EXPERIMENTAL ANALYSIS OF THE POTENTIALITIES AND LIMITS OF ASPHALT MIXTURES BY ADDING ZEOLITE

Bocci M.
Full professor – Università Politecnica delle Marche. – m.bocci@univpm.it
Virgili A.
Associate professor – Università Politecnica delle Marche. – a.virgili@univpm.it
Grilli A.
Ph.D. student – Università Politecnica delle Marche. – a.grilli@univpm.it
Pannunzio V.
Ph.D. student – Università Politecnica delle Marche. – v.pannunzio@univpm.it

ABSTRACT

The preservation and protection of both the natural and workspace environment, is one of the main objectives that concerns all developed countries. To that end, the target of the Kyoto Protocol (1997) is a 5.2% reduction in world emissions by 2012. In recent years, also in the road engineering field, the use of new pro-environmental techniques and materials has increased.

One of these materials is the Warm Mix Asphalt (WMA) made with different techniques, including the use of asphalt emulsion, waxes and paraffins, two binder components (soft and hard) and synthetic zeolite.

Such asphalt mixture, compared with the traditional hot asphalt mix (HMA), needs lower mixing and laying temperatures, allowing lower CO_2 and fume emission. Consequently there is less risk for the workers's health and a reduction in energy consumption.

Furthermore, the use of WMA allows operative benefits such as higher workability in the cold season, less traffic closing time after compaction and longer haul distances.

This study investigates the effects on workability of synthetic zeolite. A laboratory experimental program and a trial section were carried out using a HMA and a WMA with synthetic zeolite, both compacted at various temperatures. The compaction capacity at different temperatures between WMA by adding synthetic zeolite and HMA were analyzed on laboratory specimens and cores drilled from the trial section. Probably, a too heavy laboratory compaction method did not allow to highlight the workability differences between WMA with synthetic zeolite and HMA, whereas the trial section showed lower air void content in WMA with zeolite than in HMA.
Keywords: Warm mix asphalt, synthetic zeolite, air void content.

1. INTRODUCTION

As is well known, bitumen has a temperature-dependent behaviour showing low viscosity and good workability at elevated temperatures and, on the contrary, high viscosity and consistency at low temperatures. For this reason, the manufacturing of asphalt mixture developed with heating techniques, allows to mix mineral aggregates and binder and, thanks to the cohesive and adhesive forces between aggregates and binder, to obtain a material with high mechanical performance.

Obviously, the bitumen heating involves energy consumption and several problems related to polluting emissions and fumes. Hence the investigation on new techniques to produce asphalt mixtures preserving energy consumptions and natural resources is strictly necessary.

In fact, lower production and application temperatures of asphalt mixtures, without sacrificing the performance of flexible pavements, means significant improvements in terms of preservation and protection of both natural and workspace environment.

In particular, the reduction in mixing, laying and compaction temperatures for asphalt mixtures offers a significant contribution in reducing energy consumption, greenhouse gas emissions and fumes and, moreover, it may allow longer haul distances, longer construction periods and less traffic closing time after compaction.

For these reasons, there was the need to use innovative materials and, therefore, several new processes have been developed to reduce the operating temperatures of asphalt mixture avoiding to affect mechanical properties and durability of materials (Bonola M., 2006).

Nowadays, in an effort to consider environmental and economic benefits, the so-called "warm" techniques seem very promising but these technologies require further investigation in order to validate their production process, and to determine their applicability and final performance in field.

The three main technologies (U.S. Department of Transportation Federal Highway Administration) to produce WMA that have been developed are by means of the use of two-component binder system or the addition of organic additive or synthetic zeolite.

The two-component binder system called WAM-Foam® uses a blend of soft and hard bitumen. In this technique, a soft bitumen is mixed with aggregate to fully coat the aggregate. Afterwards, a hard bitumen is foamed into the pre-coated asphalt mixture. The combination of soft and foaming hard bitumen allows to decrease the mixture viscosity and, thus, to provide the necessary workability at lower laying temperatures.

