COLD MIX RECYCLING PROCEDURE DURING EXECUTION OF ASPHALT PAVEMENT STRUCTURE BASE COURSES – CROATIAN CASE STUDY

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ABSTRACT

During the past few years in the Republic of Croatia the pavement rehabilitation executed by the application of the “in place” cold recycling procedure has been applied on several national, county and local roads. The “in place” cold recycling was executed by addition of binder, of foamed bitumen or of cement mixed with certain additives.
The Paper presents results of field testing and additional laboratory testing of samples of the course stabilised with cement and the additive named “X” for the purpose of this Paper. The results of laboratory testing of 24-hour and 28-day compressive and tensile strength are presented of the prepared mixtures of recycled material of the pavement structure with addition of pure cement, of cement mixed with 2% of “X” additive and of cement mixed with 4% of the same additive, as well as the results of testing of frost and thaw resistance. The values of modulus of elasticity were determined on the 28-day old samples.
The analysis of the results of additional laboratory testing yields conclusions which indicate the necessity of further investigation of the impact the addition of “X” additive to cement has on the physical-mechanical properties of the recycled material.

1. INTRODUCTION

The period of investment into construction of new roads in Croatia is nearly over. Future investments are expected in the field of maintenance and rehabilitation of the existing road network. Therefore, more attention is being given to the systematic management of road infrastructure, where high quality, cost efficient but also environmentally acceptable solutions are being applied, like cold mix recycling of asphalt pavement structure. This technology is being applied in Croatia for the same reasons as in other countries, namely less negative influence on the environment and decrease in maintenance costs.
This paper presents several years experience in the use of the cold in-place recycling procedure in Croatia, where cement and foamed bitumen are usually added to heterogeneous materials composed of asphalt and loose pavement structure courses. The cold recycling procedure with addition of cement and other admixtures is being applied more and more lately in Croatia. The paper shall further elaborate on the experience gathered in the filed and laboratories regarding cold recycling of heterogeneous material of the pavement structure in combination with cement and admixture X.
Admixture X, according to the manufacturer's declaration, generates changes in the structure, forming additional minerals during cement hydration. These changes cause

significant increase in the strength, coefficient of elasticity and resistance to frost and thawing, at the same time keeping the consolidated pavement structure base course from cracking.
Cold recycling procedure and the use of the new admixture, according to its properties can be to a certain extent considered as stabilization of the reclaimed pavement material, which should produce a new base course.
This paper presents experience gathered during the rehabilitation of State road D515, namely its section Našice-Bračevci, and occurrences which initiated additional laboratory tests of the influence of admixture X on the reclaimed mixture, as well as result of the main and additional laboratory tests.

2. COLD RECYCLING PROCEDURE IN CROATIA

Recycling of asphalt pavements is a procedure where the damaged or worn out pavement is modified or changed into a homogenous pavement structure which can stand the demands of the planned traffic load.

There are several types of recycling procedures, depending on the place of recycling, the temperature of the process itself, properties of materials being recycled and the type of binder used. Depending on the place, we differentiate in-place and in-plant recycling. According to the recycling temperature we have cold and hot recycling, and according to the properties of material, we can distinguish between recycling of a relatively homogenous material of a course and recycling of heterogeneous material consisting of several reclaimed courses. According to the binder used, we distinguish recycling with cement, lime and cement, bituminous emulsion, foamed bitumen, combination of binders (cement and emulsion or foamed bitumen) and pure bitumen.

Cold, in-place recycling procedure is a technique mostly used today and is a technology interesting from the technical, economic and environmental aspect. Advantages of this type of recycling procedure, except the fact that the material needs no transport, are as follows:

- use of old, degraded material from existing pavement;
- Homogeneity of pavement with regard to strength and geometry;
- Reduced waste quantities and reduced exploitation of industrially made aggregate from quarries and gravel plants, with advantages regarding environmental protection;
- no heating and drying of the mixture;
- possible rehabilitation (improvement) of individual traffic lanes on multi-lane carriageways;
- less damage to the surrounding traffic network due to less transport of material;
- lower rehabilitation costs of worn out pavements;
- preserves the existing alignment;
- allows for simultaneous widening of the existing road, which is a frequent requirement during road reconstruction and change of road class;
- allows for adjustment to certain fluctuations in the composition of material being recycled;

- opening of the road for traffic during the night or weekends, including the part under construction works.

Disadvantages of this procedure are:

- poor homogeneity of the mixture in relation to the new produced mixture (in plant);
- possible occurrence of longitudinal cracks due to poorly executed connection between adjoining lanes , if works are executed under ongoing traffic;
- longer work execution period in relation to simple pavement resurfacing procedure.

