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Stability of Slopes and Embankments of Coarse Man-Made Soils

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Abstract
The suitability of soils for the construction of subgrade is determined by their road-building properties. For this purpose coarse, sandy and sandy loam soils are the most suitable. Many coarse man-made soils are formed during mining. These soils undergo significant changes in composition, structure and texture of natural minerals under the influence of weather and climatic factors. Coarse man-made soils may differ by petrographic composition and metamorphism of minerals. These multi-component systems are composed of fine-grained components and large particles varying in strength, water and frost resistance. The aggregate strength characteristic was taken as an integrated criterion for the assessment of embankment subgrade based in part on the capabilities of the test and also the need for the creation of a dense structure for multi-component coarse soils. From this, a technological classification for coarse soils was developed. The problem of using coarse soil in embankments is the possibility of soil settlements occurrence due to the large space between the particles and due to the impact of weather and climate factors. For ensuring a stable structure of subgrade, such coarse soils should be either isolated from the influence of weather and climatic factors or the structure of the subgrade should be made dense non-settling properties by means of technological solutions that envisage filling the entire space between the large particles with fine-grained materials (e.g. pit-run fines). The design solutions are developed depending on the type of coarse soil. This will protect the embankment body from the effects of weather and climatic factors, namely: wetting-drying and freezing- thawing.
To ensure durability and stability of the embankment slopes, technological solutions for creating a single strong structure were developed. Effective subgrade structures that take into account the characteristics of these materials and ensure their sustainability and stability were developed basing on the results of coal waste research.

Keywords: man-made soils, coal waste, aggregate strength rate, stability, embankment structure

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1. Introduction

For the construction of roads hundreds of millions of cubic meters of soil are needed. These raw materials are extracted from quarries which occupy large areas of potentially fertile land. At the same time, coarse man-made soils which amount is measured in billions of cubic meters are accumulated on the land surface. One of the ways of their utilization is the use in road construction.

Coarse man-made soils are non-cohesive particles of rock containing more than 50% of particles of more than 2 mm in size. Except for crushed stone, screening, pebbles and gravel, coarse soils include secondary products of mining industry such as crumbled rock of ore mining and processing enterprises and coal waste (hereinafter referred to as coal waste). The above coarse man-made soils are sufficiently homogeneous material from each source of extraction except for coal waste.

Multiple dump pits, slagheaps where huge amounts of coal waste are stored, are the specific feature of industrial regions of Ukraine. It should be noted that only 5% of the total volume of coal mining and coal-cleaning waste was utilized. It is used to fill underground space of abandoned mines and for the production of some types of construction materials.

Using coal waste as construction material in the engineering practice solves simultaneously the problem of liquidation of dump pits and brings significant economic and ecological effect. All coal mining regions have practical experience in using coal waste in road construction, for example, the construction of a highway bypass round Donetsk in the direction of Zaporizhzhia (Fig. 1). For the first time this technology was tested at the construction of a road bypass round Luhansk (Mishina, 2011; Vyrozhemsky, 1987).

Figure 1: Construction of a highway bypass round Donetsk in the direction of Zaporizhzhia

2. Using Coarse Man-Made Soils in the Embankments

2.1 Coal Waste Characteristics

Coal waste is divided by source of extraction, type of fuel, plasticity number of mineral matter, content of fuel, grading and chemical and mineralogical composition, softening interval and the degree of swelling.

It is distinguished by the way of creation as follows:

- fresh mining rock;
- unburnt mining dump rock;
- burnt mining dump rock;
- fresh coal-cleaning rock;
- unburnt dump coal-cleaning rock;
- burnt dump coal-cleaning rock;
- flotation waste

Mining rock is presented as sedimentary rock that has been changed under thermal influence, chemical and physical weathering. The instability of composition and properties is one of the main factors hindering its widespread use. However, on condition of observing the recommended methods of preparation and processing of rock, high-quality products can be obtained from it (Buravchuk, 2010, 2008).

