The application of locally developed pavement temperature prediction algorithms in Performance Grade (PG) binder selection

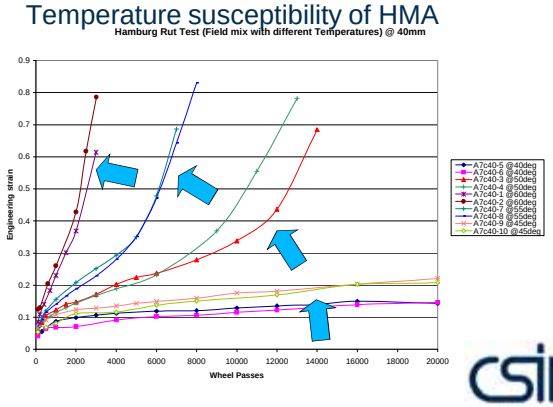
Prepared for SATC 2007

By Erik Denneman

Presentation structure

- Temperature susceptibility of HMA
- Pavement temperature prediction equations,
- Validation of prediction models,
- Performance Grade (PG) binder specification,
- Binder selection using CSIR ThermalPADS,
- Future direction.

Temperature susceptibility of HMA



Pavement temperature prediction

- Maximum daily surface temperature
- Qs + Qa - Qc - Qk - Qr = 0
- Qs = Energy absorbed at the asphalt surface from direct solar radiation.
- Qa = Energy absorbed at the asphalt surface from atmospheric radiation.
- Qc = Energy transferred from the asphalt surface to the surrounding atmosphere by convection.
- Qk = Energy transferred from the asphalt surface into the asphalt layer.
- Qr = Radiation energy emitted from the asphalt surface.

Pavement temperature prediction

- Maximum surface temperature SUPERPAVE (Huber)

$$T_{s(max)} = T_{air(max)} - 0.00618 \cdot latitude^2 + 0.2289 \cdot latitude + 24.4$$

- Maximum surface temperature Viljoen

$$T_{s(max)} = T_{air(max)} + 24.5(\cos Z_n)^2 \cdot C$$

Pavement temperature prediction

- Minimum surface temperature SUPERPAVE

$$T_{s(min)} = 0.859 T_{air(min)} + 1.7$$

- Minimum surface temperature Viljoen

$$T_{s(min)} = 0.89 T_{air(min)} + 5.2$$

Pavement temperature prediction

- Maximum temperature at depth
  - SUPERPAVE

$$T_{d(max)} = \left(T_{s(max)} + 17.8\right)\left(1 - 2.48\times10^{-3}d + 1.085\times10^{-5}d^2 - 2.441\times10^{-8}d^3\right) - 17.8$$

  - Viljoen

$$T_{d(max)} = T_{s(max)}\left(1 - 4.237\times10^{-3}d + 2.95\times10^{-5}d^2 - 8.53\times10^{-8}d^3\right)$$

- Minimum temperature at depth
  - SUPERPAVE

$$T_{d(min)} = T_{s(min)} + 5.1\times10^{-2}d - 6.3\times10^{-5}d^2$$

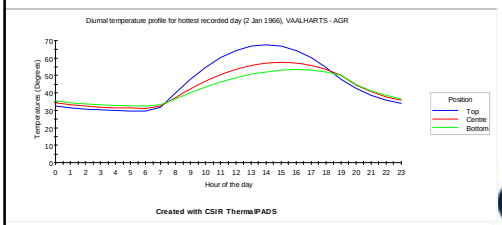
  - Viljoen

$$T_{d(min)} = T_{s(min)} + 3.7\times10^{-2}d - 6.29\times10^{-5}d^2$$

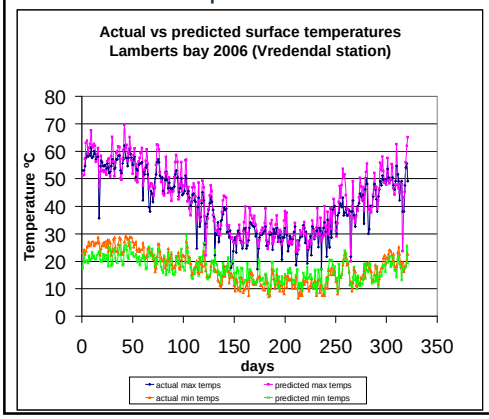
Pavement temperature prediction

- Diurnal temperature profile (Viljoen only)

$$T_{d(t)} = T_{d(min)} + \left[T_{d(max)} - T_{d(min)}\right]\sin\left[\pi\frac{\left(t - t_r - \beta\right)}{DL + 2\left(\alpha - \beta\right)}\right]$$



Validation of prediction models



Validation prediction models

Maximum surface temperature (actual - predicted)

Location	Number of days data	Viljoen equation		Superpave	
		Mean error [ºC]	Standard deviation of error [ºC]	Mean error [ºC]	Standard deviation of error [ºC]
Cullinan (R238)	93	1.72	2.59	-4.32	-3.29
Vereniging (P234/1)	92	0.31	2.48	-2.03	2.83
Cape Town (N7)	332	-3.40	2.92	1.82	6.66
Lamberts Bay (R365)	320	-2.05	3.68	3.46	7.11

Minimum surface temperature (actual - predicted)

Location	Number of days data	Viljoen equation		Superpave	
		Mean error [ºC]	Standard deviation of error [ºC]	Mean error [ºC]	Standard deviation of error [ºC]
Cullinan (R238)	93	-2.73	2.23	2.67	2.13
Vereniging (P234/1)	92	1.01	2.44	5.39	2.20
Cape Town (N7)	332	-2.80	2.85	3.23	2.28
Lamberts Bay (R365)	320	0.19	3.17	6.17	3.37

Performance Grade (PG) binder specification

- Applicable to modified and unmodified bituminous binders,
- Based on the stiffness of the aged binder,
- Takes into account traffic load and environmental condition,
- Specification for high and low temperature
  - PG x-y with x is high temperature y is low temperature
- Spec based on 100 km/hr and 10^7 E80s max.