Another technology involves the introduction of organic additives that change the temperature-viscosity curve and modify the rheology of bitumen as a function of the temperature range. Currently, two types of organic additives with low melting point are in use: synthetic paraffin wax (Graham C., 2005) and low molecular weight ester compound. Both additives provide a reduction of viscosity of the binder at mixing and compaction temperatures.

This paper regards the third process which proposes the addition of zeolite to the mixture at the same time as binder. Zeolite is a fine crystalline hydrated aluminium silicate which exists in natural environment, as volcanic rock, but in order to better control its behaviour, it can be also a manufactured synthetic zeolite.

Zeolite is principally composed of a siliceous structure with large and interconnected spaces, which can accommodate a wide variety of cations such as Na^{+}, K^{+}, Ca^{2+}, Mg^{2+} and even molecules such as water. In this context, the zeolite can hold the water in its structure at low temperatures and drive it out after heating. In particular, this absorption and desorption process through the zeolite interconnected cavities does not damage the crystal structure.

However, the natural zeolite releases the water in different quantities, times and temperatures. Therefore, in order to rationally control this process and to optimise the use of this kind of material in the asphalt mixture field, a synthetic zeolite named Aspha-Min® has been developed.

In mixing phase, the synthetic zeolite and binder are contemporarily added to pre-heated aggregate mixture. Therefore, at mixing temperature, the zeolite gradually releases a small amount of water, up to 21% of its weight, and, as a consequence of water vapour emission, generates a foaming effect in the binder.

Also in this case, the viscosity reduction and the consequent increased workability allow lower mixing and laying temperatures (Barthel W., 2004; Graham C., 2005) implying a reduction of polluting emissions up to 75% and a decline of 30% in fuel energy consumption. Moreover, for this technique a traditional asphalt-mix plant does not need any modification, in fact the synthetic zeolite, available in granular form, can be easily added by means of a dosage device.

In order to compare mixing, laying and compaction difference between conventional HMA and WMA, numerous warm mix asphalt paving demonstrations (Wayne J., 2004) have been carried out to date. The main advantages of using the Aspha-Min® process can be summarised in the reduction of the temperature mixing, laying and compaction phases showing the same final density achieved (Graham C., 2005). However, more scientific and exhaustive studies have to confirm the achieved results and evaluate the long-term WMA performance. When thorough knowledge is reached, the environmental and economic benefits of WMA will become the technology of the future.

This study is part of an overall project on WMA technologies in progress at the Università Politecnica delle Marche. The objective of this study is to better understand the effective potentialities and the limits of WMA by adding synthetic zeolite.

2. LABORATORY EXPERIMENTAL PROGRAM

In order to verify the differences between HMA and WMA by adding synthetic zeolite, a preliminary experimental project has been carried out at the Università Politecnica delle Marche.

The first step of this experimental project was to evaluate the influence of different aggregate gradations on the compaction grade, in a wide temperature range of mixing and compaction.

Mixtures, with and without synthetic zeolite, were mixed in laboratory in accordance with the aggregate gradations and bitumen content shown in Table 1. In particular, the bitumen used was a 50/70 pen. and the synthetic zeolite was added in proportion of 0,3% of weight as suggested by the producer.

Table 1 -Mixture composition of the laboratory produced mixtures

Opening [mm]		**Mixture 1** passing [%]	**Mixture 2** passing [%]	**Mixture 3** passing [%]
Riddle	15	100	100	100
	10	80	80	75
Sieve	5	50	50	40
	2	31.5	27	13.5
	0.42	15.5	14	7
	0.177	11.5	10	5
	0.075	8	6	3
Bitumen [%]		5.5	5.2	5.2

Mixture 1 was compacted, following the European standard EN 12697-31, at different temperatures by means of Shear Gyratory Compactor (SGC). The asphalt mixture specimens were compacted under constant pressure of 600 kPa, while the mould simultaneously rotates around the vertical axis with a speed of 30 rpm and a nominally constant angle of 1.25°. In particular, mixture 1, with synthetic zeolite, was compacted at a temperature range of 90 – 130°C, whereas mixture 1, without synthetic zeolite, was compacted at a range of 110 – 150°C. In these cases the mixing temperature was fixed 10°C higher than the respective compaction temperature.

