SULFUR CONCRETE HAUL ROADS AT SUNCOR OIL SANDS MINES

Dawit Abraha, Graduate student, University of Alberta Geotechnical Center, Edmonton, AB
David Sego, Professor, University of Alberta Geotechnical Center, Edmonton, AB
Robert Donahue, Professor, University of Alberta Geotechnical Center, Edmonton, AB
Kevin Biggar, Professor, University of Alberta Geotechnical Center, Edmonton, AB

ABSTRACT
Feasibility of constructing mine haul roads at the oil sands mines using concrete prepared from by-products and mine wastes (sulfur, fly ash, coke and tailing sand) is evaluated.

An extensive laboratory test program consisting of unconfined compression, split tensile and freeze thaw durability tests were carried out to characterize the physical and mechanical properties of different mix designs of sulfur concrete. A study of the geochemical interaction of sulfur concrete with the near surface environment included: short term interaction of surface exposed sulfur concrete during the construction and operational life of the haul road and long term interaction of sulfur concrete with ground water following its burial with mine wastes in the mined-out pits.

Haul road test section was designed based on the resilient modulus design method. Stress and strain distributions in the haul road cross section induced by the truck tires were calculated using finite element analysis. Required pavement layer thicknesses were then determined on the basis of the truck loads and the resilient modulus and strength of the sulfur concrete and subgrade material using the resilient modulus design method.

RESUME
La possibilité de construire les routes de prise de mine aux mines de sable pétrolifère utilisant le béton préparé des gaspillage de dérivés et mine (le soufre, la cendre de mouche, le coke, le sable de tailing) est évalué.

Un programme vaste d'essai de laboratoire se composer de les essais d'écrasement non - limitée, à la traction, et de durabilité des cycles gel – dégel ont été exécuté pour caractériser les propriétés physiques et mécaniques de conceptions de mélange différentes de béton de soufre. Une étude de l'interaction géochimique de béton de soufre avec l'environnement de surface proche a inclus : l'interaction à court terme de surface a exposé le béton de soufre pendant la construction et la vie opérationnelle de la route de prise et l'interaction à long terme de béton de soufre avec l'eau souterraine suivant son enterrement avec les gaspillage de mine dans les puits de mine.

La coupe d'essai sur route a été conçue basé sur la méthode de conception de module résilient. Les distributions de tension dans la coupe transversale de route de prise persuadée par les pneus de camion ont été calculées utilisant analyse d'élément finie. Les épaisseurs exigées de couche de trottoir ont été alors déterminées en se basant sur les chargements de camion et module résilient et la force élastique du béton de soufre et en se basant sur le matériel de subgrade utilisant la méthode de conception de module résilient.

1. INTRODUCTION

The mining of oil sands in the Fort McMurray area of Northern Alberta is a significant part of Alberta's economy. Over the last 20 years, mining methods have evolved from bucket wheel and dragline excavators to shovel and truck operation. Transportation of overburden and oil sands ore is one of the critical mining operations in shovel and truck mining method. Mine productivity mainly depends on the performance of the haul trucks that are highly dependent on the quality of the haul roads they travel on. Thus one of the key elements of the shovel and truck mining method is the haul road.

Economics of scale and expansion of the mining activity has led to the use of ultra large mining trucks with a payload capacity of more than 320 tons. The gross vehicular weight of these trucks is about 550 tons and they are expected to be even larger in the near future. Efficient utilization of these ultra large haul trucks demands well constructed haul roads. A good haul road ensures low vehicle operating and maintenance costs, low road maintenance cost, and reduced truck cycle time and full loading of trucks to maximize productivity.

Presently the haul roads at SUNCOR are constructed using crushed limestone, gravel, lean oil sand, sandy till and clayey till. These roads severely deteriorate during summer months due to material softening. Haul road performances have been below the desired standard and are having a negative impact on mine productivity. In addition, the use of these low strength and low stiffness construction materials require road sections to be built with thick layers of gravel to sustain the very large truck loads. Handling of these large construction volumes by itself is costly. Moreover the good construction materials at site, limestone and gravel, are becoming scarce over the next few years. All these highlight the necessity to find

an alternative road construction material, which can overcome the constraints and provide smooth rut free riding surface to ensure an efficient mining operation.
At SUNCOR Oil Sands mines there are abundant supplies of waste materials such as sulfur, coke, fly ash and tailing sand, which are by products of the oil sands extraction and upgrading processes. Sulfur concrete produced from these wastes can be a potential construction material for the mine haul roads. The sulfur concrete produced from these waste materials will have superior physical performance when compared to the existing road building materials. Thus haul roads can be built with reduced pavement thickness compared to the existing haul roads.

