Examination of Concrete Elements Bending Strength Reinforced by Polyethylene Terephthalate (PET) Waste

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Abstract. Ukrainian enterprises of PET (Polyethylene Terephthalate) waste recycling are still capable of processing only 1 thousand tons, and more than 10 thousand tons of PET granulate are imported to Ukraine every month. Therefore, the issue of reuse and disposal of used polyethylene terephthalate, especially in construction, is one of paramount importance. The aim of the research is experimental-theoretical study of the strength of bending of prisms, reinforced with fibers and strip reinforcement of used PET bottles. Objectives of the research: the study of the percentage of reinforcing fibers in volume (1% and 1.5%) influence on the flexural strength of concrete reinforced prisms, and the possibility of using ribbon reinforcement from used PET bottles for bending concrete elements, elaboration of proposals for the deformation method of calculation of PET fibrobone bent elements. In this research the experimental methods for determining the bending strength of prisms, reinforced by fibrous, trips and PET waste tapes; methods of materials resistance theory have been used. During the research, two concrete prisms of 400x100x10 mm were constructed and tested for compression together with two concrete prisms of three-point bend for a run of 350 mm, two PET-fibrous concrete prisms for bending with percentages of reinforcement in volume of 1% and 1.5% and two prisms for bending, reinforced with glued PET strips, with 1% reinforcement per section area. As a disperse reinforcement, pre-fabricated PET bottles of 50x3x0.2 mm were used, designed in way that the required length of sealing in the concrete is no longer than half the length of the fibers. Strip fittings are made of 4 fragments of PET bottles of 200x80x0.25 mm in size, glued with cyanoacrylate adhesive with each other, and 2 fragments of 120x80x0.2 mm in size, which glued on both ends to 4 glued sheets with a length of 30 mm. Thus, the total length of the reinforcing strip is equal to 380 mm. At the final sections of the tapes, 6 openings with a diameter of 5 mm were punched to improve the anchoring. The reinforcing strips were placed in the forms located 10 mm from the lower edge. According to the results of the tests, the average cubic strength of concrete is 31.21 MPa, of prisms - 23.23 MPa, the initial module of deformation - 28.02·10³ MPa. The flexural strength of prisms without a fibre is 58.54 kN·cm, with 1% fibers in volume - 64.31 kN·cm, with 1.5% fibers in volume - 71.84 kN·cm, and of prisms, reinforced with glued PET ribbons – 79.80 kN·cm. As a result of the tests, it was demonstrated that the strength of the tapes was not used properly, and the fracture was fragile due to the loss of adhesion to concrete. Analysis of the results of experimental studies allowed us to develop a deformation methodology of calculating PET-fiber-concrete bending elements.
1. Introduction

Polyethylene terephthalate (PET or PETE) is a complex thermoplastic polyether of teraphthalic acid and ethylene glycol, which is made on the basis of resins obtained from petroleum. The physical and mechanical characteristics of PET allow it to be used for the manufacture of containers for liquids, cosmetics, films, fibers, etc. There are 6 enterprises in Ukraine that collect and process used packaging into PET granulate and PET flakes [1]. According to the "GalPET" trade and industrial group, more than 10 thousand tons of PET granulate are imported to Ukraine every month. The main volume of material is used to make bottles that need to be disposed of after use. Domestic PET recycling companies are currently only able to process only 1 thousand tons per month [2].

One of the promising areas where raw materials from used PET bottles could be used is the construction industry. The analysis of scientific literature has shown that in Ukraine the study of carrying capacity, deformability and crack resistance of concrete elements reinforced with fibrous, strip or other reinforcement of used PET bottles has not been carried out yet. The same applies to the technology of manufacturing both fiber-concrete mix and structures.

Japanese researchers raised the question of the technology of manufacturing fiber-concrete mixture with a 20 mm long PET fiber [3]. In this paper, it is indicated that such fibers, even in content of 3% of the volume of the mixture, is easy to mix, without getting caught in the so-called «hedgehogs». This fiber is used for the manufacture of sidewalk tiles and mine structures.

The results of studies [4] say that for fibreboleton based on PET fibers is characterized by increased durability of compression and stretching for multiple freezing-thaws, as well as is exposed to the action of chemicals in comparison with ordinary concrete.

