CLEAN RESOURCES FINAL REPORT PACKAGE

Project proponents are required to submit a Final Report Package, consisting of a Final Public Report and a Final Financial Report. These reports are to be provided under separate cover at the conclusion of projects for review and approval by Alberta Innovates (AI) Clean Resources Division. Proponents will use the two templates that follow to report key results and outcomes achieved during the project and financial details. The information requested in the templates should be considered the minimum necessary to meet AI reporting requirements; proponents are highly encouraged to include other information that may provide additional value, including more detailed appendices. Proponents must work with the AI Project Advisor during preparation of the Final Report Package to ensure submissions are of the highest possible quality and thus reduce the time and effort necessary to address issues that may emerge through the review and approval process.

Final Public Report

The Final Public Report shall outline what the project achieved and provide conclusions and recommendations for further research inquiry or technology development, together with an overview of the performance of the project in terms of process, output, outcomes and impact measures. The report must delineate all project knowledge and/or technology developed and must be in sufficient detail to permit readers to use or adapt the results for research and analysis purposes and to understand how conclusions were arrived at. It is incumbent upon the proponent to ensure that the Final Public Report **is free of any confidential information or intellectual property requiring protection**. The Final Public Report will be released by Alberta Innovates after the confidentiality period has expired as described in the Investment Agreement.

Final Financial Report

The Final Financial Report shall provide complete and accurate accounting of all project expenditures and contributions over the life of the project pertaining to Alberta Innovates, the proponent, and any project partners. The Final Financial Report will not be publicly released.

CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	**Performance Evaluation of Asphalt Mixes Comprised of Asphalt Binder and Asphaltenes Derived from**
Alberta Innovates Project Number:	202101347
Submission Date:	September 25, 2023
Total Project Cost:	$299,000
Alberta Innovates Funding:	$199,000
AI Project Advisor:	Dr. Paolo Bomben

2. APPLICANT INFORMATION:

Applicant (Organization):	**University of Alberta**
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Applicant Representative Name:	Leila Hashemian
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3. PROJECT PARTNERS

Please provide an acknowledgement statement for project partners, if appropriate.

RESPOND BELOW

- The University of Alberta provided $100,000 in-kind contribution for using asphalt and binder lab facilities.

- Lafarge Canada, Husky Energy, CNOOC Energy, VCI, and other suppliers are also gratefully acknowledged for their supply of materials for this research. Alberta Transportation and Economic Corridors, the Town of Stony Plain, and Lafarge Canada are also acknowledged for their advisory role in this project.

A. EXECUTIVE SUMMARY

Provide a high-level description of the project, including the objective, key results, learnings, outcomes and benefits.

RESPOND BELOW

The research project had two primary objectives. First, enhancing the low-temperature properties of high-modulus base courses that involved utilizing Polyethylene terephthalate (PET) fibres to improve the low-temperature properties of high-modulus base courses made from Alberta oil sands-derived asphaltenes-enriched binders. Second, investigating the impact of reclaimed asphalt pavement (RAP) on asphalt emulsion stabilized base course that was also focused on exploring the effects of incorporating reclaimed asphalt pavement (RAP) on the physical and mechanical properties of asphalt emulsion stabilized base courses modified with asphaltenes. The research spanned two years and was conducted at the University of Alberta's asphalt laboratory, which is equipped with extensive capabilities in asphalt binder and asphalt mix testing.

The overarching project goals aimed to provide a comprehensive understanding of road-based course performance by demonstrating the efficacy and competitiveness of utilizing Alberta oilsands-derived asphalt binders and asphaltenes in base courses. The outcomes underscored that these materials not only enhance the cost-effectiveness and performance of asphalt pavements but also drive demand for oilsands constituents. Furthermore, the improved base course performance can reduce material requirements (via reduced thickness and extended service life), thereby contributing to a reduction in greenhouse gas (GHG) emissions compared to current practices.

Key study findings includes:

(a) Asphaltenes derived from Alberta oilsands deasphalting are valuable additives for modifying asphalt binder properties in high-modulus base courses. However, depending on the binder source, low-

temperature properties may require enhancement, which can be achieved effectively through the incorporation of fibres, leading to improved cracking resistance.

(b) Asphaltenes show promise in enhancing the mechanical properties of recycled base courses with high RAP content (up to 100% RAP) that utilize asphalt emulsion.

(c) Asphalt binders sourced from certain Alberta oilsands bitumen deposits have the potential to be modified with asphaltenes for use in high-modulus base course applications.

Overall, implementing a high-strength base course in pavement structures results in durable pavements with longer lifecycles and reduced thickness compared to traditional pavements, offering both environmental and economic benefits. This approach also leads to shorter construction cycles, particularly advantageous in regions with limited construction seasons.

The successful implementation of this research is expected to generate employment opportunities in Alberta, including direct roles related to the production of new road construction materials containing asphaltenes. Additionally, employment opportunities may arise within the Alberta oil sands industry, as well as in road network construction, material sales, exports, and potential investment endeavours.

B. INTRODUCTION

Please provide a narrative introducing the project using the following sub-headings.

- **Sector introduction:** Include a high-level discussion of the sector or area that the project contributes to and provide any relevant background information or context for the project.
- **Knowledge or Technology Gaps:** Explain the knowledge or technology gap that is being addressed along with the context and scope of the technical problem.