Apart from the benefits associated with building high quality haul roads which enhances mine productivity utilization of these waste products reduces the need for onsite waste storage or costly offsite transport or disposal of the waste products. Also it may reduce the greenhouse gas emissions associated with the offsite truck and rail delivery of the sulfur to distant customers. The use of sulfur concrete as a road construction material will also reduce the use of the diminishing aggregate supply near the SUNCOR Oil Sands mines.

2. SULFUR CONCRETE PHYSICAL AND MECHANICAL CHARACTERISTICS

The use of sulfur concrete to construct mine haul roads requires an understanding of its strength and deformation characteristics. Physical and mechanical properties of different mix designs of sulfur concrete produced from mine wastes: sulfur, coke, fly ash and tailings sand were characterized based on the results of an extensive laboratory test program consisting of unconfined compression, split tensile and freeze thaw durability tests.

2.1 Sample Preparation

Sulfur concrete is a thermoplastic material produced by hot mixing aggregate and sulfur as the binder. For it to be prepared all components of the mix have to be heated above the melting point of sulfur, which is about 119 ^{0}C. Upon cooling the sulfur quickly solidifies and binds the aggregates into hard concrete mass.

The materials used to prepare the concrete for testing (sulfur, coke, fly ash and tailing sand) were shipped from SUNCOR Oil Sands mines in Fort McMurray inside sealed barrels to University of Alberta. Different mix proportions were selected taking into consideration strength, workability of mixes and production rate of waste materials at the SUNCOR site. Samples were prepared either from sulfur and coke with or without fly ash or sulfur mixed with tailing sand with or without fly ash addition. The sulfur in all mixes was the binder while the coke, fly ash and tailing sand were aggregates.

Sulfur concrete samples were cast in 3” (76 mm) diameter cylinders using the following preparation procedure:

- Laboratory ovens were used to melt the sulfur and heat the aggregates to an optimum mix temperature ranging from 140 ^{0}C to 145 ^{0}C.
- The molten sulfur and heated aggregate were then transferred to a preheated mixing pot and thoroughly mixed until a homogenous fluid mixture was obtained.
- Samples were cast in preheated molds and compacted in three layers using a flat circular tamper.
- The surface of each specimen was finished and cured at room temperature in an upright position.
- The molds were removed after 24 hours of curing and samples were ready for testing.

2.2 Unconfined Compression Test

Uni-axial compressive loading testing was performed on triplicate 3” x 6” (76 mm x 152 mm) cylindrical samples to determine the strength and deformation characteristics including unconfined compressive strength, Young’s modulus and strain at peak stress of the different mix designs. The testing was carried out according to ASTM C39 standard test procedures as recommended in ACI 548 (1988). Averages of the data are summarized in Table 1.

Table1. Summary of compression test results

Sample Identification	Density (kg/m^3)	Failure Stress (MPa)	Young’s modulus (MPa)	Peak strain (%)
70%C, 30%S	1040	3.65	950	0.49
65%C, 35%S	1158	4.57	1150	0.48
60%C, 40%S	1220	5.17	1550	0.45
67.7%C, 30%S, 2.3%FA	1064	4.75	1300	0.49
65.4%C, 30%S, 4.6%FA	1080	8.01	1500	0.53
62.7%C, 35%S, 2.3%FA	1193	7.57	1600	0.54
60.4%C, 35%S, 4.6%FA	1217	9.75	2050	0.60
50%C, 30%S, 20%FA	1358	12.6	2750	0.53
50%C, 40%S, 10%FA	1462	24.49	3150	0.76
33.3%C,33.3%S,33.3%FA	1303	7.62	1900	0.55
67.7%Sa, 30%S, 2.3%FA	2170	28	9300	0.25
90%Sa, 10%S[1]	1873	11.7	11600	-
85%Sa, 15%S[1]	1963	21.6	16600	-
70%Sa, 30%S[1]	2086	33	17400	-
88%Sa, 10%S, 2%FA[1]	1842	13.1	12200	-
82%Sa, 15%S, 3%FA[1]	1996	27	18000	-
70%Sa, 25%S, 5%FA[1]	2070	32.2	18300	-

[1] Garcia 2002

In the sample identification column above, letters C, S, FA and Sa stand for Coke, Sulfur, Fly ash and Tailing sand respectively. The percent proportions were by mass of materials used.

