The potential utilization of the rubber material after waste tire recycling

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Abstract. This article describes the method of production of rubber granulate after the recycling of waste tires and the potential utilization of this material. The aim of this study was the utilization of rubber in the building industry, especially the use of granulate as rubber filler in concrete. It has been found that the use of rubber granulate as a substitute for natural aggregates in a concrete mix has a significant impact on the properties of concrete. Although studies on the utilization of rubber granulate in a concrete mix have been conducted in different sectors and in different research areas, it is clear that we do not know much about it yet. That is why it is necessary to continue and to obtain more information about the properties of concrete based on recycled rubber.

1. Introduction
With the development of the automotive industry, tires have become an integral part of everyday life of people. We use them almost daily, whether it is when driving a passenger car or on a public transport bus. They are also widely used in air transport, but they represent an important part of goods traffic as well.

As a result of the development of the society in the world, the demand for tires has been going up, which is associated with higher production of waste tires [1]. Waste tires are a global problem and an increasing risk to the environment, because they are not biodegradable, and they are often incorrectly stored and disposed of. These stocks represent a threat of uncontrolled fires and other environmental risks. It is estimated that almost 1 000 million tires reach the end of their lifetime each year and more than 50% of them are discarded without any further use [2–4].

The storage of tires at landfills after the end of the lifetime has been banned by the European Commission in 1999. The recycling and utilization of waste tires is therefore studied in many countries [5]. This step has forced us to rethink the view and attitude towards waste materials in order to increase their utilization and to dramatically reduce their amount required by their disposal or storage [6].

The simplest and the cheapest way of disposing of waste tires is their combustion. When burning tires, i.e. during the oxidation reaction, the largest part is converted into carbon oxides and soot. The other released substances include butadiene and styrene, aliphatic and aromatic hydrocarbons, benzene, toluene, phenylacetylene etc. The sulphur contained in tires reacts to sulphur dioxide and sulphur derivatives. We can find heavy metals, such as lead, in the combustion product as well [7]. The use of tires as a fuel is not economically attractive and, with regard to the environment, their use as a secondary raw material is more profitable. Waste tire as a raw material has a high potential in terms of its further processing and utilization. Products made from waste tires can be used in various civil and industrial sectors, such as highway construction, agriculture, seashore civil engineering, breast walls, etc. [8].
Civil engineering has been trying to face the challenge of improving the environment by looking for more environmentally friendly raw materials or by using waste materials, such as filler in concrete for several years. Metallurgical industry, which has been trying to process the produced waste in other metallurgical aggregates, as shown by research [9, 10], can serve as a role model in the utilization of waste. A possible solution for the use of natural rubber from waste tires is its use in concrete as a substitute for some natural aggregates. Concrete composites based on recycled tires have the potential to reduce the total greenhouse gas emissions, provide economic benefits, reduce the environmental problems associated with the end-of-life of tires in transport, and they also bring an eco-friendly way of recycling natural rubber from waste tires [3,8,11,12].

Studies, in which scientists examined the properties of concrete containing crushed natural rubber, have been conducted. Scientists have suggested that a concrete mix containing natural rubber granulate can increase the toughness and ductility, and it improves the acoustic absorption and resistance to heat changes. A reduction of the unit weight and better durability, when compared to conventional concrete, have been found as well. The studies have also revealed a decrease in the tensile strength due to low natural rubber stiffness and poor binding power between aggregates of natural rubber and cement articles. Pre-treatment of the surface of natural rubber granulate using NaOH solution could improve the adhesion of natural rubber and cement articles in concrete mix. This modification of the natural rubber surface has been presented by the research of “Development of waste tire modified concrete” [12,13].

2. Methods and potential of the utilization of waste tires

Tire recycling makes it possible to obtain rare materials, to save energy in relation to primary production, and to reduce the amount of waste. Used tires represent the largest share of the total volume of recycled natural rubber. A worn tire contains a number of chemicals with an energy potential, but it is also a source of secondary raw material. Tires are made of a flexible rubber material whose construction is reinforced with textile and metal materials. The composition of tire includes materials containing natural rubber, soot, steel reinforcements, oils and vulcanizing agents, synthetic rubber and textiles. Figure 1 shows the percentage composition of tires for passenger and freight transport [6,14].

When recycling tires, it is necessary to take the following measures [6,15]:

- reduce the risk of contamination during temporary storage of used tires,
- increase the usability of used tires,
- reduce the consumption of raw materials, especially those originating from non-renewable resources, and utilize used tires as secondary raw materials.

![Figure 1. Composition of tires for passenger and freight transport](image-url)

The use of tires as a source of raw materials leads to three product categories. They are rubber granules, steel wires, and nylon and textile fibres. These materials can be retroactively separated from crushed rubber using modern technologies, so the materials can be recycled or further utilized [6,14].

Waste tires are fed to a primary crusher with fixed blades that cuts them to a size ranging from 50 to 300 mm. At this stage, the tire cuttings can be used as filler, for example in a drainage system, a biofilm reactor, etc., or they are collected for secondary crushing. After the primary phase of crushing,
the rubber cuttings proceed into a granulator that cuts and shears the rubber to the dimensions of 10-50 mm. Subsequently, the material passes through a sieve with a fixed hole size. In the next step, the rubber material passes through is a magnetic separator, where steel wire particles are separated. An air-gravity separator is used to remove the textile and nylon fibres. Air is blown into the rubber material and gravity and the weights of the individual particles lead to their separation. To obtain materials with a finer fraction <10 mm, it is necessary for the material to pass through a progressive series of granulating mills (see figure 2). The resulting material is distributed under the name of rubber dust. There may be other process phases, such as a secondary collection of metallic elements, or wet grinding process resulting in a production of particles with the size of up to ≤100μm [16,17].

