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"Gheorghe Asachi" Technical University of Iasi, Romania

IMPROVED CONCRETE BLOCKS WITH DISPERSED FIBERS AS CONTRIBUTION FOR ENVIRONMENTAL PROTECTION

Radu Muntean[1*], Cătălina Mihaela Grădinaru[2],
Adrian Alexandru Șerbănoiu[2], Gabriel Constantin Sârbu[3]

[1]*Transilvania University of Brașov, Faculty of Civil Engineering, 5 Turnului Street, 500152 Brașov, Romania*
[2]*"Gheorghe Asachi" Technical University of Iași, Faculty of Civil Engineering and Building Services, 1 Prof. Dimitrie Mangeron Blvd., 700050 Iași, Romania*
[3]*"Gheorghe Asachi" Technical University of Iași, Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, 65 Prof. Dimitrie Mangeron Blvd., 700050 Iași, Romania*

Abstract

The constructions using concrete material significantly contribute to global environmental pollution as a result of the consumption of both natural resources and carbon dioxide emissions in their life cycle. Therefore, it is necessary to develop materials that ensure an increased durability for a longer life cycle of the constructions, in order to reduce their impact on the environment. This study aims to analyze the use of polypropylene fibers as dispersed reinforcement of concrete used in the manufacture of concrete paving blocks as an option to increase their durability by improving their mechanical properties and minimizing the cracking process, while the environmental pollution is reduced by recycling the polymeric waste from which these fibers are made. There were performed experimental tests, according to the SR EN 1338:2004 stipulations, over the splitting tensile strength at 3, 7, 14, and 28 days for paving blocks made of dispersely reinforced concrete with polypropylene fibers, executed by two different methods: by casting and vibration, and by vibration together with pressure-applying. The results showed an increased efficiency, as an average of improvements in the physical mechanical characteristics of the tested elements relative to the reference specimens without fiber addition, with values between 32% and 56%, which means higher mechanical strengths even from early ages, higher compaction and, implicitly, low cracking rates, resulting an extended service life and reduced or partially reduced maintenance, repair or replacements.

Keywords: fiber reinforced concrete, paving blocks, polypropylene fibers

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1. Introduction

Increased demand for construction of any kind results in a continuous and severe degradation of the environment due to the depletion of the raw materials and conventional energy sources used for the extraction, production and transport of used materials, their commissioning and their deconstruction and reintegration into the environment. Also, the lifetime service of buildings or of different building elements plays a predominant role in assessing their environmental impact through the quantity of released carbon emissions determined by the frequency of their replacement in connection of their durability (Ciocan et al., 2017; Verbitsky and Pushkar, 2018). From this point of view, an increased durability of the constructions must be ensured by finding new materials that satisfy this condition, besides preserving or improving the physical, mechanical and chemical characteristics of classical materials. This research direction is a current and a perspective concern in the construction field.

In this context, the use of the conventional concrete is somewhat limited when there is necessary

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[*] Author to whom all correspondence should be addressed: e-mail: radu.m@unitbv.ro; Phone: +40745183892

to ensure higher cracking resistance, fire resistance, contraction resistance, shock resistance, wear resistance, durability, etc. For this reason, various and in-depth studies have been carried out showing that an improvement in concrete performance can be achieved by adding into its composition dispersed fiber reinforcement from different materials (Ciocan et al., 2017; Helepciuc (Gradinaru) et al., 2018; Lee et al.,2016; Li et al., 2018; Mohod, 2015; Muntean et al., 2016; Mustea et al., 2016).

Fiber Reinforced Concrete (FRC) was defined in 1973 Report of the American Concrete Institute (ACI - Committee 544, 1973) as “the concrete made of hydraulic cements that contains fine or fine and coarse aggregates and discontinuous discrete fibers”. This definition was taken over in 1977 by Majumdar et al. (1977). Therefore, fiber-reinforced concrete (FRC) results by incorporation in concrete mix of a variable amount of different types and sizes of discontinuous fiber, with miscellaneous properties.

FRC cannot replace the conventional reinforced concrete. However, there are areas of use where FRC can be used alternatively or in addition to the classic reinforced concrete, offering constructive and economic advantages. Fields of FRC use have a wide area, including concrete pipes, tunnels, floors and sidewalks (Qin et al., 2019), supporting walls, thin facade elements, prefabricated steps, airport runways, permanent formwork (Muntean R. and Muntean G., 2015; Muntean et al., 2018, Rudnov et al., 2016), repair and consolidation works (Al-Hadidy and Yi-qiu, 2009) and others.

