THE INVESTIGATION OF THE USE OF COAL MINE REFUSE FOR SUBBASE MATERIAL AND EMBANKMENT FILL IN SOUTH DAKOTA[1]

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Abstract. Regions of the United States are experiencing a lack in quantity of conventional aggregates such as sand, gravel, and crushed rock. Central and western South Dakota are specific regions experiencing such a shortage. Past coal mining is prevalent throughout western South Dakota; these operations produced waste material consisting of refuse piles commonly referred to as “gob” piles. It is proposed that these mine refuse piles could provide a practical use as a nontraditional construction material. If so, the shortage of conventional aggregates may be alleviated with the use of coal mine refuse as an engineering material and may provide an alternate source of needed aggregate for certain applications. This research investigated if the use of nontraditional construction materials, specifically coal mine refuse, can be used as an engineering material in embankment fills and as subbase material in roadway construction.

This investigation consisted of performing laboratory tests to determine the index and engineering properties of the coal mine refuse at a readily available coal mine site. A series of laboratory experiments were performed based on the engineering requirements of embankment and roadway design from local and national specifications. Specifically, index testing consisted of specific gravity, grain size distribution, and soil classification; engineering property tests consisted of freeze/thaw susceptibility, compaction, bearing ratio, direct shear, and triaxial compression testing (with consolidation and permeability measurements).

Conclusions were formulated and recommendations are provided based on the results of the laboratory tests. The results of this research conclude that coal mine refuse sampled at an abandoned mine site in South Dakota can be used as embankment fill material and can provide limited uses for subbase applications.

Additional Key Words: geotechnical soil testing, subbase, embankment.

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Introduction

Background

The supply of high quality natural aggregates to meet the demands of the highway and building construction industries in the United States appears to be trending towards a deficiency. Most urban areas where the demand exceeds the availability of quality aggregates in a confined area are, or will be, deficient in aggregate supplies. This does not only occur in urban areas but also in rural areas, such as the upper Midwest, particularly in South Dakota. Many areas within western and central South Dakota lack high quality construction aggregates and require quality aggregate to be hauled in from many miles away. Therefore, there is motivation to investigate the use of unconventional aggregate sources to determine if these sources have sufficient engineering properties to perform within design. If sources of unconventional aggregate are deemed useful, this may partially alleviate aggregate shortages.

The South Dakota Department of Environment and Natural Resources (SD DENR) has completed an inventory of known inactive and abandoned mine lands in the state of South Dakota (Durkin and Herman, 2001). The inventory included over 900 inactive and abandoned mine lands within the specified areas of Meade, Lawrence, Pennington, and Custer counties. The inventory also included information on historic mines operated by miners years before environmental laws were adopted that require reclamation. Many of the abandoned mines in this region are coal mines which indicate a large volume of coal mine refuse is present in South Dakota. Therefore, the use of coal mine refuse as a construction aggregate could have an additional benefit of providing reclamation to abandoned mine lands that were not required to be reclaimed under early mining laws.

Objectives

A shortage of conventional aggregate in South Dakota along with an abundance of coal mine refuse is motivation to research the uses of coal mine refuse. Conducting an investigation is beneficial in determining if the coal mine refuse found in South Dakota has adequate properties to be used as an engineering construction material. The objective of this research was to determine if coal mine refuse possesses the engineering properties necessary for the material to be used for highway subbase or embankment fill material. The results were evaluated relative to specifications set by the South Dakota Department of Transportation (SD DOT) and American Association of State Highway and Transportation Officials (AASHTO) and considered the engineering properties that are typically used in the design of highway subbase and embankment fill material.

Research Plan

This research consisted of culling the literature to determine if geotechnical laboratory testing had previously been conducted on coal mine refuse similar to that of South Dakota. The literature was used to determine what type of coal mine refuse testing has been conducted and to determine if additional testing would provide benefit in determining suitability for use as a construction material outlined above. A geotechnical laboratory testing program was then developed and implemented to determine the engineering properties of the coal mine refuse from an abandoned mine site in South Dakota, focusing on the use of the coal refuse as roadway subbase or embankment fill material. The subbase is one component of a pavement system and is typically used to help lower the overall cost of the aggregate used in constructing a road. An embankment is defined as soil or rock added to current surface conditions to change the configuration of the ground surface (Coduto, 1999). Gradation for compactibility and strength for stability design were key engineering considerations used for embankment design. Coal mine waste may be used for embankment fill because of its low cost if it is determined that the material possesses acceptable engineering characteristics.

Laboratory testing followed American Society of Testing and Materials (ASTM) and/or AASHTO standards. The testing program consisted of specific gravity, grain size distribution, soil classification, freeze/thaw degradation, moisture density relation, California Bearing Ratio (CBR), direct shear, triaxial compression, consolidation, and permeability testing on coal mine refuse from bulk samples obtained from an abandoned mine land site in western South Dakota. The laboratory data was then analyzed and recommendations were provided relative to expected performance based on other materials with similar engineering properties and on results found throughout the literature. Conclusions were formulated based on the results of the engineering tests and discussion of the results.

Types of Coal Mine Refuse

Coal mine refuse falls under three classifications: mine rock, coarse coal refuse, and fine coal refuse. Mine rock particles are composed of rock fragments larger than 3 inches in diameter (Almes and Butail, 1976). Coarse coal refuse is produced during the mining and separating processes. Coarse coal refuse consists of soil and rock material comprised of shales, mudstones, siltstones, "stiff" clays and weakly cemented sandstones (Saxena *et al.,* 1984). These materials are typically found along with the excavated coal and are later separated from the coal using a flotation process. Classification of this material usually yields a well-graded sand or gravel with some silt. Coarse coal refuse is retained on the 0.6 mm (No. 30) sieve in a standard sieve analysis (Cowherd and Perlea, 1988).

