

**NOVEL MEASURES TO ATTENUATE AGGRESSIVE SALT MIGRATION AND CRYSTALLIZATION
ON A NAMIBIAN AIRPORT RUNWAY PROJECT**

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Abstract

Upgrading the runway at Rooikop airport in Namibia encountered aggressive salt migration and crystallization, with salt from new pavement layers and the non-depleting salt source of the runway substrate. A novel three-pronged solution finally prevented further salt crystallization which was being triggered by diurnal temperature variations and sea mist conditions. It consisted of a deep penetrating prime on the subbase, bitumen rubber seal interlayer between subbase and base, and the elimination of construction water in the base course by the use of dry bound macadam (DBM), overlaid with prime, slurry and asphalt.

1. INTRODUCTION

The runway of Rooikop Military Aerodrome, near Walvisbay, Namibia, was recently upgraded to meet the ICAO 4F specifications, required for Airbus A380 operation. The facility is now known as Walvis Bay International Airport (WBIA). The airport is only 10 km from the coast and within the coastal sea-mist/fog belt. The runway was lengthened from 2134m to 3440m with turning loops at both ends and the width was increased from 30m to 60m. A 15m wide non-keel widening was added on either side the old runway. A new apron with a connecting taxiway was also constructed. This upgrade was let as a turn-key, design and construct project funded by the Kingdom of Spain. The main contractor was a Spanish Consortium (INEPADE), who subcontracted the civil works to a Namibian company. The Government development agency was the Namibian Ministry of Works, Transport and Communication (NMWTC) and the operator is the Namibia Airports Company Ltd (NAC).

The design pavement structure was for in-situ compaction of the pedocrete (gypsum) and windblown desert sand, then capped with a 300mm G6 pedocrete selected sub-grade (SSG) layer. In the following text all structural layer material classifications refer to the technical Recommendation for Highways (TRH14) (CSRA, 1985).

The design initially specified several cement stabilized sub-base horizons:

- Lower Zone 200mm C4.
- Lower layer of upper zone 125mm C4
- Upper layer of upper zone 125mm C2

After construction started, the non-availability of sulphate resisting cement in Namibia dictated subbase design changes to a 425mm thick mechanically modified pedocrete layer for the inner 30m wide new keel, while over the off-keel areas the lower design traffic allowed a reduction in subbase thickness to 200mm. The new subbase material is sometimes called gypcrete, and is a gypsum (hydrated calcium sulphate) cemented and hardened layer. The material used consisted of a mix of 50% gypcrete, 30% crusher run and 20% selected dune sand. This improved the grading modulus as well as the Plasticity Index (PI) of the combined subbase material. Extensive mechanistic analyses and deflection bowl parameter benchmark analyses (Horak, 1987 and Horak et al, 2009) showed that the mechanically modified material conformed to at least G5 requirements. Modulus of elasticity determination with a (non standard) triaxial testing test method was put forward as material evaluation control; and such testing proved that this material met the TRH14 requirements for a G5 or even better (Parrock et al, 2008).

The design specified a 150mm G1 quality base course to 88% apparent relative density (ARD), which was sourced from an adjacent hard rock quarry. The asphalt surfacing was specified to be a 70mm continuously graded hot mix asphalt.

2. MANIFESTATION OF SALT PROBLEM

2.1. Background

Rooikop Airport presents a long and well documented history of blistering and salt crystallisation. Netterberg described this airport in the 1970s as one of the worst salt crystallization problems observed in the world (NAC, 2004).

The original pavement had a triple seal constructed about 1962 over water bound macadam (WBM) over gypcrete subbase and all compacted with salt water. Netterberg (1963) noted that

“...It is of interest to note that calcium sulphate is more soluble in salt water than fresh water, and this factor may have accelerated the development of the “blisters”

Over the years a number of surface treatments and asphalt overlays were laid with varying degrees of success. In 1978 the main runway and taxiways received a 75mm asphalt overlay. Further blistering occurred, albeit to a lesser degree than before. Around 1985, successful attenuation of salt crystallization was finally achieved when a virtually impermeable bitumen rubber grit seal was applied. Monitoring and research work was done by the NITRR and CSIR for the South African Department of Defence.

When the present upgrade for the airport was let to design and construct by INEPADE in late December 2005, most of the evidence of salt crystallization on the runway was “obscured” by the 1985 bitumen rubber grit seal. Construction progress was affected by delays. The first INEPADE civil subcontractor partially finished the extensions up to SSG level before cancelling their contract. The semi-completed layer work was exposed to the elements for a prolonged period before negotiations with another Namibian civil contractor were finalized during 2006.

