IMPULSIVE AND VIBRATIONAL COMPACTION OF BITUMINOUS MIXTURES

Authors:

Agostinacchio M.
Full Professor of Roads Railways and Airports – University of Basilicata – michele.agostinacchio@unibas.it

Ciampa D.
Assistant Professor of Roads Railways and Airports – University of Basilicata – donato.ciampa@unibas.it

Diomedi M.
Associate Professor of Roads Railways and Airports – University of Basilicata – maurizio.diomedi@unibas.it

Olita S.
Assistant Professor of Roads Railways and Airports – University of Basilicata – saverio.olita@unibas.it

 ISBN 978-88-902409-0-4

ABSTRACT

As well known, the laboratory testing of mechanical and volumetric properties of asphalt concrete is carried out by working on test specimens compacted according to specific reference Standards. One of the major problems, that still undertake the scientific research sector, is to successfully reproduce in laboratory the compaction process that asphalt concretes undergoes during the in situ placement. Traditionally the mainly technique of compaction is the unidirectional-impulsive one that leads to the creation of appreciably different structures from those that occur in the pavement layers. In unidirectional-impulsive compaction the aggregate moves mainly along vertical direction with limited rotation possibility, so it is difficult to reach the maximum density and resistance configuration. These limitations are overcome with the introduction of the SHRP gyratory compaction which is capable of continuously changing the direction of compaction with combined normal and tangential actions. In this paper the Authors propose an alternative to the unidirectional-impulsive bituminous mixtures compaction procedure based on the use of the vibratory compactor, a device introduced by UNI-EN-12697-32 (2007) in order to determine the bituminous mixtures' density. The objective of the study is, therefore, to assess and compare the mechanical resistance and porosity performed by bituminous mixtures, compacted by the two mentioned compaction techniques (unidirectional-impulsive and vibrational). With reference to bituminous mixtures object of study, the Authors propose correlations that allow to link mechanical and volumetric parameters of mixtures to the change of the compaction technique, the compaction energy and the compaction time.

Keywords: Asphalt concrete, unidirectional-impulsive compaction, vibrational compaction.

INTRODUCTION

Laboratory impulsive compaction of asphalt concrete, even if significantly different from what realized both during the in situ placement and, subsequently, under traffic load conditions, gives advantages in terms of execution easiness and broad diffusion, following the experience built during years of use.

To avoid losing this privilege and, at the same time, to close the gap between laboratorial experimentation and real behavior without having to make use of different testing systems, like for example the SHRP gyratory compactor, the Authors propose to use the vibrational compaction, able to reproduce material's compactness in a more adherent to reality way, also reducing executions times. To this aim, it seems useful to remind some technical and regulatory aspects linked to the two different laboratory compaction techniques.

UNI EN 12697-30 (2007) describes the operative protocol of impact compaction, finalized to the realization of cylindrical specimens of bituminous mixtures to be used in the evaluation of the principal mechanical (stability, flow, rigidity, indirect tensile strength) and volumetric (porosity, bulk density) features. The procedure makes use of an impact compactor, applying a number of strokes per side of 50 or 75, depending on the cases (see Figure 1a).

UNI EN 12697-32 (2007) standard, instead, describes the protocol aimed to determine the maximum density of asphalt concrete mixtures.

Differently from the previous case, the same cylindrical specimens are compacted by a vibrational compaction technique. This technique is based on putting the mixture in a mould of assigned dimensions and compacting it, for a time t_c of 2min±5s per side, using a vibrating electric hammer with a variable power between 750 and 1000W and an operative range of frequencies between 20 and 50Hz (see Figure 1b).

RESEARCH OBJECTIVES

In the present study the Authors propose an alternative compaction technique for asphalt concrete mixtures, based on the use of the vibrational compactor introduced by UNI EN 12697-32 (2007) standard. The objective of the work is to use this system to develop a testing protocol which, with the exception of the compacting time duration, strictly adheres to UNI EN 12697-32 (2007) standard.

This protocol has to be able to reproduce volumetric parameters as accordant as possible with those exhibited by the same mixtures of asphalt concrete compacted under the traditional impulsive technique.

The study clarifies a series of aspects linked to the real efficiency of the vibrational compacting, looking for eventual analytic correlations between mechanical and volumetric parameters exhibited by the asphalt concrete mixtures by varying the compacting technique and its associated energy.

