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Mechanical characterization of a Tire Derived Material: Experiments, hyperelastic modeling and numerical validation

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HIGHLIGHTS

- The mechanical behavior of a Tire Derived Material (TDM) is studied in details.
- Tensile, compression, simple shear and volumetric test were performed.
- Conventional hyperelastic models were used to evaluate the experimental data.
- Finite element simulations on railway track mat made of TDM have been carried out.
- Experimental and numerical results show a good agreement in a certain range of deformation.

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ABSTRACT

In this paper the mechanical behavior of a Tire Derived Material is presented in details. Tensile, compression, simple shear and volumetric test are performed. Tests showed low tensile strength, stiffening behavior under compression, hysteresis and strain rate sensitivity of the material. Four hyperelastic models were fitted to the collected experimental data to investigate the rate-independent behavior of the material when used as anti-vibration mat for railway track applications. Finally finite element simulations of tests on the railway track mat have been carried out. The comparison of experimental and numerical results shows a good agreement in a certain range of deformation.

1. Introduction

Tire Derived Materials (TDMs) deserve special interest as the reuse of tires is one of the most important topics in recycling and Environmental Engineering. According to the European Tire and Rubber Manufacturers Association, in 2012, the European Union generated approximately 3418 million tons of scrap tires. However, 37% of these scrap tires are used for energy recovery mainly as fuel in kilns to produce cement, 39% are used as recycling materials for Civil Engineering work and product applications, almost the 5% is disposed to landfill or is illegally dumped and the remaining quota is traded or sold abroad [1]. Also, the energy recovered from exhausted tires by waste-to-energy plants is a quarter of the energy needed for their production and the process itself raises obvious pollution concerns. Moreover, tires are not desired at landfills because of their large volume and 75% void space, which quickly consume areas. Also the chemical released from scrap tires can damage landfill liners that are generally installed to prevent the pollution of local surface and ground water. In response to these problems research on uses of scrap tires has created many new markets and innovative applications [2–4]. The US Environmental Protection Agency has conducted research projects on scrap tires including rubberized asphalts and protection systems against erosion of bridge piers [5]. The US Department of Energy has conducted research on innovative scrap tire uses. They investigated the development of methods for treating rubber from scrap tires in order to use it as automotive seals and gaskets, sealants, adhesives. Recycled rubber is also used to make absorptive sound barriers, playground surfaces, athletic and recreational applications [6]. Recently this kind of material has also been used to make low-cost devices for structural isolation [7–9]. Despite the advantages, a main drawback is that the recycled rubber is generally treated with procedures that require much more energy than the production of the polymers it replaces. Different kinds of materials can be obtained by recycling used tires. The aim of this paper is to investigate the mechanical behavior of a TDM with a

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low cost and an easy to implement production process. This material can be very appealing for the production of low cost anti vibration-devices in replacement of the ones made of natural rubber especially in massive applications like railway track systems [10]. The production process of the proposed material consists of the following phases:

(a) Tires are shredded into chips, mostly 50 mm in size using a rotary shear shredder with two counter-rotating shafts.
(b) Tire chips enter a granulator and are reduced to a size smaller than 10 mm while most of the steel cords are liberated by a combination of shaking screens and wind shifters.
(c) The rubber granules are selected according to their dimensions to fit the desired design mix.
(d) Polyurethane binder is added to the rubber granules mix until the mixture becomes an homogenous compound.
(e) Pads of required size and shape are obtained by hot pressing or cold forging the compound.

The compound is first leveled by a roller and then it is hot pressed together. For binding optimization, hot steam is used and pressure is applied until the polymerization of the binder is complete. Cold forging requires the mixture to be pressured in a mold. Fig. 1 shows pads made of different mixtures produced following the process described above. The industrial process previously described is particular feasible for the production of low-cost devices: it requires low energy consumption and low labor demand. It is also noted, that by changing rubber aggregates, binders, temperature and applied pressure, it is possible to produce materials with different mechanical characteristics. The elastomer used in the process is usually tire derived Styrene Butadiene Rubber (SBR). A similar process can be applied to industrial leftovers made of Ethylene-Propylene Diene Monomer (EPDM), a rubber used for the production of a wide variety of seals.

