COMPARING DIFFERENT PROCEDURES FOR THE MEASUREMENT OF THE BULK SPECIFIC GRAVITY FOR COMPACTED HMA SAMPLES

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ABSTRACT

The objective of this paper is to analyse the problem of bulk specific gravity estimation for compacted HMA samples.

A proper measurement of the bulk specific gravity (G_{mb}) for compacted HMA samples is critical and essential from many points of view.

Inaccurate measurement of G_{mb} can result in erroneous calculations for G_{mb} /G_{mm} ratio, for G_{mb} (in-site)/G_{mb} (Marshall compaction) ratio, for air voids content, Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and correlations for portable density gauges.

There are several different ways to measure bulk specific gravity; all of these use slightly different ways to determine specimen volume: a) Water displacement methods (Saturated Surface Dry (SSD); Paraffin; Parafilm; CoreLok); b) Dimensional; c) others (Gamma ray, non-nuclear devices, etc.).

SSD method, if a specimen's air voids are high, can give erroneously high bulk specific gravity. Paraffin method, used in Italy, seems to present several drawbacks (especially for high air void contents).

In Parafilm method, a more accurate volume measurement should be theoretically possible. However, in practice the paraffin film application is quite difficult and test results can be sometimes inconsistent. Dimensional method is the simplest but it is often inaccurate because it assumes a perfectly smooth surface thereby ignoring surface irregularities.

In the light of the above-mentioned facts, a model has been formalized and experiments have been designed and performed. Results demonstrate the prevailing influence of several factors in selecting the method and in estimating the void content. Correlations and critical issues are provided.

Keywords: Bulk Specific Gravity, Hot Mix Asphalts, Void Content.

1. BACKGROUND

As is well known, the Bulk Specific Gravity of the Compacted Asphalt Mixture is the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

A proper measurement of the bulk specific gravity (G_{mb}, see Figure 1) for compacted HMA (Hot Mix Asphalt) samples is critical and essential from many point of view: introduction of Superpave and volumetrics, quality assurance and acceptance criteria, influence of air void content on surface characteristics (wet friction, splash and spray, raveling, stripping, etc.) and mechanistic properties (resistance and moduli dependence on water action).

In fact, the bulk specific gravity is the basis for volumetric calculations used in HMA mix design, field control, and construction acceptance.

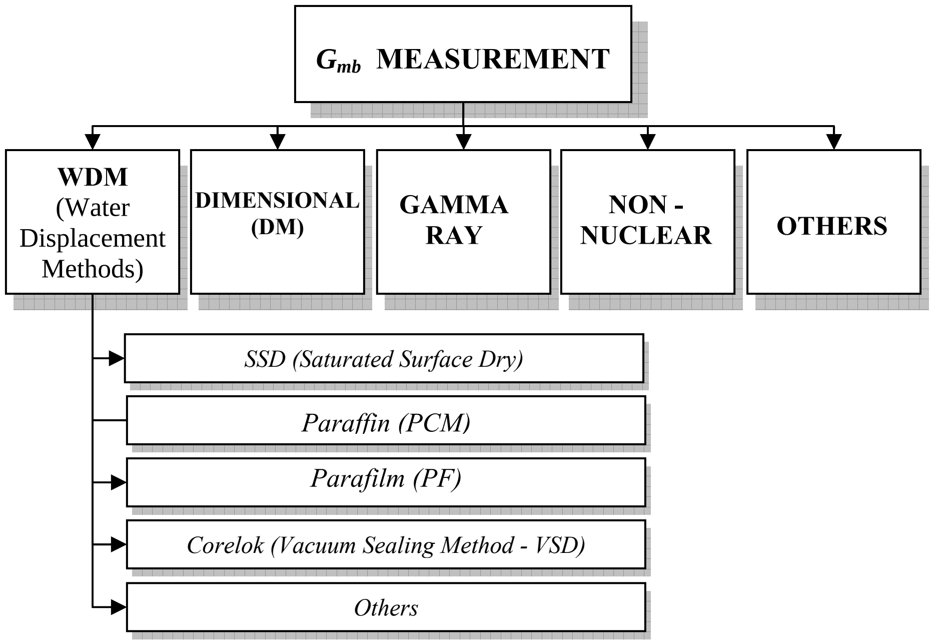


Figure 1 Main Methods for G_{mb} Measurement

Water displacement methods are based on Archimedes Principle; specimen volume is calculated by weighting the specimen in a water bath and out of the water bath. The difference in weights can then be used to calculate the weight of water displaced, which can be converted to a volume using the specific gravity of water (~ 1g/cm^3).