Figure 1 clearly shows that the strength and deformation properties of the sulfur concrete prepared from coke and sulfur improved with increase in sulfur content. This is because the coke particles are porous and absorb molten sulfur resulting in the need for additional sulfur to bind and provide strong bonding between individual particles.

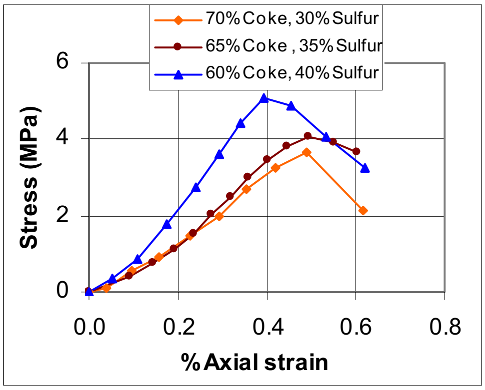

Figure 1. Effect of sulfur content on stress vs. strain curves prepared with coke as aggregate.

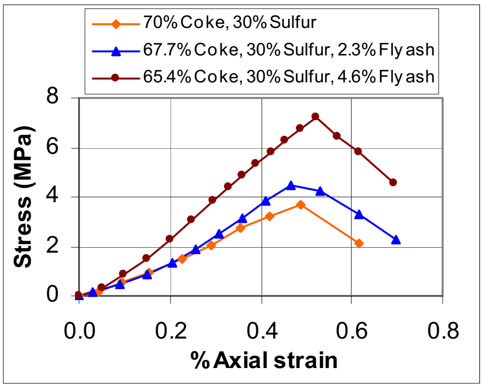

Figure 2. Effect of fly ash content on stress vs. strain curves (30% sulfur content and coke as aggregate).

Figures 2 depicts that fly ash contributes to improved strength and stiffness by acting as fine grained pore filler with the coke aggregate in the sulfur concrete. Their addition to the coke improved the grain size distribution of the aggregate and thus allows the sulfur to properly coat and cement the particles together resulting in a stronger and stiffer material.

2.3 Sonic Velocity Measurement

Sonic velocities through sulfur concrete samples were measured to determine additional elastic material properties. From the knowledge of compression and shear wave velocities and density of material Young's modulus and Poisson's ratio were calculated using theoretical relationships (Blessing 1990). The tests were carried out on triplicate 3" x 6" samples and the average data is summarized in Table 2.

Table 2. Summary of seismic velocity measurement test results

Sample Identification	P-speed (m/s)	S-speed (m/s)	Young's modulus (MPa)	Poisson's ratio
70%C, 30%S	994	599	900	0.214
65%C, 35%S	1147	673	1250	0.237
60%C, 40%S	1234	656	1300	0.28
67.7%C, 30%S, 2.3%FA	1299	709	1400	0.288
65.4%C, 30%S, 4.6%FA	1494	730	1550	0.343
62.7%C, 35%S, 2.3%FA	1523	747	1700	0.342
60.4%C, 35%S, 4.6%FA	1925	700	1600	0.393
50%C, 30%S, 20%FA	1963	900	2900	0.367
50%C, 40%S, 10%FA	1984	888	3200	0.375
33.3%C,33.3%S,33.3%FA	1494	762	2000	0.324
67.7%Sa, 30%S, 2.3%FA	3293	1411	8500	0.388

2.4 Split Tensile Test

The tensile strength of the sulfur concrete specimens was investigated using the split cylinder tensile test on duplicate 3" x 6" samples of the different mix designs. ASTM C496 test procedure was followed as recommended in the ACI 548 (1988). The test results are summarized in Table 3.

Table 3. Summary of split tensile test results

Sample Identification	Tensile strength (σ_t)(MPa)	Compressive strength (σ_c)(MPa)	σ_t/σ_c ratio (%)
67.7%C, 30%S, 2.3%FA	0.54	4.75	11.4
62.7%C, 35%S, 2.3%FA	0.88	7.57	11.6
67.7%Sa, 30%S, 2.3%FA	1.96	28	7.0
90%Sa, 10%S	0.88	11.7	7.5
85%Sa, 15%S	1.21	21.6	5.6
70%Sa, 30%S	1.93	33	5.8
88%Sa, 10%S, 2%FA	0.83	13.1	6.3
82%Sa, 15%S, 3%FA	1.19	27	4.4
70%Sa, 25%S, 5%FA	2.81	32.2	8.7

2.5 Optimum Mix Designs

Based on the aforementioned test results and production rate of the waste materials three optimum mix designs were selected for freeze/thaw durability studies and geochemical investigation of the use of sulfur concrete in a road. Two mixes contained coke, sulfur and fly ash and one contained sand, sulfur and fly ash. The stress - strain curves of these samples are shown in Figure 3.

