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Cold mix asphalt with polymeric stone for low traffic volume roads

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ABSTRACT

The use of polymer-based household waste in the wearing course of flexible pavements has been analysed, either as an asphalt bitumen modifier or as a dry additive. However, there are not enough records in which this waste is used to make up the aggregate to be used in an asphalt mix. This article presents the development carried out at LEMaC, consisting of pieces made from the mixture of household waste polymers and soils, which has been called Polymeric Stone. This material is used to design a cold-mix asphalt, and its use has been validated after evaluating a series of properties.

1. Introduction

1.1. Background

The extraordinary production of polymeric waste (sometimes misnamed as plastic waste) worldwide has led to the development of initiatives that consider its application in various solutions, many of which are related to civil engineering. Among these, it is worth mentioning, just as an example, the inclusion of these wastes in the production of Portland cement and in the manufacture of bricks, floor tiles, plates, etc. Road engineering, as a particular expression of civil engineering, has not been left out of such proposals, especially in relation to the design and construction of wearing courses. These are the main subject of study in this technical paper.

In these asphalt wearing courses, there is a history of using shredded polyethylene terephthalate (PET), waste from bottles of soda and other beverages, as a constituent material in hot asphalt. An example of this in Latin America is that carried out by Villegas et al. [1] who added this waste thorough a wet method as an asphalt modifier in Costa Rica, or the one developed by Angelone et al. in Argentina [2] who added it through a dry method. At international level, there are also experiences, such as those of the Polymix project in Spain [3]. Also worth mentioning are the applications in test sections carried out by Botasso et al. [4] with crumb rubber or that by Casaux et al. [5] with polyethylene from silo bags, being both applied by the wet process.

Another solution, although without the use of bitumen as a binder, is the one developed by Khoury et al. [6], which consists of the use of residual plastic bottles, melted together with fine soils of various nature to obtain a monolithic material, which they called plastic-soil. By this technique, the authors use a clay with a Plastic Index (PI) of 15, a Liquid Limit (LL) of 35 and 80% passing through sieve No. 200 (75 μm), and another mix with friable sand having 25% passing through sieve No.200. With the clayey soil, an average Unconfined Compressive Strength (UCS) of 18.3 MPa was obtained, while with the mixtures using sand, 35.5 MPa was achieved. Beyond the above, the authors' work does not seem to have made any progress in terms of materiality in the road works analysed.

Another precedent related to this topic is the experience of Swan & Sacks [7], who generated by extrusion and grinding a fine synthetic aggregate (which they refer to as SLAs: synthetic lightweight aggregates) by mixing residual polymers with coal fly ash and analysing its possible use in pavements as a replacement for sand. In addition, Mallick et al. also analysed SLAs added to a hot mix asphalt [8]. In any case, these experiences do not seem to have advanced the use of soils instead of fly ash or the generation of a coarse aggregate to replace the coarse fraction in mixes for pavement layers. Even Mohammed et al., in their recent comprehensive review article on synthetic aggregates used in road applications, do not cite research such as that undertaken in this study [9].

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1.2. The proposed solution

Based on the "monolithic solution" of Khoury et al. [6], the authors decided to study the possibility of developing similar high-temperature mixtures, but with a plastic such as polypropylene (PP) that has a lower melting point, with the objective of generating pieces of such dimensions that, after they have cooled, they can be crushed. In this way, an attempt was made to generate an artificial aggregate that can be used to replace the coarse and intermediate fractions of asphalt bases and wearing courses, calling it Polymeric Stone. In recent years, there has been a growing awareness that natural aggregate is a non-renewable resource and there are severe restrictions on its exploitation, due to the impact on the environment and the high volumes handled (almost 25,000 million metric tonnes per year worldwide).

The material developed could have a high potential for use in rural or suburban roads with low traffic, in a region such as central Argentina, characterized by large areas of plains with no available deposits of stone aggregates.

In the area of La Plata, the city where LEMaC Centro de Investigaciones Viales is located, the aggregates used in the construction of granular bases and asphalt layers come from the outskirts of the city Olavarría, at approximately 350 km. In this area, it is common to use granite aggregates from crushed quarries for the asphalt layers of wearing courses [10]. The cost of this material is 10 times the cost of fine soil from quarries (of intermediate plasticity and commonly classified as A-4). The challenge is therefore to produce this artificial aggregate at a lower cost than that currently used and with a minimum acceptable road suitability. From this first objective, the economic contribution that can be attributed to the reduction of environmental liabilities is an additional element of interest.

2. Materials and methods

2.1. Materials

2.1.1. Household polypropylene waste

Polymers burst onto the global market after World War II. They can be classified into three categories: polymeric resins, polymeric synthetic fibres and polymeric additives. The most prevalent resins are produced from polyethylene (36%), polypropylene (22%), and polystyrene, polyvinyl chloride, polyethylene terephthalate and polyurethane, in quantities of less than 10% of total production [11].

