Analysis of the cold recycling asphalt pavements method from Romania

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Abstract. The present paper presents a documentation on the realization of the dosages from recycled mixtures, highlighting the change in the test methods regarding the composition and the determination of the physical-mechanical characteristics according to the latest technical regulations. Practically, the structure of the new norm for cold recycled road materials aligns with the new European requirements in accordance with the provisions that the mixtures must meet, but still the problem remains on how to prepare the samples in the laboratory and determine the value of the stiffness modulus of the considered mixture, value which practically in the norm is considered based on good practice. Determining the real value of the stiffness modulus is a decisive factor in the dimensioning of the road structure reinforcement because it can considerably influence the thickness of the layers that make up the resistance structure. Therefore, the paper presents a study on the new methods of making samples in the laboratory and values of the stiffness modulus taken into account when dimensioning the reinforcement of road structures according to the composition of the considered materials.

1 Introduction

The layers of road structures at their upper level, asphalt pavement, deteriorate and deform progressively due to the exceeding of the strength of the used materials and the bearing capacity under heavy traffic. Therefore, technologies to save and re-use existing resources are more sought after than ever [1].

Recycling of asphalt mixtures is a process of producing new road pavements by using the materials from the existing asphalt layers, which after exceeding their service life are re-used or recycled according to specific technologies. In Romania these technologies are presented in the Romanian Norm AND 532 "Standard for cold recycling of road pavements" [2]. Recycling processes have arisen as a result of the need to reuse materials, which became more pronounced in the 1970s and 1980s with the sharp rise in oil product prices.

Recycling technologies are considered more advantageous due to:
- economy of materials and fuel economy;
- speed of execution;
- homogenisation of heterogeneous layers.

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Most importantly, the reused raw material does not need to be dried or heated, which means that compared to conventional recycling methods it produces a fuel saving, cold recycling also allows the use of binders to be reduced by up to 50% - the area of greatest potential savings, as binders are still the biggest cost factor in road rehabilitation [3]. With cold recycling technology, the material removed from the road surface is immediately recycled and reused, the logistics for this procedure are minimal and the duration of construction sites where cold recycling "in situ" is envisaged is considerably shorter than for conventional road rehabilitation projects.

Cold recycling of asphalt pavements can be of several types:
- recycling with bituminous emulsion and hydraulic road binders for the execution of base, subbase or binder courses, a technical solution recommended when applying recycling of degraded asphalt mix road layers;
- recycling with foamed bitumen, hydraulic road binders for the execution of foundation and base layers, a technical solution that can be recommended both for the recycling of degraded asphalt mix road layers and for the recycling of layers stabilised with hydraulic binders or mechanically stabilised;
- recycling based only on hydraulic road binders for the execution of foundation or base layers, technical solution recommended when applying recycling on degraded asphalt mix road layers.

Is important to mention that, according to the European Asphalt Pavement Association (EAPA) report from 2022, the total production of Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) in 2021 was approximately 221 million tonnes, for the EU-27 countries. For the same year, the total production of HMA and WMA in the USA was 392 million tonnes [4].

On the other hand, based on the same report, for the EU-27 countries, 72% of the Reclaimed Asphalt Pavement (RAP) was re-used, 25% was recycled and only 3% of RAP was put to landfill [4].

As an example, Table 1 shows how the reclaimed asphalt pavement was used in different countries in 2020.

<table>
<thead>
<tr>
<th>Country</th>
<th>Total amount of site-won asphalt generated in 2020 in tonnes</th>
<th>H.M.A. Production</th>
<th>On-Site Cold Recycling</th>
<th>Plant Cold Recycling</th>
<th>Unbound Road Layers</th>
<th>Other Civil Engineering Applications</th>
<th>Put to Landfill /Other Applications/Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Republic</td>
<td>2 700 000</td>
<td>15</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>Germany</td>
<td>13 800 000</td>
<td>84</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hungary</td>
<td>200 000</td>
<td>95</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Romania</td>
<td>10 425</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Slovakia</td>
<td>no data</td>
<td>53</td>
<td>30</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Slovenia</td>
<td>no data</td>
<td>29</td>
<td>10</td>
<td>1</td>
<td>25</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>USA</td>
<td>87 000 000</td>
<td>93</td>
<td>0</td>
<td>0.4</td>
<td>6.2</td>
<td>0.3</td>
<td>0</td>
</tr>
</tbody>
</table>

