

# COMPARATIVE STUDY BETWEEN GYRATORY COMPACTOR AND IMPACT COMPACTOR (MARSHALL) TO PREPARE BITUMINOUS MIXTURE SPECIMENS

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## ABSTRACT

In Spain, the manufacture of cylindrical samples has been carried out with the Marshall equipment, now called impact compactor. Specifications exist for various properties based on the results obtained from the specimens prepared with this methodology. The harmonization of European standards of bituminous mixtures with the release of the series of product standards UNE-EN 13108 and testing EN 12697, allows the possibility of manufacturing cylindrical specimens with several compaction methods: impact compactor (UNE- EN 12697-30), gyratory compactor (EN 12697-31) and vibratory compactor (EN 12697-32). The production of cylindrical specimens with the impact compactor is severely limited in the case of bituminous mixtures with coarse aggregate and mixtures produced by low temperature technology (half-warm mixes).

To address this deficiency, a working group of Asefma ( Spanish Association of Asphalt Producers) began a study to determine the compaction equivalent energy between the gyratory compactor and the impact compactor. The results obtained by both methods show equivalent levels of density and indirect tensile strength for the following types of mixtures: AC (asphalt concrete), SMA 11 (stone mastic asphalt) and BBTM 11B (gap graded), confirming that the gyratory compactor provides higher levels of reproducibility than the impact compactor.

## INTRODUCTION

The impact compactor (Marshall) tool has been traditionally used in Spain to design formulations of bituminous mixtures and to evaluate their mechanical properties. In the case of AC type mixtures, the impact compaction is performed by applying 75 blows per face, whereas in the case of PA and BBTM mixtures 50 blows per face are required.

Over the years sound correlations have been established between the samples produced in the laboratory and cores extracted from pavements by this compaction method. Correlation has been limited to finding equivalent densities and mechanical properties between laboratory and field samples.

It is interesting to note that the bituminous mixtures used in Spain, especially the AC type, are designed to minimize pavement deterioration resulting from rutting. Therefore, low bitumen content are commonly used in asphalt mixture design. This low binder content modifies compaction process, in laboratory and job sites. Therefore mix design is

conditioned by these facts, compared to formulations commonly used in other European countries .

Because of the implementation of CE marking (a mandatory conformity marking for certain products sold within the European Economic Area (EEA) since 1993) in Spain by adopting harmonized standards, new methods of compaction in the laboratory specimens were standardized. Thus, besides the impact compactor (11) other compaction methods are available: the gyratory compactor (12) and vibratory compactor (13). Gyratory compactor stands out for its potential. The interest of this new method of preparation of samples lies in the following issues:

- Allow to work with larger aggregates, being able to use a mold of 150 mm or 160 mm diameter.
- It is suitable for compacting mixes manufactured at low temperature, in particular under half-warm mixes category (taking into account the trends in the market, low temperature asphalt mixtures produced by foaming processes appear to be the most promising). Such mixtures cannot be properly compacted by impact compaction (1) (2).
- It is possible to design probes to a very controlled void content (this point is also possible with some models of impact compactor equipped with deformation probes) (4)
- According to the literature, the gyratory compactor generates less dispersion in the preparation of specimens than impact compactor.
- Former tests with vibratory compactor were not satisfactory, obtaining mixtures with very low void content, which caused its exclusion, focusing the work on the use of the gyratory compactor.

Equivalence between the level of compaction in impact and gyratory equipments has been widely described through Superpave program development. However, due to differences between the compaction equipments of Superpave program and those described in the UNE-EN 12697-30, especially the difference in the internal angle ( $0.82^\circ$  in Europe and  $1.2^\circ$  in the U.S.) connected with the different rheological characteristics of asphalt mixtures used in Spain, it has become necessary to conduct a specific study determining equivalent compaction energy by both methods.

Should be pointed out that the main purpose of this study is to obtain an alternative method to the impact compactor to produce specimens which can be mechanically characterized. In the existing regulations in Spain, tests performed using these cylindrical specimens are: water sensitivity (8) (UNE-EN 12697-12) and indirect tensile stiffness (10) (UNE-EN 12697 -26). Both test methods are based on indirect tensile methodologies, which experimentally have shown to be highly dependent on the uniformity of the samples. In this way, preparation of specimens by impact compaction generates relatively poor reproducibility levels.

