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Study of warm mix asphalt with super stabilized emulsion
Estudio de mezclas asfálticas templadas con emulsión super-estabilizada

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Abstract

Reducing the temperatures in the production of asphalt mixes is currently one the most important challenges in the field of road engineering. This paper studies one the latest technologies applied in the manufacture of warm mix asphalt, called super stabilized emulsion. The application of mixing and compacting procedures for hot mix asphalt to this type of warm mixes, was studied. Additionally, physical and mechanical properties of the mixes with super stabilized emulsion were compared with hot mix asphalt. It was concluded that the most appropriate manufacturing method for these warm mixes includes the use of a gyratory compactor. The properties of warm mixes were different than those of hot mixes, however, they were within adequate ranges.

Keywords: *Hot mix asphalt (HMA), warm mix asphalt (WMA), decreasing the energy consumption, reclaimed asphalt pavement (RAP), compacting mixes*

Resumen

La reducción de las temperaturas de producción de las mezclas asfálticas, presenta en la actualidad uno de los desafíos más importantes en la ingeniería de caminos. El presente artículo estudia una de las últimas tecnologías para la fabricación de mezclas asfálticas templadas/warm mix asphalt, denominada emulsión super-estabilizada. Se estudió la aplicabilidad de los procedimientos de mezclado y compactación de mezclas asfálticas en caliente a este tipo de mezclas templadas. También se compararon propiedades físicas y mecánicas de las mezclas con emulsión super-estabilizada versus mezclas asfálticas en caliente. Se determinó que el método de fabricación más apropiado para estas mezclas templadas es aquel que considera el uso del compactador giratorio. Las propiedades de las mezclas templadas fueron diferentes a las de las mezclas en caliente, sin embargo se encuentran dentro de rangos adecuados.

Palabras clave: Mezcla asfáltica en caliente (MAC), mezclas asfálticas templadas (MAT), reducción de consumo energético, material reciclado (RAP), compactación de mezclas

1. Introduction

The production of Hot Mix Asphalt (HMA) is a process requiring high energy consumption, with manufacturing temperatures of 150-180°C. It has been estimated that the production of one cubic meter of HMA consumes a total of 697.7 MJ (Thenoux et al., 2007). Following the signature of the Kyoto protocol on December 1997 and its entry into force on February 2005, the requirements to reduce the emissions of production processes with high energy usage have raised a significant engineering challenge. Particularly, the industry associated to the construction and maintenance of asphalt roads has met several specific challenges. Among the latter is the use of asphalt mix production techniques employing lower temperatures, such as the Warm Mix Asphalt (WMA). Nevertheless, the asphalt industry does not only aim at reducing the environmental impact by decreasing the energy consumption, but also at increasing the use of reclaimed asphalt pavement (RAP) and building better-performing pavements with higher durability. Other specific challenges are:

- *Optimization of structural design methods*
- *Improvement of construction methodologies and techniques*
- *Quality improvement of the production systems*
- *Improvement of techniques and systems for pavement maintenance management*
- *Improvement of materials specifications (for ex., Superpave).*

As of year 2000, there has been a significant development of techniques aimed at reducing the manufacturing and placing temperatures of asphalt mixes. Figure 1 shows the classification of asphalt mixes by mixing temperatures, where mixes are classified as: Cold Mix Asphalt, Semi-warm Mix Asphalt, WMA and HMA. Among them, only the WMA has demonstrated performances equal to those of the HMA (Soto and Raz, 2007; Miranda et al., 2013), which does not necessarily mean that other types of mixes are unviable for the construction of good asphalt pavements.