As it can be observed, in 2020, in Romania the total amount of site-won asphalt was re-used by applying the site cold recycling technology. The same recycling technology was used in other countries Czech Republic, Slovakia and Slovenia, but the percentages were much lower. A different strategy of reusing the RAP material was applied in other countries Germany, Hungary or USA in which these materials were re-used in the production on new bituminous mixtures.
On the other side, in must be remarked that the site cold recycling technology generally used in comparison with the plant cold recycling,

2 Technologies applied for asphalt recycling

The technology applied in the asphalt recycling industry is not related to the construction of the road complex, but to the reconstruction or maintenance of the road structure, with the aim of improving the bearing capacity and technical condition of the road surface and its adaptation to the increasing traffic.

Cold "in situ" recycling is carried out with the so-called "recycling train" consisting of specific machines. These machines can be on tires or on tracks with a vibrating beam that also pre-compact the recycled layer. At the same time, these machines also mill the asphalt layers, crumble the resulting material, dose the binders and water, and lay the resulting material. The machines are equipped with electronic systems to control dosage, temperatures and working parameters.

The recycled mix is distributed by the spreading beam in front of the spreading beam finisher (for machines with mixer), levelling system located behind the recycling machine. After distribution of the recycled mixture, pre-compaction is carried out with the finishing beam or compacting roller. Water is also important in order to achieve optimum moisture content. The last stage, levelling, is carried out with vibro-compactor rollers (sheep's foot, with smooth roller and on tires) and the self-grader required to shape the road surface according to the dimensions in the technical design. The recycling train can fit into the width of a single lane of traffic; on two-lane roads, vehicle traffic can alternate on the remaining available lane. On roads with two lanes in each direction, traffic is carried out continuously in the lane where rehabilitation works are not being carried out (parallel to the construction site), Fig. 1.

![Fig. 1. Recycling train used for foamed bitumen or bitumen emulsion [6], where: 1- Hydraulic binder - cement distributor (if applicable); 2 - Water tank; 3- Tank for bitumen emulsion or bitumen; 4- Recycler; 5- Mixed compactor; 6- Autograder; 7- Tandem compactor; 8- Pneumatic roller.](image)

The asphalt recycler, Fig. 2, uses the milling and mixing cutter, Fig. 3 (a), to granulate damaged asphalt pavement layers, simultaneously mixing and injecting water and bitumen emulsion into the mixing chamber. Milling cutters used for recycling pavement layers have a higher number of teeth than those used for stabilizing earth half or one-third more. For recycling, cutters with helically arranged teeth are used, Fig. 3 (b), while for soil stabilization they are straight or L-shaped.
The first step in a correct approach to cold recycling is to carry out preliminary studies (field and laboratory), which consists of determining the optimal technical recycling solution based on the following factors: layer thickness, granular input material and composition of the recycled mixture. The actual site situation and local climatic conditions will also be taken into account.

At the same time, it is necessary to assess the road structure in order to determine its failures, after which a measurement of the bearing capacity along the entire length of the sector is carried out, usually with Benkelman lever or dynamic load deflectometers, followed by the sampling of cores from the road structure [8]. The coring is necessary to determine the thickness of the road surface and the materials from which it is made, the level of the capping layer and the drainage conditions of the road structure. Surveys shall be carried out, minimum 4 per km, alternately (both lanes). The minimum number of samples taken is 3 per 500 m of road.

In particular, for on-site recycling with bituminous binders, the homogeneity of the road structure in transverse and longitudinal profile should be determined by sampling evenly distributed in longitudinal profile on each traffic lane (middle and edges of the traffic lanes).

Information provided:
- determination of the technical condition of the road;
- to determine the suitability of cold recycling technology:
  - maximum aggregate grain size (both bituminous layers and base/foundation layer), which must be less than 100 mm;
- for determining the milling depth:
  - thickness and number of bituminous layers;
  - the thickness of the base and subbase layers;
- for determining the type and quantity (in percentages) of natural aggregates and the binder content to be added:
  - grain size of the milled material.