Mixture 2 followed the same operating plan as mixture 1, but the compaction was carried out through Marshall method as specified on the EN 12697-30. The asphalt mixture specimen, constrained in a proper mould, was compacted under 75 pestle blows, keeping the axle of the pestle perpendicular to the base of the stamp in order to obtain a specimen height of 63,5 ± 3,2 mm.

Mixture 3, with and without synthetic zeolite, was mixed at 110°C and 130°C, and compacted at 90°C following the Marshall method.

To measure the densification of specimens the paraffin method, as specified on the ASTM D 1188, was used in all cases.

3. LABORATORY RESULT ANALYSIS

This chapter shows the results obtained from the above exposed experimental project. The results are shown in the following three tables (Table 2, 3, 4).

Table 2 -Bulk specific gravity results of Mixture 1

Mixture 1			
Mixing Temperature [°C]	Compaction Temperature [°C]	**HMA** [kg/dm^3]	**WMA** [kg/dm^3]
100	90	-	2.46
110	100	-	2.47
120	110	2.47	2.47
130	120	2.48	2.47
140	130	2.48	2.48
150	140	2.48	-
160	150	2.49	-

Table 3 -Bulk specific gravity results of Mixture 2

Mixture 2			
Mixing Temperature [°C]	Compaction Temperature [°C]	**HMA** [kg/dm^3]	**WMA** [kg/dm^3]
100	90	-	2.36
110	100	-	2.39
120	110	2.39	2.41
130	120	2.42	2.42
140	130	2.43	2.44
150	140	2.45	-
160	150	2.45	-

Table 4 -Bulk specific gravity results of Mixture 3

Mixture 3			
Mixing Temperature [°C]	Compaction Temperature [°C]	**HMA** [kg/dm^3]	**WMA** [kg/dm^3]
100	90	2.24	2.22
130	90	2.23	2.24

The bulk specific gravity for each specimen was found by means of procedure specified in the ASTM D 1188.

As can be easily noticed from the tables above there are not great differences in terms of bulk specific gravity between the HMA and WMA by adding synthetic zeolite. In fact, it can be noted that, with respect of gradation and compaction method, the bulk specific gravity values are very similar.

Finally, the real beneficial effects of adding synthetic zeolite, in terms of compaction grade, were not highlighted. Therefore, this first experimental result could lead to the affirmation that the zeolite effects cannot be investigated by means of the above described laboratory conditions. As is well known, the difference between the compaction operations in the laboratory and those in the road yards are many. In fact, in the laboratory small amounts of loose material is compacted in confined moulds and subjected to heavy compaction load that probably does not allow to evaluate the compaction capacity of the different mixtures.

Hence, the laboratory results obtained so far and the necessity to really understand the effects of adding zeolite have lead to continue the study of WMA by adding zeolite on field.

4. TRIAL SECTION

The trial section was carried out in order to investigate the real features of WMA by adding zeolite.

The trial section was composed of two lanes, the first one made with HMA, while the second one with WMA by adding synthetic zeolite. Different phases characterized the trial section construction: milling of the old asphalt pavement, mixing of WMA and HMA in a mix-plant, laying down of both materials and compaction of both materials considering different temperatures.

In this phase two lanes (2 m width) were milled with a depth of 8 cm, in order to prepare an evenness and smoothness laying bed where it was possible to lay down the different mixtures.

Afterwards, WMA with zeolite was mixed at 120°C and, during the laying down, a temperature of 114° C was measured. Secondly, HMA was mixed at 150°C and, during the laying down, a temperature of 145° C was measured. The mixture composition of both mixtures are shown in Table 5.

