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INFLUENCE OF MINERAL COMPOSITION OF MELAPHYRE GRITS ON DURABILITY OF MOTORWAY SURFACE

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The surface layer of the Konin-Września motorway section was made between July and November of 2001. Although the tests of melaphyre aggregates against grade and class requirements had confirmed that grits were the first class and grade according to the Polish standards, the motorway has been wearing rapidly with the first repairs being carried out as early as 2003. The motorway surface has been excessively worn and looks as if it were used for at least 5 years. The paper explains why the motorway surface has been worn so rapidly.

Key words: motorway, ,melaphyre grit, weathering

INTRODUCTION

The surface layer of the Konin-Września motorway section was made during the period from July to November 2001. The layer was made with granulated aggregate 0-20 mm in diameter from Borówko and Grzędy melaphyre quarry, bounded with modified bituminous mass. The tests of melaphyre aggregates against grade and class requirements had confirmed that the grits were the first class and grade (Chrzan, 1997; Wysokowski, 2000/2001) according to the Polish Standards (PN-11112:96, PN-11110:96, PN-EN 1097-2).

The binding layer of asphaltic concrete made and tested on samples that were taken from the completed motorway also conformed to the standard requirements according to Polish Standards (PN-S/96025, PN-74/S-96022). Also, the adhesion of asphalt to the melaphyre grit conformed to the standard (PN-84/B-6714/22).

After the wintertime, in spring 2002, on the surface of the roadway, distinct signs of scaling and weathering were observed on the surface of larger melaphyre grit grains. In August 2002, it was found that the number of weathered grains had

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increased and some of them lost their compactness and disintegrated (Ruttmar, 2002). Between September and November of 2003, due to the above reason, which threatened the safety of moving vehicles, partial repairs were carried out covering 1600 square metres. The surface of motorway has been excessively worn and looks as if it were used for at least 5 years.

In this paper, it is explained why the motorway has been worn so quickly.

ANALYSIS OF DECREASE OF ASPHALTIC CONCRETE STRENGTH OF MOTORWAY A2 BINDING LAYER IN RESPECT TO MINERAL COMPOSITION OF ROCKS

DESCRIPTION OF MELAPHYRE DEPOSIT (Radziszewska-Jargosz, 1982; Szuszkiewicz I Król, 1988)

The melaphyre used for road construction come from deposit that was formed from basalt-type volcanic rocks in the Permian period around 350 mln million years ago. The volcanic rocks created trachyte-basalt, trachyte and tuff-type rocks. The melaphyre deposit is exploited in the quarries of Borówno, Grzędy and Rybnica Leśna. The trachyte basalts are of two types. The first one includes rocks coloured cherry-brown, cherry-brick and grey-violet. They have chaotic structure and aphanitic texture. Cracks are filled with the ferruginous and carbonate substance.

The second type is the rock ranging from grey-brown through grey-greenish to nearly black in colour. The structure is aphanitic and the texture is dense. Course-grained breccia of chaotic texture is also found. Volcanic spalls are cemented with the ferruginous and carbonate binder. The rock spalls are grey-brown and are of various size and aphanitic structure.

The tuffs are cherry-brown, have aphanitic structure and chaotic, texture. They disintegrate into irregular small blocks. Numerous quartz grains and carbonate veins are visible.

The sedimentary rocks are cherry-brown in colour and have fine-grained structure with directional texture. They disintegrate into irregular small blocks. Rocks of lava-mudstone fraction are found in the deposit which may have been the result of lava flooding during volcano eruption of weathered layers from the previous outflow.

The exploited rock is melaphyre-type aphanite lava ranging from dark grey to black in colour; solid but intensely cracked rock. The cracks make it vulnerable to weathering and 0-10 mm sized rock is dumped as waste (Kancler, 2002a) in amount of 21% at Borówno quarry, and 15% at Grzędy quarry (Kancler, 2002b). This gives evidence that malaphyre in the Borówno quarry is built from minerals that are subject of stronger weathering than that in the Grzędy quarry. The melaphyre (Kancler, 2002a and 200b) in both quarries is built from minerals that disintegrate under the influence of temperature, air and water.