PP is the partially crystalline, thermoplastic polymer obtained from the polymerisation of propylene. It belongs to the polyolefin group and is used in a wide variety of applications, including food packaging, textiles, kitchen utensils, household appliance components, transparent films, etc., all of which give rise in the short term to a household waste of interest. These applications take place both as homopolymer (melting temperature 160–170 °C) and copolymer (melting temperature 130–168 °C), with a density of approximately 0.900 g/cm^3.

This study is dealing with a copolymer. Samples of the used residues taken with Olympus SZ61 loupe and Olympus BX51 fluorescence microscope are shown in Fig. 1a and Fig. 1b, respectively.

2.1.2. The fine soil

A fine clayey soil widely available in central Argentina is used. It is a typical soil obtained from quarries and commercially used for all types of civil applications. This soil has the characteristics shown in Table 1, which were obtained by applying the regulations of the National Highway Administration of Argentina (DNV by its name in Spanish) [12]. Prior to its use, the soil is dried at 110 °C and passed through a mortar to achieve 100% passing sieve No. 4 (4.75 mm). Under these conditions, an optical microscopic observation is carried out using an Olympus SZ61 magnifying glass to obtain images of its condition prior to mixing (Fig. 2).

2.1.3. The generated polymeric Stone

By means of a process developed at LEMaC, which is currently at the patenting stage, PP household waste is brought to melting temperature to be mixed with fine soil in a rotary kiln, in a 50%-50% weight ratio. The product obtained is poured into containers to be cooled to room temperature and the pieces thus obtained are subjected to conventional crushing in the stone industry, until the desired gradation is achieved. Fig. 3 shows a typical particle of those generated after crushing, Fig. 4a shows an image of its surface with an Olympus SZ61 magnifying glass and Fig. 4b shows an image with an Olympus BX51 fluorescence microscope.

These images corroborate the adequate dispersion of the soil grains in the polymer matrix generated. This is due to the fact that, although the mixture of the two components is equal in weight, the polymer volume represents a higher proportion, given its lower specific weight.

The physical properties of the polymeric stone to be used in the cold mix asphalt are: a compacted unit weight (UW) of 0.624 g/cm^3, a specific weight ρ of 13,758.7 N/m^3 and an absorption of 1.02%.

In order to compare the material generated with that developed by

Table 1
Soil characterisation used.

Parameter	Value
Liquid Limit (%)	35
Plastic Limit (%)	29
Plastic Index	6
Passing Sieve No10 – opening 2000 μm (%)	86.3
Passing Sieve No 40 – opening 420 μm (%)	78.0
Passing Sieve No 200 – opening 75 μm (%)	63.5
HRB Classification	A-4(3)
Dry Density (g/cm^3)	1.606
Specific Weight ρ (N/m^3)	26,026.8

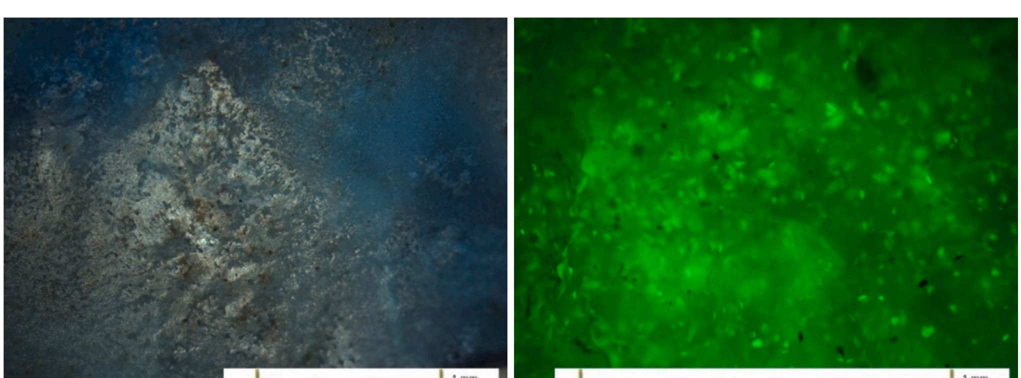

Fig. 1. Molten polymers observed with Olympus SZ61 loupe (a) and Olympus BX51 fluorescence microscope (b).