Most FRC applications are based on the idea of improving strength properties. However, the role of fiber reinforcement is not only to improve the strength, but also to control the cracking process, and thereby to improve ductility, energy absorption and resistance to impact, shock and temperature variations (Qin et al., 2019; Ramakrishan et al., 1987). The fibers have the role of controlling the cracking process and of holding the fragments together even after advanced cracking. In this way, fibers can be used advantageously in simple concrete elements but also in reinforced concrete and prestressed concrete elements, due to the fact that they transform the concrete from a brittle material to somewhat a ductile one (Barluenga, 2010).

The basic requirements for the fiber characteristics, when improving mechanical strengths and cracking delay are required, are: high elongation resistance and adequate elasticity, increased matrix adhesion, chemical stability (Ramakrishan et al., 1987). Moreover, fibers should have the ability to sustain their efforts for a longer period of time.

The physical and chemical compatibility of fibers with the alkaline media characteristic of cement pastes is also important. In the short term, fibers that absorb significant amounts of water can cause an excessively rapid loss of concrete's working capacity, almost in the same way as lightweight aggregates do if they are mixed into the concrete composition. On long term, the fibers can be attacked by the water or alkaline media present in the cement paste composition (Jianqiang et al., 2016; Yin, 2015). For this reason, a particular importance should be given to the choice of the fiber used to make the concrete according to the cement characteristics and the applicability domains.

A variety of fibers, such as steel, glass, ceramic, organic polymers (Rudnov et al., 2016; Şerbănoiu et al., 2017), inorganic materials (asbestos) or vegetal (cotton, hemp, sisal), among others (Saxena et al., 2011), has been used in concrete. The performance of the fibers in concrete significantly depends upon the geometrical shape, size and aspect ratio (Sharma et al., 2014). Plastic materials and plastic waste, in particular, can also be used in concrete mixtures as dispersed or shredded fibers (Sharma and Bansal, 2015) or as aggregate replacement (Ismail and AL-Hashmi, 2008). In the present days, plastic is produced and used in large quantities, fact that determines similar quantities of waste. Its reduced biodegradability implies a big environmental impact, problem that needs to be solved. Incorporating plastic in concrete can be a solution for preventing its direct contact with the environment, however, this method is not a dominant one for plastic waste disposal. Plastic fibers, like polypropylene ones used as a dispersed reinforcement for concrete can improve the environmental protection by reducing the quantities of plastic waste and increasing the durability of the concrete elements (Sharma and Bansal, 2015).

This paper aims to analyze the use of polypropylene fibers (PPF) for the disperse reinforcement of concrete used in the manufacture of concrete paving blocks (CPB). These building elements are used all around the world in large quantities and with a high replacement frequency due to the environment in which they work (externally, subjected to temperature and freeze-thaw variations), to the loads to which they are required, or to the aggressive action of chemical agents (anti-skid mattresses, petrol, oils etc.). PPF were chosen to carry out this study due to their very good resistance properties in the wet environment also. Therefore, the use of PPF for reinforcing CPB can be an option for improving their durability by enhancing their mechanical characteristics, by reducing the cracking process, and also by decreasing the environmental pollution by polymer waste recycling (Muntean R. and Muntean G., 2012; Shehnila, 2013).

PPF are widely used in various industries, in order to manufacture geotextiles, packing bags, different types of coats or curtains, fishing nets etc. (Qin et al., 2019). Due to their very large applicability, PPF lead to high quantities of waste (Bendjillali et al., 2011; Mohammadian and Haghi, 2013; Qin et al., 2019; Wang, 2010). PPF are 100% pure polypropylene. These fibers are resistant to alkaline media created by cement mixtures without degrading. They are non-magnetic, corrosion-resistant, chemically neutral, and they do not absorb water (Qin et al., 2019; Singh, 2011). As applications of polypropylene-fiber-reinforced-concrete (PPFRC) are pavements, bridge decks, repair and rehabilitation work for tunnels, shotcrete, etc. (Mustea et al., 2017; Qin et al., 2019; Singh, 2011).

The PPF use in concrete mix improves the flexural strength and toughness of the concrete (Li et al., 2018; Qin et al, 2019; Wang et al., 2019). The uniformity and stability of the fresh mix are improved, segregation being diminished due to the network structure formed by the polypropylene fibers (Khan and Ali, 2018; Singh, 2011). PPFRC using enables the section size reduction of the elements (Lesovik et al., 2015; Muntean et al., 2018). The early plastic shrinkage cracking is diminished, the cracks propagation and post-cracking resistance are improved (Khan and Ali, 2018; Kosior-Kazberuk and Berkowski, 2016; Li et al., 2018; Qin et al., 2019; Singh, 2011; Wang et al., 2019).

