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Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Nanotechnology in roads
Summary of SAT workshop

Prof Wynand JvdM Steyn
HOD – Civil Engineering
University of Pretoria

10 May 2017

Summary of SAT workshop – March 2017

- Workshop programme and contributors
  - **Introductory principles** of nanotechnology/science/history
  - **General application** of nanotechnology across industries - Nadine Govender
  - Principle of **particle size consideration** in road building / maintenance/deterioration - Dr Martin Mgangira CSIR
  - **Applications** of nanotechnology in the roads industry (including structures)
  - **Mineralogy** & nanotechnology – Dr Verrein
  - **Laboratory** testing, methods and equipment - Nico Herbst (Roadlab)
  - **Implementation** of nanotechnology in South Africa – Prof Gerrit Jordaan
  - **Implementation** of nanotechnology in South Africa – Herman Marais (Much Asphalt)
  - **Implementation** of nanotechnology in KZN – Naidu Consulting
- Only brief summary

What are we talking about?

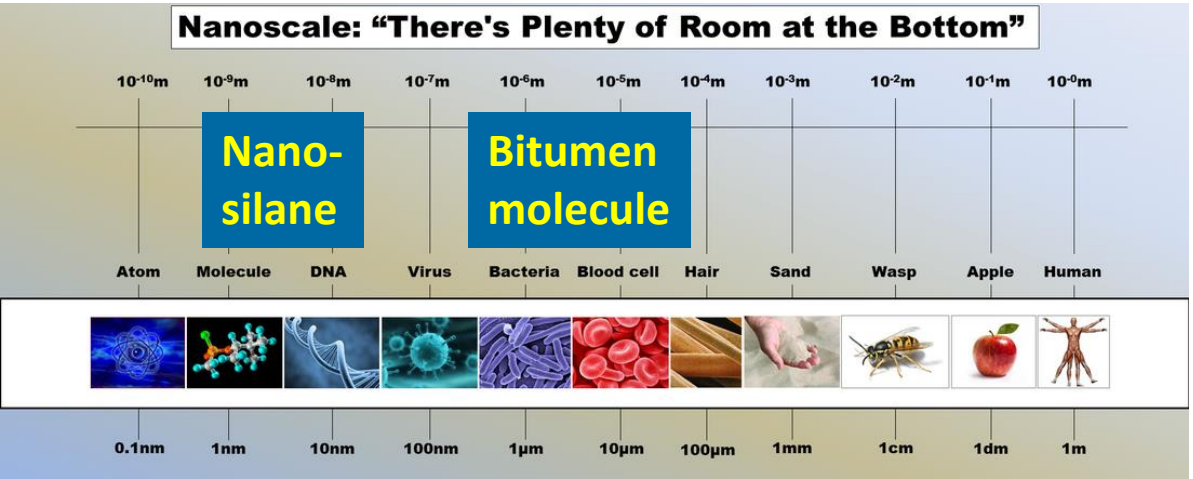
- Nano - one billionth, 10^{-9}, 0.000000001
- Nanotechnology
  - design, construction & utilization of functional structures with at least one characteristic dimension measured in nanometers
  - dimensions & tolerances of <100 nm, especially the manipulation of individual atoms and molecules
- **Physical behavior of matter display substantial changes as size decreases to nanometer scale**

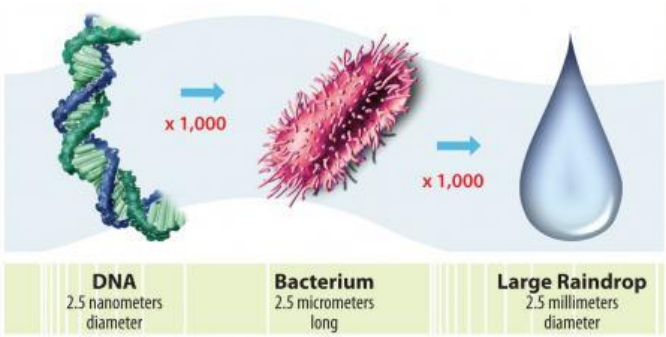
Where did it start?

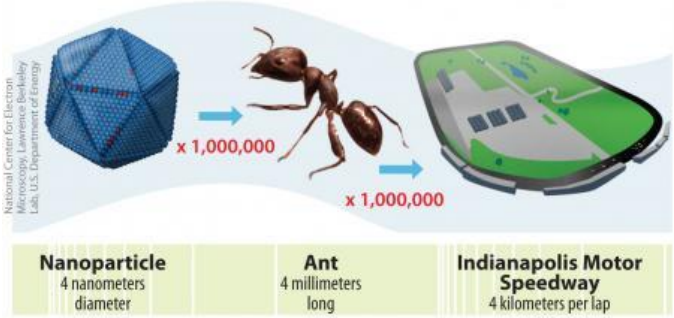
- There’s Plenty of Room at the Bottom - Richard Feynman (1959)
  - manipulate & control individual atoms and molecules
    - *Why cannot we write the entire 24 volumes of the Encyclopaedia Brittanica on the head of a pin?*

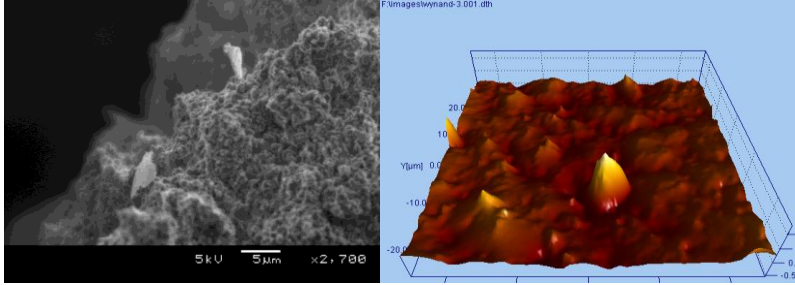
Scale

- Sheet of paper 100 000 nm
- Marble = 1 nm then Earth = 1 m
- Human hair 80 000 to 100 000 nm
- Single gold atom 0.3 nm
- Fingernail grows 1 nm in 1 second









Seeing

- Since 1930s
  - Scanning Electron Microscope, Transmission Electron Microscope, Field Ion Microscope, Scanning Tunnelling Microscope, Atomic Force Microscope, etc.

