TechBrief

The Asphalt Pavement Technology Program is an integrated national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry and academia, the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures and other tools for use in asphalt pavement materials selection, mixture design, testing, construction and quality control.

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Delta T_c Binder Specification Parameter

This Technical Brief provides an overview of the binder parameter Delta T_c (ΔT_c). Delta T_c is an indicator of the effect of aging and additives on the asphalt rheology. More specifically, ΔT_c provides insight into the relaxation properties of an asphalt binder that can contribute to non-load related cracking or other age-related embrittlement distresses in an asphalt pavement. This Technical Brief provides information for responsible deployment of the ΔT_c as a specification parameter should State DOTs be considering implementation.

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide information and clarity to the public regarding existing requirements under the law or agency policies.

Introduction

The difference in critical low temperature performance grade (PG) limiting temperatures, Delta T Critical, commonly referred to as Delta T_c (ΔT_c), is an asphalt binder parameter that provides insight into relaxation properties of the asphalt binder that can contribute to non-load related cracking or other age-related embrittlement distresses. (1) Delta T_c is a calculated value using results (creep stiffness and creep rate) from the bending beam rheometer (BBR) test. It is intended to be used on asphalt binders that have been long-term aged (rolling thin-film oven (RTFO) plus pressure aging vessel (PAV)). However, ΔT_c can also be used on recovered asphalt binders from reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) or combinations of thes with virgin asphalt binder.

Delta T_c may be used to evaluate any asphalt binder. Examples include: neat asphalt binder (asphalt binder with no additives); asphalt binder with additives; such as polyphosphoric acid (PPA) and re-refined engine oil bottoms/vacuum tower asphalt extender (REOB/VTAE); modified asphalt binder that has been blended with polymers or other asphalt additives; and recovered asphalt binder containing RAP, RAS, or combinations thereof. Generally, ΔT_c may be considered as an indicator of how effectively asphalt binders respond to aging or how effectively additives impact the response of asphalt binders to aging.

Some State Departments of Transportation (DOTs) have implemented or intend to implement ΔT_c as part of existing acceptance specifications. Additionally, national level research projects have considered and are considering ΔT_c as part of their studies.(1) This technical brief presents a review and summary of current "State-of the-Knowledge" of ΔT_c as a parameter to characterize asphalt binder behavior. The objective is to provide knowledge for responsible deployment of ΔT_c as an asphalt binder specification parameter, should State DOTs be considering implementation. As information on ΔT_c evolves and a State DOT has a pressing need to implement, the purpose of this document is to provide some preliminary considerations whether to proceed or not. The scope of this report is limited to deployment of the ΔT_c parameter into asphalt binder acceptance specifications.

An advantage of ΔT_c is that it can be calculated in a straight-forward manner from results of BBR tests already used in acceptance.

Background

The ΔT_c parameter was conceptualized during the Strategic Highway Research Program (SHRP) and later suggested as an indicator of pavement performance in a research project sponsored by the Airfield Asphalt Pavement Technology Program (AAPTP), Project 06-01, "Techniques for Prevention and Remediation of Non-Load Distresses on Hot-Mix Asphalt (HMA) Airport Pavements."(2,3) "The goal of the Project 06-01 study was to identify simple asphalt binder and/or mixture tests which can predict imminnent cracking or raveling so that pavement preservation strategies can be timed to delay or prevent damage of HMA pavements on general aviation airports."(3) The study concluded that a new asphalt binder parameter, referred to as ΔT_c had promise as a tool for neat asphalt binders that could be used to predict ductility and analyze durability-related properties of aged asphalt pavement. Since then, use of ΔT_c has evolved as a test that can evaluate relaxation properties of asphalt binders. The concept of an asphalt binder relaxation and how it relates to mixture performance can be understood by realizing that an asphalt binder exhibits some viscous behavior, even at low temperatures. Therefore, when thermal stresses build up as a pavement gets colder, the asphalt binder slowly exhibits viscous flow and stresses are greatly reduced. This reduction of stresses over time is what is known as relaxation. In general, as an asphalt binder ages, its relaxation properties are diminished, and thermal stress builds quickly. An asphalt pavement that has an asphalt binder with good relaxation properties is less likely to have durability-related cracking than an asphalt pavement with an asphalt binder with poor relaxation properties.

