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CLAY IN ROCKS

David Woodward, Alan Woodside and Joe Jellie
University of Ulster, Highway Engineering Research Group,
Newtownabbey, Co Antrim BT37 0QB, UK

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Abstract

This paper considers the effect that clay in rocks has on the performance of asphalt materials. The distinction between clay and dust is first emphasised. The processes involved in the formation of clay minerals are summarised. This considers the different types available, their properties and distribution within differing types of rock. The relationship between harmful types of clay and specific rock types is given. The paper then describes standard and non-standard methods that have been developed to determine the presence of clay minerals and assess their effect on aggregate and asphalt properties. The paper concludes by emphasising the need to consider the influence of clay minerals when trying to predict the performance of aggregate and asphalt materials used in highway construction.

What is clay?

In highway engineering the general term clay is used to describe very small particles that may have a detrimental effect on the performance of unbound and bound materials. In terms of grain size, Table 1 shows that clay refers to particles less than 4μm in diameter. However, it is very important not to assume that the term clay is the same as dust.

In highway engineering, dust is used to describe the finest size of material found in crushed aggregate i.e. <0.075mm, which is typically found as coatings on aggregate particles or is used as filler in mixes. In mineralogical terms, clay particles are typically less than 2μm but may be 10μm or more in length. The important difference between dust and clay is that there are different types of clay depending on geological occurrence and subsequent processes. Each type has characteristic properties and in relation to the performance of asphalt materials these inherent properties need careful consideration.

Some types of clay are considered to be relatively inert and have no effect on performance whilst the presence of even small amounts of others can significantly effect the performance of aggregates and bituminous materials. The harmful types are susceptible to the effects of moisture, i.e. they may absorb water and swell causing a range of problems from de-bonding of bitumen coatings to the break-up of aggregate particles due to the repetition of expansion and contraction processes.

Particle Size (mm)	*Sediment Class*	*Sedimentary Rock*
>256	Boulders	
256 – 64	Cobbles	
64 – 4	Pebbles	Gravel, conglomerate
4 – 2	Granules	Breccia
2 – 0.125	Sand	Sandstone
0.062 – 0.004	Silt	Mudrocks
<0.004	Clay	Mudrocks

Table 1 Grain-size scale for sediments and sedimentary rocks

The main types of clay mineral

Clay minerals form part of a subclass of the silicate class of minerals known as the phyllosilicates. The silicates are the largest and most complex group of minerals. Approximately 30% of all minerals are silicates. Geologists estimate that 90% of the Earth's crust is made up of silicates. The basic chemical unit of silicates is the SiO_4 tetrahedron. These combine to form six types of structure; single units, double units, chains, sheets, rings and framework structures. The structural arrangement of the tetrahedrons is what classifies the six silicate subclasses and what distinguishes their properties.

In the phyllosilicate subclass, rings of tetrahedrons are linked by shared oxygens to other rings in a two dimensional plane that produces a sheet-like structure. The typical crystal of this subclass is therefore flat, platey, book-like and displays good basal cleavage. The sheets of tetrahedrons are connected to each other by weakly bonded cations and often have water molecules trapped between the sheets. The clay minerals are distinct from other phyllosilicates by having large percentages (often 70-90%) of water trapped between the silicate sheets. Much of the water within clays is not free pore-water but contained in the lattice of the clay minerals and adsorbed onto their surface. To expel this water temperatures of greater than 100^oC are required.

There are four main groups of clay minerals:

- The Kaolinite Group - the general structure of the kaolinite group is composed of silicate sheets bonded to aluminium oxide/hydroxide layers referred to as gibbsite layers. The silicate and gibbsite layers are tightly bonded together with only weak bonding existing between the s-g paired layers.

- The Montmorillonite/Smectite Group - this group has several members which differ mostly in chemical content and the amount of water they contain. The structure of the group is composed of silicate layers sandwiching a gibbsite layer in a s-g-s stacking sequence. The varying amounts of water molecules lie between the s-g-s sandwiches.