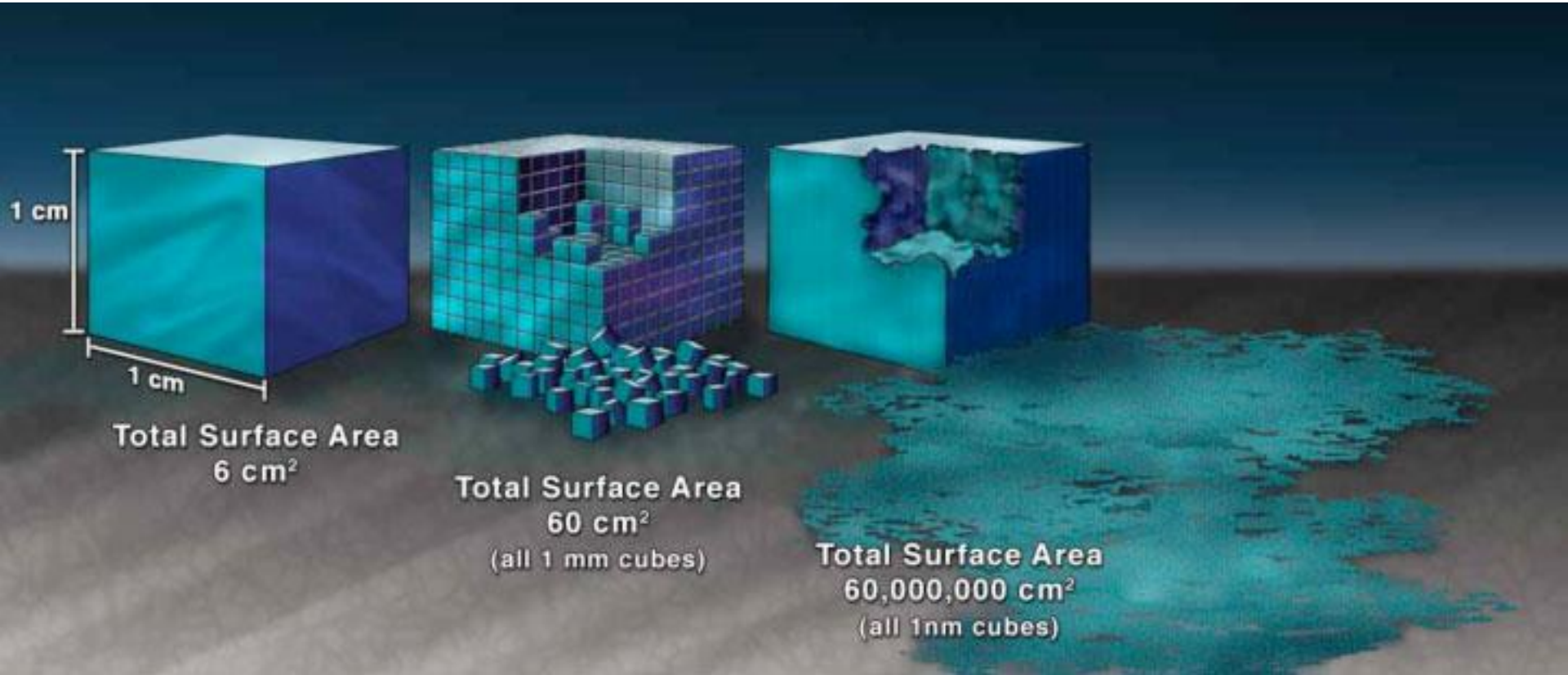
1 500 x

Why is it special?

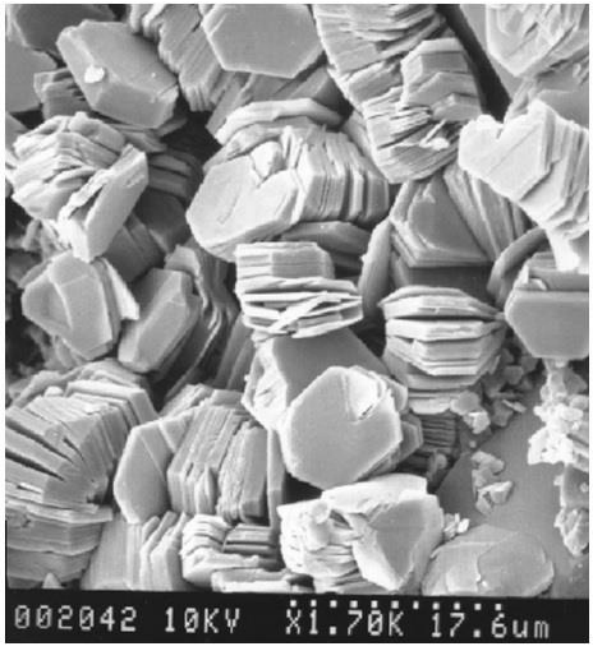
- Nanoscience / nanotechnology
  - ability to see & control individual atoms & molecules
- **New tools** - understand & take advantage of phenomena that occur naturally when matter is organized at nanoscale
- Phenomena based on
  - quantum effects
  - **expanded surface area**
- Not simply working at ever smaller dimensions
  - enables utilization of unique physical, chemical, mechanical, & optical properties of materials that naturally occur at that scale

Why is it special – Surface area

Surface area per mass of material increases, greater amount of material in contact with surrounding materials - affecting reactivity

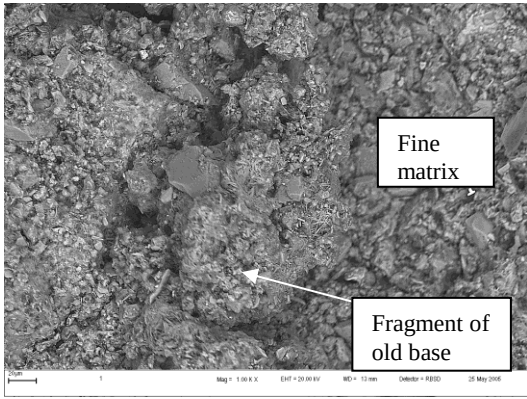


Ever heard of clay?