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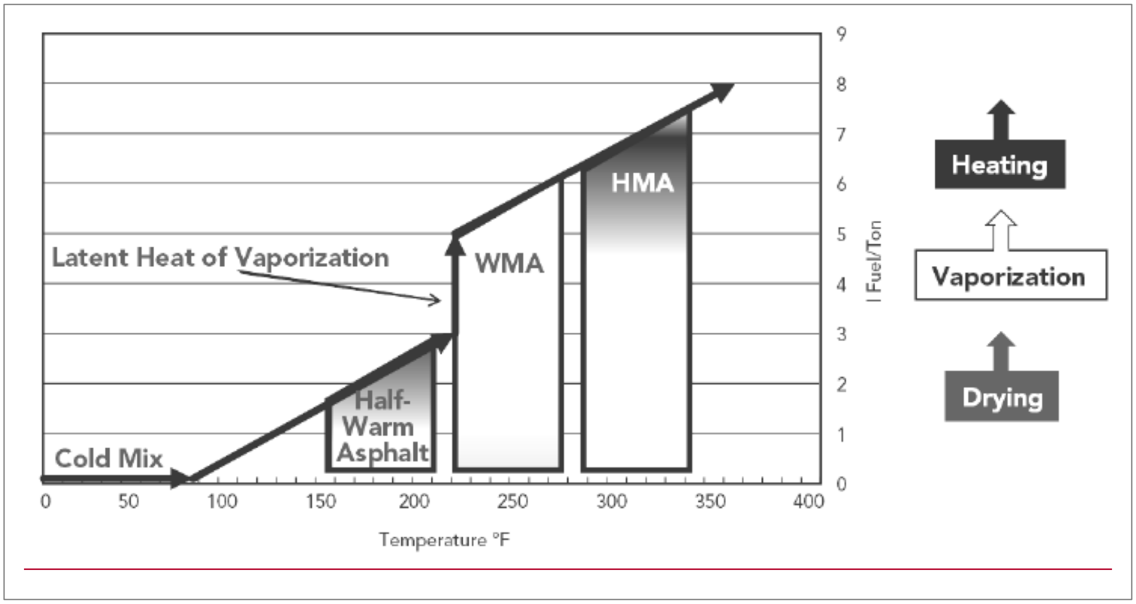


Figure 1. *Asphalt mix classification by manufacturing temperature (Porot, 2008)*

A WMA is considered as such when mixing temperatures are reduced between 10°C to 75°C in relation to temperatures used in the HMA (Mallick and El-Korchi, 2013). This asphalt mixes can be achieved by using additives or modifications in the mixing process, thus allowing a homogenous mixture without reaching temperature ranges between 160°C and 180°C. The use of WMA is becoming increasingly frequent and developed countries are leaders in this matter (NAPA, 2014; EAPA, 2013).

The use of WMA brings along a series of advantages compared with the production of HMA, and the main ones are (D'Angelo et al., 2008):

- *Reduced emissions.*
- *Energy spending reduction.*
- *Possibility of transporting the mix through longer distances.*
- *Possibility of introducing higher RAP contents.*
- *Reducing workers' exposure to vapors generated in the HMA manufacturing process.*

In the last years, different WMA manufacturing techniques have been developed, which range from modifications to the mixing plants to foam asphalt or adding different types of additives (Capitao et al., 2012; Rubio et al., 2012; Jair and Fitts, 2014). This group of techniques has recently included a new one, which uses "Super stabilized Emulsion", which are asphalt emulsions capable of remaining stable during transport and storage for long periods of time. This type of emulsions is produced with a special formulation that gives it more stability, which in the end allows producing asphalt mixes at average temperatures between 100 and 105°C. The patent of this emulsion has been registered by the Repsol Company of Spain.

The manufacturing of WMA with this emulsion is achieved by preheating the aggregates at a temperature between 115°C and 120°C, while the emulsion is kept between 60°C and 80°C (never more than 80°C); next, aggregates and the emulsion are mixed, thereby getting a final mix temperature between 100°C and 105°C, reducing the final mixing temperature between 50°C and 60°C. Unlike HMA, the mechanism that controls the mixing, placing and compacting processes in this type of mixes is not based on the asphalt viscosity (Bluffs, 2011), but rather on the stability of the emulsion.