Two types of cold recycling procedures have been applied in Croatian until now:

- in-place cold recycling with foamed bitumen, where recycling consists of milling or crushing of material from the old pavement (from 15 to 30 cm depth), with simultaneous addition of binder in the form of foamed bitumen (obtained by integrating an appliance into the recycler which adds water to the hot bitumen) into the crushed material to stabilize the recycled course and to achieve a certain degree of bonding. The mixture is then shaped and compacted into a layer to achieve a renewed pavement course in-place. In order to increase the values of previous elasticity and strength coefficients, the cement is directly added into the mixing chamber as suspension.

The above described cold recycling procedure was applied during rehabilitation of road sections:

- Vinkovci-Županja, overall length 17,8 km – State road D55,
- Pula-Šišan, overall length 720 m, remediation of county road 5134,

The technique is to be applied in rehabilitation of several more road sections.

- in-place cold recycling with cement and admixture X.

This procedure was applied during rehabilitation of various state road sections, overall length 19 km, as well as 6,55,km of county roads and 2,4 km of local roads.

3. IN-PLACE COLD RECYCLING WITH ADMIXTURE „X“ – RESULTS AND EXPERIENCES FROM THE ROAD SECTION NAŠICE-BRAČEVCI

The text bellow presents result and experience gathered on rehabilitation of a road section where the technology of in-place cold recycling with cement and admixture X was applied. Admixture X is a powder type material composed of different alkali and alkaline earth element, used as cement admixture.

3.1 General information about the State road section D515, Našice-Bračevci (from km 0+000 to km 17+170)

The road section Našice – Bračevci in the east part of Croatia. A traditional design solution was originally planned for rehabilitation of this section , with mechanically compacted base course and two asphalt courses. However, due to extra damage of the pavement structure caused by heavy traffic load and transport of material required for construction of motorway sections of the Corridor Vc Motorway Osijek-Đakovo, it was decided that the design be changed in favor of the in-place cold recycling technology with cement and admixture X. This would ultimately increase the bearing capacity of the road and

resistance to the freezing and thawing cycles caused by the presence of high ground waters.
According to this design [1], the pavement structure consists of: existing course of loose stone material thickness 25 cm; a course of recycled material, thickness 30 cm; bitumen stabilized base course thickness 6 cm and asphalt wearing course thickness 4 cm.
This pavement structure fulfills the design criteria regarding the bearing capacity of the new pavement.

3.2 Preliminary works

Sampling of the existing pavement structure materials was done in order to prepare the initial job mix formula (JMF). Three samples were taken, at chainages 4+000, 9+336 and 13+400 (right traffic lane), by milling the pavement 30 cm deep, 1m wide and 3m long. The material was then homogenized, 100kg was taken from each location and these samples were transported to the Institute IGH laboratories.
Grading analysis of individual samples showed that discrepancies between the samples were slight, and instead of defining the JMF for every sample, one JMF is sufficient to represent the complete section.
Four JMF's were prepared with a variable percentage of binder (mixture of cement and admixture X; where percentage of admixture X always remained at 2% in relation to percentage of cement).
Tensile and compressive strengths were tested on each sample after 7 and 28 days, and after 28 days and 14 freezing and thawing cycles.
The results showed that the optimal mixture was the one with a percentage of cement (class 42,5 in accordance with EN 197:1) of 48 kg/m^2 , i.e. 160 kg/m^3, where the content of admixture X remained at 2% of the total quantity of cement (0,96 kg/m^2).

3.3 Work execution technology

The following machinery was used on the construction site: backhoe loader, grader, milling machine, car cistern with water, cement spreader „Streu Master SW 16 MC“, tractor spreader for admixture X, recycler „Wirtgen WR 2000, and a group of compaction type machinery consisting of a tandem roller, static roller and a rubber tyred roller. The following diagram shows the stages of work execution and use of the mentioned machinery.