(a) (b)

Figure 1 Impact compactor and vibrational compactor

CHARACTERIZATION OF THE STUDIED MIXTURES

The experimentation has been performed on two different asphalt concrete mixtures with closed mass, respectively named Mix 1 and Mix 2, both of which usable as wearing course layer for flexible and semi-rigid pavements road.

The study has been carried out with the following phases:

- choose and characterization of the bituminous mixtures object of the study;
- preparation of specimens by impulsive and vibrational compaction;
- laboratory testing;
- elaboration and analysis of the results.

Gradation and bitumen percentage, referred to the weight of the aggregates "b_a" of the studied mixtures, are reported in, respectively, Table 1 and Table 2. Mechanical and volumetric properties of the compacted mixtures with N=50 strokes and N=75 strokes using the unidirectional-impulsive technique are summarized in Table 2. These properties are reported in terms of stability, flow and Marshall quotient (UNI EN 12697-34, 2007), in terms of indirect tensile strength "R_t" (UNI EN 12697-23, 2006) and in terms of residual voids' percentage or porosity "V" (UNI EN 12697-8, 2003).

Successively, other specimens have been prepared for the same mixtures, by using the vibrational compaction technique. In a way analogous to the previous case, the behaviors of the same mechanical and volumetric properties have been evaluated by varying the compaction time.

As already stated, this phase has been developed under strict adherence to the UNI EN 12697-32 (2007) standard, with the exception of the compaction time duration t_c, which has been decided to be varied in a wide range of amounts, precisely: t_c=4, 7, 10, 13, 27, 40 and 54s (See Tables 3 and 4).

The analysis of Figures 2 and 3 highlights that the trend of porosity and stability with the compaction time is perfectly approximated by logarithmic regression curves.

The regression curve which best approximates the behavior of the Marshall quotient is, instead, a second order parabola, while the relationship for the indirect tensile strength results as linear. Efficacy for these laws is confirmed by the high value of their correlation coefficients R^2, which, in all cases and for both mixes, is always higher than 0.9.

Table 1 Gradation of Mix 1 and Mix 2

	Mix 1	Mix 2
Open Sieves [mm]	Passing [%]	
15	100	100
10	99.1	89.5
5	61.5	59.0
2	38.8	36.8
0.42	16.6	14.9
0.18	8.4	9.9
0.075	3.7	5.9
< 0.075	0.0	0.0

Table 2 Characterization of the mixtures compacted with the impulsive technique

Mix	Marshall				Indirect Tensile	Porosity	Bituminous Content
	N	Stability [kN]	Flow [mm]	V [%]	R_t [GPa]	V [%]	b_a [%]
Mix 1	50	6.4	2.1	10.9	1.018×10^{-3}	10.9	4.7
	75	7.5	1.8	10.5	1.091×10^{-3}	10.5	
Mix 2	50	10.8	2.3	4.7	1.178×10^{-3}	10.2	4.4
	75	12.4	2.1	5.9	1.187×10^{-3}	8.8	

Table 3 Characterization of Mix 1 compacted by vibrational technique

Marshall				Indirect Tensile	Porosity
t_c [s]	Stability [kN]	Flow [mm]	Marshall quotient [kN/mm]	R_t [GPa]	V [%]
4	7.4	2.5	3.0	1.059×10^{-3}	11.7
7	10.2	2.5	4.1	1.109×10^{-3}	10.4
10	11.1	2.5	4.4	1.062×10^{-3}	9.8
13	16.0	2.5	6.4	1.131×10^{-3}	8.9
27	20.0	2.5	8.0	1.310×10^{-3}	8.1
40	19.4	2.6	7.5	1.288×10^{-3}	6.7
54	20.3	2.9	7.0	1.509×10^{-3}	6.6

Table 4 Characterization of Mix 2 compacted by vibrational technique

Marshall				Indirect Tensile	Porosity
t_c [s]	Stability [kN]	Flow [mm]	Marshall quotient [kN/mm]	R_t [GPa]	V [%]
4	12.2	3.4	3.6	1.190×10^{-3}	10.0
7	13.6	2.8	4.8	1.166×10^{-3}	9.6
10	15.4	3.1	5.0	1.225×10^{-3}	9.2
13	17.7	2.5	7.1	1.281×10^{-3}	8.0
27	19.7	2.4	8.2	1.293×10^{-3}	6.4
40	21.4	2.3	9.3	1.495×10^{-3}	5.3
54	21.8	2.9	7.5	1.523×10^{-3}	5.2