It is estimated that this type of WMA can be used in the same way as the HMA; in other words, both on the surface course as in intermediate structural layers. The project proposes a comparison of the properties of both types of mixes at the laboratory level. Since the principles controlling the WMA design prepared with super stabilized emulsion differ from the HMA design, the research project had to study the mixing and compacting processes of WMA-type mixes. It was necessary to include this last study in order to produce WMA and HMA mixes with equivalent volumetric properties and thus better interpret and validate the results of mechanical tests.

2. Objectives of the study

The main objective of the research was to study the mixing and compacting procedure of WMA mixes produced with super stabilized emulsions and evaluate their mechanical properties in relation to the HMA. The Marshall procedure and the Superpave gyratory compactor were used during the study. The evaluation and comparison of mix properties included: volumetric properties (density and void percentage), Stiffness Modulus and Indirect Tensile Strength (ITS).

3. Materials and methods

The materials used during this research correspond to aggregates coming from a riverbed deposit located near the aggregate production plant of the road concession of "La Serena-Vallenar", located at km 559.300 of Route 5 North, Region of Coquimbo, Chile. The asphalt binder was super stabilized emulsion (for producing WMA) and asphalt cement (for producing HMA). The asphalt cement used in the production of HMA corresponds to the asphalt base used in the production of the super stabilized emulsion.

The mix grading specification was the IV-A-12 standard of the Highway Manual, and Table 1 and 2 show the aggregate mix grading and their physical properties, respectively. The asphalt cement used in the hot mix asphalt and in the emulsion production was CA 24, in accordance with Chilean regulations. Table 3 shows the properties of the asphalt cement, while Table 4 shows the properties of the super stabilized emulsion.

***Table 1.** Asphalt mix grading*

Sieve ASTM	Sieve (mm)	Work Formula	Specification IV-A-12	
		Undersize	Minimum	Maximum
3/4"	20.00	100.0%	100.0%	100.0%
1/2"	12.50	90.0%	80.0%	95.0%
3/8"	10.00	80.5%	70.0%	85.0%
Nº 4	5.00	52.8%	43.0%	58.0%
Nº 8	2.50	38.5%	28.0%	42.0%
Nº 30	0.63	19.7%	13.0%	24.0%
Nº 50	0.32	12.6%	8.0%	17.0%
Nº 100	0.16	8.2%	6.0%	12.0%
Nº 200	0.08	4.9%	4.0%	8.0%

***Table 2.** Physical properties of aggregates*

Nº	Parameter	Value	Specification	Method
1	Real Dry Density	2,689 kg/m³	n/a	M.C. 8.202.20-21
2	Aggregate Grinding	96.5%	Min. 90%	M.C. 8.202.7
3	Flakiness Index	10%	Max. 10%	M.C. 8.202.8
4	Sand Equivalent	60%	Min. 50%	ASTM D2419
5	Disintegration in Sulfates	10%	6 to 16%	ASTM C88
6	AASHTO Bonding	95%	Min. 95	M.C. 8.302.31
7	Riedel-Weber Bonding	2 – 8	Min. 0 – 5	M.C. 8.302.30
8	Wear "Los Ángeles"	12%	Max. 25%	M.C. 8.202.11
9	Plasticity Index	NP	NP	ASTM D4318

***Table 3.** Asphalt cement properties*

Nº	Property	Unit	Value	Standard
A	**Before the Rolling Thin Film Test**			
1	Absolute Viscosity at 60°C, 300 mm Hg	Poises	4,339	ASTM D2171
2	Penetration, 25°C, 100g, 5 s	0,1mm	50	UNE-EN 1426
3	Ductility, 25°C, 5 cm/min	cm	>100	UNE-EN 13589
4	Stain Test	% Xilol	25	NCh2343-1999
5	Solubility in Trichloroethylene	%	99.1	ASTM D2042
6	Combustion Point	°C	>240	EN ISO 2592
7	Softening Point	°C	51.8	UNE-EN 1427
8	Penetration Index		-0.77	MC 8.302.18
B	**After the Rolling Thin Film Test**			**MC 8.302.33**
1	Heat Loss	%	-0.39	UNE EN 12607-1
2	Absolute Viscosity at 60°C, 300 mm Hg	Poises	16,975	ASTM D2171
3	Stain Test	% Xilol	25	NCh2343-1999