Fine coal refuse is a result of the washing processes at a mine preparation plant. It is pumped to the disposal area as a watery slurry, which consists of a small amount of solid, fine coal tailings along with water (Williams and Morris, 1988). Fine coal refuse is classified as a silty sand to silty clay and passes the 0.6 mm (No. 30) sieve. The ratio of coarse to fine refuse is typically about 1:1 by volume for modern mining (Cowherd and Perlea, 1988) and can be as high as 1:0 for historic mining. Most, if not all, coal mine refuse generated in South Dakota is coarse coal refuse. Therefore, this research is limited to coarse coal mine refuse.

This paper first presents laboratory testing methods and results followed by a discussion of the results; the paper closes with conclusions and recommendations.

Laboratory Testing and Results

A laboratory testing program was developed to determine the index and engineering properties of coal mine refuse from an abandoned mine site in South Dakota based on geotechnical laboratory tests that are commonly performed for civil engineering projects. The Standard Specifications for Roads and Bridges Manual (2004) and the South Dakota Department of Transportation Materials Manual (2004) were used to assist in determining which laboratory tests would be appropriate and useful to engineers and public officials planning to use coal mine refuse as an engineering material.

The developed testing program consisted of laboratory index tests and laboratory engineering property tests. The index tests included specific gravity, grain size distribution with hydrometer, and soil classification using two methods. The engineering property tests conducted include freeze/thaw susceptibility, moisture density relation, CBR, direct shear, triaxial testing, consolidation, and permeability.

Eight bulk samples of coal mine refuse were collected in August of 2004 on an abandoned coal mine site in Perkins County, South Dakota. This site was selected to obtain samples because it was considered representative for coarse coal mine refuse sites in South Dakota observed by the authors. Furthermore, as abandoned coal mine sites are located on private property, the owner of this site allowed timely access to obtain soil samples for this research. The samples were collected from three mine tailings areas on the site. The initial index test involved visually classifying the coal mine refuse into groups with similar visual characteristics as defined in ASTM D 2488-00 Standard Practice for Description and Identification of Soils (Visual Manual Procedure) (ASTM, 2000b). Three soil types were deemed sufficiently distinct to warrant separate laboratory testing. Therefore, the eight bulk samples were homogenized to obtain three materials for testing. The material was homogenized by hand mixing taking care not to alter the gradation characteristics of the material and the materials were designated Materials A, B, and C.

Laboratory Index Tests

The laboratory index tests that were conducted during this research project include specific gravity, grain size distribution with hydrometer, and soil classification using both the USCS method and the AASHTO method.

Specific Gravity. The specific gravity of the coal mine refuse was determined in accordance with ASTM D 854-02 Standard Test Method for Specific Gravity of Soils (ASTM, 2002b). ASTM (2002b) defines specific gravity as "the ratio of the mass of a unit volume of material at a stated temperature to the mass in air of the same volume of gas-free distilled water at a stated temperature." The specific gravity of a material is often used to express phase relationships of air, water, and solids in a given volume of material. The results of the specific gravity test are shown in Table 1.

Table 1. Results of specific gravity test.

Material	Specific Gravity
A	2.60
B	2.55
C	2.40

Grain Size Distribution. Grain size distribution in accordance with ASTM D 422-02 Standard Test Method for Particle-Size Analysis of Soils (ASTM, 2002a) was performed to determine the distribution of particle sizes in the three coal mine refuse samples. The distribution of particle sizes smaller than the No. 200 sieve is determined by using a sedimentation process which involves the use of a hydrometer. The testing results are shown in Figure 1. The data on the left represents the grain size distribution of the mechanical analysis; the data on the right represents the results of the hydrometer test multiplied by 100 for visualization.

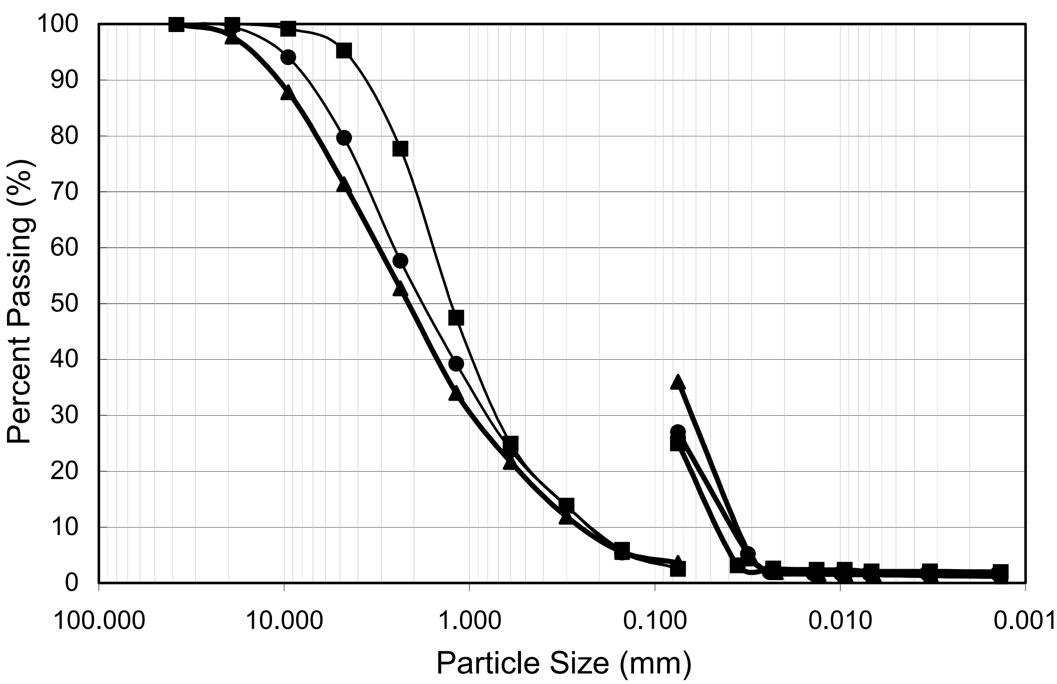

Figure 1. Grain size distribution curves for Materials A (▲), B (■), and C (●).