The Saturated Surface Dry (SSD) method calculates the specimen volume by subtracting the mass of the specimen in water from the mass of a Saturated Surface Dry specimen.

One critical problem with this method is that if air voids are high, and thus potentially interconnected (for dense-graded HMA this occurs at about 8 to 10 percent air voids), water quickly drains out of them as the specimen is removed from its water bath, which results in an erroneously low volume measurement and thus an erroneously high bulk specific gravity.

Paraffin method is very used in Italy. The method determines volume according to the water displacement principle but uses a melted paraffin wax for the external sealing (not filling!) of a specimen's internal air voids. In practice, the paraffin is difficult to correctly apply and test results are somewhat inconsistent, especially when air voids are high.

[MON 96] compared paraffin, parafilm and a specific membrane method to determine the air voids content, obtaining the following values for dense-graded courses: single-operator precision limit = 2.12 (paraffin); 4.51 (parafilm); 3.74 (membrane).

Parafilm method is basically alike the paraffin method. A thin paraffin film wraps the specimen and then weights of the specimen in and out of water are taken. However, in practice, the paraffin film application may be quite difficult and test results can be inconsistent.

Vacuum Sealing Method (VSD) calculates specimen volume like the parafilm method but uses a vacuum chamber to shrink-wrap the specimen in a high-quality plastic bag rather than cover it in a paraffin film as in the Italian tradition. This method has shown some promise in both accuracy and precision. Texture effects can be critical.

In the dimensional method, the volume is based on height and diameter/width measurements. Surface irregularities (i.e., the rough surface texture of a typical specimen) introduce inaccuracy, because, in practice, an "osculatory" volume is computed.

The gamma ray method is based on the scattering and absorption properties of gamma rays with bituminous matter. With proper calibration, the gamma ray count is directly converted to the density or bulk specific gravity of the material.

Non nuclear devices are often based on magnetic emissions. Many researches are in progress in this field.

Many papers and reports deal with SSD (AASHTO T 166) versus VSD (ASTM D 6752) comparison [CROU 03; WIL 05; COO 02; SPEL 04; MOHA 05].

In particular, in [SHO 03], a comparison between SSD and vacuum sealing method has been performed. T-statistic has been used, while in [MOHA 05] laboratory tests included three different methods of measuring air voids (vacuum-sealing, gamma ray and conventional, for U.S.A. culture, SSD).

In [CROU 03] the t-statistic was used and mixture aggregate gradation was considered as a parameter. Other statistics have been used in [WIL 05] and round robin statistic has been used in [COO 02].

In [ROM 02] two different non-nuclear gauges and AASHTO T 166 procedure have been compared.

Surface texture influence has been studied in [BRO 04], according to the following procedure:

a) measuring sand height (*SH*) for the upper (*US*) face of the cylindrical specimen:

$$SH_{US} = \frac{V_{US}}{A_{US}} \text{ (ASTM E965)} \quad \text{(Eq.1)}$$

b) computing the total surface area (*TSA*) of the specimen:

$$TSA = 2A_{US} + Ls = 2\pi r^2 + 2\pi r\overline{H} \quad \text{(Eq. 2)}$$

c) determining the total amount of macro-texture in terms of external covering volume (*CV*):

$$CV = SH_{US} \cdot TSA \quad \text{(Eq. 3)}$$

d) correlating the covering volume with the difference V-V_{DIM}, where V is, for example, the volume determined according the Vacuum Seal Method and V_{DIM} is the volume estimated by the dimensional method $(V_{dim} = \pi r^2 \overline{H})$.

In equations 1 and 2 V_{US} and A_{US} stand for volume and surface area of the upper face, Ls stands for lateral surface area, while r and $\overline{H}$ are the specimen radius and average height.

This study showed, both for the SSD method (AASHTO T 166) and the Vacuum Sealing Device Method (ASTM D 6752), a good correlation between the two volumes ($\rho^2 \simeq$ 0,85 $\simeq$ 0,87).

