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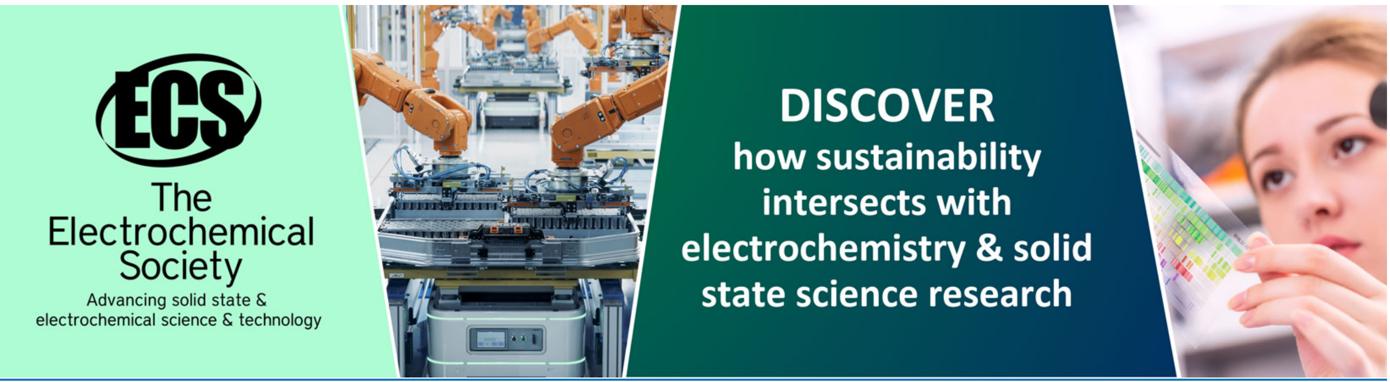

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The Mechanical Properties of Waste Tire Cords Reinforced Geopolymer Concretes

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Abstract. The article aim is to determinate the possibilities of recycling the waste textile cord from used tires in geopolymer composites. The matrix was based on fly ash from power station located in city named Skawina (Poland) and fine sand in the ratio of 1:1. The process of activation was made by 10M sodium hydroxide solution combined with the sodium silicate solution. In order to manufacture the composites the additions of 5, 10, 20 and 30% of waste textile cord by volume were applied. The research methods used: microstructure research, density, flexural strength and compressive strength tests as well as analysis of breakthroughs. The results show the influence of addition of waste textile cord form used tires on the composite properties. The addition of textile fibres causes a reduction in the weight and density of the geopolymer. For samples with 20% fibre noticed the lowest density and the highest bending strength. The highest compressive strength was obtained for the geopolymer with 5% textile fibres.

1. Introduction

Global tire manufacturing was estimated to be over 17 million tonnes in 2016 and it is growing about 4% per year through 2022 [1,2]. In European Union the tire sales was 4.89 million tonnes in 2016 [3, 4]. Disposal of waste tire rubber is one of the most important problems in waste management in all parts of the world [5]. Disposal of waste tire can be potentially harmless for environment. Not only because of fire thread on the landfills, but also due to their heavy metal and other pollutant content and risk for the leaching of toxins into the groundwater [6]. In some parts such as in European Union, disposal of waste is prohibited by regulations [7]. They should be recovered and recycled. One of the possibility is thermal depolymerisation, also known as pyrolysis [7, 8]. The main problem is that this kind of solution required very expensive infrastructure and during the process we recover only energy not the raw material. According to the newest EU regulation the pyrolysis with energy recovery is one of the less desirable methods of waste treatment.

Nowadays, the material recycling of tire products is still on very low level. It is estimate that in Poland it is only 15% by weight of used tires. It is caused by a lot of problems during processing used tires. They are multicomponent construction. It mainly consists of elastomer (rubber), metal and textile fibres called textile cord [8, 9]. The exemplary scheme for line for used tires processing is presented in the figure 1 [9, 10].

