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Technical-Economical Evaluation of Pavement Recycling Alternatives

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Abstract: Pavement recycling is becoming an increasingly important alternative worldwide for maintenance of highways, once sustainability and environmental issues have continued to receive more attention. The reference point is that of considering *the use of road materials in a closed cycle*, in which a natural material, previously used in road construction, should not be rejected in the following life-cycle.

The objective of this paper is that of analysing flexible pavement recycling alternatives techniques, including reclaimed material from flexible pavements recycled with emulsion, cement and reused in a hot-mix.

Based on the results obtained from field and laboratory tests (stiffness modulus, resistance to fatigue and permanent deformation), carried out using different materials, a set of numerical simulations were made for the design of pavement structures where those mixtures would be used, according to their characteristics and traffic specifications. The results of pavement design were obtained using the linear elastic theory in the BISAR program.

With the results obtained from the pavement design, the cost savings of using recycled materials in the different pavement structures were quantified and compared to a standard option, where new natural aggregates and binders would be used. In this analysis, the consideration of the reduction in the disposal of reclaimed pavement materials was also addressed.

The results of this research will support the production of specifications, thus facilitating a more accurate reuse of natural resources, assisting in the protection of the environment, as well as in a more effective use of financial resources available for the activity of pavement maintenance and rehabilitation.

Key words: Flexible pavement; Recycling alternatives; Mechanical characterisation; Pavement design; Economical evaluation.

1. Introduction

A road pavement has to be designed to guarantee an adequate response to the increase in the severity of the traffic loads. In addition to that, pavements have to offer a good surface quality, responding to the demands of comfort and safety.

However, even when well designed, road pavements reach a phase, at a certain point of their life, where their general condition demands the rehabilitation of theirs structural and functional quality.

The rehabilitation could be undertaken, as usual, through an overlay, with one or several layers (bituminous in general), or through the reutilisation of the existing pavement materials, eventually with an improvement of their characteristics, the case when pavement recycling takes place.

Pavement recycling is becoming an increasingly important alternative worldwide for the maintenance of highways, once sustainability and environmental issues have continued to receive more attention. The reference point is that of considering *the use of road materials in a closed cycle*, in which a natural material, previously used in road construction, should not be rejected in the following life-cycle.

Existing deteriorated material can be reused; its characteristics can be rehabilitated, recycled and improved. The old material can be used in the same application that it was initially used for, or as part of a new material (Fernandez del Campo, 2003).

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Essentially, the advantages of pavement recycling are the following hereafter highlighted, both in terms of the environment and technology.

- Environment:
  - reduction of material consumption (binder and aggregates);
  - reduction of the formation of the landfill of reclaimed materials;
  - reduction of the transport of materials, mainly aggregates (since it less new material is used).
- Technology:
  - control of the final level of the pavement;
  - correction of the longitudinal and transversal profile;
  - Elimination of cracking or the reduction of this problem;
  - lower global costs.

However, there are some limitations in the recycling techniques, which should be mentioned.

- Environment:
  - activity with some production of local pollution.
- Technology:
  - quality of the material to be recycled (existing binder and aggregate);
  - limitation of the final thickness, in certain cases;
  - mechanical characteristics of the recycled material.

The objective of this paper is that of analysing the technical-economic value of different flexible pavement recycling alternative techniques, including hot-mix recycling in plant, incorporating reclaimed material from flexible pavements and in place cold recycling with emulsion.

In order to compare the different alternatives, two case studies were considered: C1, where the existing pavement of high bituminous thickness, presents top down cracking with the depth of approximately 10 cm, being submitted to a medium-high traffic; C2, which pavement structure have the two bituminous upper layers totally cracked, and submitted to a low traffic.

The rehabilitation of pavement C1 will be done by considering two options: (i) a standard hot mix technique replacing a certain milled thickness of the upper layers; (ii) a hot mixture with the incorporation of reclaimed material from the existing upper bituminous layers.

For the rehabilitation of the structure C2 two options were considered: (i) a standard hot mix replacing the two cracked bituminous layers; (ii) a cold mix with bituminous emulsion, using the reclaimed material from the existing pavement.