RESPOND BELOW

B.1 Sector introduction

High-modulus asphalt (EME from Enrobés à Module Elevé) is one innovation for designing and constructing high-traffic roads composed of hard binders. The results of our previous research show hard asphalt binders modified with asphaltenes (from Alberta oil sands) meet and exceed the typical high-temperature performance requirements for EME; however, they do not meet the low-temperature performance criteria. One of the objectives of the proposed project, then, is to improve the low-temperature performance of high modulus base course comprised of these asphalt binders through the addition of fibres such as Polyethylene terephthalate (PET), which has been shown to be effective in enhancing the low-temperature properties of asphalt mixes.

Base or subbase course stabilization improves long-term pavement performance indices such as shear strength, modulus, moisture resistance, and durability. This can be achieved by adding asphalt emulsion to the granular base or subbase course. The main advantage of using stabilization techniques is the possibility of using high RAP content (50% to 100%) in the base or subbase course layer. Our previous research results show that the addition of asphaltenes to stabilized base courses (composed of virgin aggregates) using asphalt emulsion enhances the mix performance. However, this study investigated the use of RAP for new road construction and reconstruction of existing roads.

The research project included a two-year laboratory investigation that was conducted at the University of Alberta's asphalt laboratory, which has extensive asphalt binder and asphalt mix testing capabilities. The asphalt-treated base courses that were studied were a hot mix asphalt, a high modulus base course, and a cold mix asphalt, an asphalt emulsion stabilized base course. This research aimed to investigate:

- the effect of the addition of PET fibres on improving low-temperature properties of high modulus base courses comprised of Alberta oil sand asphalt cement and asphaltenes and
- the impact of the addition of RAP on the mechanical properties of asphalt emulsions stabilized base course

Knowledge or Technology Gaps

This proposed research investigated and understood the potential use of asphalt and asphaltenes derived from Alberta oil sands bitumen for enhancing asphalt performance in flexible pavements, building on the findings of our previous research results.

Based on the early results of the previous project, we found out that asphalt binders modified with asphaltenes derived from Alberta oil sands meet and exceed the typical high-temperature performance requirements. However, they did not satisfy the low-temperature requirements in cold regions with temperatures below -21°C. In the proposed study, polyethylene terephthalate (PET) fibres—which have been proven to be an efficient, cost-effective material to enhance the low-temperature cracking properties of asphalt mixes—were added to the high-modulus base course.

Our previous research has indicated that asphaltenes from Alberta oil sands serve as a beneficial additive to improve the quality of stabilized base course aggregates when combined with asphalt emulsions. However, we explored the potential of this technology to effectively stabilize recycled asphalt pavement (RAP) in lieu of high-quality base course aggregates. In this research project, we investigated the impact of incorporating three different proportions of RAP, replacing raw aggregates in stabilized mixes using asphalt emulsion and asphaltenes.

C. PROJECT DESCRIPTION

Please provide a narrative describing the project using the following sub-headings.

- **Knowledge or Technology Description:** Include a discussion of the project objectives.
- **Updates to Project Objectives:** Describe any changes that have occurred compared to the original objectives of the project.
- **Performance Metrics:** Discuss the project specific metrics that will be used to measure the success of the project.

RESPOND BELOW

C.1 Knowledge or Technology Description

This project aimed to unveil innovative applications for asphaltenes, which are currently regarded as a byproduct of oilsands processing. The identification of fresh non-combustion uses for bitumen-derived materials holds significance on two fronts:

- By discovering a new role for asphaltenes, once considered a byproduct, an opportunity arises for generating revenue from a material that currently holds minimal value.
- Utilizing asphalt cement modified with asphaltenes is anticipated to enhance the performance of recycled base courses.

This research explored and comprehended the potential utilization of asphalt and asphaltenes derived from Alberta oilsands bitumen to augment asphalt performance in flexible pavements, building upon the insights gleaned from our prior research endeavours.

Drawing from the preliminary findings of our preceding project, it became evident that asphalt binders modified with asphaltenes sourced from Alberta oilsands not only meet but surpass typical high-temperature performance standards. However, they fall short in meeting low-temperature requirements in colder regions where temperatures plummet below -21°C. Consequently, in this proposed study, we intend to introduce Polyethylene terephthalate (PET) fibres—recognized as a cost-effective and efficient material for enhancing the low-temperature cracking resistance of asphalt mixes—into the composition of high-modulus base courses.

Furthermore, our prior research has highlighted the effectiveness of utilizing asphaltenes derived from Alberta oilsands as an additive to enhance the quality of stabilized base course aggregates when combined with asphalt emulsions. However, the viability of this technology when replacing raw aggregates with recycled asphalt pavement (RAP) remained unclear. To address this gap, we aimed to determine if the technology is applicable in such scenarios and, if so, to identify the potential proportion of raw aggregates that could be replaced by RAP. Consequently, in this envisioned research project, we explored the impact of integrating recycled asphalt pavement (RAP) into stabilized mixes using asphalt emulsion and asphaltenes.**Deliverables and Outcomes for Research Focus I**

- Identification of the optimal fibre content based on precise mix design parameters.
- Determination of the optimal fibre length based on mix design specifications.
- Evaluation of the performance characteristics of asphalt mixes, including enhanced resistance to rutting, fatigue, and low-temperature cracking arising from the inclusion of fibres.
- Comparative analysis between the performance properties of fibre-modified samples and control samples (those without fibres). These results elucidated how fibres contribute to the enhancement of mix properties.

