

Carbonation of lime and cement stabilized layers
in road construction

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SYNOPSIS

The problem of deterioration of lime, lime-slag and cement stabilized pavement layers during curing, before sealing and in service is partly ascribed to carbonation of the stabilizer during curing and subsequent exposure to the atmosphere before sealing. The surface disintegration problem can be prevented by better construction practices. However, the long term durability of cementation appears to be in question and further research is urgently needed.

SINOPSIS

Die probleem van agteruitgang van kalk, kalkslak en sementgestabiliseerde plaveiselae tydens verharding, voor verseëling en in diens, word gedeeltelik toegeskryf aan karbonering van die stabiliseerder tydens verharding en gevolglike blootstelling aan die atmosfeer voor verseëling. Die oppervlak disintegrasie probleem kan verhoed word deur behoorlike toepassing van beter konstruksiegebruike. Die vraag van die langtermyn duursaamheid van sementering word skynbaar bevraagteken en moet dringend verder ondersoek word.

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1. INTRODUCTION

Numerous cases involving the surface disintegration of mostly lime-stabilized or lime-slag-stabilized basecourses have come to the notice of the NITRR over the last 10 to 15 years. This disintegration usually occurs after a stabilized base has been left (whether primed or unprimed) for some months prior to sealing and is often remarkably coincident with the depth of penetration of the prime: the greater the depth, the deeper the damage. Often the problem was ascribed to soluble salt damage, over-compaction, weathering, or insufficient lime content, but in many cases the reasons for failure were not apparent or it was clear that one or more additional (unknown) factors were involved.

As some confusion has arisen over the roles played by the various factors in the deterioration of certain lime, lime-slag and cement stabilized materials, it has become necessary to make a brief interim statement on the matter until a more detailed report can be prepared.

2. INTERIM RESULTS

Early in 1982 NITRR investigated an occurrence of surfacing failure and upper basecourse disintegration over many kilometres of a two-year old road. It was established that an important contributory cause of failure was carbonation of the upper part of the marginal quality lime stabilized basecourse. Other factors so far identified are the fine grained nature of the non-plastic raw material (which in an uncemented state was considered unsuitable as basecourse) and heavy and overloaded traffic. The carbonation occurs during curing and subsequent exposure to the atmosphere prior to sealing, even under a prime coat. The carbonation process involves reaction of the calcium hydroxide ($\text{Ca}(\text{OH})_2$) with carbon dioxide (CO_2) in the atmosphere to form calcium carbonate (CaCO_3). This means that the lime reverts to the limestone from which it was made and is no longer available to complete the stabilization process and to preserve the cementing compounds. Although deterioration due to the loss of lime generally only presents itself after several weeks or months, usually in the form of surface disintegration of the primed or unprimed layer, it has been found that the carbonation process itself is very rapid, affecting a layer of about 1 mm thickness per day. All lime can thus be lost from the

top 5-10 mm of a layer after the usual one week of curing. After several months almost the whole layer can become carbonated. Laboratory tests have shown that carbonation normally weakens the material (Paige-Green, 1984) usually reducing the strength to about half of that of the uncarbonated material. These laboratory findings are supported by in-situ strength tests with a dynamic cone penetrometer (DCP).

Although the layer may be weakened by the carbonation, it may not disintegrate, the weakening may not be noticed, and it may still be judged strong enough to surface. In such cases this weak upper layer may only fail later under traffic, especially if the base is of marginal quality and the traffic is unexpectedly heavy or overloaded.

Carbonation is not confined to lime stabilized materials, but also occurs with cement. Although cement stabilized materials appear to be more resistant to surface disintegration or loss of cementation, they are not immune from it. As with lime stabilization, several cases of loss of cementation of the whole layer are also known.