The results of studies [5] also say that the compressive strength and the modulus of elasticity of fibrobone on PET fibers decreased with an increase in the percentage of fibrous concrete reinforcement by volume. Obviously, this issue need to be studied further. However, in this paper the positive influence of fibers on the crack resistance for bending, the reduction of the width of the opening of shrinkage cracks, the viscous nature of the destruction is revealed. A small (up to 3.6%) reduction in the compressive strength of fibrous concrete on a PET fibril in the sizes of 50x1,2x0,3 mm with 1.5% volumetric reinforcement is indicated in the papers [6, 7]. The same effect was observed for the reinforcement of fine-grained concrete by PET-flakes [8].

In recent years, an Italian researcher Dora Foti systematically studied the mechanical properties of fibrobone with a PET bottle fiber [9-10]. Prisms 400x100x100 mm containing PET fibers of 32x2x1.1 mm size and rings having a diameter of 30-50 mm and a width of 5 mm were tested for the effects of the concentrated force applied in the middle of the run, equal to 350 mm. The percentage of reinforcement by mass was equal to 0.5 and 0.75 (0.78 and 1.16, respectively, by volume). It turned out that the bending strength of such prisms did not always exacerbate the strength of concrete prisms [9].

The above brief survey of studies allows us to draw the following conclusions:
1. The causes of a slight decrease in the compressive strength of fibrobone on a fiber made of PET bottles has not been explained yet, in comparison with usual fine-grained concrete.
2. There is no minimum percentage of reinforcement with such fiber, which would give a stable increase in flexural strength compared to concrete.
3. The question of the optimum size of fiber reinforcement of used PET bottles has not been studied yet, including conducting experiments on the removal of fibers from concrete of different classes.
4. The possibility of using the walls of PET bottles for the manufacture of strip reinforcement has not been considered yet.
5. The technology of fabrication of fittings made of used PET bottles has not been developed in the finished form yet.

On the basis of the analysis given above, for the purpose at this stage, we will test the bending strength of the prisms, reinforced with fibers and strip reinforcement of used PET bottles.

According to the goal, the following tasks were solved: the study of the influence of the percentage of fiber reinforcement in volume (1% and 1.5%) on the flexural strength of concrete reinforced prisms and researching the possibility of using bandpass fittings from used PET bottles for bending concrete
elements, developing proposals for deformation methods of calculation of PET-fiber-reinforced concrete bending elements.

2. Research program, materials of prototypes and their manufacturing

The research program [11] foresees the production of prisms of 400x100x100 mm in fine-grained concrete, testing them according to the scheme of three-point bending for a run 350 mm (Table 1), analysis of the results of experiments and the development of proposals for calculating the bending strength of the prism. To determine the strength of concrete on compression, cubes of 150x150x150 mm. were also produced.

| Code of samples | Dimensions of samples, mm | Type of test | $\rho_{f_{0}}$, % | $\rho_{l_{0}}$, % | Type of PET fittings | Mass of fibers, stripes, g |
|-----------------|--------------------------|--------------|------------------|------------------|----------------------|--------------------------|
| P 1.1           | 400x100x100              | compression  | 0                | –                | –                    | –                       |
| B 1.1           |                          | bending      | 1.0              | fibers           | 57                   |                         |
| B 1.2           |                          |              | 1.5              | stripes          | 85                   |                         |
| B 2.1           |                          |              | 1.0              | stripes          | 31                   |                         |
| B 2.2           |                          |              | 1.0              | stripes          | 31                   |                         |
| B 3.1           |                          |              | 1.5              | stripes          | 31                   |                         |
| B 3.2           |                          |              | 1.5              | stripes          | 31                   |                         |

As a disperse armature, a pre-fabricated fiber made of PET bottles of 50x3x0.2 mm dimensions, which are designed in such a way that the required length of sealing in the concrete was not longer than half the length of the fibers (Figure 1) was used. The ribbon fittings are made of 4 fragments of PET bottles in the size of 200x80x0.25 mm, glued with cyanacrylate adhesive with each other, and 2 fragments of 120x80x0.2 mm in size, which glued on both ends to 4 glued sheets for a length of up to 30 mm (Figure 1). Thus, the total length of the reinforcing tape is 380 mm. At the final sections of the tapes 6 openings with a diameter of 5 mm were punched to improve the anchoring. The reinforcing strips were placed in the forms 10 mm from the lower edge.

