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September 30, 2018

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol – 14th Floor
600 East Boulevard Ave Dept 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Please find enclosed here in the proposal titled, Investigating the Use of Fly Ash for Sustainable Asphalt Pavements.

The main criteria for a sustainable infrastructure are: minimizing impact on and the use of natural resources; reducing energy consumption; reducing greenhouse gas emissions; limiting pollution (air, water, earth, noise); improving health, safety, and risk prevention; and ensuring a high level of user comfort and safety. The potential effect of fly ash as a mineral filler in asphalt pavements in terms of sustainability lies in the efficient use of existing materials either through reworking them and changing their structures to ensuring that the properties of the materials are improved to provide a longer life. Use of fly ash as a mineral filler in asphalt pavements helps to reduce cost, conserve energy and resources, improve durability, reduce environmental impact, and enhance workability. The main objective of this project is to test the hypothesis that fly ash can be used as a mineral filler in asphalt pavements to increase the strength and durability.

The research team has the experience and expertise to complete the research within the schedule and budget. The University of North Dakota is committed to complete the project as described in the application if the North Dakota Industrial Commission makes the grant requested.

We welcome an opportunity to discuss this proposal at greater length with you and look forward to working with you.

Sincerely,

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Investigating the Use of Fly Ash for Sustainable Asphalt Pavements

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Date of Application: October 1, 2018

Amount of the Request: $53,814

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ABSTRACT

The main criteria for a sustainable infrastructure are: minimizing impact on and the use of natural resources; reducing energy consumption; reducing greenhouse gas emissions; limiting pollution (air, water, earth, noise); improving health, safety, and risk prevention; and ensuring a high level of user comfort and safety. The potential effect of fly ash as a mineral filler in asphalt pavements in terms of sustainability lies in the efficient use of existing materials either through reworking them and changing their structures to ensuring that the properties of the materials are improved to provide a longer life. Use of fly ash as a mineral filler in asphalt pavements helps to reduce cost, conserve energy and resources, improve durability, reduce environmental impact, and enhance workability. The main objective of this project is to test the hypothesis that fly ash can be used as a mineral filler in asphalt pavements to increase the strength and durability. The research team anticipates that the use of fly ash as a mineral filler in asphalt pavements will improve mechanical properties in terms of low-temperature cracking, fatigue cracking, and rutting; increase resistance to moisture damage; and reduce compaction temperature for longer paving season in addition to economic and environmental benefits. The project will be for a duration of one year. The total project cost is **$119,463**. The participants with percent cost in parenthesis are: Civil Engineering Department at the University of North Dakota (53%), North Dakota Industrial Commission (45%), and Great River Energy, Border States Paving, Strata Corporations, and North Dakota Department of Department Grand Forks District (2%).

PROJECT SUMMARY

The main criteria for a sustainable infrastructure are: minimizing impact on and the use of natural resources; reducing energy consumption; reducing greenhouse gas emissions; limiting pollution (air, water, earth, noise); improving health, safety, and risk prevention; and ensuring a high level of user comfort and safety. The potential effect of fly ash as a mineral filler in asphalt pavements in terms of sustainability lies in the efficient use of existing materials either through reworking them and changing their structures to ensuring that the properties of the materials are improved to provide a longer life.

Use of fly ash as a mineral filler in asphalt pavements helps to reduce cost, conserve energy and resources, improve durability, reduce environmental impact, and enhance workability. The main objective of this project is to test the hypothesis that fly ash can be used as a mineral filler in asphalt pavements to increase the strength and durability. Fly ash type C, fly ash type F, and lime will be used as mineral fillers in asphalt paste and asphalt mixtures. Great River Energy will provide fly ash for the project if it is funded.

Rheological properties of asphalt binder and paste will be determined using Dynamic Shear Rheometer (DSR). The viscosity of the binder and paste will be determined using Rotational Viscosity. The mechanical properties of asphalt mixes in terms of low-temperature cracking, fatigue cracking, and rutting will be determined using disk-shaped compact tension test (DCT), Semi-circular bending (SCB), Asphalt Pavement Analyzer (APA), respectively. Moisture damage resistance of the mixes will be determined following AASHTO T 283. Specimens will be compacted at various temperatures to determine whether or not fly ash can be used as compaction aid. Statistical analysis (analysis of variance and t-test) will be conducted at 5% significance level to determine equivalency between the control and fly ash-based concrete.

1. PROJECT DESCRIPTION

1.1 Objectives

The main criteria for a sustainable infrastructure are: minimizing impact on and the use of natural resources; reducing energy consumption; reducing greenhouse gas emissions; limiting pollution (air, water, earth, noise); improving health, safety, and risk prevention; and ensuring a high level of user comfort and safety *(Maher et al. 2006)*. The potential effect of fly ash as a mineral filler in asphalt pavements in terms of sustainability lies in the efficient use of existing materials either through reworking them and changing their structures to ensuring that the properties of the materials are improved to provide a longer life *(Cassar 2005)*.

The main objective of this project is to test the hypothesis that fly ash can be used as a mineral filler in asphalt pavements to increase the strength and durability. There will be five specific objectives in this project:

- To review available literature on the use of fly ash in asphalt pavements
- To determine the rheology and viscosity of binder and paste (mixture of binder and fly ash/lime)
- To determine the effect of fly ash on the properties of mixes in terms of low-temperature cracking, fatigue cracking, and rutting
- To investigate the effect of fly ash on the durability of the mixes in terms of moisture damage
- To investigate the effect of fly ash on the compatibility of asphalt mixes at lower temperature for longer construction season

1.2 Methodology

1.2.1 Selection of Materials

Two different types of fly ash (type C and F) and lime will be used as mineral fillers. Lime is widely used to reduce moisture damage in asphalt pavements. If fly ash performs as well as lime or better than lime in reducing moisture damage it can replace lime as anti-striping agent. Two binder grades (PG 64-28 and PG 58-28) that are widely used in North Dakota will be used. Great River Energy will provide fly ash for this research *(please see letter of commitment)*. Border States Paving, Strata Corporations, and North Dakota Department of Transportation Grand Forks District will provide field mixes and raw materials used in field mixes for three projects each from 2019 paving season *(letter of commitment from each company is attached)*. Field mixes with natural fines will used as a control. The research team will replace natural fines with fly ash and lime as mineral fillers in the laboratory.

1.2.2 Experimental Plan

Mineral filler type (fly ash type C and F, and lime), mineral filler content, and compaction temperature of asphalt mixes will be considered as variables. Natural fines will be used as a control. At least three specimens will be tested in each test category so that enough data will be available for statistical analysis. Table 1 shows the types of tests to determine rheological properties of binder and paste, mechanical properties of the mixes, moisture damage resistance of the mixes, and compatibility of the mixes.

For comparison purposes, the experimental plan for the *binder and paste tests* will include preparing and testing of four groups: (1) binder (control), (2) Fly ash type C and binder (paste), (3) fly ash type F and binder (paste), (4) lime and binder (paste). The experimental plan for the mixes will also include preparing and testing of four groups: (1) mixes with natural fines (control), (2) mixes with fly ash type C, (3) mixes with fly ash type F, and (4) mixes with lime. Fly ash and lime will be used as a replacement for natural fines.

Table 1. Binder and Mix Properties, Test Temperature, and Equipment

Properties		Test Temperature	Equipment
Rheology of binder and paste	Low-temperature cracking	Low	Dynamic Shear Rheometer (DSR)
	Fatigue cracking	Medium	
	Rutting	High	
Viscosity of binder and paste		Varies	Rotational Viscometer
Mechanical properties of the mixes	Low-temperature cracking	Low	DCT
	Fatigue cracking	Medium	SCB
	Rutting	High	APA
Moisture damage of the mixes	Durability	Medium	Universal Testing Machine
Compatibility of the mixes	Construction season	Varies	Superpave Gyratory Compactor

1.2.2. 1 Binder and Paste Properties

Asphalt binders are viscoelastic materials and thus behave like an elastic solid and a viscous liquid depending on the load and the temperature. Characterization of both the elastic and viscous properties of asphalt binders is archived by using a dynamic shear rheometer (DSR). The asphalt binder's resistance to shear deformation in the linear viscoelastic region can be determined by the DSR *(Huang et al. 2010)*. The complex shear modulus and the viscosity of the binder can be determined by the phase angle. In addition, DSR will be used to conduct on asphalt paste to explore the stiffening effect of different cementitious fillers (fly ash type C and F, and lime).

Original binder and pastes will be tested for rheological properties (low-temperature cracking, fatigue cracking, and rutting) and viscosity. Two binders (PG 64-28 and PG 58-28) will be used as control. Paste of binder and mineral fillers (fly ash type C, fly ash type F, and lime) will be tested. The different tests are briefly described in the following sections.

Low-temperature Cracking: Low-temperature cracking is a principal failure mode of asphalt pavements, particularly in cold areas, such as North Dakota. A 4 mm parallel plate geometry DSR test at -18°C will be used in this research to determine the relaxation modulus and creep slope. Table 2 shows the evaluation criteria.