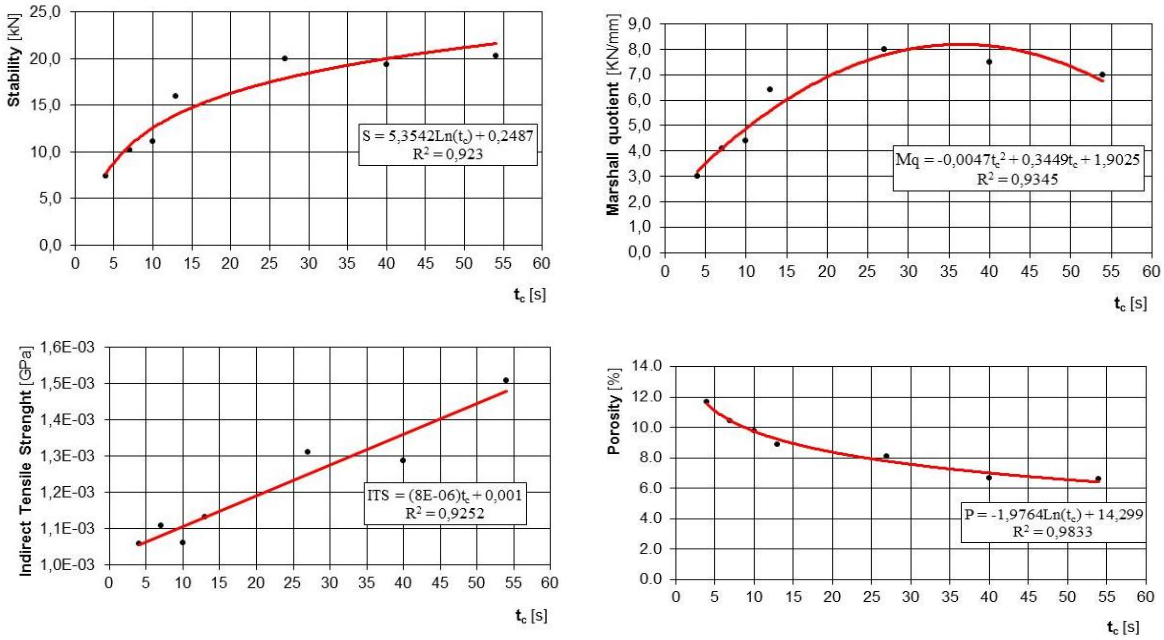

Figure 2 Real behavior and regression curves of Mix 1 mechanical and volumetric properties by varying the vibrational compaction time (t_c = 4, 7, 10, 13, 27, 40, 54s)

