsequent assessment of the solar reflectance of the mixture used in Dawson City using ASTM C1549, Determination of Solar Reflectance Near Ambient temperature Using a Portable Solar Reflectometer [9] the solar reflectance or albedo was found to be 0.22 for a fully coated specimen that would simulate the albedo of the mixture at an early age and 0.27 for a cut surface of the specimen,

[1] The albedo of solar reflectance of a surface is defined as the ratio of the reflected to incident solar light. A perfect reflector has an albedo of 1, while a surface that no reflectance has an albedo of 0.

which would simulate the albedo of the paving material with the surface aggregate exposed. Additional field measurements [10] were performed in 2013 using the ASTM E 1918, Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field [11] and the solar reflectance or albedo was found to be between 0.21 and 0.25 while the albedo of the surrounding gravel surfaces was found to be between 0.17 and 0.21.

The aerial picture taken shortly after paving (Figure 6) shows the slightly lighter colour of the light-coloured paving material used on Front Street compared to the colour of the compacted gravel in surrounding streets confirming the slight differences between the albedo of the two type of surfaces.

Figure 6. Light-coloured Pavement in Comparison to Surrounding Gravel Surfaces

6.0 DEVELOPMENT OF SYNTHETIC BINDER IN CANADA

6.1 Uses of Synthetic Binders in Canada

Traditionally, coloured paving materials have been used to provide road safety or for aesthetic reasons. Coloured surfaces allow the segregation of surfaces for specific usage such as bus lanes, bicycle paths, pedestrian causeways, and sidewalk for instance. Accordingly, safety is improved by providing better traffic flow and avoiding potential conflict. Coloured paving materials are also used to improve the visual appearance of surfaces particularly in urban settings, public places, or historical monuments. They have also been used in tunnels to improve photometric properties allowing better perception of obstacles and reducing the amount of lighting required for tunnel brightness [3].

The project in Dawson City provided evidence that coloured paving materials can be used for more than just colour but also for pavement performance. As demonstrated in Dawson City, the light-coloured pavement provides a high albedo surface useful for maintaining low heat absorption and protecting the permafrost. Extending this particular feature of lower heat absorption, light-coloured paving materials may be used to reduce the urban heat island effect [8] or to lower the temperature of surface materials and alleviate permanent deformation with lower high temperature PG binders.

Synthetic and clear binders are not new products. Synthetic binders such as Vegecol® and Bituclair® have been used throughout Europe for several decades. The Dawson City project was a success, but the logistics associated with bringing the binder in dedicated bitutainers from southern France to the Yukon was complicated and costly. The demand for such products in Canada is considerable, however the logistics constitute a significant obstacle for development. With the success of the Dawson City project, Colas Canada Inc. decided to explore the feasibility of producing a range of synthetic binders in North America. The initial aim of the work was to develop synthetic binders that could be produced with components available on the North American continent, which could reduce transportation cost and facilitate delivery. The Colas Canada Inc. GECAN laboratory in Acheson, Alberta in collaboration with the Colas S.A. Research Centre (CST) was tasked with finding the resource materials and formulating various performance grades of synthetic binders.

6.2 Developing Performance Grade Synthetic Binders

Sourcing local components and additives was the first step in the production of a synthetic binder. The components being utilized in Europe were not easily accessible in Canada. Concessions were made in regards to the colour as the usage of local components that provided the right technical properties led to the production of dark amber brown binders instead of the traditional Bituclair® golden color. Although not the preferred colour, the synthetic binders that were produced would still allow satisfactory colouration of the paving materials as shown in Figure 7.

The performance graded synthetic binders that were to be developed were based on the common binders used in Canada (i.e., PG 64-28, PG 58-28 and PG 58-34). A specific grade was also developed for the production of emulsion. While the PG 58-28 and the PG 58-34 were successfully formulated, a compromise was required for the low temperature for the PG 64-28, which ended up being a PG 64-22. The technical data related to the three PG synthetic binders is provided in Table 6.

The various binders were produced and sent to CST in France to validate the grading determined by GECAN for each of the binder. The performance grading obtained at the CST was identical to the grading obtained by GECAN. Paving material mix design work was also performed to ensure that the binders could be used for the production of coloured paving materials. Viable mix-designs were developed with both the European Bituclair® binder and the Bituclair® produced with the North American components. Although, synthetic binders were successfully formulated at GECAN, the laboratory work also revealed that the aging characteristics of the synthetic binders would have to be investigated further to ensure that the binder would perform adequately in regards to ultraviolet aging.

Figure 7. Coloured Paving Materials (Red and Beige) Produced with North American Sourced Components

Table 6. Synthetic Binder Performance Grading Data

	Binder #1	Binder #2	Binder #3
Viscosity (cP)	1,942	1,592	2,965
Lowest Temperature @ G*/sinб (C°)	69.48	61.41	58.38
Temperature @ G*/sinб (C°)	19.81	15.12	4.96
Temperature @ Lowest Value for Stiffness vs. m-value (C°)	-26.37	-30.24	-37.42
Performance Grade (PG)	**64-22**	**58-28**	**58-34**

7.0 CONCLUSIONS

The paving of Front Street in Dawson City was a unique project for its technical and construction challenges while remaining compatible with the community's heritage. The usage of a light-coloured pavement provided both a viable solution to avoid any changes in the thermal regime of the pavement structure and a compromise that satisfied the historical requirements of the community. Paving in remote areas is always challenging and paving in Dawson City with a light-coloured paving material was particularly difficult for the logistics involved in the transportation of the synthetic binder but also the production of specific aggregate.

The performance review of the light-coloured pavement indicates that the objectives set forward by the Yukon Government have been met and exceeded. The light-coloured pavement has maintained an albedo slightly above the albedo of the surrounding gravel surfaces, which has minimized solar heat absorption and related degradation of the underlying permafrost. The colour of the pavement remains close to the colour of gravel streets maintaining the frontier town aspect of Dawson City. Furthermore, the pavement evaluation performed in 2015 indicates that the pavement remains in excellent condition, therefore confirming that the underlying permafrost has not been affected by the pavement colour.

The project in Dawson City provided evidence that coloured pavement can be used for more than just colour but also for pavement performance. As demonstrated in Dawson City, the light-coloured pavement provides a high albedo surface useful for maintaining low heat absorption and low pavement temperature. Extending this particular feature of lowering heat absorption, light-coloured paving materials may be used in urban settings to reduce the urban heat island effect or to lower temperature of surface materials and alleviate permanent deformation with lower high temperature PG binders.

The technical work carried out at GECAN shows that it is possible to manufacture synthetic binders in North America using components available on the continent. The technical work also indicated that most conventional PG may be formulated, however, with the lower heat absorption of light-coloured pavement the traditional PG selection that would be applicable to a black binder may not apply the same way to a synthetic binder that may remain at a lower temperature in the heat of summer. In other words, the requirement for the high temperature PG in particular may have to be redefined in accordance to the albedo of the paving material.

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