EXAMINATION OF PERVIOUS CONCRETE MIXTURES FOR PRODUCTION OF CONCRETE PAVEMENT

Miloš Šešlija [1]
Anka Starčev-Ćurčin [2]
Nebojša Radović [3]
Danijel Kukaras [4]
Andrija Rašeta [5]
Goran Jeftenić [6]

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Summary: Concrete pavement represents a rigid pavement structure in relation to asphalt pavements. For the analysis, three pervious tests were carried out, on which the tests of compressive strength and density were performed. The examination was done at 7 and 28 days, where the samples were cured in laboratory conditions. The mixtures differ by type and amount of cement, aggregates, superplasticizers, aerators and water-cement factors. After completion of the tests, it was concluded that all three concrete mixtures fulfill the requirement for concrete pavement production, that is, the compressive strength after 28 days is greater than or equal to 40MPa.

Keywords: *Concrete pavement, comressive strength, density*

1. INTRODUCTION

The development of concrete pavements began in the time of the old Romans [1]. The pavement structures of that period consisted of a layer of crushed stone material bounded with a natural hydraulic binder (volcanic ash from Pocuoli near Naples). [2]. With the construction of the first cement macadam, in 1888 in Wrocław, a modern era of concrete pavement has started [3]. However, the first classic concrete pavement was built later, in 1891 in Belfauntn, USA, using only modest craft technologies [4]. The first machine-

[1] Miloš Šešlija, MSc CE, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia, tel: +381653990089, e – mail: sele@uns.ac.rs
[2] Anka Starčev-Ćurčin, PhD CE, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia, tel: +381637721699, e – mail: astarcev@uns.ac.rs
[3] Nebojša Radović, PhD CE, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia, tel: +381654405900, e – mail: radovicn@uns.ac.rs
[4] Danijel Kukaras, PhD CE, University of Novi Sad, Faculty of Civil Engineering, Kozaračka 2a, Subotica, Serbia, tel: +381641131231, e – mail: danijel.kukaras@gmail.com
[5] Andrija Rašeta, PhD CE, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia, tel: +381652121255, e – mail: araseta@uns.ac.rs
[6] Goran Jeftenić, MSc CE, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia, tel: +381642854098, e – mail: goran.jeftenic@uns.ac.rs

made roads appeared in Germany in 1930 [5]. In Serbia, the beginning of the construction of concrete pavements is linked to the period before the First World War and immediately after the Second World War, but soon the construction of concrete pavements on the Serbian roads completely stopped [1]. Today, concrete pavements are performed only in special places, such as toll booths on highways, petrol stations and bus stops. Concrete pavements are not widely represented in our country, but they are widely used in developed countries, mainly in the USA and in the countries of Europe (Austria, Germany, Belgium, Czech Republic, etc.) [1]. For example, in the Czech Republic, about 50% of the highways are made of concrete [3]. The advantages of concrete in relation to asphalt pavements are multiple. The rigidity and compressive strength of the concrete influence the distribution of the load over a relatively wide surface, so that the load on the subbase is low and the layers below the concrete slab have smaller dimensions compared to the layers of asphalt pavement constructions [6].
Favorable physical and mechanical properties cause less need for maintenance, repair and reconstruction of concrete pavements in relation to asphalt pavements. Namely, in the case of concrete pavements there are no deformations in the form of rutting caused by the movement of the vehicle, since the rigid pavement construction reduces the deformation of the pavement, which ultimately affects the reduction in fuel consumption of the vehicle [7].
In this paper, an overview of the pervious concrete mixtures testing is given, that is, the laboratory testing of concrete compressive strength after 7 and 28 days. Four different types of concrete mixtures, which differ in aggregate, cement and chemical additives, were used for the test.

2. EXPERIMENTAL RESEARCH

Concrete is produced on the basis of pre-determined recipes, that is, on the basis of the concrete mixture project, which should contain all the adopted quantities of component materials. The component materials of concrete are:

- aggregate (natural and crushed),
- cement (CEM I 42.5R, CEM II A-M (S-L) 42.5R),
- chemical additives (Sika ViscoCrete 3070, Sik-Aer, Sika ViscoCrete 1020X),
- water.

2.1 Aggregate

Within the research, crushed stone from the quarry "Rakovac" and natural gravel from the Drina river were used. After delivery of the aggregate, dry screening was carried out, and representative sample was obtained by the method of quartering [8]. The line of sieving of natural and crushed aggregates is shown in Figure 1.