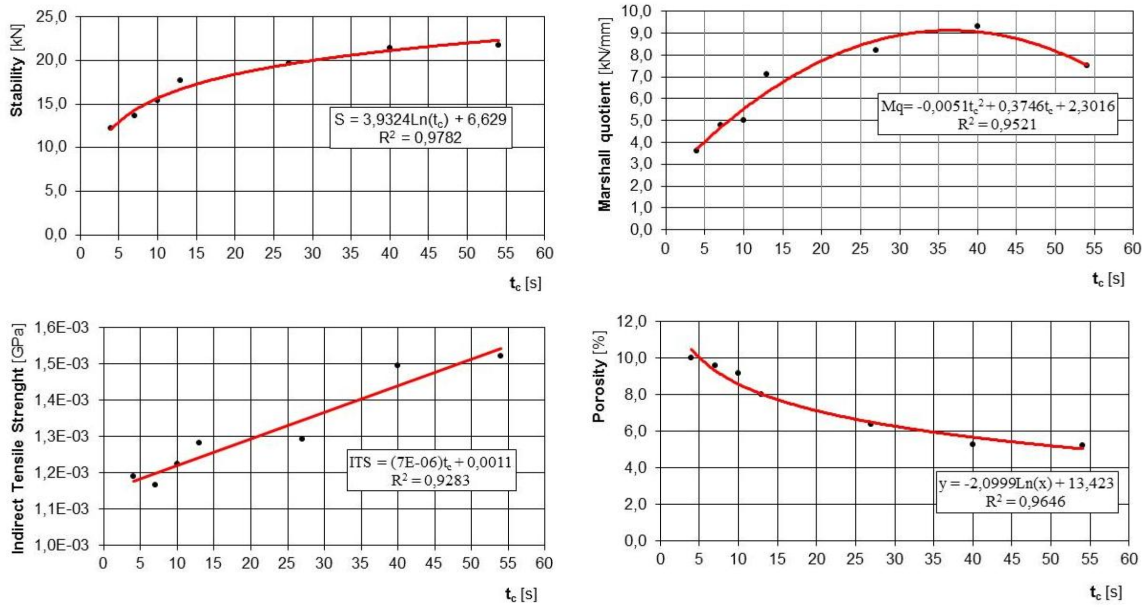

Figure 3 Real behavior and regression curves of Mix 2 mechanical and volumetric properties by varying the vibrational compaction time (t_c = 4, 7, 10, 13, 27, 40, 54s)

RESULTS' ANALYSIS

As already mentioned, the aim of this study, relatively to the investigated mixtures, is to make use of the variation laws defined in the previous paragraph to find a possible link between vibrational and impulsive compactions. It is clear that, by compacting both mixtures by the vibrational technique for a time t_c of about 4 seconds, we obtain stability (7.4kN for Mix 1, 12.2kN for Mix 2) and indirect tensile strength (1.059×10^{-3}GPa for Mix 1, 1.190×10^{-3}GPa for Mix 2) values very close to those obtained by compacting the same mixtures by the impulsive technique under 75 strokes

(7.5kN e 1.018×10^{-3}GPa for Mix 1, 12.4kN e 1.187×10^{-3}GPa for Mix 2).

Experimental results, expressed in terms of stability and indirect tensile strength, along with the percent deviation “E” as the compaction technique varies (impulsive with 75 strokes and 4 seconds vibrational), are summarized in Table 5.

It has to be noted that, for both the studied mixtures, le percent deviation “E” from experimental values is sensibly small. As already pointed out this means that, by compacting with vibration for a time t_c of 4 seconds both Mix 1 an Mix 2, stability and indirect tensile strength values are obtained, which can be compared to those obtainable for specimens compacted under the impulsive technique with 75 strokes.

In the case of impulsive compaction with 50 strokes it is still possible to obtain stability and indirect tensile strength values comparable with those exhibited by the same mixtures compacted by the vibrational technique. However, in this case it is necessary to refer to a compaction time t_c of only 3 seconds (see Table 6 and Figures 2, 3).

Table 5 Stability and indirect tensile strength values exhibited by the mixtures (N=75 strokes, t_c=4s)

Compaction type	Mix 1				Mix 2			
	S [kN]	E [%]	R_t [GPa]	E [%]	S [kN]	E [%]	R_t [GPa]	E [%]
Impulsive (N=75 strokes)	7.5	1.3	1.091×10^{-3}	2.9	12.4	1.6	1.187×10^{-3}	-0.2
Vibrational (t_c=4s)	7.4		1.059×10^{-3}		12.2		1.190×10^{-3}	

Table 6 Stability and indirect tensile strength values exhibited by the mixtures (N=50 strokes, t_c=3s)

Compaction type	Mix 1				Mix 2			
	S [kN]	E [%]	R_t [GPa]	E [%]	S [kN]	E [%]	R_t [GPa]	E [%]
Impulsive (N=50 strokes)	6.4	4.7	1.018×10^{-3}	-0.59	10.8	-0.92	1.178×10^{-3}	4.8
Vibrational (t_c=3s)	6.1		1.024×10^{-3}		10.9		1.121×10^{-3}	

On the other hand, it appears more complex a confrontation of the results for the Marshall quotient (Mq) and the porosity (P).

By working in an analogous way to the previously discussed cases, it is highlighted that to obtain an acceptable percent deviation with respect to the impulsive compaction with 75 strokes, it is necessary to apply a vibrational compaction time of, respectively, 7 seconds for Mix 1 and 11 seconds for Mix 2 (see Table 7).