Relaxation properties of aged asphalt binders, expressed by ΔT_c values, can affect a number of different types of asphalt pavement distresses, including non-load related cracking and other age-related embrittlement distresses. However, only one type of cracking (block cracking), Figure 1, has been directly correlated to ΔT_c. Several factors can contribute to other forms of disterss: fatigue, edge, longitudinal, reflection, and transverse cracking, raveling and potholes. Delta T_c, pavement structure, environment, and loading are among the factors that may contribute to these distresses. Additional information on the origins of ΔT_c and different types of asphalt pavement distresses can be found in Chapter 2 of AI IS-240.(1)

Source: Asphalt Institute

Figure 1. Example of block cracking from age-related embrittlement.

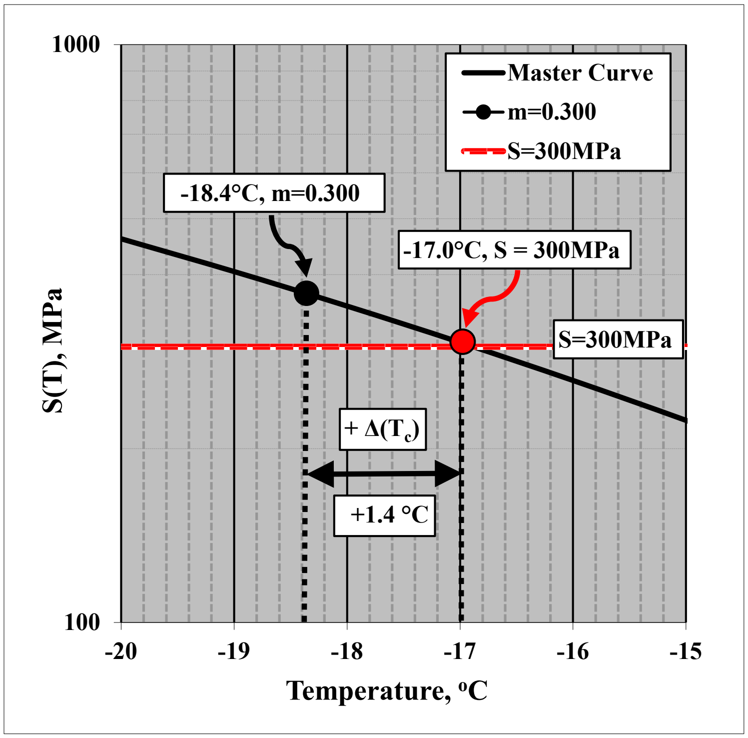
Determination of ΔT_c

The ΔT_c parameter is an indicator of how effectively asphalt binder responds to aging and how incorporation of additives may impact the response of asphalt binder to aging. Delta T_c is represented as the difference in critical low temperature values of asphalt binder according to the Superpave performance grading methodology.

Results from the BBR test per American Association of State Highway Transportation (AASHTO) T 313-2019, *Standard Method of Test for Determining the Flexural Creep Stiffness of Asphalt Binders Using the Bending Beam Rheometer (BBR),* are used to calculate ΔT_c.(4) This is a voluntary standard test procedure that is not required under Federal statute or regulation. First, the critical (or continuous) temperature (T_c) for both creep stiffness (S), designated as T_{cS}, and creep rate (m), designated as T_{cm}, at the specified AASHTO M 320-2017, *Standard Specification for Performance-Graded Asphalt Binder* or AASHTO M 332-2019, *Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep and Recovery (MSCR) Test,* conditions and limiting values of 300 MPa and 0.300 respectively. Figure 2 presents a graphic depiction of ΔT_c.(5,6) Both AASHTO M 320-2017 and AASHTO M 323-2019 are voluntary specifications that are not required under Federal law.