Table 5 -Mixture composition of the mixtures used in the trial section

Opening [mm]		**HMA** passing [%]	**WMA** passing [%]
Riddle	25	100	100
	15	79.8	90
Sieve	10	68	78.4
	5	36.8	42.3
	2	22.7	25.7
	0.4	9.4	11.9
	0.18	6.3	8.1
	0.075	3.7	4.8
Bitumen [%]		4.48	4.86

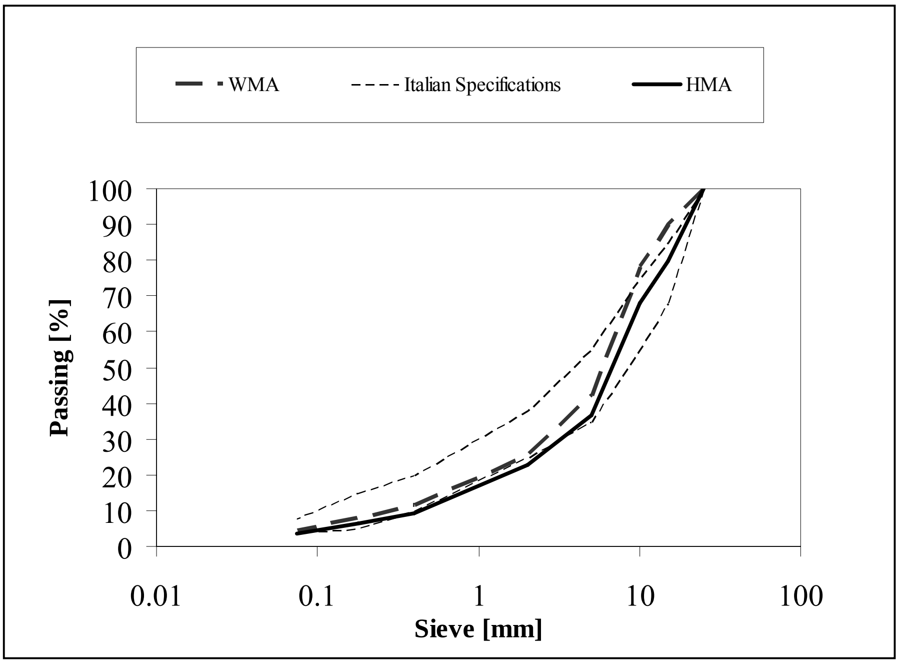

Figure 1 -Aggregate gradation of the mixtures compared with the Italian Specifications.

When the modality and the energy compaction were fixed, this operation was carried out by means of a roller and vibratory compactor (1.50 m width). Checking of temperature in each section (Figure 2) allows to compare the behaviour of both different sections with different mixtures.

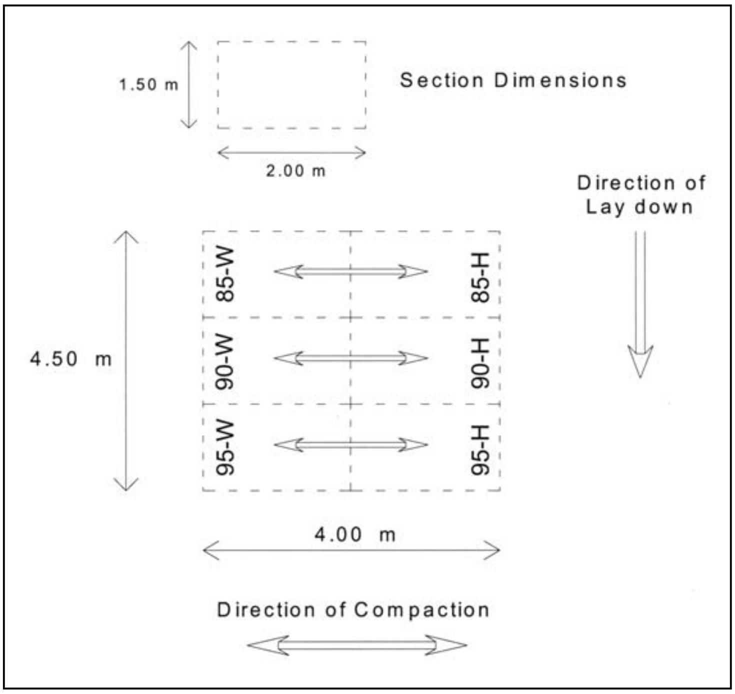

Figure 2 -Scheme of the trial section

Each section was coded by the respective temperature of compaction and kind of material. The numbers (95, 90, 85) represent the compaction temperature, while the letters (W or H) represent the kind of material. For instance, the code 95-W means that the section was a WMA with zeolite compacted at a temperature of 95°C, whereas 90-H means that the section was a HMA compacted at a temperature of 90°C.