Soil Classification. A soil classification system is a standardized “language” that provides communication between engineers and is a method of categorizing soils according to their probable engineering behavior (Holtz and Kovacs, 1981). The coal mine refuse material collected was classified using the USCS and the AASHTO soil classification method. Note that Atterberg limits tests were not conducted because the soil was nonplastic. Table 2 shows the data obtained from the grain size distribution curve used to classify each soil according to the USCS method (ASTM, 2000a) as well as the USCS classification name. All three samples classified as a SW, a well-graded sand with little or no fines present.

Table 2. USCS soil classification results.

		Material		
		A	B	C
% Retained	No. 200	96.4	97.5	97.3
	No. 4	28.7	4.7	20.4
Grain Size Data	D_{60}	3.1	1.5	2.6
	D_{30}	0.95	0.73	0.81
	D_{10}	0.27	0.22	0.23
	C_u	11.5	6.8	11.3
	C_c	1.1	1.6	1.1
Group Symbol		*SW*	*SW*	*SW*
Group Name		Well-graded sand		

Table 3 shows the data obtained from the grain size distribution curve to classify each soil according to the AASHTO method (AASHTO, 1933) as well as the AASHTO classification group. All the coal mine refuse tested classified as group A-1-a or group A-1-b soil.

Table 3. AASHTO soil classification results.

		Material		
		A	B	C
% Passing	No. 10	48	70	54
	No. 40	16	18	18
	No. 200	3.6	2.5	2.7
Class		*A-1-a*	*A-1-b*	*A-1-b*

Laboratory Engineering Property Tests

Laboratory engineering property tests conducted for this research include freeze/thaw susceptibility, compaction, CBR, direct shear and triaxial testing. Permeability and consolidation testing were also performed during triaxial testing.

Freeze/Thaw Susceptibility. Freeze/thaw susceptibility testing was conducted using AASHTO T 103-00 Standard Method of Test for Soundness of Aggregates by Freezing and Thawing (AASHTO, 2000) as a basis. This standard test method determines the resistance of aggregate degradation to a freezing and thawing environment (AASHTO, 2000). This test was deemed useful in this research to test aggregate degradation that may be present in the subbase or frost zone of a roadway or an embankment. The procedure involves freezing each sample for 24 hours and thawing each sample for 24 hours for 16 days. Significant degradation of the tested coal mine refuse is shown by the data presented in Table 4. The percentage lost is weighted based on the amount of material of each sample relative to the overall sample size. The data collected indicates that the weighted percentage lost for Materials A, B, and C is 65.6%, 71.0%, and 72.7% respectively. Thus, over 65% of each material degraded in size over the duration of the freeze/thaw test.

Table 4. Results of freeze/thaw susceptibility testing for Materials A, B, and C.

Sieve	Grain Size (mm)	Weighted Percentage Lost for Material A(%)	Weighted Percentage Lost for Material B(%)	Weighted Percentage Lost for Material C(%)
3/4"	19.0	2.3	0.1	0.05
3/8"	9.52	10.0	0.8	3.7
#4	4.75	16.8	4.5	14.6
#8	2.36	16.0	15.2	20.8
#16	1.18	10.9	25.2	16.7
#30	0.600	6.2	18.4	12.1
#50	0.300	3.5	7.0	4.7
TOTAL DEGRADATION (%)		65.6	71.0	72.7

Additional freeze/thaw testing was conducted to test the overall susceptibility of a soil to freeze/thaw degradation. Samples were subjected to the same freeze/thaw conditions and gradation characteristics (mechanical analysis) that were obtained both prior to and after freeze/thaw conditions. This allows a direct comparison of the pre- and post freeze/thaw condition gradation distribution in a direct manner. Figure 2 shows the results of the pre-testing grain size distribution compared to the grain size distribution curve after freeze/thaw testing.