Deliverables and Outcomes for Research Focus II

- Identification of the optimal combination of RAP/asphaltenes content within the asphalt emulsion stabilized layer.
- Assessment of the performance properties of the prepared mixtures, with a particular focus on their resistance to rutting, fatigue, and low-temperature cracking subsequent to the introduction of RAP.
- Comparative analysis between the performance properties of samples that include RAP and control samples (those without RAP). These results elucidated the influence of RAP on the performance characteristics of the stabilized mixtures and provided insights into the extent to which RAP and asphaltenes can be incorporated to enhance mixture properties.

C.2 Updates to Project Objectives

Project objectives did not change in the course of the project.

C.3 Performance Metrics

The table below lists the main objectives, key performance indicators, and completion targets of the project as defined in the proposal.

Key Project Objectives	Key Performance/Success Indicator	Project Completion	Commercialization Target
Using asphaltene to modify asphalt cement for application in high-modulus base course	Rheological properties of hard asphalt cement (Sheer modulus and phase angle, low-temperature properties)	High temp. performance: Min. 82°C Low-temp. Performance: Min. equal to unmodified asphalt binder	High temp. performance: 82°C Low-temp Performance: - comparable with unmodified binder
Improving the performance of high-modulus base course composed of asphaltenes modified binder using PET fibres	Mechanical properties of high-modulus base course (modulus, permanent deformation, cold temperature cracking)	Dynamic modulus @ 15°C >14,000 MPa Permanent Deformation: Max. 4 mm @ 50°C Cold. temp. cracking: Minimum -22 °C	Dynamic modulus: 14,000 MPa @ 15 °C Permanent deformation: Max. 4 mm Cold temp. cracking: comparable to the control mix
Improving performance of recycled base course composed of RAP using bitumen emulsion and asphaltenes	Mechanical properties of stabilized base course (modulus, permanent deformation, cold temperature cracking)	Indirect Tensile Strength: Min 225 kPa Tensile strength ratio: Min. 50% Permanent deformation improved by more than 50% Cold-temperature cracking potential: comparable to the control sample	Indirect Tensile Strength: Min. 225 kPa Tensile strength ratio: Min. 50% Permanent deformation: 50% improvement compared to the unmodified mix Cold temp. cracking: comparable to the control mix

D. METHODOLOGY

Please provide a narrative describing the methodology and facilities that were used to execute and complete the project. Use subheadings as appropriate.

RESPOND BELOW

Project Focus I – Enhancing Low-Temperature Performance of a High-Modulus Base Course with Alberta Oil Sands-Derived Asphaltenes-Enriched Binder Incorporating PET

Methodology

In this phase of the project, asphalt cement sourced from various Alberta oil sands suppliers were subjected to asphaltenes modification, building upon the findings of our prior project. A novel mix design (see results in Appendix) was formulated for high-modulus asphalt samples, inclusive of PET fibres with three distinct lengths (6 mm, 12 mm, and 18 mm). Subsequently, we rigorously assessed the performance attributes of these modified mixtures across a spectrum of temperatures by conducting dynamic modulus tests at different temperatures and frequencies, and conducting indirect tensile strength test at low-temperatures . Further methodology details are available in the Appendix.

Project Focus II – Modification of Stabilized Base Course Utilizing Asphalt Emulsion, RAP, and Asphaltenes

Methodology

In this part, we prepared samples that are modified with commercial asphalt emulsion from Alberta, encompassing various combinations of RAP (at levels of 50%, 75%, and 100%), raw aggregates (ranging from 0% to 50%), and asphaltenes (constituting 1% of the total mix weight in accordance with our previous project findings). Subsequently, we subjected these samples to a comprehensive evaluation of their performance characteristics, specifically targeting rutting by conducting wheel tracking test at high temperature, fatigue by conducting IDEAL-CT test at intermediate temperature, and low-temperature cracking by conducting indirect tensile strength at low temperature. Further methodology details are available in the Appendix.

E. PR OJECT RESULTS

Please provide a narrative describing the key results using the project's milestones as sub-headings.

- Describe the importance of the key results.
- Include a discussion of the project specific metrics and variances between expected and actual performance.

RESPOND BELOW

A detailed summary report, including all the research results is attached as appendices A and B. A high-level summary of results is below.

E.1 Project focus I – Enhance the low-temperature performance of a high-modulus base course composed of Alberta oil sands-derived asphaltenes-enriched binder by incorporating PET

The findings from Research Focus I indicate that asphaltenes can serve as effective modifiers to enhance the stiffness of asphalt binders. However, it was observed that modified binders may exhibit increased susceptibility to low-temperature cracking. The results of indirect tensile test at low temperature revealed this issue can be effectively mitigated by the inclusion of PET fibres, which have demonstrated a significant capacity to address this concern. Furthermore, the research confirmed the suitability of binders sourced from Alberta oil sands for the formulation of high-modulus asphalt mixes.

E.2 Project focus II – Modify the stabilized base course including asphalt emulsion and RAP, using asphaltenes

The findings from Research Focus II indicate that using asphalt emulsion and asphaltenes in recycled asphalt mixes can result in mixes with better performance properties in terms of permanent deformation at high temperatures, and cracking resistance at intermediate and low temperatures compared to those without asphaltenes. In fact, all the performance measures closely matched the expected outcomes, and there were no significant changes in how the mixes performed at low temperatures. Interestingly, after investigating the replacement of three different proportion of granular aggregates with RAP (25%, 50% and 100%) the results highlighted that the modification with asphaltenes was particularly effective when dealing with recycled mixes containing 100% RAP content.