Based on the results obtained from field and laboratory tests (stiffness modulus, resistance to fatigue and permanent deformation), carried out using the different materials, a set of numerical simulations were made for the design pavement alternative structures, where those mixtures would be used, according to their characteristics and traffic specifications. The results of pavement design were obtained using the linear elastic theory in the BISAR program.

With the results obtained from the pavement design, the cost savings of using recycled materials in the different recycling alternatives were quantified and compared to the standard option ("the reference structure"), where new natural aggregates and binders would be used. In this analysis, the consideration of the reduction in the disposal of reclaimed pavement materials was also addressed. The environmental benefits of the recycled mixture are obvious; since they reduce the need for new materials and, simultaneously that of the amount of waste materials to be disposed.

The results of this type of research will support the production of specifications, thus facilitating a more accurate reuse of natural resources, assisting in the protection of the environment, as well as in a more effective use of financial resources available for the activity of pavement maintenance and rehabilitation.

2. Alternative Recycling Techniques: Technical Evaluation

Since the alternative rehabilitation techniques have been previously defined, in this section each recycling technique is characterised in order to define its mechanical characteristics which are to be used in the design of the alternative pavement structures.

Each material, related to the different recycling alternative techniques, was obtained from the milling of the upper layers of the pavement. Firstly, the respective composition was established. Subsequently, afterwards, the physical and mechanical characterisation of each material was undertaken.

For each recycling technique, and to further support economic evaluation, the percentage of reclaimed material incorporated in the new mixture was also evaluated. Additionally to the consideration of hot recycling and emulsion techniques as rehabilitation alternatives, the cold recycling with cement is also present in this section to analyse its possibilities in future applications.

2.1. Cold Recycling with Emulsion

In Portugal, 1.900.000 m^2 of pavement recycling has already been undertaken (Martinho et al, 2004), 43% of which using the cold technique with bituminous emulsion. Despite the fact that this percentage is rather modest when compared with other European countries, there has been a significant increase in this type of pavement rehabilitation alternative in Portugal over the recent years

Cold recycling, which can be undertaken in place or at plant, aims to produce new bituminous mixtures: (i) from existing milled bituminous layers; (ii) through the mixture of the latter with existing granular layers, using a bituminous emulsion as a binder (2 to 3% in weight of residual bitumen in the first case, or 3 to 5% in the second option). In addition to these materials, the addition of new aggregates should be considered, as a function of the final quality required for the new mixture. In general, this technique is adopted in place, with the objective of improving the quality of existing materials in a thickness close to 12 cm, with a maximum of 15 cm, in this case under strictly controlled conditions.

The above mentioned thickness limitation ensures the rupture of the emulsion (separation of the water and bitumen phases, allowing the bitumen to assume its role as a binder). This rupture is chemically controlled in certain cases (cationic emulsion, with an acid emulsifier). However, this process always requires adequate conditions – the greater the thickness, the more difficult the transmission of the energy of compaction in depth. Environment heat also influences the rupture of the emulsion. Good drainage of the water constituent of the emulsion is essential, too. All these conditions can not be easily met when there is a thick layer.

Once the new layer is constructed, especial attention needs to be given to the right moment to open the road to traffic. This can only be done once the process of emulsion cure is complete. Water from the initial emulsion must disappear through evaporation and drainage, when the resistance of the layer stabilises.

The maturation process could occur over a long period (several weeks to two months, and even over six months to two years (Batista, 2004).

In order to improve the recycled layer behaviour from this point of view, with the objective of obtaining higher resistance in a short period of time, the cold recycling technique with emulsion can be aided by the addition of cement.

This technique is preferably adequate to the rehabilitation of an extremely damaged pavement, where the bituminous layers (in general of reduced thickness) and a few centimetres of the upper granular layer are involved in the recycling process, constituting a partially binded sub-base layer. The pavement rehabilitation in this situation is concluded with new bituminous layers, whose number and thickness are function of the traffic design.

