Use of ferricrete for road construction in the South-Western Cape Province

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Synopsis
As a result of the tremendous variation of the properties of ferricretes found in the south-western Cape, especially with regard to their uses for roadbuilding, it was decided to conduct an in-depth investigation to establish the reasons and extent of this variation in formation. The investigation was conducted on the in situ material in two borrowpits located in a road contract, as also on the ferricrete in the road pavement extracted from these two sources. All the tests discussed were conducted in the normal site laboratory.

The discussion contained herein reviews the origin of ferricrete, the results of the tests conducted and some recommendations as to extraction and construction procedures. The tests conducted on the in situ ferricrete deposits included such aspects as the California Bearing Ratio, the Atterberg Limits, moisture contents, stabilization and the reaction of certain primes.

Introduction
Due to the extensive use of ferricrete for basecourse and subbase, on a 30 km road contract in the Hermanus area, it was essential to determine the properties and behaviour of this material for roadbuilding purposes.

Ferricrete has been used for road construction throughout the world for many years. Because of its generally superior qualities when compared with other natural gravels, it has been incorporated in the upper pavement layers. Although it is normal to group all ferric oxide cemented material under the banner of ferricrete these materials vary extensively in characteristics and properties. Amongst the more commonly used terminology the following are referred to: ferruginized soil, nodular ferricrete, honeycomb ferricrete, hardpan ferricrete and boulder ferricrete.

As most of the above were found on the abovementioned contract it was decided to conduct a number of tests, within the capabilities of a field laboratory, in an endeavour to gain a better understanding of the properties of ferricrete. Included in this paper are some observations made by the author and the solutions to some difficulties which arose.

Formation
In order to understand the variability of the properties of ferruginized material a brief discussion on the formation of this pedogenic material is included. Pedogenic materials are formed by alluvial processes in a soil profile which have altered the physical properties of the soil, in some cases to the extent of making it a potentially useful construction material.

The cementing agent in ferricrete is hydrated ferric oxide which may be combined with an alumina oxide. Ferricrete formation is dependent on the climatic conditions which prevail or prevailed in the area and is generally associated with a relatively humid climate. During the wet seasons the iron compounds are reduced to their more soluble ferrous state below the water table. In the dry season the iron compounds are drawn up towards the surface by the capillary rise from the water table. The ferrous compounds dehydrate and oxidize during the evaporation of the water and revert to the immobile ferric state. The ferric oxide is hence deposited in or around the upper layer of material, depending on its physical state at the time this action occurs.

In some instances the ferric oxide may be deposited on the surface of the ground, resulting in the formation of a crust of "hardpan ferricrete." The difference in mobility of the iron and alumina compounds explains why the high iron content ferricretes generally increase with depth of clayey soils, as the less mobile alumina remains combined in the form of clay below the ferricrete. In the tropics, where leaching is at a maximum, some iron is also lost in solution, resulting in an increase in the alumina content of the weathering complex and the subsequent formation of latelites.1

The colour of ferricrete varies considerably, even within a fairly restricted area. Colours range from yellow, brown and red to a deep purple and depend on the degree of hydration and the presence of elements such as manganese and titanium. Photographs 1 to 7 illustrate the degree of variance of colour and characteristics of the ferricrete deposits located in two borrow areas situated along the length of the road contract.

In this case the ferrous solutions originate from the shales, but it is not necessary for ferricrete to overlie shales as the ferrous oxides can be transported some distance before the alluvial process takes place — as on hill slopes where there is a downward flow of the subsurface water (see Fig 1).

This explains why ferricrete is frequently found over relatively impermeable sandstones which may be completely dry, even though the ferricretes are saturated with water. A common feature of this movement is found where ferricrete deposits occur in the sides of hills as this is the point where the water table is close to the surface (see Fig 1). From tests conducted it has been found that the further away the ferricretes are from the shales, the lower the PI values become. It was also noted that where deposits of ferricrete are relatively deep the PI values become progressively lower from the clay layer to the top reaches of the ferricrete sometimes even becoming non-plastic at the surface.

