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Non-Metallic Materials in Rail Vehicles – Application and Recycling

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Summary
The article features the reasons for the relative lack of interest in the recycling of rail vehicles and presents available methods for recycling plastics (mechanical, raw material, biological and energetic recycling) as well as some materials made from natural raw materials. Pro-recycling activities are also discussed. It is pointed out that the success of recycling requires cooperation within social, technological, economic, manufacturing, environmental and political realms.

Keywords: plastics, mechanical recycling, raw material recycling, energy recovery, circular economy, rail vehicles

1. Introduction

Both economic and industrial growth as well as the growing population drive the demand for materials. This results in an increase in waste that pollutes the environment. For this reason, recycling has become a priority in countries with highly developed industrial sectors, both from the perspective of environmental protection and the economics of manufacturing [3]. New legal waste management acts [6–10] are to facilitate the transition to a closed-circuit economy in order to raise global competitiveness and support sustainable economic growth.

2. Recycling principles

Recycling aims to maximize the reuse of waste materials while minimizing the resources needed to process them. This helps us protect the natural materials used to manufacture those waste materials and the materials used to process them later on. Recycling covers two realms: the manufacturing of goods and the ensuing generation of related waste. The idea of recycling is to make manufacturers adopt attitudes conducive to manufacturing materials that are as recyclable as possible, i.e. with the widest possible use of materials susceptible to recycling in them. Making the consumers of those products act in desired ways, is also necessary. Recycling is a system of managing the circulation of materials that can be processed several times [19].

3. The reasons for the relative lack of interest in rail vehicles' recycling

The major causes of the lack of interest in rail vehicles' recycling are as follows:

- several decades of rail vehicles' life cycle, with rolling stock being built mostly of steel, cast iron and aluminium,
- the high complexity of rail vehicles' structures as well as the diversity and the amount of materials used, which translates into the time- and work-consuming disassembly of those vehicles,
- old vehicles' materials that might be banned in several years' time and the launch of new modified materials – difficult recycling processes [6],
- lack of the mandatory law on the recycling of rolling stock.

Rail vehicles are also subject to repair and need to be overhauled, and in this case a smaller number of selected components are replaced. Consequently, this should facilitate deliberate component management. However, this applies primarily to plastics and natural materials which have the shortest lifespan and are most frequently replaced.

4. Non-metallic materials in rail vehicles

The popularity of plastics in rail vehicles began to grow in the 1960s. New materials made using synthetic, natural or modified polymers have grown increas-

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ingly popular ever since. This phenomenon has primarily been driven by the possibility of cutting down on the weight of the vehicles to raise their speed and reduce operating expenses. In the meantime, due to the ease of modelling new materials, trains have come to be designed with even greater attention to ergonomics and aesthetics, which provides greater travel comfort. Currently, plastics in rail vehicles are used to manufacture, among others: the lining of walls and ceilings, seats, insulation materials and electrical equipment. Another important group of non-metallic materials used on rail vehicles are the more or less modified natural materials, such as: wood, cork, leather and wool, used to manufacture textiles (upholstery of seats, curtains and carpets) [13].

The total weight of all the above materials is systematically growing and currently is between 1.700 and 3.500 kg (depending on the type of vehicle), about 10% of the weight of a wagon / unit. These materials need to have pre-defined functional and fire safety properties [20, 22], i.e. some of the requirements to meet for the vehicle to be put in operation.

Then, from the perspective of the drive towards a transition to the circular economy, the methods of managing products upon the end of their life cycle should be envisaged as early as the product design stage. The rolling stock in use now includes the following non-metallic materials in these areas [14]:

- walls and ceilings: paper-phenolic laminates, polyester-glass laminates, polycarbonates, wood and wood-based products, and cork,
- floors: wood and wood-based products, cork, glass-polyester laminates, polyvinyl chloride, chloroprene rubber, ethylene-propylene rubber and carpets (polyamide, polypropylene and polyester),
- seats: polyurethane and melamine foams, fabrics (polyacrylic fabrics, polyester, and wool with polyester or polyamide), and casing (laminates, polycarbonates and modified plywood),
- tables: laminates, polycarbonate and modified plywood,
- curtains/blinds: cotton, Trevira and polyesters,
- structural elements: plywood, laminates, nanocomposites (thermoplastics) and Kevlar (aramid fibre),
- insulation and sealing: modified polyurethane foams and melamine foams, cellulose acetate, chloroprene rubber, felt, rubber and silicone,
- electrical systems:
  - lighting shades (methyl polymethacrylate and polycarbonate),
  - cable insulation (polyvinyl chloride, polyethylene,
  - polypropylene, polyolefin cross-linked by radiation and rubber),
  - pipes and ducts (modified polyamide),
  - and casing (epoxy-glass laminates),
- containers (e.g. for the water): polypropylene,
- gangways: rubber, polyester and rubber-coated fabrics.