The results of the project can be summarised as below:

Project focus I – Enhance the low-temperature performance of a high-modulus base course composed of Alberta oil sands-derived asphaltenes-enriched binder by incorporating PET

- The results of the binder performance grading tests showed that when the binders from Alberta oils sand (binder P) and crude oil (binder H) sources were modified with 12% asphaltenes, they achieved a standard high PG grading of 82°C. Whereas the continuous high PG grading for modified binders was 82°C, and 82.9°C for binder H and P, respectively. Both binder types achieved a standard low PG grading of -16°C, while the continuous low PG grading differs (-21.9°C for binder P, and -21.8°C for binder H). The PG grading of both binders becomes 82-16, which means the rate of increase in high-temperature performance grading is much greater than the rate of decrease in the low-temperature performance grading. The identical PG grading demonstrates the suitability of these binders for utilization in high-performance asphalt applications. It allows a fair comparison between the two, even though they come from different sources.
- With the introduction of PET fibres, both the maximum and bulk-specific gravity values decreased. Nonetheless, the findings indicate that the air voids within the mixtures remained consistent and fell below the required value of 6%. Therefore, the addition of PET does not affect the compactibility of different mixes.
- The results from the dynamic modulus tests reveal a consistent viscoelastic pattern across all mixtures, where higher frequencies lead to an increased dynamic modulus value. The resemblance in the response suggests that the inclusion of PET fibres does not negatively impact the expected behaviour of the HPAC mixes.
- Through evaluation of the IDT strength and fracture test results, coupled with the noted rise in tensile strength across all temperatures resulting from the inclusion of 6mm PET fibres and asphaltenes in comparison to the unmodified control mixture, it was determined that the optimal PET content is 0.15%. This conclusion is drawn from the observation of an increase of fracture energy by 19%, 22%, and 32% at temperatures of -20°C, -10°C, and 0°C, respectively, as observed in the binder H mix modified with 0.15% PET fibre of 6mm length demonstrating a much lower overall cracking potential of the PET fibre modified mixes. The highest tensile strength

improvement of 8% is observed for 0.15% PET 6mm binder H mix at the coldest test temperature of -20°C compared to the control modified mix.

- When the length of PET fibres is increased to 12mm with an optimal dosage of 0.15%, the achieved stiffness is observed as 13,717 MPa, which is very close to the stiffness achieved for mixes with 6mm PET (13,824 MPa) incorporated with the same dosage. The stiffness wass dropped by 6.1% for 0.15% 18mm PET mixes compared to the 0.15% 6mm PET mixes. However, all the mixes showed a similar viscoelastic trend with varying lengths.
- By closely analyzing the fracture energy and tensile strength results while using the optimal PET content of 0.15% at different fibre lengths, it was determined that the optimal fibre length is 12 mm. The highest fracture energy was observed in the sample with 0.15% PET and a fibre length of 12 mm, showing a 12.7% increase compared to the sample containing 6mm PET at the lowest test temperature of -20°C. At -10°C, samples with 6mm PET (5613 J/m2) and 12mm PET (5600 J/m2) exhibited comparable high fracture energy. Regarding tensile strength, 7.4 MPa and 6.8 MPa were recorded for mixtures containing 12mm PET at temperatures of -20°C and -10°C, respectively.
- The research was extended to binder P modified with 12% asphaltenes and PET fibres at the optimum dosage of 0.15% and optimum length of 12mm which exhibited a slightly lower level of stiffness in comparison to the modified H binder with the same modifications, having a dynamic modulus value of 13,467 MPa and 13,717 MPa, respectively, at 15°C and 10 Hz, which is a mere 1.8% difference.
- Enhanced cold temperature performance is evident, as both Bindr P with 0.15% 12mm fibres and the binder H with 0.15% 12mm fibres (with a continuous low PG grading of -21.8°C) exhibit fracture energies surpassing those of the control unmodified mixes at -20°C and -10°C. At -20°C, the binder H mix attains a fracture energy of 5,261 J/m2, while the modified binder P mix slightly trails behind with a value of 5,121 J/m2.
- Looking at the tensile strengths at temperatures of -20°C, -10°C, and 0°C, the modified binder H mixture shows tensile strengths of 7.4 MPa, 6.8 MPa, and 5.3 MPa, respectively, while the binder P mix shows strengths of 7.4 MPa, 6.9 MPa, and 5.6 MPa, respectively. This lag does not pose a significant difference, making the binder P a feasible alternative binder for use in HPAC mixes at low-temperature applications.
- Based on the HWT results, the modified binder H with 0.15% 12mm PET fibres demonstrated the lowest rut depth of 3.5mm once the test had concluded at 20,000 passes under a temperature of 60°C, while the modified binder P with 0.15% of 12mm PET fibres demonstrated the highest rut depth of 5.7mm of all fibre mixes. Both these rut depths are well below the 12mm threshold as specified in standard practice and show that both the modified P and H binders perform well with regard to rutting and moisture resistance. The combined effects of adding both asphaltenes and fibres showcase enhancements in rutting and moisture resistance compared to the control unmodified mixture while also improving the rutting resistance index through these

modifications. In addition to meeting the stiffness and low-temperature requirements, the combined effect of the addition of 12% asphaltenes with 0.15% 12mm PET fibres exhibits improved high-temperature performance against deformations.