![a](image1)  ![b](image2)  ![c](image3)

**Fig.1.** Fiber (a) and strip (b) fittings made of used PET bottles

**Fig. 2.** Concrete prism P 1.1 during compression test
For the production of samples in order to get concrete of the class C 2/20, the cost of materials per 1m³ was: cement of the brand 400 - 549 kg, sand - 1647 kg, water - 285.5l, fiber per $\rho_{fv} = 1\% - 14.2$ kg. for $\rho_{fv} = 1.5\% - 21.3$kg. After preparing the samples, applying and sealing the mixture, the test samples were stored under a layer of moist wood 28 days in a room with a temperature of 180 ... 200°C.

$\rho_{fv}$ – the percentage of fibrous reinforcement by volume; $\rho_t$ – the percentage of reinforcement with strip reinforcement by area.

3. Results and discussions

Tests were conducted within one week, starting 29 days after the production of samples. At first, the cubes and compression prisms were tested (Figure 2). The strength of the cubes 150x150x150 mm $f_{cu,\text{cube}}$ by the test results are 31.33 MPa; 30.61 MPa and 31.70 MPa (mean value 31.21 MPa). The mean experimental values for prisms are as follows: prisma strength $f_{c,\text{prism}}$, initial deformation module $E_{cm} = 28.02 \times 10^3$ mPa, Poisson's coefficient $\nu_m = 0.202$ limiting deformations corresponding to prism strength, $\varepsilon_{c1,c,\text{m}} = 1.98 \times 10^{-3}$ (Table 2).

**Table 2. Results of tests of prism on axial compression**

| Code of samples | $f_{c,\text{prism}}$, MPa | $f_{c,\text{prism,m}}$, MPa | $E_{cm}$, MPa $\cdot 10^{-3}$ | $E_{cm,m}$, MPa $\cdot 10^{-3}$ | $\nu_m$ | $\varepsilon_{c1,c,\text{m}} \cdot 10^3$ | $\varepsilon_{c1,c,\text{m}} \cdot 10^3$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|---------|-----------------|-----------------|
| P 1.1           | 22.95           | 23.51           | 23.23           | 28.76           | 27.28   | 28.02           | 0.208           | 0.196           | 0.202           | 2.01             | 1.95             | 1.98             |

The rest of the prism was tested according to the scheme of a three-point bend for a working run of 350 mm (Figure 3, 4). During loading of samples, deflections, deformations of extreme stretched and compressed fibers, destructive forces were controlled. The test results presented in Table 3, indicate that for $\rho_{fv} = 1\%$, the bearing capacity on average increased by 9.9%, and for $\rho_{fv} =1.5\%$ - by 15% compared with concrete samples. In the paper [9], the excess of the load-bearing ability to bend fibrobetonnoy prisms over concrete reinforcement with $\rho_{fv} = 0.88\%$ by 3.9%. Obviously, an additional substantiation and the establishment of the minimum percentage of reinforcement of PET-fibers in volume should be required.

![Fig. 3. Test of the prism with three-point bending scheme](image1)

![Fig. 4. Bending elements-prisms, reinforced with fibers and ribbons after tests](image2)

By a triangular calculation diagram of stresses in a compressed zone and a rectangular - in the stretched, bearing capacity of samples B 1.1 and B1.2 can be calculated according to the known formula:
\[ M_u = 1.75 f_{ct} \frac{bh^2}{6}, \]  

(1)

where \( f_{ct} \) – strength of concrete on stretching; 
\( b = h = 10\text{cm} \) – the size of the base of the prism.