Fatigue Cracking Resistance: The conventional AASHTO M320 G*sin (δ) parameter evaluates the fatigue performance of the binder based on the stiffness parameter. The flaw of the G*sin(δ) parameter is not to relate the damage due to traffic effect and measure the parameter under the small shear stain and fixed frequency of 10 rad/s led Linear Amplitude Sweep (LAS) approach (*Zhou et al. 2013)*. The LAS test is a DSR test on rolling thin film oven (RTFO)-aged, and pressure aging vessel (PAV)-aged binders consisting of frequency sweep and strain amplitude sweep to determine the two fatigue parameters "A" and "B" that relate the traffic and pavement structure factor. The higher A value indicates a better fatigue cracking performance whereas a higher B indicates a poor fatigue performance.

Rutting Resistance: The failure to reflect the rutting characteristics of the conventional AASHTO M320 G*/sin (δ) parameter for polymer modified and nonlinear binder strain made Multiple Stress Creep Recovery(MSCR) suitable to determine the rutting performance of binders *(Kabir 2017)*. The MSCR test uses DSR on 25 mm parallel plate geometry of 1 mm gap setting on the RTFO-aged sample for a creep-recovery test of 1second loading followed by 9 seconds rest at two stress levels (1 kPa and 3.2 kPa) using a controlled shear stress mode. It uses three parameters, non-recoverable creep compliance at 3.2 kPa (jnr_3.2), percentage difference of non-recoverable stress (Jnr _diff), and percentage recovery (R_diff), that evaluates elastic recovery of the binder and paste.

Table 2. Binder Specification Criteria

Material	Value	Specification	Distress of Concern	Testing method
Unaged binder	G*/sinδ	≥ 1.0 kPa (0.145 psi)	Rutting	AASHTO T315
RTFO residue	G*/sinδ	≥ 2.2 kPa (0.319 psi)	Rutting	AASHTO T315
PAV residue	G*.sinδ	≤ 5000 kPa (725 psi)	Fatigue cracking	AASHTO T315
Creep Stiffness(S) ≤300 MPa and Slope (m_r) ≥ 0.300 @ 60 seconds.			Low-Temperature Cracking	AASHTO 313
MSCR, Standard Traffic "S" Grade Jnr_3.2, max 4.0 kPa–1 Jnr_diff, max 75% MSCR, Heavy Traffic "H" Grade Jnr_3.2, max 2.0 kPa–1 Jnr_diff, max 75% MSCR, Very Heavy Traffic "V" Grade Jnr_3.2, max 1.0 kPa–1 Jn_rdiff, max 75% MSCR, : Extremely Heavy Traffic "E" Grade Jnr_3.2, max 0.5 kPa–1 Jnr_diff, max 75%			Rutting	AASHTO M332

Viscosity: *Suheibani (1986)* and *Tons et al. (1983)* evaluated fly ash as an asphalt extender. *Suheibani (1986)* examined the way particle size of fly ash affected the viscosity of the asphalt to which it was added, and the effect of fly ash as an extender on voids, density measurements, and mechanical properties of asphalt.

The viscosity of binder and paste will be measured using Rotational Viscometer. UND Civil Engineering will purchase Rotational Viscometer if this proposal is funded. The quote to purchase the equipment is included.

1.2.2.2 Mechanical Properties of Mixes

The primary performance emphasis will be on the load-associated distresses of cracking and rutting. The research will include basic volumetric testing of asphalt mixes in addition to performance testing of laboratory mixed/laboratory compacted, and field mixed/laboratory compacted specimens. Two private contractors (Border States Paving and Strata Corporations) and North Dakota Department of Transportation Grand Forks District will be provide field mixes with natural fines and raw materials for lab mixing. Field mixes with natural fines will be used as control. The research team will replace natural fines with fly ash type C and F, and lime using the raw materials from the field.

Superpave Gyratory Compactor (SGC) will be used to make the specimens following AASHTO standard procedure. The weight of the mix needed for a standard air void content of 7±1% in the sample will be determined. For each project, at least three specimens will be made and tested to conduct statistical analysis for each type of performance (low-temperature cracking, fatigue cracking, and rutting). This means at least 10 (3 for low-temperature cracking, 3 for fatigue cracking, and 4 for rutting) specimens per project will be tested. Performance tests are described in the following sections.

***Low-temperature cracking*:** Low-temperature (thermal) cracking can cause major damage to asphalt pavements in cold-climate regions, such as North Dakota. Some researchers demonstrated that fracture tests are able to capture low-temperature properties of asphalt mixtures *(Marasteanu et al. 2007, Zofka and Braham 2009)*. An energy-based parameter may be more suitable for describing the fracture behavior of viscoelastic materials like asphalt *(Bayomy et al. 2006)*. A disk-shaped compact tension test (DCT) has been used by many researchers *(Wagoner et al. 2005, 2006)* as a practical method for obtaining the fracture energy that was used to represent the separation behavior of asphalt concrete at relatively low-temperatures *(Kuai et al. 2009)*. The DCT can be used to measure the fracture energy of cylindrical specimens routinely obtained from both field cores and gyratory-compacted laboratory specimens *(Braham et al. 2007)*.

ASTM D7313 will be followed to determine low-temperature cracking susceptibility of the mixes. The DCT test will be carried out to analyze the low-temperature cracking resistance of the specimens. This test gives the fracture energy (G_f), which is a parameter to describe the cracking resistance of the specimens. The test will be conducted at PG + 10˚C of the low-temperature PG grade according to the standard specification. Before testing, the specimens will be conditioned for 12 hrs at test temperature. During the test, a constant Crack Mouth Opening Displacement (CMOD) rate of 0.017 mm/s will be maintained.

The geometry of the specimen for this test will be cylindrical with a diameter of 150 mm and height of 50 mm. A crack mouth opening of 35 mm will be made on the specimen after creating a flat face in the specimen. Specific dimensions of the specimens and test setup are shown in Figure 1 and 2, respectively.

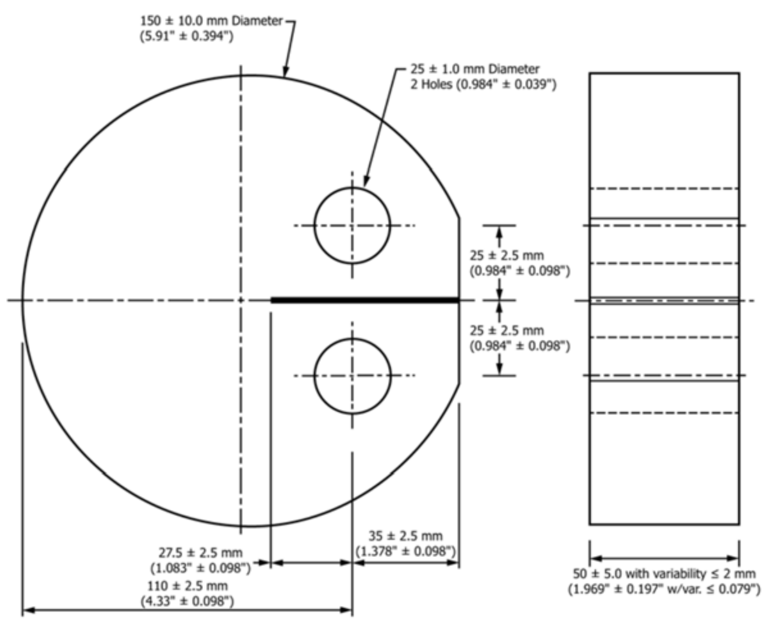

Figure 1. Dimension of DCT Specimen *(ASTM 2013)*.

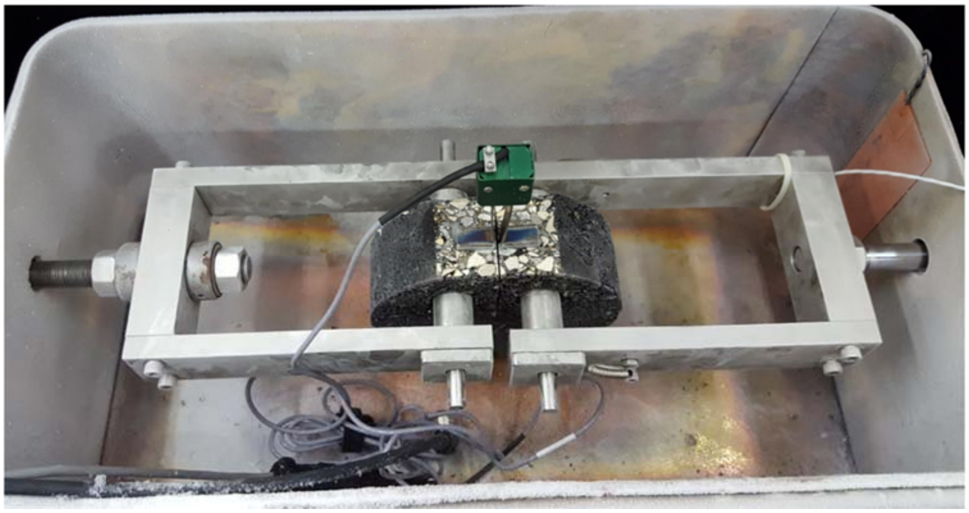

Figure 2. DCT test setup.

