ORIGINAL SCIENTIFIC PAPER OPEN ACCESS

Analysis of the hydraulic binder use for base strengthening in pavement constructions

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ARTICLE INFO

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DOI: 10.5937/engtoday2202037S

UDC: 621(497.11) **ISSN:** 2812-9474

Article history: Received 27 June 2022; Accepted 11 July 2022

ABSTRACT

The paper presents the application of cement stabilization in the world and in our country. In addition to the literature review, basic physical - mechanical tests of the pavement base without the use of hydraulic binder and with the use of hydraulic binder with different percentages of participation (3, 5, and 7%) were given. The hydraulic binder of the manufacturer LaFarge HRB 12.5 was used as a binder, and the material on which this binder was tested is a clay material taken from Subotica. Using this binder, it was concluded that any percentage of binder leads to significant improvement of the placenta and thus improves the load-bearing capacity of the pavement structure.

KEYWORDS

Hydraulic binder, Base, Pavement construction

1. INTRODUCTION

During the infrastructure building, it is sometimes impossible to avoid sections where the foundation soil or pavement base soil does not meet the minimum requirements, either in terms of load-bearing capacity or in terms of required material quality, and which the project or some general applicable regulation imposes on the material itself and its installation condition. There are several procedures, groups of soil stabilization procedures: mechanical, stabilization with lime, cement or similar hydraulic binders, bituminous binders, special chemical agents and geotextiles.

The basic mechanism for mechanical soil stabilization is thickening, then its granulometric composition must be improved. When soil stabilization is carried out with binders, hardening is achieved by connecting soil particles by mixing with binders. Necessary groups are soil stabilization procedures using geotextiles, when geotextiles (non-woven textiles, mesh) and a layer of stone material are laid over weak and unstable soil, which is used to establish the required load-bearing capacity.

The first application of soil stabilization was achieved approximately 5000 years ago, when the so-called Shaanxi-pyramids (towards the province of Shaanxi) were made of clay mixed with lime. The Chinese wall between the brick walls has a core of clay stabilized with lime, and the Chinese used the same procedure to build roads and improve the soil during the bridges building. The Indians used a mixture of clay and lime as masonry mortar, and the Romans built roads with lime and volcanic ash 2000 years ago.

The Roman road Via Appia has three of the four layers of pavement structure (1.2 m thick) stabilized with lime. The practice of stabilizing the soil with hydraulic binders (lime, pozzolan) in many countries has survived to our time. Modern soil stabilization procedures, which are based not only on experience but also on professional and scientific claims, began to develop first in the United States. Due to the very bad condition of the roads at the beginning of our century and the need to connect very remote areas, various possibilities of soil consolidation were begun to be studied.

The national reports of the World Congress on Roads (AIPCR) show that four basic stabilization procedures are applied today (mechanical, lime, hydraulic binders, bitumen) and that they have become standard techniques in more than 50 countries. The mentioned stabilization procedures have also been applied in our country since the 1960s. They are mostly standardized by SRPS standards. Stabilization, improvement of bearing capacity with the help of geotextiles, began to be applied much later (around 1960), which was conditioned by the ability of the industry to produce sufficient quantities of these materials, at low enough prices, to be rationally used in construction.

The papers encountered in the last decade are the stabilization of fine-grained soil with fly ash [1]. The authors examined low to medium plasticity clay as well as medium to high plasticity clay. The ash was used as a binder in the amount of 15 to 20%. After the tests, it is concluded that the ash can be used to improve the pavement base. Some of the authors have examined the use of ash as a material for the construction of road embankments using a hydraulic binder (lime and cement) with different percentages [2]. The authors came to the conclusion that the application of ash with or without binders can be used for road construction and give quite good test results. Some authors have examined river sludge as bedding material in pavement bases. As a binder, they used cement with the addition of ash up to 20%, on the basis of which they concluded that ash and sludge can be used as embankments of material [3]. Many papers are related to the use of waste and recycled materials [4-9] for the production of pavement layers and with the addition of binders in order to improve the load-bearing capacity in the layer.

