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Predicting the permanent deformation behaviour of the plant produced asphalt concrete mixtures: A first order regression approach

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HIGHLIGHTS

- Characterised plant produced mixtures.
- Developed an FNP parameter.
- Modelled FNP with M_R, volumetric, and gradation.
- Performed sensitivity analysis of the developed model.
- Compared the developed model with an existing model.

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ABSTRACT

Recent studies have shown that Flow number (FN) alone may not be able to describe the permanent deformation (PD) behaviour of a mix, rather additional parameters are considered, e.g., dynamic modulus (|E*|), gradation, and mix volumetric, to get better insights into PD behaviour. However, stiffness in terms of Resilient Modulus (M_R) has not been considered even after its appealing efficacy in 1993 AASHTO design guide. As such, the objective of this study is to characterise the mixtures that do not attain tertiary flow state by a new parameter, Flow Number Prime (FNP). Furthermore, the developed parameter is used to study the relationship of PD behaviour with M_R. Seven plant produced mixtures were compacted using Superpave gyratory compactor. FN test was carried out at a single temperature while M_R test was conducted at two temperatures. The M_R results show a good consistency with the FN test results. A first-order multiple linear regression model for predicting the PD behaviour is developed as a function of the M_R, the mix volumetric, and the gradation parameters. The developed model is validated, and sensitivity analysis is performed to determine the change in the PD with respect to explanatory variables. The developed model is also compared to an existing model in the literature and results indicate a better performance of the model developed in this study. The findings of this study are expected to provide valuable insights to the characterisation of plant produced mixtures and its relationship with PD behaviour, and can also help in QA/QC of the pavements during construction phases of projects whereby engineers and/or practitioners can ensure the quality based on a lesser time consuming test (M_R) on different sections of the same project.

1. Introduction

Flexible pavements manifest several distresses when exposed to repeated traffic loadings and extreme weather conditions [1]. These distresses include Permanent Deformation (PD), fatigue and thermal cracking, ageing, stripping, and to mention a few [2]. PD (also known as rutting) is one of the most serious distresses reported in the literature [3–6]. PD occurs mainly due to structural characteristics of a pavement (that is, material properties), increased tyre pressure, adverse environmental conditions, and inadequate design practices. Evidently, constructional practices in the field also have a significant impact on PD, however, such bad constructional practices may be averted inside the controlled

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atmosphere of laboratory. Moreover, PD deteriorates the pavement surface and leads to a premature failure. To minimise such premature failure, the pavement analysts and practitioners are continuously enhancing the design practices along with material properties. Such collaborative efforts have resulted in Mechanistic-Empirical Pavement Design Guide (M-EPDG) [7]–a realistic and more suitable design guide especially for the areas where excessive loadings and extreme weather conditions are two important contributing factors [5,8–11].

M-EPDG recommends three candidate performance tests namely, dynamic modulus ($|E^*|$), Flow Number (FN), and flow time for performance evaluation of AC mixtures. Characterisation of AC mixtures using $|E^*|$ and FN in the laboratory has received a significant attention in the literature [5,6,10–13]. In addition, surrogate measures, such as FN Index, are introduced [4,9] to explain the PD performance of AC mixtures when the conventional FN is inaccurate. However, most of the earlier studies focussed on the laboratory performance and recommended the use of the developed surrogate measures for the field mixtures. As such, the surrogate measures for the field prepared (or plant; these two terms are used interchangeably in the rest of the paper) mixtures and their performance have been largely ignored in the literature with a few exceptions [11,14,15]. Irfan et al. [11] characterised plant produced AC mixtures using $|E^*|$ while PD performance has been disregarded. Similarly, Li et al. [14] characterised the field mixtures using an advanced repeated load permanent deformation test and reported the compared the AC mixtures using various metrics. Moreover, Goh et al. [15] compared laboratory results with the field PD performance, however, no model was developed to express the relationship of PD performance with the explanatory variables.