***Fatigue Cracking*:** Fatigue cracking is a major intermediate temperature distress in flexible pavements, which is caused by damage induced from repeated traffic loading. Formation of cracks allows moisture intrusion that eventually leads to development of potholes. Since its introduction, the Semi-circular bending (SCB) test method has been investigated by many researchers and was found to be a suitable alternative test for estimating the fatigue fracture resistance of asphalt mixtures *(Molenaar et al. 2002, Al-Qadi et al. 2012, Biligiri et al. 2012, Mohammad et al. 2013, Birgisson et al. 2006, Shu et al. 2008, Hassan and Khalid 2010, Saadeh and Hakimelahi 2012, Kim et al. 2012)*. This method is based on the elasto-plastic fracture mechanics concept that leads to the laboratory determination of the critical strain energy release rate of mixtures using notched semi-circular samples. The major advantage of the SCB test is that different notch depths can be introduced easily on the semi-circular test specimen. Hence, the true fracture properties of asphalt mixtures with regard to the crack propagation can be evaluated directly.

There are several standards for SCB test and researchers have been working to fine-tune the standards. Different states follow different geometry, notch depth, thickness, and temperature for the test. For this research, the Illinois-Flexibility Index Tester (I-FIT) protocol will be followed.

Recommended sample thickness for this test is 50 mm. The test specimen geometry details are shown in Figure 3 and test setup is shown in Figure 4. A semi-circular geometry with 150 mm diameter and a notch of 15 mm will be prefabricated in the flat end of the semi-circle. The testing temperature will be 25˚C. The samples will be conditioned in the environmental chamber for 2±0.2 hrs. Data will be post processed to calculate the fracture energy and Flexibility Index (FI) using a software. The higher the FI value the better the mix in terms of cracking resistance (ductility). For good performing mix, FI value is greater than 4.5 whereas less than 2 is referred to as very poor mix *(Ozer et al. 2016)*.

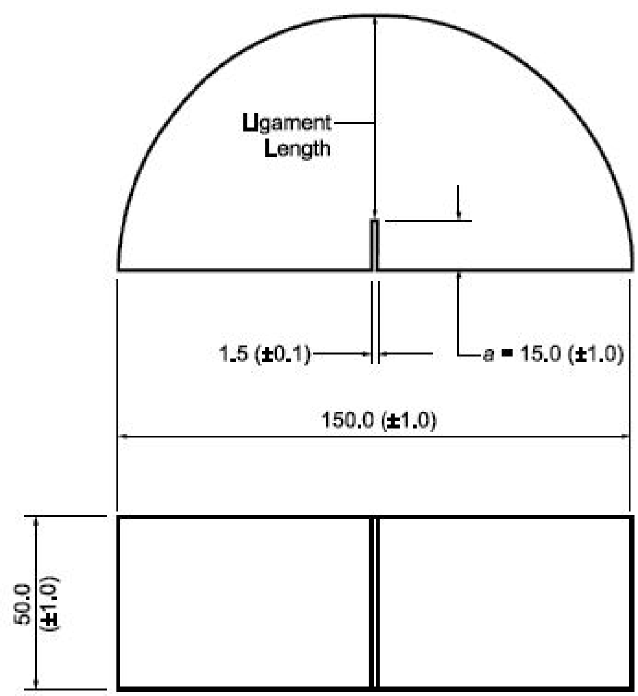

Figure 3. SCB test specimen Geometry *(AASHTO 2016)*.

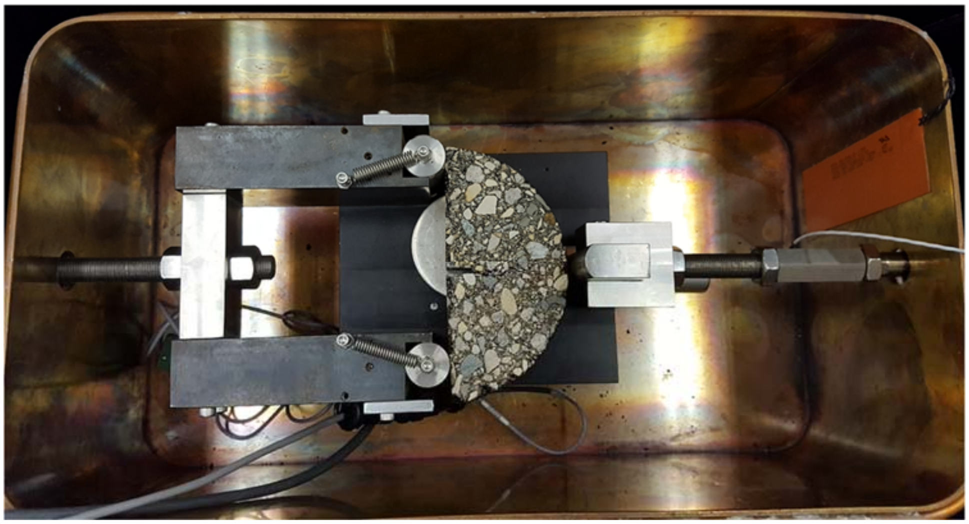

Figure 4. SCB test setup.

***Rutting Resistance*:** Rutting is one of the most common distresses in asphalt pavements. The Asphalt Pavement Analyzer (APA) is used to simulate and evaluate the mixture stripping and rutting potential. The results from APA show excellent correlation with the field rutting performance when the loading and environment are similar *(Colbert and You 2012, Witczak 2007)*. Rutting susceptibility of the mixes will be determined using APA.

This test method simulates the traffic loading and temperature effects on compacted mixtures in the laboratory. The test will be conducted according to AASHTO T 340 standard. All the specimens will be heated to high performance grade temperature for 6 hours. The load will be applied to the specimen by a steel wheels, which rest on a pneumatic hose pressurized to 100 psi for 8000 cycles. The 8000 cycles represent about 1 million "Rutting Equivalent Standard Axle Loads" (ESALs), which represents about 3 million total ESALs *(Skok et al. 2002)*.

1.2.2.3 Moisture Damage Resistance

Moisture damage in asphalt mixture is the loss of strength, stiffness, and durability due to the presence of moisture leading to adhesive failure at the binder–aggregate interface and/or cohesive failure within the binder or binder–filler mastic *(Tarefder and Zaman 2010)*. Figure 5 shows moisture damage mechanisms in asphalt mixture. Since the two mechanisms are interrelated, a moisture-damaged pavement may be a result of both mechanisms combined *(Lottman 2001)*. Fly ash as a mineral filler can result in reduced potential for stripping or moisture damage due to its hydrophobic properties *(Sen and Mishra 2010)*.

The indirect tensile strength (ITS) test (*AASHTO* T 283) provides the potential to evaluate the moisture susceptibility and predict the long-term stripping susceptibility and fracture toughness of asphalt mixtures *(Colbert and You 2012, Yongjie et al. 2009, Aksoy et al. 2005, Huang et al. 2003)*. The stripping resistance of asphalt mixtures will be evaluated by the decrease in the loss of the ITS after immersion in water for 24 h at 60°C. Specimens will be tested for ITS using the Universal Testing Machine (UTM) at a constant loading rate and temperature.

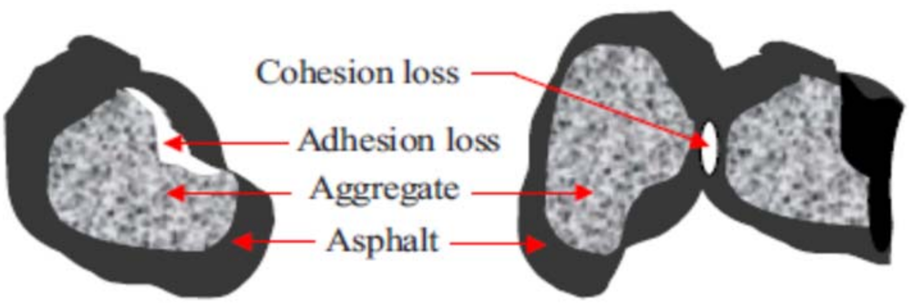

Figure 5. Moisture damage mechanisms in asphalt mixtures *(Tarefder and Zaman 2010)*.

1.2.2.4 Compaction Aid

Compaction is the process by which the volume of air in asphalt mixture is reduced by using external forces to reorient the constituent aggregate particles into a more closely spaced arrangement. This reduction of air volume produces a corresponding increase in mixture density *(Roberts et al. 1996)*. Compaction is the greatest determining factor in dense graded pavement performance *(Scherocman and Martenson 1984, Scherocman 1984, Geller 1984, Brown 1984, Bell et. al. 1984, Hughes 1984, Hughes 1989)*. Inadequate compaction results in a pavement with decreased stiffness, reduced fatigue life, accelerated aging/decreased durability, rutting, raveling, and moisture susceptibility *(Hughes 1984, Hughes 1989)*.

