Reuse of waste tire textile fibers from tires in plaster mixtures

I Khongova¹, I Chromkova¹ and V Prachar¹

¹Research Institute for Building Materials, Hněvkovského 30/65, 617 00 Brno, Czech Republic

Email: khongova@vustah.cz

Abstract. The waste tire textile fibers from tires are generated as a by-product and are classified as special waste. To avoid landfilling and incineration of this waste, it is necessary to focus on its further use. This article describes an experimental study of the use of waste tire textile fibers for plaster mixtures. Waste fibers were added in different amounts of 2.9%, 3.6%, and 4.3% related to the weight of cement, the effect of fibers on selected properties was monitored. The results of the experimental work show that the lower addition of waste fibers (2.9% and 3.6%) had a predominantly positive effect on mechanical properties. By exceeding the optimal dose of fibers, the tested properties of the plasters got worse.

1. Introduction

The increasing population is also associated with the increasing need for vehicles thus producing tires. Tires are an essential part of the economy of every country; about 17 million tons of end-of-life tires (ELTs) are produced worldwide each year. ELTs are solid wastes generated in large amounts, and the decomposition of these materials takes approximately 600 years [1–3].

Generally, there are four ways to handle ELT: recycling (3–15%), reuse (5–23%), landfilling (20–30%), and energy recovery (25–60%) [4]. Up to 60% of ELTs are used for energy recovery. The calorific value of ELT is around 26 MJ/kg, which is very similar to black coal. However, burning of ELTs is not environmentally friendly, it can emit hazardous gases that can pollute the environment. Burying ELTs in landfills or sending them to landfills is also very unecological as landfills take up a lot of space that could be used in other ways [5, 6].

The material composition of tires varies by category, i. e. passenger cars or trucks. All tires contain natural and synthetic rubbers, reinforcing materials (steel wires and textile fibers), and facilitators. Tire life can be extended by retreading, but this process cannot be repeated all the time. The ELTs are processed by cryogenic grinding or shredding in dedicated mills. The output of the process is rubber material of various sizes (cuts, shred, chips, granulate, powders, and fine powders), steel reinforcement (5–30%), and textile fibers (10%) [7, 8].

Rubber and steel are currently widely used in construction. Steel wires are being separated and used by factories to produce new steel [1]. Musci et al [9] used steel wires from waste tires as reinforcement for geopolymers. Another application of steel was investigated in the study [10], the mechanical properties of concrete with steel fibers from tire waste were tested. The reuse of steel fibers from tires as reinforcement in concrete is the most common topic in experimental studies. In civil engineering, waste rubber is used to improve the properties of concrete (increase the durability of concrete) as an additive or substitute for sand in concrete and asphalt. Rubber chips can be used to produce athletic tracks or as flexible coverage options in playgrounds and sporting surfaces [11]. Another less popular product obtained from the recycling process of ELTs is waste tire textile fibers (WTTFs).
WTTFs represent about 10% by weight of ELTs and are classified as special wastes for disposal. Usually, WTTFs are landfilled, which may pose a risk in the future, such as the accumulation of rodents, soil and underground water pollution, and the potential risk of a wildfire [7, 12]. Some authors have already dealt with the issue of WTTFs reuse, in the study [13], the influence of textile fibers on the mechanical and thermal properties of concrete was determined. Many studies [1, 5, 12] have investigated the application of fibers as a reinforcing material to strengthen sandy and clayey soils. Marconi et al [14] focused on the reuse of WTTF in plastics compounds. In a recently published article [15], WTTFs are used to produce a rubber aerogel that has super-hydrophobic properties and is suitable for oil spill-cleaning applications.

This paper aims to verify another possible application of WTTFs in plaster mixtures. The influence of the addition of WTTFs on the physical and mechanical properties of plaster and assessment of the suitability of the use of waste material in plaster mixtures are studied.