SA bitumen (source SABITA)

Pen grade	40/50	60/70	80/100	150/200
Refinery I	X	PG 64-16	PG 58-22	X
Refinery II	PG 64-16	PG58-22	PG 58-22	X
Refinery III	PG 64-16	PG64-22	PG 58-16	PG 52-22
Refinery IV	PG 70-20	PG 64-16	PG 58-22	PG 52-22

Binder selection using ThermalPADS

- Details on CSIR ThermalPADS
  - Based on Viljoen asphalt pavement temperature prediction equations,
  - Uses daily maximum and minimum air temperature to calculate:
    - Maximum and minimum surface temperature,
    - Temperature at depth,
    - Diurnal temperature profile
  - Currently contains weather data from 65 SA weather stations
  - Can be used to select Performance Grade (PG) binder,
  - Software available from www.prac.co.za

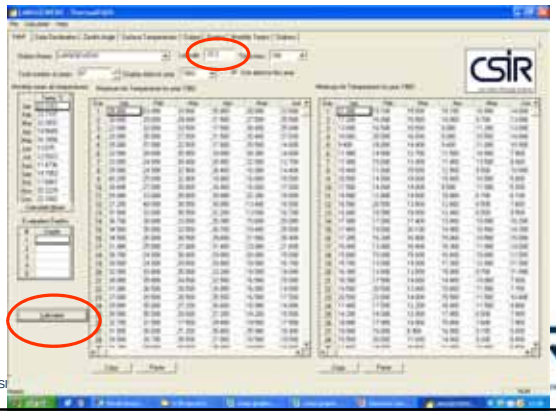
Binder selection using ThermalPADS

- Case I
  - Freeway near Darling in Western Cape
  - Lattitude -33.3º
  - Expected E80s on HMA overlay: 12E06
  - No intersections
  - Required design reliability: high
- Case II
  - Provincial road in Midrand (Gauteng)
  - Lattitude -26.0º
  - Expected E80s on HMA overlay: 6E06
  - Intersections
  - Required design reliability: medium

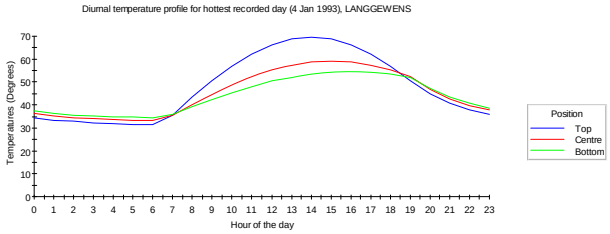
Step 1: select nearby weather station

- Confirm climate on site is similar to weather station,
- Stations selected: Langgewens (WC) & Irene (Gauteng)

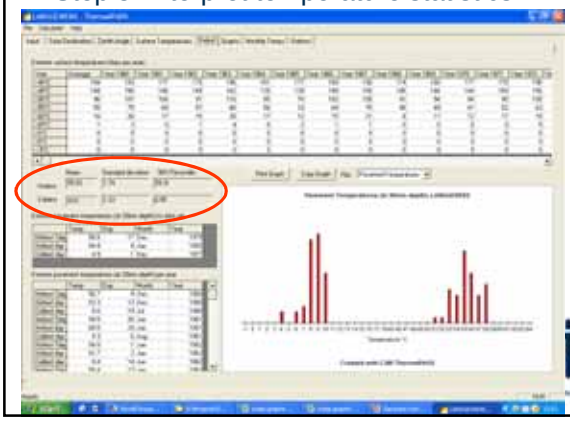
Step 2: Input latitude of road



Typical output: Diurnal temperature profile



Step 3: Interpret temperature statistics



Step 4: Determine PG grade

Road section	Darling	Midrand
Seven day average maximum temperature (20 mm depth) [Median / 98th percentily value]	55.8 ° C / 59.31 ° C	52.3 ° C / 56.1 ° C
Minimum surface temperature [Median / 98th percentily value]	9.0 ° C / 6.6 ° C	4.1 ° C / -2.1 ° C
Required design reliability	High (Use 98th percentile)	Medium
Expected traffic [E80s]	> 10E06 (increase PG)	< 10 E06
Slow moving or stationary loads (intersections)	no	Yes (increase PG)
Selected PG grade	PG 64 – 16 or PG 70 – 20	PG 58 - 16

Available PG binders in SA (source: SABITA)

Pen grade	40/50	60/70	80/100	150/200
Refinery I	X	PG 64-16	PG 58-22	X
Refinery II	PG 64-16	PG58-22	PG 58-22	X
Refinery III	PG 64-16	PG64-22	PG 58-16	PG 52-22
Refinery IV	PG 70-20	PG 64-16	PG 58-22	PG 52-22

Conclusions

- The temperature algorithms developed by Viljoen (2001) provide an acceptable prediction of extreme surface temperatures of four LTPP sections in Gauteng and the Western Cape.
- The model yields acceptable results to start implementing and validating PG binder selection in South Africa

Future direction

- Further validation required for outlying areas,
- Increase the number of weather stations from 65 to 500+,
- Link temperature prediction to HMA stiffness and rutting models,
- Take into account the effect of binder ageing,
- Include temperature prediction algorithms for other materials (concrete pavements, granular base layers).

End, thank you!