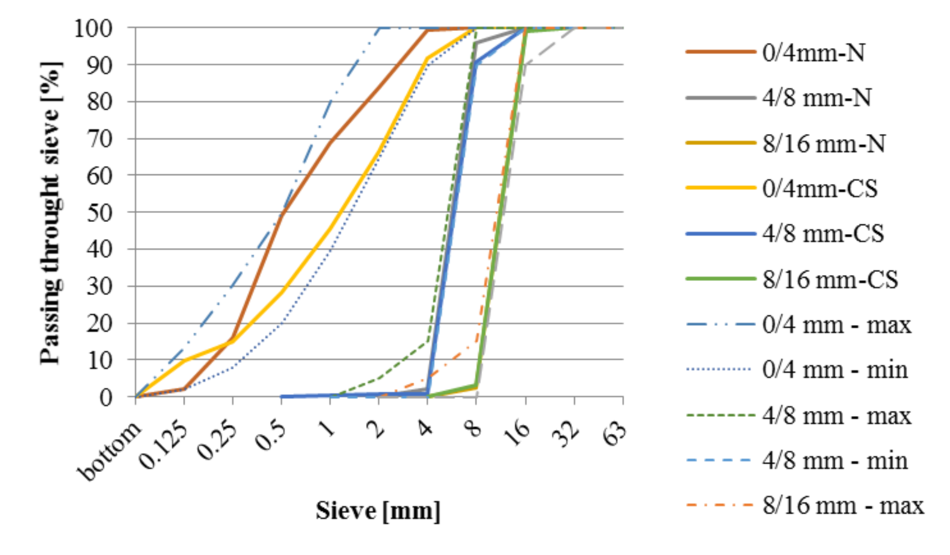

Figure 1 – Granulometric composition of natural (N) and crushed aggregates (CS)

After the granulometric composition examining, it is noticed that there are no submerged and excessive grains for natural gravel and crushed stone aggregate.

2.2 Cement

Two types of cement were used for the binder: CEM I 42.5R and CEM II A-M (S-L) 42.5R. The physical and mechanical properties of cement were tested according to the standards: SRPS EN 196-1 [9], SRPS EN 196-3 [10] and SRPS EN 196-6 [11]. Based on the obtained results, it was concluded that both types of cement satisfied the prescribed physical-mechanical properties defined in the standard SRPS EN 197-1 [12].

Table 1 – Physical and chemical properties of cement

Type of testing		CEM I 42.5R	CEM II A-M (S-L) 42.5R
Fineness (on sieve) [%]		0.30	0.40
Standard consistency [%]		28.4	28.2
Setting time	start after [min]	180	125
	finish after [min]	240	185
Volume stability (Le Chatelier) [mm]		0	0
Specific surface [cm^2/g]		4100	4100
Specific mass [g/cm^3]		3.14	3.07
SiO_2 [%]		20.76	20.65
Al_2O_3 [%]		5.87	4.96
Fe_2O_3 [%]		3.22	2.87
CaO [%]		61.22	60.72
MgO [%]		3.01	3.01
SO_3 [%]		3.18	2.84

Na_2O [%]	0.41	0.35
K_2O [%]	0.80	0.71
MnO [%]	0.16	0.17
Loss by ignition [%]	1.31	3.94

From the mechanical properties, compressive strength and flexural strength were tested on cement samples. The results of the mechanical properties test are shown in Table 2. For each mechanical property, three samples were examined, ie Table 2 shows the mean value of the tested samples after a certain age.

Table 2 – Mechanical properties of cement

Type of testing	Sample age [days]			
	CEM I 42.5R		CEM II A-M (S-L) 42.5R	
	2	28	2	28
Compressive strength	29.4	52.3	27.2	51.8
Flexural strength	6.9	8.9	6.1	8.8

2.3 Chemical additives

Two superplasticizers were used during the concrete production (Sika ViscoCrete 3070 and Sika ViscoCrete 1020X) and aerator (Sik-Aer). Addition of the superplasticizer was used for the purpose of improving the embedding and workability of the mixture and reducing the amount of water.
Aerators in the concrete structure form fine, uniformly distributed air bubbles.

2.4 Concrete mixtures

Three concrete mixtures, which are marked with M1, M2 and M3, were made for testing. During the examination process, two types of cement from the same manufacturer LaFarge were used, while for the aggregate, the combination of natural and crushed stone aggregates was used. The ingredients of all concrete mixtures are shown in Table 3. During the production of the M1 mixture, only the natural aggregate was used, while the combination of natural and crushed stone aggregates was used for the mixture M2. For the first fraction, a natural aggregate was used, while a crushed stone aggregate from the quarry was used for the second and third fractions. The M3 mixture was made by combining natural and crushed stone aggregates for the first fraction, ie 20% of the natural aggregate and 20% of the crushed aggregate. For other fractions (second and third), a crushed stone aggregate was used.

