OUR SEA, INTERNATIONAL JOURNAL OF MARITIME SCIENCE & TECHNOLOGY

NAŠE MORE

MEĐUNARODNI ZNANSTVENI ČASOPIS ZA MORE I POMORSTVO

UDK 656.6+338.48+008+001(05) CODEN NMOREE ISSN 0469-6255 E-ISSN 1848-6320 DOI 10.17818/NM

VOLUME 69 · ISSUE 1 · PP 1 - 76 · DUBROVNIK · MARCH 2022.

Contents / *Sadržaj*

MARCH 2022 VOLUME 69 ISSUE 1 NAŠE MORE pp. 1 - 76

Perspectives of Plastic Pipes use in Shipbuilding and Marine Industry

Perspektiva primjene plastičnih cijevi u brodogradnji i pomorskoj industriji

Myroslav Panchuk
Ivano-Frankivsk National Technical University of Oil and Gas
Ukraine
E-mail: myroslav_panchuk@ukr.net

Aleksander Sładkowski
Silesian University of Technology
Poland
E-mail: aleksander.sladkowski@polsl.pl

Serhii Oleksiienko
Chernihiv Polytechnic National University
Ukraine
E-mail: sv.oleks@ukr.net

Andrii Panchuk
Ivano-Frankivsk National Technical University of Oil and Gas
Ukraine
E-mail: andrii_panchuk@ukr.net

DOI 10.17818/NM/2022/1.9
UDK 629.5.06:678.5/.8
Review / *Pregledni rad*
Paper received / *Rukopis primljen:* 13. 4. 2021.
Paper accepted / *Rukopis prihvaćen:* 25. 11. 2021.

Abstract

The use of plastic pipelines allows to increase the efficiency of pipeline systems of a ship due to their extraordinary corrosion resistance, a decrease of maintenance frequency, a reduction of total operational costs, and opens a new direction in the use of plastics. The weight of plastic pipelines is considerably less than that of metal ones, which allows to decrease the weight of the vessel by several tons and to increase, due to this, its maneuverability, as well as to decrease fuel consumption, ensure easier passing of all the necessary weight regulations, and optimize vessel operation. The process of installation work performance provides for a possibility of a pre-assembly of structures, the execution of welded, glued, mechanical joints with the help of a minimum set of tools in a confined space, and decreases by 50% the time of pipeline laying on the ship. Moreover, plastic pipe manufacturing creates five times less carbon dioxide emissions, which makes it a significant environmentally-friendly alternative to metal pipes. Therefore, in the cases where it is technically possible, plastic pipelines can be used as a direct substitution of metal pipelines.

KEY WORDS
plastic pipelines
corrosion resistance
operational costs
shipbuilding
marine industry

Sažetak

Uporaba plastičnih cjevovoda omogućuje povećanje učinkovitosti brodskih cjevovodnih sustava zbog njihove izvanredne otpornosti na koroziju, smanjenja učestalosti održavanja, smanjenja ukupnih operativnih troškova, te otvara novi smjer u uporabi plastike. Težina plastičnih cjevovoda znatno je manja od metalnih, što omogućuje smanjenje težine plovila za nekoliko tona, a time i bolju manevarsku sposobnost, kao i smanjenje potrošnje goriva. Olakšava provedbu uredbi o nužnoj težini i optimizira rad plovila. Proces izvođenja instalacijskih radova pruža mogućnost predmontaže konstrukcija, izvođenja zavarenih, lijepljenih, mehaničkih spojeva uz pomoć minimalnog seta alata u skučenom prostoru, te za 50 % skraćuje vrijeme postavljanja cjevovoda na brodu. Proizvodnja plastičnih cijevi stvara pet puta manje emisija ugljičnog dioksida, što je čini značajnom ekološki prihvatljivom alternativom metalnim cijevima. Zbog toga se u slučajevima kada je to tehnički moguće, plastični cjevovodi mogu koristiti kao izravna zamjena metalnim cjevovodima.

KLJUČNE RIJEČI
plastični cjevovodi
otpornost na koroziju
operativni troškovi
brodogradnja
pomorska industrija

1. INTRODUCTION / *Uvod*

Shipbuilding is considered to be one of the biggest strategic, open, oldest and highly-competitive markets in the world. This market has been constantly growing for many years and, at the same time, has been undergoing deep changes. Lately, the shipbuilding industry becomes more and more global due to an intensification of globalization of demand for world transportation of raw materials, components or ready products by waterways [1].

A modern vessel is a sophisticated technological complex which consists of various kinds of equipment, mechanisms and other structures, the operation of which is secured by pipeline systems [2]. The appearance of new multi-functional types of equipment in use leads to an increase in the number of pipes of different configuration which are to be compactly placed on the vessel.

Regardless of the type of vessel, be it a cruise liner, an inland steamer, a sea ferry or an offshore drilling platform, on each of these objects there are pipelines, the total length of which can reach several tens of kilometers, and the diameter of which ranges from 20 to 1000 mm. Pipelines usually work in harsh conditions. They transport abrasive and aggressive liquids, work under the conditions of very high or extremely low temperature ranges, high pressure values, are exposed to marine environment and corrosion. The most common reason of pipe failure is weakening caused by corrosion [4 - 6, 11].

