

Recycling of polymer and composite waste from shipbreaking

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Abstract. A very wide employment of polymeric materials and composites based on them, both in everyday life and in other branches of the economy, and in particular in the shipbuilding industry, resulted in 304.000 jobs in 2015. tonnes of waste from fibre-reinforced composites. Therefore, it was necessary to look for new solutions to the problems of managing post-production waste and used products. New technologies for the management of post-consumer materials are to allow obtaining a cheap material that will show good functional properties, and its production will not be harmful to the natural environment. Therefore, it is important to design a technology that will allow the shipbuilding industry to follow the "zero waste" trend

Keywords: *recycling; polymers; composites; zero waste*

1. INTRODUCTION

Polymer plastics and composites based on them (i.e. polymer composites) are nowadays, due to their undoubted advantages, more and more often used in the shipbuilding industry. The most important advantages, from the point of view of suitability for the marine industry, include: low thermal conductivity, low thermal expansion, low weight, increased mechanical properties, etc. Polymer composites, most often with glass reinforcement, are used in the shipbuilding industry, including: electronics, such as control panels, main boards, in wall coverings of air tanks and tanks, air conditioning and ventilation system ducts, as structural elements of the superstructure and hull. The use of composite materials based on polymers makes it possible to reduce the weight of vessels. Reducing the weight of the product is one of the most important factors in the design process of aircraft, road vehicles and marine units. Lower structural weight allows the use of a more economical drive system and at the same time reduces production and operating costs. In addition, it also has a positive impact on the natural environment, especially when we use recycled polymer materials for the production of elements. Despite the many measurable and undoubted benefits of using polymer composites in the shipbuilding industry, unfortunately there are also serious problems arising from the storage and management of composite elements after their service life. Therefore, it is extremely important to try to identify and develop the most favorable, from the point of view of the environment and economy, solution in the field of recycling. Recycling of end-of-life ships is a very efficient and environmentally friendly activity, allowing the recovery of approximately 95% of the materials. In particular, in the light of the data that about 700 large merchant ships are scrapped every year, not counting warships [1]. Therefore, it is important to reuse them in a closed cycle, so that this branch of industry can join the "zero waste" trend, i.e. "protection of all resources through responsible production, consumption, reuse and recovery of all products, packaging and materials, without burning them, and without discharges to land, water or air that endanger the environment or human health" [2].

2. HISTORICAL SUMMARY OF SHIP RECYCLING

Until and during the 19th century, mainly metals were extracted during the disposal of ships, i.e. iron, steel, copper, bronze and lead, as well as other reusable materials. Recycling, according to the modern definition, was the use, in the 80s of the 19th century, for the construction of a new ship of steel that had been recovered from a scrapped ship. After that, these activities became very common. This process was started by a shipyard founded in 1878 in Great Britain, then already in the 21st century, the countries where the level of ship recycling is the highest and reaches the level of up to 97% are: Bangladesh, India, China, Turkey and Pakistan [3]. This is because scrapping ships poses a health risk to the people who work during the demolition. Hence, the dismantling of ships was dominated primarily by developing countries.

In the 1960s, glass fiber reinforced composites were introduced to the materials used in the watercraft sector. And the production of molds for repeated production of hull plating enabled the large-scale production of all types of boats [4]. Due to the introduction of new materials, new waste management technologies had to be introduced as well. In the late 2000s, global maritime organizations [AQASS Ltd Water Guidance, UK; International Maritime Organization (IMO, UK) National Association of State Boating Law Administrators (NASBLA, USA); Canadian Maritime Law Association (CMIA); International Council of Maritime Industries Associations (ICOMIA, UK, Belgium); Royal Yachting Association (RYA, UK)] have undertaken, either alone or in partnership, activities relating to the removal, disposal or disposal, and recycling in the marine environment, of fiberglass as a strength fraction in polymer composites, in the context of global boat end-of-life management [4]. In 2018, at the last, 12th meeting, a specially appointed London Protocol Scientific Group developed recommendations for the disposal of FRP boats [5, 6].

3. EMPLOYMENT OF POLYMER PLASTICS IN THE SHIP INDUSTRY

A ship is a very complex structure, especially in terms of the materials used. In addition to steel, other materials are used in its construction and equipment, including those that are considered harmful, such as cadmium, asbestos, lead and chromium. From the perspective of sustainable development, ship dismantling has a negative impact on the environment and the ecosystem [7].