Another use of this technique is that of the rehabilitation of the pavement at its middle life period (under 10 years), with surface cracking (from 5 to 10 cm in depth), with higher bituminous thickness (serving substantial traffic). In this case, after the cold emulsion recycling of those cracked upper bituminous layers, the rehabilitation process is completed with a wearing course of a conventional bituminous mixture.

For the establishment of structural pavement models with cold mixtures, recycled or not, in relation to different stiffness modulus and criteria design two analyse phases should be considered.

Concerning the layer stiffness modulus (measured through diametrical compression tests, considering a reference temperature of 20ºC (Batista, 2004), values obtained are systematically under 1000 MPa. Four months after the compaction phase, considering the completion of the cure phase, the modulus values are in the range of 2000 and 3000 MPa. The addition of cement, with the aim of improving control of the cure process, is responsible for higher values of the modulus.

Relating to temperature influence (Batista, 2004), it could be considered that when the reference temperature of 20ºC is adopted the evolution of the curve representing the moduli variation is similar to that observed in hot bituminous mixtures.

Concerning fatigue behaviour (Batista, 2004) it can be stated that, apart from the initial cure period (at least two months, as emphasised previously), it could be assumed that there will be a similar behaviour to that of the conventional hot bituminous mixtures.

Permanent deformation and fatigue behaviour, excluding the initial cure period, in this type of mixture is also similar to that of hot bituminous mixtures, as was demonstrated in recent research (Batista, 2004), where two different types of material were compared through uniaxial compression tests.

In conclusion, from the mechanical behaviour perspective, it could be assumed that cold recycled mixtures with emulsion are well represented by the fatigue laws usually used in the empirical-mechanical design adopted for flexible pavements. It is only necessary to adjust the modulus variation law with temperature, as suggested before, considering the law obtained for hot mixtures for 20ºC, where a modulus of 2000 MPa could usually be considered.

2.2. Cold Recycling with Cement

Cold recycling with cement is a rehabilitation technique essentially aimed at the structural improvement of pavement quality, especially when this is constituted by reduced thickness of bituminous layers and a significant thickness of granular layers, in general with low to medium traffic volume.

The preferable construction method is that of recycling in place, essentially due to the speed of the cure process, once cement is added to the deteriorated material from the existing pavement.

This recycling technique is, in general, composed of the mixture of the milled material with 6% of cement, with the resulting mixture used in the base layer, thus constituting a valuable economic alternative to the use of granular material (Taha, 2003), simultaneously solving the disposal of the milled material from an existing deteriorated pavement.

The value to be adopted for the stiffness modulus of the recycled material is dependent on several factors: (i) the quality and variability of materials available; (ii) the quality of the construction equipment; (iii) the percentage of cement. For pavement design, values in a range of between 8000 and 16000 MPa were adopted.

In a pavement recycling alternative adopted for a real pavement (Moreira, 2005), the best results were obtained with a mixture of 70% of reclaimed material with the addition of 30% of granite dust (the 70/30 mixture), using 6% of cement as a binder. The addition of the granite dust, acting as an aggregate corrector, allows the fine part of the aggregate to mix with the binder, the cement. With the mixture 100/0 (no addition of granite dust) discontinuities are created in the structure of the material due to the lack of the fine binder formed with dust mixed with the cement.

Figure 1 shows the evolution of the indirect tensile stress for the mixture 100/0 with the percentage of cement, considering different cure periods.

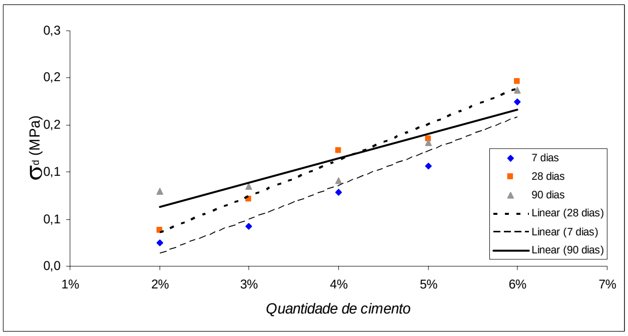

Figure 1. Indirect tensile stress for the mixture 100/0

Figure 2 shows a similar behaviour for the mixture 70/30, where there is clearly a better performance of this mixture when compared with that of the mixture 100/0.