Asphalt mix temperature directly affects asphalt binder viscosity and thus compaction. As mix temperature decreases, the constituent asphalt binder becomes more viscous and resistant to deformation resulting in a smaller reduction in air voids for a given compactive effort. As the mix cools, the asphalt binder eventually becomes stiff enough to effectively prevent any further reduction in air voids regardless of the applied compactive effort *(Scherocman and Martenson 1984, Hughes 1989)*.

Asphalt mix specimens will be compacted at different temperatures to investigate the use of fly ash as a compaction aid. This is very crucial in states like North Dakota where construction season is short. If fly ash is proven to be used as a compaction aid construction season can be longer.

1.2.2.5 Statistical Analysis

Paired t-tests will be performed to evaluate if there is a significant difference between the properties of the control, fly ash type C and F, and lime based paste and mixes *(SAS Institute, Inc. 2005)*. A paired t-test result can be expressed in terms of a p-value, which represents the weight of evidence for rejecting the null hypothesis (*Ott and Longnecker 2001)*. Significance level of 5% will be used for all paired t-tests. Analysis of variance (ANOVA) will also be conducted at the same significance level using Statistical Analysis Software (SAS).

1.3 Anticipated Results

Fly ash includes constituents such as silica, alumina, iron, and other oxides. These characteristics allow fly ash to be an effective material as a mineral filler in asphalt pavements. The research team anticipates that the use of fly ash as a mineral filler in asphalt pavements will improve mechanical properties in terms of low-temperature cracking, fatigue cracking, and rutting; increase resistance to moisture damage; and reduce compaction temperature for longer paving season in addition to economic and environmental benefits.

1.4 Facilities and Resources

1.4.1 Material Testing Laboratory and Equipment

The Department of Civil Engineering at the University of North Dakota owns a 625 square meter of research laboratory dedicated to civil engineering materials testing in Upson I Rooms 106H, 112, and 113. The laboratory is fully equipped with state-of-the-art facilities that will be used to test civil engineering materials. The equipment needed for this project are described below.

Binder and Paste Testing: The research team has rolling thin film oven (RTFO) for short-term aging of binder and paste, pressure aging vessel (PAV) for long-term aging of binder and paste, and Dynamic shear rheometer (DSR) to determine low-temperature cracking, fatigue cracking, and rutting resistances. The research team is going to purchase Rotational Viscometer to determine the viscosity of the binder and paste if the project is funded *(the quote for viscometer is attached)*.

Aggregate Testing: The research team has all the equipment needed for sieve analysis, specific gravity, bulk density, moisture content, and absorption of coarse and fine aggregates.

Mix Compaction: The research team owns Superpave Gyrator compactor to compact the specimens for mechanical properties test and determine whether or not fly ash can be used as compaction aid for longer construction season.

Mechanical Property: The research team has DCT for low-temperature cracking, SCB for fatigue cracking, and APA for rutting resistance tests.

Durability Test/Moisture Damage Test: The research team owns the equipment for conditioning of the specimens according to AASHTO standard and then test using Universal Testing Machine (UTM).

1.4.2 Human Resource and Facilities

Two quarter time graduate research assistants (one Ph.D. and one M.S.) will work on this project under the guidance of the Principal Investigators (Drs. Gedafa and Suleiman). Administrative assistant will help with payroll, hiring of students, ordering equipment and supplies.

The PIs have 4 m by 4 m office space with personal computer and high speed internet access in Upson II Room 260, which is adjacent to Upson I where laboratories are located. Graduate research assistants have office space in Upson I and personal computer with high speed internet connection. All the computers have the programs and softwares that are needed for this project.

1.4.3 Library

The University of North Dakota (UND) has seven different libraries. Chester Fritz Library is the largest library in the university and the state of North Dakota. It houses over two million print and non-print items. It is designated as U.S. Patent and Trademark depository of Federal and State documents. The library also houses a Special Collections Department preserving unique publications, manuscripts, historical records, and genealogical resources. The research team can also get any relevant publications through Interlibrary Loan (ILL) services provided by Chester Fritz Library if they are not in one of the seven libraries.

1.5 Environmental and Economic Impacts of the Project while it is Underway

The research team does not anticipate negative impacts on the environment and economy while the project is underway.

1.6 Ultimate Technological and Economic Impacts

If this project is successful, it has the potential to be transformative. It will have a huge positive impact on the environment, energy, durability of asphalt pavements, maintenance cost of asphalt pavements, cost of road users, etc. Please see the detail in "Value to North Dakota" section.

1.7 Why the Project is needed?

According to the American Coal Ash Association (ACAA) (2010) survey, about 63 million Mg fly ash (FA) was produced in 2009, of which only about 39% was reused in different applications like concrete production, structural fills, waste stabilization, road base/subbase, and soil modification. The remaining fly ash is typically disposed of in utility disposal sites *(Soleimanbeigi et al. 2013)*. Environmental concerns over diminishing landfill space in conjunction with a sharp increase in waste disposal costs created an urgent need to find new, more economical, and environmentally sound methods to recycle by-products. In addition, dwindling supplies and increasing costs of conventional highway materials as well as federal and state legislations directed research efforts toward utilizing by-products, such as coal ash, as partial substitutes and/or extenders of natural paving materials. The highway industry is capable of utilizing by-products materials in large quantities if their effect on pavement performance proves to be technically, economically, and environmentally satisfactory.

Asphalt mix consists of asphalt, aggregate, and mineral filler. The mixture of asphalt and mineral filler is usually called asphalt mastic/paste. Mineral fillers are expected to contribute to the stability of asphalt mix by reducing voids and increasing stiffness *(Jimenez et al. 2008, Antunes et al. 2015)*. Surface area, texture, type and elemental composition of mineral filler are major influencing factors affecting the performance of asphalt paste *(Jimenez et al. 2008, Huang and Zeng 2007)*. Usually, inert and active fillers are used for the preparation of asphalt paste. Stone dust, limestone, granite etc. are considered as inert filler, whereas, lime, cement, fly ash, and diatomite, etc. fall in the category of active filler. Active fillers are being used to improve antistripping and antiaging properties of asphalt mixes *(Little and Petersen 2005, Iwanski and Mazurek 2013, Cheng et al. 2015)*.

Fly ash has been used extensively in concrete production for years; however, there are limited applications in which fly ash has been used in asphalt pavements *(Ali et al. 1996, Asi and Assaad 2005, Churchill and Amirkhanian 1999, Sankaran and Rao 1973)*. The use of fly ash in asphalt materials is an attractive option because it improves performance and reduces costs and environmental impacts *(Tapkin 2008)*. However, despite the reported benefits, the application of fly ash in asphalt technology is not commonly accepted. The main effects of fly ash fillers on the performance of asphalt binder and mixes are not completely understood; therefore, further investigation of the effects of bitumen extension and the development of more sustainable, high-performance asphalt pavement with fly ash asphalt is greatly needed.

2. STANDARDS OF SUCCESS

If the performance of fly ash as a mineral filler is better than natural fines and comparable to lime, then the project will be considered as successful provided that it will be completed within the schedule and budget.

3. BACKGROUND

Paving mixtures are composed of mineral aggregates held together by an asphalt binder. The mineral aggregates are distributed throughout the mixture in sizes ranging from coarse to fine. Properly compacted asphalt mixtures produce a structure whose stability, stiffness, and wearing properties are dependent on the interlocking of the aggregate and the cohesiveness of the binder. Mineral filler is defined as finely divided mineral matter and includes material such as rock dust, slag dust, Portland cement, hydrated lime, fly ash, waste glass, etc. *(Sobolev 2003)*. A formal definition of mineral filler is the material passing a No. 200 (0.074 mm) US standard sieve. In usual practice, the mineral filler used in asphalt–aggregate mixtures is the tail-end product obtained during the crushing process of natural rock that conforms to aggregate specifications.

Tons et al. (1983) concluded that fly ash improved asphalt hardening, moisture and freeze–thaw resistance, rutting resistance, fatigue life, density, and tensile strength. *Suheibani (1986)* and *Al-Suhaibani and Tons (1991)* evaluated fly ash as an asphalt extender and found that addition of this filler provided superior fatigue life, rut depth resistance, and tensile strength. *Kumar et al. (2008)* found that indirect tensile strength of mixes with fly ash filler increases with increase in the fly ash content indicating improved resistance against low-temperature cracking and fatigue cracking. Tensile strength ratio and retained stability also increased with the increase in fly ash content. *Sharma et al. (2010)* demonstrated that fly ash additions enhance bitumen stability, tensile strength, moisture resistance, permanent strain, and rutting.

3.1 Effect of Fly Ash on Binder and Paste Performance

Faheem and Bahia (2010) reported on the interaction between the mineral filler and asphalt binder, where the stiffening effect of the filler on the binder follows a linear filling trend, demonstrating small interaction between filler and binder.