The carbonation problem is being studied in detail in the laboratory, by investigation of existing roads, and during and after construction of lime-stabilized layers on specially prepared experimental sections. It has been concluded that carbonation of the top of the layer is not the fault of the lime, slag or cement, but that of poor curing practices. For example, the practice of curing stabilized layers by spraying them twice a day with water can be harmful as it may not retard and may even accelerate the carbonation process. It has also been found that application of a prime coat does not always result in effective curing. The best practical solution appears to be to seal the stabilized layer by constructing the next layer as soon as possible. In the case of a stabilized basecourse this would mean either priming with a bitumen* primer such as MC70 or MC30 within 24-48 h and laying the surfacing as soon as possible (at most two to three weeks after compaction), or using more efficient methods of curing which keep the layer genuinely continuously moist, i.e. a spray grade emulsion, plastic sheet, or moist

*Tar primes should not be employed on a stabilized layer until it has been cured for about 10 days.

sand. In the case of lower layers, dumping and spreading of the next layer (it need not be kept deliberately moist or be compacted) has been found to be an effective means of minimising carbonation. Carbonation appears to be most rapid at relative humidities of about 50 %, and to be minimal at very low and very high humidities. Carbonation is also therefore less under humid atmospheric conditions, and such special precautions may not be necessary in such cases. In these cases curing by means of water spraying several times a day may prove sufficient. Under dry conditions it is almost impossible to keep a layer continuously moist by means of water spraying, and continuous passes of a heavy, full water bowser may also be detrimental to the partially hardened layer. Payment for curing as a separate item in terms of the actual amount of water used is recommended. After about 7 days of moist curing a base should be primed and then surfaced as soon as possible (within four weeks of compaction). In this respect tar primers have proved inferior to bitumen primers when longer exposure is envisaged (Jamieson et al, 1979). However, early sealing of all stabilized layers, whether primed or unprimed, is recommended unless special precautions are taken. A normal application of a normal primer cannot be relied upon to act as a membrane for more than a few days and carbonation will recommence as soon as the upper part of the layer starts to dry out, whether it has been primed or not. A simple carbonation test using phenolphthalein can be used on site to show this. If the upper base below the depth of penetration of any prime fails to turn red, it should already have been surfaced*.

Another, more disturbing, aspect of the carbonation problem which is being studied is its effect on the long-term durability of stabilized materials used in road construction. Field and laboratory experiments have shown a marked decrease in the strength of some lime-stabilized materials after exposure to CO₂ and even to the atmosphere, even after two years in service. This might lead to deterioration of the basecourse if it is subsequently exposed to the atmosphere, for example due to loss of the surfacing, cracking, or simply due to excessive permeability of the surfacing. By analogy with concrete technology, it appears that both the stabilizer and the reaction products can become carbonated, leading to a

*Carbonation within the depth of prime penetration is also harmful, but is more difficult to see.

loss of the cementing bonds. There is also some evidence that this also causes a loss of density in the case of stabilized materials so that the performance of the stabilized material might actually be worse than that of the untreated material. Although the PI might remain low, in other respects the stabilized material reverts to an uncemented, granular material. Whether distress of the pavement will result presumably depends on the quality of this destabilized material, the density of the stabilized material, whether it has been dedensified, position in the pavement, traffic, ingress of water, etc. If these factors are favourable, no distress may occur; if not, distress may be observed soon after opening to traffic.

Recent observations indicate that stabilized layers (both lime and cement) carbonate from the bottom upwards after sealing at widely varying rates of about 3-50 mm/year, apparently due to reaction with soil CO₂. This means that some layers can be expected to become completely carbonated and to have lost cementation and density within 3 years. If these findings are confirmed, they indicate that a 150 mm stabilized layer has a limited life of 3-50 years. By this it is meant that cementation is not permanent, not that plasticity will increase, although there is even some doubt about this. The effect of the carbonation is to steadily decrease the thickness of the cementation. This in turn probably hastens traffic-associated cracking of the layer, which in turn will accelerate the carbonation of the rest of the layer via the crack surfaces. In the case of a stabilized subbase under a crusher-run, the subbase carbonates from both top and bottom surfaces at the above rates, as well as from the faces of any cracks.