This paper presents the basic physical and mechanical tests of the pavement base with and without the addition of binders, in order to be able to compare the values and show how much the hydraulic binder has improved in terms of natural soil characteristics. As a binder, a hydraulic binder was used, which was formed by a combination of lime and cement. The percentages of soil stabilizer binder additives are 3, 5 and 7%.

2. MATERIALS

Natural material (clay material) and hydraulic binder (BeoBond C30 "LaFarge" from Beocin) were used to make the stabilized pavement base. The location of the taken sample is shown in Figure 1.

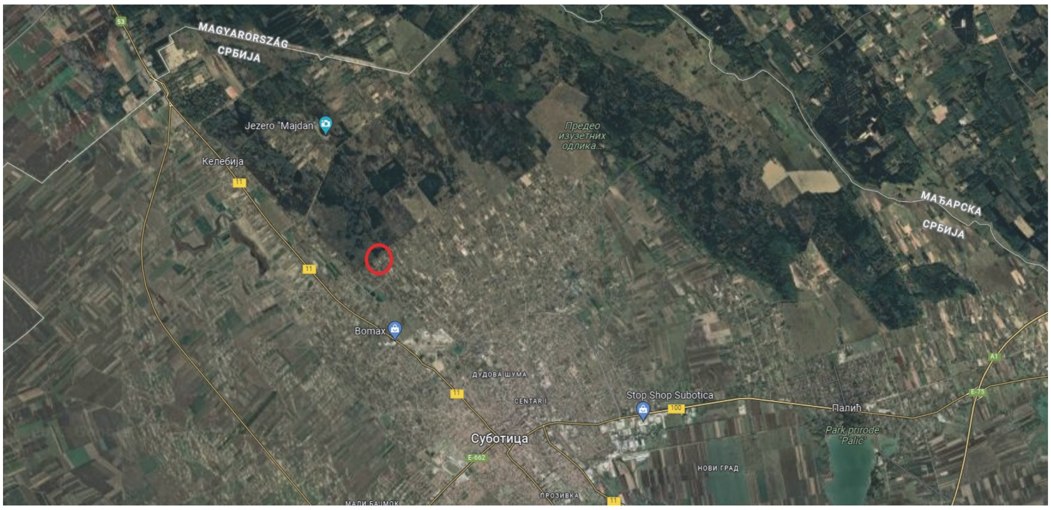

Figure 1: View of the location of the taken material sample

2.1. Clay material of low plasticity

To test this type of soil, tests were performed according to the following standards:

- determination of granulometric composition of aggregates (SRPS U.B1.018: 2005 [10], SRPS EN 933-1: 2013 [11]),
- determination of soil sample moisture (SRPS U.B1.012: 1995 [12]),
- determination of soil consistency, Atterberg limits (SRPS U.B1.020: 1980 [13]),
- determination of the ratio of moisture and dry bulk density of soil (SRPS EN 13286-2: 2012 [14]),
- determination of the California load index (SRPS EN 13286-47: 2012 [15]).

2.1.1. Granulometric composition

In order to classify the material, the granulometric composition and distribution of particles as a function of grain size were examined. The method of wet sowing with the use of distilled water was applied. To determine the granulometric composition of the clay, 300 g of material with a series of sieves were used: 4, 2, 1 mm and 500, 250, 125, 90, 63 µm. Most of the material passed through a 1 mm sieve (77%), with rare exceptions. A total of 1 sample was made, in accordance with the appropriate standards, and depending on the size of the tested particles:

- SRPS EN 933 - 1: 2013 - Tests for particle size distribution of aggregates - Part 1: Determination of particle size distribution - Screening method,
- SRPS U.B1.018: 2005 - Geomechanical testing: Determination of particle size distribution.

The tested sample can be classified into a group of very fine clay materials. The granulometric composition of the aggregate is given in Figure 2.