In the medium term, the aim of this comparative study is to apply it to the evaluation of the compactibility of asphalt mixtures in the laboratory and its correlation with the values obtained on job sites, but this task is not the immediate subject of this study.

Another reason to address this work has been the recent availability in Spain of a large number of laboratories equipped with appropriate instrumentation, allowing reproducibility studies with sounder basis, which cannot be obtained with very small number of participants. In this sense, foundation of Aleas (Association of Laboratories belonging to

Asefma) has been a catalyst for promoting collaborative works as described in this publication.

The paper is organized in stages, starting the study with the most widely used asphalt mixtures (type AC) and continuing with the other types of mixtures used in the Spanish market. This publication compiles the experience with the following types of mixtures: AC, BBTM11 B and SMA 11.

An important part of the work has been devoted to the study of the variability of both compaction methods, since in Spain a reproducibility study at such large-scale was not available.

## **OBJECTIVES AND DEVELOPMENT PROGRAM**

As already mentioned above, the main objective is to determine the equivalent energy in the manufacture of test specimens with the gyratory compactor (using the rotation angle setting at  $0.82^\circ$ ) to achieve the same density as specimens produced with the impact compactor for various types of bituminous mixtures commonly used in Spain. The types of mixtures included in this study were:

AC (asphalt concrete: UNE-EN 13108-1).

BBTM (gap graded: UNE-EN 13108-2).

SMA (Stone mastic asphalt: UNE-EN 13108-5).

PA (porous asphalt: UNE-EN 13108-7). This latter type of mixture has not been included in the experimental work because of the lack of time, but it is currently underway.

The setup of the study is the following: manufacture of specimens with impact compactor by applying 50 blows per face (for all types of mixtures) and 75 blows per face (only for AC mixtures), manufacture of specimens with the gyratory compactor with an application of 210 gyrations. The equivalent compaction energy between impact and gyratory compactor is determined by studying the compaction plots, defining gyration levels within the ranges that are contained in the standard UNE-EN 13108-20

## **EXPERIMENTAL DEVELOPMENT**

The experimental work has been organized in several stages:

- Phase 1. Initial round robin test.
- Phase 2. Equipment adjustment and compaction study on AC mixtures with 16 mm aggregate maximum size.
- Phase 3. Study for AC mixtures with maximum aggregate size of 22 and 32 mm.
- Phase 4. Study for the SMA mixtures and BBTM mixtures with aggregate maximum size of 11 mm.
- Phase 5. Study for mixtures PA (pending completion)

### Phase 1. Initial Round Robin Test.

The tested mixture belongs to AC type, with a maximum aggregate size of 16 mm, produced in an asphalt plant, splitted and delivered for each of the participants (3). An initial work protocol was designed, setting the conditioning and testing conditions (temperature, energy, time, etc ...). In this first phase there were 11 participating laboratories. Tasks were developed as follows:

- Compaction of specimens with impact compactor applying 75 blows per face and determination of the bulk saturated surface dry density (SSD) , bulk geometric density and air voids content.
- Compaction of specimens with the gyratory compactor up to 210 gyrations and determination of the bulk saturated surface dry density (SSD) , bulk geometric density and air voids content. At the same time, all compaction plots were recorded.
- Indirect tensile test (UNE-EN 12697-23,) for all specimens at 15 ° C.