- The Illite Group - this group is basically hydrated microscopic muscovite mica. The structure is composed of silicate layers sandwiching a gibbsite layer in a s-g-s stacking sequence. The variable amounts of water molecules would lie between the s-g-s sandwiches.

- The Chlorite Group – the structure of this group is composed of silicate layers sandwiching a brucite layer in an s-b-s stacking sequence. However, there is an extra weakly bonded brucite layer in between the s-b-s sandwiches, which gives the clay an s-b-s b s-b-s sequence. The variable amounts of water lie between the s-b-s and brucite layers.

Physical characteristics of clays and their effect on asphalt mix properties

Clays have very distinctive characteristics that are important when considering their effect on aggregates and bituminous materials:

- *They form microscopic to sub microscopic sized crystals* – because they are so small they have a large surface area and so even relatively small amounts of the expansive types can have a significant effect on mix properties. Also, due to their small size, simple grading to determine the "percentage dust" i.e. <0.075mm content, can give a misleading indication of the amount present.

- *They can absorb water or lose water* – this can cause unexpected aggregate mass loss or gain. For example, this may affect the calibration process for the Ignition test used to determine asphalt mix composition.

- *When mixed with limited amounts of water they can become plastic* – this can have serious consequences on the performance of unbound layers within the highway structure.

- *When water is absorbed they may expand as the water fills the spaces between the stacked silicate layers* – this can have a number of effects on performance. For example, continued repetitive wetting / drying processes can affect the aggregate / bitumen bond. Expansion of the aggregate particles could cause the asphalt material to swell affecting its stiffness and fatigue characteristics.

Most studies have shown that basic aggregates such as basalt are typically most prone to these problems. This has often been caused by breakdown of chemically unstable minerals such as olivine and volcanic glass to highly absorbent secondary clay minerals such as chlorite, iddingsite and smectite. The presence of these secondary clay minerals is detrimental to the performance of aggregate.

Where a significant quantity of unsound aggregate is present in a bitumen-bound material, break-down of the aggregate or the aggregate / bitumen bond may occur under the combined action of moisture and applied stress. The term unsound infers a material that degrades or breaks down easily, either due to mechanical action and / or weathering and / or reacts in a detrimental manner causing premature failure.

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When does clay become a problem?

Clay minerals may be present as small-scattered distributions or unsound patches interconnected by veins of such minerals within the fabric of a rock mass. When quarried the resulting crushed aggregate will contain these minerals. If initially present in significant quantities, crushing may also concentrate their occurrence in the smaller aggregate sizes and as dust coatings on the surface of the aggregate. Therefore, there are two distinct types of problem which must be considered during testing;

- The presence of unsound clay minerals within the aggregate chipping.
- The presence of unsound clay rich dust coatings.

How do you determine whether you have clay?

It is important to understand that there is no single method that can be used to quantify the harmful effects of clay. The type of parent rock can give you a clue as to what types of problem may be encountered, i.e. a weathered basalt will probably contain harmful smectites whereas a greywacke will probably contain non-absorbent illites. X-ray diffraction will identify the types present but will not quantify how much or more importantly how it is distributed throughout the aggregate particles. For this you must analyse stained thin-sections.

In the thin-section shown in Figure 1, a methylene blue dye has been absorbed to form a localised concentration in the basalt aggregate. In terms of aggregate performance this localised distribution will for example, result in better micro-texture and so improve skid resistance. In Figure 2 the clay minerals are concentrated along lines of weakness within the basalt particle. Through time, expansion of the clays will cause this particle to break into four therefore causing particle loss, change of grading or loss of strength when wetted and subjected to traffic loading.

In Figure 3 a greywacke thin-section has been stained with blue dye. In a greywacke, the coarser sand and grit particles are held together by a fine grained matrix rich in clays. As can be seen in Figure 3, even though there may be a large proportion of clay minerals present as the binding matrix, they have not absorbed the blue dye indicating they are the inert, non-absorbent type.