In the last years of the 20th century, the use of polymers in the construction and repair of ships increased rapidly, primarily as a polymer that binds layered reinforcement (glass fabric, mat) into polymer composites, binds pigments, solvents, plasticizers, siccatives and thixotropic additives into ship paints polymer, constituting matrixes and protective coatings, as well as material for an element of the ship's hull equipment or fixing the position of metal elements in relation to each other for the ship's hull equipment. Polymer composites are particularly useful for creating hulls of special low-magnetic ships. It turned out to be technologically advantageous to use quasi-knit composites as reinforcement, because it is possible to easily saturate them with polymer and vent them. Protective coatings on the hulls of special ships made of wood are also made of polymer composites, which increases the life of the hull [8].

In watercraft, the following places and possibilities of using elements made of polymeric materials and composites based on them can be distinguished (Fig. 1) [8]:

- Main drive system (1) - foundation of the engine and transmission. Corrosion protection and preventing loosening of the contact of the washers with the motor and the movement of the motor are of great importance here. This also reduces the weight of the gearbox and engine foundation.
- Generating set and auxiliary equipment (2) - the use of polymers in this place allows to simplify the foundation of the generating set and auxiliary equipment below or above the deck by eliminating foundation machining.
- Stem tube and propeller shaft supports (3) - thanks to the mounting of polymer bearings, which are lubricated with a lubricant or filtered water, drilling the hull and pressing the bearings is eliminated, thanks to which accurate alignment of the shaft lines is guaranteed.

- Rudderstock and Pintle Bearings (4) - All bearings that are normally pressed into the seat can be positioned quickly and accurately using polymer, without the need to ream the seats.
- Shaft bearings (5) - mounting the bearings on the polymer eliminates the need to machine the foundations and washers, and greatly facilitates the alignment of the shaft lines.
- Rudder gear (6) - setting the gear on the polymer eliminates the need to apply foundation machining, and at the same time also facilitates rudder alignment.
- Steering gear (7) – mounting the steering gear on the polymer eliminates the machining of the foundation and greatly facilitates steering alignment.
- Pumps in the engine room (8) - the pumps are mounted on a polymer which eliminates the need to process the foundations.
- Pumps for the load (9) - embedding the pumps on the polymer allows to eliminate the treatment of the foundations.
- Passage of cables through bulkheads and watertight underlays (10) – the use of a polymer allows for good and durable sealing of the passage.
- Large roller and ball bearings (11) - polymer bearing housings eliminate the need to machine the foundation.
- Bow thrusters (12) - embedding the rudders on the foundation eliminates the need to process the foundation.
- Anchor winch (13) - mounting the winch on the polymer allows to eliminate the foundation treatment.
- Propeller shafts (14) - polymer coating gives long-term and hard protection against corrosion on exposed shaft sections.
- Marine coating of heavily loaded elements (15) – polymer coating provides long-term protection against corrosion of centrifugal pumps, condensers, propeller and shaft.
- Rudder and hull profiling (16) – the polymer fills cavities, profiles and smoothes the surfaces of the rudder and hull.
- On-board steam pipelines, cargo heater coils, ballast pipelines, repair of tanks, valves and pipes (17) – polymer, which is reinforced with fiberglass, allows for tight, fast and high-strength repair of elements with a temperature of up to 230°C, which are loaded with pressure maximum 7 MPa.
- Safer transport and traffic in footpaths (18) - the polymer provides a much more secure footing and much better foot traffic, as well as vehicle traffic on ramps, deck and helicopter landing sites.
- Hulls covered with high-strength epoxy composition (19) – polymer coating of submarines' hulls makes them resistant to impacts, safe immersion in salt water and free movement in water.
- Sealing of pipes, openings and wires (20) – the polymer effectively seals, smoothes and bulkheads and decks.
- Mechanical repair applications (21) - Titanium filled polymer is used to repair used casings and bonds dissimilar metals without the risk of galvanic corrosion.
- Flaring of steel ropes (22) – the polymer makes it possible to replace zinc in the flaring of steel rope ends, and eliminates the problems associated with the use of liquid metal, guarantees full strength before tearing the rope from the socket and perfect resistance to fatigue, fire and impact.
- Restoration of surfaces that are resistant to erosion (23) - the polymer allows the rebuilding of worn pumps, pipe elbows, casings and heat exchangers. In addition, it also extends the life of new equipment.
- Installation of LPG/LNG tanks (24) – the polymer allows for a very good load distribution of bearings and adhesive properties at ambient and cryogenic temperatures. Allows you to simplify the assembly of any when compensation or filling of tank supports is required.

