Directions for material recovery of used tires and their use in the production of new products intended for the industry of civil construction and pavements

C Bulei¹, M P Todor¹, T Heput² and I Kiss²
¹University Politehnica Timisoara, Doctoral School, Timisoara / Hunedoara, Romania
²University Politehnica Timisoara, Faculty of Engineering Hunedoara, Department of Engineering and Management, Hunedoara, Romania

E–mail: imre.kiss@fih.upt.ro

Abstract. The management of waste from used tires is one of the major principles of recycling and reuse, which involves encouraging a high level of material recovery components, preferably by recycling. Given the current pressure on natural resources on a global scale we must fully take into account the waste in a broader framework defined by the flow of raw materials and their sustainable use. Thus, the opportunity to use various waste from used tires as raw material in order to support economic activities becomes a priority. The recycling of raw materials from waste products and their use in new production processes for their material capitalization is becoming a sustainable approach. Used tire recycling, is the process of recycling waste tires that are no longer suitable for use on vehicles due to wear or irreparable damage. These tires are a problematic source of waste, due to the large volume produced, the durability of the tires, and the components in the tire that are ecologically problematic. Although tires are usually burnt, not recycled, efforts are continuing to find value. Tires can be recycled into, among other things, typically as crumb rubber modifier in recycled pavement. The paper presents aspects of the product resulting from crushing of used tires (powder), which can be used properly valued in the street furniture field or building materials containing rubber.

1. Introductory notes
Worn tires are among the biggest and the most problematic sources of waste and because of their large shape and volume they also occupy a lot of space. However, used tires are also one of the most reusable waste. In the past, the largest share of industrial waste (including used tires) was considered unusable, the main concern for managing waste being the identification of disposal solutions and not the way we can minimize their generation or how we can reuse and valorise them. Disposal of waste tire rubber has become one of the major environmental issues in the world. Every year millions of tires are discarded, thrown away or buried all over the world, representing a very serious threat to the ecology [1]. Also, the illegal dumping of tires is a serious threat to public health through the release of chemicals and pollutants into surrounding soil, groundwater and rivers.

But nowadays the application of the principles of sustainable development implies a new approach to waste using environmentally–friendly concepts and it is necessary to re–evaluate the options for managing this waste in order to increase their use and to drastically reduce the quantities that require disposal or storage. To this end, the waste hierarchy should be applied with a focus on reuse, recycling
and recovery, while waste disposal should be interpreted as the last available option that corresponds to the highest level of resource loss and alteration [5].

![Illegal dumping of tires and the pollution danger](image1)

**Figure 1.** Illegal dumping of tires and the pollution danger

![The waste hierarchy preferences](image2)

**Figure 2.** The waste hierarchy preferences [5]

The accentuated increase in the amount of rubber waste has led to the search for ways to combat environmental pollution by reuse, revalorize and recycling. The utilization of used rubber tires for the re-use of component materials in the industry and the release for re-farming of the land on which these tires are currently stored are a priority both worldwide and nationally. We must take into account the economic potential offered by the raw material price of waste and in this sense recycling / recovery capacity should be developed and also the encouragement of the use of raw materials that are found in waste. One of the possible solutions for the use of waste tire rubber is to incorporate into cement concrete, to replace some of the natural aggregates [1].

Among the rubber products, the tires are by far the largest share, which also explains the attention paid to the reintroduction of used tires in the economic circuit while avoiding pollution. Today, over 1 billion tires are produced annually in over 400 tire factories. Thus the potential for recycling millions of used tires is clearly very important. The main source of used tires is the automotive industry, which means cars that use tires as tread. It is estimated that less than 7% of the 300 million used tires take the form of new products and about 11% are converted into electricity. Over 77% are buried, stored or abandoned. In Romania there are about 40,000 tons / year of used tires being available for recycling, the amount being continually increasing, plus uncollected and un-recycled accumulated stock.

At the end of their life-use, tires are turned into waste that either is stored or as an alternative is recycled or reused. Good waste management practices take into accounts, excepting retrofitting tires or storing them, other methods of capitalizing on reusable rubber materials. In the market economy the possibility of recycling is directly related to the recovery of residual value according to the direct proportion of the willingness to make efforts for such a process. From the recycling perspective, used tires are exceptional materials, as the number of recycling without significant quality is an indefinite one [4], [8].
Engineering recovering and recycling waste tires is an increasingly tempting area for investors and manufacturers of recycled products alike. Tire recycling allows:

- recovering precious material without reducing quality
- energy savings in relation to primary production
- reducing the amount of waste.