On the basis of the analysis of the international literature the following observations may be drawn: a) there is still a need for more researches especially when paraffin coated method is involved; b) may issues still remain unsolved on these topics; c) the correlations are greatly affected by mix properties.

In the light of above the main objectives and scope of this paper have been confined to the field of correlations for DGFC (Dense-Graded Friction Courses), where paraffin method is involved and Marshall Compaction is used.

In order to pursue the objectives a conceptual framework bas been formalized (section 2) and many experiments were designed and performed (section 3).

2. CONCEPTUAL FRAMEWORK

As is well-known, texture affects the determination of G_{mb}, especially for parafilm coated, vacuum sealing method and dimensional method.

In this study the following conceptual framework has been adopted for modelling this problem (see figure 2):

$$V_{mb} = (V_0, R_{BS}, R_{LS}, R_{US}) \quad \text{(Eq. 4)}$$

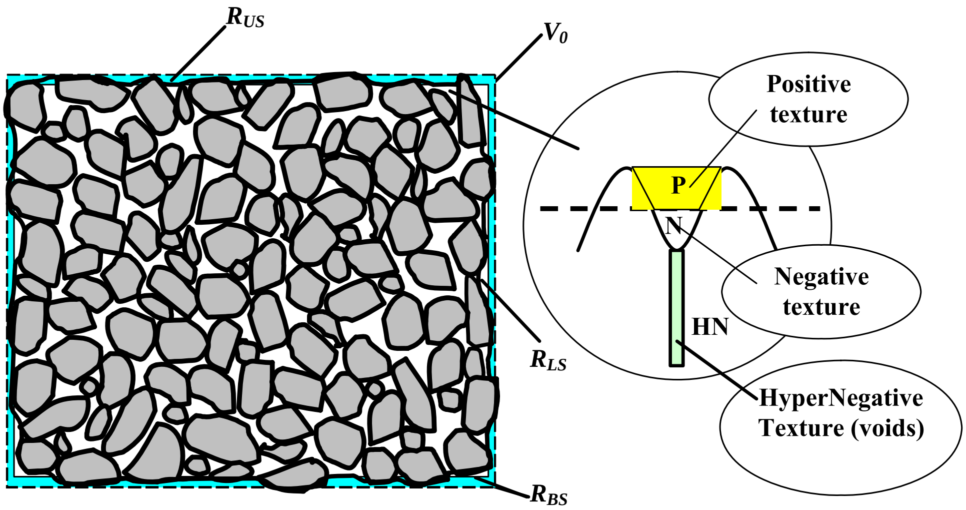
where V_{mb} stands for mix bulk volume, V_0 is an Osculatory (external) Volume, according to Dimensional Method, R_{BS} refers to Bottom Surface Roughness, R_L refers to Lateral Surface Roughness, while R_{US} refers to Upper Surface Roughness (figure 2).

Each of the above-described three components (volumes) R_i, can be splitted into three sub-components: Positive (P), Negative (N) and HyperNegative (HN):

$$V_{mb} = V_0 - R_{BS} - R_{LS} - R_{US} =$$
$$= V_0 - [R_{BSP} + R_{BSN} + R_{BSHN}] - [R_{USP} + R_{USN} + R_{USHN}] - [R_{LSP} + R_{LSN} + R_{LSHN}] \quad \text{(Eq. 5)}$$

Theoretically, the differences above-recalled among the measurement methods can be explained through the following equation:

$$V_{mb} = V_0 - [R_{BSP} + R_{USP} + R_{LSP}] - [R_{BSN} + R_{USN} + R_{LSN}] - [R_{BSHN} + R_{USHN} + R_{LSHN}] \quad \text{(Eq.6).}$$



Symbols
HN = HyperNegative texture; **N** = Negative texture; **P** = Positive texture; $\boldsymbol{R_{US}}$ = Volume referred to Upper Surface Roughness; $\boldsymbol{R_{LS}}$ = Volume referred to Lateral Surface Roughness; $\boldsymbol{R_{BS}}$ = Volume referred to Bottom Surface Roughness; $\boldsymbol{V_0}$ = "Osculatory" (external) Volume according to Dimensional Method.

Figure 2 Conceptual framework

Following this former conceptual framework, the experiments have been designed as follows.

3. DESIGN OF EXPERIMENTS

This section deals with the design of experiments. Mixes are described in § 3.1, while procedures are summarized in § 3.2.

