Development of Asphalt Mixtures for Sustainable Pavements

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Abstract. Currently, reusing materials in the industry to reduce the environmental impact generated is becoming important for society. The paving industry is not lagging behind, developing sustainable solutions. One of the main wastes generated on the roads is the asphalt material itself after its life cycle has been completed, called reclaimed asphalt pavement (RAP). However, reusing these materials and avoiding their accumulation in asphalt plants and/or sending them to landfill sites is one of the objectives of the paving industry. In this paper, a study was conducted of the use of RAP in asphalt mixtures, decreasing the manufacturing temperature of these mixtures, generating a greater environmental contribution. Three percentages of RAP were evaluated at three different manufacturing temperatures, all of them below the manufacturing temperature of a conventional asphalt mixture. Different mechanical properties, such as water sensitivity and permanent deformation, were evaluated to check their behaviour versus a conventional hot asphalt mixture. Additionally, energy consumption, manufacturing cost and the emission of greenhouse gases (GHGs) and volatile organic compounds (VOCs) were assessed. The results obtained show that the recycled asphalt mixtures manufactured at low temperature have an excellent performance, demonstrating that the use of RAP in asphalt mixtures at low temperatures is economically, technically and environmentally feasible.

1. Introduction
The superior structure of flexible pavements, comprised of layers of asphalt mixture, is the part of road infrastructure that requires the greatest investment of economic resources, and their condition directly influences user safety and most of the indirect costs of a road [1]. In Chile, almost 90% of pavements are asphalt pavements [2], very similar to what is observed worldwide, where 95% of pavement structures are asphalt [3] due to the benefits that such pavements have economically, structurally and functionally.

In the 1990s a massive construction of asphalt pavements began in Chile, which is why they are currently in a phase that requires rehabilitation work of the existing road infrastructure [4]. In addition, given the deficit of existing pavement and in the search to continue with the country’s development, there is a high demand for new road infrastructure construction. Two problems arise from this. The first is related to the rehabilitation of current pavement structures to increase their useful life, as they generate a residue as a result of pavement milling sites. However, this currently discarded milled material is a valuable residue because it is made of select aggregates and asphalt binder [5]. This
milling is reclaimed asphalt pavement (RAP). There is environmental damage because these residues must be disposed of in landfills, stockpiled in asphalt plants, and in the best-case scenario as backfill. From an economic point of view, the cost of dumping RAP increases the final cost of a rehabilitation project. In addition, the new asphalt mixtures for rehabilitation must be made completely from new materials, which entail an over-exploitation of natural and energy resources [6]. The second issue is linked to the construction of flexible pavements with conventional hot mix asphalt (HMA), since they need high temperatures for their manufacture (between 150 and 180ºC) and laying (between 110 and 140ºC). Reaching these temperatures requires a high energy expenditure, which also has a negative environmental impact and creates an inadequate work environment due to the high greenhouse gas (GHG) emissions and volatile organic compounds (VOCs) [7].

Today the concern is finding sustainable development mechanisms. In this context, the asphalt industry has been designing new procedures and products leading to energy savings, focused especially on reducing the manufacturing temperatures of asphalt mixtures [8]. Among the existing processes, the addition of chemical additives, waxes or synthetic zeolites are some of the most frequently used, the aim of which is to reduce the viscosity of the asphalt or to produce its foam to be able to manufacture, transport and implement asphalt mixtures at lower temperatures (warm mix asphalt - WMA). Considering that in Chile there are natural zeolites available in large deposits from the VII to IX Region [9], the decision was made to assess their potential as an additive to reduce the manufacturing temperatures in mixtures and to contribute to the sustainability of road paving construction processes, integrating RAP as a replacement for virgin material, thereby reducing the environmental burden of the mixtures and generating a significant economic saving from an energy and materials point of view, achieving more efficient mixtures while maintaining performance properties.