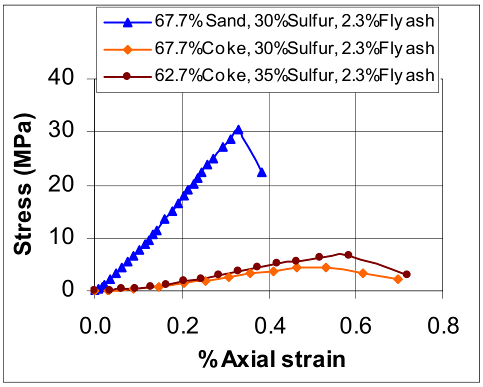

Figure 3. Stress vs. strain curves of optimum mix design samples

Figure 3 shows sulfur concrete made from coke is much weaker and deformable than the concrete made from tailing sand. This is mainly because individual coke particles are much weaker than the quartzite tailing sand particles. The dramatic decrease in stiffness is associated with the observation that coke sulfur concrete is porous with many open voids whereas tailing sand sulfur concrete has fewer visible pores.

2.6 Freeze/thaw Durability Test

The resistance of sulfur concrete to multiple freeze/thaw cycles is very important for its application in northern locations where there are large temperature fluctuations throughout a year. Rapid freeze/thaw testing was carried on duplicate sulfur concrete samples prepared using the optimum mix designs to evaluate the durability of sulfur concrete subjected to multiple freeze/thaw cycles.

ASTM C666 Procedure A was followed during the test. This involves freezing and thawing samples in water and is harsher than procedure B, which involves freezing in air and thawing in water, because the continual presence of water causes the available void spaces to be penetrated more rapidly in procedure A than in B. The temperature of the concrete cylinders submerged in water was varied from +4.4 ^{0}C to -17.9 ^{0}C back to +4.4 ^{0}C in cycles of 3.5 hours duration.

After 24 cycles all the coke specimens were found with pop-outs along the horizontal construction joints followed by sample disintegration. Consequently, it was determined that the coke mix designs had failed the freeze/thaw test and they were abandoned. The main reason for the failure was that coke particles are porous so water surrounding the samples percolated into the pores and expanded during freezing breaking the particles apart.

Unconfined compression testing was carried out on the sand sulfur samples subjected to multiple freeze/thaw cycles. The strength and deformation characteristics were compared to that of the original samples to evaluate freeze/thaw induced affects. Figure 4 shows degradation of the material when subjected to multiple freeze/thaw cycles. Failure strength decreased from 31 MPa to 24 MPa and Young's modulus reduced from 10000 MPa to 6100 MPa after 100 freeze thaw cycles. Even though the sample degradation is considerable the material is still much stronger and stiffer following 100 cycles of freeze thaw than any presently used road building material like crushed aggregate or limestone.

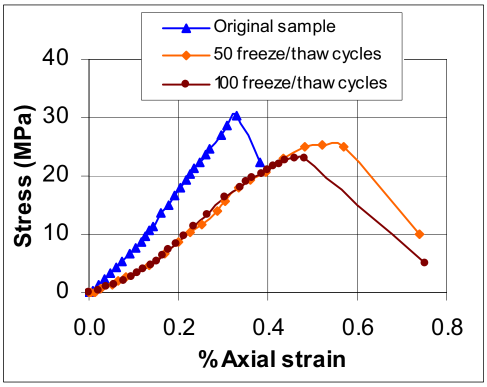

Figure 4. Effect of multiple freeze/thaw cycles on strength and deformation properties of sand sulfur concrete.
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3. GEOCHEMICAL INVESTIGATION

Geo-environmental impacts of sulfur concrete haul roads with the near surface environment were also studied. The study focused on two important aspects, the short term interaction of sulfur concrete exposed at the surface during haul road construction and operation, and the long term interaction of the sulfur concrete following its burial with mine wastes in the mined out pits. These chemical (environmental) interactions were studied separately to understand the potential environmental impact of using sulfur concrete for haul roads.

3.1 Sulfur Concrete Weathering Tests

During operation of the haul roads there is a potential for sulfur reactions due to contact with atmospheric oxygen and water from both rain and snow melt. These reactions may release acids into the surface water.