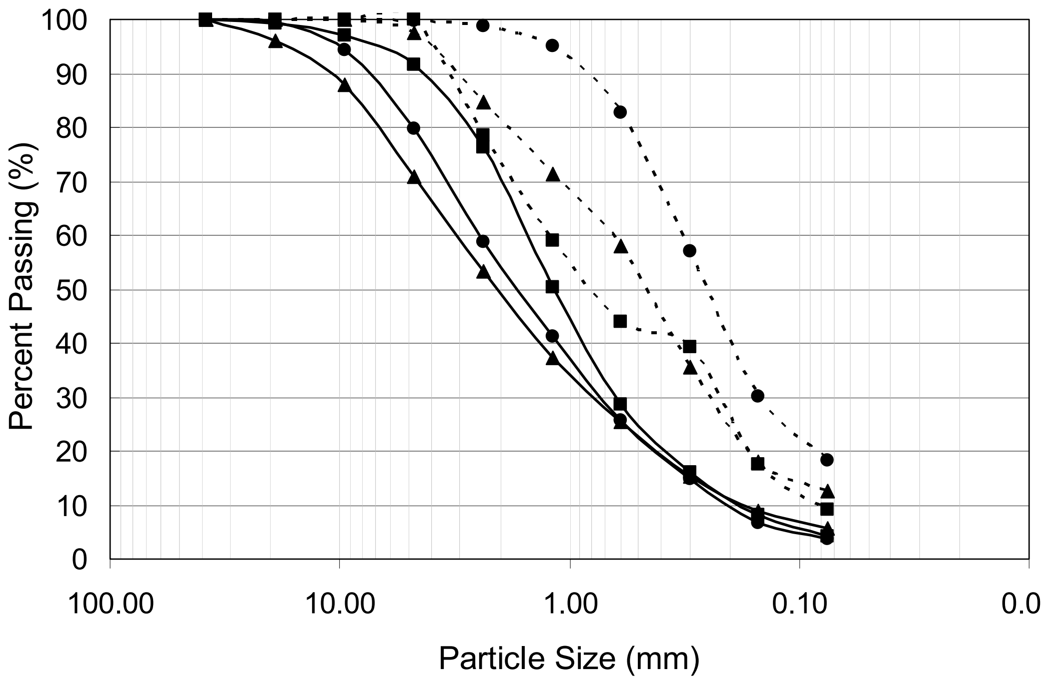

Figure 2. Comparison of pre- (———) and post (........) freeze/thaw grain size distribution curves for Materials A (▲), B (■), and C (●).

<u>Moisture Density Relation.</u> Moisture density relation (compaction) tests were performed to determine the maximum dry unit weight and optimum moisture content of each material following ASTM D 698-00 Standard Test Method for Moisture-Density Relationships of Soils and Soil-Aggregate Mixtures using 5.5-lb. Rammer and 12-in Drop (ASTM, 2000c). Four methods are specified; ASTM (2000c) recommends that Method C shall be used when the amount of material retained on the No. 4 sieve is greater than 7%, therefore Method C was used for all materials.

Table 5 shows the values of maximum dry unit weight and the optimum moisture content for the three coal refuse materials. Figure 3 shows the resulting moisture density relation curves along with the zero air voids curves for the corresponding specific gravities.

Table 5. Results of the moisture density relation test (standard energy) for Materials A, B, and C.

Material	γ_{dmax} (lb/ft^3)	OMC (%)
A	89.7	24.6
B	88.0	26.0
C	79.4	29.7

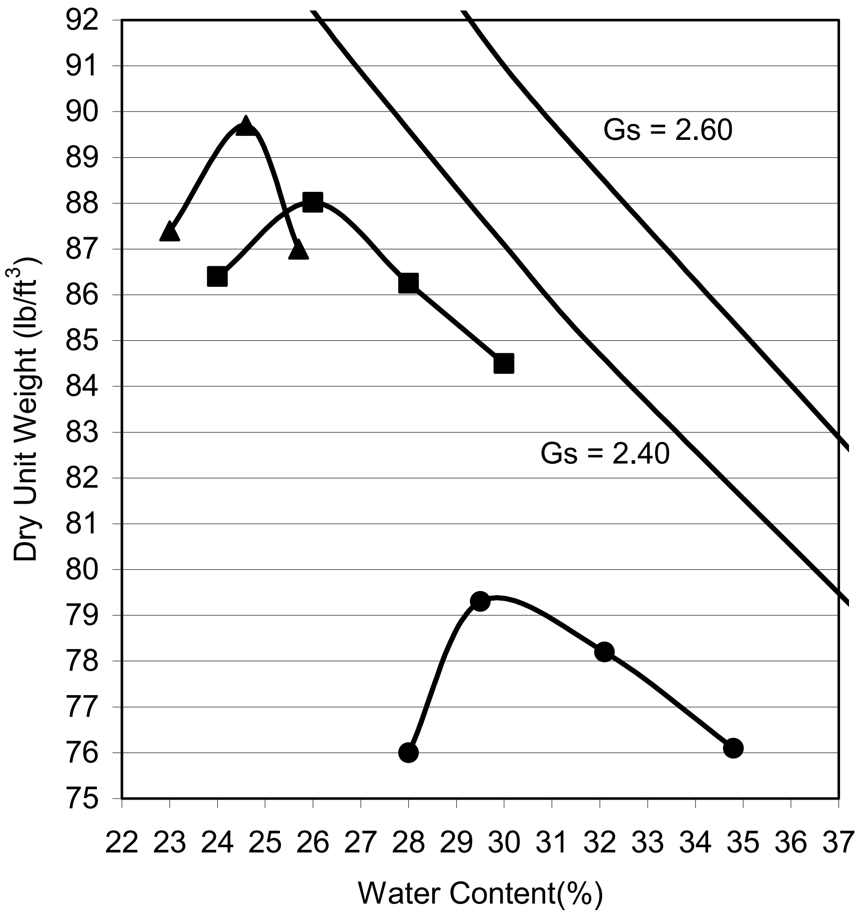

Figure 3. Standard moisture density relation curves for Materials A (▲), B (■), and C (●). Zero air voids (ZAV) curves (curves without data points) are provided for reference.

<u>California Bearing Ratio.</u> The CBR test is a penetration test which uses a standard piston to penetrate a soil; the CBR value of a particular material is the ratio of penetration stress to the bearing value of a standard crushed rock, typically limestone (Huang, 2004). The primary goal of this test is to evaluate the strength of a cohesive material having a maximum particle size of

¾" (ASTM, 1999). The CBR test correlates well with other engineering properties, especially in determining the resilient modulus of a subgrade for pavement design. The specimen for CBR testing is prepared in the same manner as a specimen is prepared in moisture density relation testing. The CBR test is performed at 95% of the maximum dry unit weight at optimum moisture content to simulate a "field" compacted condition. Table 6 shows the results of the CBR testing.

Table 6. Results of CBR testing.

