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# An alternative protocol to artificially simulate short-term ageing of binders for selected regional condition

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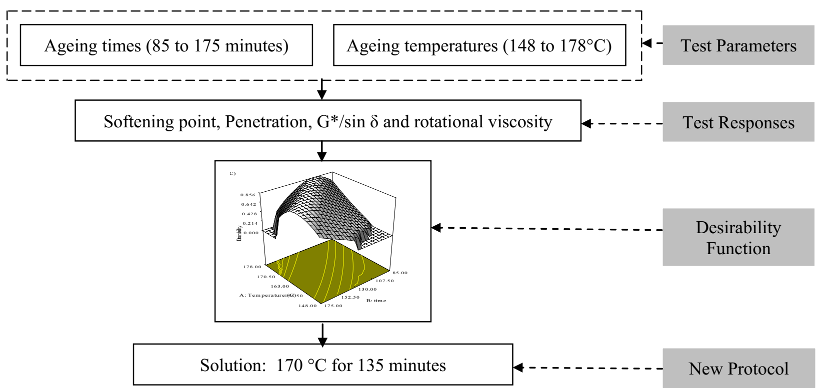
## HIGHLIGHTS

- ASTM D2872 may not be a sufficient method to simulate the short-term ageing process of binders under Malaysian conditions.
- RSM was used for determining the corresponding short-term ageing protocol.
- Each regional condition requires its own protocol for simulating short-term ageing of asphalt binders.

## GRAPHICAL ABSTRACT

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## ABSTRACT

This paper presents an alternative method for developing a laboratory short-term ageing procedure for binders that corresponds to the asphalt mixture production practices carried out in a tropical region. In this method, the ASTM D2872 procedure was adapted to artificially short-term age asphalt binders, while ageing time and ageing temperature were evaluated. A statistical technique named response surface method (RSM) was used for the design of experiment, analysis of the test results from the field and laboratory samples, and selection of an appropriate laboratory protocol. An experimental matrix was designed based on the central composite method for two basic independent laboratory factors: ageing times in a range of 85–175 min, and ageing temperatures within 148–178 °C. Several test variables, include softening point, penetration, $G^*/\sin\delta$ at 64 °C and rotational viscosity at 135 °C of three conventional binders were considered as dependent test factors (responses). The responses were analyzed using RSM to derive mathematical equations, while the corresponding time and temperature were determined from optimization of the test results. The outcome of this study indicated that the conventional short-term ageing protocol in accordance with the ASTM D2872 may not be sufficient to simulate the short-term ageing of asphalt binders in the Malaysian weather condition, where high daily temperatures, humidity, and ultraviolet are concerned. Based on the statistical analyses, both time and temperature have significantly affect the physical and rheological properties of short-term aged binders. Overall, all three binders show quadratic models for the resulting responses with the exception of two binders which show 2FI and linear models for its physical properties. The resulting optimization recommends a short-term ageing procedure at 170 °C for 135 min to appropriately mimic the field binder properties under Malaysian climate.


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## 1. Introduction

Asphalt pavement materials start to age as soon as it is exposed to heat during mixing of the aggregates with binders, in an asphalt mixture mixing plant. Throughout the entire pavement life, asphalt binders undergo two entirely different ageing processes. The first ageing process is experienced during the mixing and laying operations, which is defined as short-term ageing. It is followed by the long-term ageing that took place during its service life within 7–10 years in the field, where the asphalt binder continue to harden at a much slower rate at the prevailing pavement temperature. In the laboratory, accelerated ageing techniques were invented and designed to reproduce the asphalt binder at both ageing conditions [1].

Several studies have been conducted to verify the applicability of the rolling thin film oven (RTFO) test under various possible conditions. For instance, in the current Superpave binder specification, Hveem et al. [2] originally proposed that the rutting potential of HMA is determined by evaluating the asphalt binder that had formerly went through the short-term ageing process using RTFO test method. Li et al. [3] conducted numerous tests to evaluate the rheological properties of the recovered and original binders that were aged using standard procedures (RTFO and Pressurized Ageing Vessel), as well as some additional tests. The test results indicated that there are significant differences between the recovered and laboratory-aged binders. Lee et al. [4] studied the short-term ageing effects of nine binders using RTFO ageing methods. The test results were then compared with the field-aged binder samples and found no valid correlation between them.

Over the years, various experimental design software and mathematical models were used to understand the limitations and determine the best possible approach to simulate the ageing mechanisms under a specific condition. In literature, analysis using one factor at a time method is common to find the optimum condition of the testing materials. This method may be adequate at some extent, yet it consumes a great deal of labor, materials and time. This study applied the response surface method (RSM) to determine the corresponding combination of time and temperature that mimics the short-term ageing on site. RSM is a collection of statistical methods for designing experiments, developing models and assessing the effects of the experimental factors and optimizing the process. This method has been effectively used in several asphalt studies as summarized in Table 1. The availability of scientific supports for RSM in statistical handbooks promotes its application in different disciplines. This implies that RSM can be a potential tool in assisting a properly designed experimental research for the development of a short-term ageing procedure.