Properties
The properties of ferricretes varied considerably with regard to plasticity and linear shrinkage. In order to illustrate the variability of ferricrete within a single source, a number of field and laboratory tests were conducted, the results of which are discussed below.

California Bearing Ratio and compaction characteristics
Ferricrete produced a range of CBR values from very low, where clay was predominant and the ferricrete still very young and undeveloped, to extremely high values when crust ferricrete was encountered. The following results were obtained from ferricrete crushed from the same borrow pit.

<table>
<thead>
<tr>
<th>CBR at 100% Mod AASHTO</th>
<th>Mod density kg/m³</th>
<th>OMC Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>2360</td>
<td>11,9</td>
</tr>
<tr>
<td>184</td>
<td>2400</td>
<td>9,0</td>
</tr>
<tr>
<td>245</td>
<td>2486</td>
<td>10,6</td>
</tr>
<tr>
<td>320</td>
<td>2550</td>
<td>7,6</td>
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As discussed above the properties of the ferricrete vary with depth. This is best illustrated in Fig 2 where the CBR values were determined at different depths in the test holes. It can be seen that it is extremely important to sample the material in keeping with the use for which it is intended and the means of extraction from its source.

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The variability of the ferricrete dumped on the road from a single source produced CBR values ranging from 105 to 350 at 100% Mod AASHO density. This in itself causes difficulties when testing the compacted layers on the road, as maximum dry density and CBR values could not be assumed to persist over any acceptable length of road. It was found that to obtain the correct compaction at any point on the road a separate modified density sample had to be taken at each density hole. This involves a substantial increase in the work load in a field laboratory. (See photos 8 and 9 which show the variability in colour associated with variability of properties.)

Alterberg Limits

The iron oxides originate from a shale strata and are carried in solution either in an upward direction due to the capillary action or away from the original source by the movement of the subsurface water. The movement due to subsurface flow can be quite considerable in many instances and can carry the iron oxides some distance. The clay in the underlying strata in a ferricrete borrowpit is not carried upwards by the capillary action of the subsurface water to the same extent as the iron oxides. This results in a decrease of the plasticity index further away, both horizontally and vertically, the ferruginized material is located from the original shale source. With this in mind tests were conducted at various depths in trial holes. Results from a typical hole appear in Fig 2.

Having been faced with the problem of obtaining from a series of test holes, higher plasticity index values, which would normally have been rejected, corrective measures such as gridding and crushing were resorted to. It was established that by crushing the ferricrete a plasticity index of 12 was reduced to 8 after 24 hours and after compaction reduced even further to five. The explanation is that the parent material in the ferricrete investigated was sandstone which produces fines each time the material is processed, adding coarser grains of non-plastic granular particles into the -0.425 mm fraction which reduces the clay content.

Water content

The natural in situ moisture content can vary considerably within a ferricrete deposit depending on the host material. Values between 6 per cent and 13 per cent were observed. This determination of the moisture content was found to be sensitive to the method of drying. The methods used were a bare flame, a sand bath or an oven, with the last-mentioned giving the best results. Quick drying of ferricrete should not be resorted to as it is a relatively lengthy operation to extract all the moisture from the porous cavities in the ferruginized material. During certain of the tests conducted using a flame or the sand bath, latex water content of up to 4 per cent was recorded after the drying process. The drying procedure can thus affect the acceptance or rejection of a field density.

With the moisture problem in mind tests were conducted on an existing road built of ferricrete. The results are shown in Fig 3, these being the mean lines drawn through the results obtained. It was found that the moisture can be up to 4 per cent higher under the centreline of the road than in the adjacent gravel shoulder. Moisture contents of 11 and 12 per cent were recorded under the road where the optimum moisture content was only 7 to 9 per cent respectively. This was especially interesting as the tests were conducted during the dry season. Another interesting fact was that the maximum moisture content was never found just under the bituminous surface as is the popular belief but at about 200 to 300 mm below the surface.