### Table 3. Results of tests of bending elements-prisms

| Code of samples | \( \rho_{f_v}, \% \) | Breaking stress \( P_u, \text{kN} \) | Average breaking stress \( P_{um}, \text{kN} \) | Average value of maximum bending moment \( M_u, \text{kN} \cdot \text{cm} \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| B 1.1           | 0               | 6.57            | 6.69            | 58.54           |
| B 1.2           |                 | 6.80            |                 |                 |
| B 2.1           | 1.0             | 7.45            | 7.35            | 64.31           |
| B 2.2           |                 | 7.25            |                 |                 |
| B 3.1           | 1.5             | 7.59            | 7.70            | 71.84           |
| B 3.2           |                 | 7.81            |                 |                 |
| B 4.1           | 1.0             | 9.68            | 9.12            | 79.80           |
| B 4.2           |                 | 8.55            |                 |                 |

Substituting in the formula (1) the mean average torque of 58.54 kN \cdot \text{cm} (Table 3), we obtain \( f_{ct} = 2.01 \text{MPa} \), which may well correspond to the class of concrete C20/25.

The bearing ability of bending fiber-concrete elements B2.1, B 2.2, B 3.1 and B 3.2 for rectangular scenes in stretched and compressed zones [11] can be calculated under the formula:

\[ M_u = f_c f_{ct} \frac{b h^2}{2}, \]  

(2)

where \( f_c \) – the compressive strength of concrete on compression; 
\( f_{ct} \) – the strength of the fiber reinforced concrete on the stretch.

From this formula, using the data from Table 3, we find \( f_{ct} \). It turned out that for \( \rho_{f_v} = 1\% \) \( f_{ct} = 1.37 \text{MPa} \), and for \( \rho_{f_v} = 1.5\% \) \( f_{ct} = 1.54 \text{MPa} \), which indicates the need to improve the method of calculating the bearing capacity using full diagrams of deformation of fibrous concrete for tension, given that the strength of a fibrous concrete, calculated using formula (2), was less than the strength of concrete on tension.

The average value of the maximum bending moment \( M_u \) for samples B 4.1 and B 4.2, reinforced with PET tapes, is 79.8 kN\cdot\text{cm}. This bending moment is equal to the effort in the concrete of the compressed zone, multiplied by a pair of internal forces on the shoulder:

\[ M_u = f_c b (\lambda x) (d - \frac{\lambda x}{2}), \]  

(3)

where \( \lambda x \) -is the calculated value of the height of the compressed zone of concrete; 
\( d \) - working height (90 mm).

By solving this square equation, we find that \( \lambda x = 0.39 \text{cm} \).

Since the internal effort in the concrete of the compressed zone is equal to the effort in the strip reinforcement, we can write:

\[ f_c b (\lambda x) = f_y A_{pet}, \]  

(4)

where \( f_y \) is the calculated value of the strength of the PET tape; 
\( A_{pet} \) - the cross-sectional area of the PET tape (4 \cdot 0.25 \cdot 80 = 80\text{mm}^2).

From this equation we obtain: \( f_y = 113.25 \text{MPa} \). The experimentally obtained value of the temporary resistance of a ring-shaped PET tape is 160 MPa [9].

Thus, the strength of the stretching of the PET tape is not used enough and the stress in it for the destruction of samples is about 71% of the time resistance. Samples B 4.1 and 4.2 were destroyed brittle with exfoliation of the protective layer of concrete and the loss of adhesion of the tape with concrete.
This necessitates the search of means that would ensure the consistent operation of the tape with concrete until it reaches the tensions close to the temporary resistance.

Strength of fibrous concrete on stretching will be determined by a formula similar to that in the work [12]:

$$f_{fct} = k_{orf}^2 k_{an} \rho_{f_\text{PET}} f_{PET}, \quad (5)$$

where $k_{orf}$ is the coefficient of orientation of the fibers, equal to the cosine of angle 45°;
\[ k_{an} \] - coefficient of anchoring;
\[ \rho_{f_\text{PET}} \] - volume coefficient of fibrous reinforcement;
\[ f_{PET} \] - the strength of the PET fibrid on the tension (160 MPa [9, 10]).

To determine $k_{an}$, it is advisable to use the known dependence [13], which can be written for the removal of the fibers as follows:

$$\frac{l_{an}}{d} = \frac{\eta \sigma_f}{f_c}, \quad (6)$$

where $l_{an}$ is the length of earning fibers in concrete;
\[ d \] - reduced diameter of the fibers;
\[ \eta \] - coefficient of adhesion of fibers with concrete equal to 1 for smooth fittings;
\[ \sigma_f \] - fibre stress.