5. Recycling methods

The following types of recycling can be distinguished, as shown in Fig. 1:

1. **Mechanical recycling** – Preferred form of recycling. It consists in the mechanical grinding of segregated and purified used plastics to the form of re-granulate (recyclate) suitable for recycling. The chemical structure remains virtually unchanged. All kinds of thermoplastics can be subject to me-

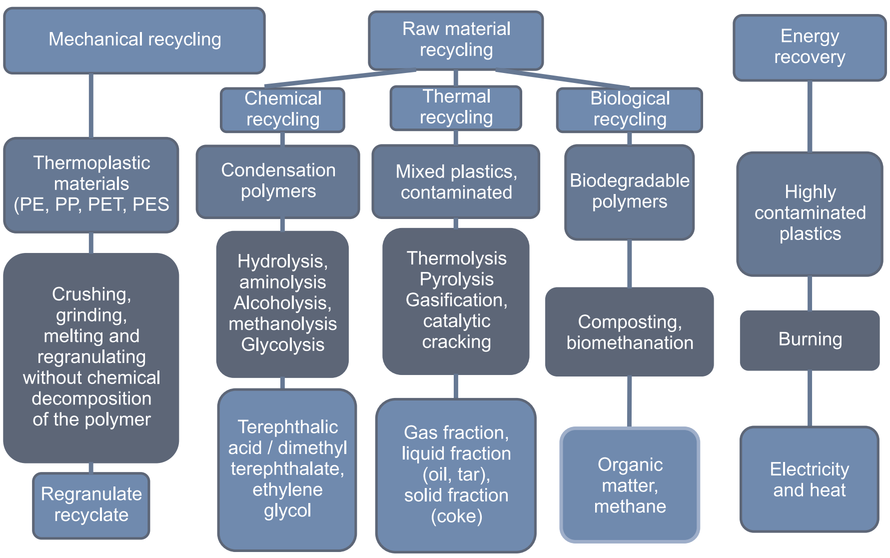

Fig. 1. Methods of recycling plastics; according to [18, 21]

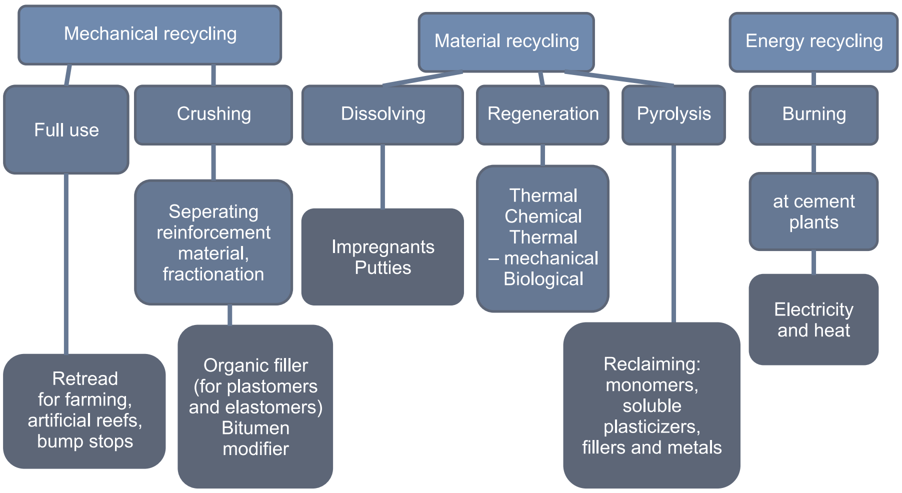

Fig. 2. Methods of recycling plastics – rubber; according to [17]

chanical recycling without deterioration of material properties. It is usually a product with a use other than originally intended. The properly designed composition translates into highly efficient recycling and adequate quality of products delivered in the recycling process [18, 21].

2. **Raw material recycling** – It consists of reclaiming raw materials previously used to manufacture a given product. The raw materials may be reused to manufacture full-value materials, and the waste that results from this method can be added to fuels and lubricants. The main advantage of this method is the ability to process plastics without prior segregation. However, the use of complicated installations, high temperature, pressure, catalysts and strict control of parameters cause restrictions in the dissemination of this group of recycling methods [18]. This kind of recycling may use:
   - chemical methods: **hydrolysis** – decomposition of e.g. PET under the influence of hot pressurized water; **methanolysis** – hot polymer degradation under pressure, by means of methanol; **glycolysis** – material degradation by heating the material along with glycol,
   - thermal methods: **pyrolysis** – thermal degradation of organic substances without oxygen at 300-600°C; **gasification** – conversion of waste in the presence of an oxidant to the amount inadequate to burn completely, at 1350–1600°C and at the pressure of ca. 15 Pa; hydrocracking – hydrogenation of polymer macromolecules at high temperatures (approx. 425°C) [21],
   - biological methods: decomposition of biodegradable plastics under aerobic (composting) or anaerobic conditions using microorganisms (biomethanization) [2].
3. **Energy recovery** – consists in burning waste and partially recovering of energy used to produce primary products. The process is applied to highly contaminated waste difficult to be recycled. However, due to the reduction of carbon dioxide emissions into the atmosphere, this technology is moving away [12].