3.1 Mixes

Five sets of DGFCs (Dense-Graded Friction Courses), namely S21, S15, S22, TN, S25, have been tested. For each set a sub set of specimens has been used for composition analyses (asphalt binder content – CNR n.38/73, aggregate grading – CNR n.4/53, aggregate apparent specific gravity – CNR n. 63/78, see figures 3 and 4 and Table 1); in figure 4, gradations are compared with Superpave 9.5mm nominal size gradation requirements.

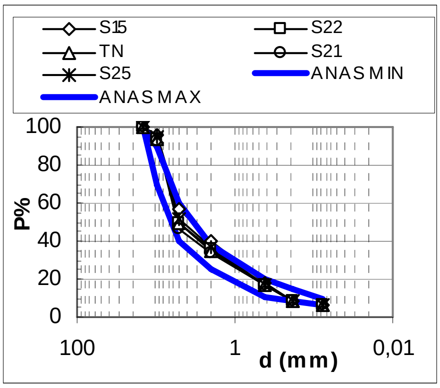


Figure 3

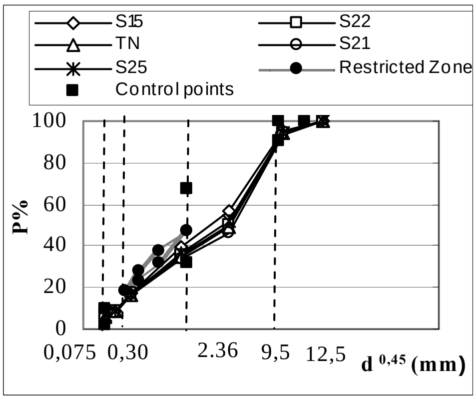


Figure 4

Table 1 HMA Composition/compaction

b	%	4,78÷5,35
γ_g	g/cm^3	2,749÷2,783
NMAS	mm	10
Compaction		Marshall

3.2 Procedures

Four different methods have been considered (see Table 2 and figure 5).

Table 2 Main procedures for G_{mb}

(**)	Indicator	Algorithm	Standard
1.	G_{mb} *(geom)(dimensional)*	$\dfrac{A}{V_{Geom}\cdot\gamma_w}$	AASHTO T 269
2.	G_{mb} *(parafilm)*	$\dfrac{A}{D'-E'-\dfrac{D'-A}{F}\cdot\gamma_w^{(*)}}$	ASTM D 1188 (abs>2%)
3.	G_{mb} *(VSD)*	$\dfrac{A}{B'-E'-\dfrac{B'-A}{F_t}}$	ASTM D 6752
4.	G_{mb} *(paraffin)*	$\dfrac{A}{D'-E'-\dfrac{D'-A}{F_p}\cdot\gamma_w^{(*)}}$	BU N40-1973 / AASHTO T 275-A (abs>2%)

Legend: *A* = mass of the dry specimen in air; abs>2%: absorption more than 2%; *B'* = mass of dry and sealed specimen; *D'*=mass of the dry, coated specimen; *E'* = mass of sealed/coated specimen under water; *F* =specific gravity of the coating determined at 25°C; F_p = specific gravity of the paraffin at 25°C; F_t = apparent specific gravity of plastic bag; G_{mb} = Bulk Specific Gravity; V_{Geom} = geometric volume of HMA sample; *VSD* = Vacuum Sealing Device. (*) the γ_w is not included in the standard. (**) test order; note that experiments are in progress and the data here reported are only a part of the entire research plan.

Figure 5 deals with the main phases of each of the four methods.