For a cement treated pavement base, the Portuguese Manual Pavement Design requires 2.5 MPa for the compression stress (σ_c) and 0.3 MPa for the indirect tensile stress (σ_d), which imply the use of the mixture 70/30 with 6% of cement and an optimum water ratio of 7%, determined with the Modified Proctor procedure.

The behaviour of the strength of the mixture over time shows clearly the influence of the cure process, such as in any soil and granular material stabilised with cement.

The behaviour of the indirect tensile stress is close to that of the simple compression stress.

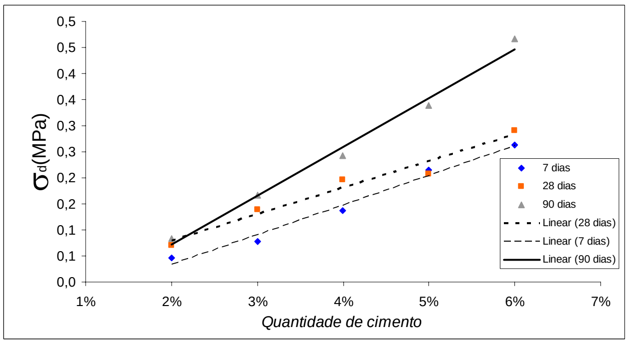

Figure 2. Indirect tensile stress for the mixture 70/30

In the case of the mixture 100/0, it is demonstrated that values of indirect tensile stress, at 90 days, are inferior to those measured at 28 days, and this for 4% of cement. Mixture 70/30 between 7 and 28 days reveals a clear increase in the values of indirect tensile stress, higher than that observed in the mixture 100/0 (Moreira, 2005).

2.3. Hot Recycling with Bitumen

Bituminous mixtures obtained from hot recycling of flexible pavements can perform as well as new hot mixtures, provided that recycled materials are correctly characterised and the final mixture is adequately designed.

Potter and Mercer (1997) carried out a study including several trials on public roads and full-scale accelerated load testing facilities. They have evaluated the performance of recycled materials used in the construction of sections of these trials. One of the main conclusions of the study was that the performance of the recycled materials was as good as that of equivalent conventional materials.

Other research, carried out by Servas et al. (1987), included the evaluation of hot bituminous mixtures after the incorporation of reclaimed material in different percentages (0, 30, 50 and 70%). In that study no clear correlation was found between the percentages of recycled material and the properties of the resulting mixture. Therefore, given an adequate mix design, the amount of recycled material to be included depends upon other factors, related to the material itself, the type of plant and even economic and ecological policies.

In the framework of experimental research (developed for a motorway concessionary, aiming at the development of the complete characterisation of the hot recycling in plant technology (Batista, et al., 2004; Picado-Santos & Batista, 2004), the final quality evaluation of the hot mixture produced in plant with the incorporation of 30 and 40% of reclaimed material was undertaken. The reclaimed material came from a relatively young pavement (9 years) and was used with pre-heating at production; the recycled material was used in a base layer of a pavement design for heavy traffic.

The existing results were obtained through the comparison of the mixture properties, incorporating reclaimed material, with those of a traditional mixture for a base course, using tests related to mixture performance.
Figure 3 shows the result of the stiffness modulus, obtained in a four-point bending test, with strain control, for three sinusoidal frequencies (1, 5, 10 Hz), considering three temperatures (15ºC (Mod15); 25ºC (Mod25); 40ºC (Mod40). This temperature spectrum is a good representation of the temperatures observed in these mixtures, in Portugal.

As can be observed, the mixtures which incorporate reclaimed material present better characteristics than the traditional mixture. This situation is the result of a more rigid final bitumen of the recycled mixtures, due to the fact that material reclaimed from the existing pavement is already more rigid than the same material of a new mixture.

