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# Modifying the Sand Concrete with Recycled Tyre Polymer Fiber to Increase the Crack Resistance of Building Structures

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**Abstract:** Recently, the use of recycled tyre polymer fiber derived from waste tires as a concrete reinforcement has received a great deal of attention. The recycled tyre polymer fiber is a promising additive to concrete for building materials which require resistance against cracking. In this work, the effect of treated and untreated fiber on the properties of sand concrete was studied. It was shown that recycled tyre polymer fiber consists mainly of different fractions of crumb rubber, fiber, and metal fiber. The main polymer components in the fiber are polyamide and polyester threads of 6.5 mm length ($l$) and 0.05 mm diameter ($d$); the ratio $l/d$ = 150; and the average fiber density is 0.923 $g/cm^3$. It was established that the addition of untreated recycled tyre polymer fiber in the amounts of 11 and 19 $kg/m^3$ into sand concrete leads to a decrease in compressive and flexural strengths by 15% and 21%, respectively. The reinforcement of concrete with the treated fiber in the amounts of 5 and 10 $kg/m^3$ increases the flexural strength by 14% and 23.4%, respectively. The prismatic strength of the concrete which contents 5 and 10 $kg/m^3$ of the treated polymer fiber was lower than that of ordinary concrete by 10.8% and 4.6%, respectively. The obtained results showed that the use of recycled tyre polymer fiber increases the crack resistance of concrete. The recycled tyre polymer fiber can be used as a cost-effective alternative to other types of low-modulus fibers to produce durable building materials.

**Keywords:** fiber-reinforced concrete; recycled tyre polymer fiber; strength; composite material; Portland cement



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## 1. Introduction

The improvement of concrete's efficiency involves not only the enhancement of its performance but also the production of new composite materials based on it [1–6]. The most promising direction is the development of fiber concrete mixture with increased strength, crack, and frost resistance, impermeability, and abrasion and impact resistance. The fiber additive to the concrete mixture reduces significantly the cracks formation and their opening, which appear as a result of shrinkage of concrete during its hardening and subsequent maintenance, which also increases the impact resistance of the concrete [7–10]. The control of the process of formation and development of cracks leads to an increase in the bearing capacity, durability, and characteristics of structural elements after the formation of cracks, as well as to an increase in the ability to protect concrete from the penetration of gas and liquid, thereby providing increased corrosion resistance [11–14].

The fiber reinforced concrete is commonly used as a pavement material for airports and highways, bridge decks, tunnel linings, and offshore platforms [15–17]. These types of products suffer from repetitive cyclic loading during their entire service life. There is an effective use of polymer fiber in an ultra-high-performance concrete for repair and for reinforcement of the bridge columns exposed to chloride-containing waters [18–20].

Tyre recycling is of great importance for the preservation of the environment around the world. Most of the tyres are usually disposed of in landfills, stored, or incinerated, which can cause a number of environmental problems [21]. Every year, more than 10 million tons of tyres go out of use in the world. Mechanical crushing remains the most popular method of tyre recycling. Due to the high proportion of mechanical processing, the main tire recycling products are rubber chips, textile, and metal cord.

The textile cord is used as a raw material for the manufacture of thermal insulation boards, for drilling wells, as well as a reinforcing filler for the manufacture of composite elastomers.

The use of recycled tyre polymer fiber and fiberglass together with recycled concrete aggregates is aimed to improve the strength properties of clay soil reinforcement [21–23].

In recent years, researchers have increased their interest in studying the effect of recycled polymer fiber tyres on the static and dynamic mechanical properties of concrete [22], on fatigue characteristics [23], and on characteristics related to durability (for example, frost resistance). It has been found that the incorporation of recycled tyre polymer fiber can reduce the shrinkage of concrete at an early age and, thus, solve mechanical and durability problems [24]. Along with the use of polypropylene fibers, the addition of recycled polymer fiber from tyres to concrete can effectively prevent the development of cracks and increase the resistance of concrete to freeze–thaw cycles due to the ability to absorb stress provided by resin particles attached to the fiber [25].

The recycled tyre polymer fiber is heavily contaminated with resin crumbs [26]. The cleaning method of recycled tyre polymer fiber from metallic and textile inclusions, as well as from resin crumbs of different fractions, was firstly proposed in the work [16]. It was determined that the untreated recycled tyre polymer fiber contains 15% of clean fiber, 20% of fibers contaminated with a fine fraction of resin granules, and 65% of resin crumbs. It was stated [27] that the fibers obtained from the recycled truck tyres consist of 52% polyethylene terephthalate, 39% polyamide, and 9% polybutylene terephthalate. The recycled fiber reduces the flowability of the concrete mixture and increases the air entrainment. The introduction of recycled tyre polymer fiber into concrete leads to a decrease in workability up to 51.5% at 20 °C, which can be explained by increased shear resistance. The air entrainment increases by 2.81 times with the addition of 15 kg/m$^3$ of the fiber in comparison with the unmodified composition. With the introduction of 10 and 15 kg/m$^3$ of fiber, the density of the concrete mixture decreases from 2390 kg/m$^3$ to 2290 kg/m$^3$ respectively. The introduction of 2.4 kg/m$^3$ of recycled tyre polymer fiber to concrete increased the compressive strength by 10% and the flexural strength by more than 50%, as compared with conventional concrete. This effect can be explained by the fiber connecting effect, which increases the resistance to propagation of cracks through the interface transition zone [28].

The recycled tyre polymer fiber has a positive influence on deformation during early age hardening of concrete. This can be explained by the presence of adsorbed water at the surface of fibers, which can serve as an additional resource of water to increase the hydration degree of cement at a later age. Thus, the introduction of 5, 10, and 15 kg/m$^3$ of fiber into concrete compensates for the shrinkage. On the contrary, with the introduction of treated fiber, the shrinkage is greater the higher the amount of fiber that is introduced. However, the introduction of the fiber leads to less shrinkage than ordinary concrete [16].

It was found that the introduction of untreated recycled tyre polymer fiber in the amount of 15 kg/m$^3$ reduces the modulus of elasticity by 7% [16].

In addition, the introduction of 4.8 kg/m$^3$ of recycled tyre polymer fiber enhances the fatigue performance of concrete by up to 58.3%, but the compressive strength decreases by 12.8%, with an increase in the fiber content from 0 to 4.8 kg/m$^3$ at 20 °C [14].

Concrete containing the untreated recycled tyre polymer fiber is more resistant to freeze–thaw cycles than concrete of plain composition due to the presence of rubber particles and to increased air absorption. The disadvantages of treated recycled tyre polymer fiber are the short length of the fiber threads and poor adhesion to the cement matrix. According to the study [29], it was determined that the fibers obtained from recycled tires have a length between 5 and 25 mm. The redispersible powders were proposed to improve the adhesion of recycled tyre polymer fiber to cement matrix, which creates polymer films on the fiber–cement paste interface, increasing the adhesion as well as the water and frost resistance [30,31].