The investigation of the rheological performance of the asphalt binders with different fillers using a DSR confirmed the feasibility of using fly ash for improving the performance of asphalt binders. It was demonstrated that fly ash can be used as an asphalt extender replacing up to 15% of bitumen at a wide range of processing and service temperatures. The best performance enhancement was achieved with fly ash Class F: the use of 15% Class F fly ash improved the grade of polymer-modified binder from PG-70 to PG-76, demonstrating a strong synergy of polymer modification and fly ash addition; the same grade shift was achieved by adding 30% Type C fly ash. Both types of fly ash when used at 60% increased the grade of reference bitumen from PG 58 to PG 64 *(Sobolev et al. 2014)*.

3.2 Effect of Fly Ash on Mixture Performance

Filler replacement with fly ash provides a considerable economy of bitumen in asphalt–aggregate mixtures designed for the equivalent stability. From the physical interaction of fly ash and binder paste, a more preferable asphalt– aggregate mixture behavior is obtained. This asphalt–

aggregate mixture behavior was investigated from the point of view of rheological properties of the mixtures, namely by carrying out fatigue tests. The fatigue life of fly ash specimens was found to be considerably higher than that of the control specimens. This is a very promising result that can be explained mainly by the stiffening and void-filling effects of the fly ash filler acting as a bitumen extender in the asphalt–aggregate mixture *(Tapkin 2008)*. *Asi and Assaad (2005)* also reported significant improvement in fatigue life of mixes with 10% replacement of the mineral filler by fly ash.

3.3 Moisture Damage Resistance

Since moisture-induced damage was first observed in early 1900s, it has been identified as one of the major causes of distress in asphalt pavements *(Kiggundu and Roberts 1988)*. Moisture in asphalt pavements causes the loss of adhesion between aggregate and asphalt paste (mixture of aggregate particles smaller than 0.075 mm in size and asphalt binder) and/or the loss of cohesion within asphalt paste, resulting in distress in the forms of stripping and raveling *(Roberts et al. 1996, Kiggundu and Roberts 1988)*. In addition, the reduced adhesive and cohesive bonding strengths and stiffness can also aggravate other forms of pavement distress, such as rutting and fatigue cracking *(Roberts et al. 1996, Kiggundu and Roberts 1988, Xie et al. 2012)*. Although its mechanisms have not been fully understood, several factors have been recognized to contribute to occurrence and severity level of moisture damage, such as asphalt binder properties, aggregate properties, asphalt mixture properties, construction practice, quality control during compaction, nature of water at the interface, dynamic effect of traffic loading, type and properties of antistripping additives, and others *(Kiggundu and Roberts 1988, Bagampadde et al. 2004)*.

Many measures have been taken to mitigate moisture-induced damage in asphalt pavements *(Anderson et al. 1982)*. A common way is adding anti- stripping additives *(Halles and*

Thenoux 2009, Huang et al. 2010). The mineral antistripping additives are usually inorganic powder added to aggregate prior to mixing with asphalt binder. They include hydrated lime, portland cement, fly ash, flue dust, and many others. Many researchers determined that fly ash had an excellent effect on the moisture resistance of asphalt specimens *(Carpenter 1952, Zimmer 1970, Xiao et al. 2012, Rongalia et al. 2013)*.

3.4 Compaction Aid

Based on the findings of *Cabrera and Zoorob (1994)*, a field trial was performed, as reported by *Tunnicliff and Root (1995)*. It was concluded from the field trial site that fly ash based mixtures could be placed and compacted at lower working temperatures using conventional practice without any adverse effect on the appearance of the wearing course. It was suggested that energy savings could be expected and a reduction in the amounts of unworkable material. Construction season can be extended as well.

4. QUALIFICATIONS

4.1 Principal Investigator (PI): Daba Gedafa, Ph.D., P.E., ENV SP

The PI has extensive research, teaching, and industry experience in civil engineering materials and infrastructure. He is a registered professional engineer (P.E.) in the states of North Dakota and Connecticut. He is also a registered Envision Sustainability Professional (ENV SP). He developed performance-related models for asphalt pavements in Kansas. He tested mechanical properties of asphalt specimens in the laboratory to validate the models *(Gedafa et al. 2012)*. The PI has an active project with North Dakota Department of Transportation (NDDOT) to determine the performance of asphalt mixes used in different districts in the state. Low-temperature cracking, fatigue cracking, rutting, and moisture damage resistance of the mixes are tested. The results will be used to develop performance-based specifications for the NDDOT.

The PI has also taught civil engineering materials course that include material testing in laboratory and report writing at four different institutions. He has been teaching civil engineering materials for eighth year at UND, two years at the University of Connecticut, one year at Kansas State University, and one year at Arbaminch University in Ethiopia. He was also the project engineer and acting project manager on construction site in Ethiopia. All of these experiences will enable him to investigate the use of fly ash as a mineral filler in asphalt pavements.

4.1.1 Pertinent Publications

1. Karki, B., Berg, A., Saha, R., Melaku, R.S., and **Gedafa, D.S**. (2018). "Effect of Nanomaterials on Binder Performance," *International Conference on Transportation and Development 2018*, Pittsburgh, Pennsylvania, July 15–18, 2018.
2. Rajib, S. and **Gedafa, D.S. (2017)**. "Effect of RAP on Cracking and Rutting Resistance of HMA Mixes," *International Conference on Highway Pavements & Airfield Technology*, Philadelphia, Pennsylvania, August 27-30, 2017.
3. **Gedafa, D.S**., Landrus, D., and Suleiman, N**.** "Effect of Nanoclay on Binder Rheology and HMA Rutting Resistance," *96th TRB Annual Meeting Compendium of Papers*, Transportation Research Board, Washington, DC, January 8-12, 2017.
4. **Gedafa, D.S.** (2016). "20-year Performance of SPS-2 Sections in North Dakota," *Proceedings of 11th International Conference on Concrete Pavements*, San Antonio, TX, August 28-September 1, 2016.

5. **Gedafa, D.S.,** Hossain, M., Romanoschi, R.A., and Onyango, M. (2016). "Effects of Binder and Mix Properties on the Mechanistic Responses of Fatigue Cracking APT Sections," *Proceedings of 5th International Conference on Accelerated Pavement Testing (APT)*, San Jose, Costa Rica, September 19-21, 2016.
6. Tolliver, S. and **Gedafa, D.S.** (2016). "Investigating the Use of Fly Ash and Nanomaterials for Sustainable Concrete Infrastructure," *International Journal of Engineering Research & Technology*, 5 (7): 173-177.
7. **Gedafa, D.S.**, Landrus, D., and Suleiman, S. (2016). "Effect of Nanoclay on Rutting Resistance of HMA Mixes," *International Journal of Engineering Research & Technology*, 5 (5): 47-52.
8. **Gedafa, D.S.**, Page, J., and Gullicks, H. (2016). "Dust from Low-volume Roads Due to Energy Sector Traffic in North Dakota," *95th TRB Annual Meeting Compendium of Papers*, Transportation Research Board, Washington, DC, January 10-14, 2016.
9. Tolliver, S. and **Gedafa, D.S.** (2015). *Investigating the Use of Fly Ash and Nanomaterials for Sustainable Concrete Infrastructure,* North Dakota Industrial Commission, Bismarck, ND.
10. Haghshenas, H.F., Khodaii, A., Hossain, M., and Gedafa, D. S. (2015). "Stripping Potential of HMA and SMA: A Study Using Statistical Approach," *ASCE Journal of Materials in Civil Engineering*, 27 (11).
11. Gedafa, D. S, Hossain, M., Romanoschi, S. A., Onyango, M.A. (2015). "Effects of Binder and Mix Properties on the Evolution of Mechanistic Responses of the APT Sections." *94th TRB Annual Meeting Compendium of Papers*, Transportation Research Board, Washington, DC, January 11-15, 2015.

12. **Gedafa, D.S.,** Kaemingk, B., Mager, B., Pape, J., Tupa, M., and T. Bohan, T. (2014). "Impacts of Alternative Yield Sign Placement on Pedestrian Safety in Mixed Use Centers," *Transportation Research Record: Journal of Transportation Research Board*, 2464: 11-19.

13. **Gedafa, D.S.,** Hossain, M., and Romanoschi, S. (2014). "Perpetual Pavement Temperature Prediction Model." *Road Materials and Pavement Design,* 15 (1): 55-65.

14. **Gedafa, D.S.,** Hossain, M., Miller, R., and Van, T. (2014). "Network-level Flexible Pavement Structural Evaluation." *International Journal of Pavement Engineering*, 15 (4): 309-322.

15. **Gedafa, D.S.,** Hossain, M., and Romanoschi, S. (2014). "Mechanistic Responses in Perpetual Pavement," *Proceedings of 12th International Conference on Asphalt Pavements (ISAP),* Raleigh, NC, June 1-5, 2014, pp. 201-210.

16. **Gedafa, D.S.**, Gullicks, H., and Page, J. (2014*). Measuring Dust from Unpaved Roads and Its Impact on Crops and Livestock*, North Dakota Association of Oil and Gas Producing Counties, Dickinson, ND.