The main aim of this study was to develop WMAs designed using natural zeolite extracted from central Chile and different RAP contents for use in more sustainable pavements. In the mixtures developed, the emissions of GHGs and VOCs, the energy consumption and cost as well as properties related to their performance, such as water sensitivity and permanent deformations, were all assessed at laboratory scale.

2. Materials and Methods
This study used asphalt binder (CA24) and fluvial aggregates crushed with a cone crusher that fulfilled Chilean specifications for asphalt mixtures.

The additive used was a natural clinoptilolite zeolite extracted from the Quinamávida deposit (VII Region). This material is a hydrous crystalline aluminum silicate with an open and porous structure [10], which can release the water of crystallization stored in its structure at 100ºC without its structure being affected, allowing it to generate microfoaming when it comes into contact with the asphalt binder.

The RAP used was reclaimed from the maintenance and rehabilitation works on the Temuco Bypass (IX region). In order to have better homogeneity of the mixture, the RAP was used in two fractions: 5/20 mm and 0/5 mm. The asphalt content of the coarse fraction was 3.3%, whereas that of the fine fraction was 7.5%.

The experimental methodology took place in three stages. The first consisted of determining the temperature reductions that made it possible to fulfill the design parameters of the national standard for each of the mixtures developed, and then some more significant performance properties were evaluated, such as water sensitivity and permanent deformations. In the second stage, the reduction in GHG emissions and VOCs emitted in their manufacture was assessed at laboratory scale. The final stage consisted of evaluating the energy output and production costs.
3. Results and Discussion

3.1. Stage 1:
An IV-A-12 particle size was considered for the design of the mixtures, where the optimal asphalt content was 5.4% s/a according to the Marshall method.

For the design of the WMAs, four percentages of natural zeolite addition were selected: 0.3, 0.6, 0.9 and 1.2% s/a and three manufacturing temperatures (145°C, 135°C and 125°C). The manufacturing temperature of the HMA was 155°C. Both the aggregates and the binder were preheated in a furnace at manufacturing temperature, while the natural zeolite stayed at 15°C. After an evaluation of the design parameters and a visual analysis of the different mixtures, 135°C was selected as the temperature for the WMAs, 0.3 and 0.6% s/a (WMA0.3 and WMA0.6) were established as the optimal percentage of natural zeolite addition, as these fulfilled all the design requirements.

In the design of WMA with RAP, mixtures were made with 0.6% natural zeolite at 125°C, 135°C and 145°C for mixtures with 10, 20 and 30% RAP. For these mixtures, the binder contribution from RAP was considered, reducing the amount of virgin binder added and maintaining the optimal binder dose calculated in the HMA design. Once the design parameters of the different evaluated mixtures had been analyzed, 3 mixtures were selected: 1) mixture with 30% RAP, manufactured at 145°C (WMAR30), 2) mixture with 20% RAP at 135°C (WMAR20) and 3) mixture with 10% RAP at 125°C (WMAR10). The design parameters of the selected mixtures are given in Table 1.

| Type of Mixture | Temperature (°C) | Asphalt binder content (% s/a) | Natural zeolite (%) | RAP (%) | Density (kg/m³) | Stability (N) | Deformation at 0.25 mm (%) | Voids (%) | VAM (%) |
|-----------------|------------------|-------------------------------|--------------------|---------|----------------|--------------|--------------------------|----------|--------|
| HMA             | 155              | 5.4                           | 0                  | 0       | 2,368          | 13,030       | 11.5                     | 4.5      | 15.2   |
| WMA0.3          | 135              | 5.4                           | 0.3                | 0       | 2,352          | 11,155       | 13.8                     | 4.9      | 15.8   |
| WMA0.6          | 135              | 5.4                           | 0.6                | 0       | 2,347          | 10,957       | 12.7                     | 5.1      | 16.0   |
| WMAR30          | 145              | 5.4                           | 0.6                | 30%     | 2,371          | 14,987       | 15.9                     | 5.3      | 15.1   |
| WMAR20          | 135              | 5.4                           | 0.6                | 20%     | 2,400          | 11,888       | 14.1                     | 4.4      | 15.1   |
| WMAR10          | 125              | 5.4                           | 0.6                | 10%     | 2,365          | 11,332       | 15.3                     | 4.7      | 16.4   |