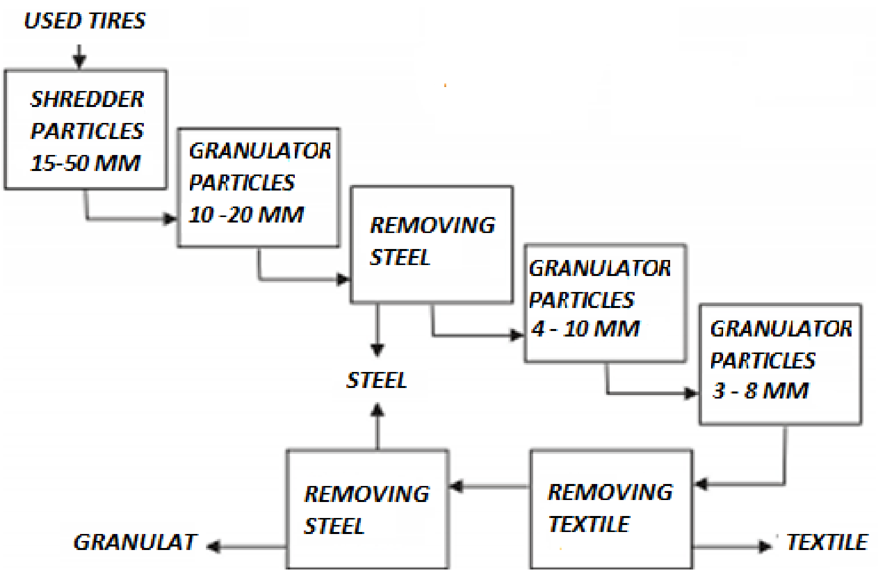


Figure 1. Diagram of a line for grinding tires [9, 10].

In the first step, tires are cut and crushed or dissolved. The rubber obtained in this way is subject to further fragmentation and thermal treatment. In the mechanical grinding process, rubber particles of various sizes, steel and textile waste are also obtained. This process is very energy-consuming and causes high noise emission. It is also possible to carry out the process in low temperatures, it happens that the rubber becomes brittle and much easier to crush.

A lot of components causes difficulties in the tire recycling process. The components such as rubber and steel can be relatively easy recovered and find the application for example in concrete industry [11, 12]. Obtained rubber part are used depending on their size. The large one as: grits and granules are used most often as surfaces of playgrounds, sports fields and as a material for sound and vibrations absorbing. The rubber dust is added to rubber mixtures, which are used for car mats, rubber mats, etc. The main problem is the recycling of the textile cord, especially because of its usually high degree of contamination with rubber material, which limits possibilities of use it after recovery [13, 14].

The problem of the re-use of textile fibres from the recycling of car tires is still not sufficiently explored. The first attempts of using a textile cord in modified mortars had a place in 2000. These tests gave positive results by improving the mechanical properties of the mortar, however, economic reasons prevented their application in practice [15, 16] Others were using textile waste as reinforcement materials for the production of polypropylene (PP) and made use of this composite in the production of car bumpers. In this case, the fibres also gave positive results, increasing bending strength, modulus of elasticity and acceptable impact strength compared to conventional PP [17]. Nowadays there are attempts to entirely utilize the waste tires granulates in geopolymers [18]. The research shows that it can be a promising way for utilization this kind of waste, but it still requires further research work.

2. Experimental procedure

Specimens based on geopolymer matrix with additions of 5, 10, 20 and 30% of waste textile cord by volume were investigated. The variables include different amount of reinforcement and reference samples based on matrix material without additions.

2.1. Materials

2.1.1. Geopolymer matrix. The geopolymer matrix were made from fly ash from the CHP plant in Skawina (Poland) and sand in the ratio 1:1. This fly ash is rich in oxides such as SiO_2 – 55.89% by mass and Al_2O_3 – 23.49% by mass. The morphology of the particles of fly ash was typical of such by-products of coal combustion and suitable for the process of alkali-activation. The process of activation has been made by 10M sodium hydroxide solution combined with the sodium silicate solution.

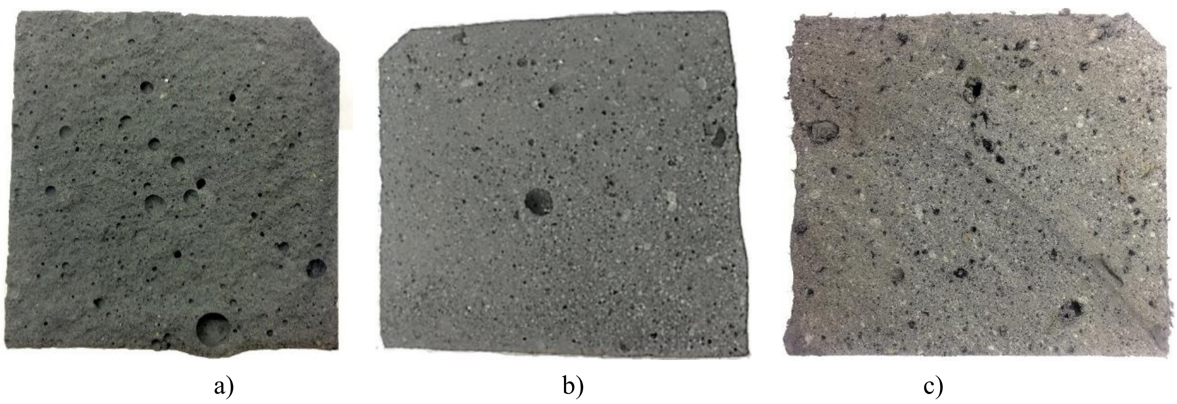
2.1.2. Waste tire cords. Textile fibres from used tires are a by-product obtained in the process of grinding a tire into a granulate. During subsequent shredding steps, the textile cord is separated from the rubber granulate. The weight of textile fibres makes up about 6% of the total weight of the tire, both in the case of passenger cars and trucks [19, 20]. The diameter of a single fibre is several tens of micrometres. The textile cord consists of numerous strands of twisted thin fibres made of cellulose, poly(butylene terephthalate) - PBT, polyethylene terephthalate - PET and polyamide-6,6 - PA66. The caravan's tire carcass consists of approximately 1500-1800 threads. They are arranged in a parallel manner and appropriately impregnated and joined with rubber [17, 20]. Fibres used for research were recovered by the Polish company Orzeł S.A.