2. Experimental part

2.1. Materials and methods

The materials used to produce plaster mixtures were Portland cement 42.5 R, lime hydrate Cemix CL 90-S, quartz sand ST 56 Střeleč, Experlit EP 150 OM, Walocel MKX 15000 PP 25 (modified hydroxyethyl methylcellulose improves workability and water retention), VINNAPAS 5010 N (polymer powder increases adhesion and flexibility), water and waste tire textile fibers. A sample of WTTFs was supplied by RPG-Recycling, which deals with tire recycling and the sale of outputs from the recycling process (steel fibers, rubber granulate, and WTTF). The obtained waste material was adjusted to the desired form before use in the plaster mixture because the WTTFs were very inhomogeneous and contained residues of rubber and steel fibers. For application to the plaster mixture, the WTTFs were cleaned, as shown in figure 1.

![WTTFs before cleaning (left) and clean WTTFs (right).](image-url)
WTTFs tend to exist in different lengths and widths (figure 2) and are composed of synthetic fibers, predominantly nylon. Fiber width was determined from 150 measurements from images taken with an Eclipse LV100ND optical microscope. Figure 3a shows the range of fiber widths and their expression in percent. The range of fiber widths from 10 to 31 μm was determined from the obtained data, the average width of WTTFs was approximately 20 μm. The length of the fibers was made by hand extended and measured. The measured values of the fiber length are shown in figure 3b. The length of the fibers ranged from 3 to 20 mm, the average length of the fibers was approximately 8 mm.

**Figure 2.** Detail of WTTFs.

![Figure 2: Detail of WTTFs.](image)
The following properties were monitored for the proposed plasters. The consistency of fresh plaster was determined by flow table (ČSN EN 1015-3). After 28 days, the plasters were tested for compressive strength, flexural strength (ČSN EN 1015-11), and adhesive strength on substrates (ČSN EN 1015-12). Another test method was chosen to determine the coefficient of water absorption due to the capillary action of hardened plasters (ČSN EN 1015-18), the test specimens were covered with a sealing material, broken into two parts, and dried to constant weight before testing.

Determination of the water vapor permeability of hardened plasters (ČSN EN 1015-19) was tested on circular specimens that were attached to a circular vessel with solution. Water vapor pressure was created using a saturated LiCl solution. The test specimens were tested in the Feutron climate chamber, where the required humidity and temperature were determined.

2.2. Sample preparation
A total of 4 test plaster mixtures were prepared, one reference and three with different addition of WTTFs. The composition of the basic mixture is shown in table 1, the amounts of water and fibers are listed in table 2. The fibers were dosed by weight. The amount of water was adjusted according to the required consistency. The waste fibers were dosed as the last component of the plaster, the mixing and homogenization of the fibers with the plaster mixture took place in a forced circulation mixer. The chosen dosing method did not allow a higher addition of fibers because there was nonuniform dispersion and agglomeration in the mixture. A suitable application for higher fiber dosing would be dispersion in water. The test specimens were stored for 7 days in controlled environment with relative humidity of (95 ± 5)% and temperature of (20 ± 2)°C, for another 21 days, the samples were in relative humidity of (65 ± 5)% and a temperature of (20 ± 2)°C.

![Figure 3. Fiber size.](image-url)
### Table 1. Composition of compounds.

| Dry component          | OM ref (%) |
|------------------------|------------|
| Portland cement 42.5 R | 26.9       |
| Cemix CL 90-S          | 9.2        |
| ST 56 Střeleč          | 57.5       |
| Experlit EP 150 OM     | 5.4        |
| Walocel MKX 15000 PP 25| 0.2        |
| VINNAPAS 5010 N        | 0.8        |

### Table 2. Amount of water and fibers.

| Mixture ID  | w (%) | WTTF (%)<sup>a</sup> |
|-------------|-------|-----------------------|
| OM ref      | 1.57  | -                     |
| OM P1       | 1.61  | 2.9                   |
| OM P2       | 1.62  | 3.6                   |
| OM P3       | 1.64  | 4.3                   |

