Recycling of secondary raw materials from end-of-life car tires

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Abstract

The huge quantity of end-of-life tires discarded annually in developed countries is posing major environmental problems due to restrictions against disposal in landfills and to difficulties in obtaining suitable products to be sold in the market as secondary raw materials.

Actually, mechanical processing of the tires in shredding, granulation and pulverization plants is not a fully satisfactory solution because of operational drawbacks (high energy consumption, considerable wear, low technical efficiency), in addition to the poor quality of the components.

A new technology has been developed at the University of Cagliari based on the use of high velocity jets of water enabling to achieve a thorough disintegration of the rubber, leaving a very clean steel product.

The rubber granules so obtained can be used either for municipal water filtration or for the manufacture of paving and building elements or as a component of surface layer in roadways, thus contributing to the improvement of living conditions in urban areas. This paper describes the main features of waterjet technology and discusses the prospects of commercial application of tire dismantling products that appear promising from both the technical and economic point of view

Keywords: car tires, recycling, rubber granules, waterjet disintegration, building materials, insulation.

1 Introduction

Presently more that 9 million tonnes of end-of-life (EOL) tires are discarded each year in the world, corresponding to about 2% of total quantity of solid waste

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produced. EU Countries contribute to this amount with a considerable figure of 3.5 million tonnes (of which about 400 thousand tonnes in Italy).

The reuse of worn tires in their original form (directly or after some suitable treatments like rethreading, reconstruction or regeneration) is still considered the most appropriate strategy, i.e. the "*Best Practicable Environmental Option*" (BPEO), on the basis of a study in which factors related to each of the different technical options available are taken into account, with particular reference to safety aspects, environmental issues, waste disposal problems and social and economic conditions [1].

However, because of the increasing use of low-profile tires, designed more for function than for durability, the average lifetime is considerably shortened, with the consequence that an increasing proportion of tires results to be inadequate for reconstruction which can be replicated no more than once or twice.

Alternative uses of EOL tires are possible, such as the construction of containment barriers, structures for marine fish shelters, but they should be considered as borderline opportunities, capable of absorbing a marginal share of the total.

Concerning the landfilling option, there are significant environmental impacts: apart from taking up a disproportionate amount of valuable landfill space, it can be a breeding ground for dangerous insects and noxious species, a source of contaminated effluents and a considerable fire hazard, resulting in a significant risk of air, water, and soil quality deterioration.

Consequently, the European Union has banned landfilling of whole tires since 2003 and shredded tyres since 2006 (EC Directive 1999/31) giving way to new end-of-use-tire management.

Parallel to this, the concept of a Tire-Derived Fuel (TDF) has been developed with the goal of eliminating tires from landfill build-up, while providing a fuel for heat and electricity generation utilities. However co-generation by direct combustion of tires in incinerators is not acceptable at the level of public opinion for its alleged pollution potential.

Finally a considerable proportion, although difficult-to-quantify, is unfortunately still abandoned in the environment or illegally burned, in spite of the attempts to control and to dissuade this practice.

Within this frame a wide field remains yet open for recovery/recycle operations, strongly recommended by EU directives, aimed at obtaining secondary raw materials for a variety of applications.

2 Potential market for granulated and pulverised rubber

From the point of view of ecology, the transformation of scrap tires from waste to resource in the form of secondary raw materials, perfectly and selectively separated and suitable for a variety of uses is becoming more and more attractive.

In fact, the rubber granules and micron-size particles obtained with an appropriate tire disintegration technology can be easily placed in the market for making:

- new tires or rubber items (wheels, rollers, ….);
- anti-shock floors and sports surfaces for inside courts or outdoor fields ;
- elements for roof covers, including tiles;
- acoustical insulation sheets for floors and walls;
- additive for road substrates;
- shaped products in blends with thermoplastic materials;
- asphalt layers modified with pulverised rubber in road paving;
- vibration dampening in rail roads, tramways and mechanical equipments;
- items for road fittings (bollards, bumps, markers, safety curbs for instance);
- objects of urban furniture (benches, delimitation barriers, garbage baskets, flower pots, and so on);
- cycling tracks;
- objects for everyday uses;
- elements for civil engineering applications;
- heat insulating materials and waterproof sheets,
- and much more.….