Recent studies have reported the inaccuracy/inability of the conventional FN for describing PD behaviour [4,9]. More specifically, when AC specimens do not reach the tertiary flow state and attain the maximum loading cycles of 10,000, it is difficult to characterise AC mixtures and subsequently, model their PD behaviour. Such a difficulty is often observed when plant produced mixtures are tested in the laboratory because of different preparing conditions, which are obviously not controlled and different from the laboratory. It is worth mentioning here that FN Index–a parameter developed as a surrogate to conventional FN–was introduced for the laboratory mixtures that can reach the tertiary flow state and to the best of authors' knowledge, no evidence exists about suitability of FN Index for the field prepared mixtures that remain in the secondary flow state at the end of the test. For such mixtures, accumulated strains is the only criterion of characterisation since FN would be same for all the mixtures. The literature review suggests the mischaracterisation of AC mixtures based on accumulated strains only [5]. Earlier studies [4,9] explained the preliminary reason of using FN Index instead of conventional FN as the problem of noise caused by attaining the tertiary flow stage. However, the applicability of FN Index, which is ratio of accumulated strain to FN, to the mixtures that do not attain the tertiary state (and problem of noise) has not been tested. All of these reasons motivated the present study to develop/introduce a new parameter to: minimise the concern of noise; characterise the mixtures that remain in the secondary flow state even after the termination of loading cycles; and capture the diverse field behaviour of AC mixtures.

Besides the under-representation and lack of guidelines for characterisation of the field AC mixtures, the correlation of M_R with PD has received little attention in the literature perhaps because of $|E^*|$–a stiffness parameter introduced in M-EPDG for characterisation of strength of AC mixtures. Understandably, with the advent of M-EPDG, the utilisation of M_R has diminished as $|E^*|$ has been used as a stiffness parameter and many studies have been conducted to characterise AC mixtures using $|E^*|$ [5,6,8,10–13] and to model PD behaviour as a function of $|E^*|$ [3–5,9]. M_R has been used as a stiffness criterion of a mix for a long time. Many inventories also exist for M_R that are becoming obsolete since M_R has been replaced by $|E^*|$ in the current M-EPDG. To this end, many research studies have emphasised on the correlation of M_R and $|E^*|$ [13,16,17]. However, M_R as an indicator of PD behaviour of an AC mix and its modelling has been largely ignored in the literature.

The objective of this study, therefore, is threefold: (a) to evaluate the performance of the plant produced AC mixtures using a new performance indicator; (b) to model the relationship of the PD behaviour of AC mixtures with M_R coupled with the other explanatory variables; and (b) to compare the developed model with the existing model in the literature.

To this end, the rest of the paper is summarised as: Section 2 reviews the FN and M_R modelling efforts. Section 3 defines the experimental design including the selection of material and the specimen preparation. Section 4 explains the laboratory test results for FN and M_R, the model development process including validation, and the comparison of the models. Section 5 discusses the results and its implications; and Section 6 presents the main findings, limitations, and future research directions.

2. Literature review

This section briefly explains FN and M_R and their modelling efforts. Providing a comprehensive and exhaustive review of the modelling studies is beyond the scope of this study.

2.1. Flow number (FN)

FN, obtained through a repeated loading test, is defined as the starting point/cycle number at which the tertiary flow occurs on a cumulative permanent strain curve obtained during the test. The FN test captures the fundamental material properties of an AC mix that correlate with PD behaviour. This test applies a dynamic haversine waveform stress with a wavelength of 0.1 s followed by a rest period of 0.9 s [18].

Table 1 summarises the studies in the literature explaining the modelling efforts of PD behaviour using FN. It can be observed that most of the studies focussed on the laboratory investigation of AC mixtures, which refers to the controlled environment exploration of AC mixtures whilst the field mixtures are rarely used. The behaviour of the field mixtures is altogether different from the laboratory mixtures since the field mixtures hardly achieve the tertiary flow state due to ageing in the field and reheating in the laboratory for compaction purpose, which seem to be the reason for not exhibiting the FN [5,6,19,20]. In such a scenario, the considered mixtures attain 10,000 loading cycles, resulting in difficulties for the characterisation of mixtures and development of an FN model. The surrogate measure, that is, FN index, was developed to characterise the mixtures when the conventional FN was unable to reveal the true material behaviour. The performance of the FN index, however, is yet to be tested. Moreover, if FN index is unable to provide insights into the performance of the field mixtures, e.g., PD and stiffness, a new parameter (that is, a surrogate measure) is required to characterise the mixtures that can be used for modelling purposes.

2.2. Resilient modulus (M_R)

M_R, also known as an elastic modulus, is a property of bounded and unbounded pavement materials characterising the elastic behaviour under dynamic traffic loading conditions [13]. M_R is used in conjunction with the elastic theory and AC mixtures are visco-elastic that tend to accumulate unrecoverable strains after certain repeated load applications.