We equate the perimeters of a round rod $d_f$ and rectangular PET fibers as follows:

$$\pi d_f = 2(b_f + \delta_f), \quad (7)$$

where $b_f$ - the width of the fibers (3 mm);
\[ \delta_f \] - the fiber thickness (0.2 mm).

Thus, we obtain the reduced diameter of fibers, which is 2.04 mm.

Using equations (6) and (7), and bearing in mind that the average length of fibers in the front of the crack is equal to a quarter of its length (12.5 mm), we find that the stress $\sigma_f = 142.34$ MPa. Thus, $k_{an} = \sigma_f/f_{fct} = 0.89$.

From formula (5) it was obtained: $\rho_{f_\text{PET}} = 0.01 f_{fct} = 0.698$ MPa, and for $\rho_{f_\text{PET}} = 0.015 f_{fct} = 1.047$ MPa, which is less than the strength of the non-reinforced concrete at the bending stroke $f_{fct} = 2.01$ MPa. Since the bearing capacity of reinforced samples was greater than such non-reinforced, the previous calculations according to the deformation model indicated the need to introduce into the formula (5) the coefficient of working conditions $k_w$ (Fig. 5):

$$k_w = 2.73 - 84 \rho_{f_\text{PET}}. \quad (8)$$

**Fig. 5.** Dependence of the coefficient of working conditions of bending PET-fibrous concrete element on the fiber reinforcement coefficient by volume
Then formula (5) will look like:

\[ f_{fct} = k_w k_{or} k_{an} \rho_{fv} f_{PET}. \]  

(9)

Calculated by the formula (9) the strength of the fibrous concrete on the tension is 1.32 MPa and 1.54 MPa for the reinforcement coefficient 0.01 and 0.015, respectively.

The coefficient \( k_w \), thus, is the ratio of the tensile strength of the fibrobone, introduced in the calculations of the load-carrying capacity by the deformation method to the strength calculated by formula (5), which allowed the convergence of experimental and theoretical data. This coefficient is an integral coefficient that takes into account the better orientation of the fibers at the faces of the samples, reorientation of the fibers after cracking, a partial precipitation of the fibers on the bottom of the form as a result of fibrobone tonnum consolidation, etc.

We have accepted idealized diagrams for tension and compression of PET-fiber concrete, shown in Figure 6. Thus, calculate the compressive stress:

\[ \sigma_{fcc} = f_{fcc} \sum_{k=1}^{5} a_k \eta_c^k. \]  

(10)

where \( \eta_c = \frac{\varepsilon_{fcco}}{\varepsilon_{fcco}} \), \( a_k \) - the coefficients of the polynomial [14].

For stretching in the ascending region of the stress diagram, it is described by Hooke's law:

\[ \sigma_{fcs} = \varepsilon_{fcs} E_{fc}, \]  

(11)

where \( E_{fc} \) - module of fibrous concrete deformation.

Figure 7 shows diagrams of deformations and stresses of a flexural element reinforced with fibers. The bending moment that PET fibrous concrete element can accept is equal to:

\[ M = M_c + M_{t1} + M_{t2}, \]  

(12)

where \( M_c, M_{t1}, M_{t2} \) the moments that are perceived by the compressed and stretched zone according to the diagram relative to the neutral axis.

Equilibrium of internal efforts is ensured by the fulfillment of the condition:

\[ N_c = N_{t1} + N_{t2}. \]  

(13)

![Diagram of PET fibrous concrete deformation](image)
Using similarity of triangles of the deformation diagram (Figure 7) and dependence of materials resistance it is possible to write down the following for the compressed zone:

\[ N_c = \int \sigma_{fc} dF = \int_{0}^{x} \frac{f_{fc}}{E_{c}} \sum_{k=1}^{5} a_k \left( \frac{\epsilon_{c}}{E_{c,1}} \right)^k b dx = \frac{x}{f_{fc}} \sum_{k=1}^{5} a_k \left( \frac{\epsilon_{c} + \epsilon_{c,2}}{hE_{c,1}} \right)^k \left( \frac{\epsilon_{c,1}}{\epsilon_{c} + \epsilon_{c,2}} \right)^k \left( \frac{\epsilon_{c,1}}{\epsilon_{c} + \epsilon_{c,2}} \right)^{k+1} \times \frac{hE_{c,1}}{\epsilon_{c,1}}, \tag{14} \]