Other advantages of the PPF are their small density, poor water absorption, good thermal insulation, chemical resistance, similar strength in dry or wet state (Qin et al, 2019), they are uniformly distributed in the fresh mix of concrete forming a network structure (Kosior-Kazberuk and Berkowski, 2016; Singh, 2011). The analysis of single fibers as bridges between the parts separated by cracks shows a uniform, three-dimensional and optimum dispersion obtained by mesh connections (Barluenga, 2010; Khan and Ali, 2018). These mesh connections are very advantageous from the point of view of the concrete element behavior in which they are incorporated because fibers start to work in a structural supportive manner when the first cracks appear into the concrete matrix, behavior similar to that of the traditional steel reinforcement. The crack has to occur for the loads to move from the concrete to the reinforcement, then fibers give ductility and support by bridging cracks and thus providing post crack strength to the concrete. So, fibers are acting as anchors between the cement paste, fine aggregates and coarse aggregates giving an increased durability of concrete before failure (Dharan and Aswathy, 2016; Patil et al., 2017).

PPF increases the fire resistance of concrete and mortars (Behnood and Ghandehari, 2009; Chen and Liu, 2004; Singh, 2011). The fibers diminish the spalling effect of fire on concrete and makes the PPFRC to correspond to the fine safety regulations. This improving effect can be explained by the fact that when the fibers melt, spaces are created to eliminate the pressure from the pores of the heated concrete (Corpas et al., 2013). The gases resulted from the fibers combustion do not contain toxic substances and do not affect human health (Singh, 2011).

The PPF use into the concrete composition was reported to improve its tensile and compressive strength in case of a fiber dosage up to 0.5% (Mohod, 2015; Qin et al., 2019), and the modulus of elasticity also (Mohod, 2015; Wang et al., 2019). The wear resistance of concrete was also increased, thereby the cost of producing quality industrial floors being reduced (Grdica et al., 2012).

The surface of PPFRC is more resistant to the action of corrosive substances, to freeze-thaw than the concrete without PPF (Qin et al., 2019). The addition of PPF prevents the concrete from eroding to the surface, thereby the steel reinforcement is protected and the refurbishment or consolidation costs are reduced. In the presence of PPF, the concrete eliminates water more slowly, in this way smaller concrete pores are formed and the amount of water that will subsequently enter into the concrete mass is decreased (Singh, 2011).

Reinforcement with PPF was reported to increase shear strength, which facilitates the reduction of stirrups reinforcement, improves the concrete durability, reduces the contraction tendency, improves cracking behavior (Khan and Ali, 2018) and achieves a favorable coating of the steel bars reinforcement to prevent corrosion. PPF concretes and mortars have increased shock resistance (Błyszko, 2017; Khan and Ali, 2018) and can be applied manually or by injection, being easy to cast-in-place (Singh, 2011).

This study aimed to analyze the effects of polypropylene fibers addition on the concrete paving blocks (CPB). There were made two types of concrete recipes and the CPB were made by two different methods: by casting and vibration, and by vibration together with pressure-applying (vibro-pressing). The analyzed characteristic of the concrete recipes was the splitting tensile strength at different ages: 3, 7, 14, and 28 days, respectively, as an evaluation from the mechanical point of view. The splitting tensile strength is a mechanical test recommended for this type of concrete elements by the EN 1338 (2004).

2. Material and methods

2.1. Material

In order to analyze the PPF effects on the mechanical properties of the cement-based mix, there were prepared two reference concrete mixes, RC1 and RC2. RC1 is a concrete recipe made with three sorts of aggregates: sand sort 0-4 mm and river gravel sort 4-8 mm and river gravel sort 8-16 mm. RC2 is a micro-concrete recipe made with only two sorts of mineral aggregates, sand sort 0-4 mm and river gravel sort 4-8 mm. Both reference recipes were made with cement type AV I 42.5R. As differences between RC1 and RC2 were the water/cement ratio used (0.5 and 0.2, respectively) and the use of a concrete plasticizer, Viscocrete 20HE, only in RC1. In the RC1 and RC2 were added 0.9 kg of 17.7 mm length polypropylene fibers per 1.0 m^3 of concrete, being obtained PPFRC1 and PPFRC2.

The components and their quantities to produce 1.0 m^3 of concrete recipes used in this study are presented in Table 1. In Fig. 1, the aspect of the PPF used in this research study can be observed, their characteristics being presented in Table 2. In order to obtain a product with an optimum quality-price ratio for concrete, simultaneous with maintaining or improving its mechanical strength different criteria were taken into account. Among these criteria were the fibers price per one kilogram, the fibers quantity recommended by the producer to be used into the concrete mix, their physical and mechanical characteristics (Table 2).