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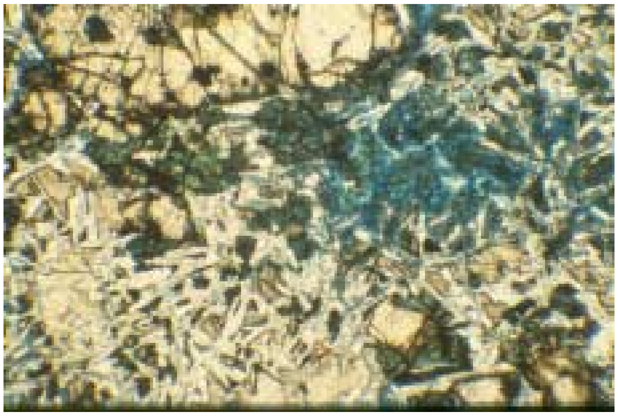

Figure 1 Stained basalt thin-section showing localised concentration of blue dye – the clay will improve surface texture eg PSV

Figure 2 Stained basalt thin-section showing localised concentration of blue dye – expansion of the clay will cause this aggregate to break into four pieces

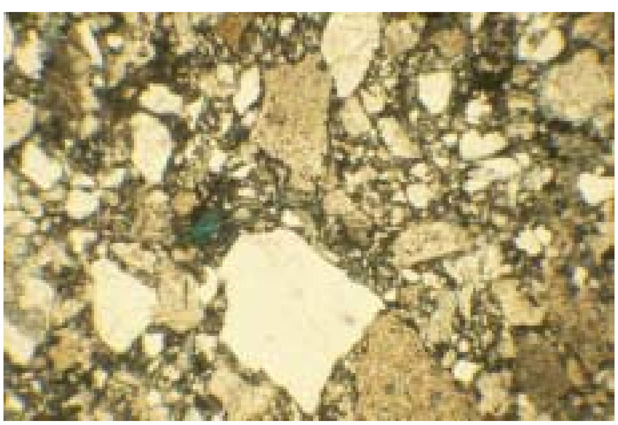

Figure 3 Stained greywacke thin-section showing very little absorption of the blue dye indicating little presence of harmful expansive clays

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Testing aggregate for clays

When it comes to testing aggregate for clay, it is important to consider that:

- They may be present as small-scattered distributions or unsound patches interconnected by veins of such minerals.
- When quarried the crushed aggregate will contain these minerals.
- Crushing may concentrate it as dust coatings.

There are a wide range of methods that may be used to test aggregate for the effects of clay. Many are non-standard and not found in BS 812. It should be pointed out that dry strength testing would not adequately highlight their presence. Rather, testing should exploit the characteristic properties of clay i.e. small size, susceptibility to moisture changes, expansion etc. Strength tests should involve soaking the aggregate in water to determine the amount of loss in relation to dry strength. Soundness tests such as soaking in salt solutions or freeze / thaw testing will exploit internal weaknesses within the aggregate.

One of the simplest methods of detection is using the methylene blue test. This method dates from the 1940’s and many versions have been developed. Cross testing of proposed CEN test methods CEN/TC 154 was carried out from 1993 to 1997. The methylene blue test was considered as part of this exercise.

Use of modified methylene blue tests

Woodward (1995) proposed two modified versions of the methylene blue test i.e. to assess samples of crushed chippings (MB_{cc}) and to assess dust coatings (MB_{dc}).

Use of the MB_{cc} test to assess the soundness of crushed chippings

This version of the methylene blue test is carried out on chippings that have been crushed to pass 0.075mm. 1g is added to 30ml of water and stirred continuously. Methylene blue dye is added in 0.5ml increments every 2 minutes with a spot test used to determine the end point.
Figure 4 shows the range of data from Northern Ireland Tertiary basalt and Silurian greywacke in the form of a box and whiskers plot (Woodward, 1995). This shows a considerable difference between the two rock types and is to be expected i.e. the method is detecting the presence of absorbent clay minerals in the basic igneous rock.