3 Tire disintegration technology

The recovery of secondary raw materials from EOL tires implies the selective separation of the constituents (rubber, steel end textiles).

With the widespread use of steel-belted radial tires (figure 1), recycling became even more difficult. The steel would now have to be removed after slicing and grinding for the full liberation of each component, thus enabling their recovery with suitable techniques.

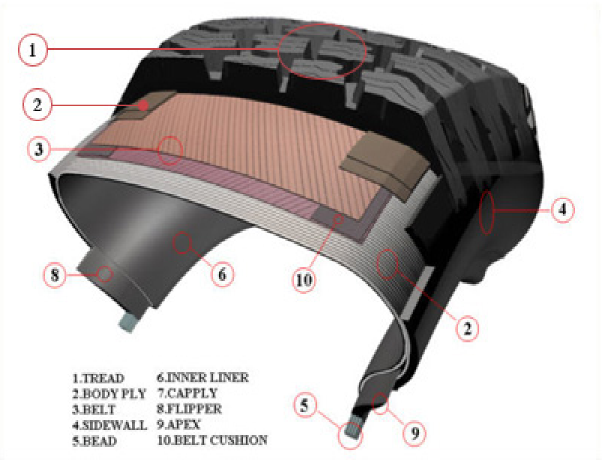

Figure 1: Structure of a radial tire.

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An adapted and improved grinding process should aim at:
- obtaining the targeted particle morphology and zero contaminants;
- optimising the energy mix and operational parameters in order to obtain recycled rubber with enhanced properties.

3.1 Mechanical processing

Up to now the technology employed for the treatment of EOL tires, besides kriogenic processes, has been that based on dry mechanical crushing operations using specialised machines according to a complex flowsheet including different sections:

- tire feeding with preliminary removal of the bead by a tearing action;
- shredding;
- granulation;
- separation of the components;
- pulverising;
- pneumatic classification.

However these plants have shown some drawbacks concerning both the operational reliability and the expected performance due to management problems and in particular to a low technical efficiency caused by frequent and prolonged stops.

The economy of the process is not satisfactory because of the high working costs (energy consumption, replacement of cutting tools and spare parts, manpower incidence) as well as for the difficulty in obtaining quality products to be sold in the market at convenient prices due to a poor selectivity of the process.

In fact, rubber crumbs and granules obtained by mechanical treatment still contain a certain quantity of metals that would preclude the use in many applications for sanitary reasons, while enough rubber remains attached to the metal wires beyond the acceptability limits imposed by steel industry. Even cement factories are reluctant to accept the shredded fraction obtained in the first step of the mechanical process.

3.2 Waterjet treatment

Waterjet technology that exploits the kinetic energy of a stream generated at high pressure through a small nozzle can disintegrate the tires with superior selectivity into products meeting the quality demanded by the market, making the process clearly convenient also on economic grounds, in spite of the relevant energy consumption [2–4].

In fact, a high velocity jet of water is capable of destroying the rubber mass into very fine particles, leaving the reinforcing structure clean and intact. The metal hank almost free of rubber can be removed by screening and magnetic separation, while the pulp containing the finely divided rubber fraction is sieved, thickened and dried. Textiles in the form of fibres can be eventually separated in some way, if necessary.

Intensive research has been carrying on over the last 20 years at the University of Cagliari concerning the application of waterjet in rock and minerals engineering.

Based on the experience gathered, a special technology for car tires covered by a patent has been recently developed up to the rim of commercial application. For demonstrating the industrial feasibility a prototype working at a pressure around 80 MPa has been constructed and successfully tested for disintegrating the thread in the form of a flat belt previously cut from the tire, while the two sidewalls free of metal can be treated separately either with waterjet or with mechanical tools (figure 2).