2.2. Methods

2.2.1. CPB made by casting and vibrating

Using RC1 and PPFRC1 recipes, CPB were made by casting and vibrating technology. For the concrete manufacture, a 200*l* concrete mixer was used (Fig. 2). The concrete made with PPF presented a high degree of homogeneity of the mixture, according to the arrangement of the fibers coming out of the fresh concrete mass (Fig. 3). For the RC2 recipe, this test was not performed due to the very small A/C ratio, of 0.2. The test results revealed that the PPF diminish the slump with about 11%, from a 4.5 cm for RC1 to 4 cm for PPFRC1. The smaller slump of the concrete with PPF is explained by better co-operation between cement paste and aggregates by means of micro-reinforcement. Due to the fibers, the concrete volumes are held together, the forces of gravity being less than the bonding forces between the matrix and the fibers. The concrete was cast in plastic moldings, and after their vibration on a vibrating table, it was stored in a specially arranged space inside the production hall. The prefabricated elements belong to the category of pavements for outdoor paving. They are rectangular in size 200 / 100 mm and 45 mm thick.

2.2.2. CPB made by vibro-pressing

The second type of prefabricated concrete blocks were made using RC2 and PPFRC2 and applying vibro-pressing technology by means of a special equipment (Fig. 4a). The concrete used is different from the one used in casted and vibrated pavers. It has a very small W/C ratio of only 0.20, which makes it a semi-dry concrete. This was the reason that led to the use of a vibro-pressing machine; a higher W/C may lead to sticking the material onto the mold's nests, thereby reducing productivity.

The resulting CPB can have different shapes and sizes depending on the mold used. For this research on fiber reinforced concrete with PPF, T-shaped pavers (Fig. 4b) having a surface of 251 cm^2, 226 mm in length and 63 mm thickness were made. The CPB were subjected to the splitting tensile strength test according to SR EN 1338: 2004 regulations. The breaking load was applied along the longest section of the pavement along a parallel and symmetrical line with the edges (Fig. 5). The tests were made on 3, 7, 14 and 28 days, being used 8 samples of pavers made of normal concrete and of concrete with PPF, respectively, for each trial, according to the SR EN 1338:2004 stipulations.

Splitting tensile strength, *T*, was calculated according to the Eqs. (1-2):

$$T = 0.637 \cdot k \cdot \frac{P}{S} \text{ [N/mm}^2\text{]} \qquad (1)$$

where *k*-correction coefficient, according to the thickness of the concrete paving block; $k = 0.75$ for $t = 45$ mm, and $k = 0.89$ for $t = 63$ mm; *P* - the breaking load [N]; *S* - loading area [mm^2].

$$S = l \cdot t \qquad (2)$$

where *l* - the mean between the loading length measured on the upper part and on the bottom part [mm]; *t* - the thickness of the CPB; $t = 45$ mm for RC1 and PPFRC1; $t = 63$ mm for RC2 and PPFRC2.

Table 1. The components of the concrete mixes

Concrete recipes	***Cement type AV I 42.5R*** [kg/m^3]	***Aggregates***			***Water*** [l/m^3]	***Plastifiant admixture***	***PPF*** [kg/m^3]	***W/C ratio***
		Sand sort 0-4 mm [kg/m^3]	***Gravel sort 4-8 mm*** [kg/m^3]	***Gravel sort 8-16 mm*** [kg/m^3]				
RC1	456	771	422	422	235	Viscocrete 20HE	-	0.50
PPFRC1	456	771	422	422	235	Viscocrete 20HE	0.90	0.50
RC2	438	1233	367	-	88	-	-	0.20
PPFRC2	438	1233	367	-	88	-	0.90	0.20

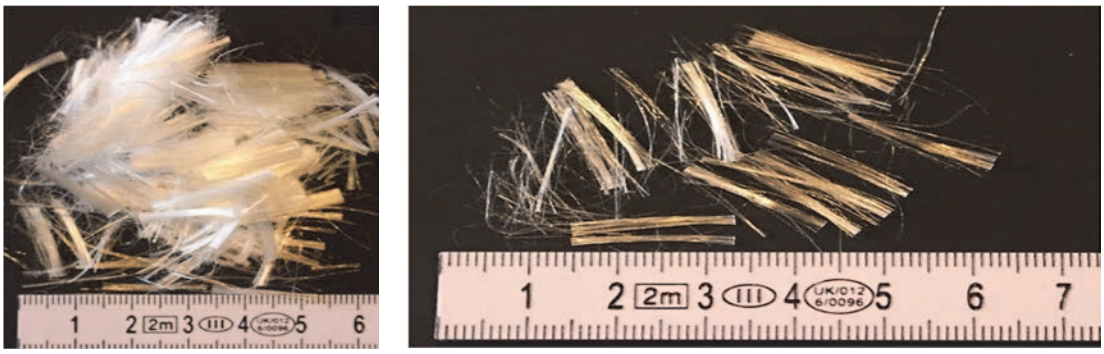


Fig. 1. The visual aspect of the polypropylene fibers used into the concrete mixes