Examples of applying the above-mentioned methods to reuse various non-metallic products are shown in the following diagrams, elaborated on the basis of [4, 5, 11, 17, 18, 21] (Figs. 2–5). The choice of a recycling method largely depends on the degree of contamination and the size of the waste stream [1–3, 12, 15, 16, 18, 21].

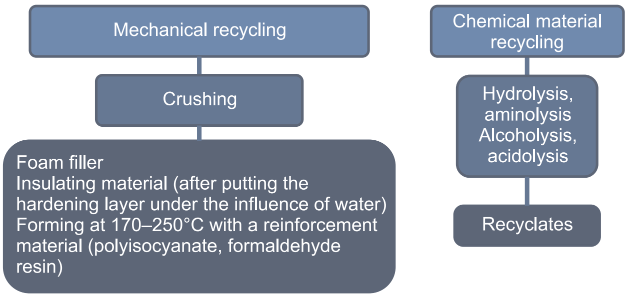

Fig. 3. Methods of recycling plastics – polyurethane waste; in accordance with [4]

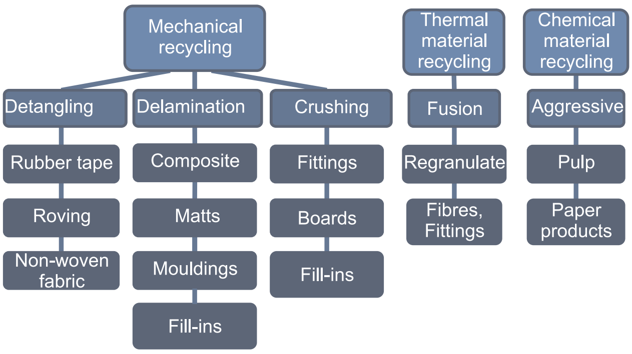

Fig. 4. Methods of recycling textiles; in accordance with [11]

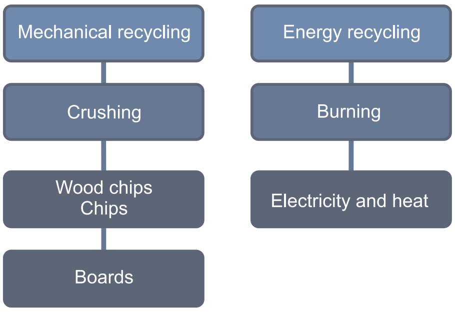

Fig. 5. Recycling of scrap wood; see [5]

6. Eco-design activities

The implementation of recycling across all sectors of the economy, in rail vehicles including, requires actions that promote recycling [3]. These actions include, above all:

- proper state legislation policy that supports recycling,
- development of waste processing technologies, primarily to maximize the use of waste,
- designing goods that consist of as many recyclable materials as possible,
- designing goods that are homogeneous in terms of the materials in order to facilitate their subsequent disassembly and segregation,
- designing products that combine various materials in a way that facilitates their disassembly into pieces made of homogeneous materials,
- designing products in a way that maximizes the amount of components suitable for reuse without processing them or with the minimum effort to recover their full value,
- an identification system for products and components of those products to facilitate the recognition and segregation of waste,
- pro-ecological education and the promotion and organization of pro-ecological habits,
- logistics of sorting and collecting used products and their components,
- processing of pre-prepared waste and reclamation of the materials they are made of.

7. Conclusions

Non-metallic products in rail vehicles intended for liquidation account for a significant weight of materials suitable for reuse, as well as waste harmful to the environment. They should be professionally recycled and / or safely disposed of. The transition to the circular economy across rail transport needs many changes in the approach to the organization, management and design of products across all design stages. First of all, it is necessary to consider the following two principles when developing the products for the rolling stock [3]:

- **clean technology** that offers greater efficiency in using natural resources,
- **design for recycling** (design that addresses recycling considerations) aimed at launching, using and then disposing of the products in a way that contributes towards generating waste and the harmfulness of waste to the minimum degree.

Thus, the success of recycling requires cooperation within social, technological, economic, manufacturing, environmental and political realms.

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