PETROGRAPHIC ANALYSIS OF MELAPHYRE

The petrographic analysis of Grzędy deposit (Radziszewska-Jargosz, 1982) shows that plagioclases are found in the form of small phenocrysts. Feldspars undergo the process of sericitization and carbonization, and weathering processes lead to kaolinization. The ferruginous substance infiltrates the strips of plagioclases. Dark minerals were completely transformed. They were replaced with hydrated iron oxides accompanied by concentrations of carbonates, and in place of olivine there is a substance that is difficult to identify. Chlorite is rarely found. Pores are refilled with calcite accompanied by ferruginous pigment. In the pores there are concentrations of chalcedony. Concentrations of limonite are often found. Apatite, ilmenite and magnetite are accessory minerals. Volcanic glass, brown or orange in colour is also found. The rock groundmass consists of heavily carbonatizated glass, perches of plagioclases, ash fraction and iron oxides.

PROPERTIES OF MINERALS FOUND IN THE MELAPHYRE DEPOSIT [Bolewski I Manecki, 1993; Bolewski, 1972; Chrzan, 1997)

On the basis of geological documentation [8] on melaphyre deposit of the Borówno quarry, the mineralogical composition of fresh samples collected from the deposit is as follows: plagioclase 45.2-75.0 %, pyroxene 0-5.81 %, oxides and hydroxides 6.1-38.7 %, carbonates 0-8.3 %, chlorite 0-4.7 %, clayey minerals 0-5.2 %, quartz 0-3.0 %, iddingsite 0-9.7%, and unidentified 0-1.0 %.

Feldspars (plagioclases)

Plagioclases are sodium-calcium (Ca, Na) feldspars. Also found, there are potassium (K), white (Na) and lime (Ca) feldspars. The feldspars, more generally called aluminosilicates, form mixed crystals where K, Na, and Ca combined in different proportions among themselves and silica. Specific density of feldspars ranges from 2.5-2.8 Mg/m^3. With an increase of calcium (Ca) content, plagioclases disintegrate easier into clay minerals, in particular into kaolinite. The kaolinization of plagioclases is commonly known among geologists. The weathering product of plagioclases that are rich in calcium is also calcite ($CaCO_3$) coloured yellowish or brown. Kaolinite is the basic component of clayey minerals coloured red or brown and with specific density 2.5-2.6 Mg/m^3, which is found in the form of dense or scaly concentrations. Wet kaolinite becomes plastic.

The clayey minerals also include montmorillonite with specific density 2.0 Mg/m^3 and in the form of white dense or scaly concentrations, which intensely swells in water, and decolourises denatured alcohol or methylene blue solution.

Bentonite of the same colour and density behaves in a similar way; it is a mixture of clay minerals of the montmorillonite group.

Feldspars also undergo the processes of sericitization and carbonisation. From the potassium feldspars, sericite is formed of scaly structure, and chlorite of scaly structure.

Micas, such as muscovite, are found in the form of lamellas or lamella concentrations. These are minerals, formed of Na, K, Al, Fe, Mg, Si elements in various combinations. Mica is found in the magma rocks rich in SiO_2 such as granites. In sedimentary rocks, it transforms into hydro-muscovite. They are green and black, yellow or brown in colour.

Sericite has the form of tiny scales and is created at low hydrothermal temperatures. Sericitization takes place when feldspar turns to sericite.

Pyroxenes

Pyroxenes belong to aliphatic silicates and aluminosilicates. Group 1 consists of Mg-Fe, Mn-Mg, Ca, Ca-Na, Na-type pyroxenes. Pyroxenes is an important group of rock-forming minerals, which are created at high temperatures and at low water pressure. They are components of magma rocks and metamorphic rocks. They are not resistive to climatic factors, therefore are rarely found in sedimentary rocks.

The colour of pyroxenes depends on iron and titanium content. At small content, it ranges from white to greenish, with larger content, it is olive, brown or dark green. Orthorhombic pyroxenes form the isomorphous series from Mg to Fe, with distinguished enstatite, bronzite, hypersthene, ferrohyperstene, eulite. Monoclinic pyroxenes include four minerals creating a diopsyde-hedenbergite series built from Ca, Mg, Fe, SiO_2.

Iron oxides and hydroxides

Hematite (Fe_2O_3) has a cherry colour in variety of shades. It is insoluble. It may instantly oxidize in weak acids. In small quantities, it is found in magma rocks, especially those coloured red. It is a component of hydrothermal formations.