According to French standards, it is recommended that the material obtained by milling should have a maximum grain size of 31.5 mm (99% passing through the 50 mm sieve) and that the passing through the 2.0 mm sieve should be 25-35% and through the 0.06 mm sieve 4-8%.

This solution of creating the sample for laboratory testing is the optimum one as it results in obtaining a grain size of the milled material identical to the one obtained during the application of the technology, while respecting the milling feed rate in both cases. On the other hand, the proportion of coarse elements, slabs, etc. resulting from milling and to be removed from the mix (usually manually) and other parameters related to the milling technology can be determined.

3 Laboratory determination

In order to determine the final mix, the following laboratory determinations shall be carried out in order to obtain the physical and mechanical characteristics in accordance with the specifications of the technical standards:
- drying the milled material in oven at a temperature of 50-60 °C;
- visual determination of the composition of the milled material (aggregate type, binder type, etc.);
- determining the grain size of the milled material;
- determination of the binder content of the milled material;
- determination of the softening point of the bitumen recovered from the milled material;
- determination of the miscibility of the bituminous emulsion with the water-cement slurry;
- determination of the grain size and the proportion of aggregate to be added to bring the mixture within the grain size range indicated by AND 532 for the layer to be produced;
- determination of the composition of the aggregate and binder mixture (quantity of bitumen emulsion or foamed bitumen required, depending on the bitumen content obtained);
- determination of the compaction characteristics.

It is necessary to check the results obtained against the recommended values, to check the results obtained in the laboratory with those obtained on an experimental section (to be carried out before the start of the construction site in order to make final corrections to the final dosages and working technology).

With the help of integrated binders, the recycled material achieves the mechanical performance required to ensure structural contribution and durability. The use of the hydraulic binder aims to ensure immediate strength during curing. It produces structural
reinforcement and improves the mechanical properties of the mix. The resulting material, obtained in combination with cement, achieves a remarkable cohesion after only 3 days of production, i.e. excellent behaviour under heavy traffic and especially under winding.

The compatibility of the bituminous emulsion with the water-cement slurry is determined by the following procedure:
- mix 100 g of cement with 50 g of water in a glass vessel until a homogeneous water-cement suspension is obtained;
- 100 g of bitumen emulsion is placed in another glass vessel;
- mix the water-cement suspension with the bitumen emulsion for 6 minutes;
- determine the breaking time of the bitumen emulsion.

The breaking time of the bitumen emulsion is at least 10 minutes. If the breaking time is less than 10 minutes, the determination shall be repeated with another type of emulsion.

The mineral skeleton is composed of:
- the material obtained by milling existing degraded road layers;
- where appropriate, filler aggregates.

To determine the final composition of the mixture, the grain size curve shall be monitored to ensure that it falls within the limits of a base course. If necessary, the grading curve shall be corrected with granular filler material using the following or a combination of grading classes, i.e.: crushed quarry aggregates: 4 - 8 mm, 8 - 16 mm, 16 - 22.4 mm and 22.4 - 31.5 mm, sand 0 - 2 mm or 0 - 4 mm mix, or crushed quarry sand.

The recommended limits for the optimum binder content of recycled road surfacing are mandatory, as follows:
- the cationic slow-break bituminous emulsion must correspond to ensuring a content of 2.0 - 4.0% residual bitumen in the total mass of the recycled mix;
- foamed bitumen in the proportion of 2.5 - 4.5% of the total mass of the recycled mixture.

The optimum hydraulic binder content shall be determined by preliminary laboratory studies as follows: maximum 2% by mass of dry mix in the case of recycled mix with bituminous emulsion and maximum 3% by mass of dry mix in the case of recycled mix with foamed bitumen.

The reclaimed binder should act as a lubricant, with the caveat that adding it in high proportions may compromise the stability of the new bituminous layer or cause exudation of the wearing surface (if it is a wearing course).

Regeneration of binder in old bituminous layers is necessary because over time, under the influence of technological and operating factors, bitumen loses its rheological properties and hardens, Fig. 4.

The new laboratory compactor, Fig. 5 (a), for the production of test samples on stabilized materials has been developed specifically for cold recycling applications, the compaction process allows the production of large test samples for performing triaxial tests as well as small test samples for indirect elasticity testing.