The results obtained are shown in Table 1:

**TABLE 1. Testing Results for Gyratory Compaction Tests, Impact Compaction and Indirect Tensile Strength**

GYRATORY COMPACTOR			
	Bulk density, ( kg/m <sup>3</sup> )		Indirect Tensile strength(MPa)
	Geometric	SSD	
Standard deviation	27	22	0,52
Average	2313	2372	3,10
IMPACT COMPACTOR			
	Bulk density, ( kg/m <sup>3</sup> )		Indirect Tensile strength(MPa)
	Geometric	SSD	
Standard deviation	26	15	0,39
Average	2318	2364	3,09

### Phase 2. Equipment Adjustment and Compaction Study for AC Mixtures with 16 mm Maximum Aggregate Size

In this development six laboratories were involved (4). The reason for the reduction in the number of participants compared to Phase 1 was to facilitate the task, since in the experimental program a preliminary task (verification and adjustment of the equipment) was included, mostly for gyratory compactors although some elements of impact compactors were verified as well. According to the results shown in Table 1, reproducibility values for gyratory compactor are worse than those the impact compactor, a fact that is inconsistent with the existing references. This verification task was designed to reduce systematic errors in the experimental conditions. The following elements were verified. In the case of impact compactor: the impact hammer: the lifting mechanism, the counting device and the compacting time. For gyratory compactor, the parts to be verified were: the internal angle, the applied force and the height control .

Two AC mixtures with 16 mm maximum aggregate size with different nature of aggregates (limestone and silica) and gradation curves were used, as shown in the following table:

**TABLE 2: Characteristics of Asphalt Mixtures Used in Phase 2.**

Mixture	AC16S	AC16D
Aggregate nature	lime	silica
Bitumen grade	35/50	50/70
Maximum density, kg/m <sup>3</sup>	2582	2462
Binder content (%)	4,4	5,13
Filler/ binder relationship	1,17	1,24

Mixtures were prepared in an asphalt plant. Later, they were sent and characterized in each participating laboratory following a strict protocol.

Series of specimens were prepared by applying 50 and 75 blows per face with an impact compactor. Also, series of specimens with the gyratory compactor were prepared by applying 210 gyrations. The subsequent study allowed determining what number of gyrations were necessary to achieve similar densities to those obtained by impact compactor. From the results obtained it was concluded that it was necessary to prepare a series of samples at 40, 60, 80, 100 and 120 gyrations. The results of the aforementioned series of samples are shown in Table 3, as well as the characterization of these specimens by testing indirect tensile strength. All gyratory compactor specimens were produced using 100 mm molds.

**TABLE 3. Testing Results for Gyratory Compaction Tests, Impact Compaction and Indirect Tensile Strength in Phase 2.**

IMPACT COMPACTOR								
	Bulk density, ( kg/m <sup>3</sup> )				Air voids (%)		Indirect Tensile Strength (MPa) Average/SD	
	Geometric		SSD					
	AC16S	AC16D	AC16S	AC16D	AC16S	AC16D	AC16S	AC16D
75 blows	2414	2387	2466	2417	6.5	3.1	<b>2.76/0.2</b>	<b>2.89/0.17</b>
50 blows	2377	2364	2424	2402	7.9	4.0	<b>2.64/0.2</b>	<b>2.62/0.28</b>
GYRATORY COMPACTOR								
Number of gyrations	Bulk density (kg/m <sup>3</sup> )				Air voids (%)		Indirect Tensile Strength (MPa) Average/SD	
	Geometric		SSD					
	AC16S	AC16D	AC16S	AC16D	AC16S	AC16D	AC16S	AC16D
40	2290	2291	2375	2361	11.1	7.0	<b>2.25/0.3</b>	<b>2.54/0.28</b>
60	2335	2326	2402	2387	9.8	5.7	<b>2.48/0.3</b>	<b>2.80/0.33</b>
80	2356	2367	2429	2411	8.9	4.2	<b>2.75/0.3</b>	<b>2.73/0.26</b>
100	2362	2378	2448	2415	8.5	3.9	<b>2.81/0.3</b>	<b>2.70/0.17</b>
120	2376	2383	2464	2426	8.0	3.4	<b>2.95/0.3</b>	<b>2.76/0.11</b>
210	2431	2400	2503	2432	5.8	2.5	<b>3.17/0.2</b>	<b>2.83/0.28</b>

It is noteworthy that the standard deviations of bulk density measurements (SSD method) are much lower for gyratory compactor than for those for impact compactor. So, in gyratory equipment SD values of 12 and 17 were obtained (for mixtures AC16D AC16S and, respectively, 210 turns) meanwhile the impact compactor values were 28 and 15, respectively (at 75 blows per face). These facts agree with former experiences shown in literature and confirm the necessity of verification procedures concluded from reproducibility results of Table 1.

