SPANISH EXPERIENCE WITH THE APPLICATION OF GYRATORY COMPACTOR AND INDIRECT TENSILE TEST IN DESIGN AND CONTROL OF COLD RECYCLED ASPHALT PAVEMENT

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Abstract

This paper summarizes the Spanish experience in the design and control of cold in-place recycling (CIR) of asphalt pavements. First, the results obtained in laboratory after the mixture design process are compared with the densities encountered in the field. Second, the application of the Superpave Gyratory Compactor (SGC) for specimen manufacture during the design stage is analyzed by varying the standard conditions of gyration angle and vertical pressure. Finally, a new design method based on the indirect tensile test is proposed.

INTRODUCTION

Cold in-place recycling (CIR) of asphalt pavements is a technique of great interest in road construction because of its environmental, economic and structural benefits.

Environmental benefits. Aged asphalt pavement rehabilitation is usually accomplished by milling of aged, cracked asphalt layers, disposal of milled material (RAP) in a landfill and placement of a new aggregate layer. Asphalt emulsion CIR allows new layers to be obtained from aged materials. In this way, the use of new materials is avoided and the negative environmental impact of landfills is reduced.

Economic benefits. Asphalt emulsion CIR is one of the most cost-effective pavement rehabilitation strategies. Two aspects play a major role in reducing costs, namely reuse of pavement materials to construct the new layer and no need to transport RAP to landfills, pay disposal fees or transport new materials to site.

Structural behavior. Asphalt emulsion CIR layers exhibit excellent structural behavior. However, their mechanical and resistance characteristics differ from those of conventional hot mix asphalt. Their modulus is smaller than that of hot bituminous mixtures (3000 MPa and 6000 MPa, respectively) but their fracture is more plastic and ductile, allowing movement of existing cracks in the underlying pavement to be partially absorbed (anti-crack mechanism).

However, cold recycled bituminous mixtures also provide very good performance from the point of view of the designed mix (emulsion type and content) and the construction process. High mixture cohesion is achieved by using the appropriate emulsion but final cohesion is also dependent upon the density obtained during compaction. The higher the final density, the higher the modulus and the cohesion of the mixture. The construction process is of particular importance since the obtained mixture is very difficult to compact. High energy compaction equipment must therefore be used (e.g. heavy pneumatic-tired rollers and vibrating rollers).

Analysis of the design method currently used in Spain reveals that the emulsion content of recycled mixtures is selected from a compression test performed on specimens. Because of the manufacture procedure, specimens have a higher density than that achieved when the mixture is placed and compacted on-site.

The objective of this study is to compare densities obtained in laboratory using different compaction procedures with those obtained on-site. In particular, the application of the gyratory compactor in specimen manufacture is analysed since, although not often used in Spain, gyratory compaction is likely to become the basic compaction method in the whole of Europe. Finally, a new design methodology for recycled mixtures with emulsion based on the indirect tensile test is proposed to better characterize these mixtures in laboratory under more similar conditions to those obtained on-site and to control the construction process.

TEST SPECIMEN PREPARATION. REFERENCE DENSITY

One of the objectives of laboratory specimen preparation is to obtain a similar product to that obtained on-site. To this end, it is very important to choose a compaction procedure capable of simulating site conditions and reaching site densities. CIR layer compaction requires equipment providing high energy compaction. This compaction procedure consists in heavy vibrating rollers compacting the layers, and then high pressure and wheel load pneumatic-tired rollers kneading them.

Laboratory compaction can be achieved using conventional impact compaction (Marshall compactor or Proctor compactor), static compaction, that is, by applying a load for a long period of time, or kneading compaction (gyratory compactor).

In the first part of this study, densities obtained on-site were compared with those obtained in the laboratory by Marshall and Proctor compaction, and static compaction with load values of 60 and 170 kN, Table 1. Static compaction of 170 kN is the established procedure in the current design method, which is based on immersion-compression test. Since the obtained densities are very high, a load of 60 kN is proposed to compact the specimens. Field density control required the use of nuclear equipment and core extraction. The equipment allowed compaction during on-site construction to be controlled and the effect of the number of roller passes to be checked. Figure 1 shows the densities measured versus the number of roller passes. These measurements were made with nuclear equipment immediately after the passing of the compactor on the layer surface. However, the value obtained is only a relative one since it is impossible to measure the mixture dry density, the reason being that nuclear equipment is unable to determine the moisture content of the sample because it cannot distinguish water from bitumen. Core extraction was used to determine the density obtained on-site after construction, and evaluate whether severe post-compaction was produced by traffic and what density was to be taken as a reference for specimen preparation.

