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CHARACTERISTICS AND ENGINEERING USAGE OF WASTE FROM COAL MINING

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Abstract

The waste accompanying hard coal production, useless from the mining industry point of view, is a useful man-made soil. This is a specific coarse-clastic material, featuring characteristics of both coarse-grained and fine-grained soils. It consists mainly of sandstone and clay-shale fragments as well as small amounts of coal. This waste, as a spoil, is deposited on mine dumps. Depending on the amount of coal, overburden pressure and oxygen access the spoil dumps may get burned. Therefore, we distinguish fresh (non-burned) and burned dumps.

The richest deposits of hard coal in Poland are situated in the area of the Upper-Silesian Coal Basin. As a result, most intensive development of hard coal mining occurred in this area. It is also here, where a vast majority of mine waste heaps (dumps) is situated. The spoil dumps are now subject to planned disposal and the area covered by them to reclamation.

The waste originating both from mine heaps and from current production is used in civil engineering.

The paper presents the description of hard coal mining waste and its technical usability.

Streszczenie

Odpady towarzyszące produkcji węgla kamiennego, bezużyteczne z punktu widzenia górnictwa, stanowią przydatny grunt antropogeniczny. Jest to specyficzny materiał grubookruchowy, charakteryzujący się cechami zarówno gruntów gruboziarnistych jak i drobnoziarnistych. W skład jego wchodzą głównie okruchy piaskowca i iłołupków oraz w niewielkiej ilości węgla. Odpad ten, jako skała płonna, odkładany jest na zwałach przykopalnianych. W zależności od ilości węgla, ciśnienia nadkładu i dostępu tlenu zwały skały płonnej mogą ulegać przepaleniu. Wyróżniamy, więc zwały świeże (nie przepalone) i przepalone. Najbogatsze złoża węgla kamiennego w Polsce znajdują się na terenie Górnośląskiego Zagłębia Węglowego. W efekcie na terenie tym nastąpił najbardziej intensywny rozwój górnictwa węglowego. Tutaj też znajduje się przeważająca liczba składowisk (zwałów) odpadów kopalnianych. Obecnie zwały skały płonnej ulegają planowej likwidacji, a tereny przez nie zajmowane rekultywacji. Odpady pochodzące zarówno ze zwałów przykopalnianych jak i z bieżącej produkcji wykorzystywane są w budownictwie inżynieryjnym.

W artykule przedstawi się charakterystykę odpadów górnictwa węgla kamiennego oraz ich przydatność techniczną.

Keywords: **Geotechnics; Soil mechanics; Coal mining waste; Geotechnical tests.**

1. INTRODUCTION

Part of rock adjacent to the deposit is mined together with hard coal in the process of its extraction. Then, during flotation, the demanded coal is separated from the rock useless to miners. So this unnecessary product in a natural way was named a waste or spoil. However, from the geotechnical point of view this waste, as a crushed rock, is a soil except that it is man-made. Referring to its origin it differs from a natural soil in a much shorter period of creation. The processes of weathering, erosion and transport, which resulted in natural soil formation, were proceeding in a geological time. Instead, the time of man-made soil (hard coal mining waste) origination is a short period of shearer or pickaxe operation. So the spoil is a young formation, whose weathering process is in the initial stage. The hard coal mining waste is divided basically into two groups:

- rock waste, originating from mining development works, making new parts of deposit available for extraction. These are usually large crumbs of spoil, mainly sandstone, which are mostly left underground, filling old gobs.
- preparation waste, originating in the processes of mechanical coal preparation in sorting plants, washers of flotation plants, consisting of a mixture of Carboniferous rocks, such as clay-stones, mudstones, sandstones. Their share ranges between 36 and 80%.

Wastes originating from various mines may differ in the mineralogical composition. These differences result from various geological structures of strata, among which mined coal deposits exist.

The waste originating from a specific mine may also differ. The waste from development work (shafts sinking and adits driving) generally consists of sandstone fragments. Instead, the waste originating from the extraction work usually consists of clay-shale fragments. Normally, both sandstones and clay-shale exist in the spoil.

In the past mining waste heaps were dumped close to mines and drawing shafts, forming so-called mine dumps of irregular or conical shapes, above track level. Fig. 1 shows the Skalny waste heap at the Bolesław Śmiały Mine in Łaziska Górne (Fig. 1). The heap is 220 years old, 92 m high, covers the area of 30 ha and it has the capacity of 17 million Mg. This is one of the largest heaps in Europe.

Now the Skalny heap is extinguished and partly reclaimed, but more or less till 2005 it was a thermally active heap (burning heap).