It can be concluded that the use of recycled tyre polymer fiber in concrete is promising and relevant, especially in those structures where increased impact resistance is required.

## 2. Materials and Methods

*Materials*

In the present work, the following materials were used:

- an untreated recycled tyre polymer fiber, obtained by recycling automobile tyres;
- a Portland cement CEM II/A-L 42.5N, in accordance with [32], with the following characteristics: specific surface area 377 $m^2/kg$; true density 2.9 $g/cm^3$; standard consistency 28.5%; setting time: initial setting time 172 min, end of setting time 234 min; compressive strength at the age of 2 days 20.0 MPa; and compressive strength at the age of 28 days 46.5 MPa. Tables 1 and 2 show the chemical and mineralogical composition of the clinker;
- a silica powder was used as a filler, with specific surface area of 288 $m^2/kg$ and with true density of 2.65 $g/cm^3$;
- a superplasticizer based on ethers of polycarboxylate was used as a plasticizing and water-reducing additive;
- a quartz sand of the 1 class in accordance with [33]. The granulometric distribution of the sand is shown in the Figure 1.

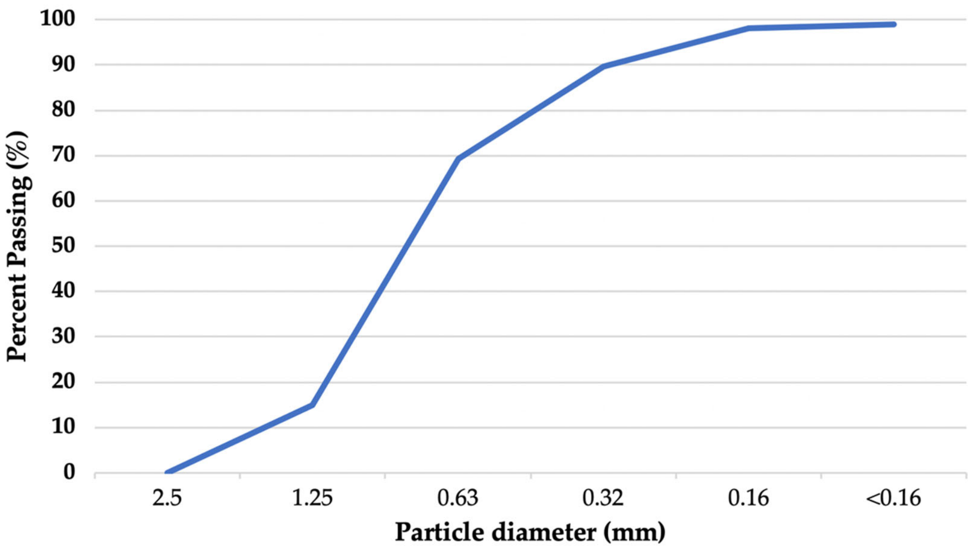



**Figure 1.** The granulometric distribution of the sand.

**Table 1.** Mineralogical composition of the clinker.

| Mineral (%) | | | | |
|---|---|---|---|---|
| $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | CaO |
| 70.1 | 7.4 | 4.8 | 12.1 | 1.5 |

**Table 2.** Chemical composition of the clinker.

| Component (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | $Al_2O_3$ | CaO | $Fe_2O_3$ | MgO | $TiO_2$ | $P_2O_5$ | $SO_3$ | $Na_2O$ | $K_2O$ | Cl |
| 21.0 | 5.2 | 58.0 | 2.8 | 5.0 | 0.3 | 0.1 | 2.7 | 0.1 | 0.5 | 0.01 |

## 3. Experimental Procedure

### 3.1. Mixture Proportioning

In this work, the effect of treated and untreated recycled tyre polymer fiber on the properties of concrete was studied. The untreated mixture of recycled tyre polymer fiber with inclusions of rubber was sieved forn 30, 60, and 120 s (Figures 2 and 3). The raw mix was first screened and then placed on to a sieve N 063. The magnet and air with the pressure of up to 6 bars were submitted in order to treat the raw mix of metal fibers.