The types of material which have so far been known to give surface disintegration problems are weathered dolerites, weathered basalts, poor quality calcretes and calcified soils, and Berea red sands. Premature loss of cementation from the bottom upwards has been noticed in all the above types of materials, as well as with laterites and weathered granite. There is reason to believe that this problem is not confined to any geological class of material. However, as the problem is aggravated by poor quality materials it can probably be minimised by paying greater attention to the durability of both the aggregate and the stabilized material than is customary at present.

While little has so far been published, research on the problem of carbonation deterioration of stabilized layers is continuing in the Soil Engineering Group who can be approached for further information.

It must be emphasized that the above findings do not indicate that one should not employ lime for stabilization, but rather that more attention should be given to proper curing of all stabilized layers, especially when stabilized with lime or lime-slag, but also when cement or cement-slag is used.

3. TESTING FOR CARBONATION

A simple test for carbonation (Netterberg, 1984) is to spray the stabilized layer with phenolphthalein indicator solution: if it does not turn bright red within a few seconds (i.e. the pH is > 9-10) the material has probably become carbonated, or the stabilizer was never present. If the untreated material (or that part of the layer which does turn red) does not effervesce with dilute hydrochloric acid (i.e. contains no carbonate), but the part of the layer which does not turn red does effervesce, it shows that the stabilizer was added, but has since become carbonated. In all the known cases of previously unexplained weakening or disintegration, whether lime or cement stabilized, the weaker or disintegrated materials have failed to turn red when so sprayed, whereas the sound materials did, even after ten years of service. It therefore appears desirable that all stabilized materials should turn red at all stages of their life if their best potential performance is to be achieved. In fact all such materials should probably possess a pH of at least 11, and possibly at least 12,0 throughout their life if their durability is to be assured. A few apparently still sound materials do not turn red when sprayed with phenolphthalein, even after up to 14 years of service. However, no comparative strength tests were carried out in these cases and the material may have been weakened. It cannot therefore be stated that such a material will be weakened or will disintegrate. However, at the present state of knowledge carbonation must be regarded as undesirable and potentially harmful, and should be prevented or minimised.

The problem of carbonation is not new and surface deterioration of stabilized layers due to carbonation has been recognised in the United States (Terrel et al, 1979). The problem is more serious and noticeable in southern Africa due to our making much greater use of stabilized base courses (often of decomposed rock) under thin surfacings here and to our practice of often leaving a stabilized layer standing for several months before covering with the next layer or seal. Most of our surface disintegration problems dating back some 20 years or more can probably now at least partly be ascribed to carbonation. It is now clear that carbonation was also a factor in the case and in the experiment described by Jamieson et al (1979).

A basecourse weakened by carbonation should not be surfaced if cementation was the aim. The carbonated layer must in such cases be removed by brooming or blading or the whole layer rejected. Careful visual inspection including tapping with a hammer or some other object is essential to detect weakening, and work is needed on the application of strength tests such as the Clegg hammer to this problem. It is not well shown by the DCP unless the weakened layer is relatively thick, and/or the penetration at every blow is recorded. Mechanistic analysis and HVS testing have also confirmed that weak layers (whether due to carbonation or other causes) within the cemented layer or on top of a cemented subbase under a cemented base are detrimental to the life of the pavement.

4. INTERIM RECOMMENDATIONS

It is difficult to make definite recommendations for the prevention of carbonation-induced durability problems at this stage. However, the following are recommended as interim measures:

1. Avoid the stabilization of poor quality materials when better materials are available which can be used unstabilized.
2. Pay more attention to durability assessment of both the unstabilized aggregate and the stabilized material. A guide to the testing of the raw material is available (Paige-Green and Sampson, 1983), although limits for stabilized materials are scarce. As an interim measure it

should be assumed that, if carbonation occurs, the aggregate will behave as if uncemented. Simple visual assessment ("pick and click") (Weinert, 1980, pp 122, 131-137) and when indicated secondary mineral (Weinert, 1980, pp 92-95, 123-130), counts and/or aggregate durability tests should always be carried out on weathered crystalline rocks (Weinert, 1980). Weinert's work was all on unstabilized materials, but he has suggested (1983, pers. comm.) that about 5 and 10 per cent more secondary minerals might be allowed for base and subbase respectively when stabilized (see his Fig. 11: The durability lines" - Weinert, 1980). Measurement of the ICL, preferably by the new gravel ICL procedure (NITRR draft Method CA 34) should always be carried out and, when judged necessary, the material checked for salts and acids according to the recommendations given by Netterberg (1979) or, when available, the new draft TRH13 on stabilization.