2. Main applications of Tire Derived Material in the construction industry

The vision of a new sustainable construction industry is motivating researchers and practitioner in developing novel eco-friendly materials and utilizations. In this trend, the re-use of rubber tires is gaining momentum, while the installation of low-cost TDM pads is spreading to different construction engineering applications. The main use of the TDMs is by far the application to railway engineering. In railway engineering, the TDM is used instead of other elastomers to reduce the vibration transmitted by the trains moving on the railway track [10]. Elastomers are included in railway track with different configurations according to the transportation characteristics and surrounding conditions. For instance, in traditional railway systems elastomers are placed underneath the ballast. The system successfully reduces the amount of ballast needed for the construction of high performance tracks. In ballastless track system the material is placed under a thick concrete slab. Thanks to a minimum maintenance requirement, the system is generally adopted where there are exceptional maintenance difficulties, for example in tunnels. Also, the life cost of this system can be lower than that of traditional railway tracks [11]. Successful applications of TDMs in railway track include a section of the Bologna–Firenze and a section of the Roma–Napoli high speed railway in Italy. Also TDMs have been used in many tramway track in Italy and metro railway track in Spain. In some application TDMs are used in floor insulations to avoid transmission of either solid and acoustic vibration in buildings. Few applications of TDMs consist of foundations insulation to mitigate vibration from industrial buildings. In other applications TDMs are used for the production of sound and noise barriers. They are also considered for playground pavements and for other recreational facilities such as race track or special sports applications [12].

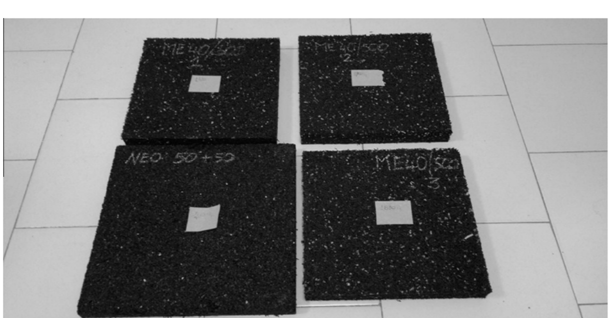
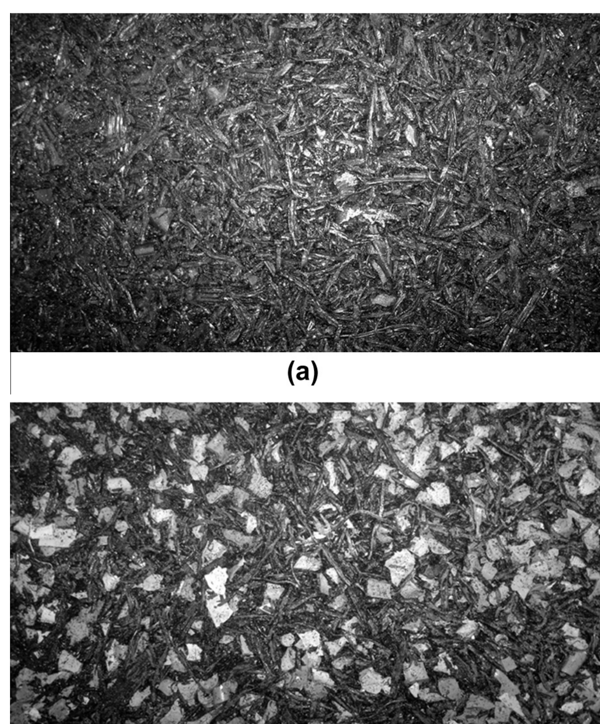


Fig. 1. Pads of TDMs for laboratory testing.

3. Mechanical tests on Tire Derived Material

The physical properties of the TDMs are greatly influenced by the technologies used in manufacturing. Tests have shown that the density and the mixture composition of the material are the parameters that affect the most of its mechanical properties. In this paper, four different types of TDMs were considered, which were obtained by using two different mixture compositions (Fig. 2) and three different densities. All the materials were made by means of the cold forging process. A different density of the material was obtained by pressing in the mold a different quantity of rubber, grains and fibers, and polyurethane binder. Table 1 lists in details the different materials compositions and specifications. Due to the lack of information on this material, experiments are required to identify an adequate form for a theoretical stress–strain curve.



(b)

Fig. 2. TDMs mixture composition a) 90% SBR fibers and 10% SBR grains b) 70% SBR fibers and 30% EPDM grains.