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Developing maturity methods for the assessment of cold-mix bituminous materials

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HIGHLIGHTS

- ▶ A maturity function was developed for conditioning effects on cold-mix materials.
- ▶ A correlation between maturity and stiffness was identified.
- ▶ Method was applied to assess climatic effects on cold-mix pavements in service.

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ABSTRACT

Cold-mix bituminous materials offer a sustainable, cost effective alternative to traditional hot-mixes. Difficulties however can be encountered when specifying cold-mix materials due to the strong influence of time and temperature on material performance. In the field of concrete technology maturity methods are routinely used for assessing materials of known curing history. This research presents the development of a maturity approach for the assessment of cold-mix bituminous materials and its application for predicting the effect of climatic variations on in situ mixture performance. A strong correlation was observed between the calculated maturity and the measured stiffness for a range of conditioning temperatures and durations thus enabling the prediction of long and short-term material performance in situ where ambient conditions are known.

1. Introduction

Cold-mix pavement materials are defined as bituminous materials mixed using cold aggregates and binder [1]. By eliminating the need to heat the large volumes of aggregate substantial savings, both financial and environmental, can be achieved in comparison with traditional hot-mix materials. Furthermore, because the compactability of the material is not related to the mix temperature, cold-mixtures are portable and are therefore ideally suited for use in the construction and maintenance of rural roads as they remove the need for portable hot-mix asphalt plants [2].

Despite the potential environmental and cost benefits associated with cold-mixes, there are a number of factors hindering their wider use. These include an inconsistent approach internationally to specifying this material and an incomplete understanding of the strength development of cold-mixes when in service. Foremost however is the lack of suitable assessment criteria for cold-mixes. Serfass et al. [3] describe cold-mixes as evolutive materials. They gain strength slowly as the material dries, developing strength over time in a manner more akin to a cementitious material [4]. This is in contrast to hot-mix materials which gain strength quickly as the material cools. Consequently traditional assessment methodologies developed for hot-mixes are often not best suited to cold-mixes. In this context, the objective of this research was to facilitate the use of cold-mix bituminous materials in Ireland by providing a maturity-based prediction method for long-term and short-term performance.

2. Conditioning regimes

Accelerated curing is required for cold-mix materials prior to laboratory testing due to its low initial strength to simulate the medium to long-term performance of the material in situ [1]. The long-term stiffness of the material will not be achieved until a substantial reduction of the moisture content has occurred. The principal difficulty involved in the testing of cold-mixes is combining a test of short duration with the requirement to simulate the working environment of the material. Leech [5] reported that the

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Table 1
Summary of conditioning regimes recommended for cold-mixes.

	Oven conditioning		In situ equivalent	Foam (F) or emulsion (E)
	T (°C)	*t* (days)		
Kekwick [7]	60	1,3,7		F, E
Bowering [4]	60	3		F
Bowering and Martin [10]	60	3	Early field life	F
Acott (1980); cited Jenkins [1]	60	3	23–200 days	F
Muthen [6]	60	3		F
Maccarrone [11]	60	3	1 year	F, E
Ramanujam and Jones [12]	60	3		F
Sabita [13]	60	2		E
Kishore Kumar et al. [14]	60	2	28 days	E
Yan et al. [15]	60	2		F, E
NRA [17]	40	28	1 year	F, E
Thanaya et al. [2]	40	18–21		E
O'Prey [8]	40	7		F
Ruckel et al. [9]	40	3	30 days	F
Jenkins [1]	40	3		F, E
Asphalt Academy (2002); cited [7]	40	3	6 months	F
Kim and Lee [16]	40	3		F
Sabita [13]	40	2		F
Ruckel et al. [9]	40	1	7–14 days	F
Asphalt Institute; cited Ruckel et al. [9]	38	1	1 week	E
Brown and Needham [19]	20	100 + 1 @60 °C	1 year	E
NRA [17]	20	28	1 month	F, E
Sabita [13]	Ambient	28		F
Sabita [13]	Ambient	7		F
Ruckel et al. [9]	Ambient	1	1 day	F

laboratory simulation of in situ curing was the most unsatisfactory part of cold-mix emulsion mixture design. Later Muthen [6] attributed the limited application of Foamix technology in South Africa to the lack of a well-documented standardised mix-design procedure.

2.1. Existing laboratory conditioning regimes

A number of commentators have investigated the multitude of laboratory conditioning regimes in use for the accelerated curing of cold-mixtures [1,7,8]. A review of the literature was conducted and a summary of conditioning regimes used and recommended for cold-mixtures is presented in Table 1. It can be seen that a number of the references specify multiple different oven conditioning regimes, designed to simulate different periods of in situ conditioning. Three distinct temperature ranges are identified in the table; ambient −20 °C, 38–40 °C, and 60 °C. With the exception of Ruckel et al. [9] a conditioning temperature of 60 °C dominated for almost 30 years [4,6,10–15]. A conditioning temperature of 40 °C gained wider use in the late 1990s. Typically conditioning at 40 °C was undertaken for a period of 3 days [1,6,8,9,16]; however other durations also appear in the literature [9,13,17]. Curing regimes at ambient temperature have more recently been used to overcome the difficulty correlating accelerated laboratory testing to in situ conditions. SABITA [13] included two ambient temperature conditioning regimes of 7 and 28 days in its recommended curing protocols for emulsion mixtures.

2.2. In situ conditioning simulation

The proposed equivalent in situ conditioning duration simulated in the laboratory is included for a number of the regimes in Table 1. There is a clear trend evident in the table with the increase in both duration and temperature of conditioning in the laboratory correlating to an extended duration of in situ conditioning. On the other hand there is considerable variation in the particular values from different researchers and little has changed since Ruckel et al. [9] reported that correlation between laboratory and field data from different locations was problematic with Thanaya et al. [2] reporting a similar difficulty in 2009.

Ruckel et al. suggested that curing the specimens for 3 days at 40 °C simulates 1 month of conditioning in the field. This contrasts with the recommendations of the Asphalt Academy (2002; cited [7]) who suggest that this conditioning regime simulates 6 months of conditioning in situ. A similar range of equivalent in situ conditioning times is apparent for 3 days of conditioning at 60 °C. Acott (1980; cited [1]) equated this laboratory regime to a very broad time span of 23–200 days of field curing whereas Maccarrone [11] estimated that this simulates an equivalent of 1 year of field curing.

2.3. Correlating conditioning regimes

Previous research by Doyle et al. [18] outlined a study to enable the correlation of different laboratory conditioning methods in which cold-mix bitumen emulsion material was tested for strength gain for a range of conditioning temperatures and conditioning durations. They identified a logarithmic increase for the stiffness of the material over time. They found that by varying time and temperature it is possible to achieve a significant range of performance values. However, they note that the objective is not to maximise the stiffness but rather to best represent what the material can achieve in the field. In situ cold mix materials gain strength over time and consequently each of the values of strength and stiffness achieved in the course of testing has relevance to a particular age of that material in situ. Brown and Needham [19] and Ozsahin and Oruc [20] reported a similar profile of stiffness gain for a number of cold-mix materials including a number of mix additives such as Portland cement, hydrated lime and calcium chloride also incorporating variation in the bituminous binder content.

2.4. Maturity methods

The maturity method is commonly used in the concrete industry to determine the strength of the material after cycles of curing at varying temperatures [21,22]. There are a number of approaches