<sup>a</sup>the amount of fibers is related to the weight of the cement

### 3. Results and discussion

#### 3.1. Workability

The addition of WTTF was expected to affect the mixture’s workability, therefore, the plaster mixture’s consistency was adjusted to the required plaster flow diameter (175 ± 10) mm. It is clearly illustrated that the increasing addition of WTTFs increases the water-cement ratio (w/c). The consistency is shown in figure 4, where the values are measured immediately after mixing the plaster mixture and then after 90 minutes. Plaster mixtures with the highest addition of waste fibers met the requirement initial consistency even after 90 minutes.

![Figure 4. Results of a consistency determination.](image-url)
3.2. Compressive and flexural strength
The compressive strength and flexural strength of the plaster mixtures were tested after 28 days, the results of strength are depicted in figure 5. The flexural strength of the reference sample (OM ref) was 1.6 N/mm². According to the results, it is clear that a certain amount of fibers positively affects flexural strength. The highest flexural strength was 2.0 N/mm² (OM P2), further increase of the fibers already resulted in a decrease of flexural strengths.

A similar trend can be observed when monitoring compressive strength. The highest compressive strength of 5.9 N/mm² was recorded for the OM P1 sample, which contained the lowest fiber addition. The OM P2 mixture also had higher compressive strength than the reference sample. On the other hand, the lowest value of compressive strength was 4.6 N/mm² for OM P3, which contained the highest fiber content. From the results, it can be concluded that a low dose of fibers improves strength; after exceeding the optimal dose, the effect is the opposite.

In the study [16], the same decreases in strengths were observed. Compressive and flexural strengths also decreased with increasing fiber addition. The optimal ratio between the matrix and the reinforcement is achieved with a lower addition of fibers, the matrix coats the fibers well and transfers the load. Higher addition of fibers disrupts the optimal ratio and thus leads to poor load transfer and lower resulting strengths.

![Figure 5. Development of compressive strength and flexural strength after 28 days.](image)

3.3. Adhesive strength on the substrate
The results of testing the adhesion to the substrate are shown in table 3. A concrete slab was used as a substrate for testing the plaster, on which a layer of plaster was applied. During testing, the adhesive strength and type of rupture are recorded. The adhesive strengths were very similar, the highest adhesive strength was 1.05 N/mm² in the plaster with the highest addition of WTTFs (OM P3), the standard deviation of all measurements was 0.10. Another monitored parameter was the type of rupture. The results show that all the proposed mixtures were damaged in the plaster so that the adhesion of the plaster is in fact higher than the measured values. The specific value of material adhesion would be determined if there were damage between the plaster and the substrate. However, based on the obtained results, it is clear that the addition of fibers does not reduce the adhesion to the substrate. The adhesion of the plaster can also be affected by the selected type of substrate, an important factor is especially the surface roughness and porosity of the material [17].
Table 3. Pull-off test.

| Mixture ID | Adhesive strength on the substrate (N/mm²) | Type of rupture |
|------------|--------------------------------------------|-----------------|
| OM ref     | 1.01                                       | Damage in plaster|
| OM P1      | 0.90                                       | Damage in plaster|
| OM P2      | 0.92                                       | Damage in plaster|
| OM P3      | 1.05                                       | Damage in plaster|

3.4. Water absorption coefficient

The capillary water absorption coefficient is an important parameter that characterizes the water absorption of porous materials and is necessary for moisture transfer simulations. The results of capillary absorption are illustrated in figure 6, the lowest value of capillary absorption was 0.3 kg/(m²·min⁰.⁵) for the reference plaster sample (OM ref). Further addition of fibers increased capillary absorption, plaster mixtures OM P1 and OM P2 had a capillary absorption value the same 0.4 kg/(m²·min⁰.⁵). The highest capillary absorption of 0.5 kg/(m²·min⁰.⁵) was recorded for the mixture with the highest fiber addition.

