Effect of reclaimed asphalt gradation on bitumen emulsion mixtures

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ABSTRACT

Nowadays, in pavement engineering field, the recycling technique which involves the use of cold bituminous mixtures is one of the most interesting and promising from the economic and environmental sustainability points of view. Unfortunately, scientific notions known so far show a big lack in terms of procedures and specifications that shall be followed in a worldwide context. This study focuses on the clarification of the preliminary steps concerning the cold recycled mixture mix design, which means determining the appropriate initial aggregate gradation.

The study has been developed involving different sources of material, which gradation has been modified according three reference grading curves: Maximum Density curve (Fuller-Thompson), MTQ Specifications (Ministère du Transport du Québec) and HPAC curve (High Performance Asphalt Concrete). The effect conferred by the gradation type has been studied by means of the mechanical properties analysis in dry and wet conditions; in addition, the distribution rate of the components inside the mixture has been highlighted by an image analysis on cut sections.

Results showed how the different gradations studied in the several mixes have led to different final voids content. As a consequence, mixtures featuring lower presence of voids have remarked a higher rigidity, directly linked to the aggregate coverage by the bituminous phase. Moreover, all mixtures have shown a strong strength decrease in wet conditions, regardless the gradation adopted.

Keywords: Cold Recycling, Gradation, Voids in the mixture, Image Analysis, Indirect Tensile Ratio

1. INTRODUCTION

The economic issues of the last decades linked to the production of new road pavements have led to the wide diffusion of new construction techniques which can enhance the environmental sustainability as well as the economic footprint. The most important aspect of these new techniques is the employment of high quantities of Reclaimed Asphalt Pavement (RAP), i.e. the milled material obtained from aged pavements, which is largely re-used in the road production together with virgin aggregates [1].

In addition to the use of RAP (up to 100%), an important step towards energy saving is given thanks to the production of Cold Recycled Mixtures (CRMs) [5]. In these types of mixtures, the binding phase is composed of bitumen (in form of asphalt emulsion) and cement, which confers adequate initial stiffness [6].

Generally, the first important part for an accurate mix-design is to have a deep control of the gradation in the aggregate skeleton. The present research focuses on this aspect, taking advantage from past studies and trying to produce CRMs with grading distributions used mostly with hot mix asphalts. The aggregate gradation in CRMs is highly important, since it is known that a uniform breaking rate of the asphalt emulsion is more developed in the finest fraction of the granular blend [10].

Some European researchers tried to develop a mix-design procedure based on the packing theory; despite several theories were studied, general results showed that packing simulation with multi-size granular materials is not simple to be applied to the mix-design [11].

In general, in bituminous mixtures, a well-graded mixture is characterized by lower air voids content, in particular if it is close to the maximum density curve (Fuller-Thompson). At the same time, the mix normally shows better mechanical performance. The principles stated by Fuller and his maximum density gradations have been widely used for many years for all types of paving mixtures containing combinations of coarse and fine aggregate [12][15].

In the region of Quebec, Canada, gradation requirements for the aggregate blend are provided by the MTQ (Ministère du Transport du Québec), which is not clear regarding cold mixes. For this research, requirements for GB-20 (Base course) were followed (Standard 4202 – Tome VII) [4], [16]].

In addition, a recent study showed how the use of an optimized step-graded aggregate mix led to a good workability and compactability, as well as improved mechanical performance (higher strength and stiffness modulus). This type of mixes is generally named HPAC (High Performance Asphalt Concrete) and they are produced optimizing the proportions between coarse and fine particles; in this manner both fractions are able to place in order to minimize air voids. It is important that proportions are carefully respected; a high percentage of medium-sized aggregate could cause the "wall effect", meaning the contact loss between coarser particles [17][17][19].

2. OBJECTIVES

The paper is based on the evaluation of the effects that aggregate gradation confers to the global mechanical properties of the CRM. For this reason, three different grading distributions normally employed for HMA mixtures are compared: Fuller-Thompson (FT), MTQ and HPAC.

First, the compactability of each mix was verified, applying a high compaction energy. Afterwards, the energy was calibrated in order to produce mixes with the same voids rate. In this way two important aspects have been investigated: the compaction ability of three mixtures having deeply different gradation, and the mechanical properties of such mixes, produced at same volume and voids content, in order to understand the influence of the solid skeleton on the strength development.

3. MATERIALS AND METHODS

3.1 Materials

The reclaimed asphalt pavement (RAP) has been sampled in a plant stockpile in Montreal Area (Canada). In order to respect gradation requirements, two different RAP fractions from different sources were employed: a 0/10 fraction and a 10/14 fraction (EN 13108-8). The RAP was characterized in terms of particles density, gradation, absorption and bitumen content. The asphalt emulsion used was a CSS-1 type with 62.8% of residual bitumen, while the cement was a Type II, for General Use with a compressive strength at 28 days of 43.9 MPa (ASTM C150). The final gradations employed in this research are shown in FIGURE 1, while main properties of the materials used are listed in TABLE 1.