Geothyte (FeOOH) ranges from brown to is red in colour. It is a product of hydrothermal activity at low temperature. It often occurs as an admixture colouring other rocks and in melaphyre vacuum. It is a product of iron mineral oxidation.

Carbonates

Calcite ($CaCO_3$) is ranging from white to brown in colour. A component of sedimentary rocks, such as limestone, chalk, marls. It is formed in the hydrothermal activity zone independently fills rock crevices.

Aragonite ($CaCO_3$) is from white to brown in colour and is found in granular or dripstone crevices of melaphyres and basalts. It is a mineral of hydrothermal zone.

Dolomite ($CaMg(CO_3)_2$) is a sedimentary rock mineral ranging from white to black in colour with density 2.8-2.9 Mg/m^3 and is found in granular or dense form.

Magnesite ($MgCO_3$) is from white to black in colour and is found in granular or dense form. It is created through metamorphism of rocks. It fills crevices in serpentinites and is a product of hydrothermal activity.

Siderite ($FeCO_3$). Its colour is ranging from grey to brown. It is a product of warm hydrothermal water activity. It turns to iron hydroxides under the influence of water and oxygen.

Chlorites

Chlorites are minerals of hydrothermal zone and may crystallize in ultra-alkaline rocks as primary minerals. They are also found in weathering zone. It is a group of package silicate minerals, containing mainly magnesium and iron, and magnesium and chromium.

They also form chlorite slates – metamorphic rocks. Chlorite is a mineral of magnesium and iron, and is dark green in colour.

Clayey minerals

Clayey minerals is kaolinite ranging from white to red or greenish in colour. It is commonly found as a product of feldspar and aluminosilicate weathering. It becomes plastic under the influence of water.

Illite. It is a products of feldspar and kaolin weathering. Commonly found as components of clay rocks such as kaolin, clay, silt, and rocks that are formed in sea environment. These minerals are chemically related and do not differ in macroscopic properties. Their colour depends on iron admixture.

Montmorillonites. They form dense wax concentrations. Their colour depends on iron admixture and ranges from white to black-brown. They swell when flooded with water. They discolour methylene blue solution. Components of sedimentary rocks and hydrothermal formations of low temperature. Montmorillonites are created as the products of magma glaze weathering in alkaline and heavily salted environment. Montmorillonite’s colour depends on iron content

Quartz SiO_2

Rock forming mineral, very durable, weatherproof. It may also be found as tridymite and cristobalite. Its colourless form is called mountain crystal, other forms are yellow, violet, black, pink, green.

Iddyngsite

It is a product of olivine metamorphosis. It has a lamellar structure. Its red colour suggests that it is a serpentine with high iron content.

A serpentine subgroup is formed by clay minerals similar to the kaolin subgroup. Mg serpentines include antigorite, lizardite and chryzotile with density 2.5-2.6 Mg/m^3. Serpentinization of magma rocks occurs at the temperature below 400 °C under the influence of water. As a result serpentinite minerals which are MgO rich (olivine) and Al_2O_3 poor rocks are formed.

Amphiboles

Amphiboles are important rock-forming ribbon silicates and aluminosilicates minerals. Four groups of amphiboles are distinguished: 1) Fe-Mg-Mn, 2) Ca, 3) Na-Ca, and 4) Na. Amphiboles also include the hornblende group usually containing Na, Ca, K, Fe, Si, Al, SiO_2 ranging from light green to dark green in colour, with density 2.9-3.4 Mg/m^3. Horneblende usually occurs in magma rocks of any type from neutral, acid to alkaline.

OXIDATION UNDER ALKALINE CONDITIONS FOUND ON THE MOTORWAY SURFACE AND FORMATION OF NEW MINERALS (Bolewski I Manecki, 1993; Bolewski, 1972)

Plagioclases

According to the geological documentation of the deposit, there is from 45.2 to 75.0 % of plagioclases in melaphyre. These minerals are sodium-calcium feldspars, which with increasing calcium content, due to the weathering process, disintegrate into kaolin, which is a clay mineral.

It may not be ruled out that the weathering process in melaphyre grits, which has begun in the deposit, will continue on the surface of the motorway.

Pyroxenes (0-5.8 %)

Pyroxene minerals are not weatherproof. It is visible in Table 1.