Problem statement for application of nanotechnology in pavement engineering

- Identify **current needs that cannot be addressed** effectively using current technology
- Identify **potential nanotechnology solutions** that may be applicable in pavement engineering field
- Marry two concepts to **identify nanotechnology solutions** with highest potential **benefit/cost ratios** & focus on specific developments in those fields

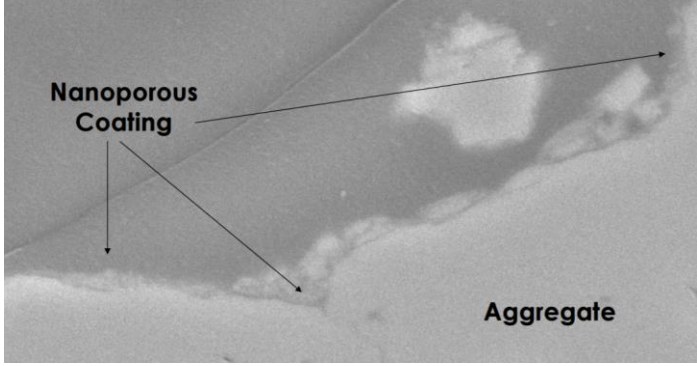


Some examples – not exhaustive

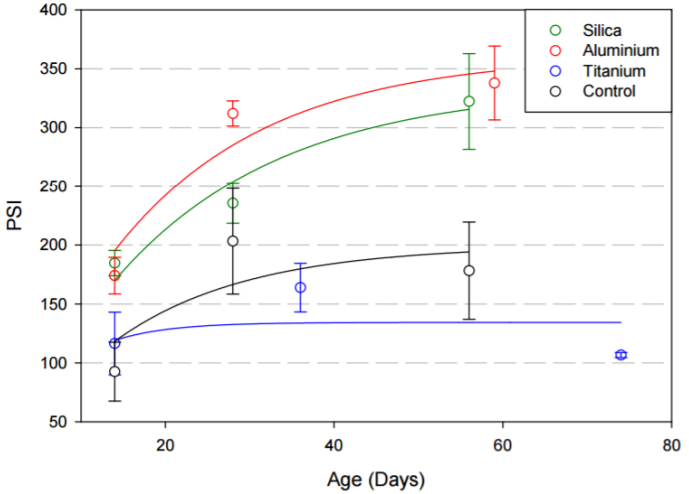
Aggregate - Thin films

- Thin films of nano-sized material deposited on surface of host material
  - change surface properties
  - **improve bonds** between aggregate & binder
  - **prevent bonding** between two materials

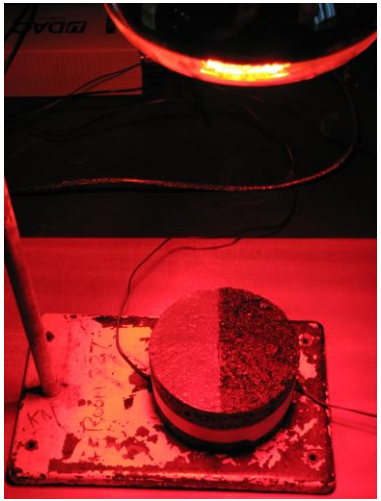
  - Know what you need / want to do!



Thin film effect on aggregate-cement paste bond

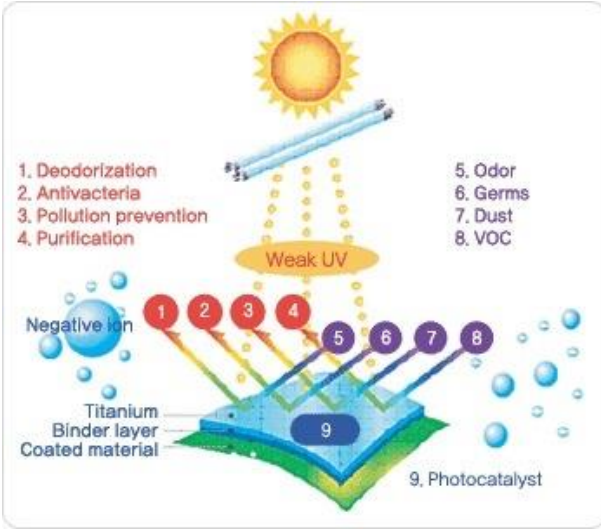


TiO_2 / ZnO



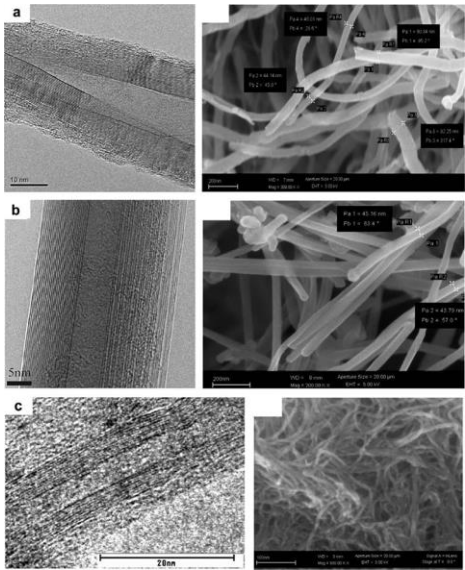
- Bitumen / Asphalt
  - Treatment against UV & ageing deterioration
  - Can affect bitumen ageing positively - sunscreen
  - Effect on binder stiffness to be evaluated

- Concrete
  - TiO_2 photocatalytic activities
  - Self-cleaning surfaces & removal of NO_x, SO_x, NH_3, CO pollution
  - Triggered by **naturally occurring UV light**
  - Application through use of concrete blocks / surfacing indicated localized decreases in NO_x



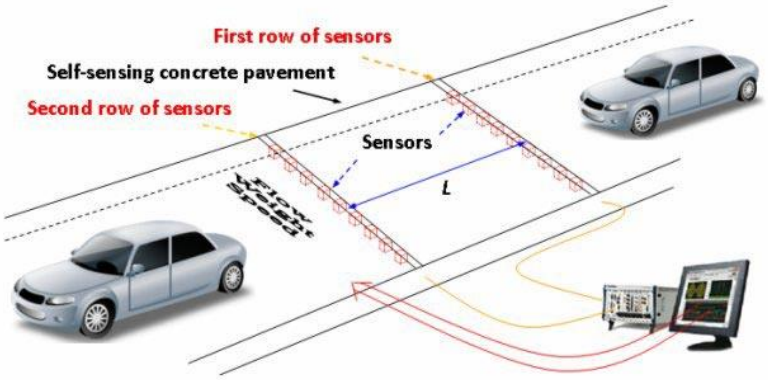
Cement / concrete - CNT

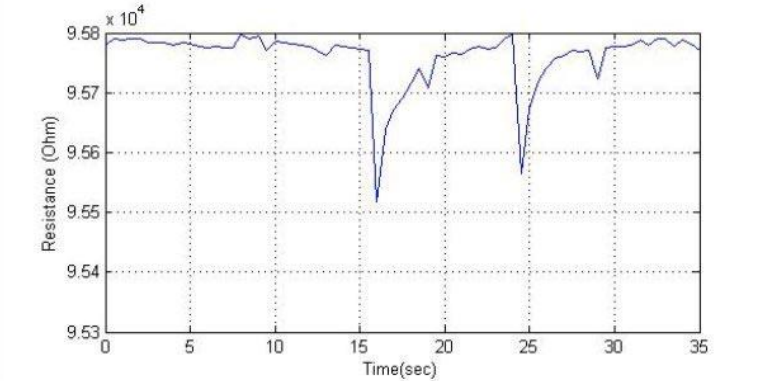
- Improvements in strength, environmental resistance, bonding
  - reinforcing concrete
  - **increase**
    - hydration rates & stronger bonds
    - compressive strength up to +70%
  - **decreases**
    - heat conductivity up to 12%
  - dispersion problems
  - does not corrode in corrosive environments