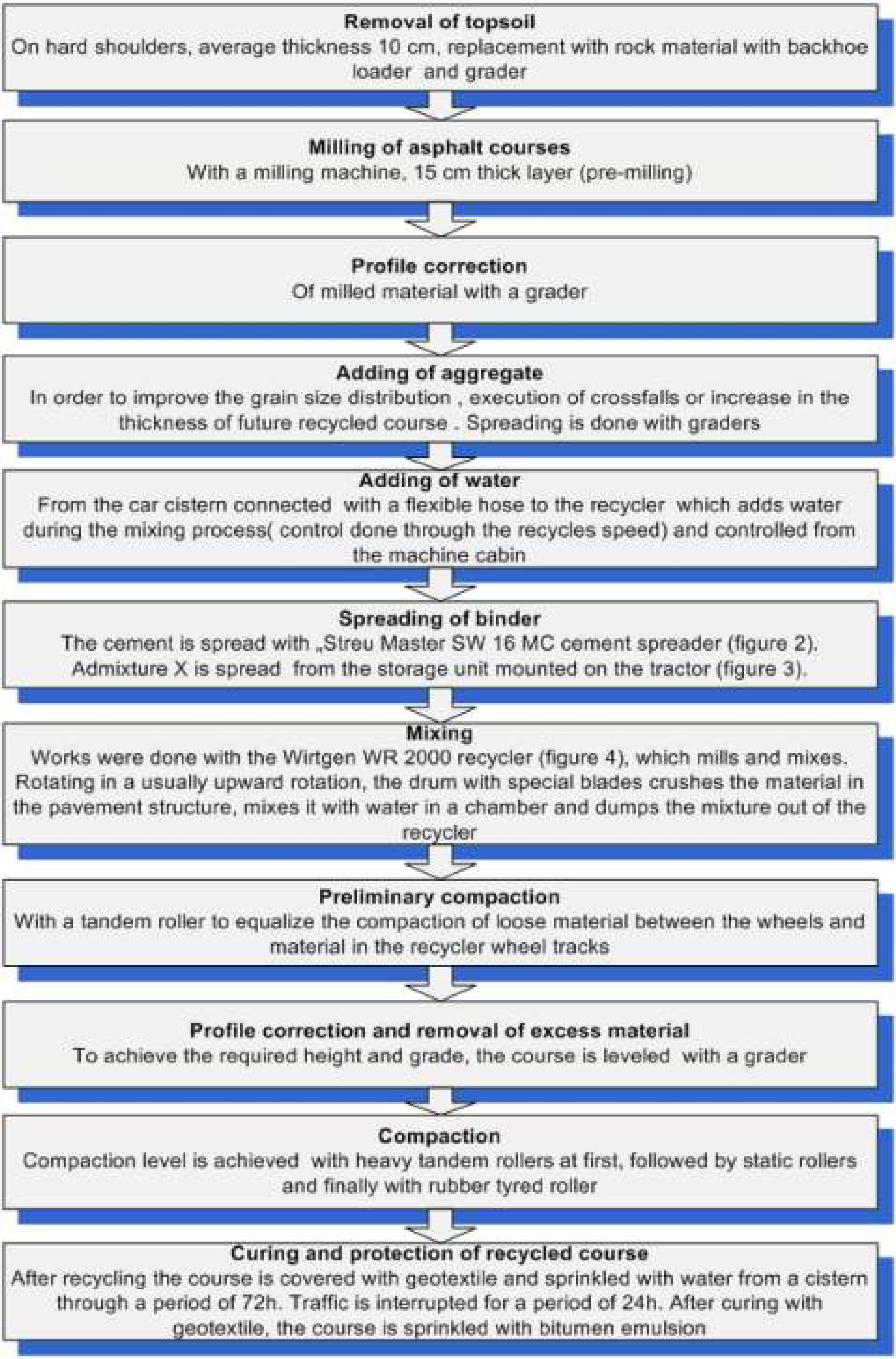

Figure 1: Work execution process

3.4 Quality control

Figure 2: Cement spreader Streu Master SW 16 MC

Figure 3: Tractor spreader for admixture X

Figure 4: Recycler Wirtgen WR 2000

3.4 Quality control

Quality control of the recycled course is done by the contractor and the client. Contractor's quality control consists of testing the percentage of cement content (once a day),

percentage of admixture X content (once a day), compaction level (1/3000 m²), thickness of course (1/3000 m²) and compressive strength after 7 and 28 days (once a day).
The following tests were done as part of the Client's quality control procedure:

- compressive strength after 7 and 28 days (once a day),
- tensile strength after 28 days (once a day),
- tensile and compressive strength on cores extracted from the course (1/7000 m²),
- compaction level (1/3000 m²),
- thickness of course (1/3000 m²),
- surface roughness (1/3000 m²).

Water content was monitored visually on the spot, and subsequently through laboratory tests. Occurrence of cracks was also visually monitored, by regular inspections of the placed course. Grading of the recycled mixture was not checked.

3.5 Results of Client's control tests

Within the Client's control, tests were implemented on two types of samples, depending on the means of sample preparation [2,3]:
- Strength tests on laboratory samples prepared in accordance with EN 13286-50 [4],
- Strength tests on samples obtained by coring, diam. 150 mm from the placed course.

Table one presents mean values of all results obtained by Client's tests.