Generally, plasters for interior and exterior use are classified in the category Wc 0 to Wc 2. The results of mixtures OM ref, OM P1, and OM P2 may be included in the category Wc 1, where the capillary water absorption coefficient is ≤ 0.40 kg/(m²·min⁰.⁵). Category Wc 1 is required for thermal insulation plasters. The OM P3 mixture belongs to the Wc 0 category where the capillary water absorption coefficient is not prescribed.

The same trend as for capillary absorption was for water absorption. With the increasing addition of fibers, the water absorption increased; only for OM P1, the measured value was lower.

Higher addition of WTTFs also required higher amounts of water to achieve the desired consistency. Water evaporates during the setting process, forming pores and capillary channels. Therefore, the water ratio is one of the most important factors that affect material’s porosity, as stated in the study [18]. The results obtained correspond to the theory mentioned above.

Figure 6. Absorption measurement results.
3.5. Water vapor permeability
Table 4 presents the results of the proposed plasters. For the reference plaster, the water vapor resistance factor was 12.2. The highest value of the water vapor resistance factor 12.4 was for the OM P1 plaster, which contained the lowest addition of waste fibers. Other plasters that contained a higher addition of fibers achieved lower values of water vapor resistance factor than OM P1 plaster. According to ČSN EN 998-1, the maximum value of the water vapor resistance factor of 15 is determined for renovation and thermal insulation plasters. All proposed plasters meet this requirement, the values obtained are favorable for ensuring the passage of water vapor out of the structure.

This test is used to determine the breathability of plasters. The lower the value of the diffusion resistance factor, the easier the movement of water vapor in the structure. Permeability is very much related to the porous structure of the material, and according to some studies, permeability is responsible for the long-term durability of materials [19, 20].

Table 4. The water vapor resistance factor of the studied samples.

| Mixture ID | μ (-) |
|------------|-------|
| OM ref     | 12.2  |
| OM P1      | 12.4  |
| OM P2      | 11.6  |
| OM P3      | 12.0  |

4. Conclusion
This experimental work aimed to verify the use of waste fibers in the proposed plaster mixtures. The morphology of the waste fibers was determined which is one of the critical factors for the material’s mechanical properties. The effect of the addition of fibers on the selected properties of plaster mixtures was monitored. The lowest addition of fibers had a positive effect on the compressive strength; with a further increase in fibers, there was a slight decrease. The application of the WTTFs also had a positive effect on the flexural strength, the mixtures containing 0.6% and 0.7% of the WTTFs had higher strengths than the reference mixture. Adhesion to the substrate is one of the most important properties of plasters. No negative effect on adhesion to the substrate was observed for all proposed plasters with waste fibers. The results of capillary absorption of plaster mixtures showed a dependence on the water coefficient. Higher water consumption and WTTF dose led to the formation of pores and capillary channels, which resulted in an increased value of the capillary water absorption coefficient. According to the water vapor resistance factor, the permeability of the plasters did not deteriorate either, all the proposed plasters even met the criterion for thermal insulation plasters.

The application of waste fibers to plaster mixtures is possible, and in particular, the low addition of WTTFs improves the mechanical properties. The disadvantage of using waste fibers is the need for purification before applying the fibers and also poorer incorporation of the fibers into the mixture. Nevertheless, all experimentally produced plasters with waste fibers achieve comparable technical parameters as commercially available products.

Acknowledgments
The present study is part of long-term conceptual development of a research organization Research Institute of Building Materials 2018-2022.
References

[1] Abbaspour M, Aflaki E and Nejad F M 2019 Reuse of waste tire textile fibers as soil reinforcement Journal of Cleaner Production 207 pp 1059–1071

[2] Mucsi G, Szenczi A and Nagy S 2018 Fiber reinforced geopolymer from synergetic utilization of fly ash and waste tire Journal of Cleaner Production 178 pp 429–440

