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Particle flow during compaction of asphalt model materials

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HIGHLIGHTS

- A lab-scale Flow Test (FT) was introduced to study flow of loose mixtures.
- It was initially used on model materials and the results demonstrated its efficiency.
- The FT results on real mixtures also showed internal particle rearrangements.
- Such findings can help for developing a field-based method for testing workability.

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ABSTRACT

Compaction is one of the key phases of the pavement construction and has been subject of research for a long time. However, very little is known regarding what really happens during compaction and how the pavement structure and the aggregate skeleton of the asphaltic layer are formed. Studies on that matter are of special practical importance since they may contribute to reduce the possibility of over-compaction and aggregate crushing. In this study, a new test method (Flow Test) was developed to simulate the material flow during compaction. Initially, asphalt materials were substituted by model materials to lower the level of complexity for checking the feasibility of the new test method as well as modeling purposes. Geometrically simple materials with densest possible combinations were tested for both dry and coated mixtures. X-ray radiography images were used for evaluating the material flow during compaction for different model mixtures. Results showed the capability of the test method to clearly distinguish mixtures with different properties from one another and also the potential of such a method to be used as an evaluating tool in the field. In addition, a simple discrete element model was applied for better understanding the flow of the model material during compaction as a basis for further improvement when moving from the asphalt model material to real mixtures. Therefore, real mixtures were prepared and tested under the same test configuration as for the model materials. The overall results of the real mixtures were found to support the model material test results.

1. Introduction

1.1. Background

Asphalt pavement construction consists of different phases from production and placement until compaction. Each phase has its own importance and influences the quality of the finalized asphalt layer directly or indirectly. The qualities of the materials as well as the efficiency of each construction phase have been studied by different researchers using a variety of test methods before, during and after road construction.

Before construction, standard test methods for aggregates and binder are applied. For example, the mixing temperature for proper coating during the mixing phase is determined using the Rotational Viscometer (RV) [1] or Dynamic Shear Rheometer (DSR) [2]. The workability of asphalt mixtures during the placement phase can be tested using the workability devices [3]. In this test method, an asphalt mixture is poured in a large pot and its resistance against a paddle with a constant rotating rate at the center of the pot is recorded. Also, Bahia, Hanz & Mahmoud, in 2011, [4] suggested using an analyzing plate at the top of the gyratory compactor to measure the resistance of warm mixtures during gyratory compaction. Despite of obtaining beneficial information from this type of compaction, it has some weaknesses when compared with real field compaction. In that case, the newly laid uncompact asphalt layer is not only pushed down by the roller compactor

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but suffers also some flow away from the compaction load due to high pressure and the free space around the load. In 2013, the importance of this flow was brought into light by Ghafoori Roozbahany, Partl & Witkiewicz [5] where it was shown that changing compaction methods for increasing the flow of mixture towards asphalt joints resulted in improving joint interface mechanical properties. Therefore, gyratory compaction does not fully describe the formation of the resisting skeleton of real asphalt layers due to its specially confined test setting.

During construction, a satellite based quality control system, i.e. Intelligent Compaction (IC) [6], has been introduced that constantly measures the density of the locations where the roller compactor passes. This method is more suitable for thick layers, e.g. subgrade, since the depth of measurements is approximately 1 m [7].

After construction, most of the quality measurements are conducted using either destructive (taking cores) or non-destructive methods, e.g. non-nuclear density gauge [9]. Despite of useful information obtained from such measurements, in case of low quality it would be very costly to replace or even overlay the poorly built road after construction. Even the maintained road in such cases never gets as smooth and convenient as a standard road. This highlights the importance of quality assurance right after production and before the construction phase.

Therefore, understanding the compaction phase is vital, in order to increase roads service lives by improving quality the mixtures in general and also lowering the costs of maintenance throughout their life span.

Based on the literature, the compaction phase can be divided into three stages, i.e. breakdown, intermediate and finishing [7,8]. Fig. 1 shows a schema of the densification during the compaction stages.