Table 3 – Quantity of ingredients for 1m³ of concrete

Mixture ingredients [kg/m³]		M1		M2		M3	
Cement		1)350		2)360		1)440	
Aggregate	0/4	45%	1868	50%	1810	40%	1667

	4/8	55%	25%	27%
	8/16	-	25%	33%
Superplasticizer		(ViscoCrete 3070) 2.10	(ViscoCrete 1020x) 2.88	(ViscoCrete 3070) 3.96
Aerant		(SikAer) 0.05	-	(SikAer) 0.01
Water		160	175	195
Water-cement factor		0.457	0.486	0.443

After the concrete mixtures were made, the following physical-mechanical properties for the given mixtures were tested:
- compressive strength,
- density.

2.1.1 Compressive strength

Compressive strength is defined as the average stress in the sample exposed to fracture force of axial pressure in the case of a certain concrete age. The compressive strength was tested on concrete blocks 15x15x15cm, and the concrete mark was defined. The samples were cured in a wet chamber and tested after 7 and 28 days. The compressive strength test was performed according to the standard SRPS ISO 4012 [13].

2.1.2 Density

In each comressive strength test, the measurement of the sample weight was done and then the measurement of the dimensions of the tested cubes was performed. After the measurements, the density of hardened concrete can be calculated after 7 and 28 days when the samples were tested.

3. RESULTS OF EXAMINATION AND DISCUSSION

After the tests were carried out, statistical data processing of the compressive strength and density after 7 and 28 days was done. Three different types of concrete mixtures were prepared, and for each of them three cubes were tested. For statistical data processing it was done:
- mean value,
- standard deviation,
- coefficient of variation.

The mean value of the sample is calculated using the equation 1:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where:
$\bar{x}$ - arithmetic average of n test results,
x_i – the value of each individual sample of the n result,
n – number of samples.
Determining the standard deviation value (σ) is performed by the equation 2:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}}$$

where:
σ - standard deviation,
$\bar{x}$ arithmetic average of n test results,
x_i – the value of each individual sample of the n result,
n – number of samples.
The coefficient of variation (C_u) is determined using equation 3, whereby the standard deviation should first be calculated:

$$C_v = \frac{\sigma}{\bar{x}}$$

где je:

C_v – coefficient of variation of the tested property,

σ – standard deviation,

$\bar{x}$ - arithmetic average of n test results.
Table 4 shows the mean values, the standard deviation, and the coefficient of variation obtained by the test. This statistical data processing also serves to determine deviations from the arithmetic average, as well as the representation of the variability, or whether it belongs to a homogeneous or hetoregenic set (C_u <30% - homogeneous set, C_u> 30% - heterogeneous set), or whether the variability is significantly lower from the arithmetic average.

Table 4 – Mean value, standard deviation and coefficient of variation of the results from the compressive strength and density test

Properties of hardened concrete		Concrete mixture		
		M1	M2	M3
7-days of compressive strength [MPa]	$\bar{x}$	28.90	43.13	45.23
	σ	0.80	0.53	0.76
	C_v	3.0	1.0	2.0

28-days of compressive strength [MPa]	$\bar{x}$	40.87	55.13	57.43
	σ	0.85	0.82	0.82
	C_v	2.0	1.0	1.0
7-days of density [kg/m^3]	$\bar{x}$	2264.0	2339.3	2338.6
	σ	0.82	1.25	5.31
	C_v	0.0	0.0	0.0
28- days of density [kg/m^3]	$\bar{x}$	2275.0	2339.0	2354.0
	σ	2.83	5.10	5.10
	C_v	0.0	0.0	0.0

After analyzing the results it was observed that standard deviation satisfies all the conditions in the test, except for the testing of the density at the age of 28 days, where the values of standard deviation are more expressed compared to other samples. The variation coefficient values are lower and all the obtained results belong to the group of homogeneous set, that is, the variability is significantly lower than the arithmetic average. The maximum compressive strength was obtained for the M3 mixture, while the minimum tensile strength was achieved for the M1 mixture.

3.1 Compressive strength

Figure 2 on the left shows the values of compressive strength after 7 days. From the figure, it is observed that the M3 mixture has the maximum achieved compressive strength values, while the minimum values have been achieved for the M1 mixture. The same case occurs for strength at pressure after 28 days. The same case occurs for compressive strength after 28 days.