[3] Júnior A B, Battistelle R A, Bezerra B S and Castro R 2012 Use of scrap tire rubber in place of SBS in modified asphalt as an environmentally correct alternative for Brazil Journal of Cleaner Production 33 pp 236–238

[4] Forrest M 2014 Recycling and Reuse of Waste Rubber

[5] Narani S S, Abbaspour M, Mir Mohammad Hosseini S M, Aflaki E and Moghadas Nejad F 2020 Sustainable reuse of Waste Tire Textile Fibers (WTTFs) as reinforcement materials for expansive soils: With a special focus on landfill liners/cover Journal of Cleaner Production 247

[6] Gheni A A, Alghazali H H, ElGawady M A, Myers J J and Feys D 2019 Durability properties of cleaner cement mortar by-products of tire recycling Journal of Cleaner Production 213 pp 1135–1146

[7] Shulman V L 2011 Chapter 21 - Tyre Recycling Waste Academic Press pp 297–320

[8] Landi D, Marconi M, Meo I and Germani M 2018 Reuse scenarios of tires textile fibers: an environmental evaluation Procedia Manufacturing 21 pp 329–336

[9] Mucsi G, Szenczi A and Nagy S 2018 Fiber reinforced geopolymer from synergetic utilization of fly ash and waste tire Journal of Cleaner Production 178 pp 429–440

[10] Samindi S M, Samarakoon M K, Ruben P, Pedersen J and Evangelista L 2019 Mechanical performance of concrete made of steel fibers from tire waste Case Studies in Construction Materials 11 e00259

[11] Mohajerani A, Burnett L, Smith J V, Markovski S, Rodwell G, Rahman M T, Kurmus H, Mirzababaei M, Arulrajah A, Horpibulsuk S and Maghool F 2020 Recycling waste rubber tyres in construction materials and associated environmental considerations: A review Resources, Conservation and Recycling 155 104679

[12] Yadav J S and Tiwari S K 2017 Effect of waste rubber fibres on the geotechnical properties of clay stabilized with cement Applied Clay Science 149 pp 97–110

[13] Medina N F, Medina D F, Hernández-Olivares F and Navacerrada M A 2017 Mechanical and thermal properties of concrete incorporating rubber and fibres from tyre recycling Construction and Building Materials 144 pp 563–573

[14] Marconi M, Landi D, Meo I and Germani M 2018 Reuse of Tires Textile Fibers in Plastic Compounds: Is this Scenario Environmentally Sustainable? Procedia CIRP 69 pp 944–949

[15] Thai Q B, Duyen K L, Nga H N D, Phung K L, Nhan P T, Chien Y W and Hai M D 2020 Advanced aerogels from waste tire fibers for oil spill-cleaning applications Journal of Environmental Chemical Engineering 8 104016

[16] Parres F, Crespo-Amorós J E and Nadal-Gisbert A 2009 Mechanical properties analysis of plaster reinforced with fiber and microfiber obtained from shredded tires Construction and Building Materials 23 pp 3182–3188

[17] Faria P, Lima J, Nabais J and Silva V 2019 Assessment od adhesive strength of an eart plaster on different substrates through different methods 5th Historic Mortars Conference ed J. I Alvarez, J. M Fernandez, I Navarro, A Duran and R Sirera (Pamplona: Universidad de Navarra) pp 51–64

[18] Lopez-Zaldívar O, Lozano-Diez R, Herrero del Cura S, Mayor-Lobo P and Hernandez-Olivares F 2017 Effects of water absorption on the microstructure of plaster with end-of-life tire rubber mortars Construction and Building Materials 150 pp 558–567

[19] Casneci L, Cappai M, Cincotti A, Delogu F and Pia G 2020 Porosity effects on water vapour permeability in earthen materials: experimental evidence and modelling description. J. Build. Eng. 27 100987
[20] Westgate P, Paine K and Richard J B 2018 Physical and mechanical properties of plasters incorporating aerogel granules and polypropylene monofilament fibres Construction and Building Materials 158 pp 472–480