- The breakdown stage is where most of the densification occurs. This stage is completed during the initial roller compaction passing and causes relatively large deformations comparing with the other two compaction stages. It is also considered as the most important stage since the majority of the layer skeleton is formed at this stage.
- The intermediate stage takes place directly after breakdown when the roller compaction continues until the desired density is achieved based on the thickness lift of the layer. Not much of deformation occurs in the intermediate stage.
- The finishing stage is normally for smoothing the surface and does not cause structural change in the asphalt layer.

1.2. Methodology

The ultimate goal of this research was to find a way for conducting representative workability tests from the breakdown stage to the intermediate stage for understanding what happens when the fresh asphalt is placed and subjected to initial roller passes.

A test method, i.e. Flow Test (FT), is introduced that may allow a closer look at the breakdown stage in a very simplified but reproducible way. In order to examine the efficiency of such a method, after few trial tests, asphalt mixtures were substituted by model materials for performing sets of feasibility tests inside and outside of the X-ray Computed Tomography (CT) and then Discrete Element Modelling (DEM) was used to explain the observed test results. Afterwards, again, real aggregates and binders were used to investigate the level of agreement between the results of model materials with the real ones.

1.3. Experimental approach

In order to simulate the flow and densification during field compaction of asphalt, a device was designed in a way that there would be a free surface area for the material to flow and create a material uplift due to the compaction pressure. Therefore, a simple container was filled with an asphalt mixture and loaded from one side, thus simulating the roller compactor when settling on the loose material and pushing the material away as shown in Fig. 2.

2. Trial test

As an initial approach, a Marshall mold was used as a container (see Fig. 3). The test was conducted in two phases; first, for tracking purposes, the mold was filled with an asphalt concrete mixture of 16 mm Nominal Maximum Aggregate Size (NMAS). A 10 mm glass ball with a similar density to the mixture aggregates (≈2500 kg/m^3) was placed into the mixture near the center of the specimen. After cooling down at room temperature, the specimen was gently taken out from the mold. Then, a 3D X-ray CT was conducted for obtaining a 3D picture of the particles inside the specimen. After that, the mixture was placed back into the mold and heated again to the compacting temperature (140 °C) before being placed under servo-hydraulic load frame with displacement-controlled mode. Although compaction in reality is a force-controlled, this mode was used for comparing the densification process of different mixtures in an experimentally more

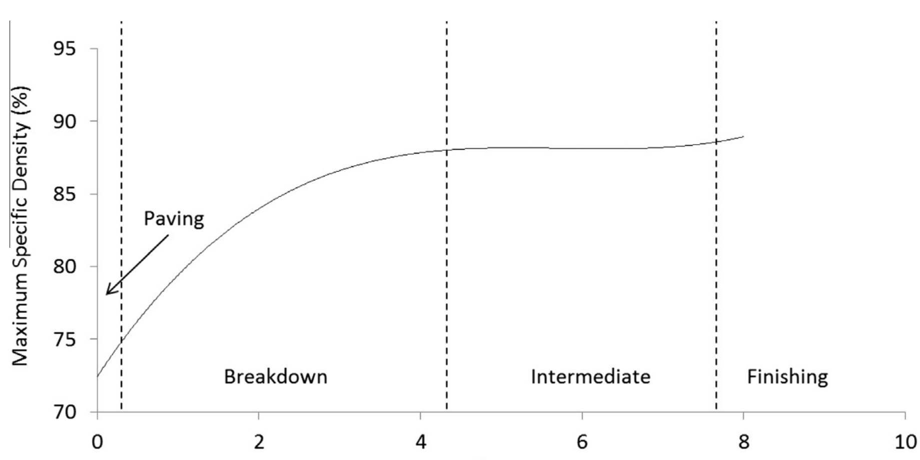

Fig. 1. Schematic densification stages of an asphalt layer during IC compaction (Nuclear Gauge (NG) measurements) according to [7].