Table 2. The characteristics of the PPF

Characteristic name	***PPF characteristics***
Material	pure polyolefins
Dosage [kg/m^3]: - minimum - maximum - fire resistant concrete	 0.6 0.9 2.0
Shape	multifilament
Diameter	32 *µm*
Length (+/- 5%)	17.7*mm* (type 177)
Density	0.91 *g/cm*^{3}
Acids/alkalis resistance	inert
Tensile strength	270 N/mm^2
Melting point	160°*C*
Color	white

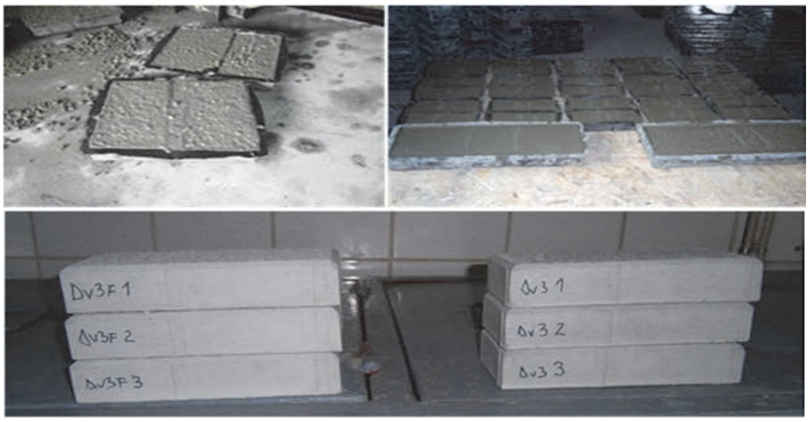


Fig. 2. Vibrating on the vibrating table and the storage conditions of the CPB

Fig. 3. The homogeneity (a) and the slump test of the PPFRC1 (b).
The workability of RC1 and PPFRC1 was determined according to SR EN 12350-2:2003

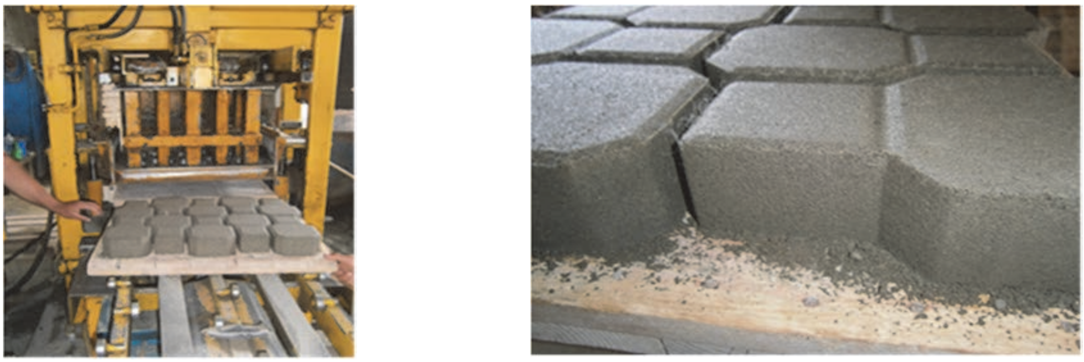

(a) (b)

Fig. 4. The vibro-pressing equipment (a) and the fresh T-shaped pavers (b)

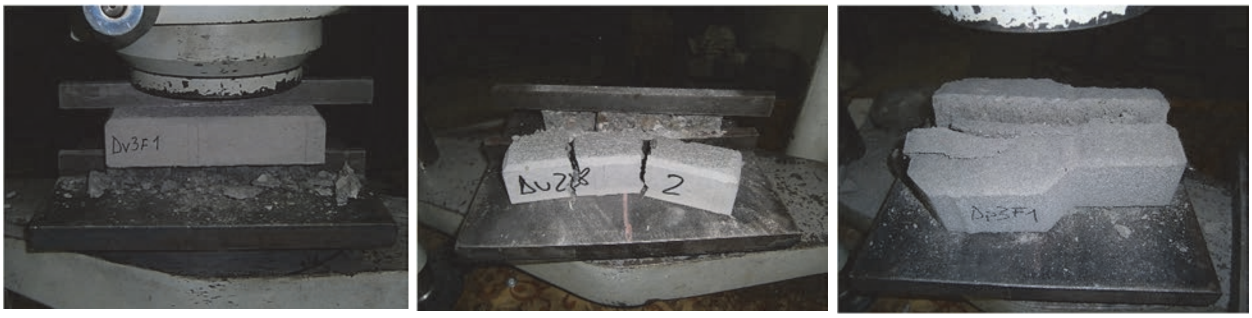


Fig. 5. The splitting tensile test applied on the longest section of the CPB

In Table 3 are presented the four types of pavers manufactured for this research and their concrete recipe.

