Cold in-place recycling of aged and deteriorated asphalt and concrete pavements

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Abstract. This study focuses on implementing two distinct recycling methods, the reclaimed asphalt pavement and the reclaimed concrete material, on classical road pavements, by totally replacing the surface or base courses with ones made with recovered materials. The majority of the road networks in the eastern European countries were built between 1950 and 1980 and are, nowadays, aged and degraded. Within this frame, the cold in-place recycling methods were developed, which can be applied to both asphalt and concrete pavements. During the cold in-place recycling process, the reclaimed asphalt or concrete materials do not leave the construction site at all, but they are processed on the spot and reused immediately. Thus, the material is granulated to the desired depth, mixed with the binding agent and water and then repaved and compacted in a new layer. One of the most significant benefits of the cold in-place recycling process is that the material is simultaneously recycled and mixed with the binding agent, enabling the road pavement to be strengthened without the need to import expensive virgin aggregates. This work describes the manufacturing technology and the equipment train used to cold recycle aged and deteriorated asphalt and concrete pavements.

1. Introduction
Nowadays, roads represent the most widely used means by which both people and goods move around for specific aims. This is due to the roads being the only communication ways that offer the so called "door-to-door" access. During recent decades, this mobility has further developed within the context of cheap fuels, expanding road infrastructure and rather loose environmental constraints [1].

Based on the component materials, the road pavements are classified into three categories, namely, asphalt or flexible pavements, concrete or rigid pavements and hybrid pavements. Asphalt pavements are made of hot mix asphalt (HMA), concrete pavements are made of Portland cement concrete (PCC), while hybrid pavement systems are composed of both materials.

The intensity of the road traffic influences not only the direct greenhouse gas emissions, due to fuel combustion, but also the road durability. In addition, besides the intensity of the road traffic, some other factors like design and construction technology, the quality of the pavement materials and local weather conditions are essential for the pavement durability. All these above mentioned factors are also of paramount importance when determining the failure modes and causes of distressed road structures and when selecting a rehabilitation strategy [2-4].

In Romania, various pavement rehabilitation techniques are used to extend the service life of roads. Based on the type of technology and component materials, the pavement rehabilitation techniques can
be classified into two main categories: traditional and modern. The traditional rehabilitation techniques consist in hauling away the materials from the distressed pavement and rebuilding the layers with virgin aggregates. This approach is related to a lack of efficiency in terms of costs and consumption of natural resources. In order to overcome these shortcomings, various modern rehabilitation techniques in which the degraded materials are recycled and reused have been developed during the recent decades [5-7].

In the case of flexible pavements, depending on the recycling technology and mixing temperature, the rehabilitation/recycling methodologies can be classified as hot recycling (HR) and cold recycling (CR). The former includes hot in-place recycling (HIR) and hot central-plant recycling (HCPR), while the latter involves three methods: cold in-place recycling (CIR), cold central-plant recycling (CCPR) and full depth reclamation (FDR) [8].

Each of the above-mentioned rehabilitation/recycling methods has its own advantages and shortcomings. However, in terms of materials and fossil fuel consumption, carbon footprint and structural behaviour, the CIR is considered to be the most advantageous rehabilitation method. In addition, CIR is the only one that can be applied to both flexible and rigid pavements [9, 10].

In the following sections of this work the manufacturing technology and the equipment train used to cold recycle aged and deteriorated asphalt and concrete pavements are described.

2. Cold recycling
As mentioned above, depending on the recycling technology, the reclamation maximum depth and the processing place, the cold recycling technique involves three methodologies: CIR, CCPR and FDR. However, some researchers consider that CIR and FDR refer to one unique method since FDR is also carried-out in-situ. Nonetheless, FDR is characterised by some unique features consisting in the full pavement depth recycling and 100% use of the recycled materials [8].