As shown in Figure 2, ΔT_c is then calculated by subtracting the BBR m-critical temperature at 60 seconds of loading ($T_{c,m(60s)}$), which is the resulting temperature where the m-value is exactly equal to the specification value of 0.300, from the BBR S-critical temperature at 60 seconds of loading ($T_{c,S(60s)}$), which is the resulting temperature where the S-value is exactly equal to the specification value of 300 MPa. This calculation is described in American Society for Testing and Materials (ASTM) D7643 Section 6.3 "Calculation of ΔT_c."(7) AASHTO PP 78-2017, Section 7, "Binder Quality Requirements for Binder Embrittlement," also discusses how to calculate ΔT_c.(8) Both ASTM D7643 and AASHTO PP 78-2017 are voluntary specifications that are not required under Federal law. The ΔT_c parameter is the mathematical difference between these two critical temperatures, expressed in degrees Celcius (°C) to one decimal point. The equation is:

$$\Delta T_c = T_{c,S(60s)} - T_{c,m(60s)} \qquad \textbf{Eq. 1}$$



Source: Paragon Technical Services, Inc.

Figure 2. ΔT_c, $T_{c,S(60s)}$–$T_{c,m(60s)}$.

To demonstrate calculations for ΔT_c, consider an asphalt binder that exhibits BBR creep stiffness values at 60 seconds of loading ($S_{(60s)}$-values) of 248 MPa and 466 MPa at –18°C and –24°C, respectively; and BBR creep rate values ($m_{(60s)}$-values) of 0.324 and 0.290 at –12°C and –18°C, respectively. Then,

$$T_{c,S(60s)} = -18 + \left[\frac{\left(-18-(-24)\right)\left(Log(300) - Log(248)\right)}{Log(248) - Log(466)}\right] - 10 = -29.9°\text{C} \qquad \textbf{Eq. 2}$$

$$T_{c,m(60s)} = -12 + \left[\frac{\left(-12-(-18)\right)(0.300 - 0.324)}{0.324 - 0.290}\right] - 10 = -26.2°\text{C} \qquad \textbf{Eq. 3}$$

Therefore:

$$\Delta T_c = -29.9°\text{C} - (-26.2°\text{C}) = -3.7°\text{C} \qquad \textbf{Eq. 4}$$

Depending on the values of $T_{c,S(60s)}$ and $T_{c,m(60s)}$, the sign of ΔT_c, is either positive or negative, which indicates whether the binder's low-temperature PG is governed by its creep stiffness "S-value" (+ΔT_c) or governed by its creep rate "m-value" (–ΔT_c). A positive ΔT_c value indicates the binder is "S-controlled" (failing the S-critieria before the m-criteria), while a negative ΔT_c value indicates the binder is "m-controlled" (failing the m-criteria before the S-criteria). The magnitude of the ΔT_c value (i.e., absolute value) indicates the degree to which the binder is m-controlled or S-controlled.

Research has shown that more negative values of ΔT_c appear to be strongly correlated to fatigue cracking and other distresses related to poor relaxation properties.$^{(3)}$ Therefore, researchers have suggested a ΔT_c specification warning limit value of –2.5°C at 20-hour PAV aging and a failure limit of –5°C, at 20-hour PAV aging, for consideration as potential specification criteria.(3) In other words, –5°C is more negative than –2.5°C; therefore a ΔT_c value of –5°C is perceived as worse than a ΔT_c value of –2.5°C. Polymer modified asphalt binders may have a ΔT_c worse than neat asphalt binders, but perform well, this is discussed later in the document.

Most asphalt binder types can be evaluated with ΔT_c, including recovered asphalt binders containing RAP, RAS, or combinations thereof. It is advisable, with such asphalt binder blends, that the quality of the total binder (i.e., virgin binder plus RAP and/or RAS) be evaluated for ΔT_c to ensure that the total asphalt binder does not have a detrimental effect on long-term durability. It should be noted that the recovery process completely blends the virgin, RAP and/or RAS binder and likely does not represent field blending that takes place in plant-produced materials. To obtain a more representative extracted asphalt binder from asphalt, extractions are suggested to be conducted using toluene as the solvent and then recover the asphalt binder using a rotary evaporator procedure as specified in ASTM D7906 (9-13) This is a voluntary standard test procedure that is not a Federal requirement.