Compaction Method		Density (g/cm^3)	Indirect Tensile Strength (MPa)	
			Dry	Wet
Marshall	Laboratory	2.180		
Proctor	Laboratory	2.080		
Static 60 kN	Laboratory	2.271	1.33	1.03
Static 170 kN	Laboratory	2.430		
Nuclear surface (*)	On-site	1.880		
Nuclear at 50 mm depth (*)	On-site	2.170		
Cores after 6 months	On-site	2.270	1.19	0.92
Cores after 18 months	On-site	2.310	1.36	1.00

(*) immediately after the compaction stage

TABLE 1 Density and Indirect Tensile Strength for Each Compaction Method

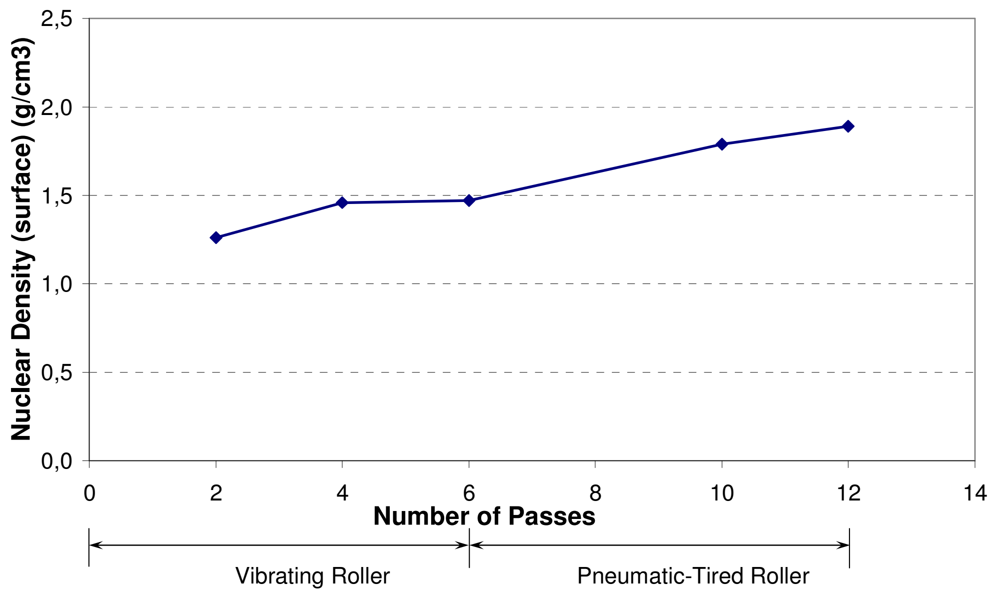

FIGURE 1 Nuclear Density (surface) Versus Number of Roller Passes.

Cores results are the most interesting of all laboratory results. Core densities were compared with those of specimens prepared by different procedures and oven cured at 60°C for 3 days. Specimens need to be cured to lose water and thus achieve field-like conditions after the curing and hardening processes subsequent to placement and compaction. Results reveal a slight post-compaction of cores extracted from the site because of traffic and the possibility to obtain field densities by static compaction of specimens with a 60 kN load. In contrast, specimens compacted with a 170 kN load have a much higher density than field density, Table 1. Specimen size is also different in both cases: for the 60 kN load, Marshall specimens were 101.6 mm diameter and approximately 60 mm in height whereas, for the 170 kN load, specimens for the immersion-compression test, were 101.6 mm in diameter and 100.0 mm in height.

USE OF THE SUPERPAVE GYRATORY COMPACTOR

Gyratory compaction has been proposed by several authors such as Salomon and Newcomb (*1*) and Cross (*2*) since this method works by kneading, which allows achieving field-like conditions. For these reasons, gyratory compaction may be used in specimen preparation for cold recycled mixture design. Other researchers, like Lee et al. (*3*), Lauter and Corbett (*4*), Mallick et al. (*5*) have also studied the possible application of the gyratory compactor in cold recycled mixture design. However, it was observed that further research is needed to determine the design compactive effort and that it should be based on field densities from CIR pavements.

To use the gyratory compactor in this study, it was first necessary to establish test conditions which allowed specimens with field-like densities to be obtained. For this reason, the effect of pressure and compaction angle on specimen density was analyzed. In this section, the results obtained for gyratory compaction of specimens are compared with the densities achieved by compaction with a 60 kN static press, which provides field-like densities, as specified above. Cationic slow-setting emulsion was selected for specimen preparation; the content used was 3.5% by mass of RAP.