Stabilization

A normal reaction when dealing with gravels which may include ferricretes, is to apply stabilization by means of lime or cement. With this in mind tests were conducted on ferricrete using both lime and cement with contents of 4.6 and 10 per cent, by mass. The results of the tests conducted are shown in Fig 4.

From the results it was found that there was no increase in strength by adding lime or cement; in fact a decrease in strength with increased stabilizing agent added was established. This tendency was particularly evident with respect to the lime stabilization. A possible reason for the lack of positive effect is that the lime and cement hydroxides may not react with the iron oxide, especially since the ferricrete samples used were only slightly plastic. It was found that the only positive contribution that the lime made to the samples tested was that the PI was lowered and the liquid limit increased marginally. This has also been verified by other authors on the subject.3

Fig 1: Formation of ferricrete on slopes

Fig 2: Comparison CBR with depth

Fig 3: Moisture content in existing roads

Fig 4: Comparison of stabilized ferricrete

Self-stabilization

It was found that if a pavement layer of ferricrete is left exposed for a length of time and subjected to several wetting and drying cycles it recementes into a hard crust. This recementing action takes place when some of the iron oxides go into solution during the wetting stage and precipitate out during the drying period. The tendency would therefore be to form a new bond between adjacent particles in the material.

To illustrate this phenomenon crushed unstabilized ferricrete was

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compacted at optimum moisture content into 152 mm concrete moulds, then stripped and sealed into watertight plastic bags. These cubes were then crushed at regular intervals for up to 100 days. The results have been presented in Fig 5. This clearly shows increased strength with time. Perhaps as a result of this phenomenon ferricrete constructed roads tend to display less problems of material fatigue with time than other roads, all things being equal.

In addition to the recementing action of ferricretes by the wetting and drying cycles, it has been found by some authors on the subject that there is a significant correlation between the ratio of the oxides of silica to iron and the mechanical strength. The iron oxides tend to replace the silica oxides during the formation of the ferricrete. The degree of replacement will determine the quality of the ferricrete and also the potential to recement effectively.

Penetration by bitumen and tar

Bitumen based products were observed to meet with varying results on a ferricrete basecourse. In the case of prime, better penetration appears to occur when the ferricrete is lightly watered prior to the spray. The reason for the lack of penetration can be traced to the fines that form part of the natural ferricrete which would be absent in the normal rock crusher run. Two types of prime were used on a section of ferricrete basecourse, namely MC30 and MSP1. The MC30 did not penetrate as well as the MSP1 but tended to bind the surface and not ravel under traffic. The MSP1 penetrated rapidly but kept the surface relatively soft.

A short section of ferricrete basecourse was not primed and a tack coat of 150/200 pen bitumen was applied with a slight increase in the spraying rate. In this case it was found that the tack coat did not penetrate and could easily be lifted like a carpet. It is firmly advocated that all ferricrete basecourse surfaces should be primed to avoid surface failure.

It is normal practice to allow the basecourse to dry before prime is applied. Due to the presence of the latent moisture which is inherent in the ferricrete this drying process cannot be strictly adhered to. The criterion adopted by the writer was that priming could be undertaken once the moisture content had dropped by more than 4 per cent below the optimum moisture content. There is a danger to this as moisture bubbles have been noticed under the first tack coat on a very hot day. To date the moisture bubbles have not extended through the full surface treatment.

A phenomenon which can possibly be directly related to this latent moisture is that when the moisture is drawn out of the ferricrete modulus it tends to lower the strength of the layer directly under the surface. This causes a tendency to slight punching of the chips into this layer under heavy traffic, thus reducing the average density of the chips. As bitumen application is directly determined by the ALD of the chip the resultant effective excess bitumen will cause bleeding.