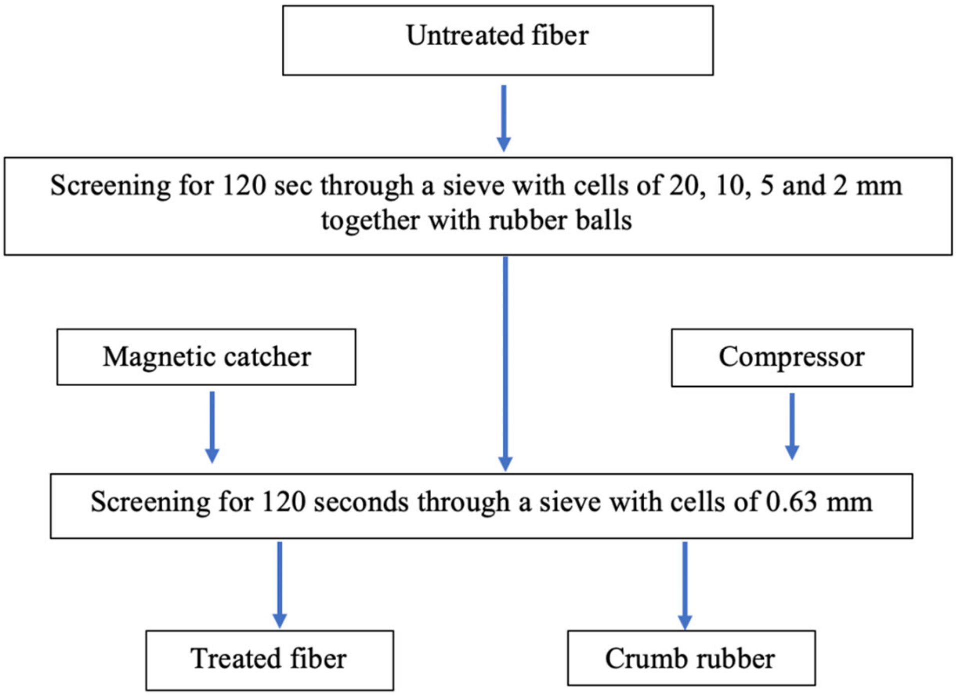



**Figure 2.** Stage of treatment of recycled tyre polymer fiber.

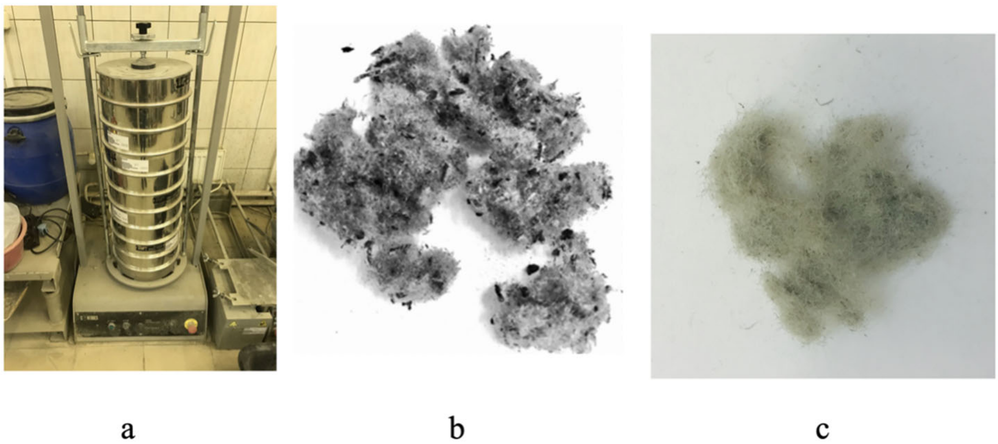



**Figure 3.** Treatment of recycled tyre polymer fiber: (**a**) sieve; (**b**) untreated tyre fiber; and (**c**) treated fiber.

Figure 4 shows the different types of untreated recycled tyre polymer fiber. In the experiment, the untreated fiber Type IV was used. Table 3 shows the composition of recycled tyre polymer fiber. The data show that the mixture is nonuniform and consists of recycled tyre polymer fiber, rubber crumb, and metal fiber. The average density of the fiber mass determined by the pycnometric method was 0.923 g/cm$^3$.

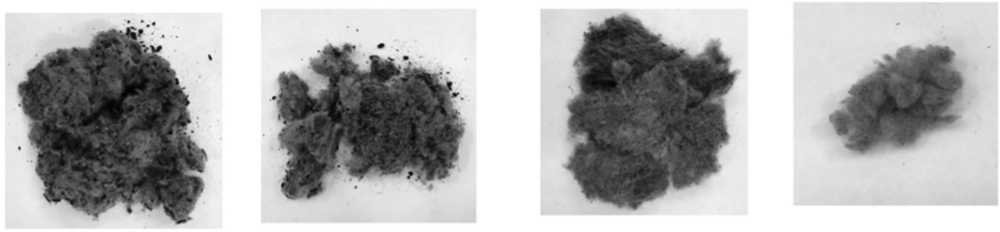



**Figure 4.** Tyre fiber types derived from tyre recycling.

**Table 3.** Recycled tyre polymer fiber.

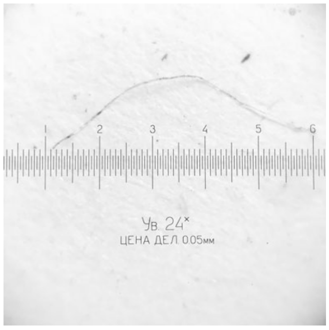
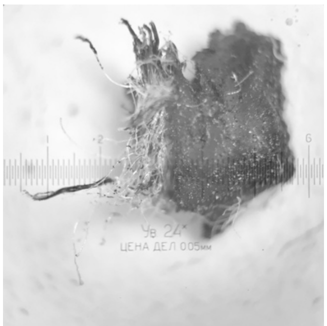
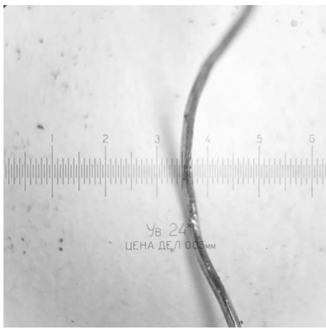
| **Component of Recycled Tyre Polymer Fiber** | **Parameters of the Fiber** | | |
|---|---|---|---|
| | **Diameter (*l*), mm** | **Length (*d*), mm** | ***l*/*d*** |
|   Treated recycled tyre polymer fiber | 0.05 | 6.5 | 130 |
|  Recycled tyre polymer fiber and crumb rubber | ≥0.05 | ≥6 | - |
|   Metallic fiber | 0.2 | ≥10 | 50 |

Figure 5 shows the FTIR spectra of treated polymer fiber. FTIR spectra were measured by the disturbed total internal reflection method on a BRUKER VERTEX 70v FTIR spectrometer using a GladyATR 50 NPVO attachment from PIKE with a diamond working element in the 4000–400 cm$^{-1}$ region and a spectral resolution of 4 cm$^{-1}$. The fiber spectra were obtained without special preconditioning.