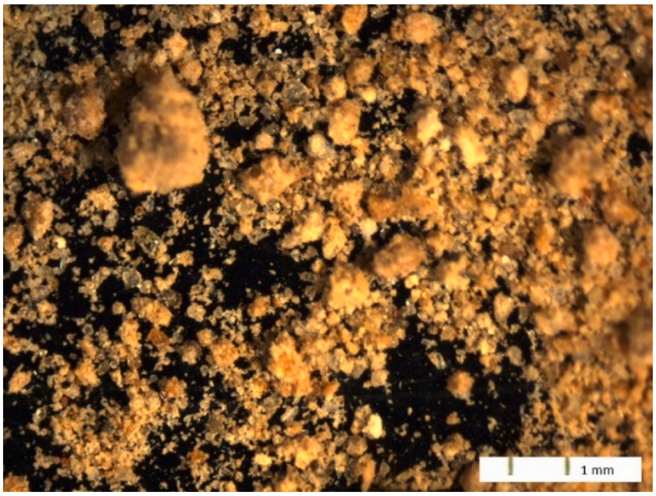

Fig. 2. Olympus SZ61 loupe image of the soil used.

Fig. 3. Image of a typical particle obtained in laboratory.

Khoury et al. [6], cylindrical specimens of 50 mm in diameter by 100 mm in height are hot moulded, allowed to cool gradually to room temperature and demoulded, according to ASTM D695-15 [13]. The density and UCS (corrected by slenderness) of these specimens are determined by testing them with a press at a loading rate of 0.17 MPa/s. The results indicate an average density of 1.335 g/cm^3 and an average UCS of 12.3 MPa; lower than the 18.3 MPa obtained with other polymers and clays by Khoury et al. [6], but nevertheless, this value can be considered for an approximate relative assessment.

2.1.4. The asphalt emulsion

The binder used in this study is a cationic slow-setting emulsion, which has the characteristics summarised in Table 2.

2.1.5. Crushing sand and lime

The gradation and compacted UW are determined for both materials. The granitic crushing sand 0–6 has a compacted UW of 1.703 g/cm^3 and the lime 0.560 g/cm^3. Additionally, the sand has a water absorption of 0.42% and an apparent specific weight ρ of 27,203.6 N/m^3, while the lime has a ρ of 2.618 g/cm^3.

2.2. Methods

The potential use of polymeric stone for the manufacture of cold asphalt concrete for wearing courses in the aforementioned type of roads is analysed through a series of tests. The composition and manufacture of the mix studied is presented below, followed by details of the tests used, and finally, the parameters obtained in terms of structural response, are finally converted into structural coefficients in accordance with the 1993 Pavement Design Guide of the American Association of State Highway and Transportation Officials (AASHTO), usually known as the AASHTO'93 Guide [14]. It is considered that this tool is still in line with the level of requirements that should be applied to studies for low traffic volume roads.

2.2.1. Mixture studied

It is proposed that the mixture of Polymeric Stone with crushing sand

Table 2
Characteristics of the asphalt emulsion.

Test	Unit	Value	Standard
On emulsion			
Saybolt-Furol viscosity at 50 °C	sec	57	IRAM 6721
Asphalt bitumen residue	% by weight	60.7	IRAM 6719
Settlement at 5 days	% by weight	7.8	IRAM 6716
Residue on sieve IRAM 850 μm (No.20)	% by weight	0.005	IRAM 6717
On asphalt residue			
Viscosity at 60 °C (Spindle 29, 1 rpm)	dPa.s	2,720	IRAM 6837

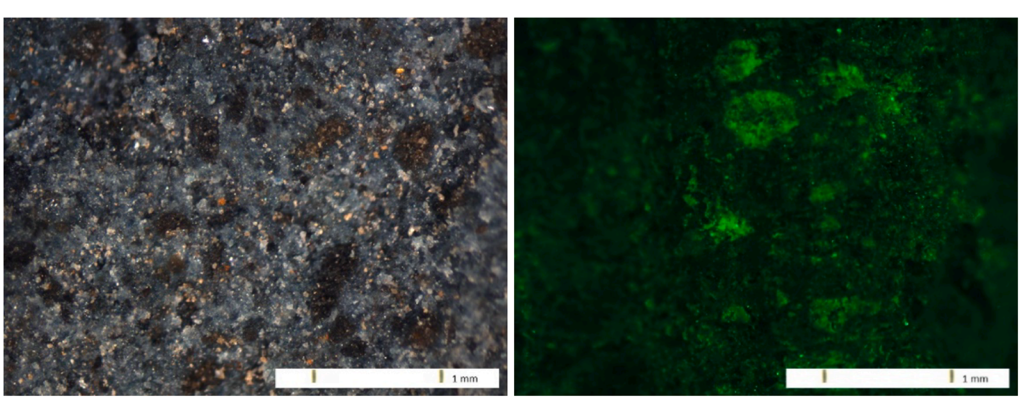

Fig. 4. Aggregate surface with Olympus SZ61 loupe (a) and Olympus BX51 fluorescence microscope (b).

and lime must meet the gradation envelope specified for 12 mm maximum aggregate size by DNV (CAC-D12), even though it is originally for hot asphalt mixtures [15]. The selected gradation, composed by 50% of Polymeric Stone (P-S), 49% of crushing sand (0–6 mm) and 1% of lime, is shown in Table 3 and Fig. 5. However, this envelope was developed for the gradation by weight, but the ρ values of each material are very different, so the composition is best designed by volume, but indicated also by weight because it is used both in the laboratory and in the plant with the foreseeable equipment.