Woodward (1995) carried out linear correlation using the basalt methylene blue data and a range of BS 812 and proposed CEN test methods. The most promising correlations are shown in Table 2. These are significant at $p < 0.05$. As expected, the Methylene Blue test is strongly linked to basalt magnesium sulphate soundness and Water Absorption properties.

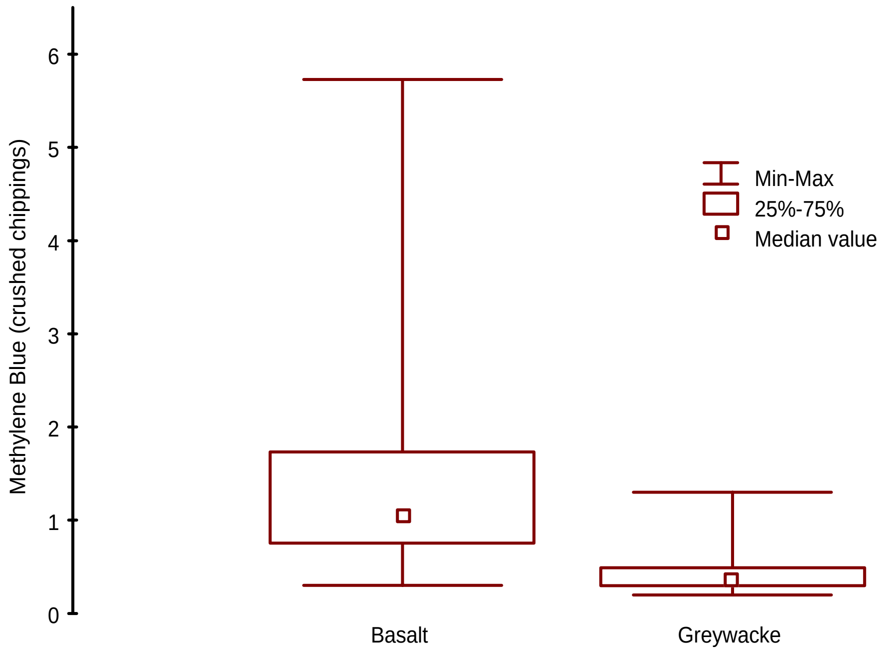

Figure 4 Box and whisker plot of MB_{cc} data for basalt and gritstone (Woodward, 1995)

	WA	*MSSV*
MB_{cc}	r = 0.89*	-0.79*

Table 2 Linear correlations determined for the basalt MB_{cc} test

Modified version of MB_{cc} to assess a heterogeneous aggregate

Many quarries produce a finished aggregate that consists of different types of material. For example, Figure 5 shows the range of basalts that are possible from a single basalt flow ranging from heavily weathered, vesicular to black sound basalt.

A modified version of the MB_{cc} test may be used to assess such heterogeneous types of aggregate e.g. sound basalt containing a small amount of vesicular and lateritic chippings. In this method, the process of obtaining the test sample and determining a final test result is more involved. The sample of aggregate is first sieved to exclude oversize and undersize particles and the nominal size of chipping recorded. The remaining material is then quartered to provide a specimen of 100 chippings.

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Figure 5 Range of basalt types possible from a single flow

The 100 chippings are visually graded into separate groups. The groups for basalt could include apparently unweathered and sound, vesicular and unweathered or weathered on at least one surface. For gritstones the groupings could include coarse grained, medium grained, fine grained, shale, discoloured, unsound material or any dyke material. A rough description of these groups is then recorded. The mass of each group is established and calculated as a percentage of the total mass. Representative samples of each group are then crushed so that it passes a 0.075mm sieve. Individual Methylene Blue tests are then carried out on each group. Table 3 shows a typical example for a basalt aggregate. The sample tested has a MB_{cc} value of 25% unsound material. Further development of this method would be to weight each of the found MB_{cc} values to produce an overall weighted value for the sample of chippings assessed.

