Cement Concrete Modular Pavement Implementation for Pedestrian and Bicycle Path

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Abstract. Cement concrete modular pavements, also known as precast concrete pavements, designed for pedestrian and bicycle paths is the advanced next-generation technology characterised as high quality, durable, quickly built and easily maintained. Polypropylene fibre reinforced concrete mixture is more frequently used to improve the properties of concrete slabs and to reduce thickness. The thickness of the slab could be reduced to 8–10 cm using the appropriate fibre. This paper focuses on the selection of slab dimensions and verification of fibre reinforced concrete mixture production method when fibres are added to the factory-made concrete mixture (available from the concrete plant) and evaluation of different surface texture of concrete slabs produced by using special texture mats. Seven different combinations of concrete slabs have been developed, constructed and tested in 21 m length pedestrian pathway in Vilnius city. The analysis of mechanical and surface characteristics of these slabs are presented in this paper. The research revealed that the most suitable (pendulum test values ≥ 55) surface texture for the pedestrian pathway is formed by using texture mats.

1. Slab dimensions selection for cement concrete modular pavement

Pedestrian and bicycle paths are an important part of road infrastructure that provides mobility for pedestrians and cyclists in urban areas and nearby. The pavement of pedestrian and bicycle paths should be stable, firm, even, relatively smooth but slip resistant to ensure comfort mobility. Pedestrian and bicycle paths should be incorporated in the surrounded area in order to ensure harmony, express the local community's individuality and improve safety and comfort in urban areas. These issues are achieved using coloured (non-black) asphalt concrete and different laying patterns of interlocking concrete paver blocks. However, these solutions are old-fashioned, and they do not reflect the needs of nowadays society and innovativeness. Previous research has shown [1–2] that cement concrete modular pavements, also known as precast concrete pavements, are suitable for pedestrian and bicycle paths, and successfully address these problems if they are properly designed.

Cement concrete modular pavement consists of prefabricated concrete slabs that are transported to the project site only after the curing period when the desirable concrete strength is achieved and installed on a prepared foundation [3]. Fabrication of slabs in a plant enables the achievement of different pavement texture and style. That is one of the most important factors in the design of pedestrian and bicycles paths in urban areas. In addition to other advantages of slabs fabrication in a plant such as better concrete quality, controlled concrete curing conditions, elimination of materials...
segregation etc., concrete modular pavements are easily removable, mechanically independent. That is the crucial aspect of getting access to underlying utilities for repair and replacement [1–3].

In accordance with the Lithuanian Roads Technical Regulation KTR 1.01:2008 "Roads", the width of the pavement of general bicycle and pedestrian paths shall be at least 2.5 m (joint) on public roads or nearby. The minimum width of the pedestrian path depends on the number of pedestrians during traffic congestion hours, and the minimum width of the pedestrian path shall be 2.0 m if separate, and the width may be reduced to 1.5 m or 1.0 m in justified cases. The minimum width of the bicycle path shall be 2.5 m, and the width may be reduced to 2.0 m if separate in justified cases. Under the Lithuanian technical regulation for construction STR 2.06.04:2014 "Streets and local roads. General Requirements" on streets and local roads or near to them, the width of the bicycle path shall be at least 1.0 m, if the cycle path is with one lane or at least 2.0 m if the path is with two lanes. The minimum pavement width for common cycling and walking paths shall be 2.3 m. The minimum width of the pavement shall be 1.5 m. Thus, the width of the pedestrian paths should not be less than 1.5 m. The width of bicycles paths with one and two lanes in streets, local roads or along them should be at least 1.0 m and 2.0 m, respectively. Due to that, and ensuring easy transportation, handling and installation it was found that optimal dimensions of concrete slab are 1.0 m in length and 1.5 m in width. The slab dimensions have been selected considering not only predominant loads but also slab extraction from precasting moulds and handling with a vacuum lift.

The objective of this paper is to produce, construct and test concrete modular pavement with different surface texture characteristics and to identify the most suitable one for pedestrian and bicycle paths.