When analyzing the use of the gyratory compactor for CIR compaction, the standard conditions for hot bituminous mixture compaction are 1.25°, 0.6 MPa and 300 revolutions. In this paper, the above conditions have been taken as a reference and in addition, the effect of compaction pressure and angle has been studied. For a 1.25º angle, pressure was established at 0.3, 0.6 and 0.9 MPa. For a 0.6 MPa pressure, the angle was set at 0.5, 1.25 and 2º. The final number of gyrations was 300 for all cases and the rotational speed was 30 rpm.

During specimen preparation, the evolution of density was recorded for each gyration of the gyratory machine. The density and indirect tensile strength of specimens were obtained after oven-curing at 60°C for 3 days. Results are shown in figures 2 and 3, and tables 2 and 3.

These tables show that the density obtained with the standard condition, 2.165 g/cm^3, is slightly lower than that obtained by static compaction with 60 KN, 2.174 g/cm^3. It was also observed that a small increase in the gyration angle permits the gyratory density to reach the static value, whereas an increase in vertical pressure of over 0.6 MPa produces decompaction, probably owing to the effect of water trapped inside the mixture.

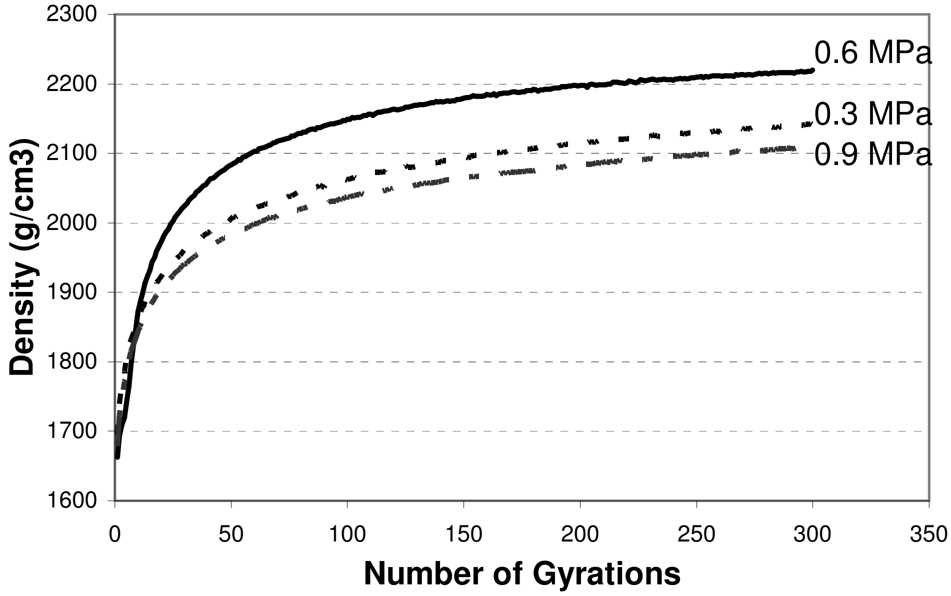

FIGURE 2 SGC Density Versus Number of Gyrations for Different Vertical Pressures.