### **Phase 3. Study for AC Asphalt Mixtures with 22 and 32 mm Maximum Aggregate Size.**

Six laboratories were involved (5) in this study. This phase includes the study of specific gravity of specimens type AC with 22 and 32 mm aggregate maximum size, which requires the use of larger molds than in the previous stage (150 and 160 mm in diameter).

The mixtures were manufactured in separate asphalt plants and their main features are shown in Table 4 :

**TABLE 4: Characteristics of Asphalt Mixtures Used in Phase 3**

Mixture	AC22S	AC32G
Aggregate nature	silicalime	lime
Bitumen grade	50/70	35/50
Maximum density, kg/m <sup>3</sup>	2488	2589-2680
Binder content, %	4,21	3,41- 3,52
Filler/bitumen relationship	1,13	1,15-1,20

The operating procedure was similar to that followed in Phase 2. According to the density values, number of gyrations to be set in the compactor would be at 80, 100 and 160. Results are shown in Table 5:

**TABLE 5. Testing Results for Gyrotory Compaction Tests, Impact Compaction and Indirect Tensile Strength in Phase 3.**

IMPACT COMPACTOR								
	Bulk density, ( kg/m <sup>3</sup> )				Air voids (%)		Indirect Tensile Strength (MPa) Average/SD	
	Geometric		SSD					
	AC22S	AC32G	AC22S	AC32G	AC22S	AC32G	AC22S	AC32G
75 blows	2269	2458	2342	2518	6.4	5.3	<b>2.27/0.27</b>	<b>2.65/0.31</b>
50 blows	2233	2401	2309	2478	7.2	6.7	<b>2.13/0.22</b>	<b>2.29/0.14</b>
GYRATORY COMPACTOR								
Number of gyrations	Bulk density ( kg/m <sup>3</sup> )				Air voids (%)		Indirect Tensile Strength (MPa) Average/SD	
	Geometric		Geometric					
	AC22S	AC32G	AC22S	AC32G	AC22S	AC32G	AC22S	AC32G
80	2213	2404	2286	2479	8.2	7.5	<b>1.57/0.42</b>	<b>1.91/0.42</b>
100	2233	2409	2296	2482	7.7	7.6	<b>1.68/0.38</b>	<b>1.67/0.50</b>
160	2265	2481	2327	2541	6.5	5.6		<b>2.45/0.80</b>

The former results were statistically analyzed also. For this study Cochran and Grubbs tests , according to UNE 82009-2 were implemented. Table 6 shows the results.

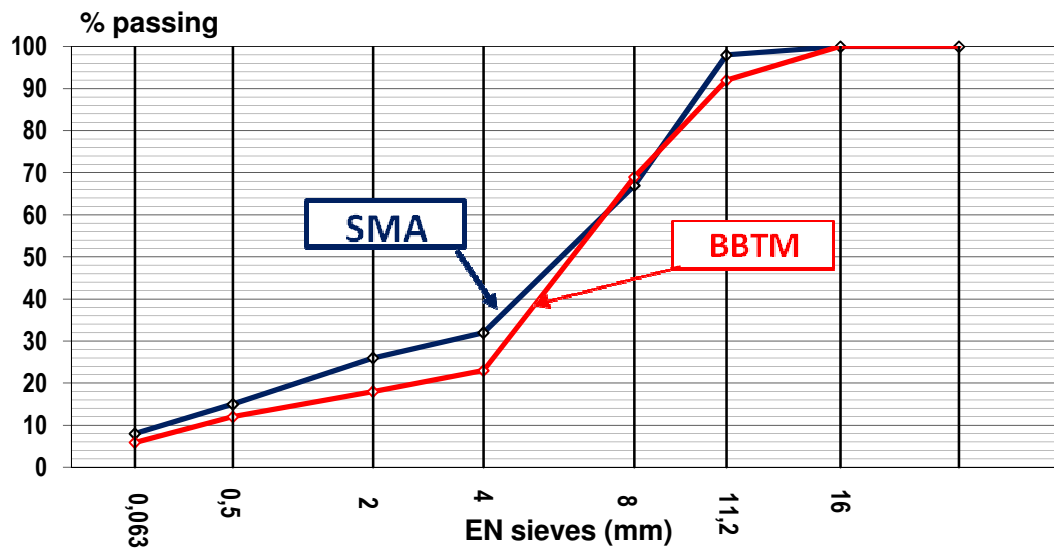
**TABLE 6. Repeatability and Reproducibility Parameters for SSD Bulk Density, Air Voids Content at Different Compaction Energies**