Table 1. Content of minerals in samples taken for the Borówno quarry (Strasser, 2002)

	Weathered samples		Fresh samples	
	BO-4	BO-2	BO-3	BO-5
(Clayey minerals, montmorillonites)	60	50	32	13
Quartz	7	3	-	-
Plagioclases	13	45	58	76
Calcite	15	-	-	-
Geothite	5	-	-	-
Amphiboles	-	2	-	-
Pyroxenes	-	-	10	11

Oxides and hydroxides

These kinds of minerals occur in melaphyre with the content ranging from 6 to 39%. They may be iron compounds, which are components of magma rocks. Geothyte (FeOOH), a product of iron mineral oxidation, may be also found, which is also a product of low temperature hydrothermal activity. The minerals undergo considerable oxidation during one-year period (visible change in aggregate colour in the storage yard). The impact of their content on grit strength in the motorway surface is difficult to determine. However, the iron oxidation process certainly reduces the strength of rock components in asphaltic concrete.

Carbonates (0-8.3 %)

Carbonate minerals such as calcite, aragonite, dolomite and magnesite are products of hydrothermal formations and are found in melaphyre. They do not undergo oxidation or weathering process. However, syderyte ($FeCO_3$) is a product of hydrothermal waters, and under the influence of water and oxygen, that is possible on the motorway surface, it transforms into iron hydroxides. It can also contains admixtures of clay minerals and calcite. That carbonate mineral may have a great impact on the strength of grits in the motorway surface.

Chlorite (0-4.7 %)

Chlorites are minerals of hydrothermal zone and ultra-alkaline magma. Chlorite is a manganese and iron mineral coloured dark green. It does not undergo oxidation and weathering. It has no influence on the reduction of grit strength of the motorway surface.

Clay minerals (0-5.2 %)

Clay minerals include kaolinite, which is a product of weathering of feldspars and plagioclases that make up 75% of the deposit. Feldspar weathering products also include illite and hydro-muscovite. Montmorillonite is a product of magma glaze weathering in alkaline and heavily salted environment. The natural weathering process that has begun in the deposit may have accelerated in alkaline environment during the winter usage of salt for motorways and roads. These minerals swell when submerged in water. Their colour is red-brown. Taking the above into account, it must be stated that the clay minerals has great impact on the strength of grits in the motorway surface.

Quartz 0-3.0 %

Very hard mineral, weatherproof. It does not reduce the strength of grits in the motorway surface. A small content in the rock causes the rock not to be resistant to weather conditions.

Iddyngsite (0-9.7% - product of olivine serpentinization)

Iddyngsite is a serpentinite with a high iron content. It is a clay-type mineral and it has great impact on the strength of grits in the motorway surface.

Unidentified minerals (1.0 %)

They may not have positive impact on melaphyre strength.

The above data shows that the following minerals have unquestionable impact on the reduction of melaphyre grit strength:

- plagioclases (content 45-75 %),
- carbonates (content 0-8 %),
- clay minerals (content 0-5 %),
- pyroxene with content (0-6 %).

This makes from 45 to 94 % of minerals vulnerable to weather conditions. Therefore, they have considerable impact on the reduction of strength and compactness of melaphyre grit applied to the upper layer of the motorway surface.

Reactions of mineral hydration are as follows:

1) Orthoclase

$$2KAlSi_3O_8 + nH_2O \rightarrow \underset{\text{(kaolinite)}}{H_2Al_2Si_2O_8 \text{ x } H_2O} + 4SiO_2 \text{ x } nH_2O + 2KOH$$

$$2KAlSi_3O_8 + CO_2 + nH_2O \rightarrow \underset{\text{(kaolinite)}}{H_2Al_2Si_2O_8 \text{ x } H_2O} + 4SiO_2 \text{ x } nH_2O + K_2CO_3$$

2) Orthoclase

$$6KAlSi_3O_8 + 4H_2O + 4CO_2 \rightarrow \underset{\text{(illite)}}{K_2Al_4(Si_6Al_2O_{20})(OH_4)} + 12SiO_2 + 4K^+ + 4HCO_3^-$$

3) Albite

$$4NaAlSi_3O_8 + 6H_2O \rightarrow \underset{\text{(kaolinite)}}{Al_4Si_4O_{10}(OH)_8} + 8SiO_2 + 4Na^+ + 4OH^-$$