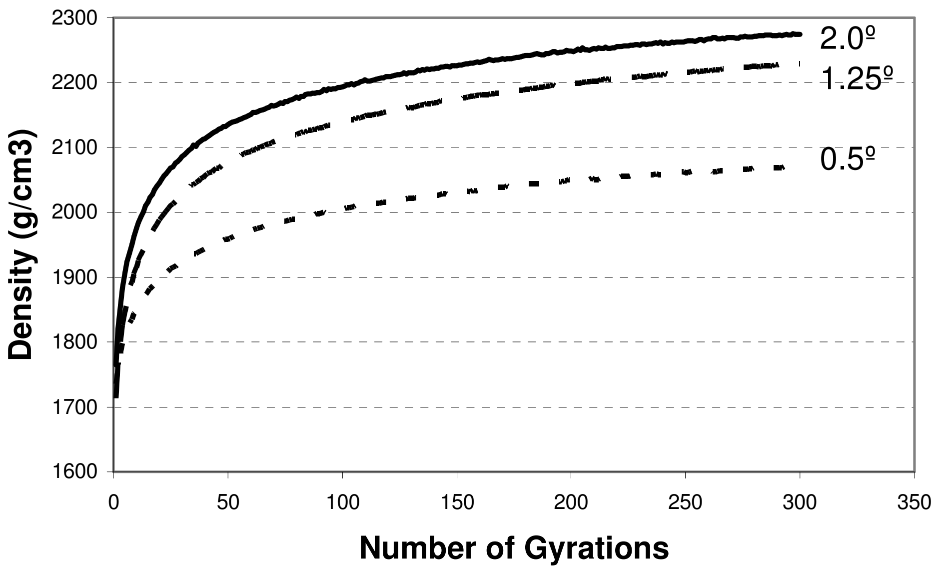

FIGURE 3 SGC Density Versus Number of Gyrations for Different Gyration Angle.

Vertical Stress (MPa)	Density (g/cm^3)	Indirect Tensile Strength (MPa)
0.3	2.133	1.41
0.6	2.165	1.67
0.9	2.087	1.18

TABLE 2 Density and Indirect Tensile Strength for Different Vertical Pressures. SGC Gyration Angle of 1.25º

Gyratory Angle (º)	Density (g/cm^3)	Indirect Tensile Strength (MPa)
0.5	2.018	0.80
1.25	2.165	1.67
2.0	2.184	1.58

TABLE 3 Density and Indirect Tensile Strength for Different Gyration Angles. SGC Vertical Pressure of 0.6 MPa

DESIGN METHODOLOGY

The most common procedure used in Spain for CIR design is to determine the strength retained after immersion-compression testing. The prepared specimens were ϕ 101.6 mm in diameter and 100.00 in height. They were statically compacted for 2 minutes with a 170 kN load, as specified by the current Spanish Standard. A series of specimens was prepared by this procedure varying the emulsion content. The content providing specimens with a retained strength higher than 75% was selected.

Table 4 shows the results of the above study. It can be observed that specimen densities are much higher than those obtainable in the field after compaction. In addition, compression strengths in dry conditions decrease as emulsion content is increased. This may appear contradictory since the emulsion is the cohesive element; thus it would seem that mixture cohesion rises with increasing the emulsion content until a threshold is exceeded and the opposite effect is produced. In other words, increasing the emulsion content causes mixture cohesion to rise too until a maximum is reached. In conclusion, compression strength does not seem to reflect this property.

Emulsion content (%)	1.5	2.0	2.5	3.0
Water (%)	3.13	2.94	2.75	2.56
Density (g/cm3)	2.41	2.41	2.42	2.44
Dry strength (MPa)	4.1	4.0	3.9	3.6
Wet strength (MPa)	2.9	2.8	3.0	3.1
Retained strength (%)	72	70	77	87

TABLE 4 Cold Recycled Mixture Design. Immersion-compression Test

Second, establishing correlations between compression strength of laboratory specimens (of 100 mm in height) and the mixture placed on-site is very difficult since it is not simple to obtain cores which, once sawn to even the surface, are sufficiently high to be compression tested with the thicknesses recycled to date. That is, we cannot know the real value of the compression strength of the constructed product. Hence, it is not easy to determine curing laboratory conditions which simulate real conditions during the service life of the product.

For these reasons, it is proposed to use a different parameter for cold recycled mixture design and control which is more related to behavior and can really be determined from testing of cores extracted from mixtures laid and compacted in the field. In the USA, resilient modulus testing, the Hveem stabilometer and cohesiometer tests (*6*, *7*), both in dry and wet conditions, and also indirect tensile testing (*1*, *8*) are used to characterize these mixtures.

In view of the above results, indirect tensile strength was selected since the determination of this property has two advantages, i.e. specimen preparation is very fast as there is less material, and cores can be indirect tensile tested as well. Thus, laboratory and on-site results can be correlated.

In order to validate the use of this test for CIR design, several series of specimens were manufactured with the average grading of the RAP from a Spanish highway close to Barcelona (C-147 Highway), table 5. This mountain highway runs through an area with high temperatures in summer and snow in winter, and an average annual rainfall of 700 mm. The rehabilitation tasks performed in this highway consisted in recycling 8 cm of pavement. Figure 4 plots the indirect tensile strength of specimens (both average and individuals values) prepared with different emulsion contents at 5°C in dry conditions and after immersion in water at 60°C for 1 day, keeping compaction fluids constant and using 60 kN static compaction after 3 days of oven-curing at 60°C. Field-like densities are obtained by this compaction method. It can be observed that after 3 days of accelerated curing, and with 3% of emulsion content, strengths equal to those obtained from cores extracted between 6 and 18 months after the above tasks are obtained. This suggests that the procedure is capable of simulating the actual behavior of the placed mixture and of assessing a property closely connected with mixture cohesion. The density of these specimens is 2.270 g/cm^3, which is between the values of the above cores. The same density was achieved using the gyratory compactor with 0.6 MPa of vertical pressure and a gyration angle of 1.25º. In addition, with the above emulsion content, the retained strength of specimens ranges between 77 and 78%.