Figure 1.
Skalny mine heap of the Bolesław Śmiały Mine in Łaziska Górne

In recent years such heaps formation is avoided in favour of central dumps. These are flat dumps, also referred to as lower dumps, filling most frequently pits after the extraction of sand used for mine backfilling.

A misleading connotation of commonly used term "waste" causes that building designers frequently have doubts about the geotechnical usability of the spoil. Sometimes this excess caution seems exaggerated in view of pretty large number of studies on hard coal mining wastes (Bela et al. 1980; Kawalec 1974; Kuhl 1955; Pieczyrak 1981, 1982, 1987, 1994, 2000, 2007; Skarżyńska 1997; Soczawa 1978, 1984; Szczerbiński and Smolińska 1968; Twardowska et al. 1988).

Polish hard coal reserves rank among the largest worldwide. The largest hard coal deposits are situated in eastern and southern China, in the US as well as in India, South Africa, Australia and Ukraine. In 2002 the world hard coal output exceeded 3.6 bn Mg, of which the largest amount was mined in China (1.1 bn Mg including lignite), USA (1.0 bn Mg, 2001), India (335 million Mg), Australia (260 million Mg), RSA (220 million Mg), Russia (180 million Mg), Poland (105 million Mg), Indonesia (103 million Mg), Ukraine (85 million Mg, 2001) and Kazakhstan (75 million Mg) (Wikipedia: Hard coal). At present Poland has drastically reduced the amount of mined hard coal. However, not so long time ago it belonged to top world producers (Pieczyrak 1987). Thereby the amount of hard coal mining waste in Poland is very significant, albeit recently the pace of its growth has decreased. It is assumed that in Polish conditions the production of 1 Mg of coal is accompanied by production of approx. 0.4 Mg of spoil. However, it is not uncommon that the proportion of both materials is 1:1 (Pieczyrak 2000).

In 2003 in Poland (data of the Central Statistical Office, 2004) 35,836 million tonnes of hard coal mining was produced. 35,041 million tonnes of this was managed, what makes 97.8% of total waste generated on a current basis. This is a high index.

Nevertheless, it is estimated that by 2003 the amount of waste accumulated on waste heaps amounts to 546,424 million Mg. Only a small percentage of fine-grained flotation tailings is used in mines underground in the form of mixture with power plant fly ashes. The basic part of coarse-grained or medium-grained waste from preparation (from heavy liquid separators and fines jigs) as well as the stone from development work is used on the surface in civil engineering.

Some time ago (final decades of the twentieth century) the removal (disposal) of mine dumps was started as well as the reclamation of the area covered by them (Fig. 2).

Figure 2.
Disposed spoil dump in the area of Ruda Śląska

Part of dumps was preserved. The aforementioned Skalny heap as well as the heap in Rydułtowy, in 2007 named "Szarlota" (Fig. 3), may be specified here. It is burned and partly afforested. This heap covers the area of 37 ha, it has the capacity of 13.3 million m^3, and it is 134 m high. It is the highest heap in Europe.

Next to fully preserved cone-shaped dump ("Szarlota"), there is another cone-shaped dump, which as a result of removal (disposal) was cut to the height of adjacent flat dump, i.e. to around 90 m (Fig. 4).

Figure 3.
"Szarlota" heap in Rydułtowy

Figure 4.
"Szarlota" heap and neighbouring another cone-shaped dump after partial removal to the height of adjacent flat dump

At present the hard coal mining wastes in Poland, originating both from dumps and from the current production, are managed on the surface in the following cases:

- levelling of subsidence areas resulting from mining operations;
- construction of hydrotechnical facilities, such as flood embankments and polders;
- road and railway construction (construction of motorway and expressway embankments for road transport and railway embankments);
- strengthening the subsoil of car parks and of industrial workshops as well as of large shopping malls.

Fig. 5 and 6 shows a road embankment constructed of burned and unburned mining waste for the Bytom ring road.

Figure 5.
Construction of Bytom ring road. Embankment layer made of unburned spoil laid on a layer of burned spoil (author Krzysztof Chlipalski, Ph.D. Eng.)

Figure 6.
Construction of Bytom ring road. Layers of embankment made of burned and unburned spoil (author Krzysztof Chlipalski, Ph.D. Eng.)

Figure 8.
Arrangement of largest mining waste dumps situated in the area of the Voivodship of Katowice (According to: Report on the environmental state in the Voivodship of Katowice in 1994. Joint publication edited by Lechosław Jastrzębski, Katowice 1995)

2. PLACE OF SPOIL OCCURRENCE IN POLAND

The richest deposits of hard coal in Poland, recognised and mined so far, are situated in the area of the Upper-Silesian Coal Basin (Fig. 7). As a result, most intensive development of hard coal mining occurred in this area (Jaros 1975). It is also here, where a vast majority of mine waste heaps (dumps) is situated (Fig. 8).

