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THE REVIEW OF TECHNOLOGIES AND MACHINES DESTINED FOR RECYCLING OF POLYMER COMPOSITES

Abstract. The paper presents technologies of dealing with waste made from polymer composites, especially that reinforced with fibers. It also presents machines used for recycling. Finally, it gives conditions of choosing technologies for waste disposal.
Keywords: polymer composites, technologies and machines for recycling.

PRZEGLĄD TECHNOLOGII I MASZYN DO UTYLIZACJI KOMPOZYTÓW POLIMEROWYCH

Streszczenie. W artykule przedstawiono technologie przetwórstwa odpadów z materiałów kompozytowych z osnową polimerową, w szczególności wzmocnionych włóknami. Zaprezentowano również maszyny stosowane do recyklingu. Podano warunki doboru technologii utylizacji.
Słowa kluczowe: kompozyty polimerowe, technologie i maszyny do recyklingu.

Introduction

There are more and more areas in which polymer composites are used. The situation looks similar for the production of reinforced materials. It leads to a bigger quantity of waste they are made from. Manufacturers of these materials are obliged to dispose of them once their operating period is over.

The list below shows the quantity of manufactured materials in several last years [1]:

– 2003 year – 200 million tonnes,
– 2004 year – 225 million tonnes (increase by 25 million tonnes),
– 2005 year – 230 million tonnes (increase by 5 million tonnes),
– 2006 year – 265 million tonnes (increase by 35 million tonnes),
– 2007 year – 260 million tonnes (decrease by 5 million tonnes),
– 2008 year – 245 million tonnes (decrease by 15 million tonnes),
– 2009 year – 250 million tonnes (increase by 5 million tonnes),
– 2010 year – 270 million tonnes (increase by 20 million tonnes),
– 2011 year – 280 million tonnes (increase by 10 million tonnes),
– 2012 year – 288 million tonnes (increase by 8 million tonnes).

It shows that in the analysed period of time (2003–2012), there was an increase in manufacturing of polymer materials by 88 million tones. Each product has a defined period of durability. Afterwards, it has to be disposed of.

Recycling of polymer composites requires certain operations. Their number and type depends on a chosen technology. Each operation in such a process requires the use of appropriate machines. Their choice conditions the possibility and correctness of the whole process.

The review of available technologies of polymer composites recycling

Storage

Waste storage is the easiest method of its disposal. Its main advantage is that there is no need to develop any technology, to design and construct required machines and devices. There are also drawbacks. One needs a certain surface to create a landfill. The other important disadvantage is the possibility of emitting harmful substances which might be leached by rain. Moreover, atmospheric conditions (especially solar radiation and acid rains) might trigger liberating of various substances.

Energetic recycling

Energetic recycling consists in reclaiming a product's energy by burning it. The outcome of this process is reclaiming the energy used for its production. The side effect is gas emission, that is substances which are the outcome of burning and the emission of nonflammable substances (e.g. reinforcing fibers if they are nonflammable) [2, 3]. This recycling method is used if there is no possibility of recycling by another method [3]. Apart from chemical composition, flammability is also influenced by a given material (packing density, structure). Porous materials are more prone to inflammation. The easiness with which inflammation can take place also depends on environmental conditions, such as heat loss (thus, also ambient temperature), oxygen availability (the pace of its inflow), pace of gas emission (being effects of combustion), air humidity. Heat of combustion for most polymers is about 14–46 MJ/kg [2, 3]. The phenomenon of ablation, which takes place during combustion (abstraction or sublimation of combustion products, is unfavourable as far as energetic recycling is concerned [2, 3].

It should be noticed that each polymer material is flammable, spreads fire and emits gases and smoke [4]. The conditions for this process are appropriately high temperature and oxygen access.