Identifying Units and Signs

In this technical brief, ΔT_c values are presented as °C. The value represents a difference in temperatures (C°) as opposed to a specific temperature. As discussed, the negative value does not represent a negative temperature but that the parameter is m-critical (creep rate) controlled. Chapter 3 of AI IS 240 provides additional information on the mechanics of ΔT_c.(1)

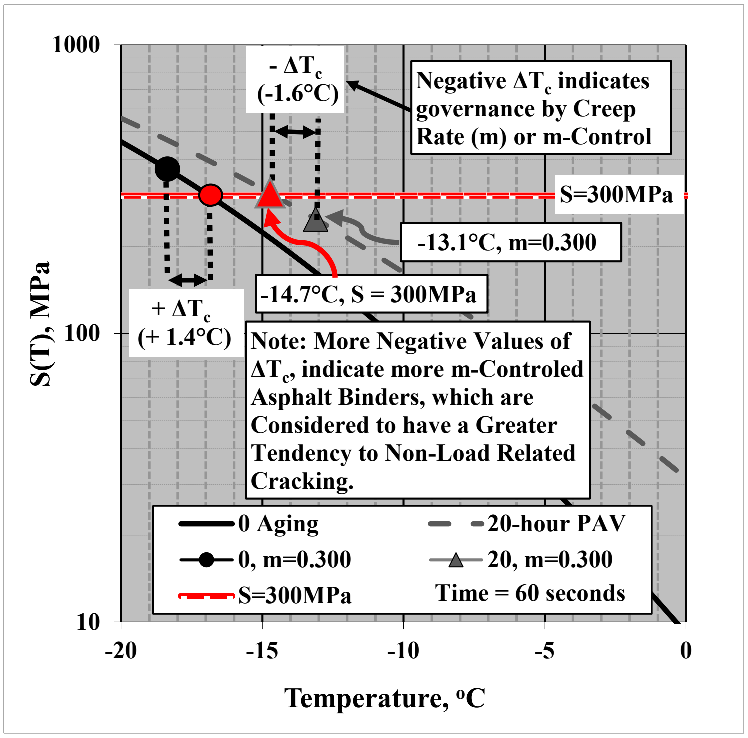
Elements Impacting ΔT_c Asphalt Binder Aging

Asphalt technologists continue to work with the ΔT_c parameter to determine what it may indicate with repect to asphalt durability. As asphalt binder ages, the ΔT_c differential generally becomes greater and more negative, indicating what is believed to be loss of relaxation properties as the asphalt binder becomes more m-value controlled. The effects of aging on the ΔT_c parameter leads to a question of concern to asphalt technologists: *what degree of laboratory aging is necessary to adequately evaluate ΔT_c as it relates to field performance?*

Asphalt binder aging studies have included extended PAV aging cycles of 40, and 80 hours, in comparison to the standard 20-hour PAV cycle, utilizing the ΔT_c parameter to evaluate aging effects on long-term duability.(3,14-19,22) Figure 3 shows the effect of standard 20-hour laboratory aging via the PAV in comparison to unaged asphalt binder. The figure is based on data from AAPTP Project 06-01 for a Gulf Southeast (GSE) crude-based asphalt binder.(3)

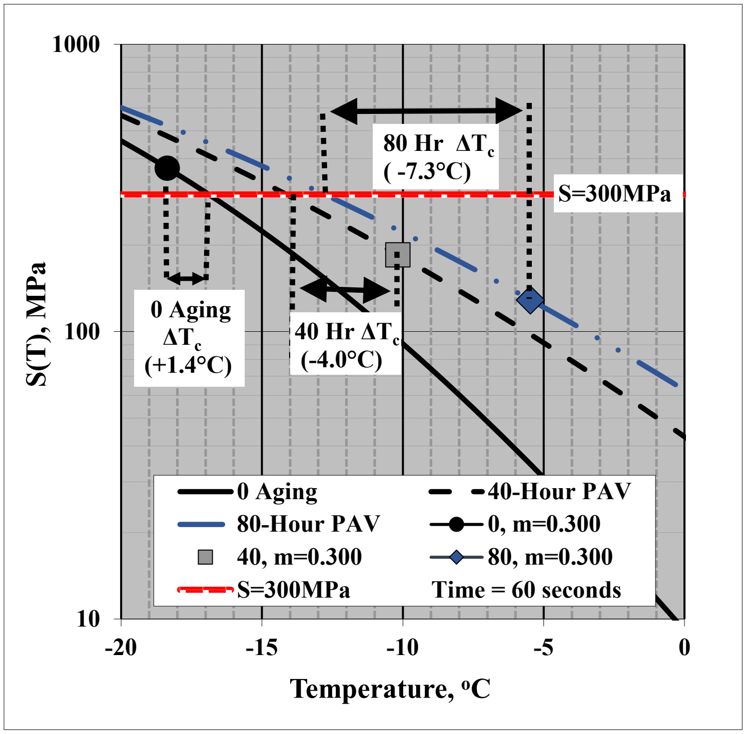
Figure 4 shows that for the same asphalt binder GSE, the effect of extended laboratory aging via the PAV for aging periods of 40 and 80-hours in comparison to unaged asphalt binder GSE.(3)