The quality of the foamed bitumen can be accurately defined in preliminary tests in the mobile foaming plant, even before the actual mixing starts. Through its simple operation, parameters such as water volume, pressure and temperature can be changed.
The laboratory foamed bitumen machine, Fig. 5 (b), can be used in order to perform:
- general testing of the types of bitumen used for their suitability for the foaming process;
- optimization of the foaming process by adjusting the temperature and the amount of water to be added;
- producing mixtures in the laboratory using different amounts of added bitumen.

The foamed bitumen production apparatus can be connected directly to the twin-shaft mixer, Fig. 5 (c), for laboratory mix production. The foamed bitumen produced is injected into the mixing process in the mixer. The materials are mixed accurately and without losses. This process produces mixtures for the samples to be tested in the shortest possible time.

It defines the best mix composition and reliably produces different mix formulations in a very short time. Injecting foamed bitumen directly into the mixing chamber of the laboratory scale mixer makes it possible to prepare mixtures according to actual conditions and produce test samples. The high mixing intensity is equivalent to that of continuous mixers used on site. The mixer has a capacity of approximately 30 kg, as well as variable speed and mixing
time settings. The laboratory mixer can be used separately for a wide variety of mixing compositions.

The unit can also be used to test the suitability of mixes by adding cement or lime in combination with foamed bitumen.

The preliminary analysis consists of procuring the raw material, determining the mix formula and testing the suitability of the test samples. This new technology can be used to determine in advance the best physical- mechanical characteristics of the recycled material.

The two laboratory machines make it possible to carry out precise analyses of the mix consisting of milled asphalt and material input.

The ability to be easily processed is one of the distinctive features of foamed bitumen mixtures. As long as it is kept sufficiently wet, the measurements compaction does not need to be carried out within a specified period of time. Another very important distinguishing feature of foamed bitumen recycled layers is that they can be opened for temporary traffic immediately after completion. The cold recycled layer is often simply covered with a thin layer of asphalt which serves as a wearing course. The focus of maintenance work is also only on the asphalt surface course, while the cold recycled layer remains unaffected. This fact can be assimilated into reduced road maintenance costs.

Cold mixes produced with foamed bitumen behave like construction materials with constant friction between particles, but with a significant increase in cohesion and strength. This material is also known as BSM (bitumen stabilized material). In BSM mixes, the aggregate is not coated, but instead the bitumen is homogeneously mixed, typically 1.5% to 2.5% of the bulk construction material mix. After final compaction, the material is characterized by excellent flexibility and high bearing capacity.

4 Design of recycled bituminous binder course

For the design of such bituminous layers, the stiffness and fatigue behaviour of the component materials shall be determined.

According to the literature review, the stiffness modulus values at 15°C determined several months after preparation, should be:

- for unbound granular materials recycled "in situ" with bituminous emulsion: 1500 - 2500 MPa;
- for materials containing 75 - 90% asphalt mixtures from old road layers: 2000 - 3000 MPa;
- for materials containing min. 90% asphalt mixtures from old road layers: 3000 - 4000 MPa.

A correlation between the Duriez test results and the stiffness modulus found in the literature review is presented in Table 2.

Table 2. Duriez test results and estimated values of stiffness modulus [9].

<table>
<thead>
<tr>
<th>Duriez test results</th>
<th>Estimated stiffness modulus at 15 °C (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In case of untreated materials, recycled with emulsion with features:</td>
<td></td>
</tr>
<tr>
<td>- R at 14 days of 1.5-2.2 MPa and r/R of min. 0.55</td>
<td>1500</td>
</tr>
<tr>
<td>- R at 14 days of 2.2-3.0 MPa and r/R of min. 0.55</td>
<td>2500</td>
</tr>
<tr>
<td>Materials containing 75-90% milled mixtures with characteristics:</td>
<td></td>
</tr>
<tr>
<td>- R at 14 days of max. 4.0 MPa and r/R of min. 0.65</td>
<td>2000</td>
</tr>
<tr>
<td>- R at 14 days greater than 4.0 MPa and r/R of min. 0.65</td>
<td>3000</td>
</tr>
<tr>
<td>Materials containing min. 90% milled mixtures with the characteristics:</td>
<td></td>
</tr>
<tr>
<td>- R at 14 days of min. 4.0 MPa and r/R of min. 0.70</td>
<td>4000</td>
</tr>
<tr>
<td>- other cases</td>
<td>3000</td>
</tr>
</tbody>
</table>
In case of recycling technology with foamed bitumen, some worldwide determinations have led to the following stiffness modulus values:

- by diametrical compression test: 2000 - 2500 MPa;
- on recycling materials containing good quality crushed natural aggregates: 2500 - 5000 MPa;
- by indirect calculation based on deflection measurements: 1000 - 2000 MPa in the first month after the layer is laid and about 5000 MPa after several years.