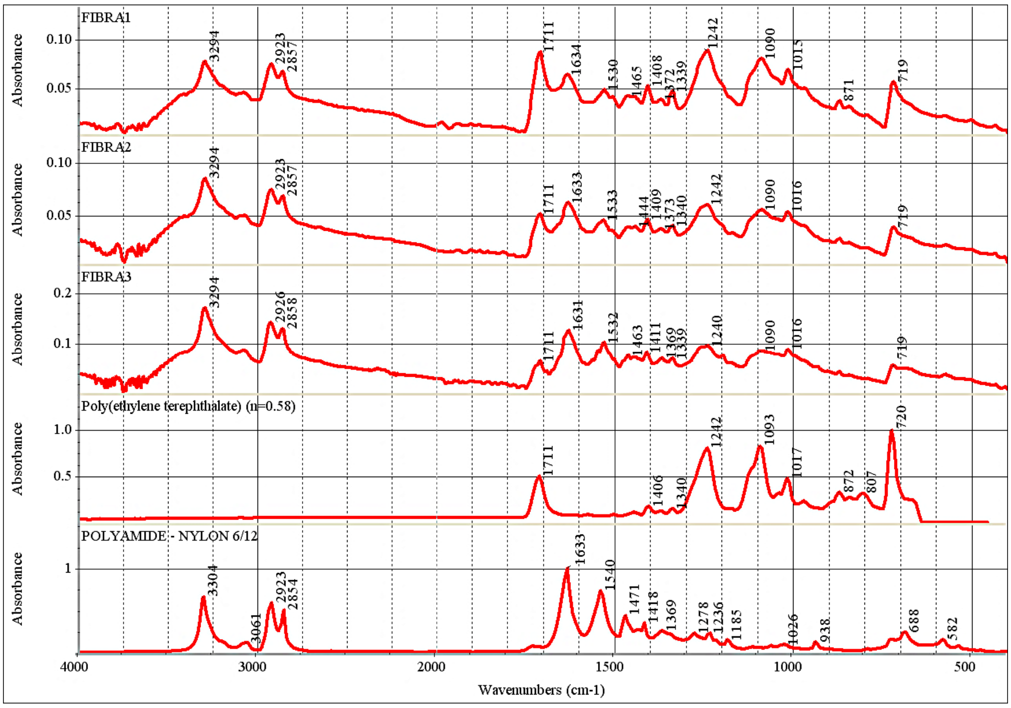



**Figure 5.** FTIR spectra of the treated recycled tyre polymer fiber.

The polymeric fiber was not homogeneous, and this indicates that the fiber was a mixture of different substances. From the comparison of the absorption bands on the experimental spectra with the literature data [34,35], it follows that the fiber used in the work was a combination of two types of fibers. This included polyamide (nylon) and polyester (polyethylene terephthalate, PET). On the fiber spectra, areas with characteristic absorption bands can be distinguished: for nylon, it is in the range of wave numbers 3300–2850 cm$^{-1}$, characteristic of valence vibrations of N–H and C–H bonds; in the range 1650–1340 cm$^{-1}$, characteristic of valence and deformation vibrations of bonds C=O, N–H, C–H; for PET, pronounced absorption bands at 1711 (C=O), 1242 and 1090 (essential O–C=O), 1016 (O–H), 870 and 719 (aromatic C–C and C–H) cm$^{-1}$; and in the high–frequency region v > 2500 cm$^{-1}$ bands, the absorption of O–H and C–H for PET has a very low intensity. The absence of pronounced absorption bands in the region of 960–920 cm$^{-1}$ indicates that the polyamide component in the fiber composition was most likely the presence of nylon-6.6 [34]. Table 4 shows the most intense absorption bands from the FTIR spectra of the fiber sample under study and their corresponding bonds according to [34,35].

The data presented in Table 4 show that the absorption bands observed in the fiber spectra were located in the wavenumber intervals characteristic of individual nylon polymers-6.6 and PET. The absence of significant shifts in the absorption bands indicates that the fiber was made from separate fibers of these two polymers combined mechanically (by torsion) without their fusion or copolymerization.

It was found that the recycled tyre polymer fiber had a density of 0.923 g/cm$^3$, length ($l$) of 6.5 mm, diameter ($d$) of 0.05 mm; and $l/d$ = 150.

**Table 4.** The absorbance bands from FTIR spectra for the fiber sample.

| Bands for the Nylon-6,6 Component [34] | | Bands for the PET Component [35] | |
|---|---|---|---|
| Wave Number, $cm^{-1}$ | Band | Wave Number, $cm^{-1}$ | Band |
| 3294 | N–H stretching, H-bonded | 1711 | C=O stretching in carboxylic group |
| 3060 | N–H overtone | 1410 | O–H deformation |
| 2923 | $CH_2$ stretching, asymmetric | 1340 | $CH_2$ bending and wagging |
| 2857 | $CH_2$ stretching, symmetric | 1242 | O–C=O bending |
| 1633 | C=O stretching | 1090 | $CH_2$ wagging |
| 1532 | N–H bending, H-bonded | 1016 | C–O bending |
| 1370 | $CH_2$ wagging | 719 | C–H benzene rings |

### 3.2. Test Procedure

In this work, the effect of untreated recycled tyre polymer fiber on the workability and strength properties of sand concrete was evaluated. The concrete mixtures were prepared according to standard methods. The workability was determined by the use of the Suttard viscometer.

The composition of the concrete mixtures is presented in Table 5. The composition of the mixtures with untreated fiber is presented in Table 6.

**Table 5.** Composition of concrete mixture with untreated fiber.

| Content of Components ($kg/m^3$) | | | | |
|---|---|---|---|---|
| Cement | Water | Quartz Sand | Superplasticizer | Fiber |
| 677 | 271 | 1354 | 1.6 | 0 |
| 677 | 271 | 1354 | 2.4 | 11 |
| 677 | 271 | 1354 | 4 | 19 |

**Table 6.** Composition of concrete mixture with treated fiber.

| Content of Components ($kg/m^3$) | | | | | | |
|---|---|---|---|---|---|---|
| Cement | Water | Quartz Sand Fraction (mm) | | Silica Powder | Superplasticizer | Fiber |
| | | 0.1–0.4 | 0.4–0.8 | | | |
| 639 | 235 | 402.4 | 939 | 128 | 3.4 | 0 |
| 639 | 235 | 402.4 | 939 | 128 | 3.5 | 5 |
| 639 | 235 | 402.4 | 939 | 128 | 4.0 | 10 |

Preparation of the concrete mixture included the following operations. Firstly, the dry components (cement, sand, and filler) were introduced into the concrete mixer. Then, all the dry ingredients were mixed for 1 min. The fiber was pre-mixed with mixing water, which was added into the concrete mixer.

In Figures 6 and 7, the influence of fiber content on the density and workability of a sand concrete mixture is presented.

The flexural and compressive strengths of fiber concrete were determined by testing specimens with a size of 40 × 40 × 160 mm at the age of 28 days in accordance with GOST 310.4-81 "Cements. Methods for determination of flexural and compressive strengths" (Figure 8). They were placed in a curing chamber. The strength characteristics are presented in Figure 9.