With this gradation, a batch is manufactured with 5.0% asphalt residue by weight of dry aggregates (8.23% asphalt emulsion). These aggregates have a moisture content of 4.8% prior to the addition of the emulsion, so that, if the water added by the emulsion is also taken into account, the total water content is 8.0%. This batch is allowed to lose moisture until it reaches a value close to the breaking of the emulsion, which occurs at around 6.0%.

Marshall specimens are prepared using procedure LEMaC-A07/99 [16], which is based on the specification of the Highway Administration of Santa Fe because this procedure is the most widely in Argentina [17]. This procedure consists of using a static compaction up to a reaction of 12 t, with the asphalt mix placed in a perforated mould to allow water to escape during the breaking of the asphalt emulsion. Being the mix in a condition close to the emulsion breaking, the specimens are moulded at a weight such that the specimen's dimensions can be around 6.35 cm in height (Fig. 6a), allowing water to escape through the holes in the mould (Fig. 6b).

Next, a technique commonly known as the "French Modified Marshall Method" is used, according to the adaptations implemented at the Laboratoire Central des Ponts et Chaussées (LCPC) [17]. From the prepared mixture, a part is taken to mould the described specimens (Fig. 7a) that are cured at 60 °C for 24 h (Group (1), the rest is used with the loose mixture subjected to the same curing to determine the Rice Density and also to prepare two more groups of specimens, one of which is heated to 100 °C for one hour and the other to 140 °C for the same period of time. At these temperatures, Marshall specimens are statically moulded to a reaction of 12 t (Group (2) at 100 °C and Group (3) at 140 °C). To illustrate the differences between the groups, Fig. 7 is included. It can be observed comparatively between Fig. 7a and Fig. 7b how a more closed texture is obtained on the surface in the second case. This would be the expected evolution that would be registered on site when the mixture is subjected to traffic and to summer cycles that allow the surface sealing.

2.2.2. Tests performed

All specimens are tested for Marshall procedure and new specimens were prepared according to the procedure stablished for Group (3) in order to evaluate the following properties:

– stiffness modulus
– permanent deformation
– moisture resistance
– indirect tensile strength
– cracking resistance

The stiffness modulus was determined at 20 °C according to the UNE-EN12697-26 standard, Annex C (test applying indirect tension to cylindrical specimens) [18].

The sensitivity to permanent plastic deformations was analysed by means of the Wheel Tracking Test (WTT), comparing the results with the specifications for a CAC-D12 mix [15]. Since there is no specified methodology for this type of mix in Argentina, an alternative methodology to that of the Roller Compactor is applied for moulding the specimens, based on the concepts developed by Angelone et al., generally known as the "IMAE methodology" [19]. This method proposes to extract cores of 15 cm diameter and locate them for the test as shown in the diagram in Fig. 8.

For the present application, the central core C (in its central 10 cm the deformation is registered) is replaced by a statically moulded specimen of the same dimensions, with an analogous methodology to that used with the Marshall specimens of Group (3), although this time in a 15 cm diameter mould. For A and B elements, cores of a conventional hot mix asphalt extracted from a low-traffic urban road are used. This produces the specimen shown in Fig. 9, which is shown during testing.

The moisture susceptibility is analysed with the retained strength by means of the modified Lottman test according to AASHTO T-283, to evaluate the durability of the mix under changes in moisture [20].

Additionally, the behaviour of the mix is also analysed using a simple technique when determining its Indirect Tensile Strength (ITS) at 5 °C, as proposed by Recasens et al. [21], with the application of the old Spanish standard NLT-346 [22].

Finally, the cracking resistance through N_{flex} factor according to AASHTO TP141-20 is determined [23]. This factor is calculated by testing indirect tensile specimens with a continuous load and deformation recording system. The test is performed at a speed of 50.8 mm/min and a temperature of 25 °C, while the 15 cm diameter specimens are moulded at the Superpave N_{design} density. Using this technique, a point cloud is obtained of the tensile stresses (S_t), according to Equation (1), occurring at certain estimated tensile strains ($\acute{\varepsilon}$), according to Equation (2).

$$S_t = \frac{2000P}{\pi Dt} \tag{1}$$

Where:S_t = tensile stress (kPa)P = vertical load (N)D = specimen diameter (mm)t = specimen thickness (mm)

$$\varepsilon\hat{A} = \frac{\mu\gamma}{D} * 100\% \tag{2}$$

Where:$\varepsilon\hat{A}$ = estimated tensile strain (%)μ = Poisson ratio, assumed to be 0.35 for asphalt mixtures at 25 °CD = specimen diameter (mm)γ = vertical deformation (mm)

With this point cloud, the continuous polynomial function that fits with a coefficient of determination (R^2) of at least 0.95 is found by regression.