2.2. Specimens
The samples were prepared using sodium promoter, fly ash and fibres (5, 10, 20 and 30% by volume of the composite). In the table 1 there is presented the addition according to volume and mass percentage.

Table 1. The content of fibres in the composite given in percent by volume and by mass.

Addition of waste textile cord by volume	Addition of waste textile cord by mass
5%	0.488
10%	0.864
20%	1.707
30%	2.530

The fly ash, sand, alkaline solution and fibres were mixed for about 20 minutes by using mixing machine Varimixer Bear (to receive the homogeneous paste). Next, it was poured into sets of plastic moulds. They have following dimensions: 20 x 5 x 10 cm. Then, the samples were subjected to vibratory removal of air bubbles. Tightly closed moulds were heated in the laboratory dryer for 24h at 75 °C. Then, the samples were unmoulded. Next, the samples was cured in laboratory condition during 28 days. Before the tests they were cut for samples proper for flexural and compressive strength tests (figure 2).



a) b) c)

Figure 2. Exemplary samples: a) geopolymer matrix without reinforcement, b) with 5% fibers addition, c) 30% fibers addition.

IOP Conf. Series: Materials Science and Engineering **416** (2018) 012089 doi:10.1088/1757-899X/416/1/012089

3. Analytical procedure

3.1. Microstructure research.
SEM type JEOL JSM 820 has been performed for microstructure investigations. The research has been made for the samples that previously had been broken while strength tests. The samples were covered with a thin layer of gold with JEOL JEE-4X vacuum sputter. The investigations were made for composite with 30% textile cord addition by volume at various magnifications.

3.2. Compressive strength test
Compressive strength tests were carried out according to the methodology described in the standard EN 12390-3. (‘Testing hardened concrete. Compressive strength of test specimens’), because of absence of separate standards for geopolymer materials. The tests involved 2 cubic samples: 50 x 50 x 50 mm. Tests were performed on an concreate press - MATEST 3000kN with speed 0,5 [MPa/s].

3.3. Flexural strength test
Flexural strength tests were carried out according to the methodology described in the standard EN 12390-5. (‘Testing hardened concrete. Flexural strength of test specimens’), because of absence of separate standards for geopolymer materials. The tests involved 2 cuboid samples: 50 x 50 x 150 mm. Tests were performed on an universal testing machine - MATEST 3000kN with speed 0,05 MPa/s.

3.4. Density
The density of the material was count on the basis of volumetric measurements and the weight of the analysed samples. The composites were treated as homogeneous material. The density was calculated by divided the total mass by total volume. The investigations were made on two specimens.

4. Experimental results and discussion

4.1. Microstructure research
The SEM observations were made for geopolymer with 30% textile cord addition. The exemplary results are presented in the figure 3.

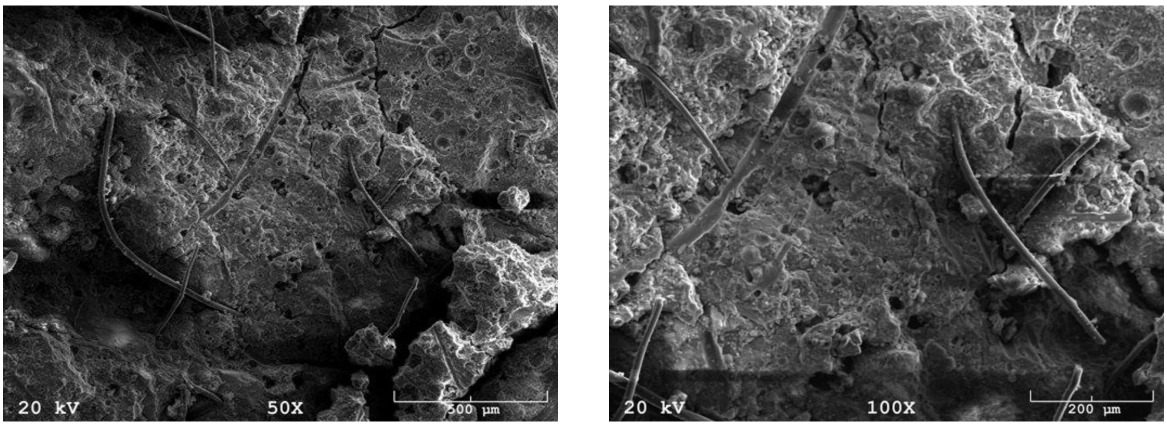


Figure 3. SEM images of fly ash based geopolymer with 30% textile cord addition.