Group	*Mass (g)*	*% of total*	*MB_{cc}*	*Remarks*
A	56.02	53.31	0.7	Appears sound
B	19.16	18.17	0.75	Similar to A but with a red tinge due to weathering of olivine's
C	3.61	3.42	0.85	Similar to B but much redder
D	14.73	13.97	1.85	Green colour with surface weathering
E	5.14	4.87	1.75	Vesicular and weathered
F	6.78	6.26	2.75	Heavily weathered - finger and thumb strength
Total	105.44	100		

Table 3 Example of a MB_{cc} test report for a heterogeneous aggregate sample

Use of the MB_{dc} test to assess dust coatings on aggregate

The presence of dust coatings on chippings may have a detrimental effect on any adhesive bond established with bitumen. Whilst the Specification for Highway Works recommends a total amount of permissible fines it does not recognise that certain types may be much more problematic than others. Certain types of dust are inert and un-reactive in the presence of moisture whereas others may expand so disrupting the aggregate / bitumen bond. The methylene blue test may be used to detect the presence of such types of dust. The method is very similar to that for chippings only the test is carried out on the actual dust surrounding the aggregate particles.

Limitations with the methylene blue test

Despite the widespread use, there are a number of basic problems with the methylene blue test. The most important is that it only gives an indication of the amount of clay minerals present, not the type. Its application to rock-types other than basalt is a problem. As shown in Figure 6 methylene blue values differ quite markedly between different rock-types. For example, greywacke values tend to be much lower and do not have the range exhibited by basalt. This is due to the types of clays associated with rock types. In Figure 6 it can be seen that the other rock types have much lower values. Rather than being applicable for all rock types it would appear to be rock type specific and highlights the problem of specifying acceptable limits that do not consider the issue of rock type.

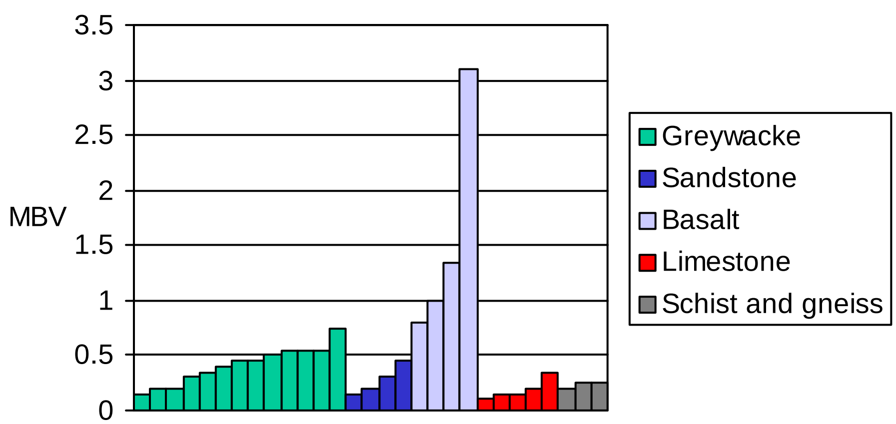

Figure 6 Range of methylene blue values for different rock types

Effect of clay on asphalt mix properties

The presence of clay either within the aggregate particles or as dust coatings can have a significant effect on asphalt mix properties. Again, the type of clay present will govern whether the effect is detrimental and leads to premature failure. Figure 7 shows two laboratory prepared samples of 30/14 hot rolled asphalt. The one on the left has been made using weathered unsound basalt whereas the sample on the right has been made using sound basalt. The samples were sliced using a diamond saw and subjected to five cycles of immersion in magnesium sulphate solution followed by oven drying.