Figure 2. Tire crushing and material separation process [16].

Natural rubber can be manufactured in various sizes, ranging from the smallest powder to granules that are used for various purposes. It is very important to make sure that the quality of recycled rubber is high so that the recycled rubber can be used as a substitute for new natural rubber. It must be completely clean and the particle size must be uniform. If these quality requirements are met, the industry will guarantee that recycled rubber is fully capable of replacing the original raw material. The outcome of the follow-up processing of rubber crumb is the material cut in different sizes and types depending on its intended use [14,18]:

- rubber chips (size of 20-50 mm)
- rubber granulate (0.8-20 mm),
- rubber dust (<0.8 mm).

The utilization of the materials from tires that are used repeatedly has been developed for many years, including the applications on road surfaces, the foundations of children playgrounds, sports playgrounds and noise barriers. There has been an increase in the number of companies that use material from tires to produce various rubber products. The utilization of crushed rubber in a mix of asphalt paving has proved to be successful due to the good compatibility and interaction between the rubber particles and the asphalt binder. A research on the use of rubber particles in concrete composites has already been documented and tested, however the information about the size of the rubber particles or their distribution in concrete, which may also influence the specific properties, is limited [14,19].

3. Use of rubber granulate in concrete

One of the possible solutions for the use of natural rubber from waste tires is the incorporation of natural rubber into concrete as a substitute for natural aggregates [8].

Eldin and Senouci (1993) have carried out primary studies on the possibility of using rubber particles from waste tires in concrete. In their study, the part of the aggregate was replaced with rubber aggregate. They have found that the concrete has lower workability, compressive strength and tensile strength. Worsening the mechanical properties was caused by the low adhesion between the surface of the rubber particles and the cement articles. The loss of compressive strength has corresponded with
the size of the rubber aggregate. Concrete, however, has demonstrated the ability to absorb large amount of plastic energy when exposed to pressure and tensile load [20,21].

A research on the strength and penetration of chlorides into concrete with rubber granulate has been carried out by Gesoğlu and Güneyisi [22]. They have pointed out to the fact that the unit weight of rubberised concrete decreases with the increasing share of added rubber, which reduced the unit weight by up to 18%. The development of rubberised concrete strength between 3 and 7 days was relatively high, with a slower hardening rate between days 7 and 28. The compressive strength was reduced depending on the percentage share of the used natural rubber. When rubber was used in concrete production, chloride ion penetration in concrete was considerably worse, but the degree of chloride penetration rate depended mainly on the amount of used natural rubber [20,22].

Ganjian et al. (2009) have examined the use of tires as a substitute for filler in concrete. They used rubber granulate as a substitute for coarse aggregate of the concrete components and rubber dust in 5%, 7.2% and 10% weight substitute was used to replace cement. Replacement of rubber increases water permeability depth in the concrete mixtures. The substitution of 5% and 7.5% tyre rubber showed mechanical properties similar to the control sample and it’s classified as low permeability according to DIN standard but the mixture with higher percentage substitution of 10% tyre rubber replacement is classified as medium [20,23]. The compressive strength of rubberised concrete can be increased through the effect of carbon tetrachloride and sodium hydroxide on the rubber aggregates in concrete [20,24]. Yilmaz and Degirmenci (2008) have found a decrease in water absorption when the size of the rubber particles in concrete was increased [25].

In paper [26], the acoustic properties of materials made using recycled rubber were tested. It has been found that these materials can effectively absorb sound when the size of the rubber aggregate and the binder content are carefully selected and its thickness is set to the desired frequency range.

4. Summary and conclusions

The objective of this article is to present the potential of the utilization of rubber granulate from waste tires as an introduction to our research. The utilization of crushed rubber in the building industry is becoming more and more frequent, and it is necessary to find ways to effectively apply this filler. The processing of crushed rubber in the building industry can be beneficial to this industry, but the most important benefit is a relief to the environment. Increasing living standards also mean more waste, which is why it is important to think about how to further process these waste materials.

The examination of the studies clearly shows that the mechanical properties of concrete with the addition of crushed rubber are rather deteriorating. The reason for decreasing compressive strength is the percentage share of crushed rubber in the concrete mix. The modulus of elasticity of rubber is many times lower than the modulus of elasticity of concrete. Rubber granulate in concrete acts as a pore, and higher content of rubber particles increases the amount of pores. This is the reason why the mechanical properties of concrete mix deteriorate. However, some physical properties of concrete are also improved for example as acoustic properties of concrete, or the weight of concrete decreases with the amount of added tire recycle.

Although concrete containing crushed rubber is not a completely new feature in the field of construction, we do not know much about it yet. That is why more research is needed in this field in order to study the properties of rubberised concrete. Further research will be focused on the design of concrete formulations where natural aggregate is replaced with rubber granulate with the fractions of 1-3 mm and 0-1 mm, which was obtained from tire recycling from Bonus-CB spol. s.r.o. company. The physical-mechanical properties of the concrete based on recycled rubber will be tested as well.

Acknowledgement

- This article was written in connection with project Institute of clean technologies for mining and utilization of raw materials for energy use - Sustainability program. Identification code: LO1406. Project is supported by the National Programme for Sustainability I (2013-2020) financed by the state budget of the Czech Republic.
- This research work has been supported by the student grant competition project SGS SP2018/12.
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