Project focus II – Modify the stabilized base course including asphalt emulsion and RAP, using asphaltenes

- According to volumetric properties and tensile strength test results of mixes prepared using asphalt emulsion and different combinations of RAP (50%, 75% and 100%), 1.5% asphalt emulsion was found to be the optimum emulsion content to be used in all mixtures.
- Asphaltenes modification increased the tensile strength of dry and soaked samples to the acceptable design limits for mixtures with RAP materials.
- Saturated TSR results satisfied the moisture susceptibility limits, unlike the freeze and thaw TSR values which performed well only for 75% and 100% unmodified RAP mixtures and 1% asphaltenes modified 50% RAP.
- Mixtures with 100% RAP performed better in rutting resistance. However, the mixture with 50% RAP responded better to ITS and TSR.
- The strength value improved greatly at the lower temperature by adding asphaltenes for each RAP content. The TSR results showed that adding asphaltenes made the mixture slightly more sensitive to moisture damage than the control samples. However, moisture sensitivity was still in the acceptable range.
- The creep compliance analysis showed that modification of the RAP and aggregate mix material with asphaltenes resulted in lower creep compliance values, indicating better low-temperature performances since it decreases the flexibility of the samples.
- With the addition of asphaltenes, asphaltenes-modified mixtures had higher FE at intermediate temperature (25°C) compared to the control samples. Thereby, it indicates mixes are more resistant to crack propagation. Also, CT-Index analysis showed that asphaltenes-modified samples had an increased cracking resistance compared to control samples.
- With the addition of asphaltenes, each content of asphaltenes had higher fracture energy at intermediate temperature compared to control samples. Thereby, it indicates mixes are more resistant to crack propagation. Also, CT-Index analysis shows that asphaltenes-modified samples had an increased cracking resistance compared to control samples.
- Permanent deformation test results using a Hamburg wheel tracker showed that adding asphaltenes improved the modified mixture's rutting resistance and moisture sensitivity compared to the unmodified mixtures. Overall, rutting resistance was higher in 100% RAP mixtures.

- In conclusion, mixes composed of 1% asphaltenes, 1.5% asphalt emulsion, and 100% RAP had better tensile strength, cracking resistance, rutting resistance, and low-temperature performance compared to the other RAP contents. Also, asphaltenes modification was a promising additive in improving the mixture's performance.

Project Specific Metrics

Project Success Metrics

Metric	Project Target	Commercialization / Mobilization Target	Comments
Low temperature performance of asphaltenes modified asphalt mixes including PET fibers			
Dynamic modulus @ 15°C	Minimum 14,000 MPa	Minimum 14,000 MPa	13,800 Mpa achieved
Permanent Deformation @ 50C	Maximum 4 mm	Maximum 4 mm	achieved
Low temperature cracking resistance	Minimum -22C	Minimum -22C	achieved
Enhance mechanical properties of stabilized base course including RAP using asphaltenes			
Indirect Tensile Strength	min 300 kPa	min 300 kPa	achieved
Tensile Strength Ratio	min 50%	min 50%	
Permanent deformation	improved by more than 50%	improved by more than 50%	
Cold temperature cracking pontential	similar to control sample	similar to control sample	

F. KEY LEARNINGS

Please provide a narrative that discusses the key learnings from the project.

- Describe the project learnings and importance of those learnings within the project scope. Use milestones as headings, if appropriate.
- Discuss the broader impacts of the learnings to the industry and beyond; this may include changes to regulations, policies, and approval and permitting processes

RESPOND BELOW

F.1 Project focus I – Enhance the low-temperature performance of a high-modulus base course composed of Alberta oil sands-derived asphaltenes-enriched binder by incorporating PET

Project learnings

- Both asphalt binder sources (crude oil and Alberta oilsands) can be successfully modified using asphaltenes for use in the high-modulus base course. The optimum asphaltenes content was 12% by the weight of asphalt for both binder sources.
- Asphaltenes modification has a negative impact on the low-temperature properties of the asphalt binder. However, the addition of PET fibres can significantly improve the low-temperature cracking resistance of HMAC mixes significantly.
- A high-modulus base course was designed using asphaltenes-modified binders and PET, and the designed mix was found to satisfy all the design requirements e.g., dynamic modulus, rutting and low-temperature cracking resistance.

Impact on Industry

- As the findings of this study demonstrate, asphaltenes can be considered an appropriate modifier for asphalt binder stiffening and modification.
- Alberta oilsands binders can be an effective solution in pavement applications and can be successfully modified using asphaltenes for high-modulus base course applications.
- Innovative asphaltenes and PET-modified mixes (e.g., binders featuring polymer fibres) could be designed for use in high-modulus base course applications in cold regions.

F.2 Research Focus II: Design and performance evaluation of stabilized base courses using asphalt emulsions and asphaltenes

Project learnings:

- The mechanical properties of recycled base courses featuring emulsified asphalt including permanent deformation and cracking resistance were found to be significantly improved as a result of asphaltenes modification. The optimum asphaltenes content was found to be 1% by weight of the mix.
- Asphaltenes modification was found to have a significant contribution in improving the high and intermediate properties of the recycled mixes, including the mix modulus, permanent deformation, and shear strength. The modification did not have a significant impact on the low-temperature properties of the mixes.
- Asphaltenes modifications were found to be more effective for the mixes composed of 100% RAP content compared to lower RAP contents (50% and 75% RAP). This could be because of the higher amount of total asphalt binder of the mix and the fact that asphaltenes mostly improve the asphalt binder properties.