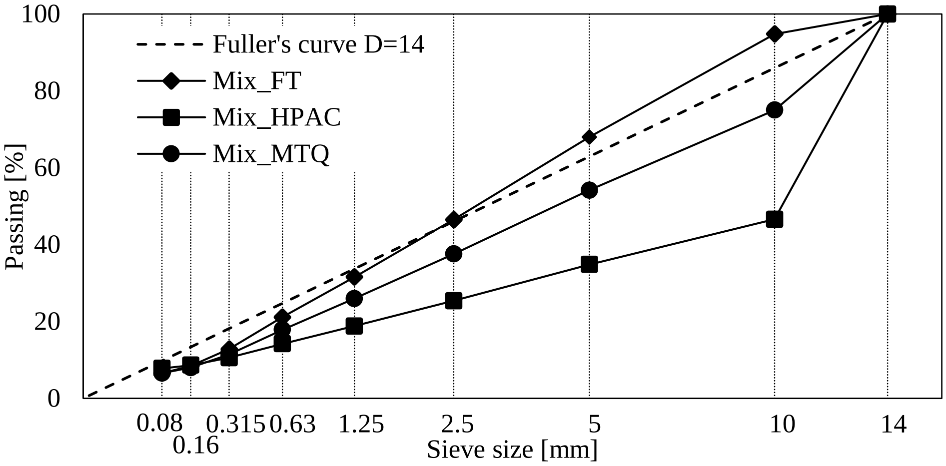

FIGURE 1 Grading Curves

TABLE 1 Main Properties of Used Materials

Property	**Standard**	**Value**
RAP0/10		
Binder content (on aggregate weight)	LC 26-006	6.10%
Nominal maximum particle dimension	LC 21-010	10 mm
Bulk Specific Gravity of the aggregate G_{sb}	LC 26-045	2.537
Water absorption	EN 1097-6	1.0%
RAP10/14		
Binder content (on aggregate weight)	LC 26-006	4.03%
Nominal maximum particle dimension	LC 21-010	14 mm
Bulk Specific Gravity of the aggregate G_{sb}	LC 26-045	2.550
Water absorption	EN 1097-6	1.0%

3.2 Mix Design

The main idea behind the mix design of the studied mixtures is to keep a fixed volume of the structural skeleton (RAP and Filler), regardless the gradation.

Differently from mix-design techniques employed normally with CRMs, the approach followed in this study allows a better control of the components in the mixture, as well as a clearer interpretation of results and their influencing factors. In this specific case, the mix-design protocol was not conducted towards the optimization of the binding agents with respect to the aggregates distribution (as it is indicated in several procedures normally followed); on the contrary, their weight (cement, water and residual bitumen) is fixed in all mixes. In this manner, the compactability and the mechanical behavior depend exclusively on the grading distribution and on the interlock level between aggregate particles.

To obtain the mentioned three different gradations, two sources of RAP and filler were properly dosed. Their theoretical maximum specific gravities, G_{mm}, are 2.479, 2.486 and 2.481 respectively for FT, HPAC and MTQ. The bulk specific gravity, G_{sb}, of filler is 2.650, whereas the bitumen specific gravity (residue in the asphalt emulsion) is 1.015. The mixture identification, as well as the components dosage, are described in TABLE 2.

TABLE 2 Mixtures Identification and Composition Summary

	Dosage on total volume[1] [%]			*Dosage on dry aggregates weight[2] [%]*		
Component	**FT**	**HPAC**	**MTQ**	**FT**	**HPAC**	**MTQ**
RAP 0/10	84.8	36.2	65.9	94.0	40.0	73.0
RAP 10/14	0	47.7	19.8	0.0	53.0	22.0
Filler	5.1	6.0	4.3	6.0	7.0	5.0
Cement	1.1	1.1	1.1	1.5	1.5	1.5
Residual Bitumen[3]	4.5	4.5	4.5	2.0	2.0	2.0
Intergranular water[4]	4.5	4.5	4.5	3.0	3.0	3.0

[1] The aggregate volume is calculated using the bulk specific gravity G_{sb}

[2] The percentage of cement, residual bitumen and water are calculated referring to the weight of RAP and filler

[3] Conferred by the asphalt emulsion

[4] Amount of water not absorbed by aggregates

3.3 Compaction and Evaluation of Volumetric Properties

The specimens' compaction was performed immediately after mixing by means of a gyratory compactor. The following protocol was adopted: undrained mould with D = 100 mm, constant pressure of 600 kPa, gyration rate of 30 rpm and angle of inclination of 1.25°. After compaction, the cylindrical specimens were immediately demoulded and weighed in order to check any material loss.