Table 3. Types of manufactured pavers

No crt.	***Manufacturing method***	***Concrete recipe used***
1	Pavers made by casting and vibrating	RC1
2	Pavers with PPF made by casting and vibrating	PPFRC1
3	Pavers made by vibro-pressing	RC2
4	Pavers with PPF made by vibro-pressing	PPFRC2

3. Results and discussion

3.1. CPB made by casting and vibrating

If there it is investigated the evolution of the mean value of the splitting tensile strength from 3 days testing up to 28 days testing (Fig. 6), there can be observed that both RC1 and PPFRC1 registered an improvement. Comparing the trendlines, it can be noticed that the increase of the RC1 was quite constant, while PPFRC1 registered a stepper positive slope (strength increase) from 14 days up to 28 days than RC1. In the last 14 days before the 28 days testing, the RC1 splitting tensile strength increased with around 5% (4.84%), while the PPFRC1`s with around 18% (18.64%).

If there are considered the initial and the final splitting tensile tests, RC1 registered values with around 17% higher, while PPFRC1 with around 30% (Fig. 6). During the curing period, the PPF had a positive and increasing influence, reaching as at 28 days PPFRC1 to register a bigger mean value of the splitting tensile strength with 31.66% than RC1. Improvements were noticed at 3, 7 and 14 days also, with 11.1%, 6.8% and 12.6%, respectively (Fig. 6). The results are in line with those obtained by Dharan and Lal (2016) or Li et al. (2016) that discovered that the splitting tensile strength is increasing for up to 1.5% of PPF addition in different kind of concrete.

Analyzing the standard deviation of the splitting tensile strengths determined for the vibrated pavers (Fig. 7) are relative homogeneous, only in the case of RC1/14, PPFRC1/7 and PPFRC1/28 being registered a smaller homogeneity. This means that, in the almost all studied cases, the 8 samples of one concrete recipe tested on the four different ages registered individual splitting tensile strength values very close to the mean.

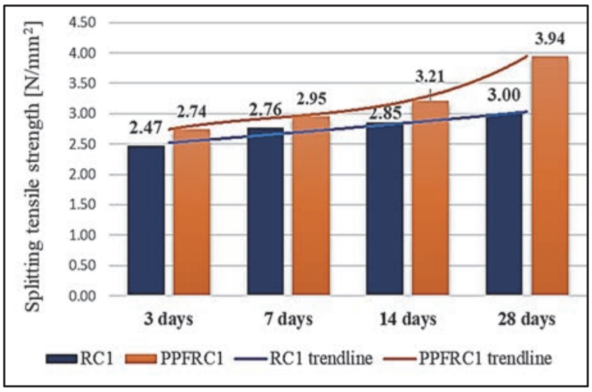
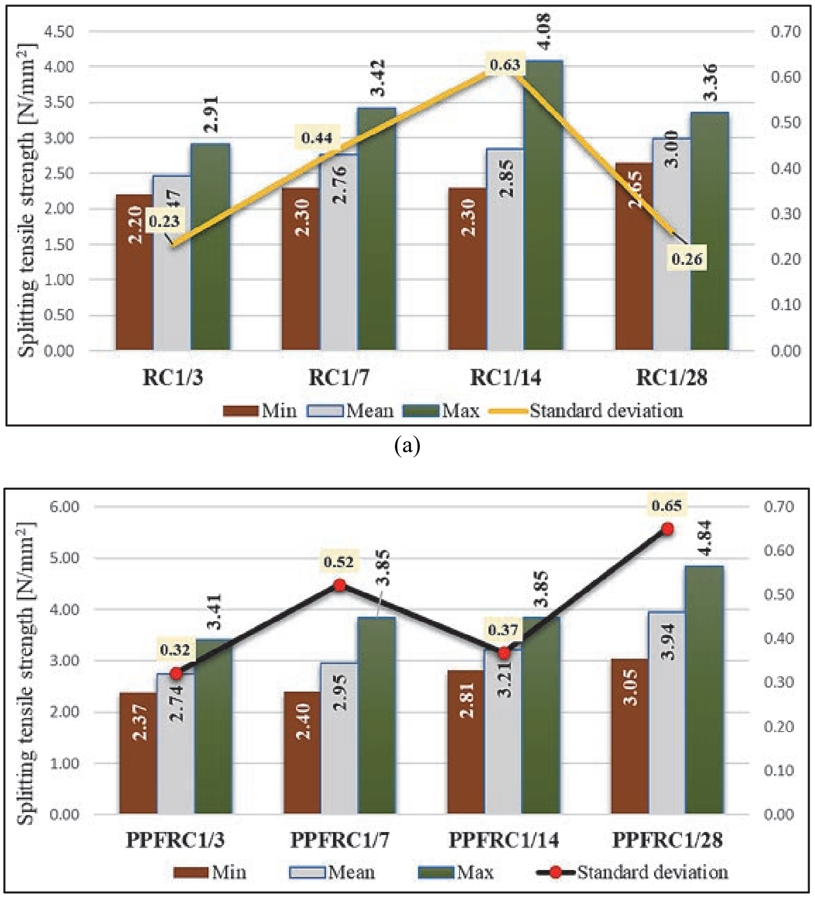