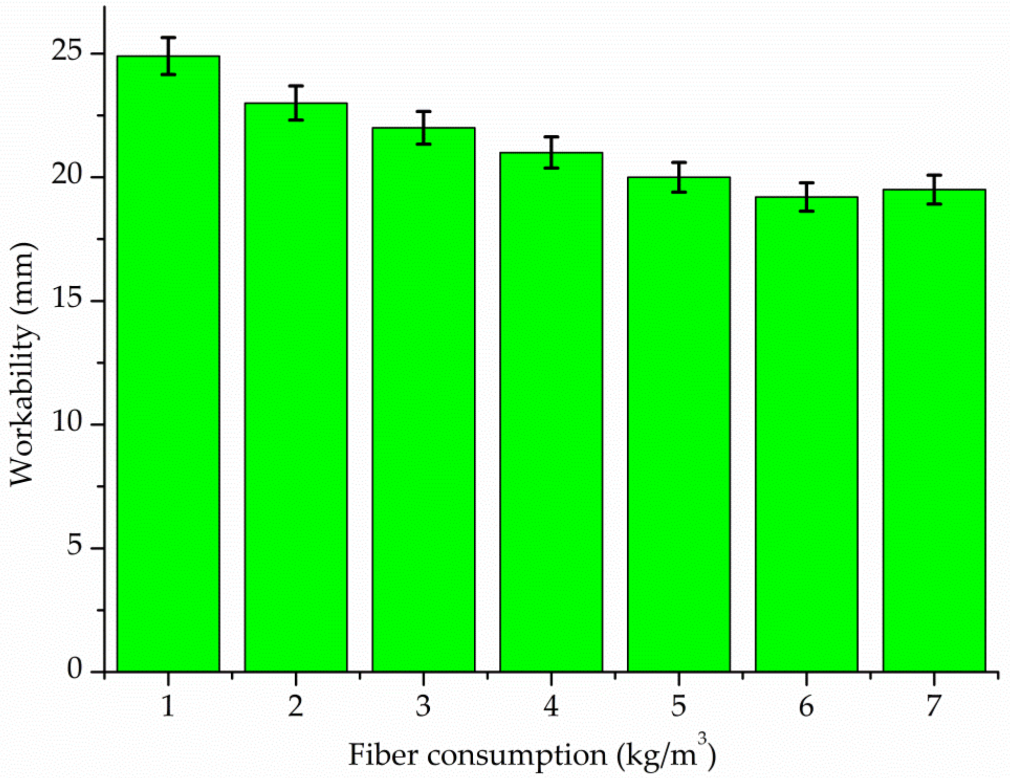



**Figure 6.** Influence of untreated fiber content on workability of concrete mixture.

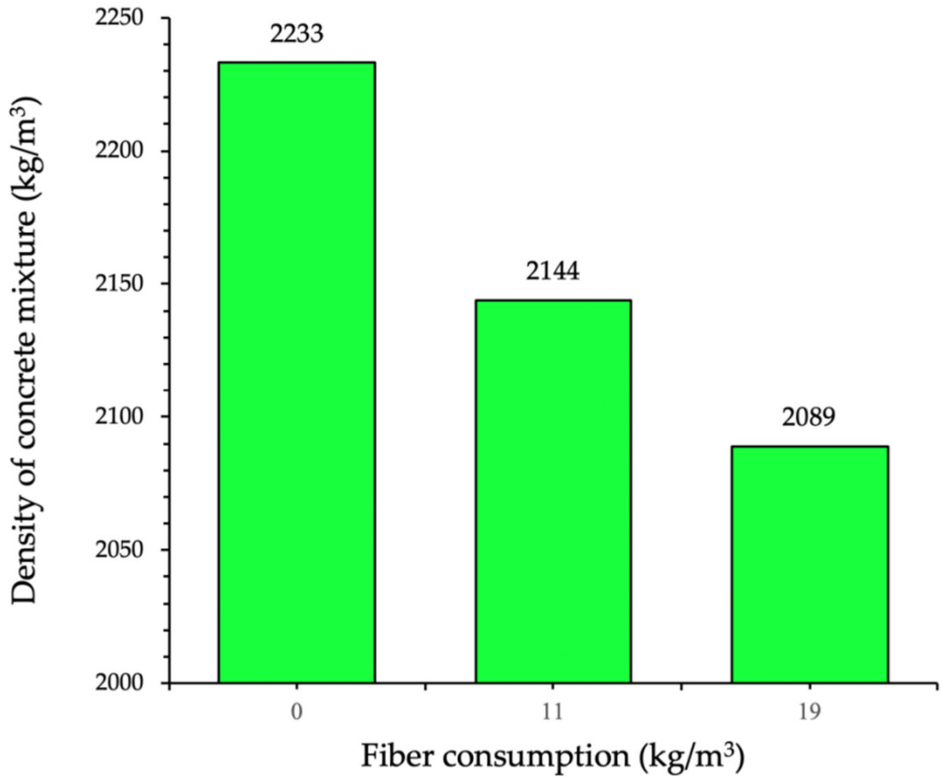



**Figure 7.** Influence of untreated fiber content on density of concrete mixture.


**Figure 8.** Testing of samples in accordance with GOST 310.4-81.

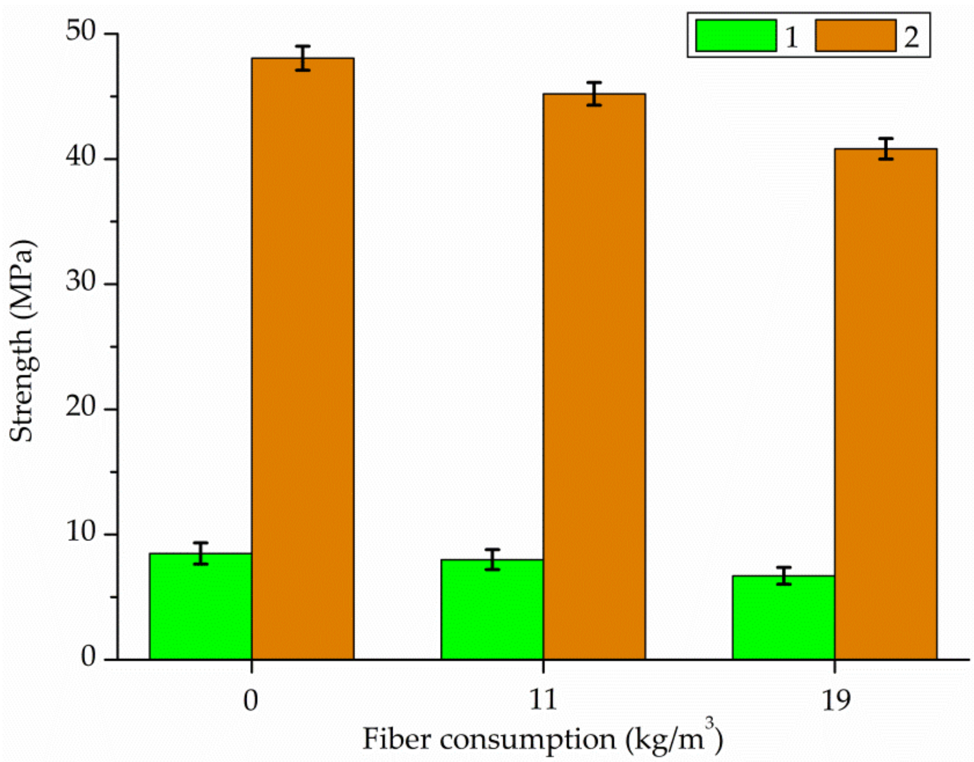



**Figure 9.** Influence of fiber content on flexural and compressive strengths of concrete: (1) flexural strength and (2) compressive strength.

The prismatic strength of sand concrete was determined in accordance with [36] by testing specimens with a size of 70 × 70 × 280 mm. The residual tensile strength of sand concrete was determined by testing specimens with a size of 70 × 70 × 280 mm in accordance with Russian set of rules SP 297.1325800.2017. Each series consisted of three samples.

## 4. Results and Discussion

It was discovered that added recycled tyre polymer fiber reduced the workability of the concrete mixture. It was determined that 1 kg of the recycled tyre polymer fiber decreased the workability of the concrete mixture by 3.6% in comparison with the plain mixture. The density of the concrete mixture was reduced by 4% for every 10 kg/m$^3$ of recycled tyre polymer fiber.

It was established that addition of 11 kg/m$^3$ of recycled tyre polymer fiber led to a decrease the compressive and flexural strength by 6% in comparison with the plain mixture. The addition of 19 kg/m$^3$ led to a decrease of compressive and flexural strengths by 15% and 21%, respectively.

The influence of treated recycled tyre polymer fiber on the technological and strength properties of sand concrete was carried out. In Table 6, the composition of the mixtures is presented. The consumption of fiber in the composition of sand concrete varied from 0, 5, and 10 kg/m$^3$, which corresponded to volume reinforcement of 0.54 and 1.08%, respectively, when 5 and 10 kg of fiber per 1 m$^3$ was introduced. Fiber was added to the concrete in consumptions of 0, 5, and 10 kg/m$^3$, which corresponded to 5 and 10 kg of fiber per 1 m$^3$ by volume reinforcement of 0.54 and 1.08%, respectively.