Specifications: > 9,000, 8-16, 4-6, >15

Two performance properties were evaluated: water sensitivity and permanent deformations. Water sensitivity was evaluated at 25°C using European standard UNE-EN 12697–12. This procedure establishes, by retained resistance to indirect tensile strength, the capacity that mixtures have to adequately resist after an accelerated process of moisture damage. All the mixtures fulfilled the European specifications (minimum value of 85% for surface layer and 80% for base and intermediate layers), recording values similar to that of the HMA.

Permanent deformation was determined using the Hamburg Wheel Tracking test under AASHTO T324. The evaluated mixtures showed a behavior similar to the HMA. The WMAs presented slightly lower rutting values. Those with the highest RAP percentage (20% and 30%) had the lowest rutting level at the end of the test. Among the WMA mixtures without RAP, WMA0.6 behaved the best. In addition, none of the evaluated mixtures presented stripping.

3.2. Stage 2:
In order to evaluate GHG emissions and VOCs, a gas collection chamber was used on the mixture production unit. Once the mixture process had begun, the chamber stored the gases produced during manufacturing, from which samples were taken. These samples were analyzed in a gas chromatograph in the case of the GHGs, and using solid-phase microextraction (SPME), gas chromatography and mass spectrometry for the VOCs (Figure 1). The results obtained were compared to those of the HMA.
With respect to the GHGs, it was observed that for the mixtures studied the SO$_2$ emission was outside the detection ranges (low 0.05%). With respect to the CO emissions, no significant differences were detected between the HMA and the WMAs, with a similar level of CO emissions for both mixtures. However, when analyzing the WMAs with RAP, reductions were observed, reaching a 6% reduction for the WMAR10 made at 125°C, 5% for WMAR20 made at 135°C and 4% for WMAR30 made at 145°C, which supposes environmental benefits. A 17% reduction in CO$_2$ levels for WMA produced at 135°C compared to the HMA at 155°C was verified, but for the samples with RAP, reductions of 30, 37 and 35% were observed for the WMAR10, WMAR20 and WMAR30, respectively. This supposes an important environmental benefit, very much in line with the commitments made in the Kyoto and successive protocols, the main goal of which is the reduction of GHGs.

With regard to VOCs, the WMAs (WMA0.3 and WMA0.6) saw decreases compared to the HMA of 8.2% and 44.8%, respectively. WMAR10, WMAR20 and WMAR30 recorded reductions in these emissions of 19.9%, 56.4% and 56.8%, respectively. These results indicate that there were significant reductions that contribute to improving the working environment in road works that involve production batches and the laying of asphalt mixtures.

3.3. Stage 3

3.3.1 Energy consumption
To calculate the energy consumption of asphalt mixture manufacturing, the temperature variation of production was considered, with energy transfer equations being applied that include the effect of temperature variation on the energy needed to heat a material [11]. These equations include the energy needed to heat the aggregates and the water they hold, to vaporize that water and to eliminate the steam.

The HMA was made at 155°C, the percentage of moisture in the aggregates was considered as 3%. In this study, 15°C was considered room temperature, the annual average of the temperatures measured from the I to the X Region in Chile, with the temperature of the remaining regions being ignored because they are very extreme, and therefore not representative [12]. On the other hand, the WMAs include a decrease in production energy because they can be made at 135°C, maintaining the aforementioned parameters. The WMAs with RAP were compared with their respective HMAs with RAP, which require overheating temperatures of the virgin aggregates according to the percentage of RAP so that, when the hot virgin aggregates come into contact with the RAP at room temperature and after a period of premixing, the production temperature of 155°C is reached, which is reduced when making mixtures with RAP and zeolites.