Table 3
Gradation of cold mix asphalt.

	Passing Sieve (%)						
Sieve	P-S	0–6	LIME	By weight	Minimum	By volume	Maximum
25 mm (1″)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19 mm (3/4″)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5 mm (1/2″)	84.9	100.0	100.0	92.5	80.0	90.0	95.0
9.5 mm (3/8″)	61.9	100.0	100.0	81.0	72.0	74.7	87.0
4.75 mm (No.4)	28.3	94.2	100.0	61.3	47.0	50.5	65.0
2.36 mm (No.8)	11.4	76.8	100.0	44.3	30.0	33.5	50.0
600 μm (No.30)	8.4	32.1	100.0	20.9	16.0	16.8	30.0
300 μm (No.50)	5.6	22.9	100.0	15.0	12.0	12.0	23.0
75 μm (No.200)	2.6	10.6	95.7	7.5	5.0	5.9	8.0
ρ (g/cm^3)	1.403	2.774	2.618				

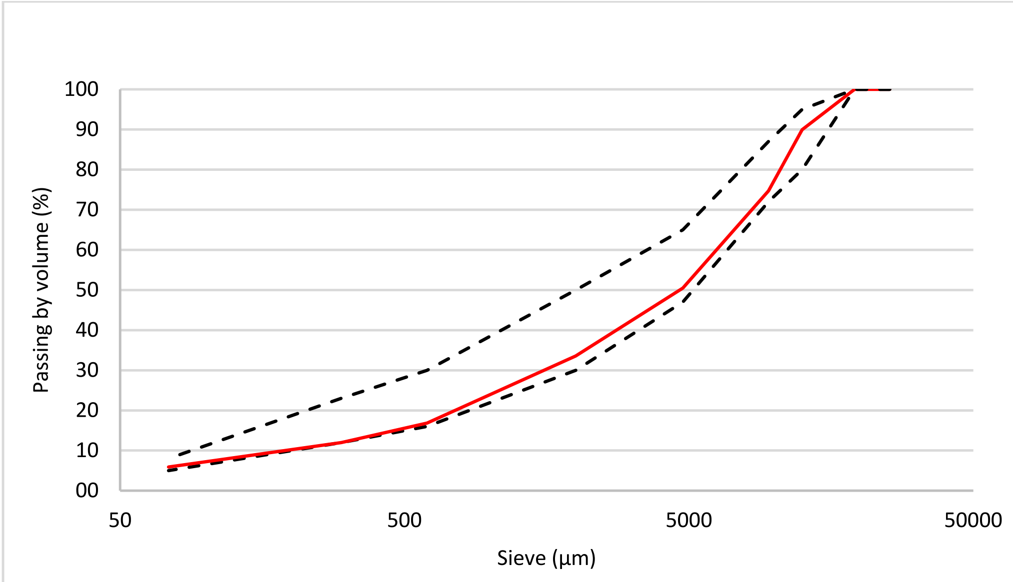

Fig. 5. Gradation of aggregates for the cold mix asphalt and specifications considered.

Fig. 6. a) placement of the mixture in the mould and b) specimen compaction.

Fig. 7. Specimens moulded with the test mixture, a) Group (1) and b) Groups (2) and (3).

Generally, this adjustment is achieved with a polynomial function with degree 5 or 6. The inflection point after the peak load is estimated by the second derivative of this function, when the curvature equals 0. The slope of the post peak stress–strain curve at the inflection point m (brittleness slope) (J/m^3) is determined using the first derivative of the polynomial equation at that point. The toughness T (J/m^3) is determined

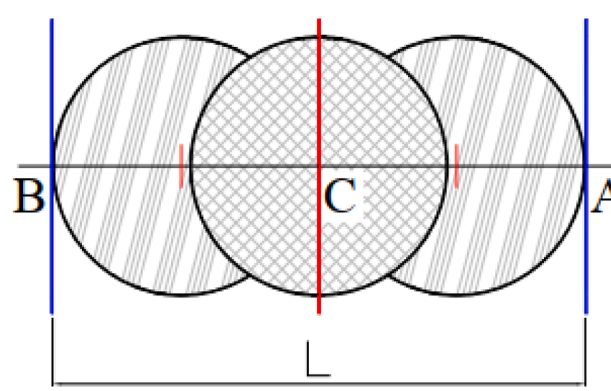

Fig. 8. Diagram to indicate the arrangement of the cores in the WTT test (). Source: [19]