Fig. 6. The mean values of the splitting tensile strength for the vibrated CPB with and without PPF

In the case of splitting tensile strength of the vibrated pavers with and without fibers (Fig. 7), the minimum and maximum values registered an increasing trend. Only in the case of RC1, is observed a decrease of these values for the 28 days testing. The minimum strength of the PPFRC1 increased with 7.7% after 3 days with 4.3%, after 7 days, with 22.2% after 14 days and 15.1% after 28 days compared to RC1. According to SR EN 1338:2004, the mean splitting tensile strength of the pavers, at 28 days, must be bigger than 3.60 N/mm^2, threshold exceeded by the PPFRC1`s, while the RC1`s reached only up to 3.0 N/mm^2.

In conclusion, in the case of all ages of testing, the pavers dispersely reinforced with PPF had a better behavior than those made of regular concrete tested in the same conditions. The efficiency of PPF use for pavers manufacture by vibro-pressing is equal to 32%, the splitting tensile strength positive difference between the pavers with PPF and those without fibers. Yin (2015) also concluded in his research that this type of fibers is appropriate to be used in concrete footpaths. Addition of limited percentages of PPF in concrete has improved the tensile strength of concrete elements, results similar to those found in literature reviews (Batayneh et al., 2007; Li et al., 2018). The increments of tensile strength improvement result from the bridging actions of the fibers in the concrete.



(a)

(b)

Fig. 7. The minimum, mean and maximum values of the splitting tensile strength, and the standard deviation of the individual values from the mean, for the vibrated CPB: (a) without PPF, (b) with PPF

3.2. CPB made by vibro-pressing

As in the case of the vibrated pavers, the mean value of splitting tensile strength of the vibro-pressed pavers had an increasing trendline, but the difference consists in that the trendline slope of the PPFRC2 is quite similar to the one of the RC2. During 28 days, the mean strength did not register high increases from one term to another, but an almost linear evolution from 1.81 N/mm^2 at 3 days up to 2.31 N/mm^2 at 28 days, meaning an increase of 27.6%; this percent is quite small if it is compared to that registered by the vibrated CPB, 43.8% (Fig. 8).

Considering the PPF effect on the concrete splitting strength, it is observed a higher positive influence than in the case of vibrated pavers: at 3 days testing, the fibers addition increased the reference concrete strength by about 38%, and then in the case of 7, 14 and 28 days testing by about 60% than the reference concrete tested in the same conditions (Fig. 8). In the splitting tensile strength evolution during the curing period, it can be observed that the RC2 registered an increase of around 11%, while PPFRC2 almost a double one (21%) (Fig. 8).

Considering the values of standard deviation calculated in the case of vibro-pressed pavers (RC2) (Fig. 9a), we may assume that the individual strengths of the tested samples were relative homogeneous. As regard the minimum values determined for RC2 and PPFRC2 during the curing period, it is evident an increasing trend. The minimum strength of the PPFRC2s increased between 39.3% and 54.0% compared to RC2s. The maximum values obtained cannot be put into a specific trend (Figs. 9a and 9b).

If the results obtained by RC2 and PPFRC2 are reported to the requirements of SR EN 1338:2004 regarding the minimum splitting tensile strength that must be attained, it will be concluded that they are not fulfilled.