From a historical point of view, these recycling methods were developed in the early 90s in countries like the United States of America, Canada, Germany, France, Spain and Australia. Later they have been implemented and used worldwide, primarily because of their potential to lessen the severe pollution issues, prolong the life cycle of pavement and save the construction costs [11–14].

3. Manufacturing technology
In general, the whole manufacturing technology of CIR is completed in situ, starting from the milling of old asphalt or concrete mixtures and ending up to reuse the material for construction of base courses, or, in some cases for surface courses on highways with low to medium traffic volume. The construction processes related to the manufacturing technology of CIR are presented in figure 1, in comparison with the traditional rehabilitation methods. For each step, the materials and fuel consumptions are marked.

Whether to reuse the reclaimed asphalt pavement (RAP) or the reclaimed concrete material (RCM) or not depends on the damage extent of the surface layer. Thus, if the surface is moderately degraded and the pavement structure is adequate (the surface course has constant thickness), the in-place recycling of bituminous and concrete materials is enough. However, if the surface layer is severely degraded and thin, reusing underlying granular material is allowed so as to obtain adequate grading characteristics. Nonetheless, in both cases, prior to the construction of the new course, the reclaimed materials should be stabilized with a small amount of road binder.

Various types of road degradations, such as cracking, rutting, ravelling, potholes or structural deformation, might appear in distinct layers of the pavement during its service life. The CIR technology can be employed in different manners to eliminate these distresses to a certain extent. Over the past years, the research on CIR technologies has been intensively conducted. The application of these rehabilitation methods generally consists in the processes that are described in the following subsections.
3.1. Pavement investigation
The pavement investigation provides information on the nature and the condition of the asphalt and/or concrete layers and on the extent of the degradations. The latter are identified throughout the basic visual inspections done during the intervention/maintenance works.

The thickness of the asphalt or concrete pavement is established and the mixes to be recycled are determined. Also, the overall roughness is evaluated and the geometrical characteristics of the base and the subgrade courses are determined. The information regarding the thickness and the components of the pavement are necessary to establish, on one hand, whether the structure has enough thickness to host the actual traffic and, on the other hand, whether there is enough thickness to perform the cutting of the surface course.

The nature of the asphalt/concrete pavements to be recycled may have a significant influence on the mix design of the recycled layers (surface or base courses). In many cases, the presence of a non-traditional mix, such as Open Graded Mix (OGM), Penetration Macadam (PM) or Sand Mix (SM) requires the usage of corrective aggregate.
The laboratory work conducted on the asphalt/concrete pavement field sampling may include (but are not limited to) the following tests:
- gradation of the recycled material, before and after, the extraction;
- characterization of the aged asphalt cement;
- compressive strength;
- indirect tensile strength;
- creep strength;
- modulus of elasticity;
- penetration;
- viscosity;
- asphalt content;
- asphaltene content;
- softening point.

3.2. Milling the degraded material
The recycling equipment train may be a single unit or a multi-unit road construction equipment. In the first case, the single unit train reclaims the asphalt or concrete materials, sizes and mixes in the binders, in the cutting drum, while the placement operation is performed with a standard screed attached to the back of the unit (the case where the reclaimed materials are used on the surface course), [12]. In the second case, the reclamation of the existing materials is performed by a milling machine, the sizing is done by a crusher unit and the mixing with a pugmill, while the placement is carried out with a basic paver [13].

The sizing of the millings is performed so as to separate the aggregate particles from one another. Most often, the typical maximum aggregate size determined as the “100 % passing on the 37 mm sieve” is used.

3.3. Stabilization
The mixing of the road binder with the asphalt or concrete millings may occur in the cutting drum and/or in a pugmill. Additionally, corrective aggregates may be introduced ahead of the milling machine and mixed in with the recycled material within the cutting drum.

The use of road binders is meant to restore the reclaimed material properties, including strength, flexibility, stability and workability. Currently, various types of road binders can be used in the CIR technology. Among the most used road binders are [8]:
- bituminous road binders (emulsified bitumen and foamed bitumen);
- cementitious stabilization agents (Portland cement, lime, fly ash, ground blast furnace, clay soil, slag);
- polymers (crumb rubber, styrene-butadiene rubber - SBR latex, modified agent and styrene-butadiene-styrene - SBS).