Towards the end of 2006 and early 2007 the aggressive diurnal temperature variations in the Walvisbay sea-mist/fog belt exposed the upward migration of salt and subsequent crystallization on completed subbase and trial sections of base course. A 2007 technical audit, done for Namibian Airports Company, found that the severity of the salt problem was a major concern and decisive action was needed to prevent the salt migration from developing further or continuing in future.

2.2. Salt migration and crystallization mechanism

Salt is inherent to the parent gypsum. Rollings et al (2003) describe the gypsum related material problem:

“... In arid conditions, calcium sulphate (CaSO_4) may accumulate intermixed with soil particles, or form as lenses or massive beds. It may be in the hydrated (gypsum), semi-hydrate, or anhydrite forms ...”

Weinert (1980) describes the occurrence in more specific terms as:

“... Soluble salts are most likely to be encountered in soils of the coastal areas and in arid and semi-arid regions, especially where N is more than 5, or as the decomposition products of sulphide minerals in a number of other rocks. In arid and

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semi-arid regions they may also be introduced into the construction material by compaction water in addition to rising from the subgrade...”.

Considerable work on salt damage to road surfacing and runways has been done in the past in southern Africa (Netterberg, 1979, Netterberg et al, 1974 and 2004; Blight, 1976, and Obiko, 2001). In order to understand the salt problem and associated damage mechanism, the description by Weinert (1980) follows:

“If dissolved, salt in the layers of a pavement may be carried upward by moisture. At some level, usually at the contact between the base and the surfacing, the moisture evaporates, especially during the day, and the salts are precipitated. During the night, this process may stop and some salt, but not all, may even dissolve again. This process is repeated over many days and nights and more and more salts is (sic) precipitated at the contact between base and surfacing. The accumulation of salts starts during the construction of the road and soon becomes noticeable. A white stain on or powdering of the prime, cracks filled with white material in thin surfacing, or surface blisters the interiors of which are filled with a white material, as well as a whitish layer on the surface of an uncovered base or unsurfaced shoulder, particularly at the edge of the surfacing, all indicate salt trouble is imminent. This is particularly the case if the white material also tastes salty. The salts eventually cause the disruption of the bond between surfacing and base or, where blisters have developed, potholing and stripping of the aggregate and loss of density and cohesion of bases, even if stabilized.”

Weinert (1980) describes the ease with which such salt crystallization can occur where sulphates are involved:

“... the process may be aggravated by the ease with which these salts hydrate. Some of these salts incorporate a considerable quantity of water in their crystal lattice. Most of the water is expelled again, i.e. the salts dehydrate, at relatively low temperatures. In the case of sodium sulphate (Na_2SO_4), for instance, this happens at about 33°C, and the water is absorbed again below this temperature. The process of hydration is associated with volume changes and, since the climate in Southern Africa is largely such that conditions of temperature and humidity required for the hydration and dehydration of most deleterious sulphates are achieved every day near the contact between base and surfacing, this volume change may in itself affect the strength of the bond between these structural layers”

2.3. Awareness of the salt problem

The NAC audit confirmed salt crystallization on all completed layers. The obvious source of salt was the gypcrete present in the sub-grade and mechanically modified sub-base layers and crystallization was visible on top of the completed sub-base layers as well as the recently completed experimental section of G1 base course. Salt was also present in test holes opened. As the G1 base course parent rock tested negative for soluble salts it is axiomatic that the salt observed in the base course was of migratory nature. Some of the triaxial test specimens of the constructed subbase material, at the site laboratory, showed evidence of salt crystallization. Close up inspection of gypsum nodules prior to mixing and compaction also showed clear evidence of salt crystallization.

The compaction of the 150mm thick G1 base course layer was required to be 88% ARD. This proved difficult to achieve. Laboratory tests and modelling done by Built Environment of the CSIR indicated that the particle form, measured in terms of rugosity, contributed to the compaction difficulties. Experimentation with bitumen emulsion as a compaction aid, roller combination and water control showed that the specified density could be achieved with considerable effort. However, the large amounts of water needed for compaction of the G1 triggered the upward salt migration in a very short period.

When the constructed base layer also exhibited very rapid salt crystallization, even though the parent rock was salt free, the alarm bells rang loud and clear. In Figure 1 crystallization can be observed on top of the base course and inside a density test hole.