where \( x = \frac{\epsilon_{c,1} h}{\epsilon_{c} + \epsilon_{c,2}}, \)

\[ M_{c} = \int \sigma_{fc} x dF = \frac{x}{f_{fc}} \sum_{k=1}^{5} a_k \left( \frac{\epsilon_{c} + \epsilon_{c,2}}{hE_{c,1}} \right)^k x b dx = \frac{f_{fc} b}{hE_{c,1}} \sum_{k=1}^{5} a_k \left( \frac{\epsilon_{c} + \epsilon_{c,2}}{hE_{c,1}} \right)^k \left( \frac{\epsilon_{c,1}}{\epsilon_{c} + \epsilon_{c,2}} \right)^{k+2} \cdot \tag{15} \]

Similarly as a result of integrating for a stretched zone:

\[ N_{t1} = \frac{f^{2}_{ct} b}{E_{c} \chi}, \tag{16} \]

\[ M_{t1} = \frac{4bf^{3}_{ct}}{3E_{c} \chi^2}, \tag{17} \]

\[ N_{t2} = \frac{(\epsilon_{c,2} E_{c} - 2f_{ct} b f_{ct})}{E_{c} \chi}, \tag{18} \]

\[ M_{t2} = \frac{f_{fc} b}{2} \left[ \frac{\epsilon_{c,2}^2}{\chi^2} - \frac{4f^{2}_{ct}}{E_{c} \chi^2} \right]. \tag{19} \]

The results of the calculation of the deformation method are obtained using Excel spreadsheet processor and are presented in Table 4.

Thus, for the reinforcement coefficient 0.01 the theoretical bearing capacity is 62.072 kN cm, and experimentally – 64.31 kN cm. For the reinforcement coefficient 0.015, these indices are 71.757 kN cm and 71.84 kN cm respectively. This indicates a good convergence of theoretical and experimentally obtained results.
Table 4. Results of calculation by the deformation method of bending PET fiber-concrete elements

| The coefficient of fiber samples reinforcement by volume, ρf | ɛc(1) | ɛc(2) | x1, cm | Nc, kN | Nτ1, kN | Nτ2, kN | M, kN·cm |
|----------------------------------------------------------|-------|-------|--------|--------|---------|---------|----------|
| 0.01                                                     | 0.00011 | 0.0002 | 3.64   | 6.956  | 4.584   | 2.372   | 43.690   |
|                                                          | 0.00015 | 0.0003 | 3.27   | 7.868  | 3.234   | 4.634   | 47.026   |
|                                                          | 0.00078 | 0.006  | 1.15   | 11.621 | 0.213   | 11.408  | 60.284   |
|                                                          | 0.00106 | 0.010  | 0.95   | 11.898 | 0.130   | 11.768  | 61.177   |
|                                                          | 0.00167 | 0.020  | 0.77   | 12.164 | 0.067   | 12.097  | 61.946   |
|                                                          | 0.00196 | 0.025  | 0.73   | 12.222 | 0.053   | 12.168  | 62.072   |
| 0.015                                                    | 0.00012 | 0.0002 | 3.71   | 7.277  | 4.537   | 2.739   | 46.339   |
|                                                          | 0.00015 | 0.0003 | 3.38   | 8.503  | 3.182   | 5.321   | 51.772   |
|                                                          | 0.00085 | 0.006  | 1.24   | 13.380 | 0.211   | 13.169  | 69.690   |
|                                                          | 0.00116 | 0.010  | 1.04   | 13.729 | 0.129   | 13.600  | 70.782   |
|                                                          | 0.00186 | 0.020  | 0.85   | 14.053 | 0.066   | 13.987  | 71.658   |
|                                                          | 0.00221 | 0.025  | 0.81   | 14.118 | 0.053   | 14.066  | 71.757   |

4. Conclusions

The problem of used PET bottles utilization is extremely acute in Ukraine. Existing capacities of six Ukrainian enterprises are able to process only 1 thousand tons of secondary PET raw materials from 10 thousand tons of granulate imported abroad. Construction is one of the industries where fibers and reinforced strips from used PET bottles can be used.