UNE sizes (mm)	Passing (%)
40	100
25	99
20	96
12.5	83
10	73
5	47
2.5	27
0.63	6.7
0.32	3.2
0.08	0.72
Bitumen content (%) by mass of agg.	3.73

TABLE 5 Grading and Bitumen Content of the RAP milled from C-147 Highway

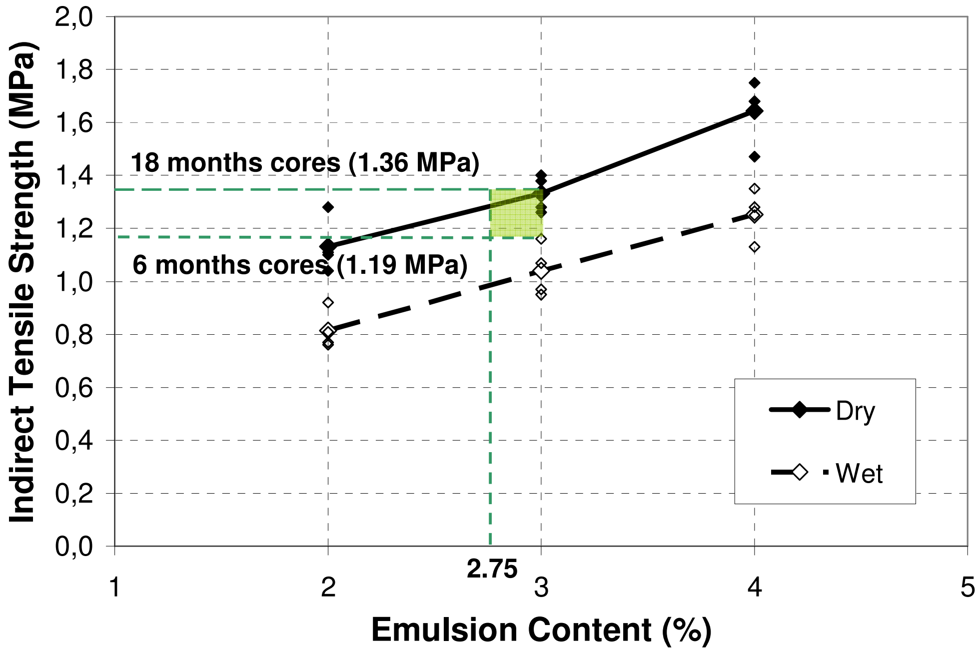

FIGURE 4 Variations in Indirect Tensile Strength at 5°C in Dry and Wet Conditions with Emulsion Content.

Based on the results obtained from different highways rehabilitated with CIR mixtures in Catalonia, Spain, the minimum emulsion content to be used in recycled mixtures should allow specimens compacted at 60 kN after a 3-day oven curing at 60°C to reach an indirect tensile strength of 1.0 MPa at 5°C and a retained strength of 75% after immersion in water at 60°C for 1 day. In figure 5, the current design procedure specified in the Spanish Standards is compared with the procedure based on the indirect tensile test.