Table 1 – Mean values of control test results

Type of tests	Test method	Test results Mean value	Design requirements
Testing the compressive strength after 7 days	HRN EN 13286-41	6,87 MN/m²	2,0 – 3,5 MN/m²
Testing the compressive strength after 28 days	HRN EN 13286-41	7,83 MN/m²	4,5 – 9,0 MN/m²
Testing the compressive strength on cores extracted from placed course after 28 days	HRN EN 13286-41	6,54 MN/m²	4,5 – 9,0 MN/m²
Testing the tensile strength after 28 days	HRN EN 13286-42	3,19 MN/m²	2,0 – 4,0 MN/m²
Testing the tensile strength on cores extracted from placed course after 28 days	HRN EN 13286-42	2,73 MN/m²	2,0 – 4,0 MN/m²
Compaction level	HRN U.B1.016	101,84 %	≥ 98 %
Thickness and roughness	-	Within 5% of required value	± 15 mm
Percentage of cement	-	Within 5% of required value	48 kg/m²
Percentage of admixture X	-	Within 5% of required value	0,96 kg/m²

Results of compressive strengths after 7 days showed that the 7-day compressive strengths ranged between 3,5 MN/m^2 and 11,0 MN/m^2, with a mean value of 6,87 MN/m^2, which is a significant deviation from the design requirements. Compressive strength after a period of 28 days ranged between 4,2 MN/m^2 and 11,3 MN/m^2, with a mean value of 7,83 MN/m^2, thus fulfilling the design requirements, while the individual values were significantly higher.
The results of compressive strength on cores extracted from placed course after 28 days ranged between 3,4 MN/m^2 and 11,1 MN/m^2. A satisfactory mean value of 6,54 MN/m^2 was obtained (after 28 days).
Indirect tensile strengths obtained after 28 days ranged between 0,43 MN/m^2 and 2,58 MN/m^2, with an indirect tensile strength mean value of 1,60 MN/m^2, i.e. recalculated bending strength of 3,19 MN/m².
Test results of tensile strength on cores after 28 days ranged between 0,71 MN/m^2 and 2,61 MN/m^2, with a mean value of indirect tensile strength of 1,37 MN/m^2, i.e. recalculated bending strength of 2,73 MN/m².
The determined tensile strength is in accordance with design requirements.
Compaction level ranged between 96,9 % to 107,6 %, with a satisfactory mean value of 101,8%.

3.6 Cracks on the placed recycled course

First cracks on the newly placed recycled course appeared one month after the work execution (Figure 5).

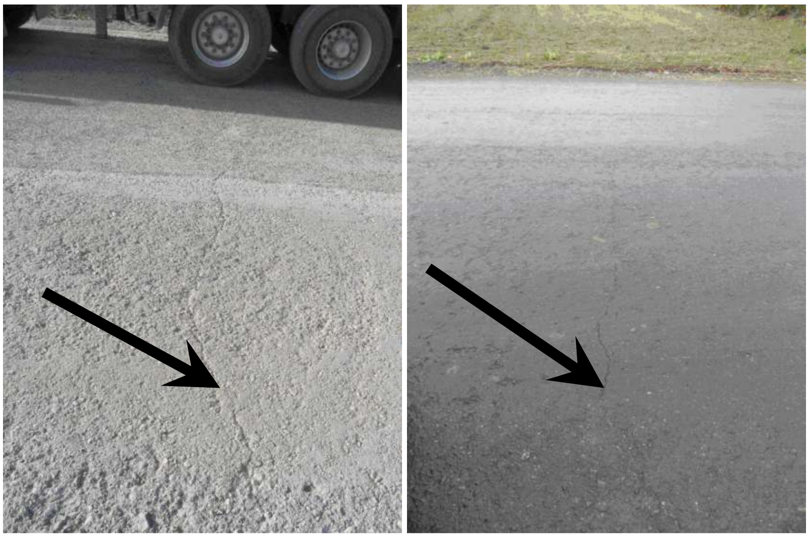

Figure 5 – Characteristic transverse crack on the recycled course (left) and asphalt course (right)

Inspection and coring, core diam. 150 mm, from the recycled course, which was done on 6 random chosen locations showed that most cracks were only surface cracks at the time. Only minor cracks went through the complete depth of the recycled course. These deep cracks were remedied with asphalt reinforcing mesh and covered with bituminized base course. New cracks on this course appeared after three more months and they also were remedied as described above.
The freezing and thawing tests were also executed. Tests were done on one sample with one crack. The sample, after 14 freezing and thawing cycles cracked in half. One assumption was that insufficient water content in the mixture or inadequate curing process

caused appearance of cracks. Therefore moisture control of the homogenized recycling material was increased in further work execution, as well as curing of the placed course. Although control of these segments was increased, transverse cracks still appeared on the executed course.

4. ADDITIOAL LABORATORY TESTS

Since cracks showed relatively fast on the executed course, additional laboratory tests of the used material were implemented. The main aim of these additional tests was to check the influence of admixture X on the reclaimed material and cement mixture.
Sampling for these additional tests was done on two occasions. The first sampling included cement (CEM II/A-M (S-V) 42,5 N, manufactured by Našicecement) and admixture X from the spreader. The second sampling included material from existing pavement structure, planed for reclaiming, which consisted of asphalt courses and material from the mechanically compacted loose base course. In order to obtain a representative sample, procedures were executed which are done during recycling. Asphalt courses were milled (crushed) with a pavement milling machine (up to 15 cm depth), and material for the remaining depth up to 30 cm was crushed by a recycler. A surface area of app. 8 m² was treated this way.