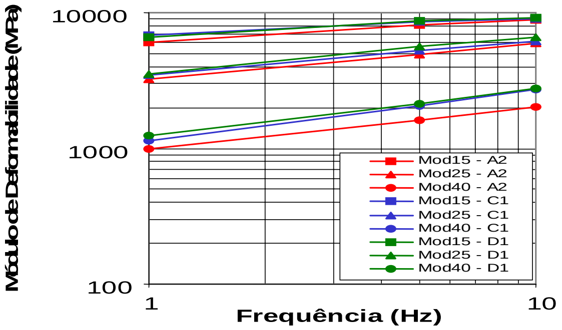

Figure 3. Stiffness Modulus: reference (A2); mixture with 30% of reclaimed material (C1); mixture with 40%

Figure 4 shows the result of the fatigue behaviour of the different mixtures, considering the temperature of 25ºC, as being representative of Portuguese conditions (Picado-Santos & Batista, 2004).

As can be seen, mixtures with incorporation of reclaimed material present closer or better characteristics when compared with the behaviour of a conventional new mixture.

In the case of 40% of reclaimed material (D1), results are even better, although as the result of a higher amount of final bitumen.

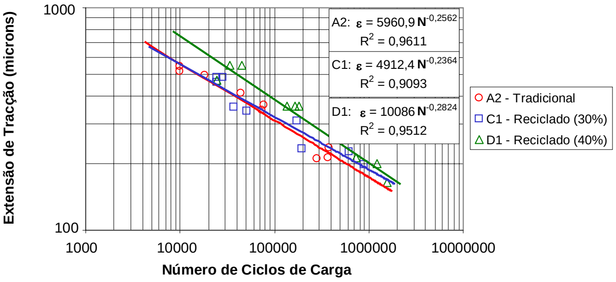

Figure 4. Fatigue laws: mixture A2 (reference), C1 (30 %) and D1 (40 %)

Figure 5 shows the resistance at permanent deformation of each mixture, obtained in "Wheel Tracking", where the load is applied during 45 minutes, under the conditions of the European pre-standard.

Regarding the resistance to permanent deformation, these results reveal that the mixtures with reclaimed material present better performance (2.5 more resistant) than a new conventional bituminous mixture.

These results allow one to conclude that bituminous mixtures produced in plant, incorporating reclaimed material, with the pre-heating of the latter, perform as well as, at least, a new conventional bituminous mixture.

Relating to the empirical-mechanical design of a flexible pavement, integrating hot recycled bituminous layers, it is sustainable at this point of the research to use the same characteristics of a new bituminous mixtures (stiffness modulus, fatigue and permanent deformation resistance), once the characteristics of the recycled material are, in general, better than the new one.

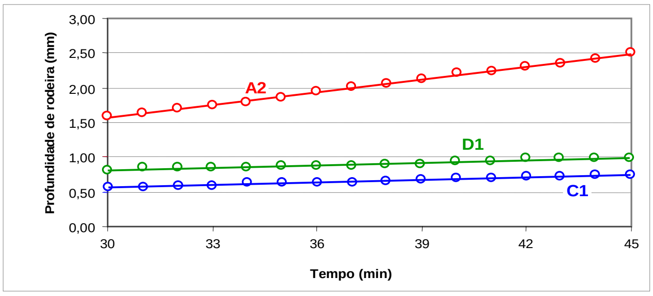

Figure 5. Permanent deformation behaviour from the Laboratory Traffic Simulator

Finally, it should be noted, as was shown in the first phase of research (Batista, et al, 2004), that the incorporation of 40% of reclaimed material is only possible when the place for the application of the mixtures is close to the plant of production (not further than 10 km), once the viscosity of the final bitumen could increase quickly, making the compaction of the mixture difficult, or even impossible.

3. Rehabilitation Design and Economical-Environmental Evaluation

3.1. Introduction

In this section, two of the main pavement recycling alternatives adopted in Portugal are analysed through their consideration in two pavement structures, C1 and C2.

The main objective of the study is that of evaluating the economical feasibility of these two recycling alternatives; hot recycling in plant and cold recycling in place with emulsion, although with the consideration of the environmental issues at hand.