The results indicated that the WMAs made at 135°C reduce energy consumption by 9%, and the WMAs with RAP reduce it between 9% and 15% compared to their reference mixtures. This is consistent with the results obtained by Prowell [8] and Harder et al. [13], who observed reductions in energy consumption for WMAs between 10 and 30% compared to a HMA.
3.3.2. Production costs

For the production costs, the reduction in fuel costs due to the reduction in energy consumption during production must be considered. The reduction in the cost of binder due to the contribution of binder to the RAP must also be considered. To this must also be added the cost of natural zeolite with which WMAs are manufactured.

From the results of the energy consumption equations and the calorific value of the fuel used in the process, the amount of fuel required to make one ton of HMA was calculated to verify the validity of the methodology used. The results were compared with the fuel consumption reported by the BitumixSur plant to produce one ton of mixture at 155°C with similar characteristics to that assessed in this study, with a difference of 1% being obtained between the theoretical calculation and the real one. Taking this into account, the same calculation was performed to obtain the variation in fuel consumption during the production process of all the WMAs, thus quantifying the fuel saving.

With respect to the value of the additive, micronized zeolite at a thickness of approximately 0.173 mm was used, with a wholesale value of CLP$680/kg according to the information given by Fertosa Chile. According to BitumixSur, 1 kg of lime has a wholesale value of CLP$70, much lower than that of the current cost of natural zeolite. This is due to the zeolite mining industry being in its early stages, essentially due to the low demand for the product, since, if we compare the production process for the two additives, the production process for zeolite is simpler and therefore should be less expensive. The zeolite production process incorporates the following stages: extraction of the stone from its natural deposit, crushing and classification according to size and packaging for commercialization. On the other hand, the process for obtaining lime, according to Alfacal, consists of extracting the limestone from the deposit, crushing and classifying it according to size, and then finally performing a calcination process in a rotatory furnace to be packaged and sold. This final stage of the lime production process considerably increases the cost of the final product. This stage is not required in the zeolite production process; therefore, it may presume that the cost of zeolite, once the industry is developed, should be at least similar to or lower than that of lime. In this context, in developing the cost analysis, an evaluation was done considering the current cost of the zeolite (undeveloped industry value - UIV: CLP$680), and another evaluation considering the cost of lime, assuming that when the industry is developed the cost of zeolite should be similar to it (developed industry value - DIV: CLP$70).

From this evaluation it was noted that WMA0.3 made at 135°C today is 5.5% higher than the HMA at 155°C; however, if the scenario is considered in which the industry was developed and lowered the cost of the additive (DIV), the final cost of the WMA would be similar to the cost of the traditional mixture, since the saving on fuel compensates for the cost of the additive.

An analysis of the WMAs with RAP revealed that in both the current scenario as well as in the case of the developed industry, the WMAs with RAP reduce their production costs between 0 and 30% compared to a HMA, with the mixture with the greatest saving being the one that incorporates 30% RAP and is produced at 145°C, considering the DIV of the additive. This same mixture in the current scenario presents a saving equivalent to 19% in its production cost compared to a HMA. The mixture with 10% RAP made at 125°C and considering the current scenario presents a cost similar to the HMA; however, if the DIV is considered, the production cost of this mixture is 11% lower than a HMA. Finally, the mixture with 20% RAP produced at 135°C presented a 10% saving compared to HMA in the current scenario, which could reach a 19% saving if the DIV is considered. These values agree with those reported by Schreck [14]; however, it must be considered that these mixtures are WMAs with RAP, which also assumes a greater environmental benefit.
4. Conclusions
The WMAs developed by adding natural zeolite and RAP comply with Chilean specifications, enabling a reduction in production and laying temperatures compared to the HMAs currently used. The results obtained make it possible to achieve reductions in energy consumption, costs, GHG emissions and COVs, contributing an alternative with good performance characteristics and lower environmental impact to the asphalt paving industry. Furthermore, the performance properties assessed indicate that low water sensitivity and low permanent deformations without the presence of stripping could be used in any layer of the pavement.

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