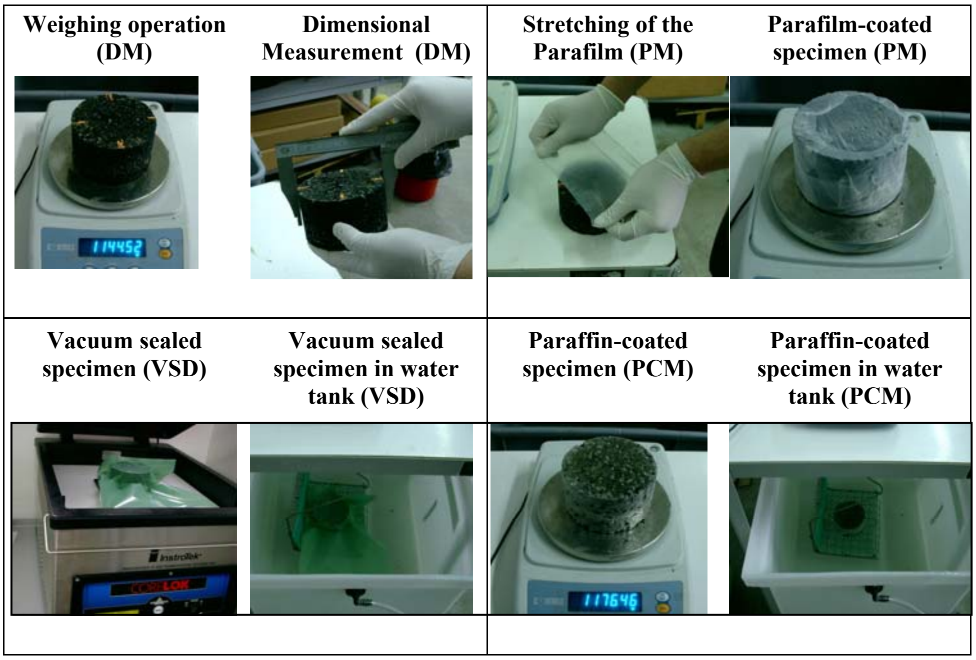


Figure 5 Main Phases for the four procedures

4. EXPERIMENTS AND RESULTS

Figures 6 to 12 show the obtained results (lines of equality are dotted), while in table 3 fitting curve characteristics are summarized. As it regards the comparison between paraffin and parafilm method, results show that “paraffin” specific gravities are always grater than “parafilm” ones and so the bulk volumes estimated by paraffin method are lower than the ones estimated by parafilm method. This occurrence seems to be related to two different biasing effects working towards the same direction: texture and (larger) interconnected voids. The larger the texture, the more the voids interconnected with the boundary of the specimen, the larger the difference between the volume containing a great amount of negative (and hyper-negative) roughness (parafilm method) and that one containing a small (or negative) amount of the negative (and hyper-negative) roughness. Definitions and concepts of positive and negative texture, summarised in figure 2, rely on the well-known texture theory of HMA pavements.

By referring to the comparison between Parafilm and VSD method (figure 7), “parafilm” specific gravities resulted to be lower than the VSD ones.

This fact could be due to the better adhesion (to the specimens) of the bags (under vacuum effects) with respect to the parafilm (without vacuum effect). Positive and negative texture could be involved.