	Average Corrected CBR	
Material	As-Compacted	Soaked
A	6.8	3.8
B	8.5	5.3
C	4.7	3.7

<u>Direct Shear Strength Testing.</u> The direct shear test was performed according to ASTM D 3080-04 Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions (ASTM, 2004b). Three specimens were tested under different normal loads to determine strength in developing the Mohr-Coulomb failure envelope. To simulate a compacted embankment or subbase, specimens were prepared in accordance with the moisture density relation test. The specimens were prepared at or near 95% of standard compactive effort on the wet side of the optimum moisture content. The specimens were prepared wet of optimum moisture content to represent conservative (lowest) strength values (Holtz and Kovacs, 1981).

The direct shear test has many advantages and disadvantages. Advantages include the test is inexpensive, fast, and simple. Disadvantages include problems controlling drainage, forced failure plane, serious stress concentrations at the sample boundaries, uncontrolled rotation of principal planes and stresses between the start of the test and failure (Holtz and Kovacs, 1981). The Mohr-Coulomb failure parameters (friction angle and cohesion) were determined by plotting the peak shear stress versus the normal stress applied to each specimen. Table 7 summarizes the results of the direct shear test for South Dakota coal mine refuse.

Table 7. Results of the direct shear testing.

Material	Peak Friction Angle, Φ (degrees)	Peak Cohesion,c (psi)	Residual Friction Angle, Φ (degrees)	Residual Cohesion, c (psi)
A	42.3	9.0	45.0	3.7
B	37.0	10.5	31.5	6.7
C	24.7	7.5	25.3	6.4

Triaxial Compression Testing. Triaxial compression testing in this research was conducted in accordance with ASTM D 4767-04 Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils (ASTM, 2004a). The purpose of the test was to obtain strength data but also to obtain permeability and consolidation parameters as well. Multi-staged loading was used to determine the shear strength of the coal mine refuse specimens at various confining pressures. Advantages to multi-stage loading are that it can obtain the shear strength from a limited number of tests and can greatly reduce the variability in the soil from one test to another (Ho and Fredlund, 1982). Testing consisted of preparing the soil specimen at the desired density (95 percent of the maximum dry density), saturating the specimen at a low confining pressure, consolidating the specimen to desired confining pressure, and shearing the specimen to a determined strain. The consolidation and shearing processes are then repeated are various confining stresses.

Pore pressure, chamber pressure, axial load, and vertical dial readings were all recorded prior to, and during, the test. Readings were recorded at 0.001% strain to develop an accurate stress-strain curve. When the desired strain was reached, shearing was stopped and the subsequent confining stress was applied. The triaxial test results are shown in Table 8.

Table 8. Mohr-Coulomb parameter results from triaxial testing.

Material	Φ (degrees)	c (psi)	Φ' (degrees)	c' (psi)
A	22.4	1.3	33.5	0.7
B	25.9	1.8	41.1	0.0
C	29.9	3.5	34.9	1.7

Consolidation Testing. During the consolidation phase of triaxial testing, consolidation data was collected. Although consolidation in a triaxial cell is obviously three-dimensional, the results were used to qualitatively assess the consolidation characteristics of the coal mine refuse. The objective of the consolidation phase of testing is to allow the specimen to reach equilibrium in a drained state at the effective consolidation stress at which the strength parameters are desired (ASTM, 2004a). Consolidation performed during the triaxial test consists of applying stress in the axial (piston) and lateral (confining pressure) directions. Axial and volumetric strain were measured as a function of time in an effort to estimate consolidation parameters of the coal mine refuse at the respective confining pressure.

Table 9 gives values of the coefficient of consolidation that results from consolidation at each of the various confining stresses for the coal mine refuse tested. Table 10 shows recompression index results from the consolidation test for each material. Based on the shape of the void ratio verses log pressure plots, the resulting slope values, and experience with similar materials, the results were deemed to be recompression index values. This means the induced compaction stress during specimen preparation was not exceeded during the consolidation phase of testing.

Table 9. Coefficient of consolidation results from consolidation testing.

	Stage	Normal Stress (psi)	Coefficient of Consolidation (in^2/sec)
Material A	1	3.1	0.0065
	2	9.3	0.0179
	3	18.7	0.0133
Material B	1	3.1	0.0026
	2	9.2	0.0010
	3	18.3	0.0119
Material C	1	8.3	0.0005
	2	12.7	0.0101
	3	16.5	0.0095

Table 10. Recompression index (C_r) results from consolidation testing.

Material	Recompression Index (C_r)	C_r / (1+ e_o)
A	0.080	0.043
B	0.065	0.033
C	0.070	0.035

Permeability Testing. After consolidation, the specimens were then permeated to determine the permeability characteristics of the soil. Permeability refers to the ability of water to travel through soil. The ASTM standard used as a guide for this test was ASTM D 2434-00 Standard Test Method for Permeability of Granular Soils (Constant Head) (ASTM, 2000d).

The constant head test is a permeability test that maintains a constant difference in hydraulic head across a sample. Measurements were recorded at designated time increments and the permeability was calculated for each confining stress on each specimen. The hydraulic gradients used at each confining stress are shown in Table 11. These gradient values were chosen to simulate various field conditions.

Table 11. Hydraulic gradient values used in permeability testing.

	Stage	Normal Stress (psi)	Hydraulic Gradient (Δh / L)
Material A	1	3.1	0.5
	2	9.3	1.5
	3	18.7	10.0
Material B	1	3.1	1.5
	2	9.2	10.0
	3	18.3	10.0
Material C	1	8.3	10.0
	2	12.7	10.0
	3	16.5	10.0

Permeability values were calculated when flow equilibrium was achieved. A minimum of four computed values were averaged to determine the permeability of the coal mine refuse at each respective confining stress. The average permeability values at each confining stress are shown in Table 12.

Table 12. Results of the permeability testing.