4.1 Testing program

The laboratory tests program included preparation of different mixtures from the reclaimed material, cement and admixture X, which would be used to test the mechanical and durability properties of the mixtures. The mixtures of cement and binder were prepared to check the influence of admixture X:
- cement 100%, - cement 98% with 2% admixture X, and - cement 96% with 4% of admixture X.
The aims of the testing program were to check the influence of:

- Composition of binder on the tensile and compressive strengths of stabilizing mixtures,
- Composition of binder on the speed of ultrasound , i.e. modulus of elasticity,
- Composition of binder on the freezing and thawing cycles,
- Longer curing period on the strength of mixture.

4.2 Preparation of samples and laboratory testing

Three different mixtures were prepared in the laboratory:

1. mixture of reclaimed material and 11% binder (cement 100%) at optimal moisture content,
2. mixture of reclaimed material and 11% binder (cement 98% and 2% of admixture X) at optimal moisture content, and
3. mixture of reclaimed material and 11% binder (cement 96% and 4% of admixture X) at optimal moisture content,

Each mixture was homogenized in the laboratory mixer for at least 5 minutes to obtain as unified mixture as possible.

Cylinder shaped samples were prepared from each mixture according to the Proctor procedure and standard HRN EN 13286-50 [4]. After preparation of samples, tensile and compressive strengths were tested as well as the speed of ultrasound pass (modulus of elasticity) and resistance to freezing and thawing cycles.
Samples prepared for the compressive strength tests were cured in laboratory conditions (20 °C and 100 % moisture content) for 1 day and 28 days. After this period, tests according to standard HRN EN 13286-41[5] were undertaken. Figure 4.2. shows samples before and after compressive strength tests.

Figure 6 – Sample before (left) and after (right) compressive strength tests according to standard HRN EN 13286-41

Samples prepared for the indirect tensile strength tests were cured in laboratory conditions (20 °C and100 % moisture content) for 1 day and 28 days. After this period, tests according to standard HRN EN 13286-42 [6] were undertaken. Figure 7 shows samples before and after tensile strength tests.

Figure 7- Sample before (left) and after (right) tensile strength tests according to standard HRN EN 13286-42

Samples prepared for the resistance to freezing and thawing cycle tests were cured in laboratory conditions (20 °C and 100 % moisture content) for 28 days. After this period, the samples were placed in an apparatus resembling a freezer (Figure 8) where the samples were exposed to freezing at a temperature of -15 °C for 16 hours and thawing for a period of 8 hours at 20 °C. During this thawing cycle, the bottom of the apparatus is filled with water allowing for capillary water rise in the samples. Compressive strength was tested after 14 cycles according to standard HRN EN 13286-41 [5].

Figure 8 – Apparatus for freezing and thawing cycles

Samples for testing the speed of ultrasound passage through the sample were cure in laboratory conditions (20 °C and 100 % moisture content) for 28 days. After this, the test itself was executed (Figure 9) according to standard ASTM D 2845 [7], which was used to calculate the modulus of elasticity (Young's, shear and bulk).

Figure 9 – Testing the speed of ultrasound passing through the sample according to standard ASTM D 2845

4.3 Results and correlations of executed tests [8]

After all tests planned by the Program were executed, the results were statistically analyzed. The tables and graphs below show average values of obtained test results.

Table 2 – Results of compressive strength tests

Period of curing / Mixture of milled material with	1 day [MPa]	28 days [MPa]	28 days + 14 cycles of freezing and thawing [MPa]
100 % cement	5,23	9,73	11,3
98 % cement + 2 % admixture X	5,23	9,85	11,1
96 % cement + 4 % admixture X	5,23	10,2	11,2