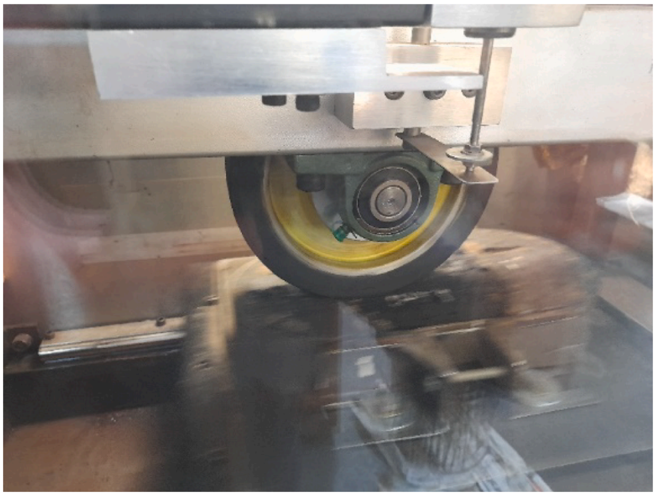

Fig. 9. WTT testing of the specimen moulded with the modified IMAE methodology.

Fig. 10. Performing the test for N_{flex} determination.

mathematically by integrating the polynomial equation from the beginning of the test up to the inflection point on the post peak stress–strain curve. Finally, the dimensionless factor N_{flex} is calculated with Equation (3).

$$N_{flex} = \frac{T}{|m|} \quad (3)$$

The N_{flex} parameter can be used to estimate the number of single axle loads (N) that would cause the fatigue failure of the asphalt concrete. Calculations are performed for a 14.2-kip (63.2 kN) axle with a tyre pressure of 100 psi (0.69 MPa), at 20 °C, applied on a 5 cm thick pavement and considering a total cracking length of 240 in (609.6 cm) in the test area. West et al. [24], in their comparative studies between laboratory tests and sections constructed with recycled asphalt subjected to the FHWA accelerated loading device (ALF), established Equation (4) and obtained results of between approximately 40,000 and 600,000 axle loads. The application of this equation would predict the serviceability of this mixture versus the pavement life in terms of $N_{63.2}$.

$$N_{63.2} = 24.2e^{2.2732.N_{flex}}.1000 \quad (4)$$

Regarding the compaction methodology to be implemented for the specimens' manufacture, as the Superpave compactor was not available, it was decided to explore the method used for WTT test. For this purpose, the correlation between the method used and the one indicated by the standard that leads to the Superpave N_{design} density must be analysed. In this regard, Nosetti et al. in their study for cold recycled mixes, [25], compared the densities and ITS obtained using a static compactor (similar to the one used in this study), a gyratory compactor and cores extracted from site sections after 15 months in service. The authors of this study concluded that static moulding yielded similar densities to those obtained with the gyratory compactor and slightly higher ITSs (only 10%). In addition, the densities of the cores were very close to those of the specimens produced by static compaction, and the RTIs were intermediate values between those obtained with both laboratory compaction devices. Given the above, and in view of the fact that this is an approximate study to establish the potential use of polymeric stone, it was decided to consider as suitable for this work the same method already used for the WTT test in order to determine the N_{flex}. Based on this assessment, 3 specimens are moulded and subjected to the N_{flex} test, following the indications already mentioned (Fig. 10).

Table 4
Average results of the specimens tested.

Specimens	Compaction Temperature (°C)	Average Marshall Density (g/cm^3)	Average Stability (N)	Average Stability/ Flow Ratio (kN/mm)	Average air voids (%)
Group (1)	20	1.473	4231	0.6	13.6
Group (2)	100	1.592	13,528	3.8	6.6
Group (3)	140	1.625	14,771	4.3	4.7

3. Results

3.1. Marshall test

All the specimens are tested for Marshall procedure and the average results are shown in Table 4. Air voids were calculated considering a Rice Density of 1.705 g/cm^3.

3.2. Stiffness modulus and Wheel Tracking test

Specimens prepared with the procedure of Group (3) are tested to determine modulus and rutting resistance. The average modulus obtained is 2,268 MPa for specimens with a Marshall density of 1.627 g/cm^3 (air voids 4.6%), considering a Poisson's ratio of 0.35.

Regarding the Wheel Tracking Speed (WTSair) and the Proportional Rut Depth (PRD), the results are collected in Table 5.

The specifications for the CAC-D12 mix state for the maximum expected level of demand (more than 1500 heavy vehicles/day in the design lane) and use as wearing course a PRD of less than 5.0% and a WTSair of less than 0.08 mm/1,000cycles [15]. Bearing in mind that these measurements are made on a Group (3) mix, which would have already been densified by traffic (with associated potential deformation), an adequate level of performance for these mixtures can be deduced from this test, as results obtained would initially qualify them for use on roads with markedly higher stresses.