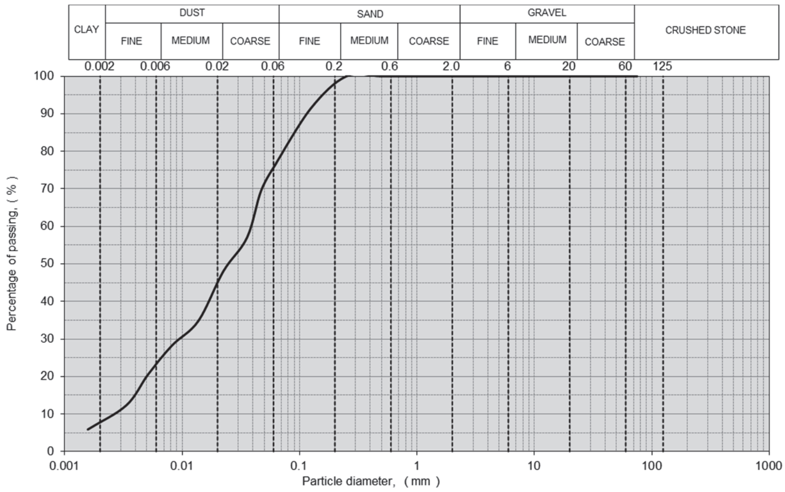

Figure 2: Granulometric composition of aggregates

According to the USCS [16] classification, the material belongs to the CL group or low plasticity clay, while according to the AASHTO [17] classification it belongs to the A-7-6 group, ie it belongs to the group with high plasticity index in relation to their yield strengths, and such materials can be highly elastic and subject to significant changes in volume.

2.1.2. Material compaction characteristics (Proctor`s experiment)

This procedure defines the optimal water content. With it the largest dry bulk density is achieved, with the applied compaction energy, and under the conditions defined by the standard:

- SRPS EN 13286-2: 2012 - Unbound and hydraulically bound mixtures - Part 2: Test methods for laboratory reference volume and water content - Proctor compaction.

In accordance with the granulometric composition, a compaction energy of 600 kN/m3 was applied, and under the assumption that the same will be applied in the field. The test results of the Proctor test are shown in Figure 3. It is observed that the maximum bulk density is 1.61 t/m^3 at an optimum humidity of 20.1%.

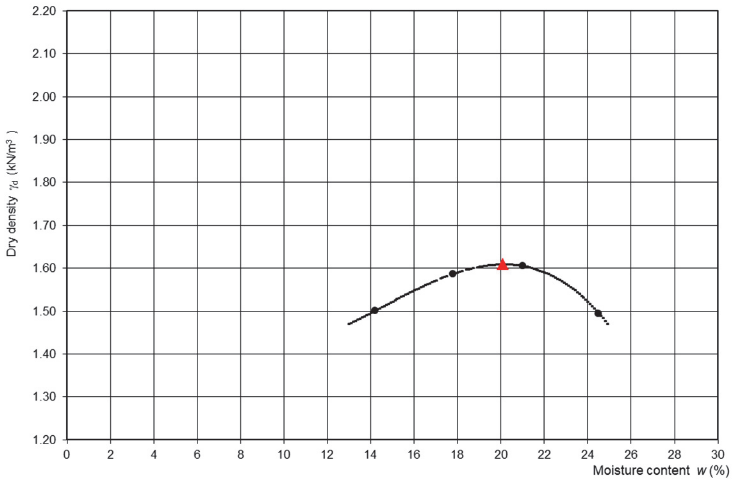

Figure 3: Chart of Proctor's test

2.1.3. Load-bearing capacity of the California load-bearing index

The California Load Index (CBR) is a number that physically represents the resistance of a standard piston to standard values. When designing pavement structures in road construction, one of the basic parameters of material quality, and in the technical conditions of construction, is prescribed as a mandatory parameter in the production of bedding. The experiment was performed according to the procedure and in the apparatus, with accessories and measuring devices that are clearly defined by the standard:

- Unbound and hydraulically bound mixtures - Part 47: Test methods for the determination of California bearing capacity index, immediate bearing capacity index and linear swelling.

After the test, the CBR value for penetration of 2.54 mm is 6.3%, while for penetration of 5.08 mm is 5.29%. In Figure 4 show the diagram of CBR.