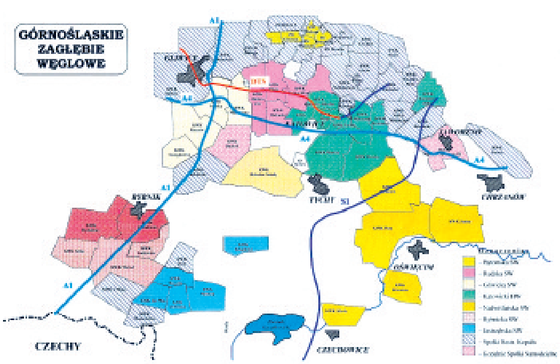

Figure 7.
Upper-Silesian Coal Basin

Nearly 97% of domestic coal production originates from the Upper-Silesian Basin (Geographical Encyclopaedia of the World, Poland, vol. X, OPRES, Cracow 1997, 251). So it is here, where the issues of mining waste disposal and management are the clearest. Hence it is no wonder that they happened to be within the main area of scientific and practical interest of the Chair of Geotechnics of the Silesian University of Technology in Gliwice and to some extent of the Central Mining Institute in Katowice (Papers of GIG (Central Mining Institute) usually refer to post-mining ground deformations and construction conditions in such an area).

3. SPOIL DESCRIPTION

In the area of Upper-Silesian Coal Basin the hard coal deposits occur usually within sandstones and shale (Kuhl 1955). So in petrographic terms the spoil is formed mainly of fragments of those geological formations. Moreover, the spoil comprises residues of coal, which was not separated during the flotation. Each of those components affects overall properties of the spoil.

The petrographic composition of the spoil is highly stochastic and depends on its origin – whether it is from development work (more sandstone and less coal) or from mining deposits (more shale and coal).

The share of sandstones decides about the spoil stiffness. In turn, the shale easily slackens and mainly due to this reason causes a decrease in the environment stiffness. Coal is the component of the lowest unit weight. Its share decides primarily about material's self-ignition capacity.

The spoil self-ignition will occur, when its composition comprises coal (at the content in excess of 30% (Kuhl 1955), when substantial overburden pressure exists and the access of oxygen is possible. The presence of pyrite is important, which most likely initiates the process of dump self-ignition (Rainbow 1987, Skarżyńska 1997).

The spoil dumps burning is a process, which does not give in to human control. Its existence is proven by smaller or larger trails of smoke, but first of all – by a specific smell. Many dumps were burned "unnoticeably". Cases are known that a spoil heap considered burned reignited after removing the top layer (e.g. to make an excavation to lay infrastructure lines).

The fight with the fire centre is enabled by carbon dioxide CO_2, compressed to 7 MPa and cooled to –50°C. In its atmosphere the fire centre extinguishes due to cutting off the oxygen inflow and taking away from the burning material so much heat that it cools down below the ignition point. These methods are expensive and seldom used to extinguish heaps. Usually fire centres are allowed to extinguish spontaneously.

Generally the hard coal mining waste is divided into fresh (i.e. unburned) and burned waste. The fresh waste is black or dark grey (Fig. 5, Fig. 9). The burned waste features a brick-red colour (Fig. 5, Fig. 10).

Figure 9.
The "Pochwacie" dump formed now at the Zofiówka Mine covers the area of 138 ha, is 75 m high and its capacity is 123 million Mg

Spoil properties depend not only on its composition (sandstones, clay-shale), the degree of slackening but also on the occurrence of burning or not.

Burned spoil is more resistant to destructive water action and the subsoil built of it is stiffer than the subsoil built of fresh spoil. However, in both cases this stiffness is substantial (Bela et al. 1980; Bzówka and Pieczyrak, 1999; Pieczyrak 1994).

As a rule, the hard coal mining waste is a coarse-clastic material (Fig. 11). According to a general rule in the soil mechanics, the soil strength and stiffness increase with growing dimensions of its grains. So a coarse-clastic soil features more favourable properties than a fine-grained soil. The hard coal mining waste, commonly referred to as the spoil, only due to its nature constitutes a valuable geotechnical material.

Figure 10.
View of a burned heap (after its opening)

Figure 11.
Spoil fragments from the Gliwice Mine dump

Spoil fragments have a disc shape and sharp edges (Fig. 12). These edges are easily broken during the compacting. As a result a favourable change occurs in the material laid, consisting in filling the voids by smaller grains created during large grains breaking. In addition, an effect of spoil dump "self-reinforcement" is observed because of the grains disc shape (Pieczyrak 1987).