Table 7 Marshall quotient and porosity values exhibited by the mixtures (N=75 strokes, t_c=4s e 11s)

Compaction type	Mix 1			
	Mq [kN/mm]	E [%]	P [%]	E [%]
Impulsive (N=75 strokes)	4.2	2.4	10.5	0.95
Vibrational (t_c=7s)	4.1		10.4	
	Mix 2			
Impulsive (N=75 strokes)	5.9	1.7	8.8	4.5
Vibrational (t_c=11s)	5.8		8.4	

This different behavior is reasonably due to the different internal structure of the studied mixtures. Relatively to stability and indirect tensile strength it was possible to obtain uniformity of behavior, but this is not true for Marshall quotient and porosity.

It is clear that the compaction guarantees the requisite of compactness (expressed in terms of bulk density of the mixture) and that the final resistance is related to the compaction grade obtained. In the case of the two studied mixtures it has been possible to determine (see Table 8) that, after a really small vibrational compaction time (t_c=4s), the bulk density “γ_V” is really close to the bulk denity “γ_M” obtained under impulsive compaction with 75 strokes (UNI EN

12697-30, 2007). Starting from what previously mentioned, it is possible to rationalize the agreement of the obtained results, at least about the behavior of the mechanical resistances (see Table 5 and 6).

Table 8 Bulk density of the mixtures by varying the compaction technique (Impulsive with N=75 strokes and Vibrational for t_c = 4, 7, 10, 13, 27, 40, 54s)

	Mix 1		Mix 2	
t_c [s]	γ_V [kg/m^3]	γ_M [kg/m^3]	γ_V [kg/m^3]	γ_M [kg/m^3]
4	2187		2256	
7	2190		2269	
10	2195		2287	
13	2248	2181	2316	2260
27	2243		2350	
40	2256		2365	
54	2262		2393	

To highlight the macroscopic effects introduced by the compaction, we proceeded preparing and sectioning along the diameter a good number of specimens. Pictures of these specimens have been taken and keenly elaborated.

In other words, after choosing an internal section with dimensions of 9.14×5.33cm (Area=A_0=48,72cm^2), centered in the specimens' section of about 10.16×6.35cm, we used a software to elaborate microscope images called "MBF_ImageJ" (open source from McMaster University) to correctly analyze the internal structure variation of the material as the compaction energy varies, both for the vibrational compaction technique at t_c=4, 7, 10, 13, 27, 40 e 54s, and for the impulsive compaction technique with N=75 strokes.

In other words, we determined, analytically and for every cutting section of the specimen, both the voids' area "A" and it's percent value "(A/A_0)" as a function of the technique and compaction time t_c (see Table 9). It appears that the behavior of the A/A_0 parameter as t_c varies results well approximated by a logarithmic regression curve (see Figure 4), thus confirming what previously found in the study of the porosity (see Figure 2 and Figure 3).

Table 9 Volumetric parameters of Mix 2 by varying the compaction technique (Impulsive with N=75 strokes and Vibrational for t_c = 4, 7, 13, 27, 40 e 54s)

t_c [s]	A [cm^2]	A/A_0 [%]
4	0.434	0.89
7	0.317	0.65
10	0.302	0.62
13	0.292	0.60
27	0.170	0.35
40	0.083	0.17
54	0.073	0.15
N=75	0.345	0.71

In Figure 5 we report the real sections of some studied specimens (to the left) and the corresponding graphic elaborations (to the right) relative to the Mix 2 case. Starting from the top, Figure 4 describes the experimental results obtained from the impulsive compaction with N=75 strokes and from the vibrational compaction for t_c equal to 4, 13 and 40s. It clearly appears the difference in compactness, homogeneity and density of the different specimens, under the circumstantiation that the red areas show the voids present after compaction. It is clear that the porosity tends to increase with the decrease of the vibration time and that the section of the specimen compacted with 75 strokes has a quite disordered and porous structure, intermediate between what exhibited by the specimens compacted for 4 and 13 seconds.