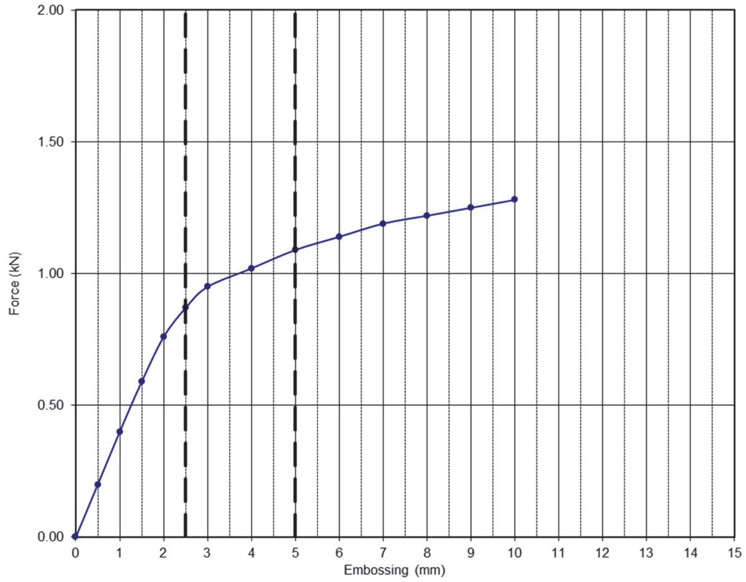

Figure 4: Diagram of CBR

2.2. BeoBond C30 "LaFarge" Beočin

The following tests were performed for testing the hydraulic road binder:

- start and end of binding time - SRPS EN 196-3 [18],
- standard consistency SRPS EN 196-3 [18],
- volume constancy (Le Chatelier rings) SRPS EN 196-3 [18],
- determination of compressive strength of cement after 7 and 28 days SRPS EN 196-1 [19],
- determination of flexural strength of cement after 7 and 28 days SRPS EN 196-1 [19].

The test results of this binder as well as the manufacturer's specifications or specifications of quality conditions prescribed by the standard SRPS EN 13282-2 are shown in Table 1.

Table 1: Results of laboratory tests of hydraulic road binder BeoBond C30 „LaFarge" Beočin

Binder characteristics	Test results	Quality conditions [20]
Start of binding time (min) [18]	180	≥ 150
End of binding time (min) [18]	215	
Standard consistency (%) [18]	37.5	
Constancy of volume (Le Chatelier rings) (mm) [18]	0.33	≤ 10
Determination of compressive strength of cement after 7 days (MPa) [19]	18.1	
Determination of compressive strength of cement after 28 days (MPa) [19]	45.8	32.5-52.5
Determination of flexural strength of cement after 7 days (MPa) [19]	9.8	
Determination of flexural strength of cement after 28 days (MPa) [19]	10.7	

After the tests, it is concluded that the hydraulic road binder BeoBond C30 "LaFarge" Beočin fulfills the prescribed requirements defined by the standard SRPS EN 13282-2 [14].

3. ANALYSIS OF RESULTS AND DISCUSSION

The mixtures made in this paper are as follows:

- reference sample without added binder,
- sample with 3% binder,
- sample with 5% binder and
- sample with 7% binder.

The tests were performed according to the requirements of the standard SRPS EN 14227-11, which include the following tests:

- determination of optimal humidity and maximum bulk density - Proctor's test with 3, 5 and 7% binder,
- determination of the California load index after 30 minutes, 4 and 28 days of immersion in water,
- determination of compressive strength after 7 and 28 days.

In addition to the above tests prescribed by the standard [20], the following tests were additionally performed:

- determination of Atterberg`s consistency limits after 5, 15 and 30 minutes, with the addition of 3, 5 and 7% binder.

From the analyzed location, it was concluded that this is a material belonging to the group of low plastic clay (CL) according to the USCS classification of materials, which has certain yield limits W_L=42% and with a plasticity limit W_P=14%. The average humidity of the homogenized material is 28%. According to the AASHTO classification, the material belongs to group A-7-6.

Figures 5 and 6 show the changes in the yield strength W_L, the plasticity limit W_P as well as the calculated plasticity index depending on the percentage of added binder over a period of 5, 15 and 30 minutes.