Table 5
Results of the Wheel Tracking Test.

Parameter	Value
PRD (%)	5.04
WTSair (mm/1000 cycles)	0.057

3.3. Moisture susceptibility

The retained strength analysed by means of the modified Lottman test is applied to a group of unconditioned specimens with an average density of 1.515 g/cm^3 (void content of 11.1%, higher than the minimum 7% imposed) and an indirect tensile strength of 0.64 MPa, and to a group of conditioned specimens with an average density of 1.505 g/cm^3 (void content of 11.8%) and an indirect tensile strength of 0.30 MPa. These strengths determine a retained strength of 47.3%, below the minimum limit set by the DNV specifications of 80% [15], although, again, it should be clarified that this value has been specified for hot mix asphalt. In this regard, Pérez Pérez et al. [26] and Nosetti et al. [25] state that there is a higher water susceptibility in cold recycled mixes (which bear some similarity to the mixes analysed here), so that their retained strength is lower than the limits generally imposed for hot mixes. This is an indication of the suitability of the mix developed for use on low-traffic roads with a limited service life.

In a complementary way, the Indirect Tensile Strength (ITS) at 5 °C, is also determined, considering the conclusions of Recasens et al. of an expected strength of at least 2.5 MPa for hot dense asphalt mixes [21]. Some years later, Martínez et al. [27] and Nosetti et al. [25] indicated a strength around 1.6 MPa for cold recycled mixtures. New specimens were then moulded with the mix under study, determining an average density of 1.644 g/cm^3 (voids of 3.6%, below the design voids), which, when tested at 5 °C using the aforementioned methodology, yielded an average ITS of 2.2 MPa. This value is below the requirement for a hot mix asphalt, but acceptable for the intended use of the mixture. It should be considered that the properties evaluated are very susceptible to the content of air voids in the mixture and therefore, the comparisons are indicative and taken as valid trends within certain ranges [28].

3.4. Cracking resistance and fatigue life

As an example of the analyses carried out using this methodology, the graph obtained for one of the specimens tested is shown. Fig. 11 shows the cloud of points obtained when testing this a specimen and a 6°-polynomial function that was used to fit the data, with an R^2 of 0.9977, which complies with the minimum established. Equations (5) to (7) show the polynomial function obtained and its first and second derivatives.

$$N_{flex} = -941.45\varepsilon'^6 + 2764\varepsilon'^5 + 260.71\varepsilon'^4 - 7079.5\varepsilon'^3 + 5698.6\varepsilon'^2 - 350.26\varepsilon' + 12.713 \quad (5)$$

$$\frac{dN_{flex}}{d\varepsilon'} = -(282435\varepsilon'^5 - 691000\varepsilon'^4 - 52142\varepsilon'^3 + 1061925\varepsilon'^2 - 569860\varepsilon' + 17513)/50 \quad (6)$$

$$\frac{d^2N_{flex}}{d\varepsilon'^2} = -(1412175\varepsilon'^4 - 2764000\varepsilon'^3 - 156426\varepsilon'^2 + 2123850\varepsilon' - 569860)/50 \quad (7)$$

As can be seen in Fig. 11, the first inflection point after the stress peak is between 1.0 and 1.1% of ε', which is verified by finding the root of the second derivative of Equation (7) with the value of ε' of 1.056%. This value is used in Equation (6) and gives the brittleness slope m of −1002.7 J/m^3. Next, the integration of Equation (5) between 0 and 1.056% gives the toughness T of 364.4 J/m^3. Using these two parameters and Equation (3), an N_{flex} of 0.363 is calculated, which is introduced in Equation (4) and gives an $N_{63.2}$ of 55,286 axle loads. After testing and analysing the 3 specimens, an average $N_{63.2}$ of 54,628 axles is reached, with a Coefficient of Variation of 1.6%, which would imply a very low variability of results.

4. Discussion

There is no specified stability value for cold asphalt mixes in Argentina. Based on the stability obtained and what is indicated in "Structural coefficients for asphalt layers related to various tests" of EICAM [29], the structural contribution coefficient of 0.45 1/inch considered for hot mix asphalt could be adopted for obtaining the Structural Number (SN) of a pavement structure.

If this mix is used at the usual thickness of 5 cm (approximately 2 in.), on a typical granular base with a structural coefficient of 0.14 1/inch at 15 cm thickness (approximately 6 in.) with a drainage coefficient of 1.0, placed on a typical subgrade in the La Plata area with a modulus of 50 MPa (7,250 psi), a Structural Number (SN) of 1.74 would be obtained. This structural contribution, in a secondary road with a reliability of 60%, a standard deviation of 0.45, an initial serviceability of 4.2 and a final serviceability of 2.0, would bear approximately 50,000 equivalent axle loads according to the AASHTÓ93 Guide (eminently empirical).