Crashed clay-shale under effect of water is subject to slackening, thus the process opposite to the diagenesis. The slackened material "seals" the dump and thereby reduces or simply excludes the possibility of spoil self-ignition occurrence. Nota bene, a characteristic feature of hard coal mining wastes is the instability of their grain composition. Spoil fragments breaking up occurs both as a result of the slackening proceeding over time and temporarily during the compacting, when weak grain edges are broken.

Tamping rollers are very useful in the embankments construction using the spoil. A higher tightness of the embankment will be obtained, when the spoil laid is wet. As a result of wet spoil (w = 10÷20%) compacting, even in case of burned rock, a "man-made conglomerate" is formed, which cannot be spread after drying, it can be only broken. So the process of wet spoil compaction is a form of antropodiagenesis (Pieczyrak 1982, 1987). The conglomerate features low porosity resulting in a difficult or simply impossible water circulation inside it and the air flow is also substantially reduced. From the self-ignition hazard point of view this is very favourable, because it eliminates the access of oxygen.

In case of compacting fresh spoil, consisting mainly of sandstone fragments, a sufficiently tight embankment sometimes cannot be obtained. Then, if at significant coal content the embankment is high, the self-ignition of spoil may occur. In such situation this hazard may be eliminated by adding a sandy clay or loamy sand. This should be practically done the way that first ca. 25 cm thick spoil layer is spread using a bulldozer and then approx. 10 cm thick layer of sandy clay is laid atop. Then a tamping roller is used (vibrating or not), which compacts and "homogenises" the spread layer of the embankment. These actions should be repeated many times, until the required height of the constructed embankment is obtained.

Figure 12.
View of examples of waste grains from the Gliwice Mine

Sandy clay and loamy sand are soils good for laying in embankments. Their small addition has insignificant influence on reduction of spoil's very high bearing capacity and stiffness, in particular when it is formed mainly of sandstone fragments.

The hard coal mining waste is a heterogeneous, coarse-clastic man-made soil. Based on grain size composition tests carried out on large samples (266, 276, 1482, 1660, 1831, 6231 kg) it may be stated that in terms of size composition the spoil corresponds to well grained gravels ($U = 5÷60$, $C_c = 1÷3$) (Pieczyrak 2000). Despite that this soil, compared with mineral virgin soils, features characteristics both of coarse-grained and fine-grained soils. Values of internal friction angle and compression modulus for the spoil are as high as in case of natural coarse-grained soils. Instead, a high value of cohesion and small water permeability make the spoil similar to fine-grained (cohesive) soils. Coarse-grained mineral virgin soils do not show viscous features. Compacted spoil reveals the delay effect (viscosity) like cohesive soils, albeit to a much smaller extent (Pieczyrak 1976, 1981).

The spoil, due to its heterogeneous and coarse-clastic nature, is sensitive to preparation consisting in large grains rejecting. The grounds to determine the spoil bearing capacity and stiffness should comprise trial loads with the application of a large plate ($A \geq 1\ m^2$). Unfortunately, until now there were few such investigations. For the same reason it is better to determine the angle of slide φ as the lower (and generally sufficiently accurate) estimate of internal friction angle ϕ than to determine it for a prepared sample (Pieczyrak 2000).

Also in terms of frost swelling the spoil reminds the cohesive soils behaviour (Skarżyńska 1997; Soczawa 1978, 1984). This phenomenon is especially clearly visible in case of methodically constructed embankments.

4. TECHNICAL USABILITY OF THE SPOIL

The hard coal mining waste is a young man-made soil, well compactable. An embankment constructed methodically of the spoil features a high bearing capacity and stiffness. An old lower dump may feature similarly high bearing capacity and stiffness.

The compacting of wet spoil allows obtaining much better effect than in case of dry material.

In general it should be stated that the spoil is suitable for construction of building embankments. The usability of fresh and burned waste is similar, although the burned spoil is stiffer and is not self-ignitable.

In case of embankment construction of a fresh spoil, containing substantial amounts of coal, it is advisable to add around 30% of sandy clay or loamy sand to increase the embankment tightness and hence to prevent self-ignition.

A characteristic feature of mining spoil, in particular the compacted one, is its significant cohesion and low permeability. So the spoil is useful to construct river and water reservoir embankments. However, in case of potable water it is necessary to make sure that it will not get saline.

Pretty steep slopes may be formed in embankments constructed of the spoil, especially where they are built of burned waste.

The only limitation in hard coal mining waste use is its frost susceptibility.

In general, mining spoil is very suitable for foundation mats, lower layers of road subgrades, for flood dykes and banks and also for strengthening of weak soils surface. Hence, from geotechnical point of view, this is a material of high technical usability.

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