	Stage	Normal Stress (psi)	Average Permeability (in/sec)
Material A	1	3.1	$1.1 * 10^{-5}$
	2	9.3	$8.1 * 10^{-7}$
	3	18.7	$1.2 * 10^{-7}$
Material B	1	3.1	$1.3 * 10^{-6}$
	2	9.2	$9.0 * 10^{-8}$
	3	18.3	$1.2 * 10^{-8}$
Material C	1	8.3	$3.7 * 10^{-7}$
	2	12.7	$1.7 * 10^{-7}$
	3	16.5	$1.0 * 10^{-7}$

Discussion of Results

This research compared the results of the current laboratory testing with that found in the literature. This research also compared the laboratory results to subbase and embankment requirements relative to the SD DOT specifications and AASHTO specifications when provided.

Specific Gravity. The specific gravities of Materials A and B are near the range of typical specific gravity values found in all soils, which is 2.60 to 2.80 (Coduto, 1999). Material C is the exception with a specific gravity lower than the range for typical soils. A possible reason is that Material C contained more carbonaceous material than Materials A and B or consisted of a different rock type than Materials A and B. Comparison to values for coal mine refuse reported in the literature (Table 13) shows the test results coincide reasonably well with the lowest reported specific gravity of 1.5 and the highest specific gravity of 2.8.

Table 13. Results of specific gravity testing performed on other coal mine refuse.

Property	Range	Average	Standard Deviation	Note
Specific Gravity	1.68 - 2.61	2.28	0.33	1
	1.81 - 2.48	2.2	0.23	2
	1.47 - 2.6	2.2	0.31	3
	2.56 - 2.57	2.57	0.01	4
Notes: (1) Moulton *et al.* (1974) (2) Fredland and Sawyer (1976), average specific gravity increased from 1.89 to 2.24 in refuse larger than No. 10 sieve. (3) McQuade *et al*. (1981) (4) Saxena *et al*. (1984)				

Grain Size Distribution. Grain size distributions reported in the literature were highly variable, as would be expected with a processed material. Therefore, it is expected that the coal mine refuse sampled at South Dakota coal mine sites would fall within the extreme grain size distribution band presented in the literature (Fredland and Sawyer, 1976; McQuade *et al*., 1981; Saxena *et al*., 1984).

More importantly, the grain size distribution of the coal mine refuse sampled in South Dakota can be compared to the specifications for subbase provided by SD DOT. A comparison between the grain size distribution and these specifications is shown in Table 14.

Table 14: Grain size distribution values of sampled materials compared to SD DOT subbase requirements.

SIEVE	PERCENT PASSING			SUBBASE REQUIREMENT *
	A	*B*	*C*	
2"	100	100	100	100
1"	98	100	100	70-100
No. 4	71.3	95.3	79.6	30-70
No. 8	52.7	77.7	57.6	22-62
No. 40	16	18	18	10-35
No. 200	3.6	2.5	2.7	0-15

Each material exceeds the range of percent passing allowed on the No. 4 sieve for a subbase in South Dakota; Material B also exceeds the requirements on the No. 8. The specification was likely formulated to allow for adequate drainage for water to permeate through the subbase while providing sufficient strength to support roadway loads. However, with soil finer than what is required for the sampled coal mine refuse, the permeability of the subbase may be affected. It is possible the permeability of the material may be lowered but it may still be used for subbase as it is possible that drainage is not affected significantly.

Soil Classification. Soil materials classified A-1 through A-3 are considered excellent materials for use in subgrade and embankments according to AASHTO (Coduto, 1999). Furthermore, well graded materials classified according to USCS are also excellent materials for subbase and embankment use (Coduto, 1999). USCS results reported in the literature (Table 15) indicated a broader range in gradation that could be less suitable as subbase and embankments material. However, the coal mine refuse sampled in South Dakota is an acceptable material for use as subbase or structural embankment according to state specifications relative to soil classification.

Table 15. Soil classification of other coal mine refuse.

USCS Classification	Notes
GM	1
GW - GP	2
GW - GP	3

Notes:
(1) Moulton *et al*. (1974)
(2) Fredland and Sawyer (1976)
(3) McQuade *et al*. (1981)
Unidentified number of samples classifed as SM.

Freeze/Thaw Susceptibility. Significant degradation was observed during freeze/thaw susceptibility testing. Degradation of the material ranged from 65 to 73 percent of the original material weight. The freeze/thaw susceptibility test consisting of individual samples separated and analyzed by size experienced degradation with the addition of water in the initial cycle, thus significant degradation was expected throughout the entire test.

The degradation can likely be attributed to the friable nature of the predominate aggregate contained in the coal mine refuse material. Freezing and thawing action caused the larger particle sizes to breakdown, thus changing the gradation of the material to a finer graded soil. Material C experienced the most freeze/thaw degradation during testing.

Coal mine refuse being used as an engineering material will be exposed to all weather elements, especially weather extremes in South Dakota. A comparison between the SD DOT specification for subbase material and the gradation of the coal mine refuse after the degradation test shows that the requirements are not satisfied. The implications of material changes during freezing and thawing cycles will likely be changes in permeability; very little strength degradation is expected because the soil is under confinement.

Moisture Density Relation and Compaction. The moisture density relation testing results of Materials A and B show similar maximum dry unit weight values and optimum moisture content values. Material C possesses a significantly lower maximum dry unit weight and higher optimum moisture content. The lower unit weight of Material C is likely due to a low specific gravity value caused by the content of carbonaceous, friable material mentioned previously. Typical maximum dry unit weight values of a well-graded sand range from 95 to 135 lb/ft^3 for soil (Coduto, 1999). The typical optimum moisture content of well-graded sands ranges from 7 to 10 percent (Holtz and Kovacs, 1981). The results indicate the moisture density relation testing values are outside the range of typical values observed for this classification of material.