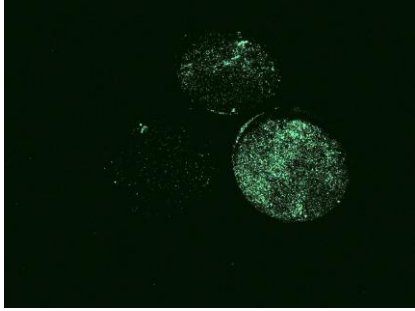
Sensors

- Sensors **embedded in infrastructure**
- Issues around bonding between sensors & matrix eliminated
- Application of CNTs in traffic monitoring
- Data transfer from sensor to DAQ still require work

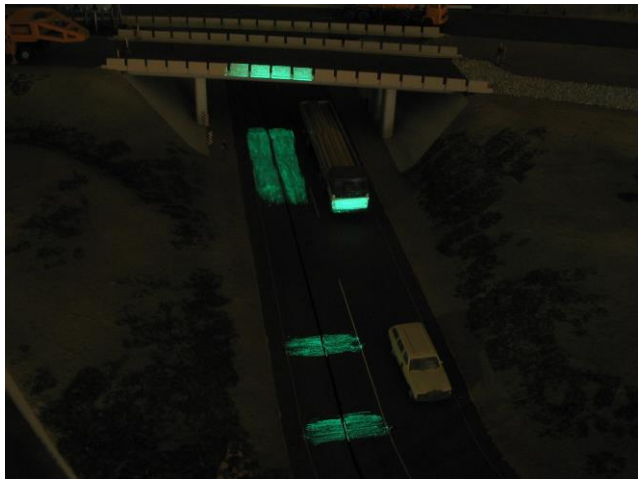




Nano-phosphor

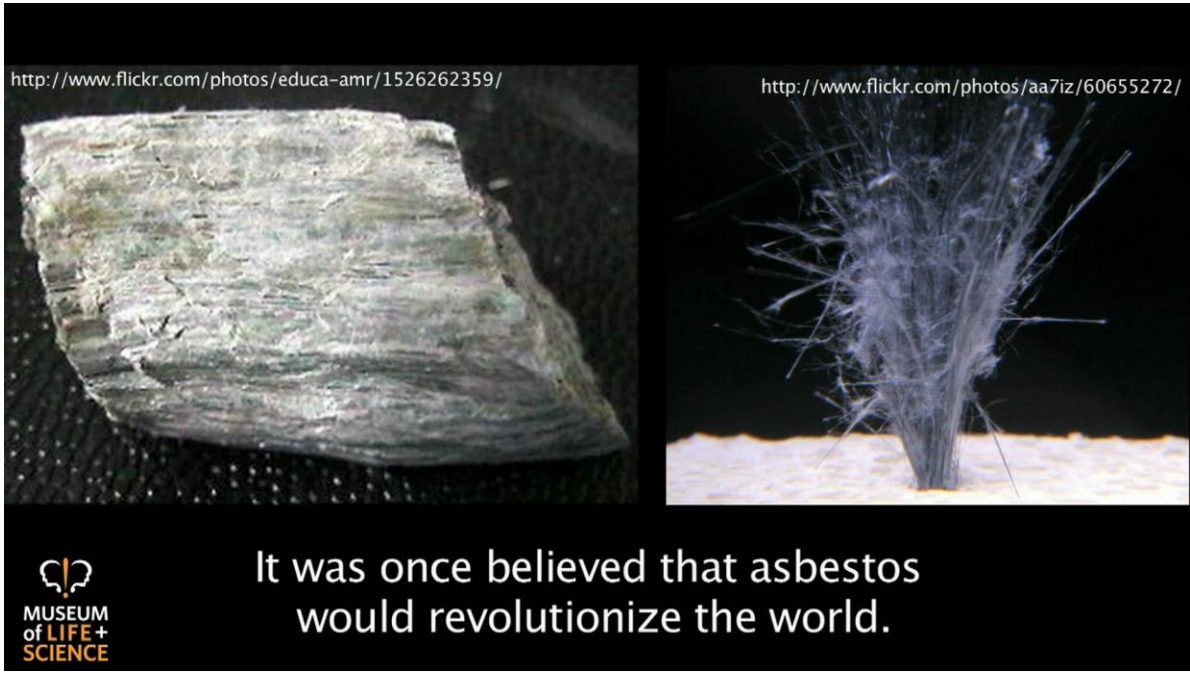


- Illumination of road pavements
  - nano-scale crystalline structures with size dependent bandgap that can be altered to change the color of light
  - road act as light source
  - not dependent on external power
  - can be added to traditional pavement materials (concrete, bitumen & road paint)



Concerns & Issues – Environment / Health & Safety

- Compatible to natural environment
- Minimize effects on natural environment
- Leaching into groundwater
- Release of materials into airways through of dust
- Exposure during construction & maintenance operations



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Much Asphalt

SAT Eastern Region Workshop: Nanotechnology

Nanotechnology in Asphalt

Herman Marais

1 March 2017

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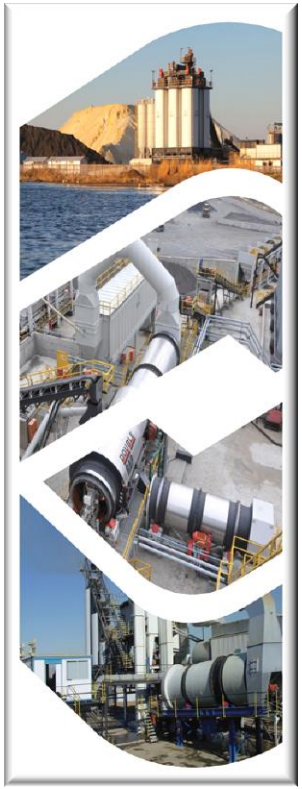
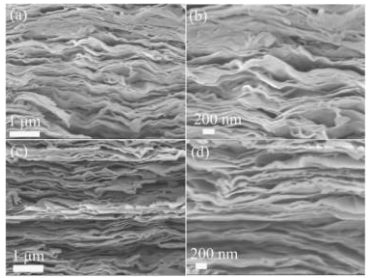
Nanotechnologies – In development



Nanoclay

- Bitumen enhanced modified with small amounts of nano-clay
- **Improved** elasticity, low temperature rheological properties, rutting resistance, crack resistance