Impact on Industry:

- Asphaltenes could be used as an appropriate modifier to enhance the mechanical properties of the recycled base course using asphalt emulsion, especially for the mixes containing high RAP contents.

G. OUTCOMES AND IMPACTS

Please provide a narrative outlining the project's outcomes. Please use sub-headings as appropriate.

- **Project Outcomes and Impacts:** Describe how the outcomes of the project have impacted the technology or knowledge gap identified.
- **Clean Energy Metrics:** Describe how the project outcomes impact the Clean Energy Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Program Specific Metrics:** Describe how the project outcomes impact the Program Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Project Outputs:** List of all obtained patents, published books, journal articles, conference presentations, student theses, etc., based on work conducted during the project. As appropriate, include attachments.

RESPOND BELOW

Project Outcomes and Impacts:

- This project demonstrated novel uses of asphaltenes, which is currently considered a by-product generated in oilsands processing, as a modifier for asphalt binder modification of high-modulus base course and stabilized soil using asphalt emulsion applications.

- The results of the project demonstrate that asphalt cement derived from different sources of Alberta oilsands could be considered a suitable material for high-modulus base course applications.

Clean Resources Metrics

Clean Resources Metrics

Metric	Project Target	Sep. 2023 status
TRL advancement	4 to 6	now 5
New products/services created	2	Completed
Publications	6	5 published journal paper 5 published conference papers 1 published book chapter 2 Msc thesis 1 PhD thesis
Students Trained (M.Sc., Ph.D., Postdoc)	2	2 PHDs 2 MScs 1 Pdf 5 undergraduates
Sector HQP Trained	6	

.Program Specific Metrics

Program Specific Metrics

GHG emissions: Actual reductions from project	Project Target
# of End Users participating	3
Unique product/process	2

The project targets were met as below:

Number of end users participated: 6 (Alberta Transportation and Economic Corridors, Town of Stony Plain, Lafarge Canada, VCI, Cenovus Energy Inc, CNOOC)

Unique product process: 2 new base courses were developed.

Project Outputs

The results of this study have been successfully published in highly-ranked conferences and journals as listed below:

Note: An asterisk (*) is used to indicate a student under my supervision

Journal Papers

J.1 Jhora, N., Kamran, F., Baghaee Moghaddam, T., Hashemian, L., (2023), "Evaluation of Mechanical Performance of Asphalt Emulsion Base Course Comprised of Reclaimed Asphalt Pavement (RAP) and Asphaltenes", *Journal of Testing and Evaluation*, accepted.

J.2 Kamran, F.*, Ghasemirad, A.*, Baghaee Moghaddam, T*, Bayat, A. and Hashemian, L. (2022), "Performance Evaluation of High Modulus Asphalt Concrete (HMAC) Prepared using Asphaltenes-Modified Binders," *ASTM Journal of Testing and Evaluation*, DOI: 10.1520/JTE20210772

J.3 Saleh, M.* and Hashemian, L. (2022), "Addressing Climate Change Resilience in Pavements: Major Vulnerability Issues and Adaptation Measures", *Sustainability*, Special Issue Incorporating Sustainable and Resilience Approaches in Asphalt Pavements, 14(4), 2410; https://doi.org/10.3390/su14042410.

J.4 Uddin, M.*, Kamran, F.*, Hashemian, L." Performance Comparison of Asphalt Emulsion Stabilized Granular Base Modified with Cement or Asphaltenes", (2022), Canadian Journal of Civil Engineering, https://doi.org/10.1139/cjce-2021-0186

J.5 Ghasemirad, A.*, Bala, N.*, and Hashemian, L., Bayat, A. (2021), "Application of asphaltenes in high modulus asphalt concrete", Construction and Building Materials, https://doi.org/10.1016/j.conbuildmat.2021.123200.

Conference Papers

C.1 Saleh M*, Ahmed N*, Baghaee Moghadam T., Hashemian L. (2023), "A novel framework for determining optimum fibre content in high-performance asphalt concrete mixes for low-temperature applications", 2023 Transportation Association of Canada (TAC) Conference & Exhibition, Ottawa, Canada

C.2 Ahmed N*, Saleh M*, Baghaee Moghadam T., Hashemian L. (2023), "The Impact of Polyethylene Terephthalate (PET) Fibres on the Cracking Resistance of High-Performance Asphalt Concrete (HPAC)", 2023 Transportation Association of Canada (TAC) Conference & Exhibition, Ottawa, Canada

C.3 Ahmed N*, Saleh M*, Baghaee Moghadam T., Hashemian L. (2023), "Evaluation of Cracking Resistance of High-Performance Asphalt Concrete Composed of Asphaltenes Modified Binder and PET Fibres", In 68th Annual Conference of the Canadian Technical Asphalt Association (CTAA), Charlottetown, PEI, Canada

C.4 Kamran, F.*, Ghasemirad, A.*, Bayat, A., Hashemian, L. (2022), "Performance Evaluation of High Modulus Asphalt Concrete (HMAC) Prepared Using Asphaltenes-Modified Binders", 101st Transportation Research Board of National Academy of Science Conference, Washington, DC, United States.

