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A study on volumetric versus surface properties of wearing courses

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HIGHLIGHTS

- ▶ The volumetric and surface characteristics of HMA specimens were analyzed.
- ▶ Gyratory compactor, roller compactor and laser profilometer were used.
- ▶ A model for predicting surface texture and volumetrics was proposed.
- ▶ The model is mainly a function of compaction effort and process.

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ABSTRACT

The main purpose of this study was to analyze the volumetric and surface characteristics of hot mix asphalt (HMA) specimens as a function of compaction process. Specimens were produced in the laboratory by two different compaction devices, a gyratory compactor and a roller compactor. The volumetric and surface characteristics (air void content, bulk specific gravity) of these specimens, as well as the relationships among surface texture, volumetrics and compaction, were investigated. Analysis of these results may allow determinations of how material movements under compaction determine volumetrics distribution and variations and surface properties. A tentative theoretical framework for synergistically pursuing texture and volumetric targets was formulated. Outcomes of this study are expected to benefit both practitioners and researchers.

1. Introduction

Pavement texture and volumetrics of hot mix asphalts (HMAs) play an important role in pavement management, expected pavement life, road safety, sustainability [1,2] and mechanistic performance [3]. The surface properties of sustainability (noise pollution reduction [4] and environmental impact [5,6]), efficiency (consumption reduction) and user safety are strongly influenced by the "texture" of the upper layer of wearing courses [7,8]. Indeed, texture, defined by ISO Standards 13473-1 as "*the deviation of a pavement surface from a true planar surface*", is related to the accident ratio [9,10]. In particular, surface texture has been found to affect friction and its evolution over time [11–15]. At high wavelengths, texture is related to roughness [16,17], which affects user comfort and has an impact on the general cost of transportation. Furthermore, texture affects drainability [18] and therefore acceptance procedures [19]. Further research, however, is needed on the evolution of texture properties as a function of time and/or compaction energy and type, both in the laboratory and on site [20].

HMA volumetric properties have been shown to depend on the relationship between G_{mm} (maximum theoretical specific gravity) and G_{mb} (bulk specific gravity). The specific gravity is the ratio of the weight in air of a volume of material at 25° C to the weight in air of an equal volume of water. HMA maximum specific gravity (G_{mm} or the corresponding theoretical maximum density, termed "Rice" density) can be derived from the ratio of the weight of a loose sample to the weight of an equal volume of water at a standard temperature of 25 °C [21]. G_{mm} is dependent on G_{se} (effective aggregate specific gravity), P_b (asphalt binder content), and G_b (specific gravity of the asphalt binder). Air voids (AVs) are determined from G_{mm} and the bulk specific gravity (G_{mb}) of the compacted mixture.

Both *in situ* and laboratory compaction processes have been shown to affect the mechanical, volumetric and surface properties of HMAs. Among the important parameters involved in and affected by compaction processes are reduction of air voids; the internal structure of samples [22–25]; transport of asphalt binders; re-orientation and segregation of aggregates [26,27];

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re-organization of aggregate-bitumen matrices; specimen surface, shape and morphology; and, consequently, surface texture, friction properties and other surface performance parameters, including drainability and noise emissions. Laboratory procedures are important in the determination of volumetrics. In contrast, on site procedures and methods, even if very useful from a management standpoint, do not present a comparable level of reliability and accuracy [28,29]. The same concept can be extended to the measure of surface texture [20].

Although there have been many studies investigating the volumetric and surface properties of HMAs, many issues require further research, including those related to the relationships among compaction level, texture spectrum and specific gravity. A unifying theoretical framework would be of great interest for enhancing our understanding of how to improve mix composition and compaction to optimize both surface and volumetric properties. Due to sample inhomogeneity and boundary factors, it has become more difficult to formulate a comprehensive theoretical model able to explain texture and volumetrics variations.

2. Research objectives and scope

The main purpose of this research was to analyze the volumetric and surface characteristics of HMA specimens as a function of the compaction process. Based on the relevance of these characteristics over the entire boundary surface of a specimen and to determine sample inhomogeneity, both the upper and lower surfaces were investigated.

HMA specimens were produced in the laboratory using two different compaction devices, a gyratory compactor (GC) and a Unical slab roller compactor (USRC).

This paper is organized as follows:

– The above introduction describes the importance of pavement bulk and surface performance.
– The experimental program is described in the next section.
– Results are presented and discussed and several equations are proposed.
– Finally conclusions are drawn.

3. Experiments and results

3.1. Experimental program

The experimental program was developed at the Department of Territorial Planning, University of Calabria (Italy), and is summarized in Fig. 1.

Two compaction devices were used, a GC (Table 1) and a USRC (Table 2). The USRC device is a mechanical, self-propelled smooth steel roller with forward-reverse control, designed according to the standard UNI-EN 12697-33. The slabs were compacted at different pressures and numbers of passes until the desired height of the slab was reached. The compaction parameters chosen for both devices are summarized in Tables 1 and 2.

Initially, only gyratory samples were produced, at three different levels of compaction, corresponding 10, 60, and 200 gyrations, respectively. In the second phase, the specific gravity of the gyratory specimens was derived for each level of compaction. Starting from these values, 3 cm- and 6 cm-thick slabs were produced by varying the weight of the material. A schematic illustration of the experimental program is shown in Fig. 1.