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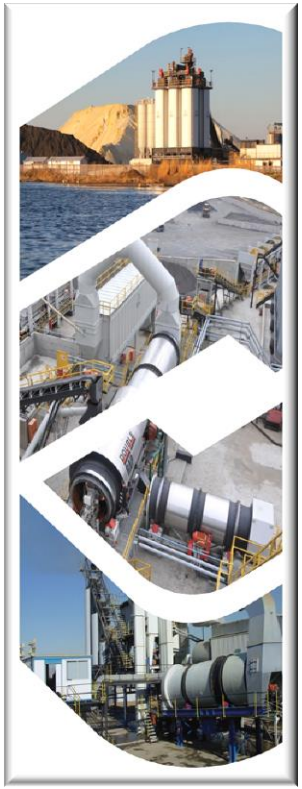
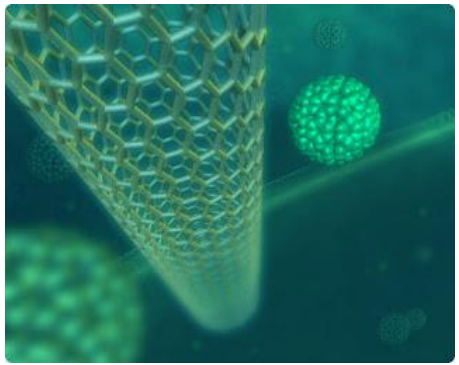
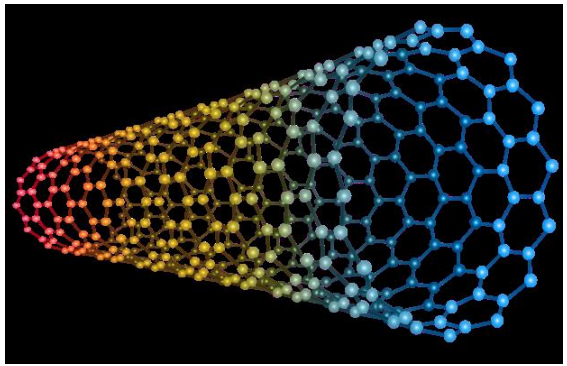
Nanotechnologies – In development



Carbon Nanotubes (CNT)

- Very few studies
- Can significantly affect **rheological properties**
- **Improved** rutting resistance, thermal cracking resistance
- **Reduced** susceptibility to oxidative aging





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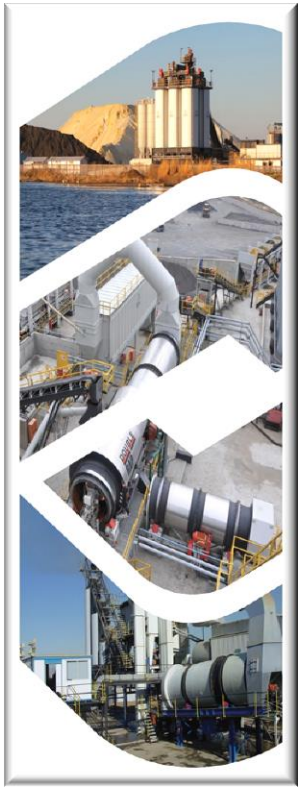
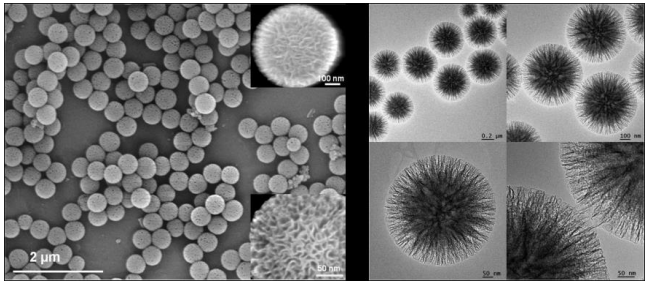
Nanotechnologies – In development



Nanosilica (NS)

- Low cost of production & high performance features
- **Reduces** binder viscosity, susceptibility to oxidative aging
- **Improved** rutting resistance, thermal cracking resistance, fatigue resistance, aggregate binder adhesion



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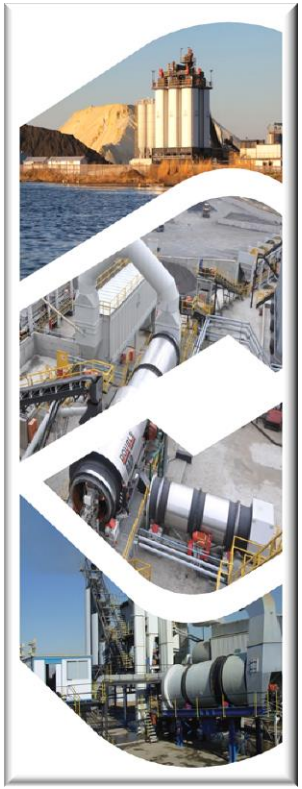
Nanotechnologies – In development



Graphene Oxide (GO)

- **Improve** high temperature, anti-aging property
- **Promote** low temperature property of base bitumen
- CO_2 emissions during heating (above 115°C) could have WMA and fire retardant advantages

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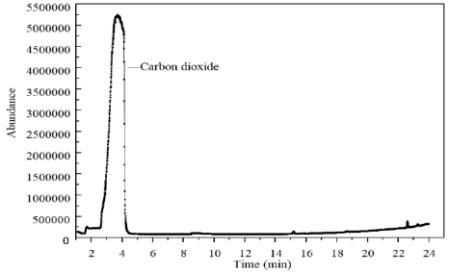


Figure 19. Gas chromatography of 3% GO-modified asphalt heated to 115 °C.

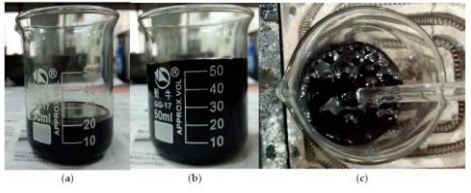
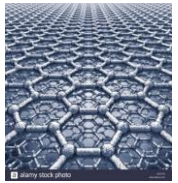
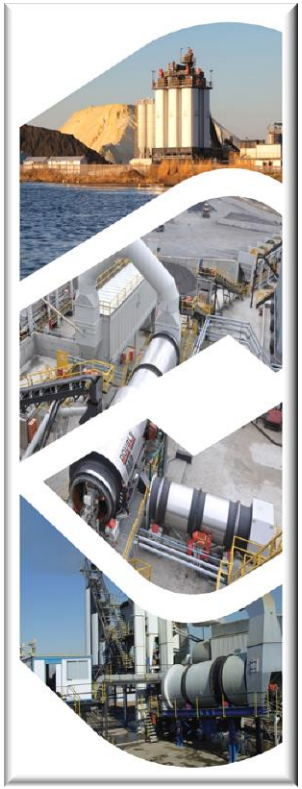


Figure 1. Boiling effect phenomenon. (a) Volume of 1% GO-modified asphalt before heating; (b) volum of 1% GO-modifed asphalt after heating; and (c) gas released.