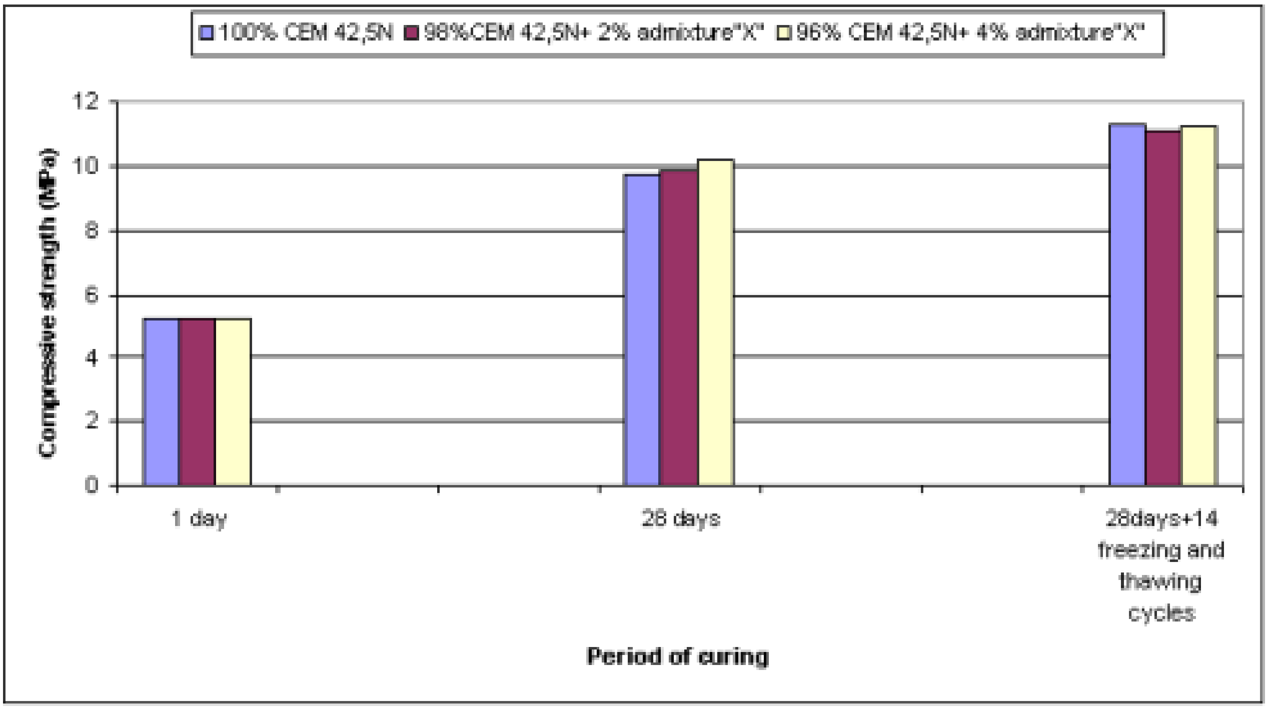

Figure 10 – Comparisons of compressive strengths

Figure 10 shows that there is no significant difference in the quality of recycled mixture which would depend on the percentage and combination of binder. All mixtures after exposure to freezing and thawing have increased compressive strengths, which means that the mixtures are resistant to freezing.

Table 3 – Results of indirect tensile strength tests

Mixture of milled material with \ Period of curing	1 day	28 days
100 % cement	1,01	2,63
98 % cement + 2 % admixture X	0,91	2,84
96 % cement + 4 % admixture X	0,98	2,69