The volume of the specimen was recorded at each gyration; this allowed to monitor the evolution of the volumetric properties, hence the voids content in the mix (V_m) and the voids filled with liquids (VFL). They are expressed as follows [20][20]-[21]:

$$V_m = \frac{V_{v,air} + V_{FW}}{V} \tag{1}$$

$$VFL = \frac{V_{RB} + V_{FW}}{V_{v,air} + V_{RB} + V_{W,F}} \tag{2}$$

Where V is the total volume of the specimen during compaction, V_{RB} is the volume of residual asphalt from emulsion, V_{FW} is the volume of the free water (or intergranular water, obtained by subtracting the absorption water from the total water) and $V_{v,air}$ is the volume of voids filled with air. It is important to highlight that values of V_m have sense if VFL < 100%, whereas loss of material could generally occur for VFL > 85%.

To have comparable results in terms of mechanical properties, the compaction energy was calibrated to reach 10% of voids in all mixes. For this reason, compaction was stopped at 142 gyrations for FT, 180 gyrations for HPAC and 83 gyrations for MTQ.

Moreover, to understand the influence of voids related to the same mix, an additional series of specimens was prepared, produced with the Fuller-Thompson gradation and voids content equal to 7.7%. The compaction curves are shown in FIGURE 2.

3.4 Testing

Prior testing, a curing procedure of 3 days was applied to the specimens, at 38 °C ± 2 °C and 60% of relative humidity (LC 26-002).

The Indirect Tensile Strength (ITS) was determined following the standard ASTM D6931. The test was performed at 25 °C ± 1°C with a loading rate of 51 mm/min, in both dry and wet conditions, reached after at least 4 hours of water immersion. In this manner, it was possible to determinate the Indirect Tensile Ratio (ITR), described as the ratio between the strength of the material in wet and dry conditions. For the four studied mixes 6 specimens were produced, for a total of 24 specimens.

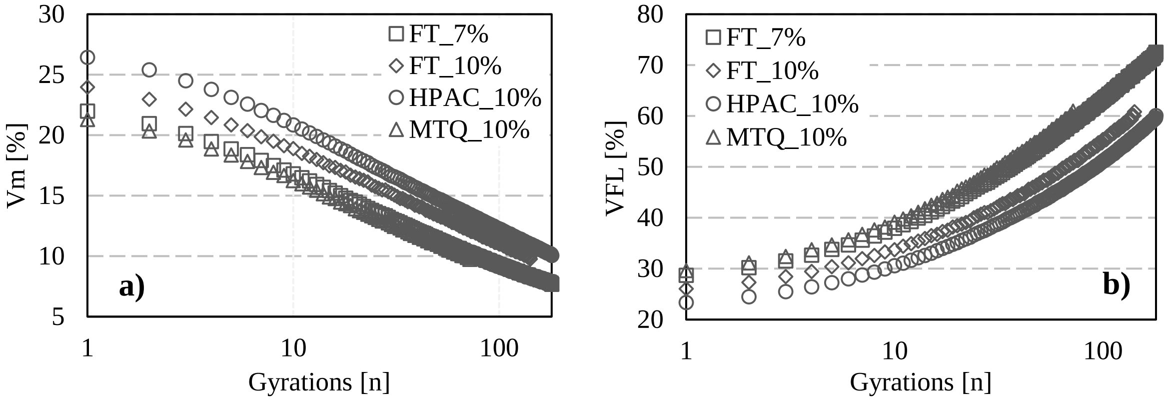

FIGURE 2 Compaction Curves:

a) Voids in the Mixture V_m; b) Voids Filled with Liquids

4. RESULTS ANALYSIS

Results from ITS test are used to describe the tensile strength of asphalt mixes, often related to the cracking resistance. FIGURE 3 compares the ITS results for all the mixes produced, showing at the same time the trend of the ITR. TABLE 3 contains the water loss of the mixes after curing, calculated as the difference between the specimens' weight after compaction and the weight reached after the curing protocol (3 days).

From the results it is clear that the mixture with higher mechanical properties is the mix produced with the Fuller-Thompson gradation at 10% of voids (FT_10%). Compared with mixes HPAC_10% and MTQ_10%, the resistance of the latter is lower. The presence of the 10/14 fraction inside the HPAC_10% and MTQ_10% mixes may have prevented an optimum distribution of the binding phase (probably due also to the small specimen size), with a higher concentration of contact points among the coarse fraction.