2. Concrete mixture selection for cement concrete modular pavement

Previous research has shown that typically the thickness of concrete slab for roads is 20–30 cm [3] and for the production of these slabs are used C30/37–C40/50 class concrete (compressive strength 27.5–40.0 MPa after 28 days respectively) [4]. However, the weight of the concrete slab of this thickness is too heavy for extraction from precasting moulds by hand and handling with a vacuum lift. Also, the pavement of the pedestrian and bicycle path is subjected to significantly lower loads than pavements of roads. Thus, there is no need to install 20–30 cm thickness concrete slab in the pedestrian and bicycle path. Moreover, the thickness of interlocking concrete paver blocks on pedestrian and bicycle paths is typically 8–10 cm. Consequently, based on selected optimal dimensions of the concrete slab (1.0 m in length and 1.5 m in width) preferable thickness of concrete slab has been calculated that is 5–6 cm. In this point, the question of ensuring a necessary bearing capacity and resistance to cracking during transportation and handling has arisen.

More than 20 years ago, Wafa [5] concluded that using fibres for concrete reinforcement, the thickness of the slabs could be reduced about twice in comparison with plain concrete slabs. Kustermann and co-authors [6] investigated fibre reinforced concrete under high dynamic impact loading. It has been demonstrated that the thickness of the slab could be reduced to 8–10 cm using the appropriate fibre. Fibre reinforced concrete is widely used in civil engineering because fibres are useful in providing greater resistance to cracking of plastic shrinkage and service related cracking. Steel fibres are often used to improve the flexural toughness of concrete while synthetic (polypropylene) fibres are more often used to reduce crack opening due to shrinkage. Buratti and co-authors [7] observed that the performance of steel fibres reinforced concrete is better than macro synthetics reinforced concrete. Jayakumar and co-authors [8] concluded that the flexural strength of propylene fibres reinforced concrete with long and short fibres is higher than in the case of concrete reinforced with short polypropylene and long steel fibres. In addition, it has been concluded that toughness of fibres reinforced concrete is better using long fibres combinations than short fibres and postcrack toughness is better in case of long steel and long polypropylene fibres combinations. Amin and co-authors [9] investigated macro synthetic fibre reinforced concrete. It has been demonstrated that the resistance to stress increased when polypropylene fibres were used during the flexural strength test with increased displacement. Guerini and co-authors [10] observed that stiffness of long fibres (steel and polypropylene) reinforced concrete is better than short fibres reinforced concrete.
Furthermore, it was observed that smoothness of polypropylene reinforced concrete surface is better than steel fibres reinforced concrete, but steel fibres influenced concrete workability less as compared to polypropylene fibres. As the density of polypropylene fibres is about 9 times lower than that of metal fibres, as well as the metal fibres are heavier, there are fewer metal fibres in the volume of the concrete mixture, which makes it easier to mix the concrete mixture.

Based on the literature analysis, it has been selected to reinforce concrete with short and long polypropylene fibres for the production of pedestrian pathway concrete slabs.

Generally, a fibre reinforced concrete mixture is produced at the factory site by adding fibres to a dry mixture of aggregates, binder and additives before adding water. The objective of this paper is to evaluate fibre reinforced concrete mixture production method, when fibres are added to factory-made C30/37–C40/50 class concrete mixture (available from the concrete plant).

3. Experimental research

3.1. Test site and materials

An existing pedestrian pathway located nearby Road Research Institute of Vilnius Gediminas Technical University building in Vilnius (Lithuania) was selected for the installation of concrete modular pavement. The width of this pedestrian pathway is 1.5 m, so it was suitable for the installation of concrete slabs. It was selected a 21 m long straight section. The pavement of selected pedestrian pathway was concrete blocks. So, it was decided to remove these concrete slabs and to install a prefabricated concrete slab after levelling and pre-compacting the existing base course.