The patent search conducted allows us to conclude that experimental research of concrete reinforced elements with fibers and reinforced strips from used PET bottles has not been carried out in Ukraine before. Foreign studies of the problems raised in this paper are insignificant and indicate the necessity to research both the issues of calculation and design, as well as the technology of manufacturing the fittings of used PET bottles.

An increase in the percentage of fiber reinforcement in concrete volume up to 1.5% led to an increase in the bearing capacity of concrete reinforced bending elements by 15%.

The greatest force effect (36.3%) has been achieved with reinforced PET bottles, compared with concrete elements. However, the nature of the destruction of samples, under-utilization of the strength characteristics of PET bottles, indicates the necessity to find ways to increase the anchoring capacity of these tapes.

Further research is required in terms of the designation of optimal geometric parameters of the fibers, its anchoring in concrete, bearing capacity at larger volumetric percentages of reinforcement, including the development of fibers technology fabrication and the technology of manufacturing fiber-concrete mix.

At the same time, it is expedient to calculate the bearing capacity not using rectangular scenes in compressed and stretched zones but using a deformation method.

Accepted idealized deformation diagrams of PET fiber-concrete describe the actual work of this material under load which allowed to obtain good convergence of theoretical and experimental results.

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References

[1] O. I. Kovalenko, O. G. Osmakov, O. M. Shniruk. Research of physico-mechanical and thermophysical properties of secondary PET. *Materials of the VII International Scientific and Technical WEB-Conference «Composite Materials» (March-April 2014): NTUU KPI.* pp. 139 – 143, 2014.

[2] Methods of PET recycling [Electronic resource]. - Mode of access: http://www.galpet.com.ua.

[3] T. Ochi, S. Okubo, K. Fukui. Development of recycled PET fiber and its application as concrete-reinforcing fiber. *Cement and Concrete Composites.* № 29. pp. 448-455, 2007.

[4] J. P. Won, C. I. Jang, S. W. Lee, [et all]. Long-term performance of recycled PET fibre-reinforced cement composites. *Construction and Building Materials.* № 24. pp. 660 – 665, 2009.

[5] S. B.Kim, N. H. Yi, H. Y. Kim, J. H. J. Kim, Y. Ch. Song. Material and structural performance evaluation of recycled PET fiber reinforced concrete. *Cement and Concrete Composites.* № 32. pp. 232 – 240, 2010.

[6] J. Kim, C. Park, S. Lee. Effects of the geometry of recycled PET fibre reinforcement on shrinkage cracking of cement-based composites. *Composites.* № 39. pp. 442–450, 2008.

[7] F. Pacheco-Torgal, Y. Ding, S. Jalali. Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview. *Construction and Building Materials.* № 30. pp. 714 – 724, 2012.

[8] Zhi Ge, Renjuan Sun, Kun Zhang, Zhili Gao, Pengcheng Li. Physical and mechanical properties of mortar using waste Polyethylene Terephthalate bottles. *Construction and Building Materials.* № 44. pp. 81 – 86, 2013.

[9] D. Foti. Preliminary analysis of concrete reinforced with waste bottles PET fibers. *Construction and Building Materials.* № 25. pp. 1906 – 1915, 2011.

[10] D. Foti. Use of recycled waste pet bottles fibers for the reinforcement of concrete. *Construction and Building Materials.* № 96. pp. 396 – 404, 2013.

[11] R. Shmyh, V. Bilozir, A. Vysochenko, [et all] Carrying capacity of bending concrete elements reinforced by fibro and stripes taken from used polyethylene terephthalate bottles. *International Scientific and Practical Conference World science.* № 2 (30). Vol. 1. pp. 88 – 93, 2018.

[12] F. N. Rabinovich. Disperse reinforced concrete. M.: Stroyizdat, 176 p., 1989.

[13] A. A. Gvozdev, S. A. Dmitriev, Yu. P. Gushcha. New in the design of concrete and reinforced concrete structures: monograph / by ed. A. A. Gvozdev. - M.:Stroiizdat, - 204 p., 1978.

[14] State Construction Norms of Ukraine V.2.6-98: 2009 Constructions of buildings and structures. Concrete and reinforced concrete constructions. Key provisions [Effective from 2011-07-01]. Kind. officer Kyiv: Minregionstroy of Ukraine, 71 p., 2011.