Chapter 4 of AI IS 240 sumarizes additonal work from AAPTP Project 06-01 as well as work from various industry researchers with regard to the effect of asphalt binder aging on ΔT_c.(1,3)



Source: Paragon Technical Services, Inc.

Figure 3. Effect of 20-hour PAV aging time on ΔT_c.



Source: Paragon Technical Services, Inc.

Figure 4. Effect of 40, and 80-hour PAV aging time on ΔT_c.

RAP and RAS

Similar to extended aging of virgin asphalt binder, combining pre-aged materials such as RAP, or RAS, with a virgin asphalt binder could result in an asphalt binder with a more negative ΔT_c .

Table 1 presents ΔT_c data from a National Cooperative Highway Research Program (NCHRP) Project 09-12, October 2000.(18) The impact of RAP on ΔT_c as compared to non-aged asphalt binders is shown by results of addition of RAP binders recovered from reclaimed pavements in three distinctly different climatic regions: hot wet, (A); cold wet, (B); and hot dry (C). Thus, exhibiting distinctly different stiffness values for recovered asphalt binder: low stiffness (A); medium stiffness (B); and high stiffness (C).

Table 1 shows that addition of recovered RAP binders to virgin PG 52-34 and PG 64-22 produced either decreasing positive values or more negative ΔT_c values with increasing RAP contents. Additionally, data from NCHRP 09-12 revealed that harder recoved RAP binder caused greater decay in ΔT_c than softer recoved RAP binder. Transprotation Research Board (TRB) E-Circular 241 also revealed a trend that more negative ΔT_c values had a direct relationship to pavement fatigue life.(22)

Table 1. Effect of RAP on ΔT_c.

Asphalt Binder Blend	0% RAP	10% RAP	20% RAP	40% RAP
PG 52-34 Plus RAP A	2.2	–0.1	–0.7	–0.8
PG 64-22 Plus RAP A	–1.9	–2.8	–3.1	–1.7
PG 52-34 Plus RAP B	2.2	0.2	0.1	–0.7
PG 64-22 Plus RAP B	–1.9	–2.7	–2.8	–4.4
PG 52-34 Plus RAP C	2.2	0.4	–1.0	–2.8
PG 64-22 Plus RAP C	–1.9	–3.4	–5.1	–4.8

Source: Paragon Technical Services, Inc.

RAS asphalt binder is highly oxidized and very stiff; therefore, RAS is expected to impact ΔT_c to a higher degree than experienced with RAP asphalt binder.(18–20) Calculations of the ΔT_c of RAS asphalt binder is not as straight forward as with RAP asphalt binder due to RAS binder stiffness. This highlights some of the issues with ΔT_c. Extraction and recovery comingles the RAS and virgin binders whereas this does not occur to the same extent in the field. Table 2 presents estimated ΔT_c data from RAS binders from the National Center for Asphalt Technology (NCAT) Report 16-01 as reported in TRB E-Circular 241 and additional data from AI IS 240.(1,21–23)

Chapter 4 of AI IS 240 provides additonal summary information from TRB E-Circular 241 and NCAT Report 16-01, as well as work from various industry researchers with regard to the effect of RAP and RAS on ΔT_c.(1,22,23)

Table 2. Estimated ΔT_c of RAS Binder.

RAS Source	T_c High	T_c Low	ΔT_c (°C)
New Hampshire	163.0	12.0	–33.0
Oregon	152.0	14.0	–37.0
Texas	122.0	–7.0	–23.0
Wisconsin	146.0	16.0	–40.0
Wisconsin	146.0	6.0	–31.0

Source: Paragon Technical Services, Inc.