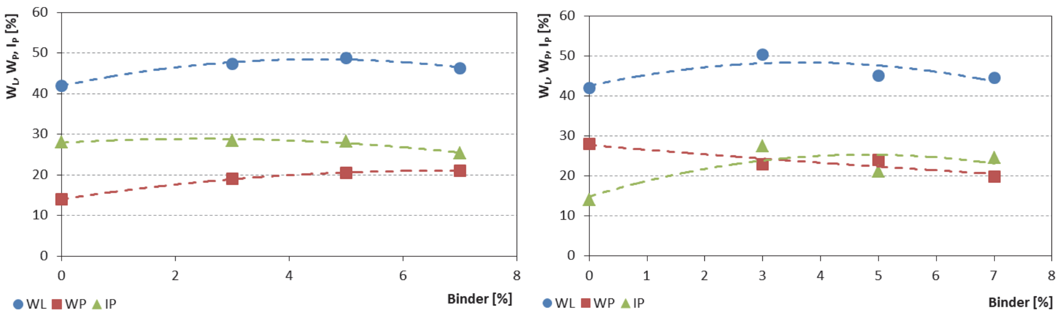

Figure 5: Change in Atterberg`s limits of consistency for the function of added lime after 5 minutes (left figure), after 15 minute (right figure)

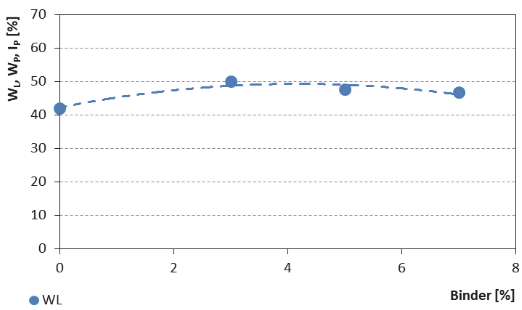

Figure 6: Change in Atterberg`s limits of consistency for the function of added lime after 30 minutes (left figure)

The change in the yield strength is negligible and ranges from 40 to 50%, and the plasticity limit increases from 14 to 28%, with a maximum value of 28% being achieved with 0% binder addition. The plasticity index decreases with increasing amount of binder. The minimum value of the plasticity index was achieved with 28.3% with a share of 5% binder. The plastic limit could not be determined 30 minutes after the addition of the binder at different participation values.

Figures 7 and 8 shows the flows of change in yield strength, plasticity as well as changes in the calculated plasticity index as a function of time.

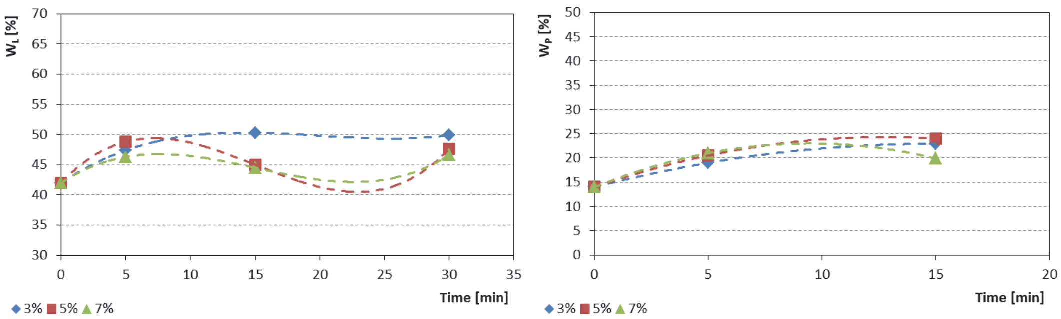

Figure 7: Change in the flow rate limits for the function of time for different percentages of added binder (left figure); change in the plasticity limits for the function of time for different percentages od added binder (right figure)

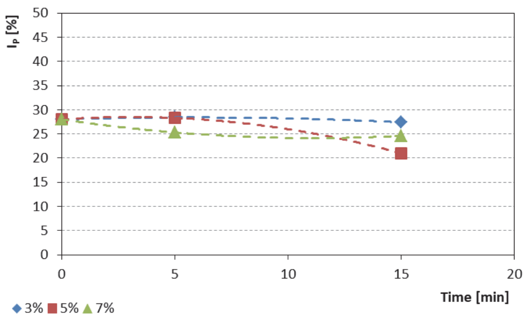

Figure 8: Change in the index of plasticity for the function of time for different percentages of added binder

The materials have reduced yield and plasticity limits, and there is not much difference in the achieved minimum value of the plasticity index with 3 and 5% of the binder addition.