The source of the salt was the gypcrete fraction of the blended subbase and, even more importantly, the underlying in situ gypcrete formation. The compaction water used was potable and so was not adding to the salt, yet before the G1 base course was dry enough for priming, a salt dust layer and visible crystals would form on its surface.

The bitumen emulsion in small concentrations was found to act successfully as a compaction aid by reducing the water required and thus it reduced the risk of immediate salt formation. The value of the emulsion addition was also that the white salt crystallization was clearly contrasted in colour in the darkened granular mix. In Figure 2 the salt crystallization is clearly observed in the treated and overnight aerated emulsion mix prior to compaction.

If much higher bitumen emulsion concentrations, such as 4% to 5%, were to be used, a typical emulsion treated base (ETB) would result. Even though this would meet structural strength requirements, improve densification and provide a much less permeable layer, the very high cost implications ruled this option out.



Figure 1. Salt dust on trial section of G1 base surface and density hole soon after construction.



Figure 2. Aerated G1 emulsion mix showing evidence of salt crystallization appearing overnight.

2.4. Possible prevention measures

Weinert (1980) states that:

“It would be difficult and probably costly to prevent the upward movement of salts and it would not be possible to keep the salts permanently hydrated. Therefore, the best remedial measure still appears to be the provision of an impermeable surfacing and possibly the sealing of the shoulders as well. Priming the base and laying of the impermeable surface seal should be done as soon as possible after completion of the base because this will ensure that the salts remain largely hydrated. .”

NAPA (1987), Obika (2001) and Netterberg (1979) produced various guidelines for causes, tests and cures of salt blistering on road and airfields. Inter alia, the best practice is summarized as follows:

- Electrical conductivity tests and limits.
- The approval testing of any completed layer must be done as a matter of urgency and any such constructed layer should be covered with loose material of the next layer within 2 days.
- If crystallization is evident on top of such a completed layer, within or longer than the prescribed 2 days, the top 20mm to 25mm should be scraped and removed.
- A heavy tack coat should be sprayed on top of the completed layer within the required 2 day period once the moisture content has dropped below 50% of optimum.
- Special care should be taken that the final asphalt layer should have reduced permeability.

3. TREATMENT OF THE SALT PROBLEM

3.1. Background and rationale

The trial section of G1 base course was monitored for salt migration. A set of experiments involving wetting, drying and brooming of the surface was done. These results showed that the salt crystallization mechanism is highly dependent on the diurnal variation of temperature in the pavement and the presence of the fog/sea-mist. Once established via water intrusion into the base course the salt crystallization functions like a “perpetual salt machine”. These observations justifiably raised concerns regarding the potential for subsequent damage and contamination of the base course. The compaction water being used in the base course was assisting the salt migration up through the base course. Therefore covering of the subbase with the new base layer within 48 hours and compacting with water actually contributed to salt contamination of the base material, with immediate evidence of salt migration due to the environmental conditions linked to diurnal cycles.

Parallel salt and conductivity measurements confirmed that excessive salt concentrations existed due to the presence of gypsum and that the potential for salt migration was axiomatic. Salt content tests over a period of 8 days showed that environmental changes, such as the Walvis Bay fog/sea-mist, triggered accelerated salt crystallization on the surface of the subbase. The washing action of the excess salt observed initially on top of the subbase surface did not prevent such aggressive salt crystallization from recurring later when the mist moisture once more initiated the salt mechanism. It also proved that, once the base had been constructed on the sub-base, the salt still migrates through the base layer precisely as described earlier by Weinert (1980). Given the above observations clearly questions the validity of the much vaunted notion that “*rapid successive layer construction*” will serve to attenuate the migration of salt.

The following novel measures were introduced to attenuate the aggressive salt migration and crystallisation:

- The salt concentrate on the sub-base surface was broomed to windrow when the moisture content in the layer dropped below 2.5% and then discarded.
- The constructed sub-base was not to be exposed to water again after drying out
- Prime to the sub-base was to be applied immediately after brooming.
- The subbase surface was sealed with the application of an impermeable bituminous membrane to prevent any further upward salt migration.
- The base course was constructed without water.

These measures would result in the desired state of moisture equilibrium in the upper pavement by cutting off water and salt migration from the lower horizon of the structural system to any overlying layers for whatever reason. The novel applications of a subbase vapour barrier and base course construction without any construction water were identified as the best way to prevent salt migration and crystallization formation.