Table 4. Properties of the Super Stabilized Emulsion

Nº	Property	Unit	Value	Standard
1	Saybolt Furol Viscosity at 25°C	SFs	128	ASTM D 7496-11
2	Saybolt Furol Viscosity at 50°C	SFs	70	ASTM D 7496-11
3	Content of Asphalt Residue after Distillation	%	68.95	UNE EN 1428
4	Fluidifier Content after Distillation	%	0	UNE EN 1431
5	Residue on Sieving of 0.5 mm	%	0.05	UNE EN 1429
6	Rupture Index	-	75	UNE EN 13075-1
7	Creep Time for 4 mm at 40°C	s	10	UNE EN 12846
8	Sedimentation Trend (7 Days)	%	0.05	UNE EN 12847

The following protocol was establish to produce the specimens of both warm and hot mixes:

1. Preparation of materials
2. Manual mixing
3. Compaction

The main differences appear during the materials' preparation stage; in warm mixes, aggregates were preheated at a temperature of 120°C, while the emulsion was kept at 60°C. On the other hand, in hot mixes, both materials were preheated at the final mixing temperature (155°C). In the manual mixing stage, for both cases, the mixing process of aggregates and binders was done by keeping the final mixing temperatures, corresponding to 105°C-110°C for warm mixes, and 150°C-160°C for hot mixes. In the last stage, compaction was made by impact (Marshall compactor) and rolling (gyratory compactor).

The Stiffness Modulus testing was based on the UNE-EN 12697-26-C standard, "Stiffness Measurement for Asphalt Mixes through Indirect Tensile Strength Test of Cylindrical Specimens". For the ITS test, the UNE-EN 12697-23 standard was used "Determination of the Indirect Tensile Strength of Bituminous Specimens". Both tests used Marshall and Superpave specimens.

4. Results

Results Obtained with the Impact Compactor

Figures 2 to 5 show the results of physical and mechanical properties of the mixes obtained with the Marshall Impact compactor:

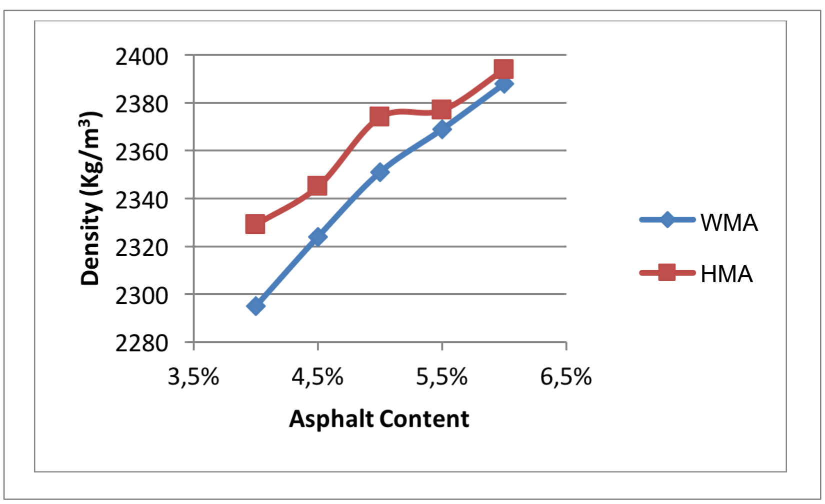


Figure 2. Densities achieved with the impact compactor

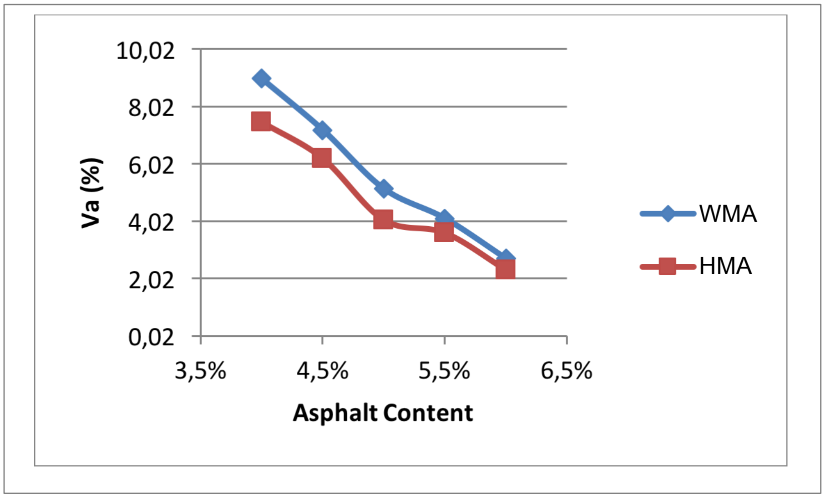
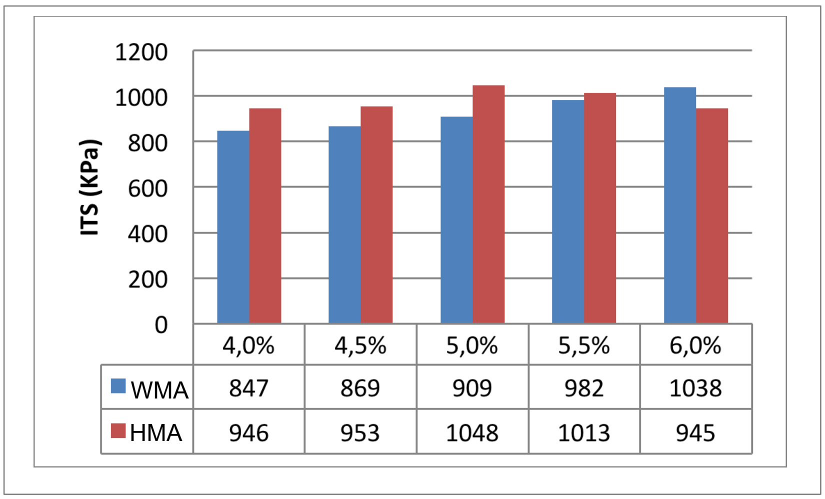
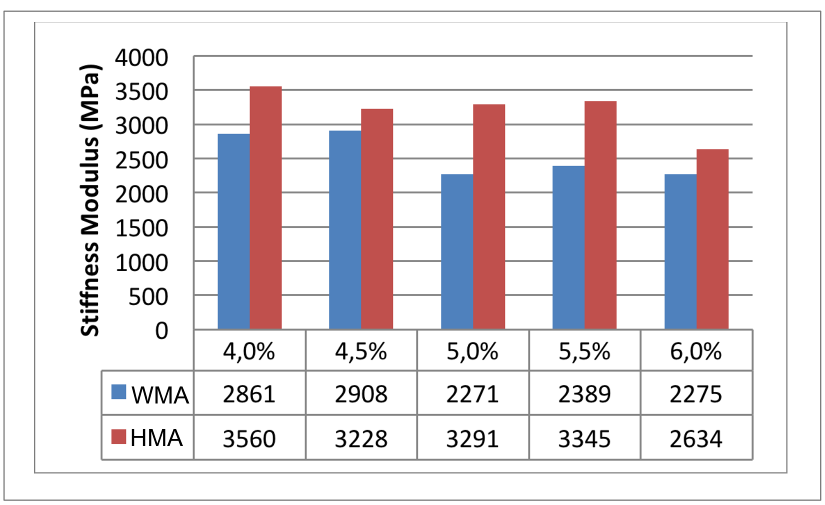


Figure 3. *Voids obtained with the impact compactor*



	4,0%	4,5%	5,0%	5,5%	6,0%
WMA	847	869	909	982	1038
HMA	946	953	1048	1013	945

Figure 4. *Resistance to indirect tensile strength, impact compactor*



	4,0%	4,5%	5,0%	5,5%	6,0%
WMA	2861	2908	2271	2389	2275
HMA	3560	3228	3291	3345	2634

Figure 5. *Modulus subjected to indirect tensile strength, impact compactor*

Results Obtained with the Gyratory Compactor

Figures 6 to 9 show the results of physical and mechanical properties of the mixes obtained with the gyratory compactor:

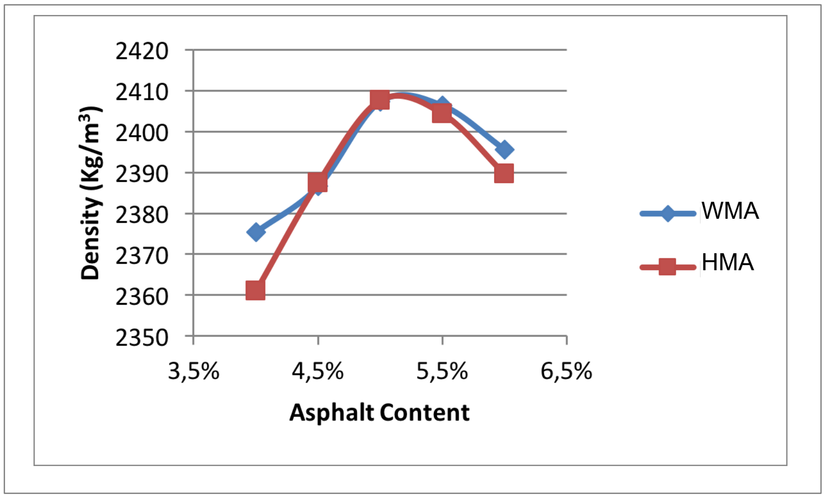


Figure 6. *Densities achieved with the gyratory compactor*

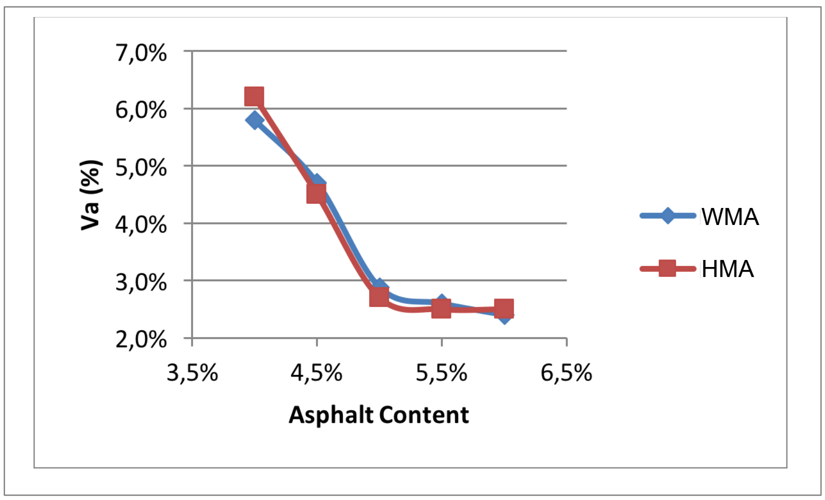
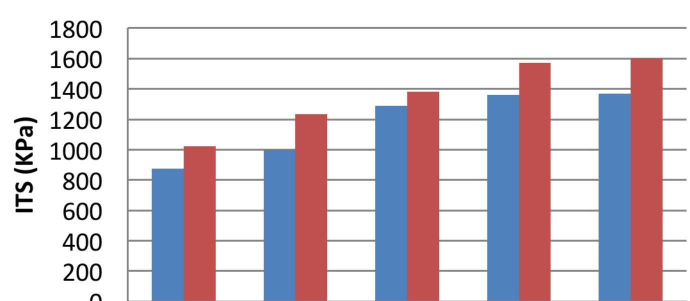


