ALTERNATE SHIFT FACTOR RELATIONSHIP FOR DESCRIBING THE TEMPERATURE DEPENDENCY OF THE VISCO-ELASTIC BEHAVIOUR OF ASPHALT MATERIALS

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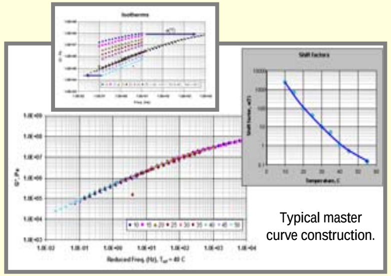
Introduction

Master curves describe the dependence of viscoelastic behavior on temperature and provides a useful tool for engineers and scientists. If the curves can be represented in functional form they can more readily be applied to the analysis and design of engineering structures such as pavements.

In the construction of master curves, isotherms of modulus tested at multiple temperatures are shifted by applying a multiplier (shift factor) to the frequency (or time) at which the measurement is taken so that the individual isotherms of stiffness combine to form a single smooth curve of stiffness versus frequency or time (the master curve).

The amount of shift used at each particular temperature is analyzed to determine a shift factor - temperature relationship.



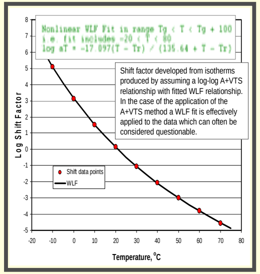
Typical master curve construction.

If functional forms are fitted to the shape of the master curve plot and to the shift factor relationship this interpolation becomes rapid and easy to apply in computer software. The resulting equations can be employed to extrapolate the data beyond the observed range of temperatures and frequencies.

Approaches

In the development of master curves two basic approaches can be distinguished:

- Free shifting - the shifts are determined from successive pairs of isotherms to form a smooth curve with the resulting shape of the master curve and shift factor functions being independently derived each time a master curve is constructed. Particularly when the nature of the temperature /frequency susceptibility of a material is unknown, the free shifting type of analysis is much preferred because it enables the shape of the individual isotherms to strongly influence the shape of the master curve.



- Constrained shifting – in this approach an underlying model is used to force the master curve and/or shift factors to fit a predefined functional form. Constrained analysis can be very useful if the data is relatively noisy with correspondingly ill-defined isotherm shapes (provided that a particular functional form of master curve is known beforehand to be appropriate).

Equations and the Kaelble Function

Typical function forms for master curves

Binder	Mix
$S(\xi) = S_{glassy}[1+(\xi/\lambda)^{\beta}]^{-\kappa/\beta}$	$\log E^*(\omega) = \delta + \frac{\alpha}{\left[1+\lambda e^{(\beta+\gamma(\log \omega))}\right]^{1/\lambda}}$

ξ and ω are reduced parameters which include effect of shift factor

Arrhenius equation

$$\log a_T = a\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)$$

Linearized Arrhenius equation

$$\log a_T = a + b\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)$$

Kaelble equation

$$\log a_T = -\frac{C_1(T-T_d)}{C_2+|T-T_d|}$$

WLF equation

$$\log a_T = -\frac{C_1(T-T_g)}{C_2+(T-T_g)}$$

Second degree polynomial

$$\log a_T = aT^2+bT+c$$

Modified Kaelble equation

$$\log a_T = -C_1\left(\frac{T-T_d}{C_2+|T-T_d|}-\frac{T_r-T_d}{C_2+|T_r-T_d|}\right)$$

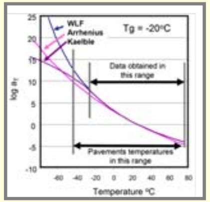
Why the Kaelble Function …?

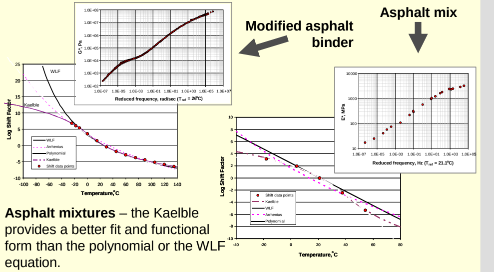
The modified Kaelble has benefits as follows:

Asphalt binders - the T_d parameter as defined by Kaelble has a very similar meaning to the defining temperature (see Christensen-Anderson model).

Filled binders/modified binders – the Kaelble provides a better functional form than either the WLF or Arrhenius formats.

Note: Above T_d Kaelble is identical to WLF

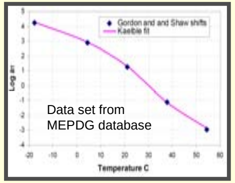




Asphalt mixtures – the Kaelble provides a better fit and functional form than the polynomial or the WLF equation.

Analysis of many mixtures from the MEPDG database was not possible with WLF or Arrhenius formats and was an impetus for conducting this work.

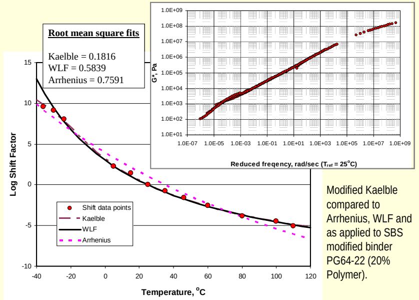
Kaelble allows curves which are sigmoid in shape to represent the shift factor function fits data for mixes better than other forms.



SUMMARY

The method offers significant advantageous but some additional study should be performed to check the robustness of the procedure with mix and binders samples. With regard to application of this method we would note the following:

- Asphalt binders - the T_d parameter as defined by Kaelble is an inflection point in the shift factor relationship similar to the defining temperature.
- Avoids the need for two different functional forms to describe the shift factor relations above and below the glass transition temperature.
- For filled binders/modified binders – the Kaelble provides a better functional form than either the WLF or Arrhenius formats.
- Mixes – the Kaelble provides a better fit and functional form than the polynomial or the WLF equation.
- In the application of the A+VTS method a WLF fit is effectively applied to the data which can often be considered questionable.
- The Kaelble formulation of the shift factor provides an elegant method for extrapolating and interpolating data when used with models such as the Christensen-Anderson (or CAM and CAS formats) for the of binder data, and with the sigmoid models (Witczak or Richards) for mix data.



Modified Kaelble compared to Arrhenius, WLF and as applied to SBS modified binder PG64-22 (20% Polymer).

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