17. Romanoschi, S., Lewis, P., **Gedafa, D.S.**, and Hossain, M. (2014). *Verification of Mechanistic- Empirical Design Models for Flexible Pavements through Accelerated Pavement Testing*, Report No. FHWA-KS-14-02, Kansas Department of Transportation, Topeka, KS.

18. **Gedafa, D.S.,** Hossain, M., Romanoschi, S., and Gisi, A. (2013). "Effect of Aging on Dynamic Modulus and Fatigue Life of Superpave Mixes." *ASCE's Airfield and Highway Pavement 2013: Sustainable and Efficient Pavements*, Los Angeles, CA, June 9-12, pp. 1040-1050.

19. **Gedafa, D.S.,** Hossain, M., and Romanoschi, S. (2013). "Prediction of Asphalt Pavement Temperature," *ASCE's Airfield and Highway Pavement 2013: Sustainable and Efficient Pavements*, Los Angeles, CA, June 9-12, pp. 373-382.

20. **Gedafa, D.S.,** Uppu, K. K., Hossain, M., Ingram, L. S., and Kreider, R. (2013). "Verification of Performance-Related Specifications for Superpave Pavements." *Transportation Research Board 91st TRB Annual Meeting Compendium of Papers,* Transportation Research Board of the National Academies, Washington, D.C., January 13-17, 2013.

21. **Gedafa, D.S**., Hossain, M., Romanoschi, S., and Gisi. A.J. (2013). "Flexible Pavement Design Simulation Using MEPDG," *Journal of Civil Engineering and Architecture,* 7 (11): 1375-1384.

22. **Gedafa, D.S**., Hossain, M., and Romanoschi, S. (2013). "Effect of Traffic Speed on Stresses and Strains in Asphalt Perpetual Pavement," *Journal of Civil Engineering and Architecture,* 7 (8): 956-963.

23. **Gedafa, D.S**. (2013). "Safety Analysis for Older Drivers at Signalized Intersections," *Journal of Civil Engineering and Architecture*, 7 (5): 626-632.

24. **Gedafa, D.S.**, Hossain, M., Ingram, L. S., and Kreider, R. (2012). "Performance-Related Specifications for PCC Pavements in Kansas," *ASCE Journal of Materials in Civil Engineering*, 24 (4): 479-487.

25. **Gedafa, D.S**., Hossain, M., Siddique, Z.Q., Fredrichs, K., and Meggers, D. (2012). "Curling of New Concrete Pavement and Long-Term Performance," *Journal of Civil Engineering and Architecture,* 6 (2): 121-131.

26. **Gedafa, D.S**., Hossain, M., Miller, R., and Steele, D. (2012). "Surface Deflections of

Perpetual Pavement Sections," *ASTM Special Technical Publication,* 1555: 192-204.

27. **Gedafa, D.S.,** Hossain, M., Miller, R., and Van, T. (2012). "Relationship between Cracking and Center Deflection." *91st TRB Annual Meeting Compendium of Papers,* Transportation Research Board of the National Academies, Washington, D.C., January 21-26, 2012.
28. **Gedafa, D.S.,** Hossain, M., and Ingram, L. (2012). *Review of Data in Construction Management System (CMS) and Quality Control and Quality Assurance (QC/QA) Databases to Improve Current Specifications for Superpave and Concrete Pavements in Kansas*. Kansas Department of Transportation, Topeka, KS.
29. **Gedafa, D.** (2012). "Impacts of Alternative Yield Sign Placement on Pedestrian Safety in Mixed Use Centers," UND Senate Scholarly Activities Committee, Grand Forks, ND.
30. **Gedafa, D.** (2012). "Flexible Pavement Temperature Prediction Model," UND Graduate School, Grand Forks, ND.
31. **Gedafa,D.S.**, Hossain, M., Ingram, L. S., and Kreider, R. (2011). "Performance-Related Specification for Superpave Pavements." *Transportation Research Record: Journal of the Transportation Research Board,* 2228: 78-86.
32. **Gedafa, D.S.,** Mulandi, J., Hossain, M., and Schieber, G. (2011). "Comparison of Pavement Design using AASHTO 1993 and NCHRP Mechanistic– empirical Pavement Design Guide," *Proceedings of 1st Transportation and Development Institute of the ASCE Congress*, Chicago, IL, March 13-16, 1: 538-547.
33. **Gedafa, D.S.**, Khanum, T., Hossain, M., and Schieber, G. (2011). "Effect of Construction Environment on JPCP Performance," *Proceedings of 1st Transportation and Development Institute of the ASCE Congress*, Chicago, IL, March 13-16, 2: 834-843.

34. **Gedafa, D.S.**, Hossain, M., Romanoschi, S., and Gisi, A.J. (2010). "Field Verification of Superpave Dynamic Modulus," *ASCE Journal of Materials in Civil Engineering,* 22 (5): 485-494.

35. **Gedafa, D.S.,** Hossain, M., Miller, R., and Van, T. (2010). "Estimation of Remaining Service Life of Flexible Pavements from Surface Deflections," *ASCE Journal of Transportation Engineering*, 136 (4): 342-352.

36. **Gedafa, D.S.**, Hossain, M., Romanoschi, S. A., and Gisi, A. J. (2010). "Comparison of Moduli of Kansas Superpave Asphalt Mixes," *Transportation Research Record: Journal of the Transportation Research Board,* 2154: 114-123.

37. **Gedafa, D.S.**, Hossain, M., Miller, R., and Steele, D.A. (2010). "Network-Level Testing for Pavement Structural Evaluation Using a Rolling Wheel Deflectometer," *ASTM Journal of Testing and Evaluation*, 38 (4): 439-448.

38. **Gedafa,D.S.**, Hossain, M., Ingram, L. S., and Kreider, R. (2010). "Composite Pay Index for Superpave Pavements in Kansas," *Proceedings of 11th International Conference on Asphalt Pavement*, Nagoya, Japan, August 1-6, 1: 709-718,

39. Romanoschi, S., Onyango, M., and **Gedafa**, **D.S.** (2010). "Accelerated Pavement Testing Validation of the Response and Distress Models for New Flexible Pavements in the Mechanistic -Empirical Design Guide," *Proceedings of 11th International Conference on Asphalt Pavement*, Nagoya, Japan, August 1-6, 1: 532-541,

40. Liu, L., Manepalli, V. S., **Gedafa**, **D. S.,** and Hossain, M. (2010). "Cost Effectiveness of Ultrathin Bonded Bituminous Surface and Modified Slurry Seal," *Proceeding of the 1st International Conference on Pavement Preservation*, Newport Beach, CA, April 12-16, pp. 317-329.

41. **Gedafa, D.S.,** Siddique, Z. Q., Fredrichs, K., Meggers, D., and Hossain, M. (2009). "Curling of New Concrete Pavement and Long-Term Performance," *Proceedings of the 2009 Mid-Continent Transportation Research Symposium*, Ames, Iowa.
42. **Gedafa, D.S.**, Hossain, M., and Romanoschi, S. A. (2009). "Simulation of Flexible Pavement Design in Kansas," *Proceedings of the 2009 Mid-Continent Transportation Research Symposium*, Ames, Iowa.
43. **Gedafa, D.S.,** Hossain, M., Miller, R., and Van, T. (2009). "Estimation of Remaining Service Life of Flexible Pavements from Surface Deflections," *88th TRB Annual Meeting Compendium of Papers,* Transportation Research Board of the National Academies, Washington, DC, January 2009.
44. **Gedafa, D.S**., Hossain, M., and Miller, R. (2009). *Implementation of the Rolling Wheel Deflectometer (RWD) for Pavement Structural Data for the Kansas Pavement Management System.* Federal Highway Administration, Washington, D.C.
45. **Gedafa, D.S**., Hossain, M., and Romanoschi. S.A. (2009). *Field Verification of KDOT's Superpave Mixture Properties to be used as Inputs in the AASHTO Mechanistic Design Guide for Pavement Structure*. Kansas Department of Transportation, Topeka, KS.

4.2 Co-Principal Investigator (Co-PI): Nabil J. Suleiman, Ph.D.

4.2.1 Pertinent Experience

- Dr. Suleiman conducted a research project on the rut resistance of Warm mix asphalts in comparison with hot mix asphalt. Field cores were sampled and tested using the asphalt pavement analyzer for dry and wet cycles.

- ❖ The Co-PI conducted rut resistance research experiments for the NDDOT. Such projects included testing 4.75 mm fine mixes for use in thin overlay and maintenance applications. The findings were published in the Transportation Research Record: Journal of Transportation Research Board. Coarse-graded mixes were also tested for rut resistance and water permeability. The results were presented and published at The 4th International Gulf Conference on Roads, Doha, Qatar. The Co-PI also conducted research on rut resistance of different local Superpave mixes. The results were presented and published in the Proceedings of the 5th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV5), Park City, UT.
- ❖ The Co-PI also modeled the response of pavements under various traffic and seasonal conditions, and published his work in the Journal of the Transportation Research Board.
- ❖ In 2009, the Co-PI published a book with VDM publishing titled: "Truck Configurations and Highway Pavements: A Methodology to Model and Assess Impacts."
- ❖ The Co-PI also has field experience. Earlier in his career, he worked for a highway consultant in South Dakota and was in charge of a road construction project (project engineer) in the Black Hills area.