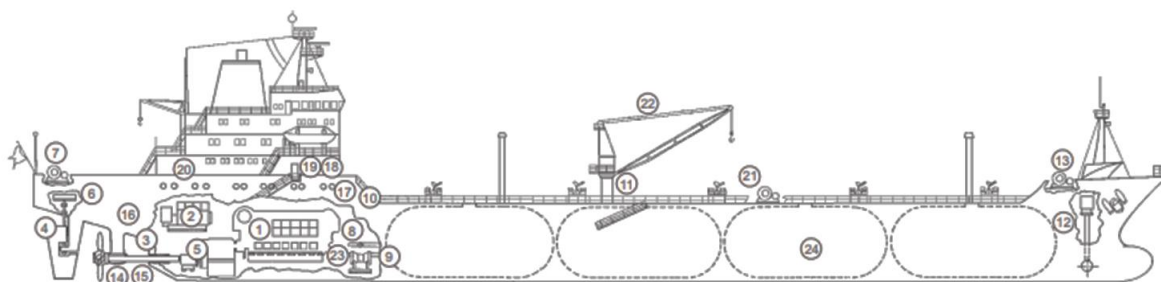


Fig. 1. Places of application of polymer materials on the example of a bulk carrier (description of markings in the text above) [9]

The approval and the possibility of using the materials in the production of vessels may take place after the material meets the requirements specified in the regulations related to the classification and construction of sea-going vessels. According to these records and requirements, the action of sea water, oil and other aging factors must not reduce the mechanical properties of the laminate which is reinforced with glass fiber by more than 30% of the original values. In the case of structures or products that are subject to loads, the minimum content of glass fiber in the laminate should be 25%, while in laminates that are reinforced with fiberglass mats, this value should not exceed 35% [10]. For the production of superstructures and hulls of vessels, reinforcements (mats, fabrics) made of specific fibers are allowed:

- carbon (high modulus HM, intermediate modulus IM fibers, high strength HT/HS),
- glass (S/R glass, E glass),
- aramid with a high Young's modulus.

The use of other types of fibers shall be specially agreed with PRS [10]. The basic fiber that is commonly used in the production of vessels has become E-glass fiber. For the construction of superstructures and hulls, it is allowed to use multi-layer reinforcements, which are sewn from unidirectional layers laid at different angles to each other. Two-layer reinforcements (biaxial) are two unidirectional layers arranged perpendicularly to each other and at an angle of $0^\circ/90^\circ$ or $-45^\circ/45^\circ$ to the carcass axis. Multi-layer reinforcements (multiaxial), in turn, are several unidirectional layers sewn together, which are arranged in relation to each other at different angles. These reinforcements are stiff, especially when they have a high basis weight. Their use requires consideration of hull curvatures and lamination technology. In addition to unidirectional fabrics, it is also allowed to use narrow reinforcements, which are composed of rovings glued to the foil, additionally secured with a mesh [10].

Table 1 presents the estimated amount of waste from vessels in the form of composites reinforced with glass fibres.

Tab. 1.

Estimated amount of waste containing glass fibers (thousand tonnes) [5, 6, 11-13]		
Country	Number of boats in operation MMF in 2018, [thousand pieces]	Estimated amount of waste, [thousand tone]
Finland	~790 000	~7,8 (in 2018)
France	~546 000	~5,4 (in 2018)
Germany	~500 000	~5,2 (in 2018)
Netherlands	~500 000	~5,5 (in 2018)
Spain	~190 000	~44,5 (until 2015)

Expected amount of waste by 2030 approx. 46.5 thousand. tone [5, 6, 11-13].

4. METHODS OF DISPOSAL AND RECYCLING OF VESSELS

Research conducted around the world in the field of environmentally safe "scrapping" of FRP boats has shown that, depending on the region of the world, there are several acceptable options for the disposal, recycling and reuse of the composite material:

- The National Association of State Boating Law Administrators (NASBLA-USA) [14] in a published report from 2009 stated that in 32 US states, the best option for managing abandoned boats is to carry out the utilization by mechanical cutting of the hull structure and dumping waste on land containing glass fibres.
- The Nordic Council of Ministers (Norden) in a report published in 2013 stated that no Nordic country (Denmark, Iceland, Norway, Sweden, Finland, Greenland, Åland and the Faroe Islands) had an environmentally friendly boat decommissioning system and showed no concern about the environment, and the vessels were disposed of as a result of their incineration and storage on land. It was the same in Great Britain.
- The Canadian Maritime Law Association (CMIA), in a report published in 2016, stated that the disposal of vessels should be oriented towards commercial activities, and that an acceptable option for disposal of boats should be the disposal of waste containing glass fibers at sea.
- Other European Union countries, including Germany and France, already in 2016 banned the landfilling of waste containing glass fibres. Probably the methods of disposal used so far are not of commercial interest due to the inability to generate economically justified and profitable benefits from recycling. The documents and reports show that the "scrapping" of boats is most often done as a result of their mechanical destruction, and the resulting polymer waste containing glass fibers is stored in separate landfills.