Values of moisture density relation reported in the literature were in the typical range of 90 to 105 lb/ft^3 for maximum dry unit weight with some extremes reported as high as 123 lb/ft^3 and as low as 81 lb/ft^3. The optimum moisture content reported in the literature was significantly lower than the values found in this research. The reported optimum moisture content range was from 5 to 15 percent for all material tested. Table 16 presents moisture density relation results conducted by Moulton *et al*. (1974) on coal mine refuse that distinguishes between “fresh” (material obtained directly from an active refuse hopper) and “old” (material that had been in a spoil pile exposed to the environment for a few to several years) refuse. Table 17 presents results by additional researchers.

Table 16. Moisture density relation results of West Virginia coal mine refuse (from Moulton *et al*., 1974).

Sample Identification		Maximum Dry Density (lb/ft^3)	Optimum Moisture Content (%)
Mine No.	Age		
1	Fresh*	93.8	7.6
	Fresh	94.6	7.4
	Old	90.8	15.4
2	Fresh	96.9	5.6
	Old	97.6	14
3	Fresh	114.7	7
	Old	121.2	9.2
4	Fresh	123.8	8
	Old	114.5	10.8

Notes:
* indicates coarse coal refuse

Table 17. Results of moisture density relation tests performed on other coal mine refuse.

Energy Type	Mold Size (in)	Max. Dry Unit Weight (lb/ft^3)	Optimum Moisture Content (%)	Notes
Standard	6	104.7	10.4	1
Standard	12	108.7	6.8	1
Modified	6	114	5	1
Standard	6	81.0 - 120 *	4.3 - 15.0 *	2

Notes:
* Range of values reported
(1) Fredland and Sawyer (1976), refuse labeled coarse and "old"
(2) McQuade *et al*. (1981), refuse labeled coarse and "old"

The optimum moisture contents determined in this research are higher than reported in the literature and are likely related to material gradation. The low unit weights found in the coal mine refuse for this research are attributed to the low specific gravity of the refuse. The amount of fines (the materials passing a No. 200 sieve) also indicates a material that requires more moisture to obtain a higher relative degree of compaction.

Material with a low unit weight is typically not used for subbase material. However, this does not exclude the possibility of its use as a subbase or as a structural fill material for embankments. If optimum moisture is to be achieved to gain maximum dry unit weight, some measures may need to be taken to ensure the water content remains high while the material is compacted for an embankment or subbase. The embankment or subbase should be constructed in layers and water should be added to each layer to achieve greater compaction.

AASHTO does not specify a particular unit weight or optimum moisture content that a material must possess to be considered for engineering projects. However, the SD DOT (SD DOT, 2004b) does specify the percent of maximum dry density and a range of water contents a material must achieve to meet SD DOT specifications; these specifications are shown in Table 18.

Table 18. Compaction specifications (from SD DOT, 2004b).

Optimum Moisture of Embankment Soil	Density Specification (% Max. Dry Density)	Moisture Specification (% of Optimum Moisture)
0% to 15%	95% or Greater	-4% to +4%
15% or Greater	95% or Greater	-4% to +6%

California Bearing Ratio. CBR values between 0 and 3 have a general rating of very poor and CBR values between 3 and 7 have a rating of poor to fair (Bowles, 1992). The primary use for material with this low of a CBR value is subgrade. Subbase material has a typical CBR value of 7 to 20 (Bowles, 1992). The Asphalt Institute (1984) states the CBR should have a minimum value of 20 for subbase materials. The corrected CBR values are below, or are at the boundary of being acceptable, depending on the design guidance used. Neither the SD DOT nor AASHTO specify minimum CBR requirements for subbase or embankment material. Note that the values obtained in this research do not match the typical values a CBR should possess according to the soil classification. Material classified as a well-graded sand (SW) typically has a CBR value ranging from 20 to 50 (Bowles, 1992). The low CBR values obtained in this research are likely attributed to the nature of the material discussed previously.

Direct Shear Testing. Based on testing, Materials A and B show similar Mohr-Coulomb strength parameters, however Material C shows lower values than Materials A and B. This difference is likely attributable to the factors discussed previously. The results of the direct shear test appear to be typical for soils where friction angles of various sands range from 28° to 45° (Holtz and Kovacs, 1981).

Direct shear testing results of coal mine refuse were not found in the literature. Neither the SD DOT nor AASHTO provide minimum shear strength standards a material must possess for use in subbase or embankment fill application. Given that the materials tested for this study to not have low Mohr-Coulomb strength parameters, the direct shear testing results could be favorable for coal mine refuse to be used as subbase or embankment fill material, depending on the strength requirements of the specific application.

Triaxial Compression Testing. The strength parameters obtained from triaxial testing indicates friction angle values ranging from 22.4° to 29.9° and cohesion values ranging from 1.3 to 3.5 psi (total stress). These values are comparatively lower to the range identified in the direct shear test, which is to be expected. The results of the effective stress parameters (friction angle varying from 34 to 41 degrees and cohesion varying from 0 to 1.7 psi) coincide well with the range of typical values of sands shown by Holtz and Kovacs (1981). Typical effective friction angle values in stability analysis for coal waste embankments found in the literature vary from 26 to 40 degrees (Holubec, 1976). Cohesion is at or near zero which is expected of sandy materials.

Triaxial testing presented in the literature consisted of both consolidated—drained (CD) and consolidated—undrained (CU) testing. Table 19 presents CD testing by Moulton *et al*. (1974) and Table 20 presents CU testing by various authors. These results indicate the compacted refuse has substantial strength. Specifically, the coarse aggregate has no cohesion and a high friction angle which would be expected for a subbase material. The strength results of the triaxial test performed on South Dakota coal mine refuse match well with these results found in the literature.

Table 19. Consolidated drained triaxial compression test results of fine West Virginia coal mine refuse (Moulton *et al*., 1974).