Based on literature analysis, it was selected 0.05 m thickness, 1.00 m length, and 1.50 m width concrete slabs. All concrete slabs were produced at the factory using factory-made concrete mixture, which properties are given in table 1. Factory-made concrete mixture was transported to modules pavement production site and reinforced with micro and macro polypropylene fibres in 400 l volume mixing machine. The properties of micro and macro polypropylene fibres are given in table 2. The amount of micro and macro fibres was 0.9 kg/m³ (0.43% by volume) and 4 kg/m³ (0.01% by volume) respectively, as it was recommended by the producer. The mixing of fibre reinforced concrete mixture and the addition of fibres were performed according to the instructions of fibre producers. Fibres were added to factory-made concrete mixture. Thus, the processes of design and control of fibre reinforced concrete mixture were skipped in order to test the simplicity and speed of production of such fibre reinforced concrete in the construction site. All slabs were compacted in prepared moulds with needle vibrator.

The surface of 14 concrete slabs was produced by gluing a synthetic special texture mat (see figure 1) into the concrete mould. Eight concrete slabs were made with a rough surface texture using special texture mat (see figure 1 (a)) and two of them were coloured with red pigment. Six concrete slabs were made with less rough surface texture using special texture mat (see figure 1 (b)) and two of them were coloured with red pigment. The surface of two concrete slabs was coloured with red powder. Others concrete slabs were produced typically – smooth texture and grey colour. Overall, there were produced 20 concrete slabs (see table 3).

| Property                                | Class  |
|-----------------------------------------|--------|
| Compressive strength                    | C35/45 |
| Exposure of corrosion induced by carbonation | XC4    |
| Exposure of corrosion induced by chlorides other than from sea water | XD3    |
| Exposure of freeze/thaw attack          | XF4    |
| Chloride content                        | Cl0.2  |
Table 2. Characteristics of micro and macro fibres used in this study

| Characteristics      | Type or Values |
|----------------------|----------------|
| Fibre Type           | Polypropylene  |
| Description          | Micro, Macro   |
| Shape                | Smooth         |
| Length l, mm         | 13, 40         |
| Diameter Ø, mm       | 0.022, 0.7     |
| Aspect Ratio l/ Ø    | 590, 57        |
| Tensile Strength, MPa| 380, 500       |
| Elastic Modulus, GPa | –, 6           |
| Density, kg/m³       | 905, 922       |

Figure 1. Rough (a) and less rough (b) surface texture mats (www.companero.biz)

Table 3. Type of concrete slabs

| No.         | Quantity | Surface texture and colour                  |
|-------------|----------|---------------------------------------------|
| From 1 to 6 | 6        | Rough texture, grey (natural) colour        |
| From 7 to 10| 4        | Less rough, grey (natural) colour           |
| From 11 to 12| 2      | Smooth texture, grey (natural) colour       |
| From 13 to 14| 2       | Smooth texture, coloured using red powder   |
| From 15 to 16| 2       | Rough texture, red colour pigment           |
| From 17 to 18| 2       | Less rough texture, red colour pigment      |
| From 19 to 20| 2       | Smooth texture, grey (natural) colour       |

Note: The numbering of concrete slabs is in accordance with the installation sequence on the test site.
At factory site produced and from precasting moulds extracted, then transported (after 28 days of concrete curing) to test site concrete slabs were installed using vacuum lift in early fall of 2019 (see figure 2).

3.2. Test methods
During the production of concrete slabs, it was prepared 114 cubic specimens, 76 beam specimens and 76 cylindrical specimens. The compressive, flexure and tensile splitting strength of specimens made of the concrete mixture without and with fibres were determined.

Three cubic specimens of 100 × 100 × 100 mm in size were prepared for each of concrete mixtures. Compression tests were performed after 28 days of concrete curing. Compressive strength was determined by standard EN 12390-3.

Flexural strength was determined by standard EN 12390-5 for each of concrete mixtures. The four-point bending tests were performed on beam specimens sized 100 × 100 × 400 mm (two specimens for each concrete mixture), with a span length of 300 mm. Flexural strength tests were performed after 28 days of concrete curing.

Tensile splitting strength was determined by standard EN 12390-6 for each of concrete mixtures. Tests were performed on cylindrical specimens sized 100 mm in length and diameter after 28 days of concrete curing.