Re-refined Engine Oil Bottoms

Re-refined Engine Oil Bottoms (REOB), vacuum tower asphalt extenders (VTAE), and other fluxing agents for softening and adusting low temperature parameters of asphalt binders are known to impact ΔT_c. While not every source of REOB affects ΔT_c to the same extent, REOB typically affects ΔT_c in REOB modified asphalt binders through more negative values of ΔT_c, as compared to the base asphalt binder being modified. The most significant effect of REOB on ΔT_c is typically directly related to dosage level, with higher REOB contents exhibiting more negative values of ΔT_c.(24)

The response of ΔT_c to REOB content has been shown to exhibit more negative values of ΔT_c with increasing REOB content. Producers limiting REOB use levels in asphalt binder formulations may be of better service than State DOT ΔT_c parameter specification limits alone. With respect to softer asphalt binders with lower low-temperatues, extended PAV aging (e.g., 40-hour PAV) may be desirable. Chemical and intrumental methods are available to detect presence and content of REOB in asphalt binders. Implementation of such methods may also be more functional than limiting REOB use by aging and ΔT_c parameter specifications.

Chapter 4 of AI IS 240 and AI Informational Series IS-235 "State-of-the-Knowledge, The Use of REOB/VTAE in Asphalt," provide additonal summary information on work from various industry researchers with regard to the effect of REOB on ΔT_c and use guidelines for REOB.(1,25)

Elastomeric Polymer Modification

Asphalt binder blended with a polymer modifier can also be evaluated for ΔT_c; however, there are concerns on the validity of characterizing polymer modified asphalt binders using ΔT_c.(22,26,27) Certain features of elastomeric polymer modification may have a worsening effect on ΔT_c and therefore make it appear as if polymer modified asphalt binders are exhibiting diminished durability.

Table 3 presents an example of experimental data using one PG 64-22 asphalt binder and two different levels of elastomeric modification. The results are counterintuitive as it is fairly well accepted among asphalt pavement materials engineers that elastomeric polymer modification enhances both low- and high-temperature performance of asphalt materials.

Elastomeric polymer modified binders generally exhibit a higher elastic component as evidenced by lower phase angle at a given temperature or stiffness. Because of the effect on phase angle, it is believed that some elastomeric polymer modified asphalt binders exhibit lower (more negative) values of ΔT_c; however, this does not necessarily equate to more non-load related distress.(1,26,27)

Table 3. ΔT_c Data for Neat PG 64-22 and Polymer Modified PG 64-22.

Asphalt Binder	**ΔT_c (°C)**
PG 64-22 (Neat)	–3.6
PG 64-22 + 3.0% Steryne-Butadiene-Styrene (SBS)	–3.9
PG 64-22 + 7.5% Steryne-Butadiene-Styrene (SBS)	–7.5

Source: Paragon Technical Services, Inc.

Combined Effects

Combined effects of aging using RAP, RAS, and REOB with repect to impact on ΔT_c should be considered. It is not unusual to encounter combinations of all of these concepts in a single paving system.(1) Specifications incorporatingthe ΔT_c parameter in asphalt binder acceptance specification may not identify combined effects that may make, for example, a balanced mix design (BMD) approach more suitable for evaluating potential long-term pavement durability.

Implementation of ΔT_c

Some engineers favor implementation of ΔT_c as a "PG-plus" State DOT requirement to the AASHTO M 320 and/or AASHTO M 332 specifications.(5,6) Those engineers favoring ΔT_c as a specification parameter lack consensus on the degree of PAV aging limits and specific limits to ΔT_c values.(1) However, there does appear to be common concern of a need to better simulate field aging in the laboratory matched by a need to obtain expeditious result of quality control and acceptance testing.(1)

AI IS 240 suggests a systematic approach for consideration in implementation of ΔT_c. This framework entails the following five steps:(1)