5. TRIAL SECTION RESULTS ANALYSIS

By using loose materials of WMA with zeolite and HMA, Marshall specimens were compacted with 50 pestle blows at different temperatures by means of a Marshall compactor. The bulk specific gravity values were measured by using the paraffin method as specified by the ASTM D 1188. The bulk specific gravity results are shown in Figure 3.

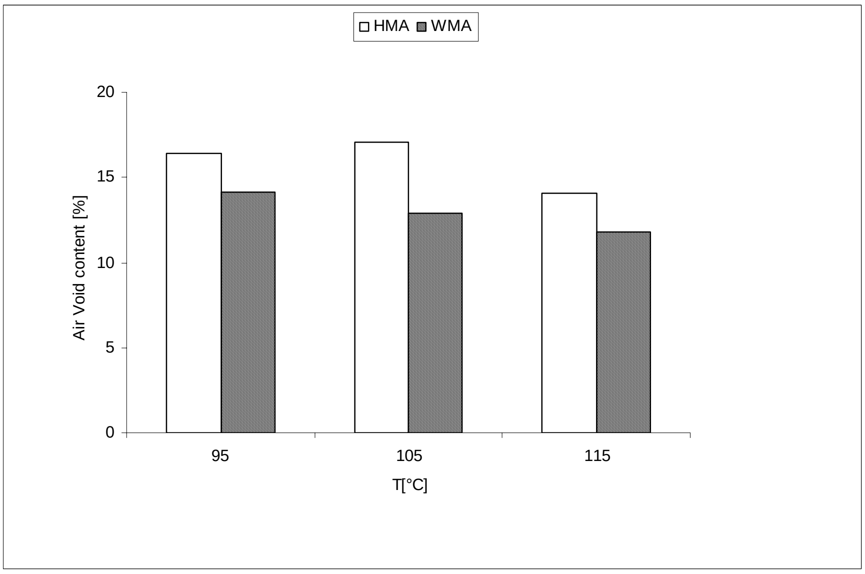

Figure 3 -Air void content comparison

From Figure 3, it can be noticed that, at the same temperature, WMA with synthetic zeolite shows lower air content than HMA.

Moreover, for each section five cores were drilled. The cores were used to define the air void content (ASTM D 1188), in order to verify the capacity of a WMA by adding synthetic zeolite being compacted at lower temperatures and, therefore, having lower void content. Figure 4 shows the results of the air void content comparison.