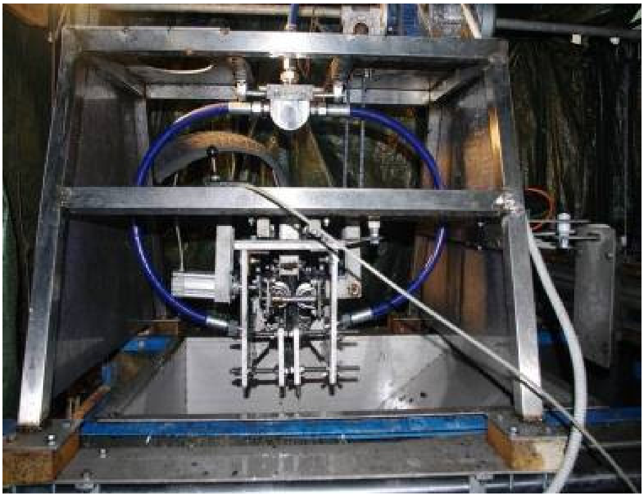

Figure 2: Prototype of the waterjet unit for tire disintegration at the University of Cagliari.

The process requires a quite high level of power for the compression of the water; the specific energy consumed being around 1 kWh per kg of rubber. On the other side, manpower incidence can be low by implementing a high degree of automation with a limited consumption of spare parts since the wear problems typical of mechanical cutting tools are overcome.

The waterjet disintegration process is highly selective concerning the steel-rubber pair, as shown in figure 3. As for textiles, a fraction of them remains interwoven with the steel wires and can be removed by ventilation, while fine fibres passing the sieve mesh are collected with the rubber. A fluff of long textile fibres sometimes incorporating rubber pieces can be separated by screening.

4 Characteristics of the products obtained

Owing to the possibility of concentrating a great force on a small space (a jet issued by a nozzle 1 mm in diameter can carry several tens of kW as a function

Figure 3: Result of waterjet selective disintegration of a car tire thread.

Figure 4: Fine (left) and coarse (right) fractions of rubber after screening at 1 mm.

of pressure), the rubber fraction obtained with the above described waterjet technology is characterised by a very fine size distribution (even more than 80% by mass below 1 mm). Moreover the rubber particles are very irregular in shape (figure 4).

Not surprising is the fact that a high degree of de-vulcanisation (> 75%) due to the rupture of sulphur bonds is also achieved as a result of the strong shearing actions involved.

These properties make the products very much appreciated by the market, especially the rubber fraction that can be used for manufacturing a variety of objects in combination with a gluing substance.

The coarser rubber granules are suitable for some civil engineering applications like for instance the preparation of rubberised asphalt in roadways

5 Application of recycled rubber in wastewater remediation

Coarse rubber granules can be efficiently used for the treatment of municipal seepage waters as well as for the clarification of natural waters containing suspended solids. Some successful results are even claimed concerning the remediation of waters contaminated by heavy metals or organic pollutants [5, 6].

For proving the concept some tests have been done at the University of Cagliari.

Results obtained show that a satisfactory efficiency in the removal of suspended solids (either organic or inorganic) can be achieved with rubber granules, somewhat better than that with conventional sand.

The size of the granules should be coarser than 1.5 mm in order to avoid clogging as well as for limiting the pressure loss across the bed.

6 Application of recycled rubber in road construction

The upper layer of roads can be constructed with asphalt concrete that consists of a mixture of asphalt as a binder and a mineral aggregate laid down in layers and compacted, achieving interesting advantages concerning both safety and environmental disturbances [7].

In fact, compared to Portland cement, asphalt concrete surfaces generate less roadway noise especially at higher speeds of vehicles.

The idea that highway design could be influenced by acoustical engineering considerations including the selection of surface paving types arose in the very early 1970s.

6.1 Paving with rubberised asphalt

Waste materials, such as rubber granules resulting from the disintegration of old tires that might otherwise be discarded, can be added to asphalt concrete, obtaining the so called rubberised asphalt concrete (RAC). Widely used in the USA and in Germany, this special pavement material is gaining increasing interest all over the world also because of its high durability as well as for its ability to further reduce road noise.

After about one year, asphalt rubber overlays resulted in up to a 12 decibel reduction in road noise, with a typical level of 7 to 9 decibel [8]. Rubberised asphalt has been used for more than 20 years to renovate the surface of highways and city streets after reaching their normal technical life.