To provide an assessment of potential acid generation under field conditions a series of leaching studies were conducted on intact sulfur concrete samples. The chemical stability of sulfur concrete samples when alternately exposed to highly reactive deionized (DI) water and the atmosphere at regular intervals was studied. The experiment was conducted to mimic operational conditions when the haul roads are in daily use with surface exposed to climatic variation. The test procedure was as follows:

– Triplet sets of sulfur concrete samples were prepared in 6" x 12" plastic cylinder molds based on the optimum mix designs.

- The hardened samples were covered with 15 cm of aggregate at field moisture capacity, the optimum moisture content for sulfur oxidation (Tan 1982).
- The containers were stored at room temperature (20^0C) covered with a simple plastic cap to reduce moisture evaporation but allow atmospheric oxygen interaction through out the study.
- The samples were allowed to sit for 6 weeks so that geochemical reactions could occur.
- After 6 weeks the aggregate was saturated with known volume deionized water and was allowed to drain, the drain water was collected and analyzed for pH and electrical conductivity (EC). The test results are summarized in Table 4.

Table 4. Summary of leaching test result

Sample Identification	pH	Electrical Conductivity (µS/cm)
67.7%C, 30%S, 2.3%FA – 1	6.62	580
67.7%C, 30%S, 2.3%FA – 2	5.72	1350
67.7%C, 30%S, 2.3%FA – 3	6.23	1180
62.7%C, 35%S, 2.3%FA – 1	6.21	1250
62.7%C, 35%S, 2.3%FA – 2	6.84	1170
62.7%C, 35%S, 2.3%FA – 3	6.66	900
67.7%Sa, 30%S, 2.3%FA – 1	6.64	1065
67.7%Sa, 30%S, 2.3%FA – 2	6.8	1290
67.7%Sa, 30%S, 2.3%FA – 3	7.09	1060

Deionized water with pH = 6.63 and EC = 6.21 µS/cm was used to flush the samples. Compared with the results in Table 4 there is an insignificant change in pH of the drain water indicating that minimal chemical reactions occurred. The change in EC value is partly attributed to dissolved dust particles washed from the aggregate surface during the first flush. The same mass of deionized water was flushed through the same mass of aggregate as used in these experiments to determine the effect of the aggregate only. The drained water had a pH of 8.06 and the EC value increased to 440 µS/cm. To provide a chemical signature of the components dissolved, elemental and ionic constituent concentrations of the drained water samples will be measured using inductively coupled plasma mass spectrometry (ICP/MS) and ion chromatography analytical methods in the near future.

3.2 Long term geochemical stability of sulfur concrete mixtures

In the long term, the haul roads constructed with sulfur concrete will be buried with mine wastes in the mined out pits when the oil sands mine is abandoned. Hence there might be diffusive release of contaminants from the buried sulfur concrete into the groundwater. The potential of diffusive release of contaminants was examined by studying the chemical stability of sulfur concrete samples when submerged in deionized (DI) water and in composite tailing (CT) release water, which is the most likely water type which will be in contact with the sulfur concrete when buried with the mine waste.

The tests were conducted under inert atmospheric conditions to mimic the deep deposition of the materials in absence of oxygen when the sulfur concrete is disposed in the mined out pit. For low porosity sulfur concrete in still water the dissolved chemical mass released to the water is the result of dissolution from the surface of the material followed by diffusive transport within the water phase. The test procedure was as follows:

- Triplet sets of sulfur concrete samples were prepared in 6" x 12" plastic cylinder molds based on the optimum mix designs.
- Porosity of the samples was determined through precise measurement of the mass of the constituents and sample dimensions.
- The samples were then overlaid by a liter of DI or CT release water and stored in Nitrogen filled bags at room temperature (20 ^{0}C).
- pH and electrical conductivity (EC) of the water was measured on a weekly basis and water samples were taken at regular intervals. Test results are summarized in Figures 5 to 8.