3.2. Vapour barrier to subbase horizon

3.2.1. Prime and tack component

Prime and tack coat experimental sections were constructed and monitored over time to evaluate performance. Applications included the use of MC30, SS30, SS60, 1/4 quick-drying tar prime and even the use of plastic sheets on the sub-base and trial section base layers. Various application rates were trialed.

Depth of penetration was determined to be a cardinal parameter. Penetration and blister formation were observed after 7 days minimum. Salt blisters formed where MC30, SS30 and SS60 were applied. In some cases, loose films formed on top of the base and sub-base. This observation ruled out the use of the latter as such loose layers without penetration will not promote the essential requirement of minimal permeability. However, experiments with applications of tar prime proved to be achieving desirable results. The 1.5 l/m² application of the tar prime achieved penetrations of up to 30mm and such application rate was rated as the best application.

3.2.2. Permeability of prime component

Initial relative observations of permeability were gained by pouring water on the tar primed sections and comparing it with the same action on top of the untreated surfaces of the base and sub-base. It clearly indicated a reduction in permeability. A modified type of a Marvil test was thereafter carried out. It was briefly done as follows:

- A section of primed sub-base (1.5l/m²) was left to cure for 24 hours.
 - A minimum 20mm penetration depth of the prime was observed.
 - A sand density apparatus ring was placed on the surface as normally done for a MARVIL test and a 300mm “header tank” was fitted. The flow area was calculated as 0.0179m².
 - Flow measurements were done on; a control section, and on a treated section of sub-base.
 - The rate of loss was noted at 60second intervals whereafter it was noted in multiples of minutes as the tests progressed.

Relative values of permeability were determined over a time until equilibrium permeability was reached. Tar prime application retarded infiltration. The tests indicated retardation of as much as 30% representing a reduction of infiltration by a factor of 2.5 to 3. This went part way towards contributing to an impermeable membrane at the subbase horizon. Temperature related vapour movement determines the mobility of the salt. In light of the latter it was necessary to prevent the longer term potential activation of this salt migration and not merely effect retardation at the layer interface. Therefore, the application of an impermeable seal at the interface was indicated.

3.2.3. Bitumen rubber seal

The tar-prime only retarded water from infiltrating through to the subbase. In order to complete the vapour barrier, the imperviousness at the interface would have to be enhanced. Netterberg and Bennet (2004) and Netterberg (1979) clearly indicated that the permeability of the surfacing layer normally has direct correlation with extent of salt crystallization. Work done on various seal types by Netterberg (1979) has shown that the permeability of a bitumen rubber seal (BRS) is generally the lowest of the standard type of

seals used on roads. The latter fact was supported by the history at Rooikop which when the runway was finally capped by a 6/7mm BRS, this successfully attenuated the salt crystallization and it performed well for some 20 years. The bitumen rubber seal was chosen because it is tough, and has the inherent tensile strength to resist tearing during construction of the base course on top of it.

The overall integrity of the vapour barrier was ensured by the application of a BRS to the primed layer interface, with the specification: bituminous binder 150/200 pen, added rubber crumb of 25%, spray rate: 1.8 l/m², chip size: 9.5mm (precoated), chip application: 125m²/m³, and dune sand blinding.

3.2.4. Dry base construction

A base type had to be found which would be structurally as strong or stronger than a G1 granular base, but required no construction water. Waterbound macadam bases (WBM) have traditionally been used for the construction of airport pavements in South Africa as well as the rest of the world. As far back as 1956 the base of the original Cape Town International Airport was WBM using ballast railed in from the railways quarry and has performed very well over the years based on past performance as well as tests done with accelerated pavement testing (APT) (Horak, 1983 and Horak and Triebel, 1986). Historically WBM construction was labour intensive, but after World War II mechanized construction techniques favoured a well graded crusher-run, later refined to G1 and G2 materials, placed in one operation and compacted with modern compaction equipment.

As mentioned before, the base layer of the original Rooikop runway also consisted of a nominal 2 x 65mm = 125mm WBM. The good performance in the old pavement enhanced the view that there was no doubt that this would be as good, if not a structurally better alternative to the G1.

The arid nature of the area offered the use of Dry-Bound Macadam (DBM) as an alternative. This was attractive as the OMC would be zero and as such no further water would be required for the completion of the pavement structure, DBM was therefore recommended as an alternative to the G1 base.