Currently, used tires have become the largest share of the total amount of potentially recyclable rubber. The technical solutions that are used take the aim at returning them to the economic circuit but in a limited number of cycles. The worn tire contains a number of chemicals with energy potential, but it is also a source of secondary raw material. The tires are made of flexible elastomeric rubber material, the structure of which is reinforced with textile and metallic materials. A tire is composed of several materials with a rubber content ranging from 46–48%, carbon black between 25–28%, steel inserts between 10–12%, oil and vulcanizing agents between 10–12% and inserts synthetic yarns and textiles between 3–6%. Tires contain potentially valuable constituent components, such as carbon black, organic oils and steel, extracting these materials in a cost–effective way is extremely difficult. Only a few of the technologies are viable, the others being only pilot stations, have not been used at the industrial scale yet. Thus, used tires pose problems even for the most sophisticated waste management systems. The tires are made up of complex polymeric materials with a large addition of
various other components, the recovery of this added value being a dangerous operation and leading to high energy consumption.

2. Methods and directions of recovery of rubber waste

Most of the rubber waste is discarded and the natural decomposition lasts a long time because of their structure, stabilizers and additives from their composition. Worn tires are not wanted at landfills due to their high volume, which quickly consumes valuable space.

Two major problems arise: large quantities of waste are accumulated and environmental pollution is produced. Worn tire holes can grow rapidly, creating not only land use problems, but also environmental hazards, since (the dumps) can self-ignite, and causing long-lasting fires. Accumulation of increasing inventories of used tires raises particularly serious environmental problems, as:

- occupying extensive areas with environmental pollution and set aside of potentially productive land (a temporary solution may be to reduce the volume and surface occupied by using pre-slicing machines)
- being a potential fire hazard
- may become a growing environment for dangerous parasites and insects
- are not biodegradable (the decomposition period in the natural environment is over 80–100 years).

The major advantage is that rubber wastes can be reused by recycling and can be used in various fields depending on the design properties. Two solutions to these problems would be:

- recycling and reuse of waste
- recovery of waste materials.

Actions to be taken for recycling tires at a high rate concern:

- reducing the risk of pollution by temporary storage of worn tires
- increasing the utilization rate of the used tires
- reducing the consumption of raw materials, especially those from non-renewable sources, by using used tires as secondary raw materials.

The main directions of recovery of the used products and the rubber waste, grouped in descending order of the technical efficiency of the process are:

- reuse of used rubber products in the same quality as the original product by repair and retreading
- reuse for other rubber products
- recycling as material reintroduced into regenerated elastomeric compositions or rubber powder
- the use as a source of various starting materials, such as carbon black or pyrolysis oils
- use as a fuel for the production of thermal energy, for the manufacture of cement or for steel
- reuse as modification agents for various materials, especially for road construction.

Recycling abandoned tires is a difficult global problem. If real tires can be redeemed, they turn from pollution sources into raw materials. Using a well–designed tire management plan, we can focus on net benefits and used tires can be transformed from a major source of pollution into an important source of income. It is important to find ingenious and innovative solutions to store and reuse waste.

Figure 5. Rubber waste that can be used for granules
In case of used tires, they can be ecologically destroyed and the material obtained can be used for other purposes. Recycling of used tires results in three categories of products (rubber granules, steel inserts and synthetic yarn inserts and textiles) that can be recovered allowing for massive energy and raw materials savings.

These many possibilities of capitalizing on non–recoverable worn tires make them a material with great potential. The industry has discovered many qualities of worn tires: their structural strength when in use, their flexibility when turned into granules, or their calorific power when used as fuel.

Tires are mainly used in two ways:
- material capitalization, by recycling with grain conversion
- thermal (energy) recovery by co–incineration in cement plants.
- Material capitalization refers to the use of non–recoverable worn tires in various applications:
  - whole tires can be used in dykes or hydrographic or anti–noise screens
  - coarse chopped tires can be used to build the chassis or as a substrate for draining water for sports grounds
  - fine ground tires can be used to obtain rubber granules, which can be used to produce different rubber products, heat insulating, sound absorbing or agro–touristic arrangements
  - fine ground tires can be used for powder coating, which can be used in asphalt mixes, which has resulted in good results in reducing vehicle rolling noise, reducing the risk of skidding and guaranteeing a long lasting life for roads.

![Figure 6. Tire derived materials](image)

![Figure 7. Tire processing](image)

The problem of recovery of used tires cannot be considered solved at present, not even worldwide, being a generally accepted and expanded solution with technical and economic advantages. However, there have been adopted in the world various variants, the most remarkable being the milling (at ambient temperature, cryogenic or wet process) with powder–coating. Recycling of used tires implies many processes, from material recovery, cutting, grinding, granulating or other operation that causes changes in the nature or composition of the used tire by industrial processes in order to obtain raw
materials. From used tires, following a grinding and sieving process, rubber and powder granules can be used to make new products.