Composite materials are unevenly built. Due to this fact, in their case combustion can take place under the influence of smaller energy. As a result of combustion, the surface of a given element is covered with coke [3]. Gases which are the result of combustion create a porous structure in a given material, which facilitates further combustion. Ablation is a highly unfavourable phenomenon in energetic recycling. This phenomenon consists in evaporation or sublimation of composites or combustion products. This is an unfavourable phenomenon as it absorbs a part of energy. It should be noticed here that fluoropolymers and the majority of reinforcing fibers have their heat of combustion at the level of heat necessary to provoke inflammation. This makes the energy balance value approach zero. Polymer heat properties depend on its structure. They are influenced by chemical chain structure, occurrence of double bonds and branching, content of aromatic and heterocyclic rings placed in the para-position and function groups [3]. It should be noticed here that there are also heat-resistant polymers. Among them we can find: polymers containing heteroatoms, carbocyclic chain polymers, ring polymers containing function groups in the main chain, and heterocyclic polymers.

Material recycling

Material recycling consists in processing material in such a way so as it can be used in manufacturing of new products. There are two basic directions of acting in this technology: using waste as strengthening or using waste as a filler decreasing the price of material.

To use waste as material for manufacturing of other materials (Waste segregation and use, Segregation and processing of municipal waste), the following operations should be performed:

- sorting of elements destined for recycling – parts have to be divided into groups according to certain criteria. Such a division can concern a type of product (e.g. division into foils and packaging, etc.);
- size reduction – waste must be given a form which makes it possible to use it once again and process it further on, facilitating the next stages of the process. Size reduction can be performed with the help of a granulator, mills for comminution of plastics. In case of composites with a base

of thermoplastic materials, there is a tendency to avoid the construction of working chambers and cutting constructions [5]. Plastic comminution takes place most frequently as a result of triggering off shear stress in comminuted material [5]. This stress occurs on the surface created by cutting edges. The stress is triggered by multiple hole discs or cutting knives. In disintegrating machines for thick-walled products made from plastomers cutting constructions are avoided.

- washing – it is easier to remove impurities from comminuted material. In this case, this impurity might be the residue of substance which a given part had contact with (containers must be washed from all substance residue which used to be there), or a substance which this material had contact with during storage.
- drying – it is an operation subsequent to the previous operation.
- extrusion moulding – it is a necessary operation during the manufacture of polymer material. It makes it possible to unify the material content and to process it further.
- pelleting – manufacturing material from moulded products, which can be directly used in product production (e.g. via injection technology or extrusion moulding).

It should be noticed here that recycled material has worse properties than material produced as new. It is mainly connected with the occurrence of impurities and material degradation. It can be the result of various factors [6]. Thus, it limits the possibilities of material recycling to a finite life cycles.

As the properties of material being the product of the recycling process after consequent life cycles worsen, it can be used for other products. An example of using polypropylene can be as follows: 1. a radiator, 2. an element of a ventilation system, 3. an air filter casing, 4. rugs, 5. fuel created as a result of thermal degradation.

Feedstock recycling

The effect of feedstock recycling is obtaining a substance which a given polymer was made from. It is linked most often with the reaction of depolymerisation.

This technology concerns only plastics which can be subject to depolymerisation. These are mainly polymers created by polycondensation, polyaddition and those which are (less frequently) products of the polymerase chain reaction. Polymethacrylate is a material especially recommended for feedstock recycling. It is due to thermal depolymerisation easily taking place [7].

Hydrolysis is one of the feedstock recycling methods. This reaction consists in decomposition of polymers created in the reaction of polycondensation. This reaction is triggered by steam.

Recycling of composites with a base of degradable materials

The first operation in case of separating reinforcing elements from the basis is matrix degradation.

Degradation is a process leading to decreasing the molar mass of particles of smaller length.

Degradable materials can be subject to the process of degradation due to the operation of [8]:

- increased temperature (thermal degradation),
- forces – (the so-called mechanical degradation). It can be caused by
- internal stresses, rolling, milling,
- ultrasounds,
- ionising radiation,
- sunlight,
- presence of: oxygen (thermo-oxidising degradation),
- ultrasounds,
- oxygen,
- water, acids, alkalis,(hydrolytic degradation),
- corrosive agents,
- weather conditions,,
- biological agents.