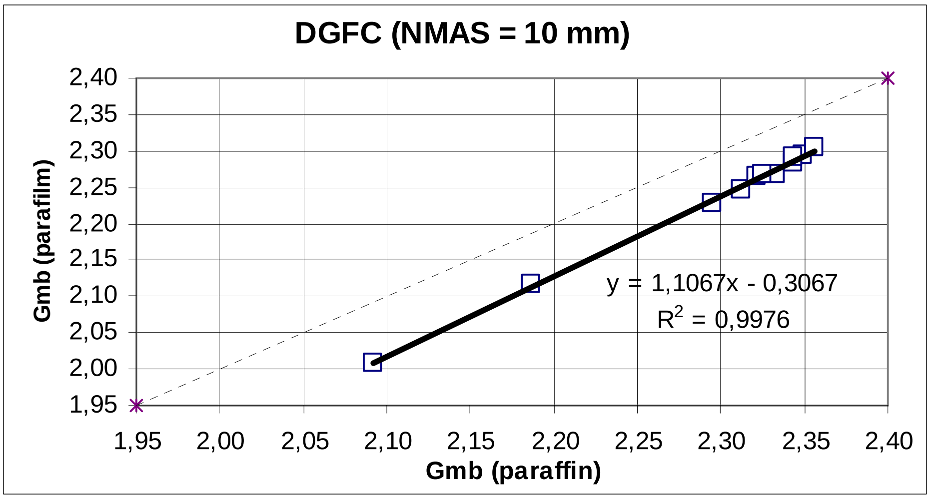


Figure 6

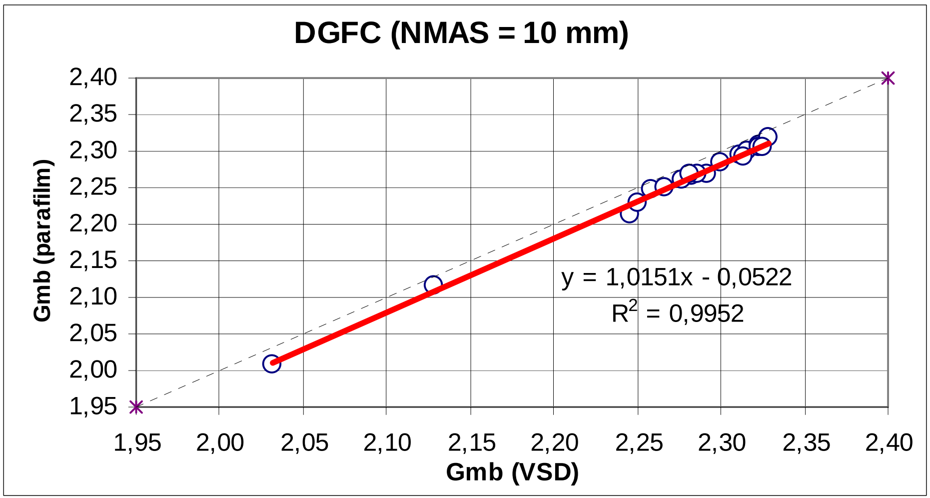


Figure 7

Concerning parafilm vs dimensional (or geometric, DM) method (figure 8), “parafilm” G_{mb} resulted greater than the other, due to a clear effect of texture consideration for the dimensional method.

“Paraffin” specific gravities resulted higher than VSD ones (see figure 9). The explanation of this experimental evidence could be the some as above mentioned for paraffin and parafilm comparison. Importantly, also for paraffin vs dimensional and VSD vs dimensional method (see figure 11), it is possible to explain these facts in terms of the “osculatory tendency” (P+N+HN, see figure 2) of the dimensional volume.