Figure 7. *Voids obtained with the gyratory compactor*



	4,0%	4,5%	5,0%	5,5%	6,0%
WMA	875	998	1291	1360	1370
HMA	1023	1234	1380	1570	1600

Figure 8. *Resistance to indirect tensile strength, gyratory compactor*

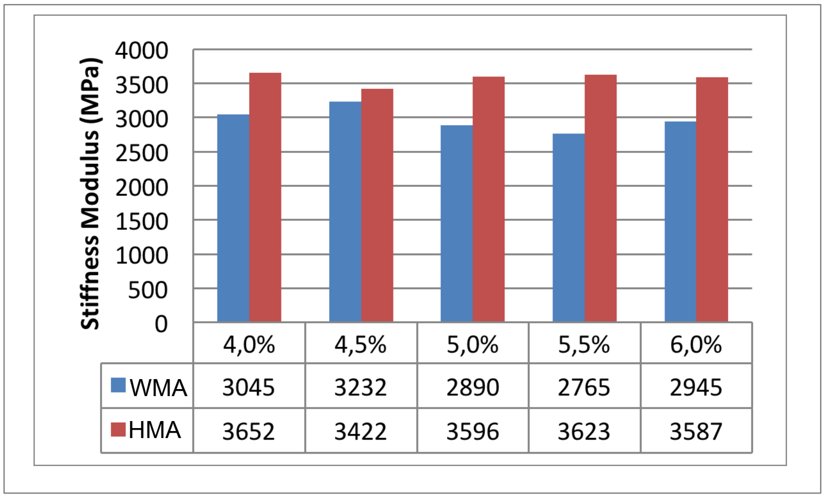


Figure 9. *Modulus subjected to indirect tensile strength, gyratory compactor*

Figure 2 and 3 show that, with all asphalt contents, the compaction level reached with the Marshall compactor by the HMA was higher than that of the WMA. This densifying difference was more evident in low asphalt contents and it decreased as the asphalt content increased. However, when using the gyratory compactor, the densification varied depending on the asphalt content, sometimes achieving a higher densification in WMA and sometimes a higher densification in HMA.

The Stiffness Modulus did not reveal many variations in relation to the asphalt content, both in WMA and HMA. However, in all cases, it did reveal a greater modulus of the HMA versus the WMA. Regarding the Modulus variations of the mixes by type of compaction, it cannot be analyzed directly, due to the density differences obtained for a same asphalt content, depending on the compaction method; nevertheless, variations in the Modulus did not have a great magnitude.

Regarding the ITS, differences were not as clear as in the stiffness test; however, in most cases (except with the 6% asphalt content in specimens compacted by impact) the HMA showed greater resistance than the WMA. In the same way as in the modulus tests, no significant variations were evidenced in relation to resistances as a result of the asphalt content, both for specimens compacted by impact and specimens compacted with the gyratory compactor.

5. Conclusions and recommendations

Based on the results obtained, the following can be concluded:

- *The use of impact compactor for densifying WMA with super stabilized emulsions does not allow achieving the same volumetric properties as in the HMA. The presence of water vapor and the lower temperature of the asphalt residue prevent from obtaining better results. Nevertheless, the densification of warm mixes through the gyratory compactor did maintain densification levels similar to those of hot mixes, which allowed making comparative tests between both type of mixes.*
- *The resistance and modulus of the WMA with super stabilized emulsion were lower than in the HMA, even in the cases where the WMA was more densified (for example, in the case of 4% asphalt content and gyratory compaction). This can be explained by the low mixing temperatures, which entail a lower initial aging of the asphalt in the mixes. Anyway, the values obtained for resistance and modulus are within normal ranges of hot mix asphalt.*
- *It is recommendable to use the gyratory compactor as a mix design methodology for WMA with super stabilized emulsion and, initially, to use volumetric properties as design criteria. However, just as in the design of HMA, additional tests are recommended: susceptibility to humidity and rutting. The latter does not exclude to incorporate other tests such as resistance, Modulus and fatigue.*
- *In general terms, WMA with super stabilized emulsion showed a good performance. A paper*

written by the same authors for this conference presents additional laboratory tests and an evaluation of the mixes on a field trial test. In that study, mixes with different contents of recycled material were prepared.

6. Acknowledgement

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7. References

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