Machines and devices required in composite recycling technology

There are the following machines and devices used in recycling of waste made from polymer composites [7, 9]:

- technological lines for waste washing and drying,
- sorting line,
- containers for waste with a hydraulic system of pressing ,
- chamber presses,
- channel presses,
- perforators,
- storage containers,
- belt conveyors,
- screening drums,
- sorting chambers,
- magnetic separators,
- systems of aromatic sorting,
- blade mills,
- technological lines for waste comminution,
- spiral conveyor,

– tearing machine,
– hammer mill,
– fluidized bed.

Technological line for waste washing and drying

To submit waste to further processing in order to use that material, the first operation is the removal of impurities. Impurities are understood as: labels and product markings, product or material residues, dirt coming from waste storage. The process of waste washing has got its chronology. First, the waste comminuted by a mill is conveyed by a spiral conveyor to a worm powered by a screw agitator drive [7]. The worm turns and moves the waste to a washing tub, filled with a washing medium (which can be e.g. water), where turbines with blades start turning. Their movement makes the medium move and the waste to move in the direction of the second spiral conveyor powered by a spiral separator drive. It moves the waste to the tub. There, the blades moved by the spiral separator drive let the waste be washed and moved to a turbo centrifugal separator. At the same time, the washing medium is placed in the settling tank and fed to the beginning of the whole line thanks to a circulation pump. The waste in the turbo centrifugal separator is initially dried thanks to a rotating rotor. It is powered by a separate engine. Additionally, the waste is moved to silo cyclone located in the silo. There it falls onto the silo stirrers, where a silo screw is located. The silo stirrer and the screw have separate engines. The washed and dried waste leaves the line.

Technological line for washing comminuted waste

The first element of the technological line for washing comminuted waste is a belt conveyor which passes the waste to the comminuting machine [10]. The material coming from that recycling stage is passed by the belt conveyor to the washing device. It is washed there. The next operation is waste centrifuging. Then, it is sent to the silo.

Technological line for waste comminuting, washing and drying

The first element of the technological line for waste comminuting, washing and drying is a conveyor belt which passes the waste to the mill's charging hopper [7, 9]. There the moving rotor comminutes the material and moves it to the spiral conveyor (often consisting of several worms), which transports it to the washing tub. After the washing operation, the material has to be dried. It is done with the help of a centrifugal separator or a dryer. Finally the material lands in the silo.

Sorting line

Both general waste and selectively collected waste are subject to sorting [7]. It is placed in the buffering zone. From there, it can be transported to a special container for special waste or to a container for high volume waste (regardless of material types). High volume waste and some waste from the buffering zone are sent to the line where plastic bags are torn (at this stage some waste taken out of the bags can be transported to a container for hazardous waste), and then the waste which is to be subject to further recycling is initially milled in initial comminuting mills. The next stage of this technology is initial sorting. It is followed by magnetic separation which aims at extracting ferromagnetic material from the milled material. Next, the milled material should be divided into fractions, according to its size and material. This division can look as follows [7]: <120, <80, <49, <20 and (in the sorting chamber) the division into ballast to be stored and extracted materials (polymer materials, glass, paper).

Waste container with a hydraulic system of pressing

Waste storage in the shape in which they are delivered would require very large surfaces for storage. It is linked with the fact that products made from the materials in question have usually a bigger volume (external dimensions) that the materials' real volume. It is caused by, among all, a type of product made from composites (e.g. containers) and construction solutions (e.g. reinforcement with a net of ribs). The hydraulic system of pressing is to decrease the waste volume by applying pressure on it [7, 9].

Chamber presses

Chamber presses are the elements of the recycling via storage line. They can be categorized according to the number of chambers: 1-, 2-, 3- chamber ones. A 1- chamber press consists of: a motor operator, a press body, a slide, a cross-beam, a shore, a matrix, a board track (pillars and liners), chambers, etc. The working part of this press is in a chamber with strengthened side walls. This press does not require a press tool.