Case C1 presents the following characteristics:

- Pavement with the structure presented in Figure 6, with a 5 cm wearing course of bituminous mixture (0/16), a layer of bituminous macadam (0/25) with a total thickness of 23 cm, and a granular sub-base (0/50) of 20 cm;
- The traffic design for the initial life period of 20 years was computed as being 40x10^6 ESALS (80 kN);
- At present, the pavement is 7 years old;
- The deterioration observed is that of top-down cracking with a depth of 10 cm. Concerning the granular sub-base this presents a good condition as well as the subgrade, where an equivalent stiffness modulus of 60 MPa could be considered;
- The pavement to be rehabilitated is 10 km in length with two lanes of 8.0 metres in width; this rehabilitation will cover a total surface of 160,000 m^2.

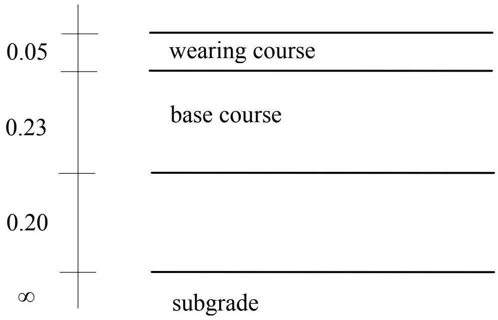

Figure 6. Pavement structure of case C1

The pavement of case study C2 presents the following characteristics:

- Structure with the composition presented in Figure 7, with a bituminous wearing course of 5 cm (0/16), a base layer of bituminous macadam (0/25), with the thickness of 7 cm, a granular base course (0/40) of 20 cm and a granular sub-base (0/50) with the thickness of 20 cm;
- The initial traffic design calculated for this pavement was of $2x10^6$ ESALS (80 kN);
- At present, the pavement is 12 years old;
- This pavement presents a highly deteriorated condition in all layers, requiring intervention at the level of reconstruction;
- From "in situ" evaluation of the condition of the pavement, and for the subgrade, an equivalent stiffness modulus of 60 MPa could be assumed.

In terms of rehabilitation, this will be designed for a 10-year life period, with the traffic design of $1,5x10^6$ ESALS (80 kN). The total length of the road to be reconstructed is 10 km, with one lane of 8.0 m in width, resulting in an intervention of 80,000 m^2.

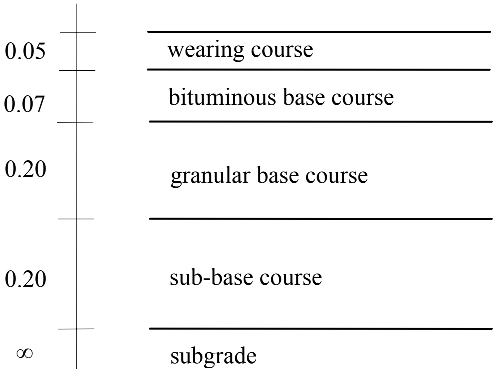

Figure 7. Pavement structure of case C2

3.2. Case Study C1

In general, a pavement in this condition would be rehabilitated considering these three phases: (i) firstly milling the cracked bituminous thickness (in this case, 10 cm); (ii) the reclaimed material being transported to a landfill; (ii) the construction of a conventional overlay with one or two hot bituminous layers.

At this phase of the design analysis, the rehabilitation traffic design is considered as the "residual traffic" to be supported by the pavement structure, which is considered to be proportional to the remaining 13 years: $13/20x40x10^6$ ESALS(80kN)=$26x10^6$.

After milling the upper 10 cm of cracked bituminous layers, the initial structure still possesses 18 cm of bituminous mixtures. Considering the age of the structure, these 18 cm are considered to have a "residual structural value" equivalent to the age, that is 18x13/20=11.7 cm. Thus, the existing pavement, at the age of 13 years, is constituted of a bituminous thickness of 11.7 cm, over the initial granular composition and subgrade.

In a first option, a traditional rehabilitation design, considering the existing granular sub-base as well as the initial subgrade characteristics, using the Shell design method (Claessen, 1977), was adopted. In these conditions, the conditional design criterion was that of permanent deformation, requiring the placing of 27 cm of new bituminous mixtures (Table 1). Table 2 presents the volumetric characteristics of the new bituminous layers.

