D.5.1. Improved components for the milling and mixing process

Introduction:
Wirtgen GmbH, together with COPCISA and UPC, defined what aspects in the current cold recycling process could be enhanced. Two main aspects were defined as follows:
• To improve the overall grading of the milled material and
• To improve the effective mixing of the material that is being milled with the added binding agent(s).

Wirtgen GmbH then studied the various components on a milling machine that could possibly affect the above listed aspects. With the aim to improve the aspects of grading and mixing, the following studies were undertaken:
WP 5.1.a: Effect on grading of the material to be recycled by changing the milling drum speed, \(v_1\) and the machine rate of advance, \(v_2\).
WP 5.1.b: Effect on mixing improvement of the material with the binding agent(s) by changing the cutting tool positioning on the milling and mixing drum.
WP 5.1.c: Effect on the mixing improvement of the material with the binding agent(s) by changing the internal shape of the milling and mixing chamber.

This report aims at explaining the theoretical study that took place and the changes that were made to certain components on existing milling and recycling machines. Furthermore, these components were tested on actual job sites. Although the actual test phase is defined under WP 6.1., we have decided for reasons of a logical reporting sequence to include the results of the practical tests in this report.

The next step in the study was to define a current milling and recycling machine. At the beginning of year 2000, Wirtgen stopped the production of the 2100 DCR. A new milling and recycling machine, the 2200 CR, replaced the redundant 2100 DCR in the middle of year 2000. We therefore decided, for reasons of progress, that any new research and development would be carried out on components of the 2200 CR.(Fig.1a and1b)
Fig. 1a: The milling and recycling machine, Wirtgen 2200 CR, defined for changes of components to improve milling and mixing.

Fig.1b: Schematic of 2200 CR to show the various components:

- Control panel for microprocessor-controlled injection systems
- Injection bar for emulsion, water or slurry
- Powerful diesel engine
- Tamping screed with tampers
- Heated pump and delivery piping for hot bitumen
- Injection bar with individual expansion chambers for foamed bitumen
- Mechanically driven milling and mixing rotor
- Spreader auger
W.P. 5.1.a: Milling drum speed, v₁, and machine speed, v₂

The first step was to define various milling drum speeds. Increasing or decreasing the diameter of the various belt pulleys will change the milling drum speed. There are three belt pulleys, one at the drive unit, being the motor, one at the milling drum, which is connected to the planetary gearbox located within the milling drum and one at the belt tensioner, which is used to activate rotation of the drive to the planetary gearbox. A study took place to determine what speeds would be possible without placing undue strains on the components such as the milling drum, the planetary gearbox or the drive unit. A schematic of this is shown in fig. 2. Three different milling drum speeds were defined, these being 73,1 rev/min; 92,8 rev/min and 104,6 rev/min. The speed of 92,8 rev/min is the standard milling drum speed. This means that the only component change to test this variable would be two belt pulleys.

![Schematic of how the drive unit energy is transferred to the milling drum](image)

*Fig. 2: Schematic of how the drive unit energy is transferred to the milling drum*

The next step was to define at which machine advance speeds v₂ the test should be carried out. The usual advance speeds for a recycling machine with a paving screed are between 3 and 6 m/min. It was decided to carry out the theoretical study at advance speeds, v₂, of 3 m/min and 5 m/min.
To determine the effect of changing the advance speed and the milling drum speed, these variables were analysed on a computer animated simulation program. As a first simulation, the advance speed was kept constant at 3 m/min and the three different milling drum speeds were varied. This was repeated with an advance speed of 5 m/min.

The simulation program uses these defined variables and for each series draws the path that the milling pick would take. These were then plotted and the maximum theoretical particle size for a depth of 15 cm, which was defined between the consortium partners at the kick-off meeting, was measured. The portion in which the milling tool is in the actual cut has been plotted and shown schematically in fig. 3.a to 3.f.

\[ a) \quad v_{1,1} = 73.1 \text{ rev/min} \]
\[ b) \quad v_{1,2} = 92.8 \text{ rev/min} \]
\[ c) \quad v_{1,3} = 104.6 \text{ rev/min} \]

Fig. 3.a - c: Schematic showing the simulation of varying the milling drum speed, \( v_1 \), while keeping the machine advance speed, \( v_{2,1} \), constant at 3 m/min.
From the simulation discussed and schematically shown above it can be clearly seen that theoretical maximum particle size can be measured. These are summarized in table 1 below.

Table 1: Theoretical maximum particle sizes by varying milling drum revolution speed and machine advance speed.