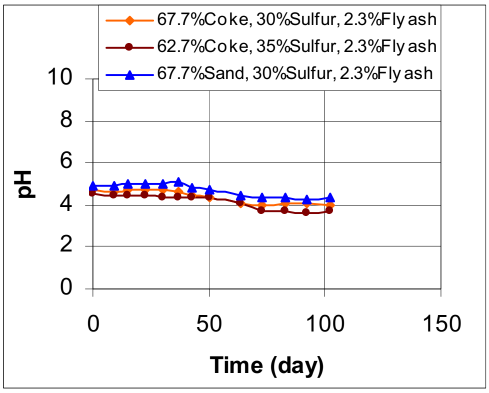

Figure 5. pH data for DI water overlaid samples

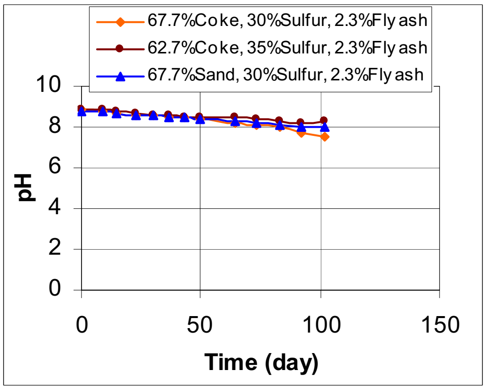

Figure 6. pH data for CT release water overlaid samples

After about 100 days the change in pH and EC values of all the samples covered by DI water and CT release water are not significant indicating that minimal chemical reactions took place over this time duration.

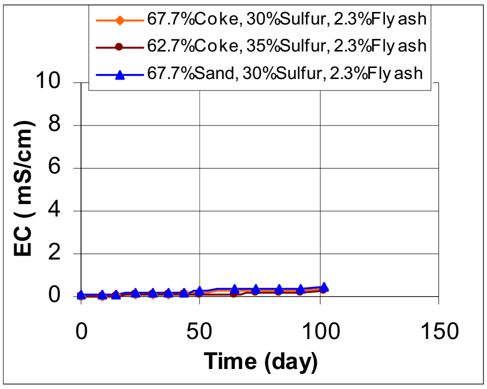

Figure 7. EC data for DI water overlaid samples

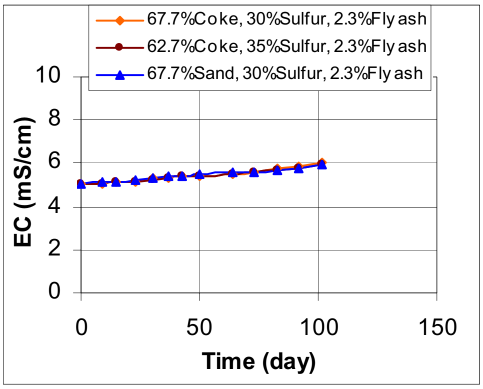

Figure 8. EC data for CT release water overlaid samples

The elemental and ionic constituents and their concentrations will be measured to provide a chemical signature of the components solubilized from the sulfur concrete. This will allow the mass rate of individual elements and ionic compounds released from the sample into the water to be determined. This data will establish multi species diffusive dissolution rate for sulfur concrete specimens.

4. RESILIENT MODULUS BASED ROAD CROSS SECTION DESIGN

Recent research on design of haul roads has highlighted a shift towards the use of the resilient modulus based method rather than the popular CBR design method for haul road cross section design. In this method the road cross section is treated as a composite beam and it is assumed that the road adequately supports haul trucks as long as the vertical strains in the pavement layers remain less than critical strain limits, and the stress level in any layer of a haul road cross section does not exceed the bearing capacity of the material used in that layer. When the vertical strains in the pavement layers exceed critical strain limit value then the road ceases to act as a composite beam and can no longer adequately support the haul truck.

In resilient modulus design, pavement layer thicknesses are selected in such a way to limit the vertical strain caused in pavement layers of the road to avoid excessive straining of the layers, and the stress level in any layer of a haul road cross section to be less than the bearing capacity of the material used in that layer. Based on field observations (Morgan et al. 1994) found that the critical strain limit was about 1500 micro-strain at the top of subgrade while (Thompson and Visser. 1997) noted that the limit was around 2000 micro-strain at the road surface. So for typical haul roads vertical strain limits between 1500 and 2000 micro-strain has been established.

4.1 Resilient modulus test

For a given stress in a pavement layer, the induced strain is a function of the modulus of the material. The resilient modulus used in this design method is determined from triaxial cyclic load tests. The nature of the test is similar to the cyclic loading experienced in a road subjected to moving wheel loads. The test procedure is summarized as follows:

- Testing was carried out on 4" x 8" sulfur concrete samples inside a triaxial cell at room temperature.
- Confining pressure of 10 kPa and cyclic deviatoric stress of 600 kPa was applied, which is equivalent to inflation tire pressure of CAT 797 haul truck.
- The load cycle time was 3.08 seconds composed of 0.45 seconds loading and 2.63 seconds resting time.
- Load and axial deformations were continuously measured during the test and the results are shown in Figures 9 and 10.