Construction

Extraction from borrowpit

It is very important to stipulate the manner by which ferricrete should be excavated from a source. Although it is more economical to rip a borrowpit and load directly to the road, it is far safer to instruct a contractor to stockpile the material before use. Where stockpiling is encouraged the following benefits will be realized:

1. Better mixing of the variable ferricrete.
2. Better control on a more homogeneous material on the road.
3. Reduction of high PI values possibly avoiding additional processing.
4. The possibility of excavating greater depths of ferricrete which may exhibit higher PI values.
5. Greater confidence in the maximum use of a source especially where limited supplies occur.
6. Whether crushed or not improved gradings can be obtained.

As discussed above ferricrete varies considerably and in certain instances crushing may be necessary to produce a workable layer material. Normally gradings can be taken after crushing but these will vary considerably within a borrowpit, thus causing some problem in setting the crusher screens. It is strongly advocated that short test sections of crushed material be compacted on the road and gradings taken to establish the pattern of breakdown compared with the crusher gradings. This could influence the crushing pattern.

Fig 5: Crushing strength time for unstabilized ferricrete

Layers

Because of the nodular or rounded shape of some ferricretes, even after crushing, the tendency to segregate during mixing on the road is a problem. When laying ferricrete for the first time the grader operator should be open to a revision of his normal techniques to achieve a desired product.

When processing a layer of ferricrete it should be completed with the final cut while moist and fresh. If left for any length of time the layer surface becomes firm and will ravel excessively if trimming is attempted. Ferricrete is very sensitive to moisture change. The ideal is thus to compact slightly above the laboratory determined optimum moisture content. This induces lubrication within the material and higher densities are obtained.

Surface finish

Ferricrete will, if prepared properly, present a very good finished surface (refer to photos 10 and 11). Because of the stone shape the initial brooming should be completed during shushing, whilst the material is very wet. The final brooming can be done when dry but must be carefully controlled to avoid raveling. In some cases handbrooming must be resorted to in place of the mechanical broom to safeguard the surface finish.

Conclusion

Although the tests conducted were limited by the equipment available in a site laboratory the objectives of the investigation were realized. The aim was to illustrate the properties and variability of the group of materials called ferricrete and to highlight some of the problems which can occur when dealing with these materials.

To summarize the above the following should be borne in mind:

1. Ferricrete is a collective name for different materials which have been cemented by iron oxides and as such possess varying physical and structural properties which must be taken into consideration when testing a borrowpit.
2. A ferricrete deposit varies in properties both with depth and location within that deposit. Exploration must therefore be extensive.
3. Ferricrete deposits may be located some distance away from the original source of the iron oxide. If this occurs the plasticity index of the material may be very low.
4. If high PI values are encountered the engineer should investigate the possibility of reducing this by crushing or gridrolling. The addition of lime would assist in reducing the effect of the clay content.
5. Some ferricretes will recement if exposed to wetting and drying cycles. The strengths achieved are often far in excess of a comparable rock crusher run or natural gravel stabilized with cement.
6. Construction techniques must be adopted to suit the ferricrete material to avoid segregation in the layers.
7. Before specifying different types of prime, tests should be conducted to determine the penetration effects.
8. Ferricrete should not be surfaced without the use of prime.
9. Ferricrete bases should be allowed to dry out as much as possible before priming to avoid possible blistering of the prime by latent moisture in the ferricrete nodules.

Acknowledgements
I wish to thank Messrs Van Vuuren and Visagie of the Jeffares & Green Inc site laboratory at Hermanus for their time and effort in conducting the experiments necessary for the presentation of this paper. Appreciation must also be extended to Dr F Netterberg of the NITRR for his assistance and valuable advice. I would like to note that the views and observations contained in this paper are my own and, although not designed to cover the full spectrum of the ferricrete group of materials, must be viewed as an attempt to generate active thought on this subject.

References