SEM investigations give a preliminary information about fibers distribution and the coherency between waste cord fibers and the geopolymer matrix. The observations in low magnification (20x and 50x) allow to estimate that the fibers distribution was regular. The investigations in high magnification (100x and more) allow to evaluate the fibers coherency to matrix as good (for the further research mechanical tests are needed).

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4.2. Compressive strength test
Results for compressive strength test are presented in table 2.

Table 2. The average values for compressive strength tests.

The content of fibres by volume [%]	d_1 [mm]	d_2 [mm]	force [kN]	Compressive strength [MPa]
0%	50.31	50.34	67.551	26.671
5%	50.27	48.80	79.974	32.592
10%	50.73	49.30	59.068	23.640
20%	50.87	50.92	47.894	18.534
30%	49.62	54.01	51.468	19.207

The best result for compressive strength tests are for composites with small amount of fibres. The addition of 5% textile fibres give -32.59 MPa. The lowest compressive strength value is observed for material containing 20% of the cord, it is 18.53 MPa. Significant reduction of compressive strength values for samples with 20% and 30% fibre content could be influenced by the use of more sodium hydroxide during manufacturing process, which could lead to excessive reduction of the density of the tested material.

4.3. Flexural strength test
Results for flexural strength test are presented in table 3.

Table 3. The average values for flexural strength tests.

The content of fibres by volume [%]	d_1 [mm]	d_2 [mm]	force [kN]	Compressive strength [MPa]
0%	50.49	49.11	2.692	4.960
5%	51.28	49.45	2.443	4.389
10%	50.78	49.46	2.611	4.730
20%	52.33	49.92	2.951	5.085
30%	53.50	48.70	2.615	4.638

The addition of a textile cord slightly affects the value of bending strength of the tested composite. The most significant change is for 20% of fibers addition, it was increased by 0.13 MPa (for 5%, 10% and 30% a decrease in flexural strength were noted).

Additionally, after the flexural strength test the breakthroughs for the samples were examined. In the figure 4 the pores remaining after manufacturing process are visible, however, voids are much smaller in relation to voids visible on the geopolymer sample without additives. On the surface of the breakthrough, the textile cord fibers are visible.

Figure 4. Breakthroughs of samples with 20% and 30% of textile fibers

Comparing with the material without the reinforcement the breakthroughs have more ductile character. The crack is slightly visible as a small line in the middle of samples.

4.4. Density

The results of density calculations are presented in table 4.

Table 4. The average values for density.

The content of fibres by volume [%]	a [mm]	b [mm]	h [mm]	volume [cm^3]	weight [g]	density [g/cm^3]
0%	52.072	50.246	50.972	133.3643	223	1.672112
5%	48.994	49.841	51.759	126.3920	208	1.645673
10%	49.114	49.221	51.079	123.4823	205	1.660157
20%	47.891	50.200	52.483	126.1759	206	1.632642
30%	49.515	49.589	53.758	131.9980	217	1.643965

On the basis of the presented data, we clearly notice a decrease in the density of the material with increasing the amount of the textile cord. The lowest density was noted for the material with the addition of 20% fibres and it amounted to 1.633 g/cm3. The highest result for 30% amount of fibres is probably the results of voids in materials (pores during manufacturing the sample). The decrease in density is related with the mass reduction. It is a beneficial phenomenon for many applications, because for example reduction of the cost of transportation.

5. Conclusions

The composites with addition of 5, 10, 20 and 30% of waste textile cord by volume were investigated. The conducted research shows that the use of these waste textile cord as an additive to a geopolymer-based composite material is possible. The addition of textile fibres reduces the weight and density of the geopolymer. For the geopolymer with the addition of 20% by volume, the lowest density was connected with the highest flexural strength. Additionally, introduction of reinforcement change the character of breakthrough from brittle to ductile. The highest compressive strength was obtained for a geopolymer with an addition of 5% by volume of fibres.

The results show that the addition textile fibers recovered from end-of-life tires to geopolymer can be a promising way of their utilization. On the basis of waste materials it is possible to receive the composite with good mechanical properties that could be used in construction industry. The industrial application required further research such as: water absorption, durability, cost-effectiveness and corrosion resistance.

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