The process of fine milling of single-material waste is an economic and perspective alternative in current practice and recycling of used tires. Thus, the rubber powder (millimeter granules) will serve to manufacture various rubber products, some of the rubber granules resulting from recycling being used for the production of products for the civil engineering and pavement industry (thermo–acoustic insulation for buildings, work floors, flooring for playgrounds, floors for sports grounds, and so on), another part of the resulting rubber powder being used for the production of technical articles made of recycled rubber.

Figure 8. Tire rubber processing

In the scheme from Figure 8, there are presented some possibilities of using this material by grinding. First, from the used and rebutted tires and other rubber products there can be obtained as intermediate products (rubber sections), rubber milling (2–5 mm) and rubber powder (0.25–2 mm), which can be then dimensionally sorted and used in various application domains. Obviously, each of the transformation processes is a distinct technological process, however the prices of the intermediate products are even higher as the fineness of the material is more advanced. In the same scheme there are presented the technologies for processing the intermediate products until the final products are obtained.

3. Rubber pavers – a solution for recycling rubber waste

Due to the increasingly serious environmental problems presented by waste tires, the feasibility of using elastic and flexible tire–rubber particles as aggregate in concrete is investigated several studies [1-9].

Investigations and research into the recent use of rubber particles in concrete has been well documented. However, information on the rubber particle sizes or their distributions within concrete which may also influence the concrete properties is still limited. Tire–rubber particles composed of tire chips, crumb rubber, and a combination of tire chips and crumb rubber, were used to replace mineral aggregates in concrete. These particles were used to replace different percent of the total mineral aggregate’s volume in obtained concrete [1-9]. Properties of concrete with different rubber sizes and distributions were studied by several studies [1-9]. It was concluded that there is a promising future for the use of discarded tire rubber as a partial substitute for fine aggregates in concrete, which can result in huge environmental and sustainability benefits [1-9].

A large variety of waste materials are considered feasible and even much valuable additives for concrete. Rubber obtained from scrapped tyres is considered as the most recent waste materials that have been examined because of its vital use in the construction field [9]. The recycled rubber tyre waste is a promising material in the construction industry and the sole reason for this is the
lightweight of the resulting concrete when the rubber tyre is incorporated in it as an aggregate replacement (partial or complete) [9].

The management of end-of-life tires is a great environmental challenge. Recycling of waste rubber tires in civil engineering is considered as ecological and economical solutions due to the advantages it can offer. It preserves natural resources and produces an eco-friendly material. The application of recycle waste tires into civil engineering practices, namely asphalt paving mixtures and cement based materials has been gaining ground across the world [4].

A new possibility consist in producing advanced aesthetic and functional materials by using recyclable materials (rubber, plastics) for the development of ceramic composites. In practice, this means that recycled rubber can be used as a filler in new blends for the development of new composites. Since their appearance, the composites have been used in a wide variety of applications due to their outstanding performance. Having high mechanical characteristics and superior design and manufacturing capabilities, composite materials have superior advantages over traditional materials.

**Figure 9. Rubber pavers (or elastic flooring)**

Rubber pavers (or elastic flooring) are an aesthetic and efficient paving solution in several areas of use where the comfort and adhesion of the surface is a priority regardless of weather conditions. The most common areas of application of rubber pads, with the proviso that they can be used for the same applications as tiles in the case of land and public playgrounds (alleys, pavements around the house, around the garden, patios, terraces, anti–slipping stuff). The careful choice of raw materials as well as state–of–the–art technology used in the manufacturing process are some important aspects that place these products first in terms of quality and differentiate it from the other traditional paving options (concrete, wood, stone, brick or other solutions). Sorting the rubber granules is very important because it helps to ‘uniformize’ the distribution of cohesive forces to the granules, which gives the product a very good stability in time.

Advantages of using elastic pavers:
- impact shock absorption – elasticity, comfort
- protection and safety – prevents hitting in case of a fall
- long lifetime – resistance
- instant drainage – avoiding water build–up
- impermeable surface – anti–slip
- increased resistance to environmental factors
- neat appearance – cleanliness and safety
- heavy traffic resistance.
Rubber flooring can be used both outside and inside. They are obtained from a new manufacturing technology with recycled rubber granules combined with a polyurethane binder and pigments for colouring. Thanks to the colour impregnation process even during the manufacturing process, the colour resistance is very high and the plates do not discolor no matter the cleaning process and the frequency of the operations. Being processed at high temperatures and pressures, they acquire elasticity and reliability characteristics.

Due to its properties, the rubber pavement is the wise choice of floor regarding to covering. Being anti-slippery and elastic, the risk of injuries caused by moisture is almost completely reduced. Additionally, the product made from recycled rubber granules is not absolutely toxic, being also a top heat and sound insulator. Since it carries heavy loads, the ecological pavement can support any type of furniture (street or home, indoor or outdoor).