The source quarry for the DBM complied with the normal requirements of aggregate crushing value and flakiness index and the electrical conductivity was < 0.15 Sm⁻¹. The structural fraction of the DBM (nominally -75 + 25mm) was paver placed in a single layer. The following method statement is indicative of DBM placement and construction:

- Paver place 200mm loose layer to achieve 150mm consolidated thickness.
- Apply static roller passes until no further movement is detected
- Distribute the “first pass” dry dune-sand filler using chip-spreader with cover to a “no bare patch” condition
- Apply successive 6-pass vibratory roller to DBM “lock up” condition and sand infiltration is complete.
- Blind up any bare patches with filler and “final roll”
- Broom off all excess filler
- Apply water spray to surface and follow immediately with a 1.0 l/m² application SS60 cut back with 25% water

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- Primarily placement quality of the DBM was ensured by strict control of the placement methodology, but visual as well as density controls were also done.

Laboratory trials had indicated:

- Un-filled rodded density of 1518 kg/m³
- Filled rodded density of 2120 kg/m³

Visual monitoring of inter-particle void filling after final compaction was done by saturating a 500 x 500mm patch of DBM with diluted water soluble wood glue and left to cure overnight. This allowed an inspection hole to be made next morning without the dry sand pouring out of the voids.

- Nuclear back scatter density determinations were also done.
- Average coarse fraction lay down density behind paver: 1409 kg/m³ (Coefficient of Variance (CV) was 5.6%)
- Average compacted coarse fraction density: 1511 kg/m³ (CV was 5.0%)
- Average compacted 6-pass “filled” density: 2114 kg/m³ (CV was 2.0%)

DBM surfaces tend to be loose and unstable when unconfined by a surfacing and this is worsened when cohesionless (non-plastic) filler is used. Wetting on completion and the early application of a 1.0 l/m² (SS60 + 25% water) prime stabilized the surface long enough to allow for an emulsion slurry application. The Marshall criteria for the slurry were:

- stability > 7kN
- flow 2mm - 6mm
- air voids content 2% - 6%

3.2.5. Asphalt surfacing

A pavement design check indicated that the original 70mm continuously graded asphalt layer could be reduced to 50mm. The alternative design report contemplated nominal 19mm Fuller gradation to a 0.45 index. The report also considered that the target binder content at 4.8% was low for airport use, given durability considerations and was only sustainable if a BRS was pulled over the final asphalt surfacing as well. The proposal to add a surface friction course, such as a bitumen-rubber grit seal, can be seen as the final “belts and braces” proposal to prevent any future salt migration from happening based on the Rooikop crystallization history. This proposal was not accepted by the developing agency for various contractual reasons. However, it is the intention of the NAC, that a durable surface friction course will be applied in the near future once full jurisdiction and operation is transferred.

4. STRUCTURAL STRENGTH

The structural strength was checked using various mechanistic analyses. Elastic moduli determinations on DBM are problematic if they are done with triaxial testing (Parrock et al, 2009 and Horak, 1983), and this was a difficulty with the subbase layer. Load considerations required 500MPa minimum effective elastic moduli for this layer, but triaxial cell diameter and large aggregate size ratio was less than 2, preventing this equipment to be used in this instance. Plate bearing tests also proved to be inaccurate and cumbersome.

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A detailed Falling Weight Deflectometer (FWD) traverse to a high density grid (10m x 10m) was therefore done and analysed in detail. Back analysis by using three different software packages proved that the DBM presented effective elastic moduli in excess of 500MPa.

Using the same FWD traverse a benchmark methodology, using the deflection bowl parameters, Base Layer Index (BLI), Middle Layer Index (MLI) and Lower Layer Index (LLI) was used to evaluate the pavement structure in depth. A criterion for a sound warning and severe relative structural capacity developed elsewhere was used very effectively to identify potential weak spots in the DBM as well as the rest of the pavement structure (Horak and Emery, 2009). No significant deficient areas were identified in the DBM.

A concern was also expressed that the bitumen-rubber seal vapour barrier at the base/subbase layer interface could induce slip when exposed to the horizontal forces of braking of the design aircraft. A detailed evaluation of the slip potential at various interfaces was therefore done (Horak et al, 2009). The conclusion reached was that horizontal forces are not only dissipated very effectively at those depths in the pavement structure, but the inherent better elastic characteristics of the vapour barrier would also improve the structural strength and afford greater inter-layer slip resistance.