After installation of concrete slabs in the test site, measurements of slip/skid resistance of a cement concrete modular pavement surface were performed by standard EN 13036-4 using pendulum device on the left, axis and right side of each concrete slab. In addition, measurements of surface texture characteristics were done at two randomly selected locations of each concrete slab:

- mean texture depth by standard EN 13036-1 using a volumetric patch technique;
- mean profile depth by standard ISO 13473-1.
4. Results and analysis

4.1. Mechanical characteristics

Results of compressive, flexural and tensile splitting strength for all concrete mixtures are presented in figures 3–5. A box and whisker plot also called a box plot, the analysis was performed, which displays the minimum, first quartile, median, mean, third quartile, and maximum. A level of 95% of confidence was applied.

From the results of compressive strength (see figure 3), it is evident that the usage of fibres for concrete reinforcement reduces the compressive strength. The average compressive strength of plain concrete is 56.13 MPa while of fibre reinforced concrete is 39.45 MPa (reduction is about 30%). The results of compressive strength of plain and fibre reinforced concrete vary in the similar range: 28.4 MPa (from 43.7 MPa to 72.1 MPa) and 41.3 MPa (from 24.1 MPa to 65.4 MPa) respectively.

Figure 3. Results of compressive strength

Figure 4. Results of flexural strength
The results of flexural strength are presented in figure 4. The analysis shows that fibres reduce the flexural strength of concrete, similar to that was found in the compression test. The average flexural strength of plain concrete is 5.83 MPa while fibre reinforced concrete revealed the flexural strength of 5.05 MPa (reduction is about 13%). The results of flexural strength of plain and fibre reinforced concrete vary in these ranges: 3.59 MPa (from 4.52 MPa to 8.11 MPa) and 3.92 MPa (from 3.41 MPa to 7.33 MPa) respectively, and both presents outliers above the third quartile.

Tensile splitting strength results (see figure 5) show that the average tensile splitting strength of fibre reinforced concrete (3.03 MPa) is 7% lower than that of plain concrete (3.27 MPa), and this decrease is much lower than that was found during compressive and flexural tests. Also, the results of tensile splitting strength of plain concrete vary in 1.8 times less range than that of fibre reinforced concrete: 1.48 MPa (from 2.42 MPa to 3.90 MPa) and 2.65 MPa (from 2.02 MPa to 4.67 MPa) respectively.

![Figure 5. Results of tensile splitting strength](image)

**Table 4.** Descriptive statics of the mechanical properties (values in MPa)

| Mechanical property          | Concrete reinforcement | Min  | Max  | Mean  | Standard deviation |
|------------------------------|------------------------|------|------|-------|--------------------|
| Compressive strength         | Not reinforced         | 43.7 | 72.1 | 56.13 | 6.24               |
| Flexural strength            | Fibre reinforced       | 24.1 | 65.4 | 39.45 | 9.83               |
| Tensile splitting strength   | Not reinforced         | 4.52 | 8.11 | 5.83  | 0.68               |
| **Flexural strength**        | Fibre reinforced       | 3.41 | 7.33 | 5.05  | 0.89               |
| Tensile splitting strength   | Not reinforced         | 2.42 | 3.90 | 3.27  | 0.38               |
| **Fibre reinforced**         |                        | 2.02 | 4.67 | 3.03  | 0.66               |