The mix that showed the lowest resistance was the FT_7%. Considering that it was produced following the same composition and procedure used for the FT_10%, but with a higher number of gyrations, the reason of such result could be related to the high compaction effort. Apparently, if an excess of energy is applied to a mixture with a close gradation (such as Fuller-Thompson), it could prevent a full hydration of cement, which, on contrary, could be trapped in the bituminous phase (or worst, in an extremely soft bitumen around RAP particles). The higher water loss in FT_7% compared to FT_10% could be directly linked to an incomplete (or absent) cement hydration. To better understand this aspect, a deeper investigation of internal chemical reactions should be performed, in order to have a clear view of how both binding agents behave.

Moreover, the same mix (FT_7%) showed higher water susceptibility. At the opposite, all other mixes do not seem affected by the water effect. Despite the initial water content was the same in all mixes, FT_10% and HPAC_10% had more residual water after curing, although the water loss level was still very high for a 3 days-curing.

The Image Analysis was carried out by an image processing software, applying a greyscale to the original picture and fixing a colour threshold in order to represent coarser aggregates in black and the binding phase (with fine particles and voids) in white. It is clearly showed how the aggregate distribution is different in the three mixes. Moreover, it can be asserted that the aggregate coverage is well-distributed in all the cases; in fact, it is highlighted how the percentage values representing the white area in the pictures slightly differ among the three distributions (FIGURE 4).

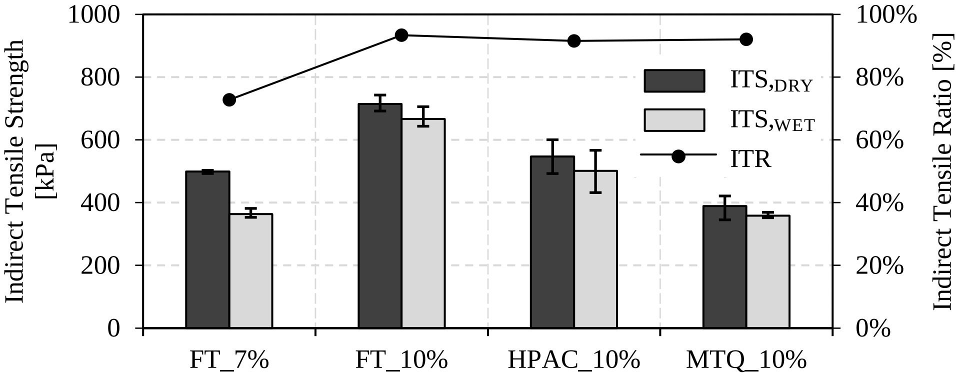

FIGURE 3 Indirect Tensile Strength Results (ITS and ITR)

Mixture	FT_7%	FT_10%	HPAC_10%	MTQ_10%
Water loss	93%	89%	88%	101%

TABLE 3 Water Loss in the Tested Mixes After Curing

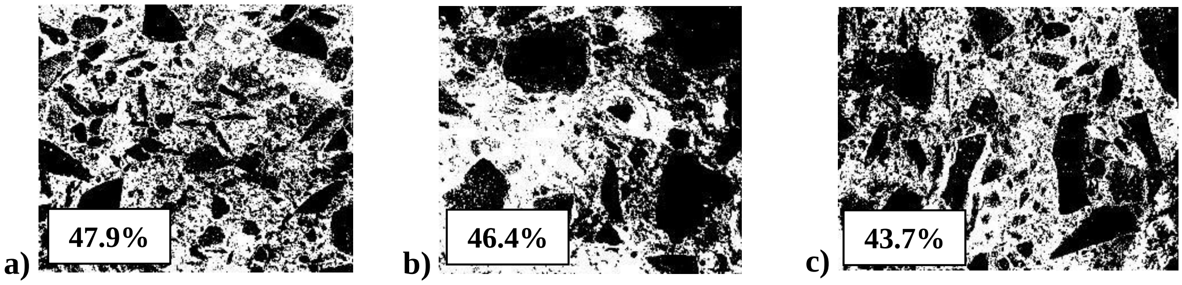

FIGURE 4 Image Analysis: a) FT Mix, b) HPAC Mix, c) MTQ Mix

At last, it is possible to observe that gradations exactly represent what expressed in FIGURE 1: FT is characterized by a uniform gradation, HPAC shows mostly coarse aggregates and MTQ is in the middle.

5. CONCLUSIONS

In the present research, the effect of typical aggregate gradations to produce Cold Recycled Mixtures is studied, considering three completely different distributions. The compaction effort was calibrated to reach same voids content. The main results are summarized as follows:

- The gradation that led to higher ITS was the Fuller-Thompson distribution, if compared with other gradations with same voids content;
- At the same time, high strength can be obtained with a step-graded distribution (HPAC). This can be achieved through an optimization of proportions between coarse and fine particles;
- A curing protocol of 3 days at 40°C allowed an almost complete loss of water.

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