The range of values characteristic for one- chamber presses [7, 9]:

- working pressure: 23–70 [kN],
- compression degree: 85–90 [%],
- pressing cycle time: 10–30 [s],
- mass of pressed foil: 40–240 [kg],
- loading volume: 0,1–0,5 [m^3],

The final product of waste processing in the chamber press gets a shape of the element being the reflection of the chamber. Its dimensions are like the chamber's.

Channel presses

Channel presses are elements of waste disposal via storage [11, 12]. Their operation is analogical to chamber presses, but instead of a closed chamber of a defined volume, they have a channel of a constant cross-section. This channel does not have a wall from one side. The pressure exercised on the material in this press gives the waste the shape of the section and makes it move through the empty channel.

The final product of waste treatment in the channel press has a constant cross-section and its length depends on the time of the process or planned length of the final product.

Perforator

While being pressed, waste coming from products of a defined volume (e.g. bottles, containers, etc.), poses a threat of explosion [7, 9]. Additionally, there is no possibility of getting an appropriate degree of compression. To avoid such phenomena, a perforator is used.

Its first element is a charging hopper where elements destined for perforation are placed. It has four walls, without an upper casing. In its lower part, there is a perforator with holes to move comminuted elements in the direction of the roller. Its surface is covered with splines with sharpened edges. They move the disposed material to the lower part of the perforator where it is collected. When its amount is big enough, the splines make the material break. This process takes place as many times as it is necessary to achieve elements small enough to get through the holes in the perforator.

The final product of waste treated with the perforator looks similar to the final product of milling moulding pieces.

Container

Containers are destined for long-term waste storage. They can be categorized in several ways: open and closed containers, those with rolling sets (for relocation) and stationary ones (with handles for carrying them). There are containers differentiated because of their internal volume and a type of protective surface, etc. There is a separate group of containers, press containers, which have a possibility to decrease the waste volume by exercising pressure on it.

Examples of technical parameters of a container [12]:

– pressing force: 320 kN,
– device's length: 6210 mm,
– capacity: 20 m^3,
– engine power: 55 kW.
– dimensions of the filling opening: 1985 mm x 1120 mm.

Spiral conveyor

Comminuted material must be transported to the collection point, or to the place where the next operation will be carried out. It can be transported by a belt conveyor or a spiral conveyor.

The spiral conveyor is used to transport comminuted waste or waste of small dimensions. It consists of a worm fixed by a bearing at the ends of the conveyor's body. The worm is powered by an engine. Above it, there is a charging hopper. The whole machine is fixed to the ground.

Belt conveyor

With the help of a belt conveyor, waste can be transported to the charging hopper or the material coming from the separator can be transported to further recycling. This conveyor consists of a roller (fixed by a bearing to one of the feeder's foundation plates, coupled with the rive0, an axis (fixed by a bearing to the foundation plate located at the last part of the conveyor), supporting elements (minimizing the belt's deflection), and a belt (to transport waste).

Examples of technical parameters of a belt conveyor [12]:

- belt shape: flat or trough-like,
- construction type: stationary, mobile, self-propelled,
- belt's width: 200, 260, 400, 500, 500, 600, 800, 1000, 1200 mm.

Drum sieve and cascading sieve

The drum and cascading sieves are to separate from comminuted material the waste made from materials which are not subject to further recycling (due to their properties) [12].

Sorting chamber

A sorting chamber is a room through which the belt conveyor passes. Workers separate here manually waste from various materials (e.g. paper, plastic, glass).

Magnetic separator

The magnetic separator is a machine which separates ferromagnetic elements from waste. It consists of a magnet (permanent or electromagnet), a belt conveyor, the conveyor's drive and a body.

The magnetic separator moves waste on the belt, transporting it in the direction of the magnet. Thanks to its operation ferromagnetic elements are separated from other waste (they stick to the magnet).

Tearing machine

The tearing machine is a machine where waste made from cloth is placed. Its task is to comminute this cloth into elements with a relatively small surface. This machine consists of a charging hopper where cloth pieces are placed, a set of tearing elements (rollers or liners) covered with splines, a container for material which gets out, a bearing and an engine.