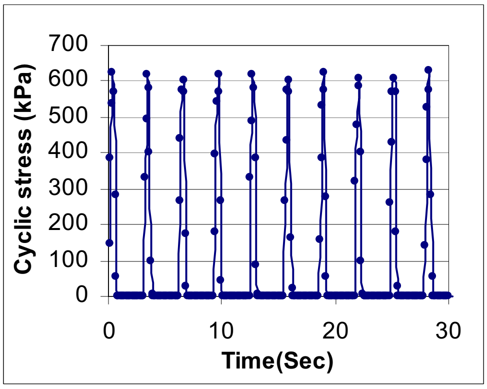

Figure 9. Cyclic stress vs. time plot

Figure 10 shows that all the deformation that occurred in the specimen during loading was recovered during unloading. No plastic strain accumulation was observed in the sample. This was because the applied cyclic stress, 600 kPa, was much lower than the failure strength of the material which is 31 MPa; it fell well within elastic range of the material leading to only recoverable elastic deformations. Thus the resilient modulus is nearly the same as the elastic Young's modulus of the material.

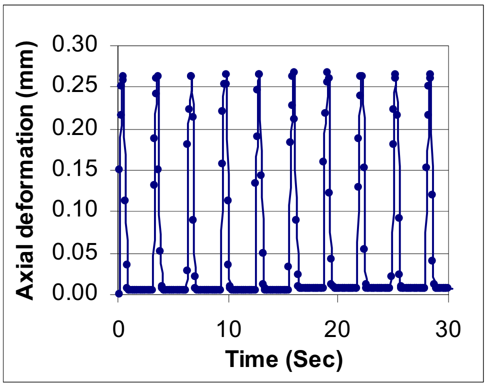

Figure 10. Axial deformation vs. time plot

4.2 Finite Element Analysis Using Sigma/W

For designing haul roads it is imperative to understand the stress and strain distributions in the haul road cross section induced by the haul truck tires. Finite element stress and strain analysis was done using Sigma/W, a two dimensional finite element program for calculating stresses and strains.

The objective of the modeling was to analyze vertical stress and strain distributions in the pavement layers for different combinations of pavement layer thicknesses. The haul road cross section is adequate if the stress at any point is less than the bearing capacity of the material and the vertical strain is less than the critical strain limit, established to be between 1500 to 2000 micro-strains. The adequacy of the haul road cross-section for the design truck load was then examined using these stress and strain criteria for the different models.

The load distribution on the road surface beneath a tire was assumed to be uniform over a circular area (Kumar 2000). A typical axis symmetric model which was used to analyze the effect of layer thicknesses on strain bulbs below a single tire is shown in Figure 11.

The design truck used in the analysis was CAT 797 which has an inflation tire pressure of 600 kPa with tire foot print area of 1.68 m^2 (0.73 m radius). Typical subgrade material at SUNCOR site, lean oil sand, has a resilient modulus of 30 MPa (Kumar 2001). Surface gravel with resilient modulus of 300 MPa was placed on top of sulfur concrete layer in order to act as wearing course. Figure 11 shows 0.9 m sulfur concrete layer with modulus of 8000 MPa covered by 0.3 m surface gravel. The thicknesses were determined by trial and error to satisfy the strain limit and bearing capacity criteria.

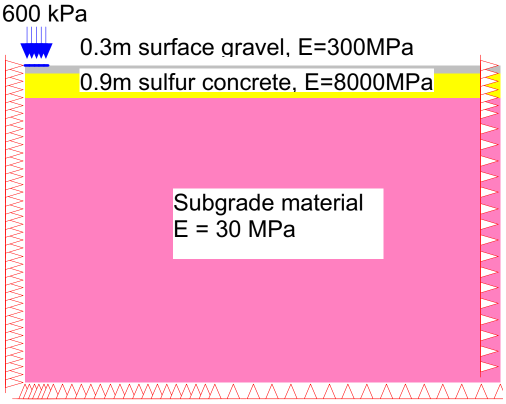

Figure 11. Typical axis symmetric model used in Sigma/W analysis

The top boundary of the model represents the surface of the haul road and thus is a free boundary. The left and right vertical boundaries are restrained in the horizontal direction while the bottom boundary is restrained in the vertical direction. The right and bottom boundaries were selected to be at a reasonable distance from the tire, so that the boundary conditions did not affect the stress and strain beneath the tire.