The California load index was tested on the samples after 30 minutes, after 4 and 28 days of immersion in water. Table 2 shows the CBR values for a given time period.

Table 2: CBR values for a given time period

Binder (%)	after 30 minute		after 4 days		after 28 days	
	Direct loading capacity index	Category	Direct loading capacity index	Category	Direct loading capacity index	Category
3	29	IPL25	63.8	CBR50	88	CBR50
5	27	IPL25	71.9	CBR50	>100	CBR50
7	22	IPL20	67.7	CBR50	94.8	CBR50

The immediate load index, which was determined 30 minutes after the construction of the test body, belongs to the IPL25 category with 3 and 5% of binder, and the IPL20 category with 7% binder. CBR values determined after 4 days of immersion in water from the test body and results, belong to the CBR50 category with 3, 5 and 7% binder. No swelling of the material was registered on the test samples that were tested after 4 and 28 days of immersion in water for all three cases of the percentage of binder participation.

Compressive strengths after 7 and 28 days are shown in Table 3.

Table 3: Hardness values for pressure

Binder (%)	Rc, 7 (MPa)	Rc, 28 (MPa)	Category
3	-	0.75	Rc 0.5
5	0.481	1.23	Rc 1.0
7	1.25	1.78	Rc 1.0

Compressive strength values with 5 and 7% of binder reach the last value of the maximum category according to the requirements of the prescribed standard SRPS EN 14227-11, which is Rc 1.0 and which guarantees the achievement of permanent strength parameters.

Figure 9 shows the change in optimal humidity and maximum bulk density of the material depending on the percentage of added binder. As the percentage of binder increases, the optimum moisture content of the material increases and the maximum bulk density decreases.

The optimum moisture content of the material with 5% of binder increased by 1%, and the bulk density decreased from 1.61 to 1.56 g/cm^3.

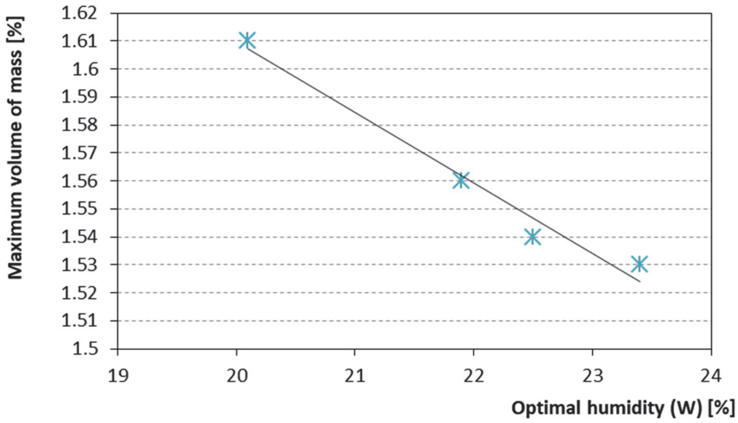

Figure 9: Change of the maximum volume of mass for the function of optimal humidity of the material for different percentage of added connective tissue

4. CONCLUSION

According to the conducted tests, the following can be stated:

- for more efficient installation of materials in the layers of the pavement construction, in terms of achieving the necessary parameters for material compaction, a percentage of 5 and 7% binder is recommended,
- with a percentage of 3% binder it is considered that the compressive strength would decrease by 20%, while the best values are achieved with a 7% binder addition using the standard [20],
- to achieve maximum effects in terms of load-bearing capacity, compaction and all analyzed segments from this paper, it is necessary to use a percentage of 5% binder,
- using a percentage of 3% or more percentage of binder during preparation will not cause swelling of the material, which accelerates enough that the binder quite quickly regulates the water in the layer.

ACKNOWLEDGEMENTS

This research (paper) has been supported by the Ministry of Education, Science and Technological Development through project no. 451-03-68/2022-14/ 200156 "Innovative scientific and artistic research from the FTS (activity) domain".

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