5. CONCLUSIONS

- As in many other arid areas of adverse evaporation/precipitation imbalance the upward mobility of salt and consequent distress was shown to be a reality. However, with innovative construction methodology and correct material selection the problem can be effectively attenuated.
- In combination, a winner was found in the three-pronged intervention of:
 - The selection of priming medium on top of the subbase for maximum penetration,
 - An application of bitumen-rubber seal on top of the subbase, formulated for toughness and reduction in permeability,
 - The placement of a dry bound macadam base course layer with no construction water.
- Preventative construction methodology to counter a “salt problem” based on the principle of “rapid successive layer placement” cannot be as effective as that developed at WBIA.
- It is essential that engineers thoroughly acquaint themselves with ambient conditions prevailing during the planning phase of a project.

KEY WORDS

Salt damage, blisters, runway, vapour seal, drybound macadam, bitumen rubber seal

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REFERENCES

Blight, GE., 1976. **Migration of subgrade salt damages to thin pavements.** Transportation Engineering Journal, Proceeding of the American Society of Civil Engineers, Vol 102, pp 779-791.

CSRA, 1985. **Guidelines for Road Construction Materials - TRH 14.** Committee of State Road Authorities, Department of Transport, Pretoria.

Horak, E., 1983. **Waterbound Macadam Pavements** (Afrikaans), M Eng Thesis, University of Pretoria, South Africa.

Horak, E. and Triebel, RHH., 1986. **Waterbound Macadam as base and as drainage layer.** Research Report 446. NITRR, CSIR, Pretoria and published in Transportation Research Board publication, Washington DC, USA. January 1986.

Horak, E., 1987. **The use of surface deflection basin measurements in the mechanistic analysis of flexible pavements.** Proc Sixth Int. Conf. Structural Design of Asphalt Pavements, Ann Arbor, Michigan, USA, 1987.

Horak, E., Emery, SJ , Maina, J, and Walker, B., 2009. **Mechanistic Modelling of Potential Interlayer Slip at Base Sub-base level.** Proc. 8th Int. Conf. Bearing Capacity of Roads, Railways and Airports, Urbana, Champagne, Illinois, USA.

Horak, E. and Emery, SJ., 2009. **Evaluation of airport pavements with FWD deflection bowl parameter benchmarking methodology.** 2nd European Airport Pavement Workshop, 13-14 May 2009, Amsterdam.

Obika, B., 2001. **The prevention and repair of salt damage to roads and runways.** Botswana Roads Department Guideline No 6, Gaborone.

NAC, 2004. **Salt damage to Walvis Bay (Rooikop) airport surfacing and concrete.** Letter from Dr Frank Netterberg to Namibian Airports Company: 24 December 2004.

NAPA., 1987. **Quality Control for Hot Mix Asphalt Manufacturing Facilities and Paving Operations.** National Asphalt Pavement Association, Quality Improvement Series 97/87.

Netterberg, F., 1963. **Report on an investigation of Rooikop Airfield.** Unpublished technical note. NITRR, CSIR, Pretoria.

Netterberg, F, Blight, GE, Theron, PE and Marais GP., 1974. **Salt damage to roads with bases of crusher-run Witwatersrand quartzite.** Proc Second Conf. on Asphalt Pavements for Southern Africa (CAPSA). Durban, pp7.34-7.53.

Netterberg, F., 1979. **Salt damage to roads - an interim guide to its diagnosis, prevention and repair.** IMIESA. Johannesburg Vo l 4. No 9, pp13-17

10th CONFERENCE ON ASPHALT PAVEMENTS FOR SOUTHERN AFRICA

Netterberg, F. and Bennet, RA., 2004. **Blistering and cracking of airport runway surfacing due to salt crystallization.** Proc Eighth Conf. on Asphalt Pavements for Southern Africa. Sun City, pp956-974.

Parrock, A. Strydom, JS. and Rieger VJ., 2008. **Why stabilise? Using triaxial tests for determining pavement stiffness and shear strength parameters of mechanically modified layers.** Jrnl S. African Inst.Civil Engineering Vol 50 No 1, 2008, pp 2–12, Paper 626

Rollings, RS. Rollings, MP. and Sharp KG., 2003. **Tropical pavement materials.** 21st ARRB and 11th REAAA Conference, Cairns, Australia.

Weinert, HH., 1980. **The Natural Road Construction Materials of Southern Africa.** Pretoria, Academia