The above analysis can also be performed using an eminently mechanistic model, such as Weslea 3.0 [30], which uses Equation (8) as the transfer function for the N_f axles causing fatigue damage to the asphalt mix, where ε_t is the maximum horizontal tensile strain (in microstrain) at the bottom of the asphalt layer.

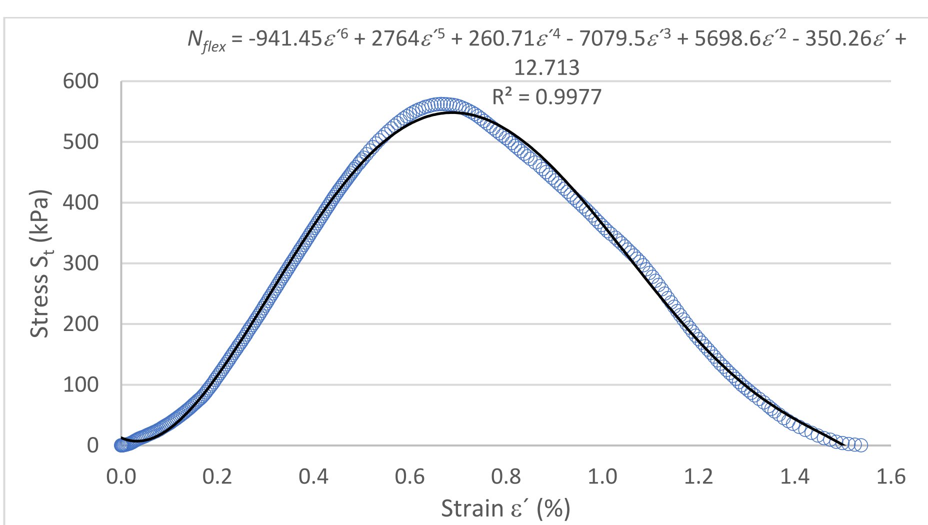

Fig. 11. Cloud of points obtained with a specimen with N_{flex} test and 6°-polynomial function.

$$N_f = 2.83x10^{-6}\left(\frac{10^6}{\varepsilon_t}\right)^{3.148} \quad (8)$$

With this software, a pavement structure can be designed consisting of 5 cm of an asphalt mixture with the modulus obtained as the stiffness modulus (i.e., 2,268 MPa) and 15 cm of a 200 MPa base (comparable to that used in the analysis using the AASHTÓ93 Guide), over the natural subgrade of 50 MPa modulus already specified; considering the layers are bonded and with Poisson ratios of 0.35, 0.40 and 0.45 respectively. Regarding the load applied, the AASHTO dual single equivalent axle load of 80 kN (20 kN per footprint) is assumed, with a tyre pressure of 100 psi (689.48 kPa) and a centre-to-centre spacing of 34.3 cm. With these data, an ε_t of 526.81 μ is obtained and, therefore, when applying Equation (8), a fatigue life of 59,158 equivalent axle loads is obtained. On the other hand, if the single axle load of 63.2 kN considered by West et al. [24] with 31.6 kN per footprint and a tyre pressure of 100 psi (689.48 kPa) is assumed with the same pavement structure, an ε_t of 538.0 μ is obtained and, therefore, when applying Equation (8), a fatigue life of 55,368 axles is calculated for the asphalt layer.

As can be seen, the results obtained by considering the $N_{63.2}$ from the N_{flex}, and the analysis of the pavement structure with the AASHTÓ93 Guide and with the Weslea 3.0 model for the AASHTO equivalent axle and the axle analysed by West et al. [24] are not very different. A validation of the analyses performed and a conservative fatigue life of 50,000 AASHTO equivalent axle loads can therefore be proposed.

5. Conclusions

For a cold asphalt concrete consisting of 50% Polymeric Stone, 49% 0–6 crushing sand and 1% lime, plus 5.0% residual asphalt by weight of dry soil, a structural coefficient of 0.45 1/inch could be considered.

Its use would lead to a service life on low traffic roads of around 50,000 AASHTO equivalent axle loads, which would not be a negligible value for this type of application.

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J. Julián Rivera: Conceptualization, Methodology, Formal analysis, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Nicolás D. Battista:** Methodology, Investigation, Writing – original draft. **Adrián Oviedo:** Investigation. **Oscar R. Rebollo:** Investigation. **Ignacio Zapata Ferrero:** Methodology, Investigation. **Enrique A. Fensel:** Investigation. **H. Luis Delbono:** Investigation. **Adriana H. Martínez:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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