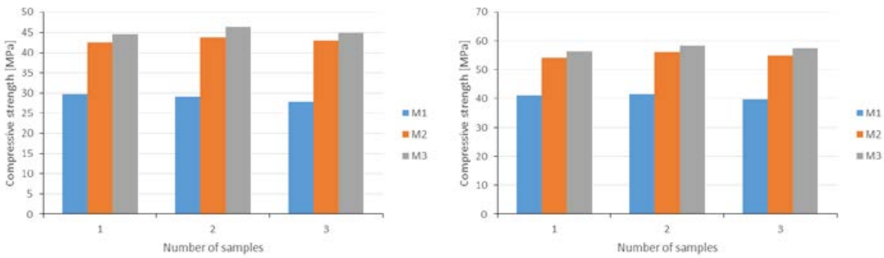

Figure 2 – Compressive strength after 7 days (left) and after 28 days (right)

All tested mixtures satisfy the requirement of SRPS U.E3.020 standard [14], that is, all tested compressive strength values after 28 days are greater than or equal to 40MPa. If the values are equal to or greater than 40MPa, concrete mixtures can be applied to the production of concrete pavements for heavy traffic loads. Mixture M1 is the only mixture that is at the limit, while the other two mixtures (M2 and M3) significantly satisfy the prescribed conditions.

3.2 Density

The volume of hardened concrete after 7 days is shown in Figure 3 on the left, while after 28 days it is shown in Figure 3 on the right. The maximum value of the density after 7 days is approximately the same in the mixtures M2 and M3, since for the first sample the mixture M2 has a higher density than the M3 mixture, while in the second sample the higher value was achieved for the mixture M3 and smaller for the mixture M2. Observing the third test sample after 7 days, it is noticeable that both mixtures (M2 and M3) have uniform values of the density. The minimum value was significantly achieved in the M1 mixture for density after 7 days. Comparing density values after 28 days, it is noticeable that the maximum value was achieved for the M3 mixture, and the minimum value was achieved for the concrete samples of the M1 mixture.

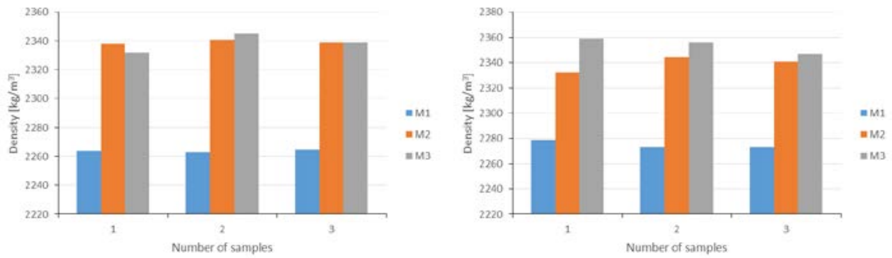

Figure 3 – Density after 7 days (left picture), density after 28 days (right picture)

4. CONCLUSION

Based on analyzed tests for different types of concrete mixtures, the following can be concluded:

- the granulometric composition of the aggregate used for the preparation of concrete samples has no deviation from the reference area,
- the compressive strength test shows that the concrete samples made from the M3 mixture have maximum values and satisfy the criterion that the strengths are greater than 40MPa,
- the density values of the samples are not uniform and depend on the water-cement factor and the chemical additives used in the preparation of concrete samples.

The general conclusion for all concrete tested samples is that they satisfy the requirement of SRPS U.E3.020 standard [14], that is, all values are greater than or equal to 40MPa, and can be used to produce concrete pavements for heavy traffic loads.

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ИСПИТИВАЊЕ ПОРОЗНИХ БЕТОНСКИХ МЕШАВИНА ЗА ИЗРАДУ БЕТОНСКОГ КОЛОВОЗА

Резиме: *Бетонски коловоз представља круту коловозну конструкцију у односу на асфалтне коловозе. За анализу је извршено испитивање три претходне пробе, на којима су касније извршена испитивања чврстоће при притиску и запреминске масе. Испитивање је вршено након 7 и 28 дана, при чему су узорци неговани у лабораторијским условима. Мешавине се разликују према врсти и количини цемента, агрегата, суперпластификатора, аераната и водоцементног фактора. Након извршених испитивања закључено је да све три бетонске мешавине* *испуњавају услов за израду бетонског коловоза, односно да је чврстоћа при притиску након 28 дана већа или једнака од 40MPa.*

Кључне речи: *бетонски коловоз, чврстоћа при притиску, запреминска маса*