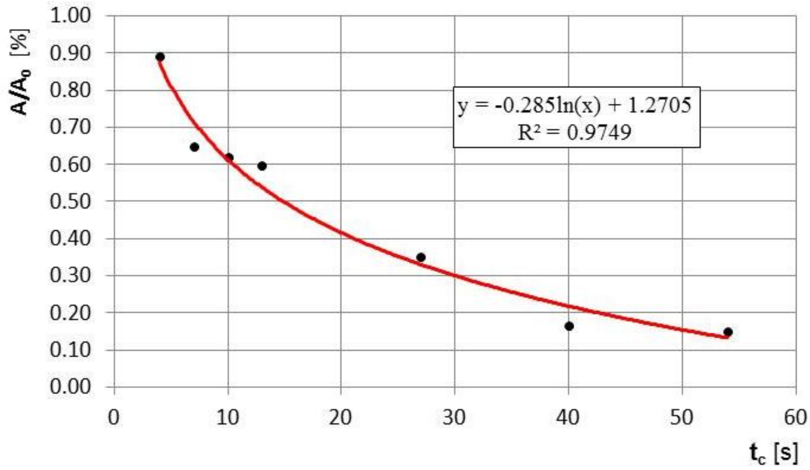

Figure 4 Real behavior and regression curve of the voids percentage in Mix 2 by varying the vibrational compaction time (t_c=40, 13 and 4s)