A first series of specimens with a size of 70 × 70 × 280 mm was tested to determine the prismatic strength in accordance with [36]. A second series of specimens with a size of 70 × 70 × 280 was tested in accordance with Russian set of rules SP 297.1325800.2017 to determine the residual tensile strength of sand fiber concrete. The test pattern of the specimens in accordance with the set of rules SP 297.1325800.2017 is presented at Figures 10 and 11. An incision with a width of 2 mm and a depth of 12 mm was made. Loading occurred in two stages: at a rate of 0.05 mm/min before crack formation and at a rate of 0.2 mm/min after crack formation.

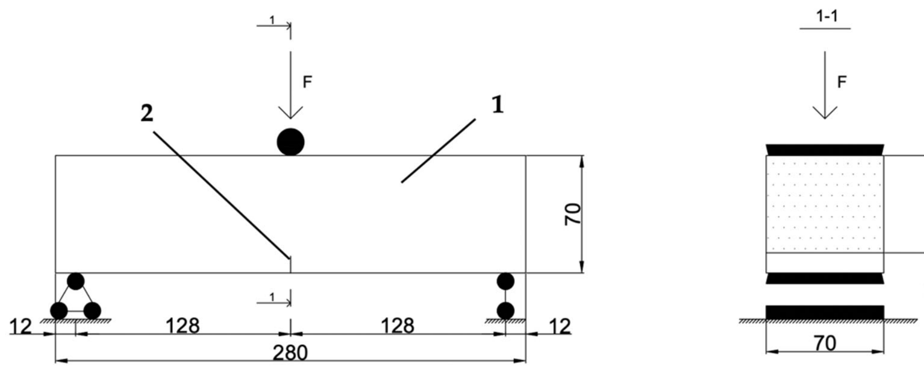



**Figure 10.** Scheme of determining the residual tensile strength of specimens: (1) sample and (2) incision.

The dosage of plasticizer was selected in order to maintain target slump flow diameter of 22 ± 2 mm. The density of the plain concrete mixture was 2241 kg/m$^3$, while the density of the concrete mixture with content of 5 and 10 kg/m$^3$ treated fiber was 2252 and 2256 kg/m$^3$, respectively. The density of the plain concrete was 2263 kg/m$^3$, while the density of the concrete with content of 5 and 10 kg/m$^3$ treated fiber was 2200 and 2263 kg/m$^3$, respectively.

The flexural strength increased uniformly when the content of the fiber increased (Figure 12). The reinforcement of the composition with fibers of 5 and 10 kg/m$^3$ increased the flexural strength by 14% and 23.4%, respectively.

The compressive strengths of concrete were determined by testing specimens with a size of 40 × 40 × 160 mm at the age of 28 days, and the prismatic strength was determined by testing specimens with a size of 70 × 70 × 280 mm. It was found that the higher the fiber content, the lower the strength of the concrete: the prismatic strength was lower by 10.8% and 4.6% with a fiber content of 5 and 10 kg/m$^3$, respectively (Figure 13a). The fiber added to the concrete mixture in the amount of 5 kg/m$^3$ reduced the compressive strength by 13.4%, which can be explained by the presence of recycled polymer fiber with low modulus of elasticity. Thus, the fiber occupied a certain part of the working cross-sectional area of the matrix, weakened it, and reduced its strength. The addition of fiber in the amount of 10 kg/m$^3$ to the concrete mixture strengthened the matrix by 3.7% (Figure 13b), which can be explained by an increase in the degree of hydration of the cement paste near the fiber surface due to its high water-holding capacity. At the same time, an interfacial transition zone was formed near the fiber, which provided higher concrete strength.