In the light of Regulation (EU) No 1257/2013 of the European Parliament and of the Council of 20 November 2013 on ship recycling [15], which aims to facilitate early ratification of the Hong Kong Convention both in the Union and in third countries by applying proportionate controls with regard to ships and ship recycling facilities under this Convention, ships that are waste and that are subject to transboundary shipments for recycling purposes are subject to the provisions of the Basel Convention of 22 March 1989 on the Control of Transboundary Movements of Hazardous Wastes and their Disposal and to Regulation (EC) No 1013/2006 of the European Parliament and of the Council. Through efforts involving inter-agency cooperation, an agreement was reached on the introduction of mandatory requirements at a global level to ensure an effective and efficient solution to the problem of unsafe and unreliable ship recycling in the form of the Hong Kong International Convention (15 May 2009) on the Safe and Reasonable environmentally recyclable ships. The Hong Kong Convention explicitly allows its Parties to adopt more stringent measures consistent with international law for the safe and environmentally sound recycling of ships in order to prevent, reduce or minimize negative impacts on human health and the environment. Currently, port state inspectors are appointed to inspect certification and actively conduct research for the presence of hazardous materials. In the light of Regulation (EU) No 1257/2013 [15], a recycling plan shall be developed for a given ship. The ship recycling plan addresses all ship-specific aspects that are not covered by the ship recycling facility plan or that require special procedures. The ship recycling plan shall be developed by the ship recycling facility operator in accordance with the relevant provisions of the Hong Kong Convention and taking into account the relevant IMO guidelines and, taking into account the information about the ship provided by the shipowner, explain whether and to what extent preparatory work - such as pre-treatment, identification of potential hazards and removal of inventory - to take place at a different location than the ship recycling facility identified in the ship recycling plan. The ship recycling plan should:

- specify where the ship will be placed during the recycling process and a concise plan for the arrival and safe placement of the specific ship to be recycled,
- include information on defining, maintaining and monitoring working conditions in the hazard-free zone and the safe zone for conducting the so-called hot work - for a specific ship, taking into account characteristics such as its design, configuration and previous cargo - and other necessary information on how to implement the ship recycling plan,

- include information on the type and amount of hazardous materials and waste that will be generated as a result of recycling a particular ship, including those materials and waste identified in the inventory of hazardous materials, and information on how they will be managed and stored at the facility ship recycling as well as in subsequent plants.

The ship recycling plan is approved by the competent authority in accordance with the requirements of the country where the ship recycling facility is located.

At Thommann Recycling sp. z o.o. mainly coiled tanks made of carbon or glass fiber, yachts and boats, as well as boatbuilding moulds, elements of gliders, cars, trams and trains as well as surfboards, etc. are recycled. The obtained recyclates are mainly used to produce products such as covers and rings for sewage systems, parking posts and drain grates, hydrants and gas boxes (Fig. 2, Fig. 3). The company recycles about 2.000 tonnes a year [16].



Fig. 2. Recycled products - boat molds and boats [16]



Fig. 3. Products of Thornmann Recycling sp. z o.o. from recycled materials [16]

5. CONCLUSION

Analyzing the available literature, it was found that material recycling is still the most commonly used method of recycling. The aim of this method is to reprocess waste into products with a use value. In many respects, this process is economically very demanding and is aimed only at a specific group of materials. However, at the moment, despite all the imperfections, it is often chosen by large companies. Therefore, it would be advisable to popularize chemical recycling. Using the chemical method, we will obtain the primary raw material (monomer) for the production of polymeric materials. However, it must be remembered that although it seems simple in principle, the matter is complicated. Therefore, commercial chemical recycling is practically non-existent yet, but this solution seems to be the most advanced in many respects. Chemical recycling fits perfectly into the concept of the Circular Economy. This concept, in turn, should be associated with the Circular Economy Package proposed by the European Commission, which assumes that by 2025 Poland must recover half of the polymer plastics contained in packaging waste, and by 2030 already 55%.

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