Burnt rock can be found in many dump pits, mainly in their lower part (Maydukov, 2009). In the areas of burnt rock small particles (usually up to 1 cm) of oxidized loose coal are contained. Voids between them are filled with fine grain material. Accumulation of rock mixed with coal stored in huge slagheaps causes oxidation and spontaneous ignition followed by gas emission.

By lithology this rock is a mixture of sedimentary rock associated with coal seams, namely: mudstone, siltstone, sandstone, shale, limestone and pyrite (Yanov, 1981). Physical and chemical properties of the rock are significantly changed within the slagheaps influenced by thermal-oxidation.

By the degree of natural thermal processing dumping rock can be divided into:

- unburnt rock (virtually no debris of burnt rock, low mechanical strength. This is mainly fresh coal mining and coal-cleaning waste);
- poorly burnt rock (characterized by a high content of burnt rock particles);
- burnt rock (characterized by the absence of unburnt particles, particles of rock are of red color range).

Compared to dump rock, coal mining waste is characterized by a high content of coal in the rock, more stable grading and substance composition, lower sandstones and sulfur content, and higher mudstones content.

Burnt rock is more resistant to the destructive influence of water; soil layers built using it have better strength characteristics than soil layers built using fresh coal waste. However, in both cases strength characteristics are significant. According to a general rule of soil mechanics, soil strength and rigidity increases with the upsize of its grains. Thus, coarse soil has better values of strength and rigidity than fine-grained soil. Dump mining rock is a valuable geotechnical material due to its properties.

2.2 Classification Features of Coal Waste

It should be noted that the specific feature of coal waste is heterogeneity of its grading. Reducing to coarse particles of mining dump rock occurs as a result of weathering involving weakening the material over time and at short-term processing - at compaction when the break of weak grains edges occurs.

The study (Vyrozhemsky, 2013) proposes to classify coal waste by aggregate strength rate. This indicator shows the possibility and the need to create dense structure of multi-component coarse soil.

Procedure for determining the aggregate strength rate includes determining the number (%) of indestructible particles under the influence of climatic and technological factors. Climatic factors are the cycles of wetting-drying and freezing-thawing. Technological factors include soil compaction during construction of the embankment. Strength of the aggregate system at compaction serves as a possibility criterion for creating dense structure.

Table 1 shows the classification of coal waste as multi-component coarse soil by aggregate strength rate.

Soil type		Description	Characteristic value for		
			Original state	Initial state of weathering	Final state of weathering
Aggregate strength		Aggregate strength rate A, %		≥ 95	
		Frost resistant , %		≥ 95	
conditionally aggregate strength	I type	Aggregate strength rate A, %	From 85 to 95	From 80 to 90	From 75 to 85
		Frost resistant, %	From 50 to 70	From 60 to 80	From 70 to 95
	II type	Aggregate strength rate A, %	From 80 to 90	≥ 75	≥ 60
		Frost resistant, %	From 50 to 70	From 60 to 90	
Aggregate weak		Aggregate strength rate A, %	≤75	≤ 60	
		Frost resistant, %		–	

Table 1: Classification of coal waste by aggregate strength rate

Determination of characteristics of the rock in its original state (A_0) involves only reducing the number of particles at compaction. The initial state (A_3) provides three cycles of climate impact and compaction effects. The final state (A_{10}) provides 10 cycles of climate impact and compaction effects. One cycle of wetting-drying involves total immersion of large particle samples in the water for 2 hours and drying them up to reaching the constant weight by the samples within 22 hours.

When weak hydrolabile material is used, its destruction occurs followed by the creation of a significant number of fine grains at compaction during construction. Further effect of weathering cannot cause subsidence strains. In case of 25-35% of fine grains, most of pores between the particles are filled with fine grains promoting creation of a stable structure. So, aggregate weak soils are the soils which aggregate strength rate (A_O) is lower than 75%, and further, over three cycles of wetting-drying (A_3) it will be less than 60%. Most coal waste composed of mudstones and siltstones has high strength in its natural state (150 MPa). It is badly split by compaction efforts. At the same time, the destruction varying in intensity degrees occurs under the influence of weathering. This type of soil called conditionally aggregate strength. It is hard to compact. Special design and technological measures are provided for its using. Relatively aggregate strength coarse soil also behaves differently at weathering. One part of it is being intensively destroyed at the initial stage of weathering (II type) and the other part of it is being destroyed over its life cycle with a small but constant rate (I type). This implies the need that conventionally aggregate strength soils are divided into two soil types.