- Identify the problem ΔT_c is intended to address.
    - Delta T_c is primarily aimed at non-load related asphalt pavement distress that is tied to lack of durability exhibited by asphalt binders. More negative ΔT_c may have at least an indirect effect on most forms of cracking in asphalt pavements; however, block cracking of age-embrittled pavements is the asphalt pavement distress directly related to ΔT_c. (1)
- Determine whether ΔT_c is the most favorable alternative.
    - Delta T_c may is not a fix-all to asphalt pavement cracking. Other specification parameters may offer better alternatives to a specific distress. It is encouraged to consider all available alternatives to achieve the stated goals.
- Select aging method to ensure ΔT_c measurements are representative.
    - To ensure that the ΔT_c parameter is relavent to the asphalt pavement distress to be addressed, choose a laboratory aging protocol that accurately simulates in-service aging of representive pavements and samples.
- Evaluate existing pavements that exhibit diverse cracking behavior.
    - Evaluate in-service aged asphalt pavements of a range of cracking behaviour caused by age-related embrittlement. Actual in-service aged pavements, with no additional laboratory aging, better represent expected performace, specifically the upper one-half inch (12.5mm) of the field aged pavement.
- Evaluate ΔT_c results obtained to determine simulative aging protocol.
    - Thoroughly evaluate ΔT_c test results from evaluation of binder recoved from in-service aged asphalt pavement to arrive at the necessary aging protocol to simulate the in-service ΔT_c values obtained.

A complementary element to the framework is a concerted effort with all entities working together regionally to facilitate uniform transition for the asphalt industry.(1)

A State-by-State review of the Asphalt Institute "*US State Binder Specifications*" database of published asphalt binder specifications showed 11 State DOTs had adopted a ΔT_c specification parameter.(28) This is consistent with State DOTs reported by AI IS-240 to have adopted a ΔT_c specification parameter.(1) Most, but not all, of these State DOTs adopted a minimum limit for ΔT_c of –5.0°C. The indicated basis for this specification value is AAPTP Project 06-01.(3) There appears to be an even split between State DOTs using 20-hour and 40-hour PAV aging protocols, with States in warmer climates (using PG 64-XX binders) tending toward 20-hour PAV aging while States in colder climates (using PG 58-XX binders) preferring 40-hour PAV aging.

Alternatives to ΔT_c and Ongoing Research

Cracking may be the predominant distress affecting pavement performance in some regions of the United States. Over the past several years numerous new asphalt binder cracking properties have been evaluated and ΔT_c is just one such property considered. State DOTs desiring to address age-related embrittlement by specification means other than or in addition to the ΔT_c parameter may wish to consider alternate approaches.

Correlations between ΔT_c and other rheological parameters have been suggested.(29) Specifically, one relationship supports the findings from AAPTP Project 16-01 regarding the Glover parameter, $G'/(\eta'/G')$. Where G' is the storage shear modulus and η' is the storage dynamic viscosity. In this relationship it has been suggested that the Glover parameter could be converted to a rheological specification parameter represented by $G^*(\cos\delta)^2/\sin\delta$ at 15°C and 0.005 radians/second with limits greater than or equal to 180 MPa.(30) This specification is referred to as the Glover-Rowe (GR) parameter and has been considered as a surrogate to ΔT_c. Others have proposed using both GR and ΔT_c in conjunction as cracking indices, since the GR parameter may be more responsive to stiffness and ΔT_c more responsive to relaxation.(31) Relationships of other rheological parameters have also been discussed such as the Rheological Index (R) as a parameter describing the shape of the rheological master curve which is critically related to the shape of the relaxation spectra and ability of a material to relax stresses. Additionally, master curve related parameters have been suggested to include Cross-over Temperature (T_{VET}) and Cross-over Modulus (G^*_C).(14,30,32,33 33)

Asphalt technologists have suggested specifications limiting S at the critical m-value.(34) For example, specification limits for acceptable ΔT_c values or specification of a minimum S-value where the m-value meets the current specification limit of 0.30. Establishing a minimum S-value acceptance criteria is a reasonable alternative and does a reasonable job of screening asphalt binders with large negative ΔT_c as well as limit the effects of improper use of deleterious additives. Similar ongoing research indicates that the ΔT_c parameter may be more effective at identifying effects of deleterious additives in asphalt binders than as a predictor of asphalt binder cracking and durability.(35) Similarly, the ongoing research prefers a minimum S-value for a given m-value with the exception of incorporation of modeling concepts to suggest variable S-value minimums applied to variable m-values for specific values of ΔT_c. For example, if $\Delta T_c = -8$°C then the specification limit would be a minimum S-value of 125 MPa, with an allowable increase of the minimum S-value to 150 MPa for m-values greater than 0.32. In consideration of these observations of the ΔT_c parameter's functionality to identify deleterious additives, it is understandable that the ΔT_c parameter could be used to identify presence of non-bituminous asphalt binder components; however, as discussed, more straightforward methods of restricting use of unwanted asphalt binder additives are possible.