4) Potassium feldspar

$$4KAlSi_3O_8 + 4H_2O \rightarrow \underset{\text{(kaolinite)}}{Al_4(OH)_8Si_4O_{10}} + 4K_2O + 8SiO_2$$

MINERALOGICAL TESTS

The testing of samples collected from the Borówno quarry was carried out both on fresh solid, not weathered samples, and on weathered, low-cohesion samples in a laboratory in Austria (Strasser, 2002). The petrographic study (Strasser, 2002)] determined, as it is specified in the Polish geological documentation of Borówno melaphyre deposit (Szuszkiewicz i Król, 1988), that in the melaphyre there are clayey minerals and plagioclases wich undergo weathering into silica and clayey minerals. The contents of plagioclases in both cases were very high in samples from Borówno

(58 to 76 % according to Austrian study and from 45 to 75 % according to the Polish study).

Samples were collected from the Borówno quarry and were designated as:

- BO-2 -brittle grains taken from key aggregate 16/22, brown, able to be ground with fingers,
- BO-3- sample taken from fresh grain,
- BO-4- sample able to be ground with fingers,
- BO-5- sample from 2nd production level, BO-6- sample from 2nd level at the road.

In brittle and weathered samples, higher percentage of clayey minerals was found, which form as a result of plagioclase disintegration. During the weathering process, clayey mineral such as kaolinite and quartz are formed from plagioclases (potassium feldspars). Hence, an average content of clayey minerals, quartz and plagioclases in weathered samples BO-4 and BO-2 equals to the average sum of clayey minerals and plagioclases in fresh samples BO-3 and BO-5.

Weathered samples:	Fresh samples:
BO-4 = 80%	BO-5 = 89%
BO-2 = 98%	BO-3 = 90%
average 89.0%	average 89.5%

Table 1 shows that montmorillonite and quartz are formed from plagioclases. In alkaline environment montmorillonite is formed, and kaolinite is formed in the acidic environment. In the weathering process, iron hydroxides are formed (such as geothyte), which is not present in samples taken from the fresh rocks. The study shows that pyroxenes also disintegrate into iron hydroxides and calcite, which were not present in the fresh samples.

On the basis of tests and analysis, it may be stated that melaphyre and its minerals, used for the top layer have undergone oxidation and weathering processes that cause rapid disintegration of melaphyre and compactness of the motorway top layer.

FINAL DISCUSSION AND CONCLUSIONS

The petrographic analysis shows that melaphyre is built from the minerals, which undergo weathering and oxidation under the influence of water, temperature and air, and therefore it should not be used for top layers of roads and motorways.

In the melaphyre deposit of Borówno quarry, the intense and developed processes of weathering and oxidation take place, which is obvious, considering 21% of waste being dumped. This 21% of waste confirms the petrographic appearance of the rock in which there are minerals not resistant to weathering and oxidation processes. The rock is not weatherproof, and this is a reason of rapid disintegration of melaphyre grits contained in asphalt. The mineralogical analysis of the rock applied to asphalt mass makes it possible to explain the reason of rapid deterioration of the new motorway surface. It can be said that the rocks containing more than 45% of minerals that are not resistant to oxidation and weathering processes despite conforming to all standard requirements should not be used for the top layers of motorways. This type of rock includes melaphyres and gabbros.

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Polish Standards

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PN-B-11110 Surowce skalne lite dla produkcji kruszyw łamanych stosowanych w budownictwie drogowym.

PN-84/B-06714/22 Oznaczanie przyczepności do bituminów.

PN-EN 1097-2 Badanie mechanicznych własności kruszyw.

PN-S/96025 Badanie mieszanek mineralnych i betonów asfaltowych.

PN-74/S-96022 Badanie masy z betonu asfaltowego przy układaniu i wykonaniu.

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W artykule podano skład mineralny melafiru i omówiono trwałość zawartych w skale minerałów pod kątem wpływu czynników atmosferycznych. W wyniku analizy stwierdzono, że badany melafir zawiera ponad 50% minerałów nieodpornych na czynniki atmosferyczne. Zaistniałe szybkie zużycie powierzchni górnej warstwy autostrady wytłumaczono nadmierną zawartością minerałów szybko ulegającym przemianie w warunkach panujących na powierzchni górnej warstwy autostrady.