Table 1. C1: final thickness and mechanical characteristics

Layers	Thickness (cm)	E (MPa)	ν
Wearing Course	5,0	3570	0.35
Base Course	22,0	3660	0.35
Sub-base course	20,0	120	0.30
Subgrade	-	60	0.35

Table 2. C1: volumetric characteristics of the bituminous layers

Characteristics	Wearing Course	Base Course
bitumen content by volume (%)	11.4	9.0
voids in mixed aggregate (%)	15.3	16.0
aggregate content by volume (%)	84.7	84.0
voids content (%)	3.9	7.0

In this option, and considering that the existing pavement has a remaining bituminous layer of 18 cm, equivalent to 11.7 cm of new mixture, the required overlay, made of new bituminous mixtures, will have a thickness of 15.3 cm (27.0-11.7). Considering an overlay of 16 cm, this could be composed of 5 cm for the wearing course, plus a bituminous binder course of 11 cm, placed over the remaining 18 cm of the existing bituminous mixture.

From the economical point of view, and considering the cost of mixtures in Portugal, this rehabilitation option will have the total cost of: (5 cm x €1/m^2/cm + 11 cm x € 0.7/m^2/cm) x 160,000 m^2 = €2,032,000.

This cost does not takes into consideration the economic-environmental cost of milling the existing 10 cm, its transport and the cost of its deposit in a landfill. On average, the total cost is closer to €20/m^3. In this case, considering the volume of 16,000 m^3, the total cost would be of €320,000.

As stated in the previous section 2.3, hot recycled bituminous mixtures present characteristics similar to those obtained with new mixtures, and in certain conditions even reveal higher performance.

Thus, the recycling alternative technique will comprise the use of the reclaimed material from the existing pavement to be incorporated in the bituminous macadam (0/25), the latter presenting the thickness of 14 cm. The remaining 2 cm (to complete the required 16 cm, previously calculated) will be filled with a new wearing course of micro-concrete asphalt.

From the technological point of view, the experimental research undertaken allows one to add a percentage of 40% of reclaimed material into the new alternative mixture. In economic terms, only the cost of the recycled mixture will be considered, without taking into account the reduction in the material to be transported and deposit in a landfill.

The incorporation of 40% of reclaimed material, in terms of bitumen and aggregates, leads to a savings of approximately the same amount as in the new mixtures (Oliveira, et al, 2005). In Portugal the distribution of cost of a bituminous mixture per square metre could be considered as follows: bitumen (60%), aggregates (15%); production (25%). Thus, the reduction, using the recycled mixture is 24% (0.4 x 60%) in terms of bitumen and 6% (0.4 x 15%) related to aggregates. In this way, a bituminous macadam with 40% added reclaimed material, instead of €0.7/m^2/cm, will cost 0.49€/m^2/cm (0.7(100% - (24+6)%) x 0.7)).

Considering this costs, the total cost for this recycling alternative with 40% of reclaimed material is: (2cm x €1.1/m^2/cm + 14 cm x € 0.49/m^2/cm) x 160,000 m^2 = €1,449,600.

The recycling alternative, compared to the traditional rehabilitation alternative, presents a total savings close to 30%(100 x (1 - €1,449,600 / €2,032,000))

3.3. Case Study C2

The structure of this pavement presents a high degree of deterioration. Thus, it is assumed that all the layers have a value corresponding to 50% of a well graded granular. Therefore, the existing pavement corresponds to a thickness of 26 cm.

Adopting the procedure for the pavement design used in section 3.2, and adopting the same characteristics for the different bituminous layers, the results presented in the Table 3 were obtained for the conventional option of rehabilitation.

Table 3. C2: conventional rehabilitation design: thickness and mechanical characteristics

Layers	Thickness (cm)	E (MPa)	ν
Wearing Course	5.0	3570	0.35
Base Course	10.0	3660	0.35
Sub-base course	26.0 (52.0/2)	150	0.30
Subgrade	-	60	0.35

In order to prevent possible crack propagation from the existing bituminous layers, a SAMI (stress absorbing membrane interlayer) should also be considered (with the cost of 1.0€/m^2).