<table>
<thead>
<tr>
<th>Milling drum revolution speed, $v_1$ [rev/min]</th>
<th>Machine advance speed, $v_2$ [m/min]</th>
<th>Theoretical max. particle size [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>73,1</td>
<td>3</td>
<td>41</td>
</tr>
<tr>
<td>92,8</td>
<td>3</td>
<td>32</td>
</tr>
<tr>
<td>104,6</td>
<td>3</td>
<td>29</td>
</tr>
<tr>
<td>73,1</td>
<td>5</td>
<td>68</td>
</tr>
<tr>
<td>92,8</td>
<td>5</td>
<td>54</td>
</tr>
<tr>
<td>104,6</td>
<td>5</td>
<td>48</td>
</tr>
</tbody>
</table>
Analysing the theoretical results in table 1, one can summarize that by increasing the speed of the milling drum speed from 73.1 rev/min to 104.6 rev/min the rate of advance can be increased from 3 m/min to just under 5 m/min while still obtaining the same maximum particle size. This increase in advance speed of the milling and recycling machine would increase the production by just under 60 % without theoretically any detriment to the quality of the grading. On the other hand, if a different asphalt in terms of stiffness is encountered the grading could be controlled by varying the milling drum speed.

W.P. 5.1.b: Changes to the milling drum
The aim of a milling drum in a standard milling machine is essentially to mill the asphalt and to transfer the milled material to the conveyor belt, whose function is to load the material that has been granulated onto a tip truck. The arrangement of the milling tools on the milling drum affects two criteria, these being:

- The degree of granulation. The greater the line spacing from one milling tool to the next, the larger is the maximum granulate size. Furthermore, the more often the milling tool strikes the existing road at a certain point within a revolution of the milling drum, the faster the milling machine can advance.

- The efficiency of transferring the milled material to the conveyor belt. As the conveyor belt is located in front and in the centre of the milling drum chamber, all the milled asphalt needs to be transferred to this central location. In addition, so called “kickers” are introduced onto the milling drum to further enhance the transfer of the milled material onto the conveyor belt.

A milling drum in the 2200 CR needs to fulfil, in addition to the above two criteria of granulating and conveying the material, another main criteria. This is the mixing efficiency criterion. It is usual for various binding agents to be added to the milled material in the cold in-situ recycling application. Therefore an additional priority of the milling drum is to mix the material efficiently.

Currently, the milling drum on the Wirtgen recycler 2200 CR is equiped with the standard milling drum, fig. 4, which is used in the Wirtgen milling machine W 2200. The aspects discussed above are fulfilled to an acceptable level but has potential for improvement. Wirtgen decided, together with the consortium partners, to spend some research and design time on improvements to the standard milling drum.
The general approach was to include extra vanes to create a paddle type effect to improve the transportation of the material to the centre and to improve the mixing efficiency. In addition, reducing the spiral angle from 24 ° to 12 ° allowed changes to the cutting tool arrangement, as can be seen in fig. 5 to 7. This new spiral angle allows more space between the cutting tool holder for the extra vanes and allows more space for the material to be in a suspended state, which could possibly improve the mixing efficiency. In addition, the criterion of maximum particle size could possibly be affected with the changed cutting tool arrangement. This will have to be seen in the test phase of the milling drum.
Fig.: 6 Newly developed milling drum. Milling width: 2200 mm.

Fig.: 7 Newly developed milling drum. (without picks)
W.P. 5.1.c: Changes to the milling and mixing chamber

Another criterion for efficient mixing of the binding agents with the milled material is conveying the material out of the rear gate of milling chamber. To get efficient mixing within the milling and mixing chamber there needs to be enough space available for the material that has been milled and the binding agent that is being added. This means that the rear opening of the milling and mixing chamber needs to be balanced to the maximum depth that is generally recycled. The main challenge here is that the depth varies from 15 to 25 cm, depending on the general approach to in-situ recycling technology within different countries. For this reason Wirtgen decided to have another look at the milling and mixing chamber of the 2200 CR.

Two factors were considered for trial:
- Increasing the rear gate opening of the milling and mixing chamber
- Increasing the volume within the milling and mixing chamber

The following solutions were found:

The main challenge here was to retain the stiffness of the rear gate so that the same gate could be used when milling asphalt were the function of the rear gate is to keep the surface behind the milling drum clean. It was possible to increase the rear gate opening area from 0,94 m² to 1,10 m². This is an increase of 17 % ! (Fig.8 and 9)

Fig.: 8 CAD drawing showing the detail of the rear gate component. The shaded area is the theoretical area were the material exits the milling and mixing chamber.
Fig.: 9 Newly developed rear gate of the 2200 CR to be tried in the experimental phase of the project.

Allowing the rear gate to swing and be fixed in various positions solved the variable mixing chamber (Fig.10 and 11) concept to improve the mixing efficiency. Here a 50 % increase of the theoretical mixing volume from 0.42 m³ to 0.63 m³ could be achieved.