A number of advantages can be claimed for this product:

- it does not reflect cracks from the existing pavement;
- it is more durable and skid-resistant than conventional asphalt;
- it reduces traffic noise and provides a smooth, quiet ride.

Rubberised asphalt is also suitable for filling the cracks formed in the roads as the effect of displacements caused by heavy traffic. If these cracks are left unsealed, deterioration of asphalt pavements is accelerated due to moisture creeping under the asphalt layer and subsequent erosion of the base. The pavement begins to sink and crumble, causing more cracks to form and creating holes that may become dangerous for the vehicular traffic. This process is accelerated by freezing cycles during cold winters.

6.2 Speed bumps

Sturdy and solid speed bumps can be made from recycled rubber tires. This convenient feature allows to run essential cabling or piping underneath each speed bump whenever necessary.

Rubber speed bumps are interesting because of their flexible composition that easily conforms to almost any type of asphalt or concrete pavement. Each speed bump also features highly-visible, embedded reflective tape which gives them even greater visibility, especially in the dark hours.

Moreover, rubber speed bumps are naturally resistant to extreme temperatures and weather conditions, UV rays and road salt. They will not crack, break, peel or crumble.

6.3 Protection barriers

Conventional protection barriers made with shaped steel bands are sometimes responsible of severe accidents, especially when motorbikes are involved. The addition of proper fittings made with recycled rubber for eliminating the sharp edges and for gradually absorbing the kinetic energy of the impacting body may contribute in reducing the risk of fatal injuries.

7 Application in rubber flooring

Rubber floors can be produced using recycled rubber obtained from worn-out tires, mixed with a binding agent such as polyurethane or other gluing substances, thus helping to save the environment and to preserve the natural resources.

The most beneficial feature of rubber pavements is the safety factor, owing to their superior slip resistance and shock absorption, featuring a relatively soft, low impact surface, meaning that they are strong yet comfortable flooring material. They are also sound proof.

For these reasons rubber floors are the safest and most suitable alternative product for those high traffic areas, especially near nursing homes, hospitals, day care centres, schools, supermarkets and gymnasiums.

Some other great benefits of rubber pavements include durability: they are long lasting and will not crack and chip like other flooring materials. They perform well in both indoor and outdoor applications and represent a versatile solution not affected by water, ice, snow or any extreme weather conditions.

Finally they are relatively cheap to buy and install, easy to clean and do not absorb bacteria, making them a hygienic choice.

There are various reasons to choose this kind of material for different applications such as driveways, walkways, playgrounds and other various outdoor applications.

Another key characteristic of rubber pavers is their adaptability to interior and exterior applications. It is because they can be made available in a variety of shapes, colours, patterns, textures and finishes that rubber pavers are becoming increasingly popular.

8 Products for playgrounds and landscaping

For making shaped objects from finely ground rubber some requirements must be met implying:

- an optimized sintering process including dosing chamber and pre-heating phases;
- an official approval for the developed products in order to eliminate a negative attitude towards the use of waste materials for urban furniture items;
- the selection and development of a new concept for urban innovation aimed at creating a safe, comfortable and friendly environment;
- the introduction of simulation programs into the design process of recycled products, enabling to predict and assess the final product performance.

Recycled rubber products can be used for manufacturing a variety of items to be applied in playgrounds and gardens [8]. For playground safety such items consist of rubber mulch, rubber tiles, rubber mats, flexible curbs, shock absorbing bumpers and walkways.

The process used to create rubber mulch from old tires helps to reduce the content of metal and toxic elements, while adding UV protection, so that the mulch looks good and remains clean over a long time.

Shredded rubber mulch and rubber nuggets resist the biologic, chemical and physical agents that commonly attack plants and structures made with either natural or artificial materials.

Moreover they create a hostile environment for termites, ants, and other bugs and insects.

The health and safety performance of rubber mulch playground and landscape products make them ideal for schools, daycares, parks, homes, offices, and other institutions.

9 Application in sports facilities

Crumb rubber obtained from recycled tires is and ideal material for athletic fields, golf paths, arenas, gymnasiums and indoor sporting complexes where flexible and soft surfaces are of outmost importance.