Sample Identification		Average Initial Dry Density (lb/ft^3)	Average Initial Water Content (%)	Shear Strength Parameters	
Mine No.	Age			c (lb/ft^2)	Φ (degrees)
1	Fresh*	94.5	10.6	0.0	40.8
	Fresh	88.1	Dry	288.0	34.6
	Old	89.7	14.0	0.0	39.0
2	Fresh	80.6	Dry	0.0	38.0
	Old	92.0	19.2	144.0	30.3
3	Fresh	N/A	N/A	N/A	N/A
	Old	119.3	10.9	288.0	29.6
4	Fresh	124.4	9.2	288.0	31.6
	Old	112.2	13.8	432.0	27.0

Notes:
* indicates coarse coal refuse

Table 20. Consolidated undrained triaxial test results for other coal mine refuse.

Φ (degrees)	c (psi)	Notes
25 - 42	0 - 14	1
33 - 39	*	2
27 - 40	0 - 6	3

Notes:
* Not reported
(1) Butler (1976)
(2) Almes and Butail (1976)
(3) Saxena *et al*. (1984)

These test show a range of values of the Mohr-Coulomb strength parameters of coal mine refuse sampled in South Dakota. Neither the SD DOT nor AASHTO specify strength requirements for subbase or embankment fill material. Based on Holubec (1976), the coal mine refuse sampled possesses considerable effective strength and would be adequate for subbase or embankment fill material.

Consolidation. Consolidation parameters determined from testing in this research are typical for sands. Typical coefficient of consolidation values for clays are less than 5.5×10^{-4} in^2/sec (Coduto, 1999) with results from this research exceeding this value. The recompression index values in the range of 0.05 to 0.10 indicate a very slightly compressible material (Coduto, 1999). A compressibility index of 0.0226 for coal mine refuse was reported by Moulton *et al.* (1974). This was lower than the compressibility index values found for the South Dakota coal mine refuse. Neither SD DOT nor AASHTO specify consolidation requirements for materials used as subbase or embankment fill material. Based on the consolidation test, the coal mine refuse sampled in South Dakota would likely be an adequate material for subbase fill and structural embankment fill.

Permeability. The results of the permeability testing are low for soil material classified as a well-graded sand. Typical permeability values of a well-graded sand range from 4 x 10^{-4} in/sec to 4 x 10^{-1} in/sec (Coduto, 1999). The low permeability values can possibly be attributed to degradation of the material during specimen compaction, producing fines, thus reducing the permeability of the coal mine refuse. Moulton *et al.* (1974) stated that laboratory permeability values were significantly lower than field permeability values. This was due to the degradation associated with the compactive effort exerting a disproportionate influence on the laboratory test values. Compaction not only reorients the particles to reduce permeability, but could crush or break friable materials into finer particles (Almes and Butail, 1976). It is also possible that the coal mine refuse contain materials that may affect the viscosity of the testing fluid. The carbonaceous or sulfuric material that is typically present in the coal mine refuse may be reducing the rate at which water moves through the soil.

Permeability results reported in the literature (Table 21) range from 4 x 10^{-3} to 4 x 10^{-8} in/sec. These results are similar to the results found in the permeability tests conducted on the South Dakota coal mine refuse. One case was noted to have a permeability value as low as 4*10^{-9} in/sec on very dense compacted coal waste with some degree of weathering (Holubec, 1976). The values computed in this research match well with the reported values in the literature. However, these values are lower than what would be desired to promote drainage beneath a pavement section. Water entering the subbase could affect the base layers under the roadway deteriorating the integrity of the base material if water cannot drain by gravity. An embankment with impeded drainage could likely exhibit increases in hydrostatic pressures under undrained loading conditions that could adversely impact the integrity of the embankment. Therefore, further investigation into the permeability of coal mine refuse may be necessary to determine the appropriateness as a subbase or embankment fill. Neither the SD DOT nor AASHTO specify permeability requirements for subbase or embankment fill material.

Table 21. Results of permeability tests performed on other coal mine refuse.

Property	Range	Notes
Permeability (in/sec)	$4*10^{-6}$ to $4*10^{-8}$	1
	$4*10^{-5}$ to $4*10^{-7}$	2
	$4*10^{-3}$ to $4*10^{-6}$	3
	$5.5*10^{-5}$ to $3*10^{-8}$	4

Notes:
(1) Moulton *et al*. (1974)
(2) Holubec (1976)
(3) Almes and Butail (1976)
(4) McQuade *et al*. (1981)

Conclusions

The testing conducted on the coal mine refuse for this research and additional testing provided in the literature has provided sufficient information to form conclusions on the usefulness of the coal mine refuse as an engineering material, primarily for subbase and embankment fill material.

Subbase Use. It is recommended that the coal mine refuse sampled in South Dakota have limited use as a subbase material. The justification is based low bearing ratio indicated in CBR testing, gradation, freeze/thaw susceptibility, and the low permeability of the coal mine refuse. The strength characteristics shown by the results of the direct shear and triaxial test are adequate for a subbase material. The material possesses little compressibility as indicated by the results of the consolidation test. Settlement is not likely to occur with this material and the coal mine refuse will not compress under typical loads applied to the pavement if the material were to be used as subbase material.

Embankment Fill Use. It is recommended that the material sampled in South Dakota be used as embankment fill material. This recommendation is based primarily on the strength testing results. The material appears to possess adequate strength with low compressibility characteristics. However the low permeability characteristics of the sampled coal mine refuse could be a concern under undrained loading conditions.

<u>Additional Testing.</u> Many more coal mine sites will obviously need to be tested to add to the data presented in this paper. The results of this study provide a solid basis for further investigation to determine the usefulness of the coal mine refuse as an engineering material.

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