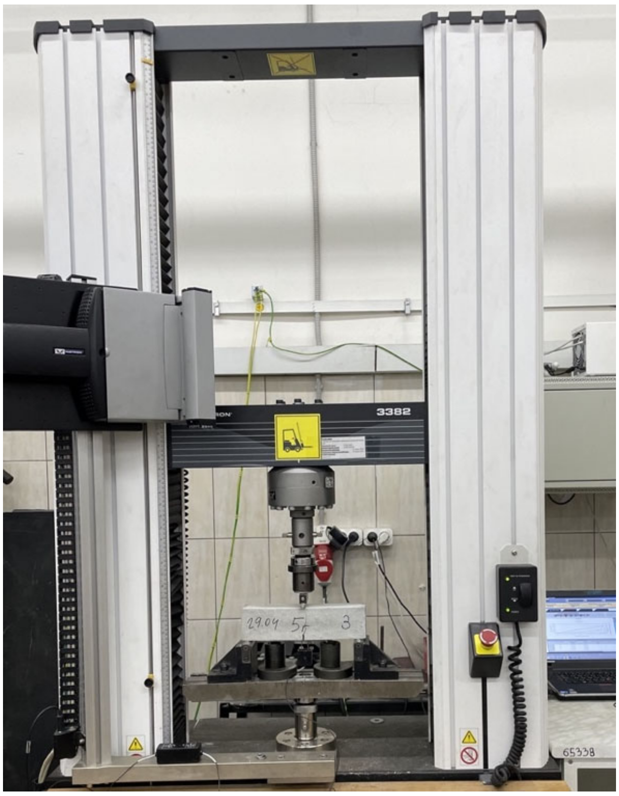



**Figure 11.** Testing of the samples in accordance with GOST 24452-80.

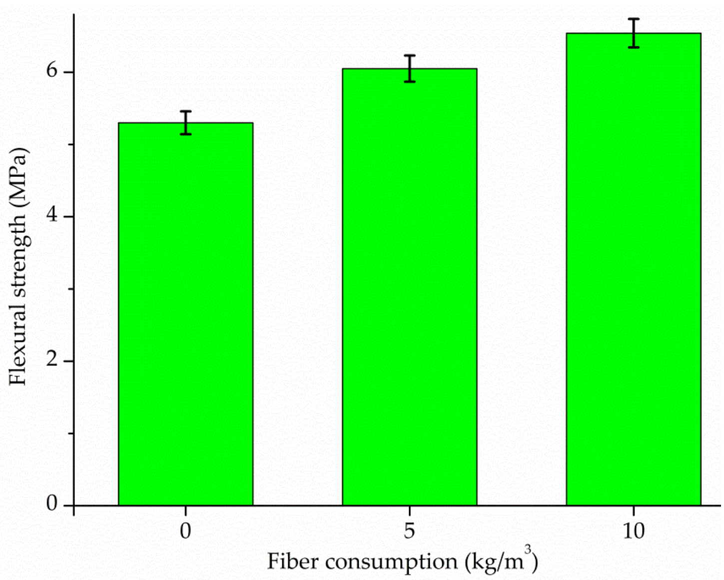
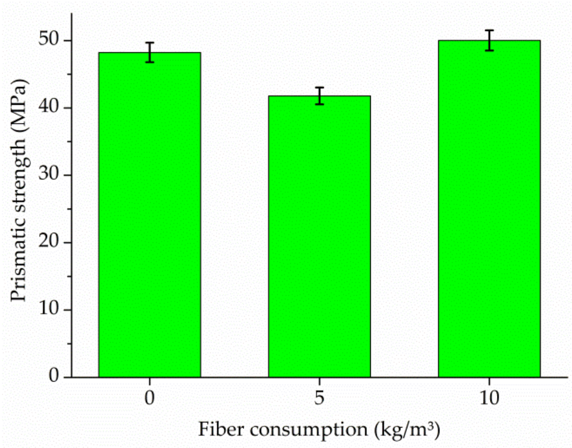
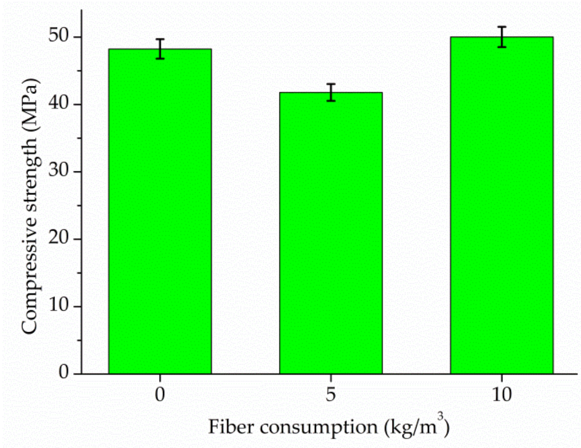



**Figure 12.** Flexural strength of the concrete with different fiber content.




(**a**)




(**b**)

**Figure 13.** Strength of concrete with different fiber content: (**a**) compressive strength and (**b**) prismatic strength.

The fiber derived from tyre recycling is the low-modulus fiber. The elastic modulus of polyamide fibers is within 1900 MPa. The use of polymer fibers in concrete does not increase the tensile, compressive, or bending strength of the concrete under the static load, since concrete is unable to transfer static forces to fibers that have lower elastic modulus values compared with concrete.

The effect of the fiber on crack resistance of sand concrete was evaluated by tests to determine the residual tensile strength. The dependence of crack mouth opening displacement on applied load was established. Figure 14 shows the curve for the first series of plain concrete. Figure 15 presents the curves for the second series with fiber content of 5 kg/m$^3$. The results of the tests for the third series of specimens with a fiber content of 10 kg/m$^3$ are presented in Figure 16. The number of the curves is explained by the rejection of unsatisfactory results.