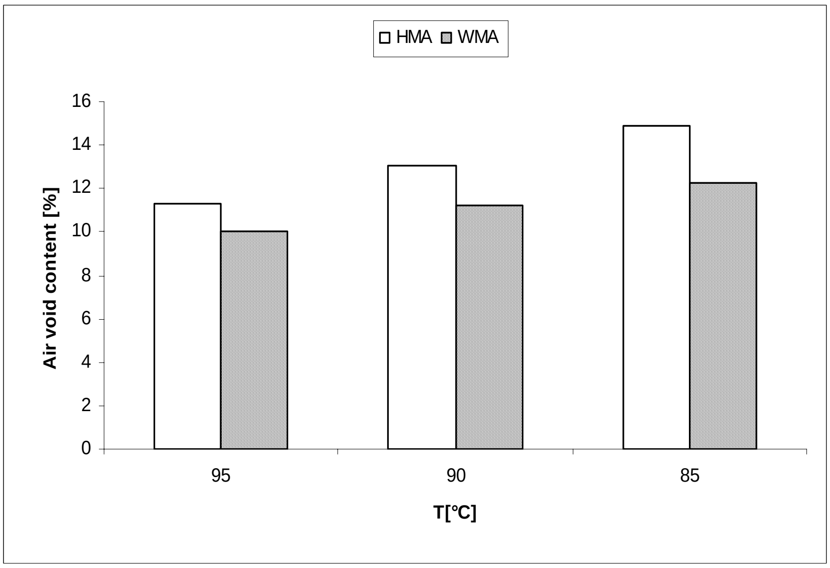

Figure 4 -Air void content comparison

Figure 4 illustrates that the WMA cores with zeolite are, with respect to the compaction temperature, more compact than the HMA with higher values in correspondence with lower temperature. Moreover, as shown in Table 6, it is possible to make explicit the air void content differences between the two mixtures for each temperature

Table 6 -Air void content differences

between HMA and WMA

Temperature [°C]	Δ Air void content [%]
95	1.28
90	1.83
85	2.62

From Table 6 it can be noticed that the benefits of using synthetic zeolite are more noticeable as the temperature is lowered. Probably, the compaction ability of WMA by adding synthetic zeolite increased the workability on field instead of in laboratory. It should be remembered that the void content is higher than that in a real construction, in both the mixtures, because the compaction was done with a lower number of passes.

6. CONCLUSIONS

The comparison of results allowed to make the following conclusions:

- In the laboratory, for each compaction condition, there are not considerable differences in terms of bulk specific gravity between the mixtures with zeolite and the traditional mixtures;
- By considering asphalt mixtures produced in asphalt plant there are considerable differences in terms of air void content between specimens compacted with Marshall method and cores compacted with roller and vibratory compactor;
- The air void content analysis of WMA and HMA, both laied down and compacted at different temperatures (95, 90, 85°C), show that WMA allows a higher compaction potentiality at each selected temperature;
- In particular, considering mixtures with more than 10% of air void content, an appreciable benefit of using WMA can be noted at 85°C. In fact, WMA cores showed the 12,25% of air void content, whereas the HMA cores showed the 14,87% of air void content;
- Further study will focus on the mechanical characteristic of WMA in order to verify whether the mechanical properties became modified with the adding of synthetic zeolite.

REFERENCES

ASTM D 1188: Bulk specific gravity (GMB) and density of compacted bituminous specimens using paraffin or parafilm.

BARTHEL W., MARCHAND J.-P., VON DEVIVERE M. (2004) – “Warm asphalt mixes by adding a synthetic zeolite” – *3rd Euroasphalt and Eurobitume Congress UK.*

BONOLA M., DE FERRARIS M. (2006) – “Low energy bituminous mixes : the state of art.” – *Rassegna del Bitume*, 54/06, pp. 47-63.

CIRS (Centro Interuniversitario di Ricerca Stradale e Aeroportuale) – Italian Specifications, 2001.

EN 1297-30: Test methods for hot mix asphalt, Part 30: Specimen preparation by impact compactor.

EN 1297-31: Test methods for hot mix asphalt, Part 31: Specimen preparation by gyratory compactor.

GRAHAM C. HURLEY, BRIAN D. PROWELL (June 2005a) - “Evaluation of Aspha-Min® zeolite for use in warm mix asphalt” – *NCAT Report 05-04*.

GRAHAM C. HURLEY, BRIAN D. PROWELL (June 2005b) – “Evaluation of potential processes for warm mix asphalt” – *Annual Meeting AAPT, 27-29 March 2006, Savannah, Georgia.*

GRAHAM C. HURLEY, BRIAN D. PROWELL (June 2005c) – “Evaluation of Sasobit® for use in warm mix asphalt” – *NCAT Report 05-04*.

U.S. Department of Transportation Federal Highway Administration. Warm Mix Technologies and Research. www.fhwa.dot.gov/pavement/wma.html. Accessed June 14, 2007.

WAYNE JONES, P.E. (2004) – “Warm mix asphalt pavements: technology of the future” – *Asphalt magazine*, Fall 2004, pp. 8-11.