All the changes to the components discussed above were incorporated in a prototype milling and mixing chamber. This enhanced milling and mixing chamber (Fig.12), together with the changed milling drum and the pulley discs form part of Deliverable 5.1.
WP 6.1. Testing the deliverables from WP 5.1.

In order to determine if this theory also pertains to the praxis we recommended that the developed components should be tested on the test track. Unfortunately, there was no Wirtgen 2200 CR available in Spain or Sweden for testing on the actual pre-determined test tracks defined for the PARAMIX project. Therefore we had to find a client in or in the vicinity of Europe that had a Wirtgen 2200 CR and was willing to test these new components. A suitable client, who had a recycling job at hand, was found in Rumania.
Recycling-Jobsite in Rumania

Machines:  Concrete layer granulation:  W 2200
           Base course construction:  WR 4200 + WM 1000

Existing road:
In May 2003 the regional road between Bucharest and Pitesti was structurally rehabilitated using the cold recycling technology. The existing 22 to 26 cm thick, 40 year old concrete road was covered by a surface dressing as can be seen in Fig. 13.

![Pavement structure before and after rehabilitation](image)

Job data:  75.000 m² (7,5 m width x 10 km)
Binding agents used:  4,5 M.-% Foamed bitumen + 2,0 M.-% Cement
Compaction water used:  2,0 to 3,0 M.-%

Rehabilitation method
The following working steps were undertaken:

- A Wirtgen W 2200 granulated the existing concrete up to a depth of 26 cm (Fig. 14 to 18). At 3 m/min an ideal grading, suitable for the use of foamed bitumen, was achieved.
- A Dozer and/or grader were used to distribute the granulated concrete and to establish the correct cross fall and longitudinal profile (Fig. 19).
- Thereafter the recycling train, consisting of the Wirtgen Recycler WR 4200, the Wirtgen cement slurry mixer WM 1000, and a 30 t Bitumen tanker, was used to recycle the granulated concrete (Fig. 20 to 24). The granulated concrete was milled to a depth of 20 cm, mixed with 4,5 % Foamed bitumen, 2,0 % Cement and from 2 to 3 % compaction water in the form of a cement slurry in the twin shaft pugmill mixer. At the exit of the mixer the material is spread transversely by a spreading auger and paved with a Vögele AB 500...
TV paving screed, equipped with tampers and vibration to achieve pre-compaction of the mixture (Fig. 21 and 25).

- Compaction of the cold recycled base layer was completed with two 12 t single drum vibratory rollers to achieve compaction in the lower area of the layer and one 15 t Pneumatic tyred roller to finish off the compaction in the upper part of the layer and, with the addition of water sprinkled onto the surface, to close the surface of the base layer.

Fig. 14: Existing pavement – Surface treatment that has broken off in areas resulting in an uncomfortable ride for the road user.

Fig. 15: Granulating with the Wirtgen milling machine of type W 2200. Betek Concrete-cutting tool: type W1 – 13.
Fig. 16: Granulated concrete with a uniform grading which was well suited for the application of foamed bitumen as a binding agent.

Fig. 17: Concrete layer thickness of up to 26 cm
Fig. 18: Close up of the “blue” (i.e. hard) concrete layer

Fig. 19: Granulated material is distributed by a dozer. The transverse and longitudinal profiles are achieved by means of a grader
Fig. 20: The cold recycling train, consisting of Wirtgen Recycler WR 4200, the Wirtgen cement slurry mixer WM 1000 and a 30 t insulated bitumen tanker.

Variant: Metered injection of foamed bitumen; Cement and water is pre-mixed and injected by the slurry mixer WM 1000.

Fig. 21: The cold recycling process with foamed bitumen and cement slurry.
Fig 22: Construction of the cold recycled layer with the binder combination foamed bitumen and cement (in form of cement slurry)

Fig. 23: The WM 1000 produces the cement-water mixture and pumps the cement slurry into the twin shaft pugmill mixer of the recycler WR 4200
Fig. 24: Flexible hoses transfer the cement slurry and the hot bitumen from the WM 1000 and bitumen tanker to the recycler WR 4200.

Fig. 25: Build up of the Wirtgen Recycler WR 4200
Fig. 26: Compaction is achieved by two single drum vibratory rollers (not shown here) and a pneumatic tyred roller to close the surface of the cold recycled base layer.

Fig. 27: Closed surface achieved by the pneumatic tyred roller
Fig. 28: Half the road width being 3.75 m is recycled and profiled in only one pass of the recycling train, thereby reducing the number of longitudinal joints.

Fig. 29: After final compaction the cold recycled layer can be opened to traffic. After the adjacent lane is recycled the entire width is sprayed with a tack coat followed by the paving of a 4 cm hot mixed asphalt wearing course.
Results from the practical test in Rumania:

Up to this stage the contractor has only had contracts similar to the one described above. That being recycling of concrete roads.