Overall, 36 samples were produced (see Table 3):

– 12 Gyratory compacted specimens (6 for the bituminous mix herein termed MA and 6 for the bituminous mix herein termed MB, see Section 4.1);
– 24 Roller compacted specimens (12 for MA and 12 for MB).

At the end, the actual density of each slab sample was calculated to verify whether the fixed $\%G_{mm}$ at each level of compaction was reached.

Each GC specimen was cut with a wet saw into three parts (bottom, center, top) to separate the top and bottom parts (see Fig. 2). The slabs ($30.5 \times 40.5 \times h$ cm) were cut and divided into 9 sectors. The central zone measured 15 cm × 15 cm and only the top surface of this compacted zone was analyzed (see Fig. 2). The central part of the 6 cm-thick slabs was divided into two parts (top and bottom, each ≈3 cm thick).

Table 4 summarizes the tests performed (see also Fig. 2).

In reference to texture measurements, MPD (mean profile depth), ETD (estimated texture depth), and RMS (root mean square) are indicators referring to surface texture (for microtexture wavelengths of 0.5–50 mm), regardless of texture wavelength. In contrast, L_t is the texture level for a given wavelength λ. Note that the lowest wavelength that can be measured depends on the minimum step of the device and that the latter interacts with the diameter of the spot of the laser device. Therefore, it is relevant that the highest frequency that can be represented correctly by a sampled signal (f) is half the sampling frequency (f_s) and that, if the signal contains frequency components above the Nyquist frequency (i.e., above $f_s/2$), these will be misinterpreted as lower frequencies in the spectrum of the sampled signal, a phenomenon known as "aliasing". Furthermore, the required evaluation length depends on the frequency analysis to be performed. For one-third-octave bands, the evaluation length (l) must be at least (5 to) 15 times $\lambda_{\max}$, where $\lambda_{\max}$ is the longest (one-third-) octave-band-center wavelength used in spectral analyses. These requirements imply that the octave-band levels, or one-third-octave band levels, determined under these evaluation lengths will be within a 95%-confidence interval of approximately ±3 dB of the true band levels (ISO/TS 13473-4:2008(E)).

By referring to volumetrics, and hypothesizing that AV = 0, G_{mm} will represent the specific gravity of a mixture. G_{mb} would therefore represent the actual specific gravity ($\leqslant G_{mm}$) corresponding to the actual air void content, AV ($\geqslant 0$). Despite G_{mm}, the definition of which is independent of the state of matter of components (bitumen ≈ liquid; aggregates ≈ solid; air ≈ gas), G_{mb} and AV will be affected by the actual characteristics of the bituminous mixture. Thus, for a given aggregate gradation and bitumen content, the lowest AV can be appreciably greater than 0 and the highest G_{mb} much lower than G_{mm}, regardless of the level of compaction. Furthermore, P_b indicates the content in terms of liquid phase, while G_{sb} provides a measure of aggregate density, with both affecting compaction performance.

3.2. Materials

The first step was to select two different asphalt mixes and to produce gyratory compacted samples and slab specimens in the laboratory at different energy levels and at two different thicknesses. Table 5 shows aggregate gradation and the main aggregate and asphalt binder properties for both of the mixes studied.

The two mixes had the same gradation (BRZ, below the restricted zone), but were composed of different types of aggregate, limestone for MA and limestone + basalt for MB. The aggregate blend used for MB contained 30% by mass of basaltic material (aggregate size > 5 mm). In contrast, only limestone aggregate was used in the MA mix, with a nominal maximum aggregate size of 9.5 mm.

3.3. Gyratory compacted specimens

Figs. 3–7 and Table 6 summarize results and analyses performed on the gyratory compacted specimens. Eqs. (1)–(5) refer to the proposed model.

The volumetric properties of GC specimens are summarized in Fig. 3. In the top panels, the x-axes indicate air void content and the y-axes indicate the number of gyrations (N). In the bottom panels, the x-axes indicate the number of gyrations and the y-axes indicate $\%G_{mm}$.

These results indicate that:

– Increased compaction energy (number of gyrations) resulted in increased $\%G_{mm}$ and decreased air void content.
– The center of each specimen was always denser than its top and bottom. However, the cutting process may have caused appreciable changes in the top and bottom surfaces of the central part of the specimens [28]. Furthermore, X-ray computed tomography and image analysis techniques showed similar reductions in air void content [23]. A study of air void homogeneity using gamma-ray measurements indicated that the maximum compaction level was obtained approximately 5 cm from the surface (i.e., at the center of the specimens) [31].
– The air void content was always higher at the top than at the bottom of specimens.
– The air void content of the MA mix was similar to that of the MB mix.

Fig. 4 illustrates texture levels ($L_T(\lambda)$, or $L_{\mathrm{TOP}} - L_{\mathrm{BOT}}$, y-axis) as a function of wavelength (λ, mm, x-axis).

An increase of around 20 dB was observed for transitions around wavelengths of 0.5–5 mm, regardless of the number of gyrations and of the position at the top or bottom (see Fig. 4a–d).

Moreover, regardless of mix, a higher number of gyrations yielded lower levels of texture, especially in the domain of macrotexture (wavelengths in the range 0.5–50 mm, see Fig. 4a–d).

Top surfaces usually had higher texture levels than bottom surfaces, for each wavelength in the macrotexture domain (Fig. 4e). In this domain, the difference $L_{\mathrm{TOP}} - L_{\mathrm{BOT}}$ ranged from 1 to 5.