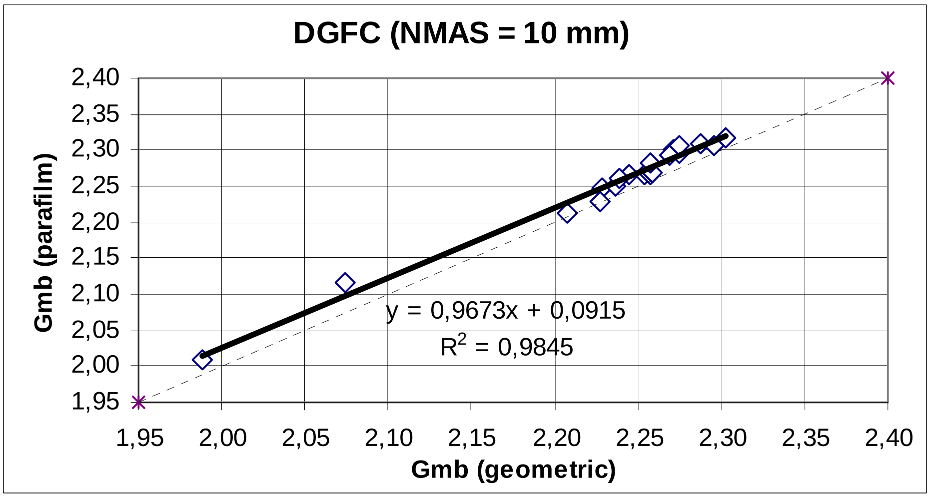


Figure 8

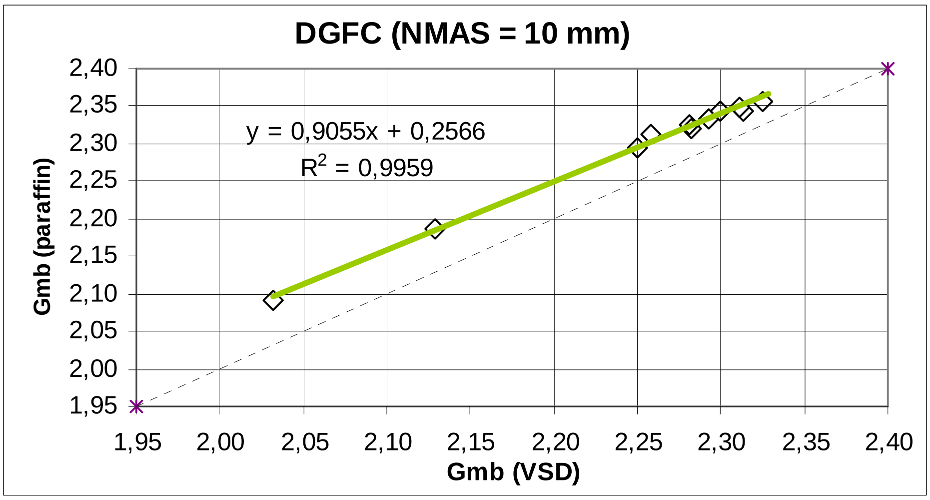


Figure 9

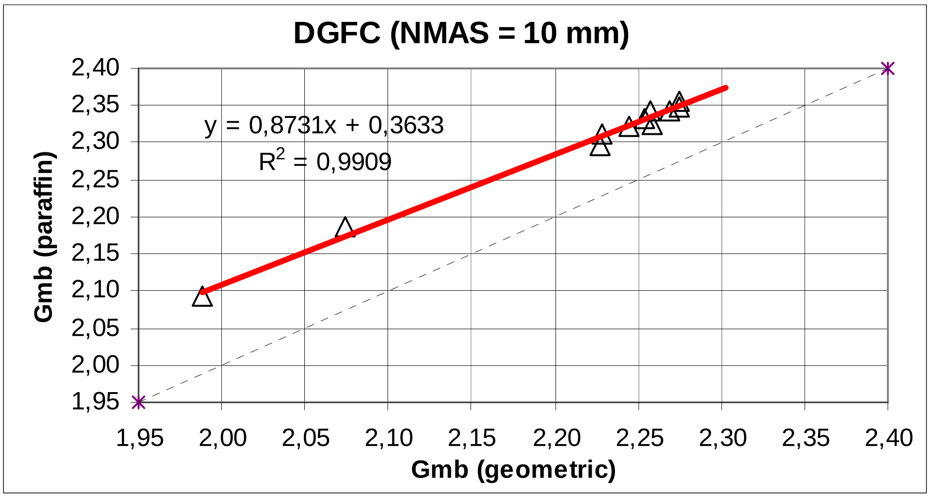


Figure 10

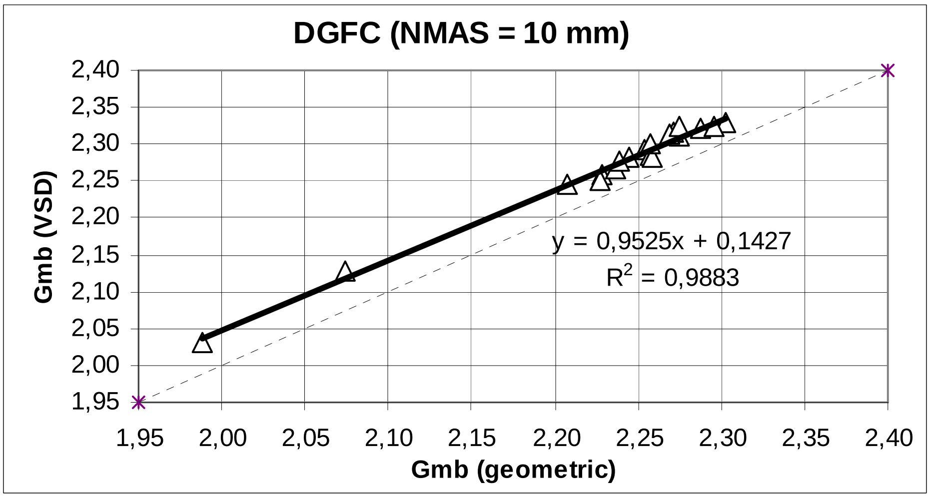


Figure 11

Finally, figure 12 and table 3 show the relationship of the dimensional method with each of the remaining ones. Note that it results:

$$G_{mbparaffin} > G_{mbVSD} > G_{mbparafilm} > G_{mbgeom} \qquad \text{(Eq. 7)}$$

And, then:

$$V_{mbparaffin} < V_{mbVSD} < V_{mbparafilm} < V_{mbgeom} \,. \qquad \text{(Eq. 8)}$$

Pore filling Effect (HN)	Vacuum Effect (N)	Osculatory Effect (P)