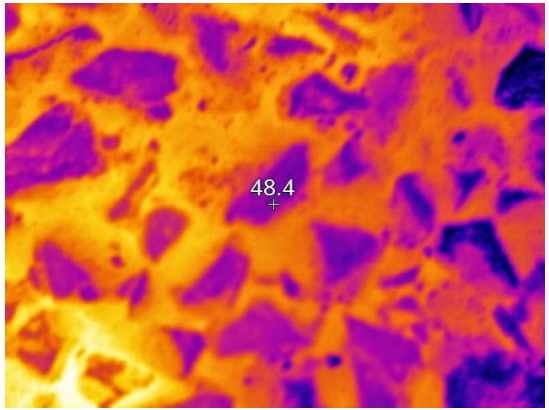


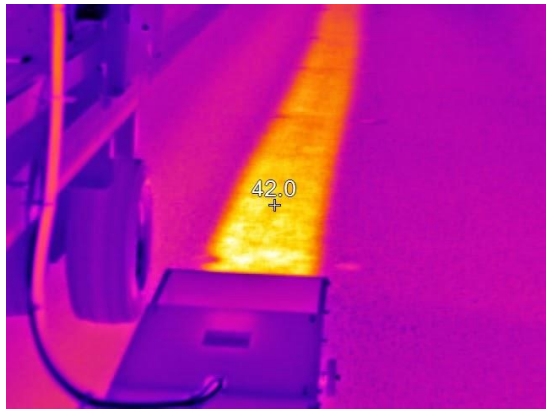
Nanotechnologies – In development



Iron Nano particles

- Magnetic Iron Oxide Nano particles (MIONP)
- Similar to treating cancerous tumors (magnetic hyperthermia)
- Asphalt heated up in just a few seconds which **“heals” micro-cracks**
- Quite costly at present
- Test Steel Slag fines as cost effective alternative





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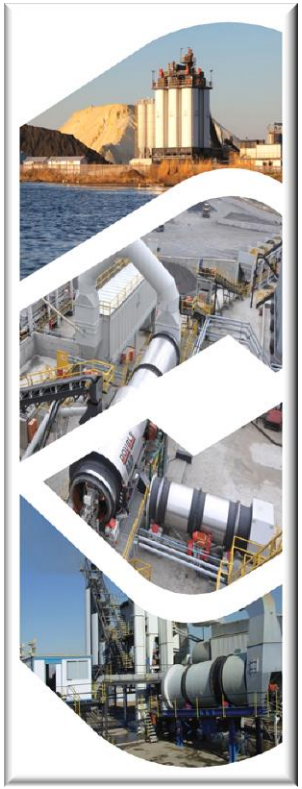
Nanotechnologies – Opportunities



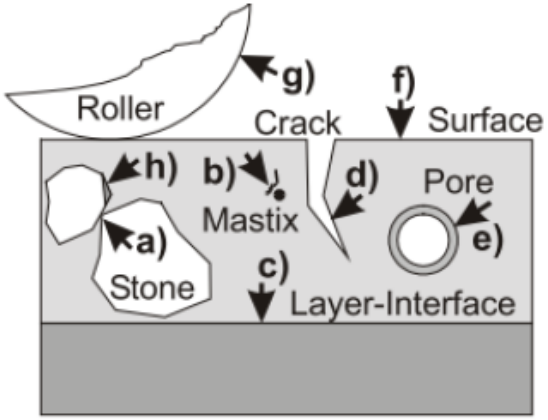


Figure 3. Schema to visualize focus areas for nanoscience and technology with respect to asphalt pavement structures:

a) Bond between stones (shear and tension)

b) Mastic (stiffening, cohesion, durability, compaction improvers)

c) Bond between layers (tack coats)

d) Self-repair (healing) and rejuvenating agents

e) Oxidation of binder films and binder inhomogeneities

f) Surface properties (friction, optical properties, water repellent, abrasion resistant, self-cleaning), sealcoats for surface protection

g) Anti-adhesion surface for rollers during compaction

h) Bond, adhesion between stone and mastic

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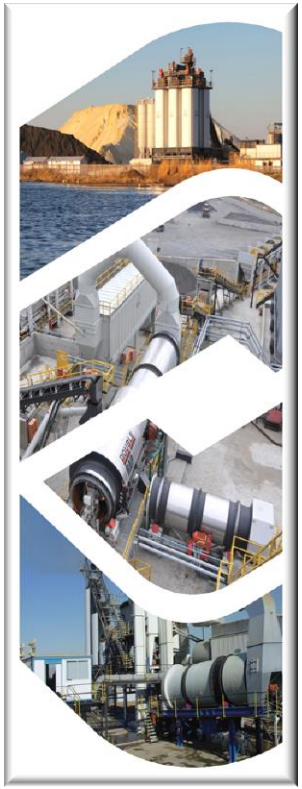
Much Asphalt

Zycotherm
Grey Water Study Phase 2



TCT TRANSPORT FOR CAPE TOWN

sabita

GREY WATER ON MEW WAY

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GREY WATER STUDY PROJECT

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Zycotherm
Grey Water Study Phase 2

CONCLUSION

- Found that EVA modified mixtures with a combination of additives performed the best
- Clear benefit of adding 1% SASOBIT® as compaction agent
- Zycotherm Nano Technology showed improved resistance to Grey Water damage

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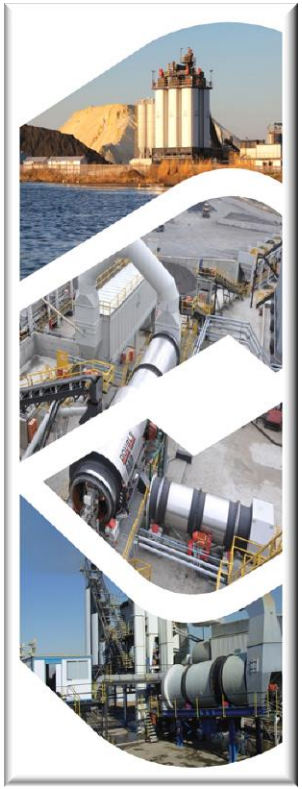
Zycotherm - Adhesion Promoter