Coarse soils of the first type are more resistant to weathering. Such soils having the aggregate strength rate of 95% ≥ A_O ≥85% are less prone to destruction under the influence of wetting-drying;

Soils of second type in the initial state are also strong enough 90%≥ A_O ≥80% but influenced by weathering during the initial period sharp loss of strength occur A_3 ≤75%, followed by the transition to weak soils category.

The presence of a large number of strong water resistant particles in coal waste mixture is possible. These soils will be classified as aggregate strong. They are practically not destroyed at compaction and under the influence of climate factors.

2.3 Laboratory and Field Testing of Coal Waste

In this work coal waste of various coal fields of Ukraine were studied and the change in physical and mechanical properties (grading, aggregate strength rate, etc.) of dump mining rock and coal-cleaning waste influenced by road climatic factors typical for road subgrade performance was defined.

Grading of original mining coal waste of various coal fields of Ukraine is given in Figure 2.

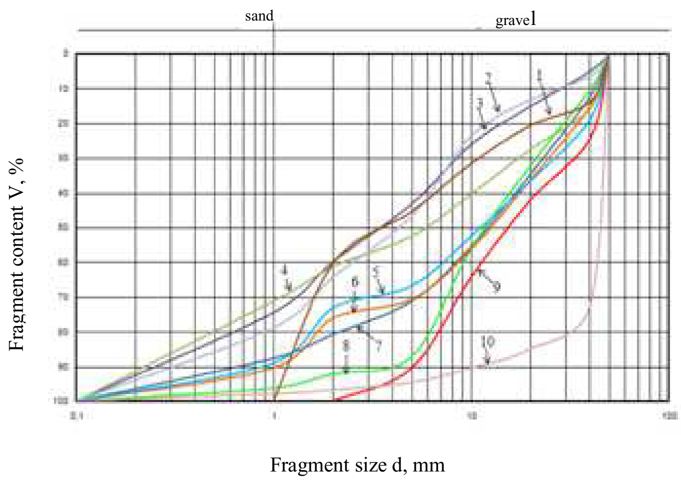


Figure 2: Original grading: 1. Coal waste of mine number 8 (Burnt rock, the Volyn region); 2. Coal waste of "Chervonohradska" mine (burnt rock); 3. Coal waste of mine number 8 (Unburnt rock, the Volyn region); 4. Coal waste of mine number 4 (Burnt rock, the Volyn region); 5. Coal waste of "Chervonohradska" mine (fresh rock, the Lviv region); 6. Coal waste of E.T. Abakumov mine (burnt rock, the Donetsk region); 7. Coal waste of the PSC "EVRAZ Dniprodzerzhynsk chemical recovery plant"; mine; 8. Coal waste of coal cleaning plant "Luhansk"; 9. Coal waste of mine number 5 (Burnt rock, the Luhansk region); 10. Coal waste of mine number 7 (Burnt rock, the Luhansk region)

Grading of original coal waste from the mines and dressing works was determined for a start. This indicator differed significantly for burnt, fresh and unburnt rock.

Then the research of climatic and technological impacts on stability of large particles in coal waste was conducted. This resulted in determining the aggregate strength rate of coal waste (a mixture of coarse soils) used for evaluation of strength of the entire system and the changes in its structure under the compaction effects after 3 and 10 cycles of wetting - drying and compaction. Original state (0 wetting-drying cycles) involves particles destruction only by compaction. The research results to determine the aggregate strength rate of coal waste of various coal fields of Ukraine are given in Figure 3.