	50 blows	75 blows	80 gyrations	100 gyrations	160 gyrations	210 gyrations
<b>S<sub>R</sub> density</b>	21,2	19,6	12,8	16,2	15,9	12,1
<b>R density</b>	59	56	36	46	45	34
<b>S<sub>r</sub> density</b>	7,5	6,1	9,8	6,5	7,1	7,2
<b>R density</b>	21	18	28	18	20	20
<b>S<sub>R</sub> air</b>	1,2	0,8	0,5	0,5	0,6	0,5
<b>R air voids</b>	3,3	2,2	1,3	1,4	1,7	1,4
<b>S<sub>r</sub> air voids</b>	0,3	0,3	0,3	0,3	0,3	0,3
<b>R air voids</b>	0,9	0,8	0,9	0,8	0,9	0,8

#### Phase 4. Study of SMA and BBTM Asphalt Mixes with 11 mm Maximum Aggregate Size.

Gradation curves of both mixtures are shown in Figure 1. SMA 11 mix contains mylonite as coarse aggregate, while BBTM mixture contains quartzite. Both mixtures use limestone

sand as fine aggregate and polymer modified bitumen PMB45/80-65 as binder. Bitumen content of the mixture is 6.1% for SMA and 5.2% for BBTM, having filler / bitumen relationships of 1.2 and 1.1, respectively.



**FIGURE 1. Gradation curves of SMA and BBTM mixtures studied in phase 4.**

To carry on the study (6) on these types of mixtures, these were referenced by impact compaction with 50 blows per face (according to Spanish specifications).

Series of specimens were produced with the impact compactor (50 blows) and the gyratory compactor, firstly at 210 gyrations and then at a number of gyrations which provide the reference density obtained by impact. The results obtained showed that the compaction energy range is 80, 100, 120 gyrations for SMA mixture and 100, 120 and 160 gyrations for BBTM mixture.

The characterization of the samples was performed similarly to that described in previous phases. Results are shown in Table 7.