Hammer mill

This is a machine which comminutes a given object into pieces whose dimensions make the realization of the next recycling process stages possible. There are two mill constructions, differing from each other in dimensions of chips obtained: powder, coarse fraction [9]. Powder measures below 100 micrometers, and coarse fraction up to 20mm [9]. The process of waste milling can be divided into the following stages: 1. Feeding the material to be milled into the charging hopper; 2. Sliding the material to the mill's casing; 3. Waste comminuting by hammer hitting; 4. Collecting the milled waste through a fan; 5. Moving the milled waste to the collection point.

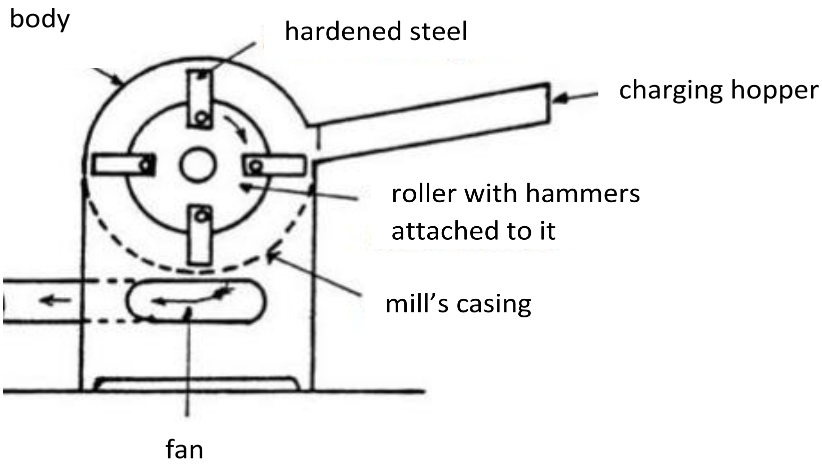

Fig. 1. Diagram for a mill for comminuting composite waste

Blade mill

These are characteristic properties for blade mills: dimensions and charge's shape, sieves' size, number and geometry of cutting blades, fan's roller's bearing, vibration damping and operation silencing. The task of the blade mill is waste comminution [7]. The element where waste destined for comminution is placed is the charging hopper. From there, the material is transported to the roller with blades attached to it. It is powered by an engine. The roller is fixed in the comminution chamber [12]. The whole mill is placed in the casing fixe to the foundation plate with wheels.

Fluidized bed

It is a device serving to extract fibres from composites. Its task is the decomposition of resin which is the matrix of composites.

There are the following operations which constitute the process of treating composite waste in the fluidized bed: 1. Collecting hot air from the fan and moving it to the heated fluidized bed; 2. Collecting comminuted material; 3. Increasing the material's temperature; 4. Creating a heated air stream and comminuted material moving to the hopper; 5. Creating a whirl from the mixture in the hopper; 6. Separating fibers from the matrix.