The vertical strain distributions beneath a single tire from the Sigma/W analysis are shown in Figure 12. An axis symmetric model allows only one circular load (tire) at a time in the model. So the effect of stress/strain bulb interaction couldn't be studied directly using Sigma/W program. However, the principle of elastic superposition allows superposition of elastic stresses and strains. Therefore, the axis symmetric model was used to generate the vertical strain distribution below a single tire and the results were then numerically superimposed to simulate strains beneath multiple tires. The most critical case was the back axle of the truck, which has four tires; the front axle has only two tires. Moreover, there is very little interaction between the front and back tires of the truck. Figure 13 depict vertical strain distribution beneath two adjacent tires of the rear axle. The total vertical strain distribution beneath all four tires on the back axle is shown in Figure 14.

Study of Figures 12 to 14 reveals that interaction between adjacent tires affects the vertical strain levels in the subgrade layer. The maximum strain level in the subgrade increased from 550 to 1000 micro strains and from 550 to 1100 micro strains when two and four tires were considered, respectively. The effect is not significant in surface course and sulfur concrete layers because the strain bulbs are not wide enough to interact in those layers. Though interaction between the pairs of tires at the opposite end of the rear axle of the truck has little effect on maximum strain level, the strain bulbs extended deeper and wider in the subgrade layer.

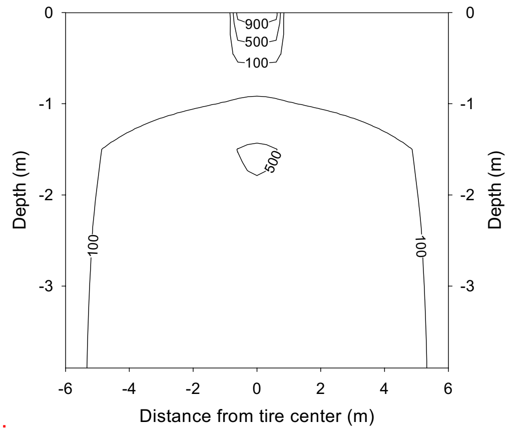

Figure 12 Vertical strains beneath single tire (in micro-strains)

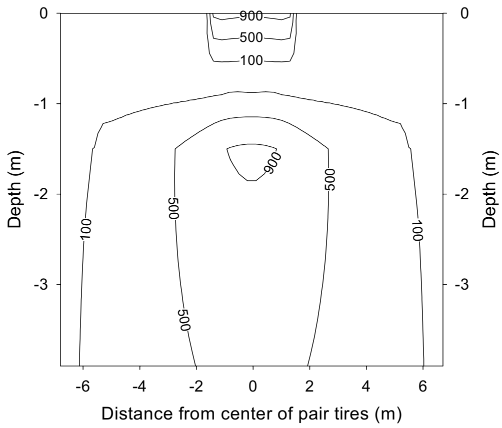

Figure 13 Vertical strains beneath two adjacent tires (in micro-strains)

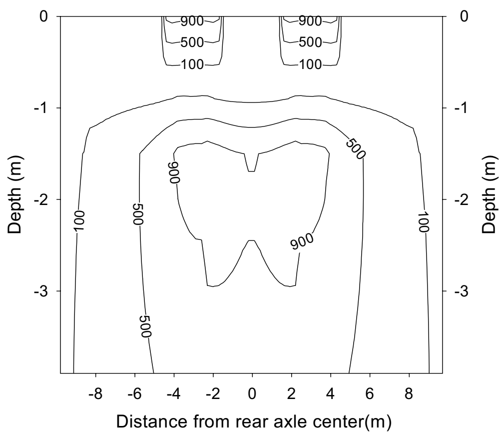

Figure 14 Vertical strains beneath four rear tires (in micro-strains)

The maximum vertical strain in any layer is less than the critical strain limit of 1500 to 2000 micro-strains and the stress level in any layer is also less than the bearing capacity of the material in that layer. Both the strain and bearing capacity criteria are satisfied for the pavement cross section shown in Figure 11. Thus it can be concluded that haul road constructed with 0.9 m sulfur concrete covered by 0.3 m surface gravel can adequately support CAT 797 mine haul truck.

5. CONCLUSION AND RECOMMENDATION

Sulfur concrete produced from oil sand mine wastes (sulfur, tailing sand and fly ash) is much stronger and stiffer than the existing haul road building materials at SUNCOR Oil Sands mines. Thus improved haul roads can be built with reduced pavement thicknesses using tailing sand sulfur concrete.

Since sand sulfur concrete is a new material for haul road construction it is recommended to build instrumented haul road test section and monitor the truck haul road interactions and geochemical interactions of sulfur concrete with the environment under varying climatic conditions prior to implementing wide spread use of sulfur concrete haul roads.

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