The stabilized material should be assessed by means of the wet-dry-brushing test (TMH1 Method A19). While no limits are available for local materials, it can be accepted that materials which pass the usual United States limits will probably perform well and that materials which fail badly will perform poorly. Other, possible, more rapid tests are the strength loss between unsoaked and soaked specimens (and the soaked moisture content), in particular after a rapid vacuum saturation technique (Dempsey and Thompson, 1973; Allen et al, 1977). The wet-dry-brushing test carried out at MAASHO compaction in MAASHO moulds on minus 19 mm material prepared as for the CBR test may be more applicable to local conditions of use and is suggested for parallel use with the standard test.

While it may be difficult to interpret the results of some of the above tests they will at least qualitatively indicate good and poor material and it is only by their wider use that we shall gain sufficient experience to set limits. As this experience will take any individual authority or firm a long time to gain, it is recommended that results of all durability testing together with the results of all ordinary testing, and when possible, a reference sample (10-50 kg), should be sent to the Institute. The

data will provide a picture of what to expect with different materials and the sample will be used to provide any supplementary data. It is hoped that a simple and quick test such as the vacuum saturated UCS or moisture content can be correlated with the wet-dry-brushing test from this data. While 50 kg of representative material is preferred, a smaller sample, even just soil fines prepared for Atterberg limits might prove valuable if comprehensive durability testing was carried out or if field performance data are available. Old data carried out some years ago relevant to existing construction are also solicited. The Institute is also prepared to help interpret the durability results and to carry out limited specialised testing.

It is also strongly recommended that representative samples should be taken from stockpiles or windrows of current construction and subjected to durability testing as discussed and data and a sample forwarded to the Institute. In due course this information will be correlated with the performance of the road and limits for the various tests formulated.

3. Do not economise on the stabilizer.
4. Obtain the highest density (i.e. lowest permeability) possible to limit the rate of possible ingress of CO₂ and water. At the same time avoid over- and delayed compaction, especially of fast-reacting materials which harden rapidly, which results in weakening of the layer (Netterberg, 1982). Local soils often contain natural non-plastic pozzolans which react rapidly with lime and which require compaction times akin to those of cement. In other cases the material may have to be modified first, allowed to cure for a few days (use PI tests to indicate when to compact) and then compacted, with or without added stabilizer. All laboratory testing must take these factors into account. Hardening rates also increase with temperature: for example, 5 hours at 40 °C might be about equal to about 48 h at 23 °C! Compaction times may therefore have to be drastically reduced in hot weather if adequate densities are to be achieved. Spray a membrane of heavy tar or bitumen on the

layer below in the case of important roads in order to prevent the upward ingress of soil CO₂, which is believed to be the major cause of loss of cementation. Even a heavy application of prime might be better than nothing.

5. Pay particular attention to good curing as already described, and seal or cover the layer as soon as possible.
6. Reseal in good time to prevent ingress of rainwater and atmospheric CO₂.

5. CONCLUSIONS

1. Field and laboratory evidence has indicated that carbonation of lime, lime-slag and cement stabilized materials is a significant problem in southern Africa.
2. Carbonation is not due to the stabilizing agents being out of specification, but a combination of poor material, poor construction practice, and possibly insufficient lime, as well as other factors.
3. Careful curing techniques are imperative for the successful use of lime, lime-slag and cement in stabilization to obtain the required performance and to avoid the building in of detrimental weak layers, especially on top of a basecourse.
4. Some doubt is cast upon the long term durability of cementation resulting from all stabilizers and further research is urgently needed.
5. Interim recommendations are made which should help to minimise the problem.
6. The Institute should be kept informed of all stabilization work involving marginal materials under construction or design at present, as well as any distress or failure which can be attributed even partly to carbonation.

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