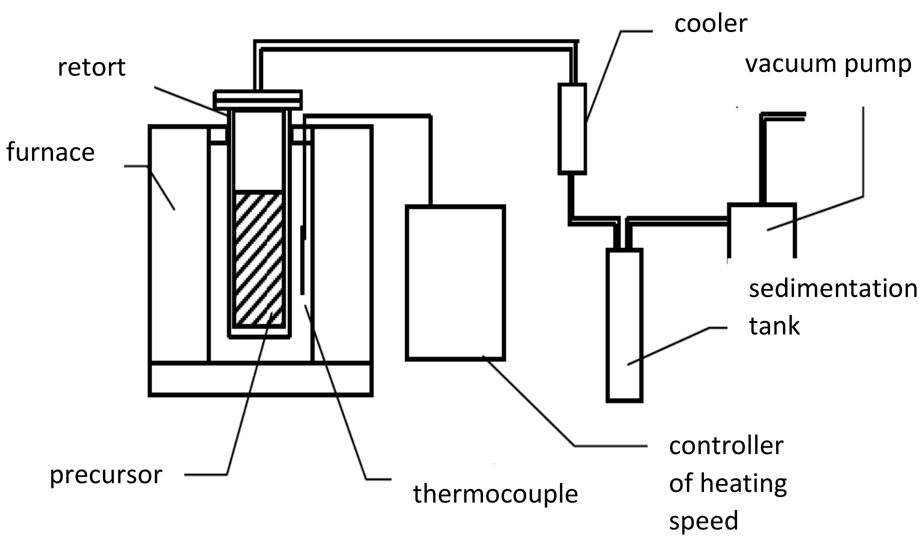

Fig. 2. Device for resin carbonisation

Choosing a recycling technology for polymer composites

The choice of a recycling technology depends on a few factors. They are, among others, the amount of waste, material it is made from, available technologies, financial means that can be allotted to a given technology development. Storage seems to be the least favourable technology as it permanently excludes a certain surface from use. Additionally, weather conditions might trigger the emission of hazardous substances. On the other hand, it does not require the purchase of machinery and specialist equipment or the implementation of a given waste treatment technology.

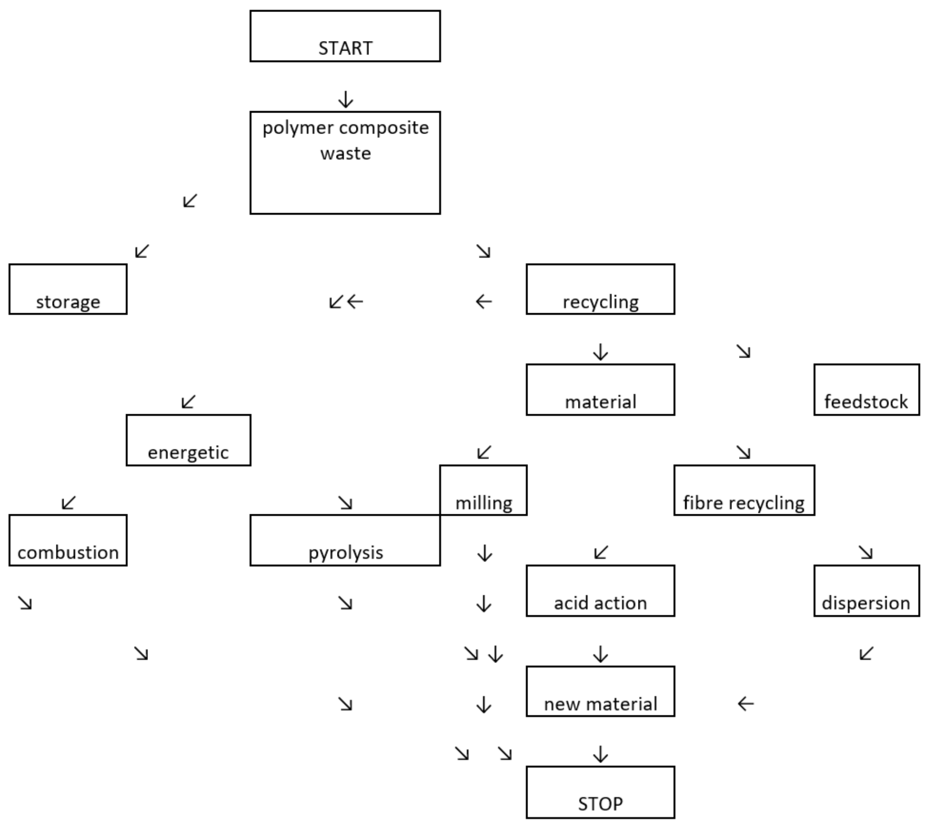

Fig. 3. Algorithm for choosing a recycling technology

Conclusion

As yet the most often use technology destined for utilization of waste materials (made of polymeric composites) was to store it. Information carried in the paper shows, that more and more economic are becoming methods of recycling waste materials. the chosing of methods depends on the quantity and kind of wastes. the adwantage of recycling technogies is partly getting back of invested funds. The advantage of storage is that there is no necessity buying technological line destinated for recycling, but it involves the use of large area.

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