The value of the Poisson's ratio is considered to be 0.35, based on experiments carried out to date worldwide. The calculation of the design of a road structure with a base or foundation layer obtained by cold recycling with bituminous binders is based on the traffic intensity, thus determining the type and thickness of the road surface. According to French standards, the traffic classes according to the annual average daily traffic (in heavy vehicles) are those shown in Table 3.

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>Average daily traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5</td>
<td>0</td>
</tr>
<tr>
<td>T4</td>
<td>25</td>
</tr>
<tr>
<td>T3</td>
<td>50</td>
</tr>
<tr>
<td>T3+</td>
<td>85</td>
</tr>
<tr>
<td>T2</td>
<td>150</td>
</tr>
<tr>
<td>T2+</td>
<td>200</td>
</tr>
<tr>
<td>T1</td>
<td>300</td>
</tr>
<tr>
<td>T1+</td>
<td>500</td>
</tr>
<tr>
<td>T0</td>
<td>750</td>
</tr>
<tr>
<td>T0+</td>
<td>1200</td>
</tr>
<tr>
<td>T6</td>
<td>2000</td>
</tr>
<tr>
<td>TS</td>
<td>3000</td>
</tr>
<tr>
<td>TS+</td>
<td>5000</td>
</tr>
</tbody>
</table>

Depending on the traffic class, the type of surfacing is also chosen for recycled road surfacing as follows:

- for low traffic roads (traffic class at most T3) the recycled layer can be protected with a bituminous treatment or a bituminous slurry;
- for roads with a traffic class between T3 and T1, a very thin asphalt surface is recommended to be used;
- for traffic classes T2+ - T1+ a minimum 4 cm thick asphalt surface is recommended to be laid;
- for other traffic classes additional studies are required for the pavement.

5 Conclusion

The "in-situ" cold recycling process with bituminous emulsion or foamed bitumen and cement slurry in water has a number of advantages:

- maximum use is made of existing road structure material, with minimal input materials (aggregate production is reduced);
- transport is greatly reduced compared to conventional solutions (transport by construction machinery with high impact on the road network and the environment is reduced);
- asphalt mix production is reduced compared to conventional solutions;
- the complete recycling train occupies only one lane of the road, and traffic on the new recycled layer can be carried out within a few hours of completion of compaction;
- the layers resulting from recycling are thick, bound, homogeneous and have a good bond with the layers immediately above or below;
- the road foundation is in no way affected by the recycling of the road surface. During this process, analyses can be carried out on the foundation while visually observing its condition. The moisture content of the milled material and the filler
material is not a problem, as the amount of water in the cement slurry can be adjusted;
- all materials used are quality controlled in accordance with the standards in force, and the quantity control is carried out by the recycler's own computers;
- the process is fast compared with conventional solutions, which is an advantage in that traffic is diverted for less time.

The disadvantages of these technologies are as follows:
- the characteristics of existing road surfacing materials which are not suitable for recycling (coarse fragments, paving stones, high clay content, high heterogeneity, etc.);
- the low bearing capacity of the lower road layers or sub-base, which would not allow the recycling equipment to move, maintain a constant milling depth and achieve an adequate degree of compaction;
- the presence of geotextiles in the layers to be recycled;
- unfavourable climatic conditions (low temperatures, frequent rainfall, etc.) in which case proper homogenization and maturing of the recycled material would not be achieved;
- the elasticity modulus and fatigue strength are lower than those obtained for hot bituminous layers;
- the relatively low thickness of the recycled bituminous emulsion layer due to the need to allow the evaporation of the water initially contained in the material;
- protecting the recycled layer with at least one hot bituminous layer or bituminous treatment depending on the technical class of the road.

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