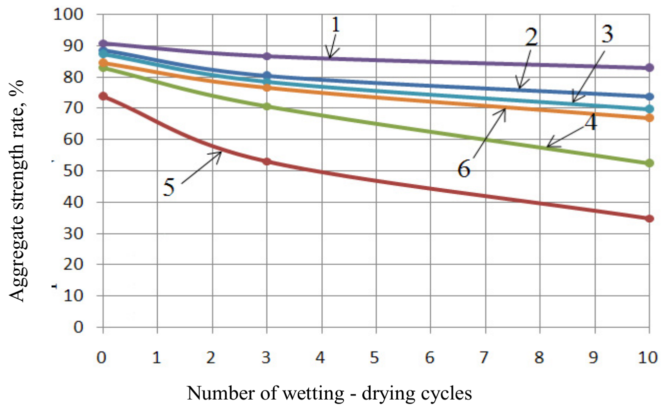


Figure 3: Graph of aggregate strength rate change: 1. Coal waste of mine number 4 (burnt rock, the Volyn region); 2. Coal waste of mine number 8 (Burnt rock, the Volyn region); 3. Coal waste of "Chervonohradska" mine (burnt rock); 4. Coal waste of "Chervonohradska" mine (fresh rock, the Lviv region); 5. Coal waste of mine number 1 (fresh rock, the Volyn region); 6. Coal waste of mine number 8 (Unburnt rock, the Volyn region).

The analysis of the research results showed that burnt rock has the highest aggregate strength rate and the lowest value is typical for fresh rock.

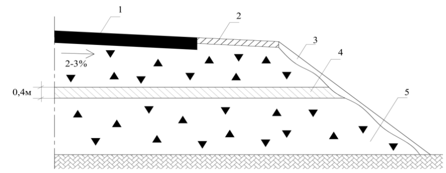
2.4 Design Solutions for the Embankments Built of Coal Waste

Development of rational structures of embankments containing coal waste is carried out consistently and based on specified properties of the rock, height and width of the embankment.

When using fresh mining rock or fresh coal waste, the calculations of the embankment cross-section basing on spontaneous ignition criteria is carried out. The need for placement of insulating layers on the appropriate height of the embankment and the installation of a protective screen on the slopes is determined. As soon as the need for placement of insulating layers on the appropriate height of the embankment is determined by calculations, the protective insulating layer of loam, screening or burnt rock of 0.4 m thickness is arranged every 2.5 m of the layer of fresh rock to avoid the possibility of exothermic heating of rock in the embankment (Fig. 4).

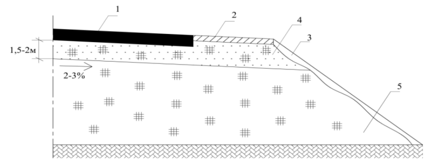
During the construction of subgrade using aggregate weak coal waste dense structure is achieved at compaction. Under the influence of compaction efforts coarse particles are destroyed that is followed by formation of a significant amount (50%) of fine particles. This allows creating a stable soil structure which is potentially not prone to subsidence.

Designing of the embankment structure based on aggregate weak rock is performed basing on the creation of dense structure potentially not prone to subsidence which is achieved at compaction. To ensure reliability of the embankment body performance, it should be stabilized by inorganic binder material. At the same time, covering of the embankment with the vegetation soil including grass seeding is provided by the design (Fig. 5).



1 – pavement
2 – hard shoulder
3 – layer of vegetation soil
4 – thermal insulating layer
5 – fresh mining rock or fresh coal-cleaning waste

Figure 4: Embankment structure based on fresh coal waste or fresh mining rock



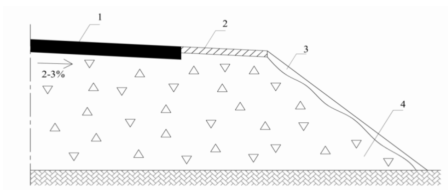
1 – pavement
2 – hard shoulder
3 – layer of vegetation soil
4 – work embankment layer of aggregate weak coal waste reinforced with inorganic binder
5 – embankment body with aggregate weak coal waste stabilized by inorganic binder

Figure 5: Embankment structure based on aggregate weak coal waste

In case of aggregate strong coal waste, the embankment structure is not different from the type structure for coarse soils, except for the elements that are introduced, if necessary, in accordance with fireproof calculations (Fig. 6).