4.2.2 Pertinent Publications

1. **Suleiman, N.** (2011). "Evaluation of North Dakota's 4.75 mm Superpave Mixes for Thin Overlay Applications." *Transportation Research Record: Journal of the Transportation Research Board,* 2204: 58-64.
2. **Suleiman, N.** (2009). *Truck Configurations and Highway Pavements: A Methodology to Model and Assess Impacts*, ISBN 978-3-639-13513-8, VDM Publishing, Saarbrücken, Germany.

3. **Suleiman, N.** (2008). "Evaluation of Coarse-Graded HMA Pavements in North Dakota Using the Asphalt Pavement Analyzer." In *Proceedings of 4th International Gulf Conference on Roads*, Doha, Qatar.
4. **Suleiman, N.** (2007). "Modeling Flexible Pavement Response to Truck Loads Using Finite Element Simulations." *International Journal of Pavements,* 6:158-169.
5. **Suleiman, N.**, and Varma, A. (2007). "Modeling the Response of Paved Low Volume Roads under Various Traffic and Seasonal Conditions," *Transportation Research Record: Journal of the Transportation Research Board,* 2: 230-236.
6. **Suleiman, N.** (2007). "Evaluation of North Dakota's Local Superpave Mixes' Performance Using the Asphalt Pavement Analyzer." *Proceedings of the 5th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV5)*, Park City, UT, pp. 247-252.
7. **Suleiman, N.** (2006). "FEM Application for Highway Pavement Analysis and Design: State-of-the-Art Review." *Transportation Research Board (TRB)* Annual Meeting Compendium of Papers, Washington, D.C., January 2006.
8. **Suleiman, N.** (2006). *Review and Analysis of Construction Claim for Equitable Adjustment: Mandaree Streets Project*, Final Report, Research Sponsored by the Department of the Interior-Bureau of Indian Affairs, 2006.
9. **Suleiman, N.** and Varma, A. (2002). "A Methodology to Assess Impacts of Alternative Truck Configurations on Flexible Highway Pavement Systems," *Transportation Research Record: Journal of the Transportation Research Board,* 1809:140-159.

10. **Suleiman, N.** (2002). *A State-of-the-Art Review of Cold in-Place Recycling of Asphalt Pavements in the Northern Plains Region,* Final Report. Research Sponsored by NDDOT, 2002.

5. VALUE TO NORTH DAKOTA

The objectives of transportation engineering can be defined as the supply of a safe, durable, economical, and sustainable infrastructure for the movement of goods and people. America's infrastructure received a grade of D^+ in 2017, and trillions of dollars are needed to raise the grade to B grade according to an ASCE report *(ASCE 2017)*. With the continual repair of the aging US transportation infrastructure and increasing transportation volumes on US highways, there is an urgent need for paving materials with improved performance and longer service lives. Such high-performance paving materials not only perform better, they also can meet the sustainability objectives by incorporating substantial quantities of industrial by-products, such as fly ash. Highway industry is capable of using materials in large quantities if their effect on pavement performance proves to be technically, economically, and environmentally satisfactory. There are several studies available for use of fly ash in the construction of highway embankment *(Basak et al. 2004)*.

The use of fly ash as a mineral filler in asphalt pavements can have environmental as well as economic benefits through the reduction of greenhouse gases, diversion of fly ash from landfills, and reduced use of natural resources *(Jachimovicz and Bentur 2008, Garboczi 2009)*. Durable transportation infrastructure results in a saving of billions of dollars in maintenance cost (savings for federal, state, local, and city highway agencies), reduced vehicle operating cost and travel time (savings for traveling public), and an improved safety for the society (savings for highway agencies, traveling public, insurance companies, etc.). In addition to economic and ecological benefits, the use of fly ash as a mineral filler in asphalt pavements could improve its workability and durability.

5.1 Economic Impact

In 2007, the United States produced 131 Mt of coal combustion products. While 43 percent were used beneficially, nearly 75 Mt were disposed of *(Coal Ash Facts 2013)*. Since 2003, Great River Energy has been a Champion of EPA's Coal Combustion Products Partnership (C2P2) to promote the benefits of coal combustion products – including fly ash. As a C2P2 Champion, Great River Energy has developed and committed to goals to increase the use of fly ash. Great River Energy produces about 440,000 tons of marketable fly ash per year at its Coal Creek Station. Fly ash sales have steadily increased *(Great River Energy 2003)*.

Together with the economic considerations, using fly ash in asphalt–aggregate mixtures alters the mixture behavior in a beneficial way *(Ali et al. 1996, Churchill and Amirkhanian 1999, Asi and Assaad 2005)*. Beneficial use of coal fly ash in 2004 and 2005 resulted in energy savings valued at approximately $700 million *(EPA 2008)*.

5.2. Energy and Environment

Stronger, longer-lasting structures that save taxpayer dollars and minimize environmental impacts can be built using fly ash. Using fly ash also saves the energy needed to extract and process other materials for these same uses *(EPA 2008)*.

Cabrera and Zoorob (1994) found that, based on a workability index at various temperatures, fly ash as a filler in hot mix asphalt (HMA) could be mixed and compacted at temperatures as low as 110°C and 85°C, respectively without any detrimental effects on engineering and performance properties. They concluded that there could be a considerable savings in energy without an additional asphalt binder requirement.

5.3 Landfill

By using fly ash instead of disposing of it in landfills, the environmental degradation and energy costs associated with mining virgin materials can be avoided. Environmentally and economically it makes more sense to use existing materials than to mine new ones.

- A savings of $320,000 in landfill disposal costs for every 85,000 tons of fly ash used in making concrete products *(Great River Energy 2003).*
- America is able to reduce the need for additional landfills by recycling fly ash. For each ton recycled, space equivalent to 455 days' worth of solid waste is saved in a landfill *(EPA 2008)*.

6. MANAGEMENT

Two graduate research assistants (one Ph.D. and one M.S.) will work on this project under the supervision of the two investigators (Drs. Gedafa and Suleiman). The research team will submit quarterly progress reports and make sure that the project will be completed within the schedule and budget.

7. TIMETABLE

Tentative project start and completion date will be February 1, 2019 and January 31, 2020, respectively. The research team shall submit to the commission quarterly reports summarizing the project's accomplishments and expenditures. The research team will submit quarterly reports on April 30, 2019; July 31, 2019; and October 31, 2019 assuming that the project will start on February 1, 2019. The research team will follow the timing of the reports that will be specified in the contract if this project is funded.

The research team will submit comprehensive final report to the commission within the time specified in the contract. The report will include a single page project summary describing the purpose of the project, the work accomplished, the project's results, and the potential applications of the project. The rest of the report will explain these subjects in detail as well as the total costs of the project, a summary fiscal accounting of the entire project, any plans for developing or putting to commercial use the results of the project, and whether and in what manner the project met or failed to meet the standards referred to in subsection 7 of section 43-03-04-01.

8. BUDGET

Table 3 shows an itemized project cost that include the money requested from North Dakota Industrial Commission (NDIC) and matching fund. Two principal investigators (Drs. Gedafa and Suleiman) and two quarter-time graduate research assistants (one Ph.D. and one M.S.) will work on this project. The research team would like to request about 45% of the total project cost from NDIC to achieve the project's objectives. If less funding is available than that requested, all the objectives may not be met and the results may be inconclusive.

8.1 Budget Justification

8.1.2 Salary

One year salary for quarter time (10 hrs/week) graduate students (one Ph.D. and one M.S.) and two weeks summer salary for principal investigators (Drs. Gedafa and Suleiman) has been requested from North Dakota Industrial Commission (NDIC) for their effort in this project.

8.1.3 Fringe Benefits

Fringe benefits have been calculated as 2.5% and 33% of the salary for graduate students and principal investigators, respectively.

8.1.4 Materials and Supplies

Budget has been requested to purchase lime so that we will compare the performance of fly ash to lime. Some supplies for testing of asphalt paste and specimens will be purchased.

8.1.5 Travel

The research team will travel to construction sites to collect field mixes and raw materials to replicate field mixes in the laboratory. It may also be used to travel to national and/or international conference (s) to make presentations based on research results.

8.1.6 Indirect Cost

Indirect cost has been calculated as 39% of the modified total direct cost (MTDC), which excludes equipment cost and graduate student tuition.