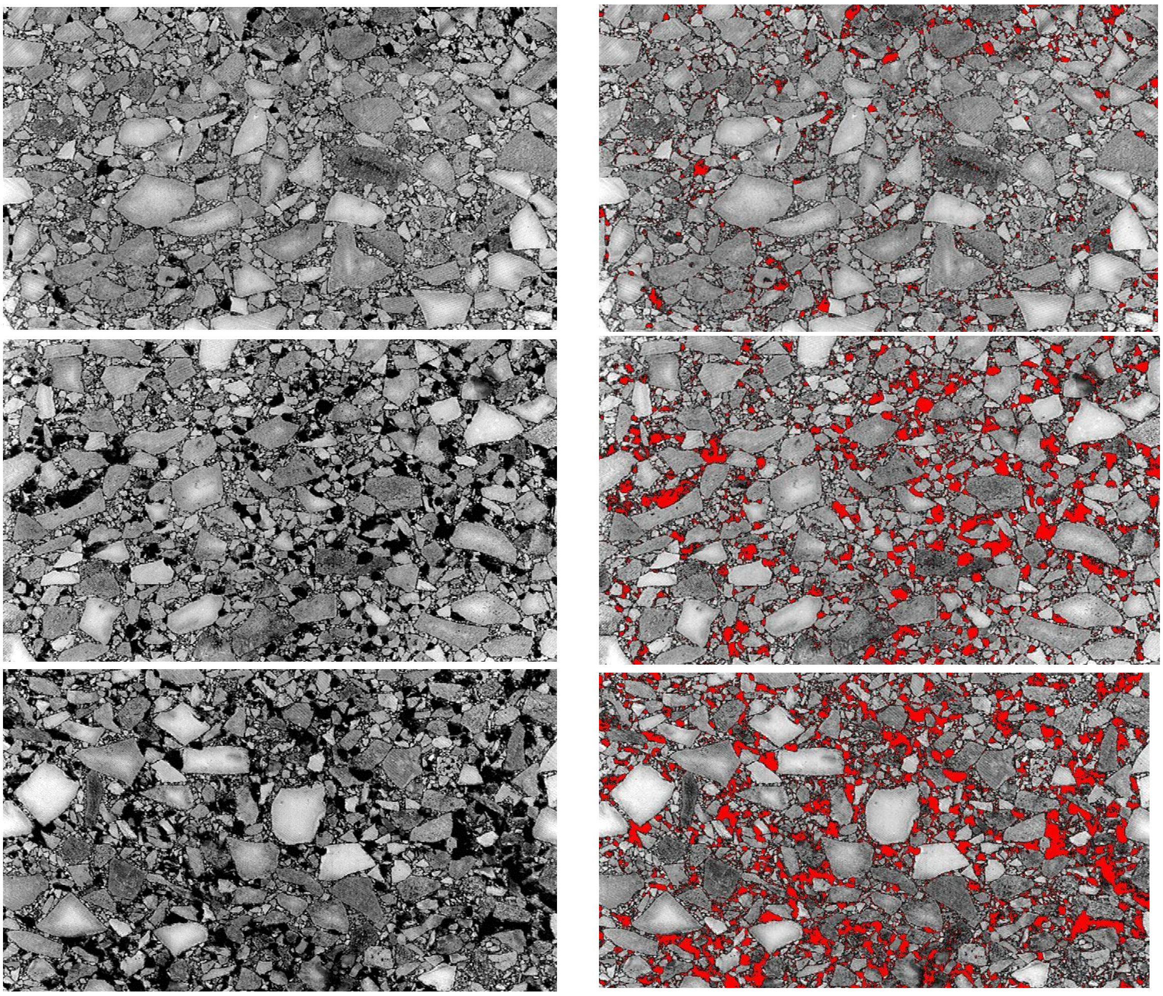

Figure 5 Longitudinal sections of specimens compacted (respectively, from top to bottom) with the vibrational technique for t_c=40, 13, 4 seconds and with the impulsive technique with N=75 strokes (Mix 2). Real (to the left) and elaborated (to the right) sections.

These experimental findings, relevant for both studied mixtures, highlight a good aptness by them to be effectively compacted. We could also observe that the two studied mixtures have a gradation of stone aggregates quite near the one of maximum density defined by the curve of equation $P(\%)=100\cdot(d/D)^{-1/2}$ (Fuller's parabola), where "P" represents the passing percentage through the sieve of opening "d" and "D" represents the maximum diameter of the aggregate (see Figure 6).

Based on these considerations we could thus state that asphalt concrete mixtures with comparable mechanical performances have gradations near to the maximum density curves. To fully confirm the validity of what reported, it should be necessary to extend the experimentation to a much broader number of mixtures, by carefully varying the gradation of aggregates and/or the bituminous binder percentage. Also, since the gradation is able to sensibly condition the compaction effectiveness, it should not be excluded a different behavior for those mixtures which are characterized by gradations sensibly different from Fuller curve.

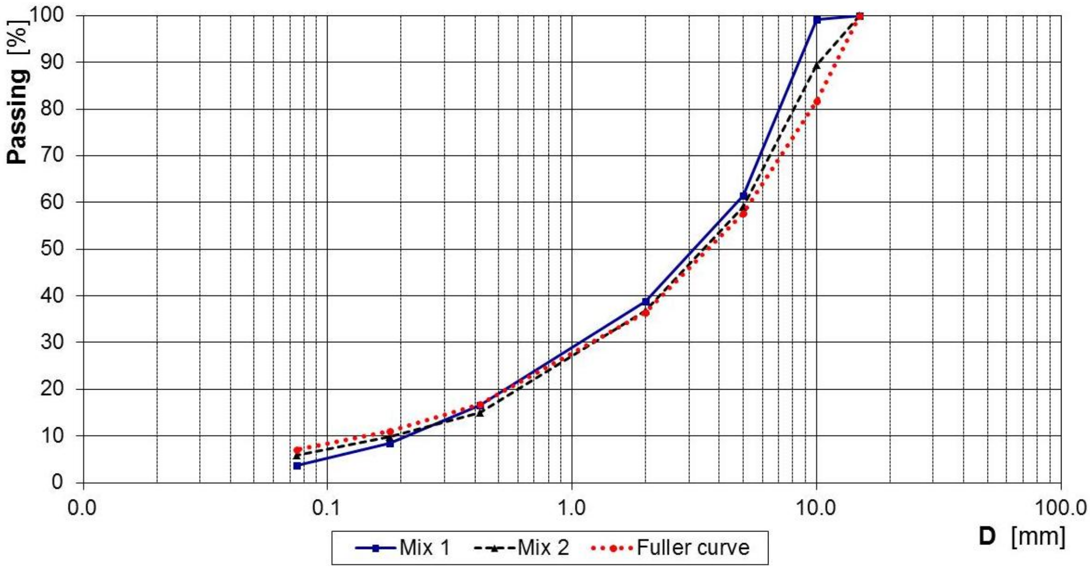

Figure 6 Gradations of the studied mixtures and maximum density curve (Fuller's parabola)

CONCLUSIONS

The necessity to outacheive the traditional unidirectional-impulsive technique to make the compaction more adherent to the reality has addressed the Authors to new compaction techniques for the bituminous mixtures.