C.5 Kamran, F.*, Souparni, S.*, Hashemian, L. (2021), "Impact of Asphaltenes on Permanent Deformation of Stabilized Base Course Using Asphalt Emulsion", In 2021 TAC Conference &

Exhibition, online (Oral Presentation and third-place winner of the 2021 Transportation Association of Canada (TAC) Student Paper Award).

Dissertations (completed)

MSc

T.1 Nusrat Nazim Jhora, (2023), "Evaluation of Mechanical Properties of Asphalt Emulsion Base Course Using Reclaimed Asphalt Pavement (RAP) and Asphaltenes"

PhD

T.1 Farshad Kamran, (2023), "Design and Performance Evaluation of Road Base Courses Comprised of Asphalt Emulsion and Asphaltenes Derived from Alberta Oil sands"

H. BENEFITS

Please provide a narrative outline the project's benefits. Please use the subheadings of Economic, Environmental, Social and Building Innovation Capacity.

- **Economic:** Describe the project's economic benefits such as job creation, sales, improved efficiencies, development of new commercial opportunities or economic sectors, attraction of new investment, and increased exports.
- **Environmental:** Describe the project's contribution to reducing GHG emissions (direct or indirect) and improving environmental systems (atmospheric, terrestrial, aquatic, biotic, etc.) compared to the industry benchmark. Discuss benefits, impacts and/or trade-offs.
- **Social:** Describe the project's social benefits such as augmentation of recreational value, safeguarded investments, strengthened stakeholder involvement, and entrepreneurship opportunities of value for the province.
- **Building Innovation Capacity:** Describe the project's contribution to the training of highly qualified and skilled personnel (HQSP) in Alberta, their retention, and the attraction of HQSP from outside the province. Discuss the research infrastructure used or developed to complete the project.

RESPOND BELOW

H.1 Economic:

Overall, incorporating a high-strength base course into pavement structures offers substantial economic advantages both in construction and delayed rehabilitation of roads. It leads to the creation of durable pavements with extended service life and reduced thickness requirements compared to conventional pavements. These benefits translate into significant cost savings. Additionally, this approach reduces construction cycle times, which is particularly advantageous in regions with short construction seasons, further enhancing cost-efficiency. Also, using RAP can result in substantial cost savings, particularly when the price of virgin materials is high. As this was a lab study, a full quantification of costs can only be done when a road is modeled/designed.

H.2 Environmental:

The outcomes of this research are expected to foster the broader use of asphalt cement derived from Alberta oilsands within the asphalt industry. This shift holds the potential to make a substantial contribution to reducing greenhouse gas (GHG) emissions. The utilization of asphaltenes in high-modulus base courses and bitumen emulsion stabilized base layers is anticipated to lead to reduced asphalt thickness requirements and prolonged pavement service life. These developments are pivotal in curbing GHG emissions associated with road construction. Furthermore, the incorporation of Reclaimed Asphalt Pavement (RAP) diverts aged asphalt from landfills or disposal sites, promoting more sustainable construction management and minimizing the environmental impact linked to the disposal of old pavement materials and reduction of GHG. Use of asphaltenes in road works diverts them away from combustion in transportation fuels.

H.3 Social:

The successful implementation of this research is poised to generate both direct and indirect employment opportunities. Direct employment prospects will arise in the production of pavement materials, driven by increased demand for asphaltene-modified materials. Moreover, this endeavour is expected to sustain existing jobs within the Alberta oilsands industry. Additionally, it will create employment opportunities in road network construction using these new materials, facilitate material exports, and open doors to potential investment ventures. These developments contribute to economic growth and job creation, fostering social well-being and economic prosperity.

H.4 Building Innovation Capacity:

Two postdoctoral fellows, one research assistant, two Ph.D. students, two MSc students, and six undergraduate students were recruited to this project and trained at the UofA’s asphalt lab. Each of this highly qualified personnel gained hands-on experience with state-of-the-art equipment and techniques and will be well-positioned to contribute further to knowledge creation in this field, either in industry or academia. Finally, after commercialization, additional research opportunities will continue to be generated.

I. RECOMMENDATIONS AND NEXT STEPS

Please provide a narrative outlining the next steps and recommendations for further development of the technology developed or knowledge generated from this project. If appropriate, include a description of potential follow-up projects. Please consider the following in the narrative:

- Describe the long-term plan for commercialization of the technology developed or implementation of the knowledge generated.
- Based on the project learnings, describe the related actions to be undertaken over the next two years to continue advancing the innovation.
- Describe the potential partnerships being developed to advance the development and learnings from this project.

RESPOND BELOW

I.1 long-term plan for commercialization

This project was limited to laboratory investigations. It is expected that in the future, field trials will be conducted in collaboration with transportation agencies and road authorities. The long-term goal, after proving the potential benefits of using asphaltene and asphalt cement derived from Alberta oilsands bitumen in terms of improved pavement quality and performance in cold regions, is that a portion of this investment will be allocated to deploying the asphalt mixes constructed from these materials in Alberta and other provinces in Canada. The quantification of GHG emissions is another objective that will be pursued in conjunction with the construction of test road sections for field trials.