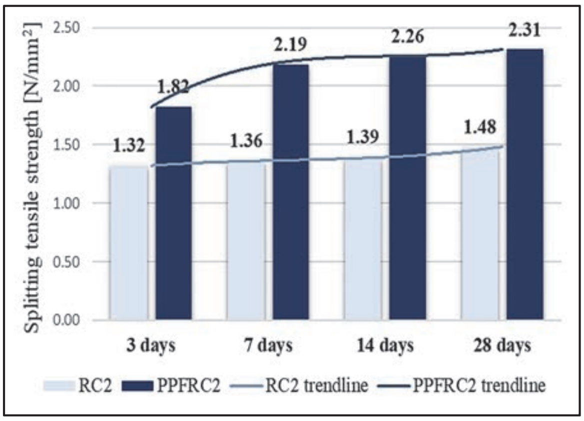
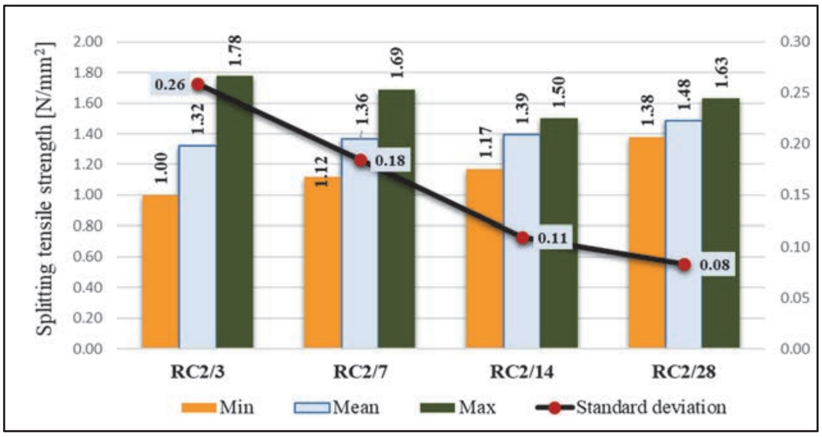
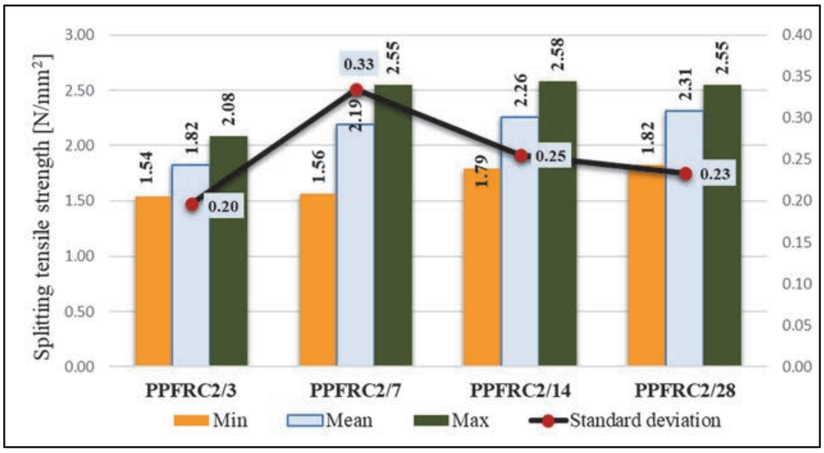


Fig. 8. The mean values of the splitting tensile strength for the vibro-pressed CPB with and without PPF



(a)



(b)

Fig. 9. The minimum, mean and maximum values of the splitting tensile strength, and the standard deviation of the individual values from the mean, for the vibro-pressed CPB: (a) without PPF, (b) with PPF

In conclusion, in the case of all ages of testing, the vibro-pressed pavers dispersely reinforced with PPF had a better behavior than those made of regular concrete tested in the same conditions. It can be noticed that efficiency of PPF use for pavers manufacture by vibro-pressing is equal to 56%, the splitting tensile strength positive difference between the pavers with PPF and those without fibers.

4. Conclusions

External paving blocks made of PPF reinforced concrete have a higher strength than those without fibers since the very close term they are executed. This allows them to be safely handled and transported even before the 28-day term. Also, these pavements can be put in work more quickly, which means saving space for storage, a simpler logistics for the manufacturing company that can manage better the storage, the pallet packing, the loading and delivery of its various prefabricated products.

In the case of vibro-pressed pavers, an earlier work-up ensures continuous hydration of the cement paste, this resulting in increased mechanical strength. Due to the environmental impact generated by the partial or total destruction of such pavements during their handling, storage or transport, the improvement of mechanical characteristics, especially at early ages, leads to lower energy consumption through a material saving and the labor force needed to replace the destroyed ones with new ones. For the beneficiary of an external pavement made of such pavers, the benefit of higher mechanical strengths from early ages, of greater compaction and, implicitly, of low cracking rate means extended service life and maintenance, repair or partial replacement costs are significantly reduced. In this way, a positive effect on the environment mainly through the prolonged life of these types of products is achieved.

Improvements in terms of ductility were also observed in concrete that was reinforced with polypropylene fibers relative to the conventional one.The polypropylene fibers act as a crack arrester for the concrete during the loading, helping in delaying the propagation of cracks. Polypropylene fibers interact with the cement matrix creating additional sliding surfaces and somewhat “softening” the structure of concrete which determines a higher deformation at early-age of fiber reinforced concrete.

From the point of view of the manufacture technology of preparing and the put in work process of the reinforced concrete with polypropylene fibers, it was found that a better mixture is obtained when the fibers are added to the wet mixed concrete and putting into work requires a more careful vibration.

Regarding the application of concrete, it can be noticed that the presence of fibers produces greater adhesion to the formwork (a phenomenon of "hanging" of the fiber pulp). The phenomenon is explained by the fact that for low-thickness elements the amount of material is relatively small and then its weight cannot overcome fiber adherence. For this reason, a more fluid mixture should be made for such elements, possibly by addition of additives.

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