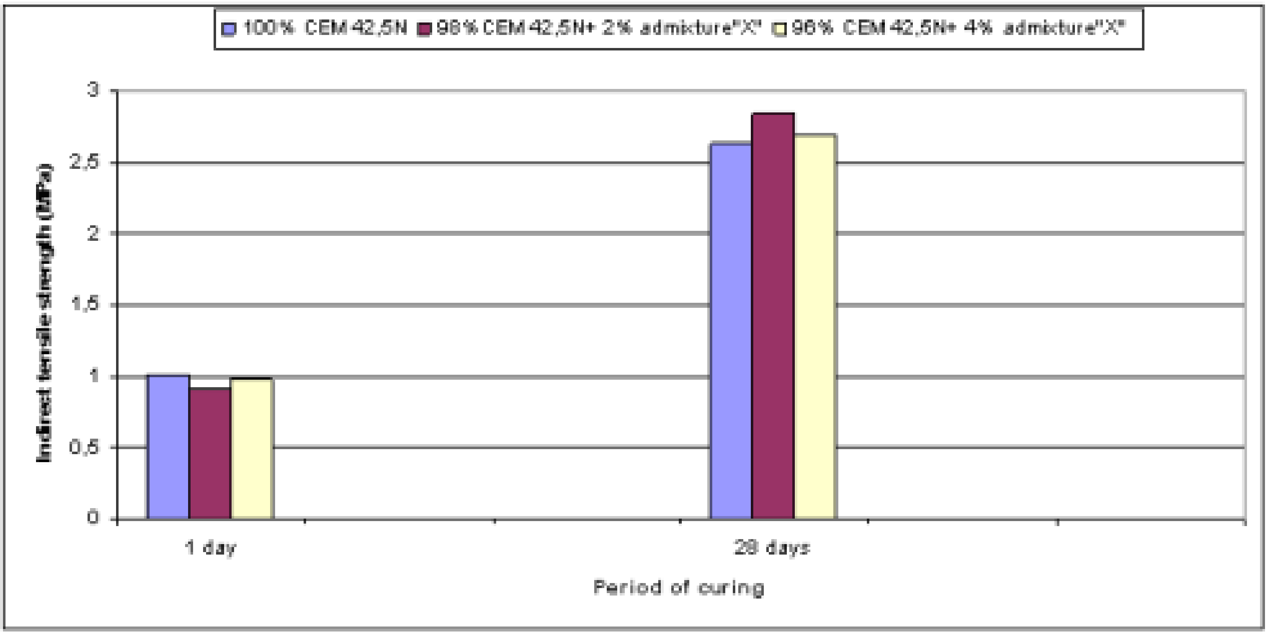

Figure 11 – Comparison of tensile strengths

On property stressed on the admixture X declaration is the significantly increased resistance to tensile stress. Analyzing the results (table 3 and graph in Figure 11), it can not be concluded that the differences in results obtained on samples with only cement added as binder and samples with a mixture of binder are a significant difference. Actually the difference is such that it can be assigned to the heterogeneous property of material.

Table 4 – Results of the dry bulk density tests

Mixture of milled material with	Compaction energy [MJ/m³]	Water content [%]	Dry bulk density [Mg/m³]
100 % cement	2,7	optimum	2,221
98 % cement + 2 % admixture X	2,7	optimum	2,226
96 % cement + 4 % admixture X	2,7	optimum	2,245

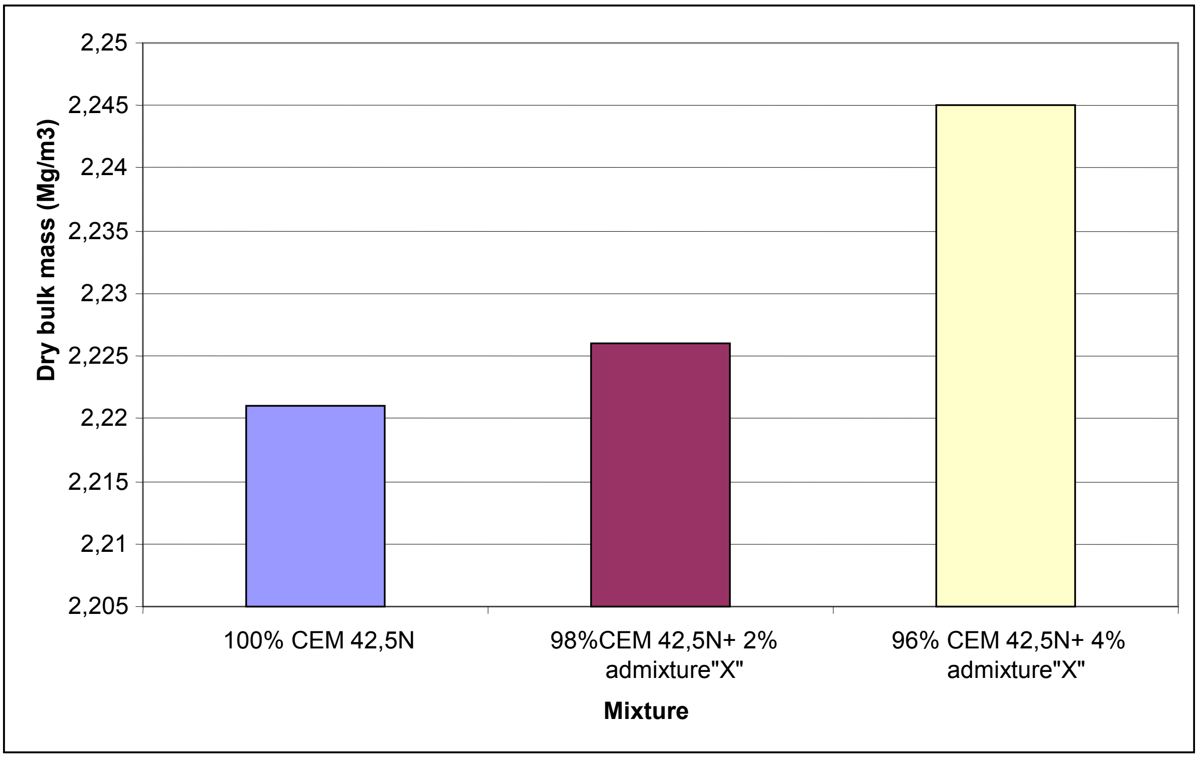

Figure 12 – Comparison of dry bulk density

Since the difference between the dry bulk density where only cement was added, and the mixture placed on road section D515 (Našice-Bračevci; 98 % cement and 2 % admixture X) is only 0,005 Mg/m³, it can be concluded that admixture X does not influence the level of compaction at the construction site itself (table 4 and graph given in figure 12). Larger discrepancies of dry bulk density occur when the course is not compacted with adequate equipment or when adequate technology – number of compaction passes is not defined.