Boil Test (ASTM D 3625)	Percentage of retained Coating		
	After 10 min	After 1 hr	After 3 hr
Neat mix	50%	30%	10%
Modified mix	100%	95%	95%

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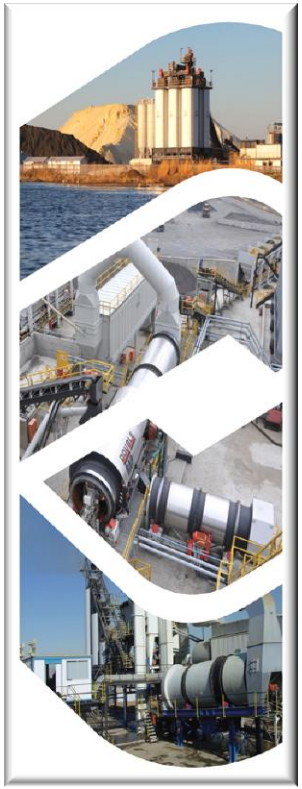
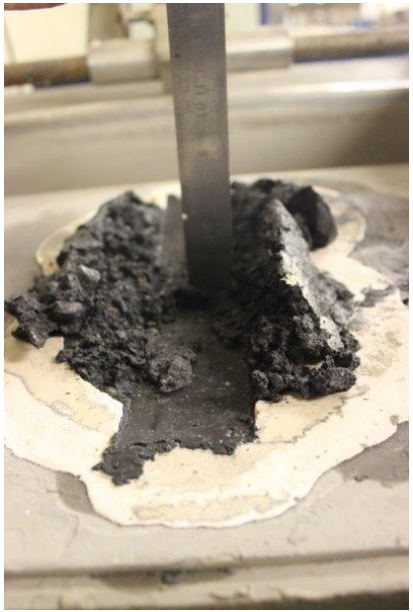
Zycotherm - Bitumen Rubber



Before



After

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8TH AFRICA TRANSPORTATION TECHNOLOGY TRANSFER CONFERENCE

Practical application of Nano-technology in roads in southern Africa

Prof. G. J. Jordaan, UP

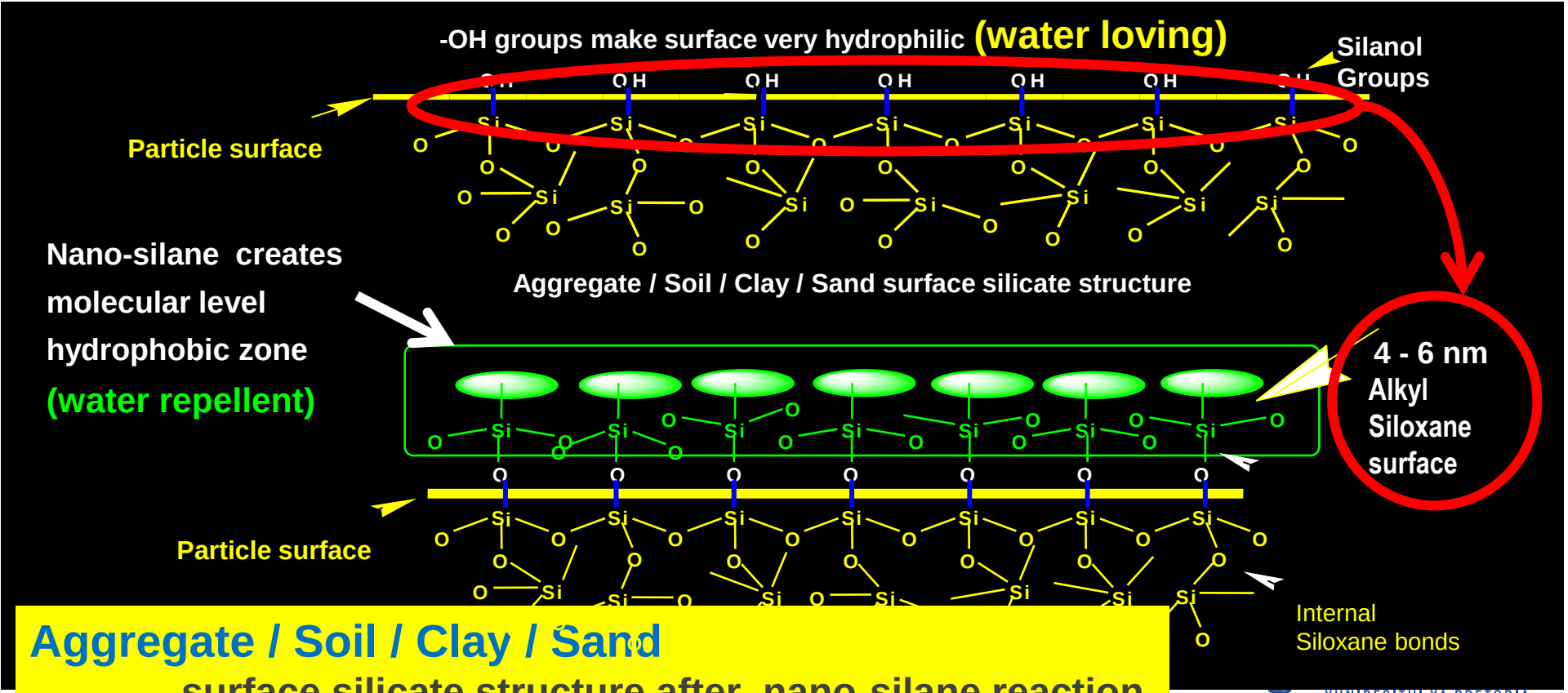
Mr. A. Kilian, GPDRT, SA

Mr. N. Muthivelli, RAL, SA

Mr. D. Dlamini, MPW & T, Swaziland

THE “free energy” ACTION

Chemical bond



Aggregate / Soil / Clay / Sand

surface silicate structure after nano-silane reaction

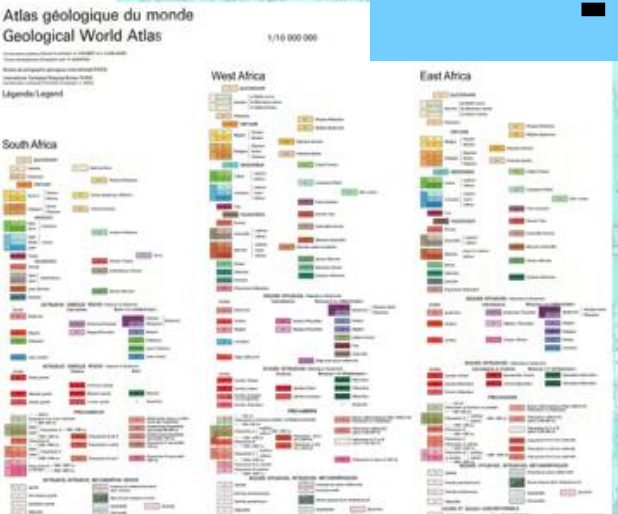

oasis
PREPARED WATER
Nano – "water-proofing" Agent added
Normal Stabilising agent
2014 11 11

Pavement design

Back to basics

Consider basic available natural materials

- Geology



Weinert (1980):

Southern Africa – "Unique"

- Seasonal Rainfall
- High Temperatures
- ~ weathering characteristics

"Problem materials" e.g.