3.4. Placement and compaction
Once the mixing of the reclaimed asphalt/concrete with road binder has been completed, the recycled material is placed either on the road base or on the road surface course. When the technology is applied for the construction of the surface layers, the placement of the recycled mixture requires more compaction energy than does the placement of regular hot bituminous mixtures. However, in both cases, the use of a heavy pneumatic roller, combined with large double vibrating drum roller is typically enough. The rolling patterns performed to achieve the compaction degree are established on test sections. In more recent applications, nuclear gauges (devices that use radioactive sources to measure parameters such as thickness, density, moisture or fill level) are used to monitor the density as well as the moisture content of the reclaimed material during the compaction process [8, 13]. The moisture content is the most important parameter for compaction. On one hand, if the moisture content is low, the reclaimed mixture is harsh and will not compact properly. On the other hand, if there is too
much moisture, the reclaimed mixture will also not compact due to the excess of water and absence of air voids.

The compaction degree is commonly limited to 98 % of the density of the Marshall field compacted specimen. The compacted mixture internal void content ranges between 12 and 15 % [8]. During the first year of service, a decrease in the void content of up to 0.5 % may occur, due to compaction by traffic.

4. Structural performance of CIR courses
The most commonly accepted understanding of the structural performances of cold recycled asphalt mixtures is based on two antagonistic principles that were postulated in the early development of CIR [14-16]. One concept is based on the incipient assumption that the aged asphalt mixtures are inert and thus, the reclaimed aggregates should be treated as “black aggregate”. The second concept assumes that an aged asphalt mixture can still be active and thus, the addition of a rejuvenating agent should restore its original characteristics. In time, it was found that both concepts are applicable, depending on the characteristics of the asphalt mixtures. In some cases, the asphalt can not be reactivated and, after milling and stabilizing, it can be used only for the construction of base courses. In other cases, the asphalt can be reactivated and used for the construction of surface layers. Similarly, the reclaimed concrete materials can be used either as aggregates in new concrete mixtures or as materials for road base construction.

The strength and the fatigue life of the CIR road layers will increase during the first years of service. The increase is preeminent in the first few months (3 - 5 months), while after this period the structural performance will still increase, yet at a lower rate [8].

The structural performance of the CIR courses is a subject of interest for many research teams, including ours. In a recent published work, our research team focused on implementing the CIR technology on a classical road pavement by totally replacing the base course with one made with reclaimed materials. For this purpose, four flexible pavements were constructed, instrumented and tested on an accelerated pavement testing (APT) facility, while capturing the structural condition. After the accelerated test had been done, the authors concluded that the pavement structure that included a structural layer made with stabilized RAP material presents better fatigue performance in situ than the reference pavements made with classical layer components, which are considered high-performance road base materials in Romania. This confirms that the recycled materials can be used successfully for road construction. More information related to this experimental program was presented in [17].

5. Conclusions
The construction/rehabilitation of roads implies significant consumption of traditional energy resources, particularly petroleum and virgin aggregates, which may lead to severe environmental issues. In the last decades, several recycling technologies were developed to allow the reuse of asphalt and concrete materials. Generally speaking, any road recycling technology consumes less raw materials and fossil fuel and lowers the pollutant emissions.

Among the recycling technologies, the CIR may be considered a well-proven road rehabilitation technology. Moreover, it is a viable engineering and economic alternative to the traditional rehabilitation methods and it can be applied for a wide range of traffic and pavement distress situations.

This work describes the manufacturing technology and the equipment train used to cold recycle aged and deteriorated asphalt and concrete pavements. Based on the road course that is constructed with the reclaimed materials, the particularities of the CIR technology were identified and described. Additionally, some of the most important advantages of the CIR road layers were discussed.
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