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Figure 7 HRA samples containing unsound and sound basalt after five magnesium sulphate soundness cycles

As clearly shown, the salt solution has been absorbed by the unsound aggregate, causing expansion during drying leading to disruptive failure. The sound aggregate in the other sample has remained relatively uneffected. It was noted that the unsound test specimen also expanded during testing suggesting that the presence of clay in an asphalt mix may contribute towards repetitive expansion/contraction resulting in cracking of the asphalt layer.

Further samples were prepared and subjected to simple soaking in water. Figure 8 shows a typical sample containing a mix of sound and unsound coarse basalt aggregate after five wetting/drying cycles. Again, failure of the weathered unsound basalt particles is evident. It should be noted that the aggregate has failed internally and not at the aggregate/bitumen bond.

Figure 8 HRA sample containing unsound basalt aggregate that is failing due to repetitive soaking and drying

Figure 9 shows the effect of clay filler on asphalt mix stiffness for two SMA mixes. In both cases, the aggregate grading, aggregate type (greywacke) and bitumen content was kept constant. The only difference was the type of filler used, i.e. a lime-based filler and a weathered basalt or laterite filler with Methylene Blue values of 0.15 and 5.4 respectively. Their dry Indirect Tensile Stiffness Modulus (ITSM) was determined prior to soaking in water for 24 and 72 days after which their stiffness was again measured.

It can be seen that the SMA containing the lime filler remained unaffected due to soaking in water. However, after a small drop in value after 24 hours, there was an increase in value after 72 hours for the SMA containing the lateritic filler. This suggests that the clay in the unsound lateritic filler is absorbing water through the bitumen coating, starting to expand and so affecting mix stiffness. Clearly, this is affecting the method where a laboratory study may not accurately relate to in-service performance.

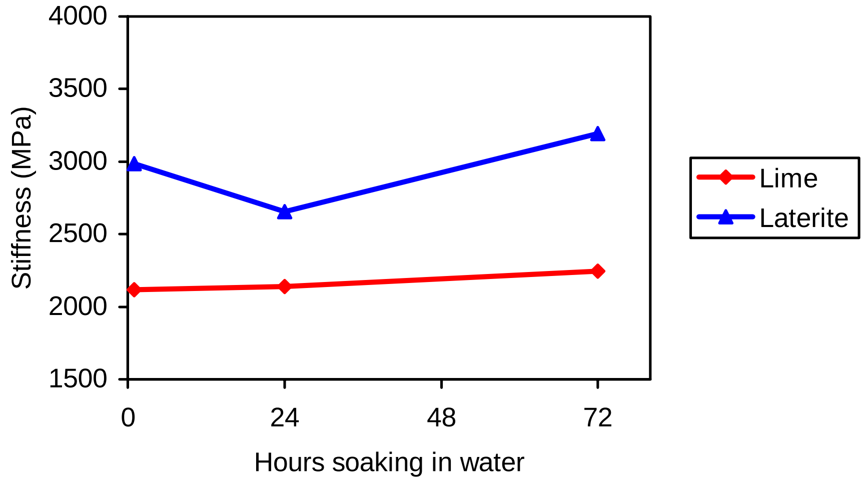

Figure 9 Effect of soaking in water on asphalt mix stiffness for two types of filler in SMA

Conclusions

This paper has considered the issue of clay in rocks and its effect on the performance of aggregate and bituminous mixtures. It has been shown that of the many types of clay present, not all are detrimental to the performance of asphalt mixtures. Some are inert and can be considered simply as filler, whereas others are moisture sensitive and need careful assessment. This assessment is not a simple process. Consideration has to be given to in-service performance i.e. is loss in aggregate strength the issue, or can the presence of expansive clays account for unexpected mixture properties such as increase in retained stiffness?

One of the simplest methods used is the methylene blue test. Of the many versions available, these can be modified to suit the conditions e.g. the assessment of dust coatings. The limited examples given clearly demonstrate that this method, like others used in highway engineering, are rock type specific and illustrate that caution should be given to national specification limits that do not account for this.

In conclusion, the presence of clay and its effect on the properties of aggregate and asphalt mix properties should not be under-estimated.

References

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