In this study it is given a contribution to the better comprehension of the potential uses of the vibrational compaction as a substitute of the traditional technique which, as known, even along to a number of assets related to the broad diffusion and easiness of realization, has a limited ability to efficiently reproduce the operative reality.

Specifically, an alternative procedure has been proposed, based on the usage of a vibrational compactor, that is an instrument introduced by UNI EN 12697-32 exclusively to determine the maximum density of bituminous mixtures.

The experimental phase, developed with reference to two mixtures for wearing course layers, and the critical analysis of the results have led to highlight a number of analogies in the behavior.

In particular, by analyzing the behavior of the mechanical and volumetric properties by varying compaction energy and technique, we could find a high correlation between the two different techniques, at least about stability and indirect tensile strength.

About other parameters, however, like Marshall quotient and porosity, it was not possible to find a so close and clear analogy in the behavior. The natural prosecution of the study will, therefore, be aimed to search and use of other significant variables, like for example the gradation and its distribution in relation to the maximum density curve, but also the binder and/or filler percentage, considering that these rates can sensibly condition the performance of the asphalt concrete mixtures, both from a mechanical and volumetric points of view.

REFERENCES

CNR B.U. n.30 (1973). "*Determinazione della stabilità e dello scorrimento di miscele di bitume e inerti lapidei a mezzo dell'apparecchio Marshall*".

CNR B.U. n.38 (1973). "*Determinazione del contenuto di legante di miscele di bitume ed aggregati lapidei*".

CNR B.U. n.39 (1973). "*Determinazione della porosità o percentuale dei vuoti di miscele di aggregati lapidei con bitume o catrame*".

CNR B.U. n.40 (1973). "*Determinazione del peso di volume di miscele di aggregati lapidei con bitume o catrame*".

CNR B.U. n.134 (1991), "*Determinazione della resistenza a trazione indiretta e della deformazione a rottura di miscele di aggregati lapidei e bitume*".

Yue, Q.Z., Bekking, W., Morin, I., (1995). "Application of Digital Image Processing to Quantitative Study of Asphalt Concrete Microstructure". *Transportation Research Record*, 1492, pp. 53-60.

Khan, Z. Wahab, H., Asi, I., Ramadhan, R., (1998). "Comparative study of asphalt concrete laboratory compaction methods to simulate field compaction", *Construction and Building Materials*, Volume 12, Issues 6–7, 1 September 1998, Pages 373–384.

UNI EN 12697-8 (2003). "*Metodi di prova per conglomerati bituminosi a caldo - Determinazione delle caratteristiche dei vuoti di provini bituminosi*".

Hunter, A.E., Airey, G.D., Collop, A.C., (2004). "Aggregate Orientation and Segregation in Laboratory-Compacted Asphalt Samples", *Transportation Research Record: Journal of the Transportation Research Board*, Volume 1891, Issue 1, Pages 8-15, 01/01/2004.

Hunter, A.E., Airey, G.D., Collop, A.C., (2004). "*Effect of asphalt mixture compaction on aggregate orientation and mechanical performance*", Proceedings of CAPSA 2004 - 8th Conference on asphalt pavements for Southern Africa, 12-16 September 2004, Sun City, North West Province, South Africa.

UNI EN 12697-1 (2006). "*Metodi di prova per conglomerati bituminosi a caldo - Contenuto di legante solubile*".

UNI EN 12697-23 (2006). "*Metodi di prova per conglomerati bituminosi a caldo - Determinazione della resistenza a trazione indiretta di provini bituminosi*".

UNI EN 12697-30 (2007). "*Metodi di prova per conglomerati bituminosi a caldo - Preparazione del provino mediante compattatore a impatto*".

UNI EN 12697-32 (2007). "*Metodi di prova per conglomerati bituminosi a caldo – Compattazione in laboratorio di miscele bituminose mediante un compattatore a vibrazione*".

UNI EN 12697-34 (2007). "*Metodi di prova per conglomerati bituminosi a caldo - Prova Marshall*".

UNI EN 12697-35 (2007). "*Metodi di prova per conglomerati bituminosi a caldo – Miscelazione in laboratorio*".

UNI EN 12697-2 (2008). "*Metodi di prova per conglomerati bituminosi a caldo - Determinazione della granulometria*".

http://www.macbiophotonics.ca (2012).