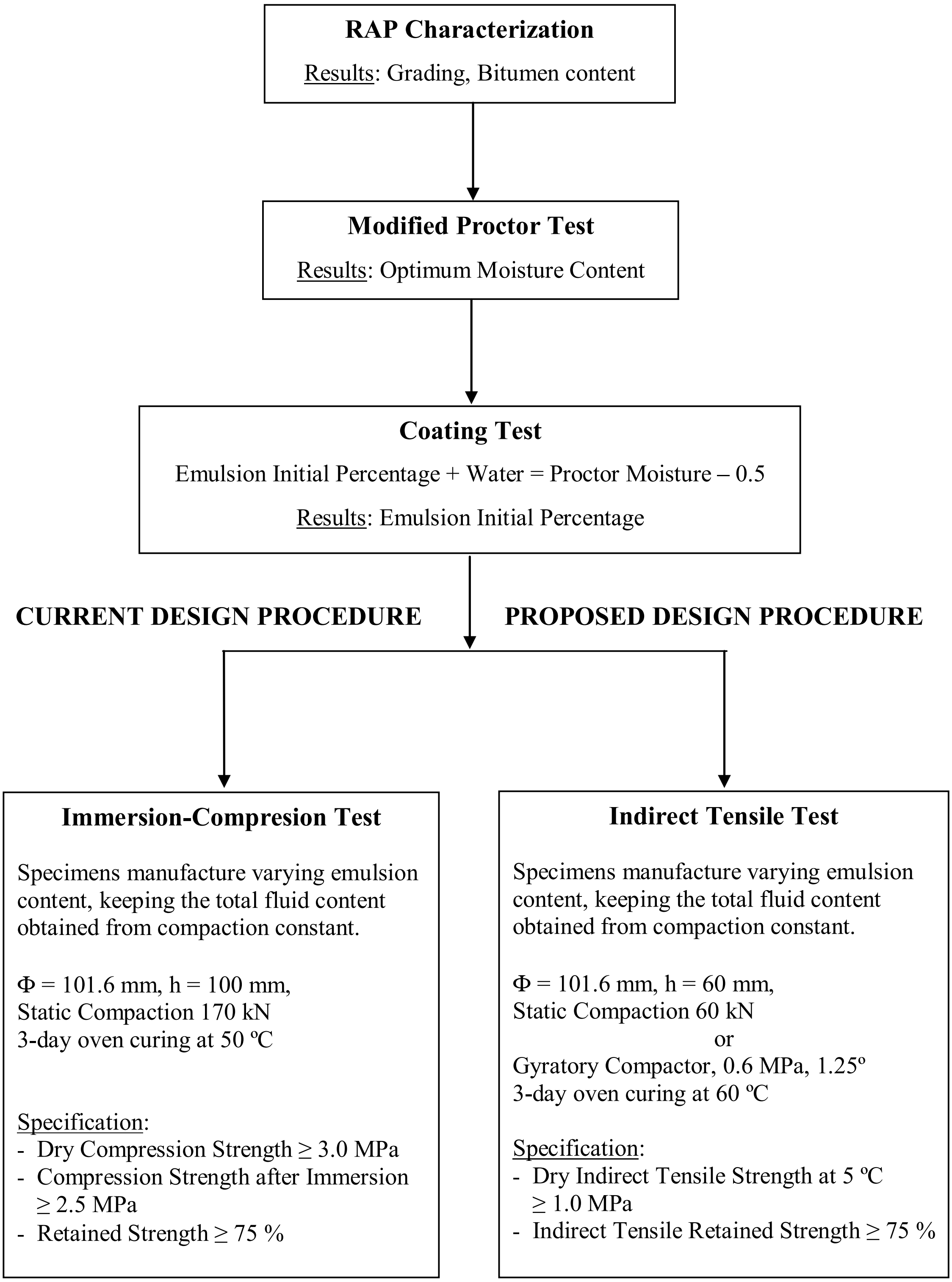

FIGURE 5 Spanish Standard Design Procedure and Proposed Procedure.

CONCLUSIONS

The Spanish experience with cold in-place recycling has been analyzed in this paper. Different compaction procedures for specimen manufacture have been analyzed and their results have been compared with those obtained in the field. The mechanical test used in

Spain to evaluate the strength of recycled mixtures has also been discussed. The most outstanding conclusions of this paper are as follows:

- While comparing field densities by means of cores extracted from recycled layers with those obtained in laboratory during the design stage, it is observed that static compaction of 170 kN, as currently specified in the Spanish Standards, leads to higher densities than those obtained on-site. This means that the mixture design is developed under conditions that will never be reached. On the other hand, if the compaction process is performed with 60kN, densities are very similar to the final values of the placed and compacted mixture.
- The application of the gyratory compactor has shown that similar densities can be obtained with the standard conditions (0.6 MPa and 1.25ºC). In this case, the gyration angle is the variable parameter able to increase density.
- Mixture cohesion rises with the increasing emulsion content until a maximum value is reached. Then, the opposite effect is produced. For this reason, the indirect tensile test is proposed as a design procedure.
- Specimens for the indirect tensile test can be manufactured in laboratory both with a static compaction of 60 kN and a gyratory compactor. It is shown that field-like densities are obtained with both procedures. The use of the gyratory compactor is, however, recommended since it is likely to become the regular compaction procedure in Europe after the harmonization process which is now taking place is finished.

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