**TABLE 7. Testing Results for Gyrotory Compaction Tests, Impact Compaction and Indirect Tensile Strength in Phase 4.**

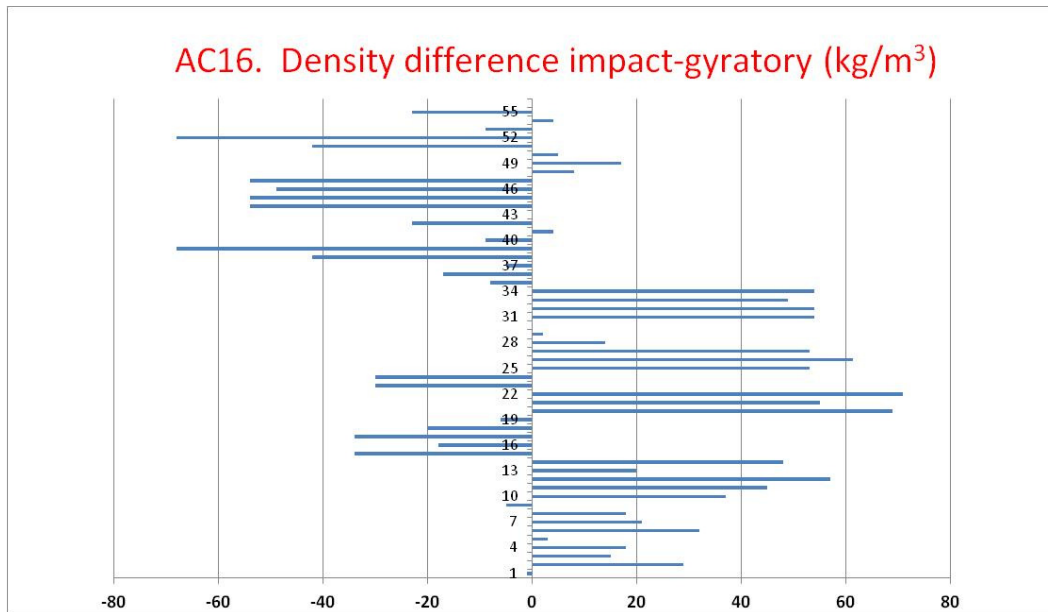
IMPACT COMPACTOR						
	Bulk density (kg/m <sup>3</sup> )				Indirect Tensile Strength (MPa)	
	SMA 11		BBTM 11		SMA 11	BBTM 11
	Geometric	SSD	Geometric	SSD		
50 blows	2318	2397	2134	2145	2.32	1.66
GYRATORY COMPACTOR						
Number of gyrations	Bulk density (kg/m <sup>3</sup> )				Indirect Tensile Strength (MPa)	
	SMA 11		BBTM 11		SMA 11	BBTM 11
	Geometric	SSD	Geometric	SSD		
80	2313	2412			2.40	
100	2317	2414	2084		2.47	1.49
120	2329	2418	2092		2.62	1.49
160			2135			1.57
210	2360	2426	2145		2.42	1.63

Table 8 details the statistical analysis regarding specific gravity. Repeatability and reproducibility parameters were obtained for both types of compactors. For comparison purposes, bulk densities at 100 gyrations for SMA mixture and 160 gyrations for BBTM mixture were used as reference.

**TABLE 8. Results of Standard Deviation of Repeatability and Reproducibility**

	S <sub>r</sub>		S <sub>R</sub>	
	SMA 11	BBTM 11B	SMA 11	BBTM 11B
SG geometric (impact)	17.8	15	47.1	77
SG SSD (impact)	8.1		31.1	
SG geometric (100 gyrations)	17.7		26.2	
SG SSD (100 gyrations)	9.2		15.1	
SG geometric (160 gyrations)		30		59

After finishing the studies at laboratory scale, verification of the former results was carried out with samples taken from asphalt plants during their ordinary operations. The purpose of this study is to check that the laboratory-scale findings are applicable in day to day quality control activities. Figure 2 shows the data collected for AC16 asphalt mixtures. Each bar corresponds to the difference in bulk density observed between samples prepared by impact and gyrotory compactor. The data correspond to different laboratories and mixtures within the typology AC16.



**FIGURE 2: Differences in SSD bulk density of samples taken from asphalt plants.**

It can be seen that differences in specific gravity have no clear trend. This means that variability in the test is the main source of errors, rather than systematic differences in both compaction methods. (Variability is cumulative: specimen manufacture and the test method).

Similar studies are underway for all types of mixtures described in this paper.

## CONCLUSSIONS

- Number of gyrations to obtain the same specific gravity as impact compaction are the following:

MIXTURES	Gyrations equivalent to 75 blows per face	Gyrations equivalent to 50 blows per face
AC32	160	80
AC22	160	100
AC16	100	80
BBTM11B	--	100
SMA11	--	160

- In all cases, it has been taken into account the categories specified in Table C.1 of standard UNE-EN 13108-20.
- Verification results on samples taken from asphalt plants during ordinary operations show that the equivalence between compaction systems for different types and gradations of bituminous mixtures is satisfactory, confirming the recommended energy levels. However, it is advisable to continue this work to have a higher number of results which confirm the above conclusions.

- In many cases, gyratory compactor show results with better reproducibility (lower  $S_R$  values).
- The results coming from the indirect tensile tests provide no clear information about performance of asphalt mixtures specimens compacted by both methods.

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