I.2 Plan for the next two years

Considering the results of this study, the plan for the next two years is:

- enhance understanding of low-temperature properties of the developed asphaltenes-fibre-modified mixes;
- design a pavement section composed of the developed base courses and compare their thicknesses with conventional pavement sections
- understand the benefits of using the developed HMAC and cold stabilized/recycled mixes in the pavement structure compared with the benefits of conventional pavements.
- Investigate the possibility of using asphaltenes in cold mixes as an alternative to cement, which is the commonly used additive in these mixes

I.3 Potential partnerships

This may include but is not limited to connecting with parties interested in innovative construction materials for roadways, potential industry partners that currently have stockpiles of asphaltenes, RAP, asphalt suppliers, and roadway authorities.

J. KNOWLEDGE DISSEMINATION

Please provide a narrative outlining how the knowledge gained from the project was or will be disseminated and the impact it may have on the industry.

RESPOND BELOW

This project has resulted in ten papers to date (five journal papers accepted/published and five conference papers accepted/published, one received the best student paper award). Furthermore, the results have been or will be presented at the following academic conferences: the Canadian Technical Asphalt Association (CTAA) Annual Conference, the Transportation Research Board Annual Meeting, and the International Airfield & Highway Pavements Conference, Academic Alliance for Road Research of Canada /Alliance Académique en Recherche Routière du Canada - A2R2C, pavement seminar and Alberta Municipalities Pavement Management Group Meeting. Each of these conferences is well-recognized in the transportation industry, and the research presented at these conferences has reasonably wide exposure.

K. CONCLUSIONS

Please provide a narrative outlining the project conclusions.

- Ensure this summarizes the project objective, key components, results, learnings, outcomes, benefits and next steps.

RESPOND BELOW

The two-year research project conducted at the University of Alberta's asphalt laboratory focused on two main objectives. Firstly, it aimed to improve the low-temperature properties of high-modulus base courses (HMAC) by utilizing Polyethylene terephthalate (PET) fibres in conjunction with asphaltenes-enriched binders derived from Alberta oil sands. Secondly, the study investigated the impact of incorporating reclaimed asphalt pavement (RAP) on asphalt emulsion-stabilized base courses, specifically examining the physical and mechanical properties when modified with asphaltenes. The project sought to provide a comprehensive understanding of road-based course performance, showcasing the efficacy of utilizing asphalt binders and asphaltenes from Alberta oilsands.

The study involved a comprehensive laboratory investigation to formulate and create two high-quality base courses. For HMAC, an assessment of the applicability of asphalt binders derived from oil sands was conducted by preparing hard asphalt binders from both oil sand-derived sources and commercially available asphalt binder sources, with subsequent comparison of the results. To enhance the low-temperature properties of HMAC mixes, three different lengths of PET fibres (12 mm, 15 mm, and 18 mm) were incorporated, and the optimal PET content and length were assessed. The performance properties of all designed mixes were evaluated through Hamburg wheel tracking tests at high temperatures and indirect tensile strength tests at low temperatures.

To explore the feasibility of substituting high-quality base course material with RAP in stabilized mixes using asphalt emulsions and asphaltenes, granular aggregates were replaced with three varying proportions of RAP (25%, 50%, and 100%), and the physical properties of the mixes were assessed. Additionally, the mechanical performance of the designed mixes was evaluated through Hamburg wheel tracking tests at high temperatures, IDEAL CT tests at intermediate temperatures, and indirect tensile strength tests at low temperatures.

The study's findings revealed that asphalt binders obtained from Alberta oilsands can be effectively modified with asphaltenes for applications in high-modulus base courses. Additionally, asphaltenes derived from the deasphalting process of Alberta oilsands prove to be valuable additives for enhancing asphalt binder properties in high-modulus base courses. However, the need for enhancing low-temperature properties, depending on the binder source, was identified. This enhancement was successfully achieved by incorporating fibres, resulting in improved resistance to cracking. The optimal fibre content for this application was determined to be 0.15% of the total mix weight, with a fibre length of 12 mm being the most effective.

Furthermore, asphaltenes demonstrate potential in improving the mechanical properties of stabilized base courses with asphalt emulsion and asphaltenes at high and intermediate temperatures and negligible negative impact at low temperature when RAP was replaced by the granular material. The most favorable outcome was observed when 1% asphaltenes, by the weight of the mix, were added to 100% RAP. This result may be attributed to the higher quantity of total binder present in the 100% RAP mixes, coupled with the tendency of asphaltenes to primarily interact with asphalt binder.

Overall, incorporating a high-quality base course in pavement structures could lead to pavements that are durable, possess extended lifecycles, and exhibit reduced thickness compared to traditional pavements, offering concurrent environmental and economic benefits. This approach also results in shorter construction cycles, proving particularly advantageous in regions with limited construction seasons. The study's findings illustrated that these materials could improve the cost-effectiveness and performance of asphalt pavements and generate increased demand for oilsands constituents. Moreover, the enhanced base course performance has the potential to decrease high quality material requirements, reducing thickness and prolonging service life, thereby contributing to a reduction in greenhouse gas (GHG) emissions compared to conventional practices.

In the subsequent phases, it is crucial to design pavement sections that incorporate the formulated mixes as base course materials. This step is essential for comprehending the advantages of employing these materials in pavement structures, particularly in terms of thickness reduction. Additionally, the construction of pilot projects is imperative to validate the findings from laboratory tests and to monitor the long-term pavement performance, including that of the innovative base course materials. These pilot projects serve as a necessary precursor to commercialization, ensuring the practical viability and effectiveness of the developed base course materials in real-world applications.