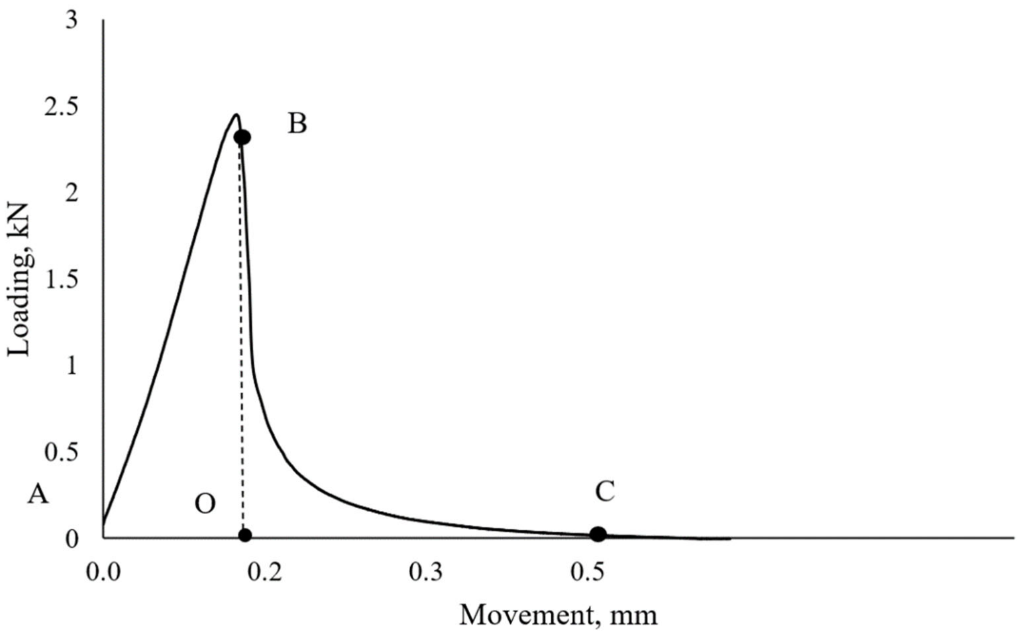



**Figure 14.** Load–displacement curves of cut faces of plain concrete specimens.

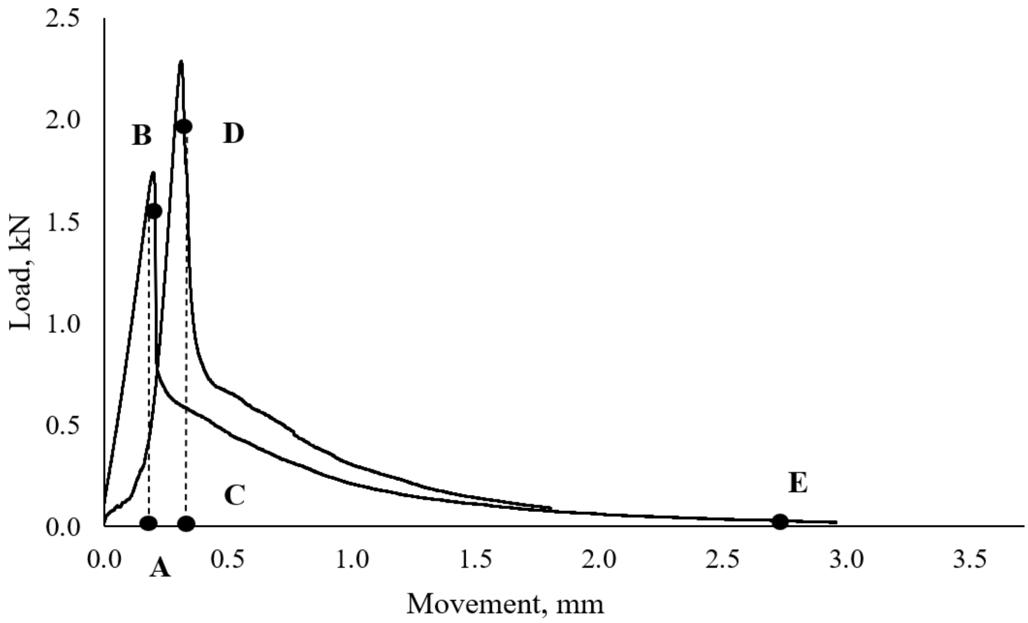



**Figure 15.** Load–displacement curves of cut faces of concrete with 5 kg/m$^3$ of fiber content.

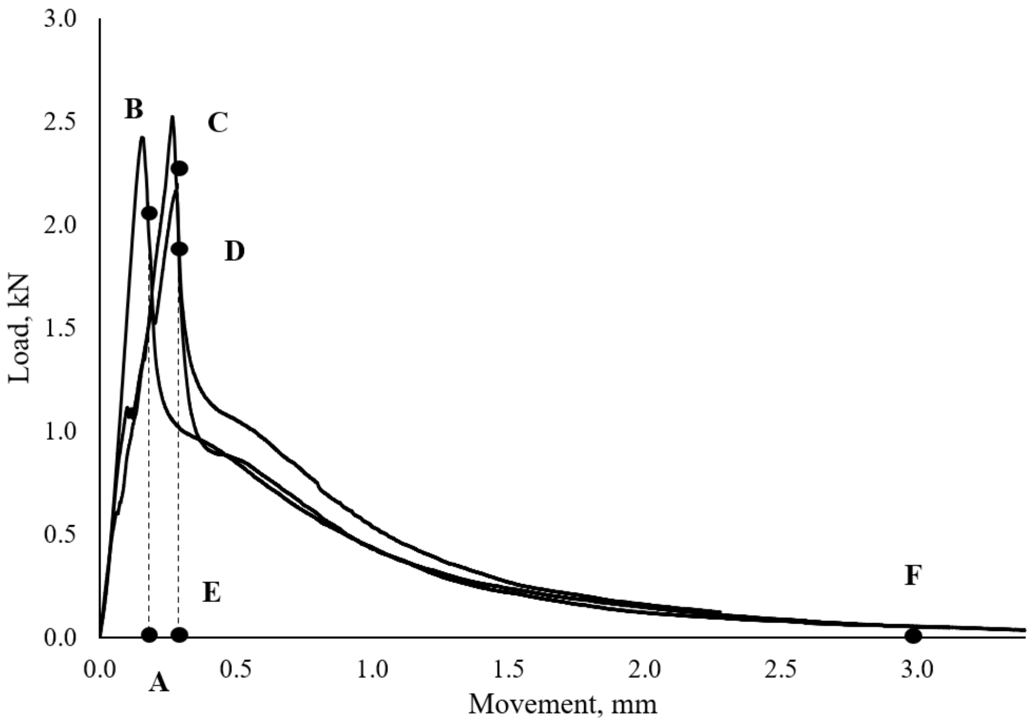



**Figure 16.** Load–displacement curves of cut faces of concrete with 10 kg/m$^3$ of fiber content.

In Figures 14–16, the plastic deformation zone of plain and fiber concrete is presented. They were situated after the peaks: area OBC of plain concrete; areas ABE and CDE of concrete with 5 kg/m$^3$ of fiber content; and areas ABF, ECF, and EDF of concrete with 10 kg/m$^3$ of fiber content. On the experimentally obtained graph of the dependence of displacement on load, points from A to B were selected. The segment AB represents linear work during loading of the sample, and the angle of inclination of the segment AB to the axis of displacement was numerically equal to the modulus of elasticity. The energy of destruction was numerically estimated by the area under the curve bounded by a segment omitted from a point perpendicular to the axis of displacement. The average area under the graph of plain concrete was 771 units, the area of the concrete with 5 kg/m$^3$ of the fiber was 1549 units, and the area of the concrete with 10 kg/m$^3$ of the fiber was 2369 units. Consequently, it was necessary to expend 2 times more energy to destroy the samples when the fiber concrete content was 5 kg/m$^3$ and 3.1 times more energy when the fiber concrete content was 10 kg/m$^3$. It can be explained that as the number of fibers in composite increases, so does the work required to extract the numerous fibers from the cement–sand matrix of the concrete.

The angle of inclination of the curve in the elastic deformation zone of to the axis of displacement for plain concrete was 66 degrees; for concrete with 5 kg/m$^3$ of the fiber, the angle was 76 degrees; and for concrete with of 10 kg/m$^3$ of the fiber, it was 81 degrees. It can be concluded that concrete with fiber is characterized by a more elastic process of destruction, i.e., fewer deformations at equal stress values.

It is noted that samples with 5 kg/m$^3$ of recycled tyre polymer fiber showed the lowest results of compressive strength, prism strength, and crack resistance among the series. This can be explained, for example, by the presence of large particles of the rubber crumbs, which turned out to be a weak link in the body of the composite matrix.

## 5. Conclusions

In this study, the characteristics of recycled tyre polymer fiber obtained from recycled tyres and their effects on the properties of sand concrete were experimentally investigated. Two types of mixture were used. The first type included untreated fiber, the composition of which was determined. It was established that it had an organic origin and was represented by polyamide and polyester fibers. The fiber obtained from recycled tyres was treated using a screen, compressed air, and a magnet. The second type of concrete mixture was obtained from treated fiber. On the basis of the results of this study, the following conclusions can be drawn:

1. The characteristics of workability and strength properties of compositions with untreated fiber with contents of 11 and 19 kg/m$^3$, corresponding to 1.2% and 2.1% Vf, and treated fiber with content of 5 and 10 kg/m$^3$, corresponding to 0.54% and 1.1% Vf, respectively, were studied.
2. The FTIR spectroscopy analysis showed that the recycled tyre fiber consisted of polyamide and polyester and had a density of 0.923 g/cm$^3$, length ($l$) of 6.5 mm, diameter ($d$) of 0.05 mm; and $l/d$ = 150.
3. The effects of untreated tire fiber on density, workability, and strength properties of sand concrete were determined. It was found that the workability of concrete decreased by 3.6% for 1 kg/m$^3$ of recycled tyre polymer fiber introduced into the concrete mixture. The density of the concrete mixture was reduced by 4% for every 10 kg/m$^3$.
4. It was found that the increase of untreated recycled tire fiber in the mixture led to a decrease in both flexural and compressive strengths.
5. It was found that the treated fiber reduced the strength when it was added in an amount of 5 kg/m$^3$; with an increase in the content up to 10 kg/m$^3$, the strength exceeded the strength of plain concrete.
6. The addition of fiber increased the crack resistance of concrete. It was determined that a low content of recycled fiber did not influence the strength characteristics of concrete, and it was characterized by the strength of the matrix. The increase of recycled fiber content decreased the strength slightly due to the fact that low-modulus fiber could not act as a reinforcement but occupied some part of cross-sectional area of the samples and weakened them. Then, the strength increased slightly due to the modification of the cement paste near the surface of the fibers and the creation of a connected network of interfacial transition zones with higher strength and hardness.

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