4. Concluding remarks
Nowadays the disposal of waste from used tires represents a considerable problem. In their state of waste the tires are very difficult to degrade and occupy a substantial amount of space in the landfill. If 20–30 years ago, they were stored in huge quantities all over the world, nowadays worn tires are either used in the cement industry as an alternative fuel or converted by recycling into new products such as street furniture or materials of rubber–containing construction. The industry has discovered many qualities of used tires: their structural strength when used in their entirety, their versatility when converted to rubber granules, or the calorific power when used as fuel. These numerous possibilities of capitalizing the used tires make them a material with great potential.

One of the environmental problems is the worrying increase in the amount of such waste and it is obvious that this trend must be stopped. Their destruction by burning on open sites is not allowed due to toxic smoke. Their burning in incinerators consume a substantial amount of energy to bring them in the right state of combustion, create large quantities of ash, and require sophisticated filtration systems for hazardous substances that are released in large quantities (heavy metals, especially zinc, fine dusts, sulphur oxides, including the danger of releasing dangerous substances). The same problems arise from their burning in cement kilns, where, in general, the injection rate of the rubber is, due to pollution, of max. 20% of batch. In addition to direct combustion, as a more environmentally friendly alternative, the development of technologies and installations for energy recovery of used tires through pyrolysis and pyrolysis followed by gasification is being investigated. That’s why, obtaining fuel from used tires all over the world is an important market for recovery of tire waste. But material recovery by using worn tires in various applications is a great challenge for those who handle managing this type of waste.

In some countries used tires are used by co–incineration in cement factories. In others, the accent is placed on their recycling. Thus, recycled tires can be used as substitutes for fossil fuels under controlled conditions, or they can become completely new products. The cement factories are for Romania the priority destination of used tires for now. The trend is to focus on recycling, to obtain secondary raw material from used tires by turning them into rubber granules. There is a potential market for rubber–containing rubber products from the tire recycling process, an inadequately exploited direction yet with unquestionable potential and valences in terms of the quality and durability of these products. However, in Romania there are not many economic operators to carry out granulation and there is no sufficient development of a derivative market for the by–products that can be obtained from these granules. Unfortunately, there is no good internal demand for these granules.

Rubber pavers have become very popular in recent years in our country as well. Their popularity is due to the large variety of models, sizes, colours and thicknesses, qualities that successfully serve multiple areas of use. Thanks to the innovative technology, the elastic pavers are environmentally friendly, being granular rubber products, offering added strength and reliability, both in abrasion and heavy traffic. Ideal for both impact surfaces with playground protection and anti–skid surfaces, the elastic pavers will be a real inspiration of elegance and style wherever they are placed. They can be used for decorative purposes, but also for industrial applications due to their high durability. Elastic
pavers are the most stable rubber–based granular products and are therefore ready to handle all demands and have much more advantages over traditional paving options in concrete, wood, stone, brick or other solutions.

Rubber pavers are specially designed for areas where the risk of falling and hitting is high, and the manufacturers of such materials have developed a range of product lines suitable for many exterior or interior types designed to protect against the most diverse risks. Outside, it offers the advantage of resistance to repeated freeze–thaw cycles, and additionally the tile composition allows drainage of water, so the pavement is easy to dry.

References
[1] Thomas B S and Gupta R C 2015 Long term behaviour of cement concrete containing discarded tire rubber, *Journal of Cleaner Production* **102** 78–87
[2] Khaloo A R, Dehestani M and Rahmatabadi P 2008 Mechanical properties of concrete containing a high volume of tire–rubber particles, *Waste Management* **28**(12) 2472–2482
[3] Su H, Yang J, Ling T-C, Ghataora G S and Dirar S 2015 Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes, *Journal of Cleaner Production* **91** 288–296
[4] Yazdi M A, Yang J, Yihui L and Su H A 2015 Review on application of waste tire in concrete, *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering* **9**(12) 1648-1653
[5] Batayneh M, Marie I and Asi I 2007 Use of selected waste materials in concrete mixes, *Waste Management* **27**(12) 1870-1876
[6] Sukontasukku P, Chaikaew Ch 2006 Properties of concrete pedestrian block mixed with crumb rubber, *Construction and Building Materials* **20** 450–457
[7] Rafat S and Tarun R Naik 2004 Properties of concrete containing scrap-tire rubber – an overview, *Waste Management* **24**(6) 563–569
[8] Toutanji H A 1996 The use of rubber tire particles in concrete to replace mineral aggregates, *Journal of Cement & Concrete Composites* **18** 135–139
[9] Alam I, Mahmood U A and Khattak N 2015 Use of rubber as aggregate in concrete, *A Review International Journal of Advanced Structures and Geotechnical Engineering* **4**(2) 92–96