Table 4 summarises the results on compression, flexural and tensile splitting tests concrete samples considered in this study. The experimental results showed that mechanical properties, like compressive, flexural and tensile splitting strengths, of fibre reinforced concrete is about 16% lower than that of plain concrete. This fact is proved in the scientific papers [8, 10–12], no significant differences can be observed or mechanical properties, like compressive strength, of fibre reinforced concrete can be even lower than that of plain concrete. In addition, it was observed that after flexural
and tensile splitting tests the fibre reinforced concrete specimens split into half (see figure 6), while the fibre reinforced concrete specimens stayed on the fibres after fracture and cracking. So, this indicates sufficient adhesion between fibres and concrete. This property has been confirmed by the research of other scientists [13–15], that there is an appreciable increase in postcrack energy absorption capacity and ductility due to the addition of fibres. Table 4 showed that standard deviations of fibre reinforced concrete mechanical properties is about 54% higher than that of plain concrete. This can be explained by inefficient mixing method of fibres in the concrete mixture. The obtained effect is negative. Therefore, in the production of fibre reinforced concrete mixture, the priority should be given to the addition of fibres before adding water. Also, it is important that the fibres would be dispersed uniformly throughout the mixture. Introduction of the fibres through a wire mesh basket will help even distribution of fibres. Moreover, one of the reasons for poor mixing may be too small fibres content, which was selected according to the fibres manufacturer's recommendations for the minimum quantity. By increasing the minimum amount of fibres specified by the manufacturer, it is likely that better properties of the fibre reinforced concrete mix could be achieved. The latter insight is intended to be researched by the authors in other studies.

Figure 6. A crack in the polypropylene fibre reinforced concrete specimen after the flexural test

After the use of path for 10 months, even with the winter maintenance activities (de-icing with sodium chloride and lightweight snow removal machinery) all slabs does not have any distresses or defects.

4.2. Surface characteristics
Surface characteristics such as mean profile depth, mean texture depth and skid resistance play the main role in pedestrian safety. Figure 7 illustrates the skid resistance of cement concrete modular pavement made of different type of concrete slabs. The analysis of pendulum test values indicates that concrete slabs No. 11, No. 12, No. 13, No. 14, No. 19 and No. 20 with smooth (texture was not formed using texture mats) texture has lower pendulum test values (vary from 38 to 50) than others (vary from 54 to 71). In addition, it was observed that pendulum test values of concrete slabs, which surface was coloured with red powder (concrete slabs No. 13 and No. 14), are lower than 40. And, no significant differences can be observed comparing pendulum test values of concrete slabs, which surface texture was formed using different texture mats (rough and less rough texture).

Results of mean profile depth are presented in figure 8. A mean profile depth of the concrete slabs, which surface was formed using texture mat with rough texture, was about 0.08 mm. The concrete slabs with a smooth texture and concrete slabs, which surface was formed using texture mat with less rough texture, have the lowest mean profile depth (lower than 0.05 mm). It is averagely 0.04 mm, while the mean profile depth of concrete slabs, which surface was coloured with red powder, varies from 0.09 mm to 0.13 mm.
Results of mean texture depth are presented in figure 9. Mean texture depth of the concrete slabs, which surface was formed using texture mat with rough texture, was about 0.27 mm. The concrete
slabs with a smooth texture and concrete slabs, which surface was formed using texture mat with less rough texture, have the lowest mean profile depth. It varies from 0.22 mm to 0.24 mm, while the mean profile depth of concrete slabs, which surface was coloured with red powder, varies from 0.27 mm to 0.30 mm.

![Figure 9. Results of mean texture depth](image)

Mean profile depth, mean texture depth and skid resistance test results shows that the most suitable surface texture for the pedestrian pathway is formed by using texture mat (with rough or less rough surface texture) when sufficient skid resistance is ensured. Also, a rough surface is obtained when the surface was coloured with red powder, but then the skid resistance is insufficient (pendulum test values are less than 40), and values are lower than that of concrete slabs, which were not coloured and surfaces were not formed by using texture mats.