- Smectite…….
- Mica…….

- Cohesion-less sands
- Organic material
  - Crushed shell (West coast)
  - Pulverised corral (East coast)

Gauteng Province:
GPDRT:
Johannesburg North:
Road K46 –
New dual-carriage high capacity road
7 – 10 MESA

Gauteng Province:
GPDRT:
Heidelberg West:
Road D1884 -
Rehabilitation of rural road
~ 3.0 MESA

Limpopo Province:
RAL
Thohoyandou::
Road D3718 –
Rehabilitation of Township road
~ 1.0 MESA

Swaziland
SMPWT:
North of Manzini:
Road D29 – New road linking several villiages
~ 0.5 MESA

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D1884 Gauteng – Rehabilitation (G7)

GAUTENG
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

Formula	UCS(dry)	UCS(wet)	UCSw/UCSd %
0.7% GE-NANO P	2 269	2 139	94%
0.7% GE-NANO P	2 173	2 093	96%
AVE (kPa)	2 221	2 116	95%

Formula	ITS(dry)	ITS(wet)	ITSw/ITSd %
1.2% GE-NANO P	383	142	37%
1.2% GE-NANO P	391	124	32%
AVE (kPa)	387	133	34%

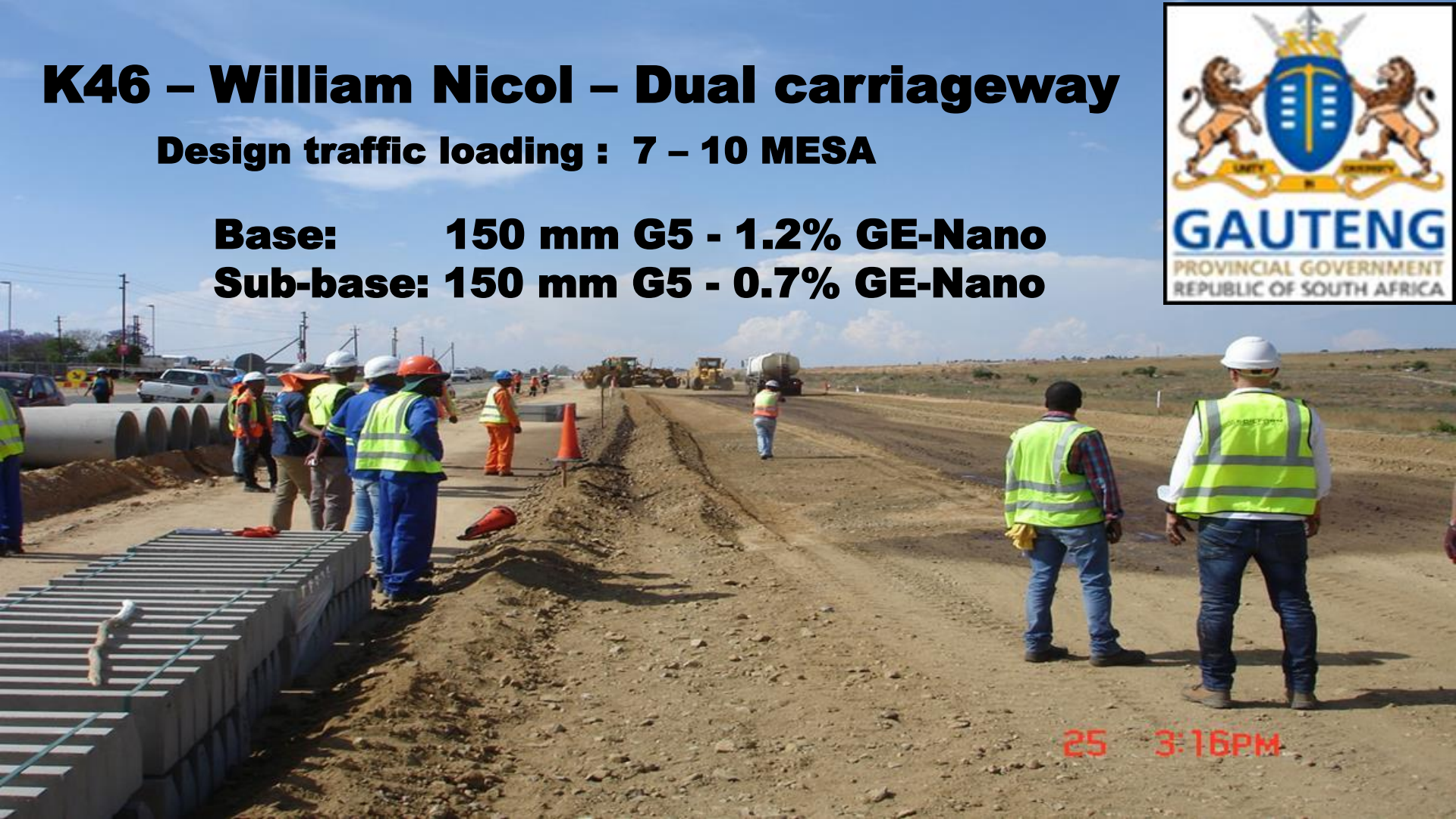

25 January 2016
ROADS AGENCY LIMPOPO
Together for better roads
Primed surface open to traffic for almost 2 months
2016 1 25

K46 – William Nicol – Dual carriageway

Design traffic loading : 7 – 10 MESA

Base: 150 mm G5 - 1.2% GE-Nano
Sub-base: 150 mm G5 - 0.7% GE-Nano

GAUTENG
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA




0.7% NME4


Sub-base condition
25 February 2017
Rain Dec 2016: >100 mm
25 1:10PM

1 week after base placing:
2017 > 200 mm Rain

Challenge

- How to actively establish link between using benefits that nanotechnology offer & improved understanding & application of materials science into improvements of transportation infrastructure

- Important
  - Focuses on improving our knowledge & management of available resources
  - ***Nanotechnology does not replace good engineering***

- Analogy – blood samples
  - Small amount of blood (0.01%) – test for correct parameters – identify illness and cure with appropriate medicine
  - No blood sample required to fix a broken leg or tell you that smoking is bad for your health