Table 5 – Test results of the modulus of elasticity

Modulus of elasticity / Mixture of milled material with	Compaction energy [MJ/m³]	E (Young) [GPa]	E (shear) [GPa]	E (bulk) [GPa]
100 % cement	2,7	12,84	4,52	26,41
98 % cement + 2 % admixture X	2,7	13,82	4,89	26,52
96 % cement + 4 % admixture X	2,7	13,41	4,73	27,13

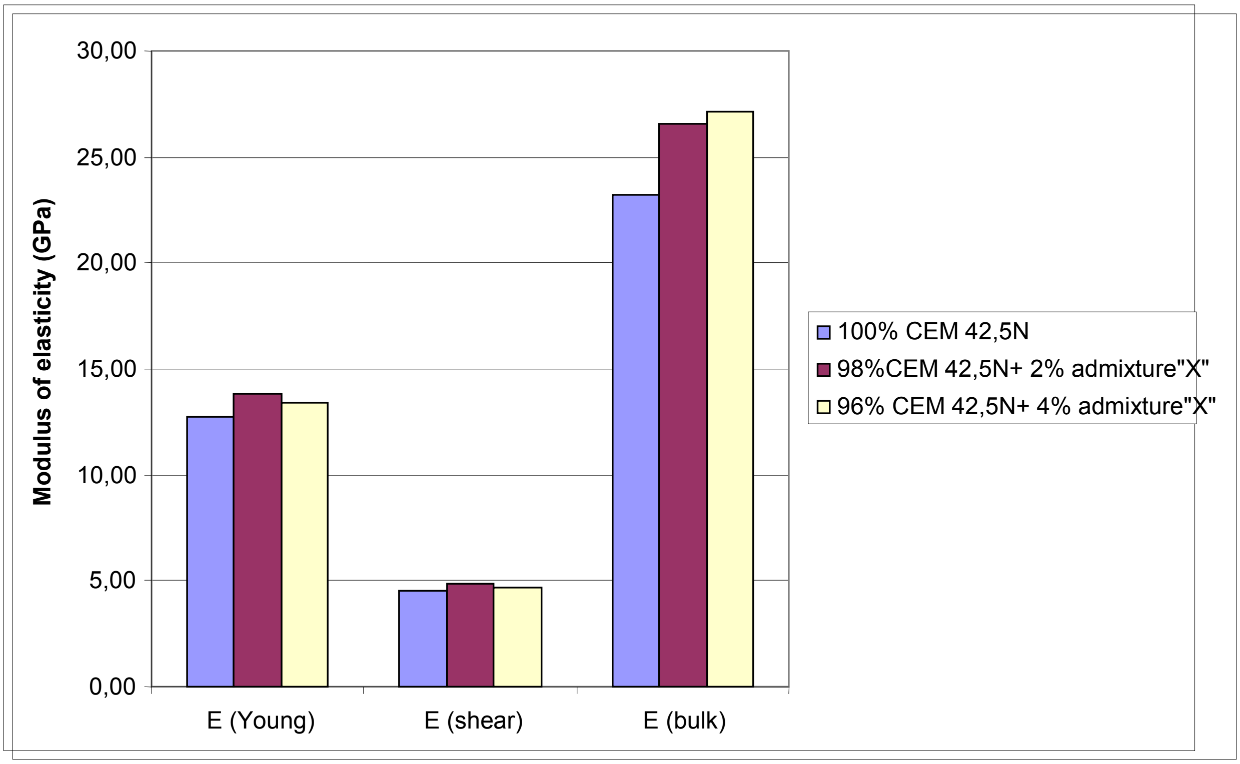

Figure 13 – Comparison of the modulus of elasticity

The average value of all modules of elasticity indicates some very small differences between the mixtures (table 5 and graph in Figure 13), and statistically, they could represent the same group of test results.

5. CONCLUSION

During the recent years, the cold recycling procedure was used during rehabilitation of state, county and local roads throughout Croatia. This paper presents some experiences gained during the preparation of the cold recycling with addition of binder consisting of cement and admixture X.

Work execution of the rehabilitation of state road D515 and its section Našice – Bračevci showed that despite some results which fulfill the design requirements on the average (but not individually), transverse cracks did appear and they reflected on the asphalt courses. Additional tests of the influence of admixture X on the mixture did not give adequate answers on its influence in the course itself and relatively high compressive strengths were recorded.

On the basis of test results (monitoring of the rehabilitation of state road Našice – Bračevci) and additional laboratory tests it was actually very hard to determine what is the exact action and influence of admixture X in the mix and the base course. Test will be further undertaken in this respect, to finally determine the contribution of admixture X.

Recycling of the pavement structure with new additives requires further detailed research and confirmation prior to the start of widespread use in the road rehabilitation works.

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