Table 3. Budget for the Project

	NDIC	Matching Fund		Total
		UND Civil Engineering	External Agencies*	
Salary				
Dr. Gedafa (PI)	4,790	9,580		14,370
Dr. Suleiman (Co-PI)	5,105	10,210		15,315
Grad. Res. Ass't (Ph.D. stu.)	12,353			12,353
Grad. Res. Ass't (M.S. stu.)	11,114			11,114
Total Salary	**33,362**	**19,790**		**53,152**
Fringe Benefits				
Dr. Gedafa (PI)	1,581	3,162		4743
Dr. Suleiman (Co-PI)	1,685	3,370		5055
Grad. Res. Ass't (Ph.D. stu.)	309			309
Grad. Res. Ass't (M.S. stu.)	278			278
Total Fringe Benefits	**3,853**	**6,532**		**10,385**
Grad. Student Tuition				
Ph.D. Student		10,248		10,248
M.S. Student		10,248		10,248
Equipment		6,065		6,065
Materials and Supplies	500		2,500	3,000
Travel	1,000			1,000
Total Direct Cost (TDC)	**38,715**	**52,883**	**2,500**	**94,098**
Modified Total Direct Costs (MTDC)	**38715**	**26322**	**2500**	**65,037**
Indirect Cost (39% of MTDC)	**15,099**	**10,266**	**0**	**25,364**
Total Project Cost	**53,814**	**63,149**	**2,500**	**119,463**

*Great River Energy will supply fly ash for the research; Border States Paving, Strata Corporations, and North Dakota Department of Transportation Grand Forks District will supply field mixes and raw materials from 2019 paving season. Letters of commitment are included.

9. MATCHING FUNDS

Matching funds will be provided by UND Civil Engineering (about 53% of the total project cost), and Great River Energy, Border States Paving, Strata Corporations, and North Dakota Department of Transportation Grand Forks District (about 2% of the total project cost).

9.1 Budget Justification

9.1.1 Salary

One month salary of the two principal investigators' (PIs) time on the project will be used as matching funds.

9.1.2 Fringe Benefits

The fringe benefits of the two PIs (33% of one month salary for each) will be used as matching.

9.1.3 Graduate Student Tuition

UND civil engineering department will cover graduate student tuition (21 credit hours for each graduate) for the project period. Only 50% of the tuition is included as matching since the students will only work quarter-time.

9.1.4 Equipment

UND civil engineering will purchase a new rotational viscometer to determine the viscosity of asphalt binder and paste if this project is funded by North Dakota Industrial Commission. Paste is the mixture of asphalt binder and fly ash/lime. The quote for the equipment is included.

9.1.5 Materials and Supplies

Great River Energy will supply fly ash for the research. Border States Paving, Strata Corporations, and North Dakota Department of Transportation Grand Forks District will supply field mixes and raw materials from 2019 paving season. Letters of commitment are included.

9.1.6 Indirect Cost

Indirect cost has been calculated as 39% of the modified total direct cost (MTDC), which excludes equipment cost and graduate research assistants' tuition.

10. TAX LIABILITY

No outstanding tax liability owed to the state of North Dakota or any of its political subdivisions.

11. CONFIDENTIAL INFORMATION

There is no confidential information in this proposal.

12. REFERENCES

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GREAT RIVER ENERGY™

1611 East Century Avenue
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September 19, 2018

Daba S. Gedafa, Ph.D., P.E., ENV SP, M.ASCE
Chair and Associate Professor of Civil Engineering
Civil Engineering Department
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Great River Energy is supportive of your research to investigate the use of fly ash as a mineral filler in stone matrix asphalt (SMA) and hot mix asphalt (HMA). The use of fly ash as a mineral filler may result in asphalt pavements that are stronger and more durable. It can also have environmental as well as economic benefits through diversion of fly ash from landfills and reduced use of limited natural resources. Great River Energy is committed to provide fly ash that will be used as a mineral filler in this research if it is funded. Great River Energy highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Al Christianson
Director, Business Development & Government Affairs

BORDER STATES PAVING INC.
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September 19, 2018

Daba S. Gedafa, Ph.D., P.E., ENV SP, M.ASCE
Chair and Associate Professor of Civil Engineering
Civil Engineering Department
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Border States Paving is supportive of your research to investigate the use of fly ash as a mineral filler in stone matrix asphalt (SMA) and hot mix asphalt (HMA). The use of fly ash as a mineral filler may result in asphalt pavements with increased strength (stability) and durability.

Border States Paving used fly ash as a mineral filler on SMA projects in North Dakota and South Dakota. Border States Paving believes that fly ash has the potential to be more widely used as a mineral filler or partial replacement for hydrated lime in SMA and HMA asphalt pavements.

The use of fly ash as a mineral filler may also have environmental as well as economic benefits through diversion of fly ash from landfills and reduced use of limited natural resources.

Border States Paving is committed to providing field mixes and raw materials for laboratory testing for three projects from the 2019 paving season. This commitment includes materials, labor and equipment.

Border States Paving recommends this proposal for funding by Lignite Research Council.

Sincerely,

Korey Bender
Border States Paving, Inc.

STRATA CORPORATION SINCE 1910

PO Box 13500
Grand Forks, ND 58208-3500
701.746.7491

September 19, 2018

Daba S. Gedafa, Ph.D., P.E., ENV SP, M.ASCE
Chair and Associate Professor of Civil Engineering
Civil Engineering Department
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Strata Corporation is supportive of your research to investigate the use of fly ash as a mineral filler in stone matrix asphalt (SMA) and hot mix asphalt (HMA). The use of fly ash as a mineral filler may result in asphalt pavements that are stronger and more durable. Strata Corporation will consider the use of fly ash as mineral filler in asphalt mixes in cooperation with our clients if the cost and the research show good performance. Strata Corporation is committed to provide field mixes and raw materials for laboratory testing for three projects from 2019 paving season. This commitment includes materials, labor and equipment. Strata Corporation highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Dale Johnson

Strata Corporation

Quality Control Manager

Aggregate Division

North Dakota Department of Transportation

Thomas K. Sorel
Director

Doug Burgum
Governor

September 24, 2018

Daba S. Gedafa, Ph.D., P.E., ENV SP, M.ASCE
Chair and Associate Professor of Civil Engineering
Civil Engineering Department
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Material Availability for Your Research Proposal**

Dear Dr. Gedafa:

North Dakota Department of Transportation (NDDOT) Grand Forks District is supportive of your research to investigate the use of fly ash as a mineral filler in stone matrix asphalt (SMA) and hot mix asphalt (HMA).

The use of fly ash as a mineral filler may result in asphalt pavements that are stronger and more durable. NDDOT has allowed the use of fly ash as a mineral filler in two SMA projects. NDDOT Grand Forks District will consider the use fly ash as a mineral filler in asphalt mixes if the research shows good performance.

The University Of North Dakota will be allowed to obtain field mixes and raw materials for laboratory testing from three projects, pending availability of funds, within the Grand Forks District during the 2019 paving season.

Sincerely,

Curtis Dunn
Highway Materials Coordinator
Grand Forks District
North Dakota Department of Transportation

1951 N. Washington St. • Grand Forks, North Dakota 58203-1420
District Information: (701) 787-6500 • FAX: (701) 787-6515 • TTY: 711 • dot.nd.gov
General Information: 1-855-NDROADS (1-855-637-6237)

BASIN ELECTRIC POWER COOPERATIVE
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September 20, 2018

Daba S. Gedafa, Ph.D., P.E., ENV SP, M.ASCE
Chair and Associate Professor of Civil Engineering
Civil Engineering Department
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Dear Dr. Gedafa:

Re: **Letter of Support for Your Research Proposal**

Basin Electric Power Cooperative is supportive of your research to investigate the use of fly ash as a mineral filler in stone matrix asphalt (SMA) and hot mix asphalt (HMA). The use of fly ash as a mineral filler may result in asphalt pavements that are stronger and more durable. It can also have environmental as well as economic benefits through diversion of fly ash from landfills and reduced use of limited natural resources. Basin Electric Power Cooperative highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

David D. Raatz

David D. Raatz
Sr. VP of Asset Management,
Resource Planning & Rates

/lc
By email: daba.gedafa@engr.und.edu
Cc: Lignite Research Council

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September 19, 2018

Daba S. Gedafa, Ph.D., P.E., ENV SP, M.ASCE
Chair and Associate Professor of Civil Engineering
Civil Engineering Department
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: Letter of Support for Your Research Proposal

Dear Dr. Gedafa:

Minnkota Power Cooperative is supportive of your research to investigate the use of fly ash as a mineral filler in stone matrix asphalt (SMA) and hot mix asphalt (HMA). We are supportive of the idea that the use of fly ash as a mineral filler may result in asphalt pavements that are stronger and more durable. We are hopeful that it can be shown to also have environmental as well as economic benefits through diversion of fly ash from landfills and reduced use of limited natural resources. Minnkota Power Cooperative highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Gerry Pfau
Sr. Manager of Power Production

Humboldt Mfg. Co.
875 Tollgate Rd,
Elgin,IL 60123
USA
Tel: 1.708.456.6300
Fax: 1.708.456.0137
www.humboldtmfg.com

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Grand Forks,ND 58202-8115
USA

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Terms: Credit Card
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Customer Tax ID

-

***Estimated Lead time after receipt of order based on current stock status**

#	Item Code	Description	Harmonized Code	Qty	Unit Price	Total
1	H-1637.3F	Rotational Viscometer and Rheometer	9027.80.3500	1	$5,980.25	$5,980.25

Subtotal	**$5,980.25**
Shipping & Handling	$85.00

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