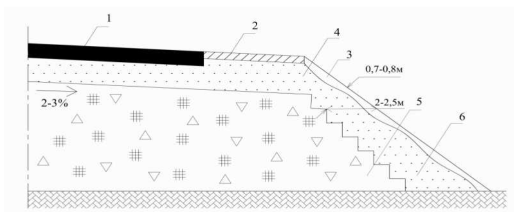
It should be noted that such coal waste contains in its composition a certain amount of hydrolabile rock which at road operation could be potentially destroyed causing subsidence and uneven deformation. In this case, the most efficient option would be to fill the maximum number of pores between coarse particles with fine-gain. Then even at the destruction of particles, the deformation of the whole system will be minimal as the newly formed particles will not be able to move in the body.

Embankment structure with conditionally aggregate strength waste provides isolation of embankment body from the influence of weather and climatic factors (Fig. 7). For this purpose protective screen on the slopes are used which prevent weathering of rock and penetration of moisture into the embankment body. The thickness of protective screen is calculated basing on waterproof and frost resistance conditions. Cohesive soil or the rock of slagheaps reinforced by inorganic binder can be used as the material for protective screens. However, to ensure reliability, durability and stability of the embankment, its body must be stabilized by cement or lime.



1 – pavement
2 – hard shoulder
3 – layer of vegetation soil
4 – aggregate strong coal waste

Figure 6: Embankment structure based on aggregate strong coal waste



1 – pavement
2 – hard shoulder
3 – layer of vegetation soil
4 – work embankment layer
5 – embankment body of conditionally aggregate strong coal waste
6 - protective screen

Figure 7: Embankment structure based on conditionally aggregate strong waste

Using different types and grades of coal waste in one structural element is unacceptable during the construction of road subgrade. Application of different types and classes of rock in various structural elements of the embankment is allowed by making appropriate changes to the design and technology of works performance.

3. Conclusions

Secondary products of coal industry (coal waste) are very specific coarse soil. The studies have shown that coal waste contains a mixture of strong waterproof particles and hydrolabile elements that can soak and of fine-grained component mainly formed during weathering. Density and strength of coal waste depend mainly on the lithification of coal containing rock. The highest strength is the rock that was exposed to burning (burnt rock); the lowest strength is specific unburnt and weathered rock. Coal waste relating to special types of soil can be used in subgrade only after a comprehensive study of their physical and mechanical, strength and deformation properties. Standard research techniques considering specific characteristics of coal waste as well as non-standard research techniques (such as aggregate strength rate) were used for this purpose. The analysis of the research results showed that dump mining rock is heterogeneous by its structure and properties. In the same slagheap along with a dense, well-burnt material, you may find weak, unburnt or poorly burnt rock. Grading also varies greatly within the slagheap. In this regard, it is necessary to apply optimal grading composition for pavement structure. Stability of characteristics of dump mining rock in structural layers of subgrade and pavement depend on road and climatic operating conditions. Since the studies have shown that coal waste containing particles of varying strength and resistance to weathering, it cannot be always used for the construction of subgrade without prior stabilization or strengthening by inorganic binder. This is especially true for unburnt rock. Unburnt and poorly burnt rock can be used in the subgrade structure only if proper waterproofness is ensured. Burnt rock may behave satisfactorily in embankment structuresof pavement provided that the load and especially subgrade wetting during the road operation are considered. Stabilization or strengthening by cement increases adhesion between coal waste particles due to setting and bonding. Coarse soil gains bearing capacity and becomes water and frost resistance. To use coal waste in the construction of strong, sustainable and stable embankments, it is necessary to classify them. An aggregate strength rate characteristic is taken as an integrated criterion for evaluating the possibility and the need to create a dense structure of multi-component coarse soil. Strength of the aggregate system following compaction is regarded as a criterion for evaluating the possibility of creating dense structure. Resistance to weather and climatic factors impact is regarded as the criterion of possibility. If the particles are prone to weathering, they need to be isolated from the impact of weather and climatic factors, i.e. it is necessary to create the appropriate conditions that prevent subsidence of embankment. It should also be noted that the use of coal waste for the construction of strong, sustainable and stable embankments involves the necessity to develop special structural and technological solutions according to their classification.

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