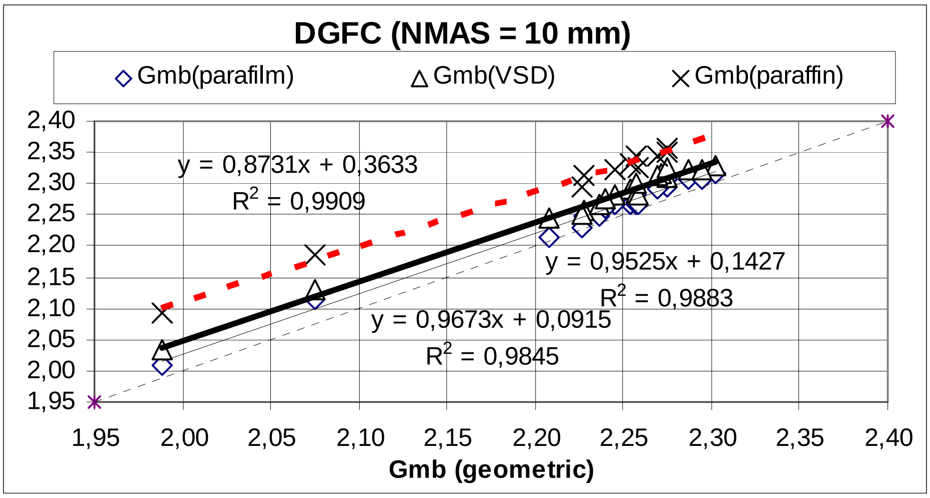


Figure 12

In table 3, for each comparison between $G_{mb}s$, p-values are shown. They refer to the probability that the null hypothesis (no difference between the means) is true. t-statistic has been used (2-tailed; Paired Samples Test, see last four columns in table 3). Moreover, table 3 shows the ranking in terms of max distance between compared $G_{mb}s$ (in percentage, estimated in the range 2,1 ÷ 2,4). Note that the maximum distance and minimum distance have a maximum for the comparison Paraffin (PCM) vs Geometric (DM).

Table 3

Comparison between		**Fitting Curve**	**Min Distance (%)**	**Max Distance (%)**	**Intercept**	**Mean**	**Lower**	**Upper**	**Significance (p-value) 2-tailed**
PCM	**DM**	y = 0,8731x + 0,3633	2,45	4,61	2,86	0,082	0,073	0,092	0,000
PM	**PCM**	y = 1,1067x - 0,3067	2,11	3,93	2,87	-0,062	-0,068	-0,055	0,000
PCM	**VSD**	y = 0,9055x + 0,2566	1,24	2,77	2,72	0,044	0,037	0,050	0,000
VSD	**DM**	y = 0,9525x + 0,1427	1,20	2,05	3,00	0,037	0,032	0,041	0,000
PM	**DM**	y = 0,9673x + 0,0915	0,54	1,09	2,80	0,018	0,014	0,023	0,000
PM	**VSD**	y = 1,0151x - 0,0522	0,67	0,98	3,46	-0,018	-0,021	-0,0156	0,000

The following observations can be drawn: 1) the simplest method (dimensional) and the Italian most used method (paraffin coated) have the greatest distance (2% ~ 5%); 2) the other methods have a lower gap; 3) many hypotheses should be proposed in the field of the "best descriptor"; it remains quite unclear the assessment of the best G_{mb} indicator; research is still needed on this topic.

MAIN FINDINGS

In the light of the above, the following conclusions may be drawn: 1) bulk volumes estimated by the dimensional method are greater than that estimated by the parafilm, VSD and paraffin method; nine fitting curves have been estimated; 2) Physical explanations may be related to (hyper-negative, negative, positive) texture consideration in the bulk volume: maximum values for the dimensional method, minimum values for the paraffin coated specimens; 3) fitting curves have been obtained and, due to the appreciable significance, this could constitute a former support, well-grounded in experiments, for QC/QA (Quality Controls/Quality Assurance) procedures in-site; 4) for a certain extent, the conceptual framework above hypothised seems to be validated: a dimensional method in which the three components of R are negligible vs, at the other extremity, a paraffin method in which there is a certain risk to considerer also some of the connected voids (Hypernegative texture). More research is needed on this topic.

Future research will aim to extend experiments to in-field and superpave giratory compaction.

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