Using this data, the total cost of this rehabilitation alternative is the following: (5cm x €1/m^2/cm + 10 cm x €0.7/m^2/cm + € 1.0/m^2) x 80,000 m^2 = €1,040,000

The recycling alternative considered in this case is constituted of a cold recycled layer with emulsion (3% of residual bitumen), with the thickness of 15 cm. The mechanical behaviour is that presented in section 2.2. In this way, its modulus, considering the reference modulus of 2000 MPa at 20ºC, will be 1400 MPa at 25ºC, assuming the same evolution as that of hot bituminous macadam, given by the expression of Shell (Claessen, 1977) for the temperature between 20ºC and 25ºC.

Table 4 presents the results of the pavement design for this alternative. In this case the existing granular sub-base will provide 15 cm to the new cold recycled layer, ending up with the equivalent thickness of 18.5 cm.

Table 4. C2: rehabilitation with cold recycling: thickness and mechanical characteristics

Layers	Thickness (cm)	E (MPa)	ν
Wearing Course	5.0	3570	0.35
Recycled Base Course	15.0	1400	0.35
Sub-base course	18.5 ((52.0-15.0)/2)	120	0.30
Foundation	-	60	0.35

In this case, the SAMI layer is not considered since the new recycled layer eliminates the upper 15 cm of cracked bituminous layer.

The total cost of this alternative, using a cold emulsion layer with the thickness of 15 cm, at the cost of €3/m^2, is: (5cm x €1/m^2/cm + € 3/m^2) x 80,000 m^2 = €640,000.

In this case the savings obtained using the recycled alternative is close to 40% (100 x (1 - €640,000.00 / €1,040,000)).

This type of alternative, when the conditions of production and, especially, the construction conditions follow the required recommendations, is a worthwhile solution, once eliminate the problem of cracking propagation from the existing pavement through the new bituminous layers.

4. Conclusions

At present, and for the future, the main concern of any road administration will be that of guaranteeing a sustainable quality of the constructed road network, both from the structural and functional point of view, where the environmental impact of any technological solution will need to be increasingly evaluated.

In this context, pavement rehabilitation alternatives, which considers the reuse and recycling of materials, play a decisive role, when compared to the traditional strategy of placing a new overlay, they lead to a clear savings in terms of the technical-economical-environmental impact, for the road administration, users in particular and society in general.

Today, several recycling alternatives could be considered in any rehabilitation design. Among these, hot mixture in plant, in place cold emulsion mixture and in place cold cement mixture, are well known and have been adopted.

Thus, the most sustainable policy should be the recycling in place of deteriorated pavements, as well as the reuse of reclaimed materials, from pavements and other origins, in new pavement mixtures.

This paper dealt with the analysis of the technical-economical-environmental value of two recycling alternatives: hot mixture in plant and in place cold emulsion mixture. They were analysed, using as reference a traditional solution, where an overlay made up of one or several bituminous mixtures layers is considered.

Concerning recycling material alternatives, their physical and mechanical characteristics were previously obtained in laboratorial and in place studies. For the reuse of reclaimed material from an existing pavement, it was concluded that a percentage of at least 40% is feasible which represents an important savings from both the economical and environmental point of view.

The pavement design undertaken for the different alternatives in the two cases studies, C1 and C2, allows one to conclude that it is possible to obtain a reduction of between 30% and 40%, in the total cost of the rehabilitation, when compared to the traditional solution of placing an overlay.

In terms of future research work, the test trials under real traffic conditions, where those recycling alternatives were constructed, will be followed by monitoring their structural and functional performance evolution. With the results from this research project, in the next few years, it will be possible to improve the reliability of the rehabilitation pavement design, as well as provide guidelines for the technological point of view.

In addition to the monitoring of the pavement trials, the research in this field will be supported by pavement trials with alternatives recycling solutions constructed and followed in a new Accelerated Load Facility, jointly managed by the University of Minho an the University of Coimbra, in Portugal.

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