This material is designed to provide extra cushioning for increased safety and reduced chances of athletic injury. A surface made with crumb rubber also dries quickly by draining moisture, and it prevents the accumulation of dust and mud so play can continue even under adverse weather conditions.

Benefits claimed by manufacturers include also lowered maintenance costs, reduced wear and tear, prevention of bare spots, less abrasive power compared to sand, improved drainage and water retention.

Nowadays, horse arenas for dressage, animal pens, and fillers for sports equipment are among the other applications that are made with rubber chips from recycled tires. Crumb recycled rubber is also used together with binders to manufacture children's flooring to provide protection in playgrounds. Up to 20% of binders (adhesives) are added for manufacturing agglomerated rubber products.

Other ingredients (fillers) such as carbon black, organophilic clays, softeners and surfactants are used to stiffen or strengthen the rubber, to improve the workability of the material and to enhance some properties such as UV or fire resistance. However the use of some chemicals may might cause problems when these products are used, as in the case of coming into contact with children.

10 Application in urban furniture

Until now, crumb rubber as a main raw material has been seldom used for manufacturing high quality products in a complete production line including grinding, mixing and sintering stages.

An industrial production process implies firstly the definition and the design of the items to be used in urban environment such as bollards, jiggle bars, pavements and rubber sidewalks, among others.

According to the characteristics of elasticity of the used tires, employing them to fabricate urban furniture will mean an improvement in the urban comfort. As a result, a new market for the crumb-recycled rubber will emerge to use it as a raw material for high-valued products, reducing also the actual dependency of petrol-derived raw materials.

The issue of an eco-label, showing the benefits of recycled rubber for urban furniture can help to overcome the emotional barriers against the use of waste materials for feared health problems [9].

10.1 Bollards and step posts

Properly designed bollards made with recycled rubber will be more robust, flexible and longer lasting than existing recycled plastic and wooden competitors, thanks also to an integrally moulded galvanised steel core.

Maintenance free and virtually resistant to graffiti and vandalism, they are ideal for open spaces or roadside verges.

The bollards can be manufactured by pressure moulding from 90% recycled rubber and can be produced in a variety of colours like black, brown red and green. All the finished products are aesthetically pleasing and would not look out of place even in the most prestigious areas and in historical city centres.

10.2 Anti vibration pads

A major use of moulded rubber products is in the air conditioning industry, which uses rubber mats to damp the sound emitted by air conditioning units, usually located on the roofs of office blocks. The mats absorb vibration, therefore reducing the noise emitted by the units when in use.

10.3 New concepts in building design

Whole car tires can be used as integral structural elements in the construction of environmentally friendly houses according to unconventional building design. Tires are formed into walls and then filled with dirt and sealed in with a stucco-like material. They provide great insulation, while reclaiming huge amounts of used rubber.

There is growing interest in sustainable architecture or green buildings and builders and designers are oriented towards the use of more environmentally friendly material for construction and decorating.

The U.S. Green Building Council provides support for sustainable building projects and property owners investing in environmental design [10].

Within this frame, recycled rubber is a common choice for preparing an underlay seam for roofs and floors. This concept involves the application of a layer made of suitable material like recycled rubber.

This is usually done for soundproofing purposes to prevent noise, generated by television, radio or footsteps, from being heard in other rooms either above or below.

In the case of flooring, a sound dampening layer provides added comfort for walking or exercising on wooden or tiled floors, while roofing sheets or tiles are used also as a waterproofing measure.

11 Conclusions

Ground rubber obtained from end-of-life tires represents a very interesting new material for construction engineering, allowing to achieve a number of advantages in a variety of possible applications, especially in urban contexts where safety, landscaping and heat/sound insulation are a major concern.

Rubber recycling is also attractive on economic grounds since the heavy burden of tire disposal in landfills is avoided with clear environmental benefits and a cheap secondary raw material is made available entailing considerable savings of natural resources.

Waterjet is a suitable technology for disintegrating the tires into products meeting the market specifications for both crumb rubber and steel.

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