5. Conclusions
This paper presented a study of the design, prefabrication and installation, of thin synthetic fibre reinforced cement concrete slabs with different texture for the pedestrian path. The mechanical and surface characteristics were tested, as well. The results have shown that compressive, flexural and tensile splitting strengths of fibre reinforced concrete is about 16% lower than that of plain concrete. This can be explained by inefficient mixing method when fibres were added not to the aggregate mixture but to the factory-made concrete mixture. The chosen method of addition of fibres to the factory-made concrete mixture is not suitable for improving the strength properties of concrete slabs compared to a standard concrete mix. Measurements of surface characteristics have shown that the most suitable (pendulum test values are not less than 55) surface texture for the pedestrian pathway is formed by using texture mat with rough (skid resistance values vary from 58 to 71) or less rough surface (skid resistance values vary from 54 to 69) texture. Also, a rough surface (mean profile depth is not less than 0.05 mm) was obtained when the surface was coloured with red powder (mean profile depth vary from 0.093 mm to 0.128 mm), but then the skid resistance is insufficient (pendulum test values are less than 40). And, concrete slabs which surface was coloured with red powder has a lower
skid resistance than that of concrete slabs, which were not coloured and surfaces were not formed by using texture mats (pendulum test values are greater than 40, but less than 55). The skid resistance of concrete slabs with a smooth texture is not sufficient (lower than 55, and mean profile depth is lower than 0.05). In this case, some texturing actions should be applied, seeking to reach skid resistance limit values. After the use of path for 10 months, even with the winter maintenance activities (de-icing with sodium chloride and lightweight snow removal machinery), all slabs do not have any distresses or defects.

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**References**

[1] Gražulytė J, Vaitkus A, Laurinavičius A and Čygas D 2019 Concrete modular pavement type selection based on application area *The 13th Int. Conf. Modern Building Materials, Structures and Techniques* (Vilnius: VGTU Press) pp 318-23.

[2] Vaitkus A, Andriejauskas T, Šernas O, Čygas D and Laurinavičius A 2019 Definition of concrete and composite precast concrete pavements texture *Transport* 34(3) pp 404–14

[3] Vaitkus A, Gražulytė J, Kleizienė R, Vorobjovas V and Šernas O 2019 Concrete modular pavements - types, issues and challenges *Baltic Journal of Road and Bridge Engineering* 14(1) pp 80–103

[4] Vaitkus A, Kleizienė R, Vorobjovas V and Čygas D 2019 Mixture strength class and slab dimensions' effect on the precast concrete pavement structural performance *Baltic Journal of Road and Bridge Engineering* 14(3) pp 443–71

[5] Wafa F F 1990 Properties and applications of fiber reinforced concrete *Engineering Science* 2 pp 49–63

[6] Kustermann A and Keuser M 2004 High strength fibre reinforced concrete (HSFRC) under high dynamic impact loading *The 6th RILEM Symposium on Fibre-reinforced Concretes*, ed M di Prisco, R Felicetti and G A Plizzari (RILEM Publications SARL) pp 1217–26

[7] Buratti N, Mazzotti C and Savoia M 2011 Post-cracking behaviour of steel and macro-synthetic fibre-reinforced concretes *Construction and Building Materials* 25(5) pp 2713–22

[8] Jayakumar V J, and Anandan S 2014 Composite strain hardening properties of high performance hybrid fibre reinforced concrete *Advances in Civil Engineering* 2014(3) p 9

[9] Amin A, Foster S J and Gilbert R I 2017 Material characterisation of macro synthetic fibre reinforced concrete *Cement and Concrete Composites* 84 pp 124–33

[10] Guerini V, Conforti A, Plizzari G, and Kawashima S 2018 Influence of steel and macro-synthetic fibers on concrete properties *Fibers* 6(47) p 14

[11] Caggiano A, Cremona M, Faella C, Lima C and Martinelli E 2012 Fracture behavior of concrete beams reinforced with mixed long/short steel fibers *Construction and Building Materials* 37 pp 832–40

[12] Soulioti D V, Barkoula N M, Paipetis A and Matikas T E 2011 Effects of fibre geometry and volume fraction on the flexural behaviour of steel-fibre reinforced concrete *Strain* 47 pp 535–41

[13] Sivakumar A and Santhanam M 2007 Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres *Cement and Concrete Composites* 29(8) pp 603-8

[14] Khaloo A and Afshari M 2005 Flexural behaviour of small steel fibre reinforced concrete slabs *Cement and Concrete Composites* 27 pp 141–9

[15] Pelisser F, Santos N A, Rovere H and Pinto R 2010 Effect of the addition of synthetic fibers to concrete thin slabs on plastic shrinkage cracking *Construction and Building Materials* 24 pp 2171–76