A correlation has been reported between ΔT_c and phase angle (δ) ,suggesting it may be possible to specify a minimum δ at a given asphalt binder stiffness for long-term aged asphalt binders.(36) Considering the fact that both the ΔT_c parameter and δ are related to relaxation, this may facilitate asphalt binders that are not prone to age-related cracking such as asphalt binders modified with elastic polymers. As with minimums for S-value, minimum δ could also be used in companion to ΔT_c limits.

Recent work by the Western Research Institute (WRI) under NCHRP Project 09-60 builds on previous research to address durability and cracking issues related to asphalt binders.(37) The ΔT_f parameter was put forward by the NCHRP Project 9-60 researchers as the asphalt binder property relating most closely to durability. Extensive studies of asphalt binder blends with known issues continually related back to ΔT_c. While the ΔT_c parameter distinguishes between good and poor neat asphalt binders, it did not address anomalies previously identified with elastomeric polymer modified asphalt binders. To address this, the NCHRP Project 9-60 researchers included fracture testing of the asphalt binder using the Asphalt Binder Cracking Device (ABCD) asphalt binder fracture test to evaluate the strength of modified asphalt binders and combined the two to evaluate durability. Including the failure property addresses the nonlinear response of modified asphalt binder systems that have proven to perform well in cracking. Suggested ΔT_c parameter specification limits and recommendations, from the project researchers, for employing the ABCD test are presented in the final report of NCHRP Project 09-60.(37)

Summary

This document is a review and summary of the current "State-of the-Knowledge" of ΔT_c as a parameter to characterize asphalt binder behavior. It relies on a recently released "State-of-the-Knowledge" document by the AI entitled: *Use of the Delta Tc Parameter to Characterize Asphalt Binder Behavior*.(1)

The objective is to provide knowledge and technical support for responsible deployment of ΔT_c as a specification parameter into asphalt binder acceptance specifications should State DOTs be considering implementation. In particular, the purpose is to provide some preliminary considerations, a "yellow light" so to speak, if a State DOT has pressing needs and wants to proceed with implementation while acknowledging that information on ΔT_c continues to evolve.

A systematic structured approach to implementation of the ΔT_c parameter as per the AI's implementation guidelines provided by AI IS-240 is discussed.(1) This approach consists of five steps framework of: clearly identifying the problem ΔT_c is intended to address; determination of whether ΔT_c is the most favorable alternative; selection of the most appropriate aging method; a structured approach for sampling and testing laboratory-produced and in-place cores for the purpose of gaining sufficient data to ensure that a proposed ΔT_c specification would be relevant; and evaluation and presentation of ΔT_c data as well as potential alternatives to a ΔT_c specification parameter.

Finally, alternatives to the ΔT_c parameter and on-going research are presented to assist in implementation decisions and provide a snapshot of research activities.

The ΔT_c parameter's original intended purpose was forensic in nature as a parameter to stage application of preventative maintenance treatments, it has evolved into something of much broader focus. Among industry professionals there is general acceptance that the ΔT_c parameter is an effective tool to gauge asphalt durability, with general consensus that wider, more negative, values of ΔT_c are highly related to development of block cracking.(1) Use of ΔT_c as a specification parameter is less accepted with most suggesting use be limited to an evaluation tool with –5C° at 20-hours of PAV aging as a limiting value.(1) There appears to be an even split between State DOTs using 20-hour and 40-hour PAV aging protocols, with States in warmer climates (using PG 64-XX binders) tending toward 20-hour PAV aging while States in colder climates (using PG 58-XX binders) preferring 40-hour PAV aging.(1) Of those in favor of implementation of the ΔT_c parameter for specification purposes there is a good starting point with –5C° as a limiting val.(1) There is not full agreement that this would be universal.(1)

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Delta Tc Binder Specification Parameter

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