This paper proposes an alternative protocol for the adaptation of ASTM D2872 [16] in artificially short-term ageing of binders to suit selected regional conditions using RSM. In this study, the RTFOT was applied, while ageing time and ageing temperature were evaluated. The RSM technique was used for the design of experiment, analysis of the results from laboratory and field data and selection of an appropriate laboratory protocol. Experimental matrix was designed based on the central composite method for two basic independent laboratory factors, namely ageing time and ageing temperature. Softening point, penetration, $G^*/\sin\delta$ at 64 °C and rotational viscosity at 135 °C were considered as the responses. Analysis of variance (ANOVA) was conducted on the obtained results to determine the significant factors for predicting the rheological properties of binders. The responses were analyzed using RSM to develop mathematical relationship between test responses and test factors (ageing time and temperature). The corresponding time and temperature that are similar to field results were determined from optimization of the models. In this approach, the required target values for selecting the appropriate time and temperature were first defined. The resulting combination of time and temperature were then determined from the target values. The use of RSM not only decreases the number of samples required for testing, but it also provides the possibility of determining the short-term ageing properties of binders at any selected condition.

The aim of this paper is firstly to present a concise account of the ageing phenomenon of asphalt binders in general. Secondly, to propose a new approach in developing a short-term ageing protocol that will suit any asphalt mixture production practices based on the RSM. This paper also investigates the interaction effects between experimental factors (ageing time and temperature) on ageing properties of asphalt binder. The research plan of this paper is illustrated in Fig. 1.

## 2. Materials and experimental procedures

### 2.1. Materials and methods

Three different penetration grade binders were used in this study, namely binder 80/100 from asphalt plant A, binder 80/100 from asphalt plant B, and binder 60/70 from asphalt plant B. Binder A was obtained from a quarry situated in Penanti, Penang, while, binders B were obtained from a quarry in Taiping, Perak. For easy reference, binders are labelled in accordance with the designation of the asphalt plant, followed by its penetration grade (A80, B80 and B60). Two classical physical properties of binders including penetration and softening point, as well as two Superpave properties of binders (viscosity and rutting factor ($G^*/\sin\delta$)) were selected for laboratory evaluation of binders. Based on these parameters, appropriate laboratory ageing duration and temperature will be identified. Table 2 summarizes the rheological properties of the virgin and RTFO aged binder according to ASTM D2872.

The asphalt binders were taken at the same time as the mixtures were produced to ensure the chronological order of the binders and mixtures were of the same source. All binders and mixtures collected were stored in sealed containers to minimize oxidation and premature ageing. The first stage involves collecting unaged binders from the bitumen tanks. Subsequently, asphalt mixtures were collected in the asphalt plants from the silo right after production and before transportation to site. These mixtures were produced using A80, B80, and B60. The binders from mixtures were then extracted and recovered by means of a rotary evaporator according to ASTM D5404 [17] standard procedure. The recovered binders were tested for its penetration, softening point, viscosity and Superpave rutting parameter. The results are shown in Table 3. The three unaged binders (A80, B80 and B60) were also short-term aged in the laboratory subjected to different ageing times and temperatures. Selection of the ageing durations and temperatures and their experimental design will be discussed in the following section.

**Table 1**
Use of RSM in asphalt studies.

| No. | Material | Software used | Design factors | Number of responses | References |
|---|---|---|---|---|---|
| 1 | Mixture | Design Expert 9.0.6.2 | 3 | 5 | Nassar et al. [5] |
| 2 | Mixture | Design-Expert | 4 | 6 | Hamzah et al. [6] |
| 3 | Binder | Design-Expert | 3 | 2 | Hamzah et al. [7] |
| 4 | Mixture | – | 3 | 3 | Haghshenas et al. [8] |
| 5 | Mixture | Minitab® 15.1.30.0 | 4 | 1 | Khodaii et al. [9] |
| 6 | Mixture | – | 2 | 2 | Haghshenas et al. [10] |
| 7 | Mixture | MINITAB Software (15) | 3 | 3 | Kavussi et al. [11] |
| 8 | Mixture | MINITAB Software (15) | 3 | 3 | Kavussi et al. [12] |
| 9 | Mixture | Design-Expert | 3 | 6 | Hamzah et al. [13] |
| 10 | Mixture | Minitab: Release15 | 2 | 3 | Khodaii et al. [14] |
| 11 | Binder | – | 2 | 2 | Valencia et al. [15] |