Considering that ships will have a service life of 20-50 years, the design decisions made at the beginning of the vessel design influence the expenditures for decades. During designing, it is important to be able to make provision for effective maintenance of systems and maintainability of structures. Therefore, design for maintainability (DFM) can be defined as a design for "relative simplicity, time and resource saving, with which a ship can be maintained or restored to a necessary condition, when maintenance is performed by personnel with specific skill levels using established procedures and resources on each level of maintenance and repair [3].

Equipping of ships and marine structures with process equipment is mainly done in a limited space. Pipes make up a significant part of the process equipment and are usually manufactured beyond the shipbuilding yard. In this case, delivery delays, material replacements, various modifications of design solutions are possible, ultimately leading to an ineffective performance of works. Thus, design, manufacturing and installation of pipeline systems pertain to complex production processes [4].

It is known that ships, submarines, marine structures and other marine structural components face increasing environmental challenges. This requires the use of appropriate materials which demonstrate an increased resistance to the negative effects of marine environment and do not need any maintenance for a long time [7, 8]. In addition, corrosion resistance and little weight are key factors for vessels in order to meet design requirements and work with high speed, maneuverability and reliability [9].

Currently, the pipes which are mainly used for ship systems and pipeline systems are steel, copper, copper-nickel, brass, bimetallic, made of aluminum-magnesium and titanium alloys. The material of pipes is selected depending on the type of the transported medium (product), its pressure and temperature [10]. Considering this, metal pipelines usually have a big weight, require maintenance within a relatively short operation time, and their lifetime is significantly reduced by corrosion, which decreases the reliability of the system as a whole [11]. Improvement of the mentioned indicators is relevant at present. One of the most effective ways to improve the efficiency of pipeline systems is the use of pipes made of polymer materials.

2. PECULIARITIES OF POLYMER MATERIAL USE IN SHIPBUILDING / *Posebnosti primjene polimernih materijala u brodogradnji*

The modern shipbuilding industry is one of big consumers of polymer materials. Considering this, the fields of their use are quite diverse, and the perspectives of application are practically unlimited. Polymers are used for manufacturing hulls and hull structures, in the manufacturing of details of ship mechanisms, devices and instrumentation, for ship painting, cladding of rooms and their heat insulation, soundproofing and vibration insulation. Due to the use of polymer materials, performance characteristics of ships improve significantly, their reliability and durability rise, the construction duration and labour intensity decrease [12].

In the last decades, marine industry has been widely using polymer materials and polymer-based composites due to excellent technical properties they offer. Saving of weight and costs, as well as environmental sustainability are the main factors that have caused an increase in the use of these materials for various marine sectors [13].

According to the data from Mouritz et al. [14], investigations were conducted to compare the cost, weight and design characteristics of big patrol boats made of steel, aluminum, or polymer-based composites. Research has shown that the structural weight of a patrol boat made of glass fiber reinforced plastic (GRP) sandwich is 10% less than the structural weight of an aluminum boat and 36% less than that of a steel boat of similar dimensions.

Besides, the use of hybrid polymer-based composites, such as hybrid glass-carbon reinforced polymer composite (GCG2C) helps in the best way to achieve a long-term preservation of mechanical properties, which are necessary for the materials to efficiently work in the marine industry. Hybrids (GCG2C) have a very high flexural strength of 462 MPa with the lowest tendency to water absorption. In a similar way, hybridized flax and carbon fiber composite can be used to replace 6061 aluminum, as it provides about 141% improvement of vibration damping properties, 252% improvement of tensile strength while reducing the weight by 49%. The use of jute and carbon fibers as reinforcements for hybridized composite structures also fosters an improvement of vibration damping properties, as well as economic and environmental sustainability [15].

Some useful properties of modern polymer composite materials facilitating their use in the marine industry are good strength-to-weight and stiffness-to-weight ratios, increased dimensional stability, structure flexibility, lower manufacturing and maintenance costs, lower electrical and magnetic signatures, reduced wear, low moisture absorption, corrosion, impact and resistance, increased vibration damping properties, soundproofing, resistance to aggressive seawater, improved efficiency, high load-bearing capacity, lower inertia, increased buoyancy, and a high level of acoustic transparency [16 - 18].

Erosion-corrosion damage is a significant problem for marine structures. Especially it concerns pumps, impellers, valves, heat exchanger pipes, and other hydraulic equipment, as well as equipment used in marine technologies, oil and gas production, etc. It is generally known that the industries transporting sludges and other particle-laden fluids in the pipes for marine industries spend millions of dollars annually for the repair of material damage. In a recent study [6], the erosion-corrosion phenomenon was ranked as one of the five most widespread forms of corrosion damage in oil and gas industry.

As more and more costs are invested in restoring material degradation due to erosion-corrosion damage, this topic sparked a big interest during the last decades. Table 1 shows the corrosion damage costs for different types of ships. Based on the data in table 1, a conclusion can be made that the total repair costs for the global shipping sector constitute 5 billion 232 million dollars. Examples of plastic uses have been studied in detail in many papers on plastics obtained from fossil fuel. Currently, plastics which are made of renewable resources are at development stage, and their current market penetration is not big enough to have a significant impact on general results.

However, it is worth mentioning the future important role of renewable resources in plastic production [20]. There are two categories of plastics made of renewable energy sources. One option is the production of monomers for the obtainment of new polymers, such as PLA. A commercial challenge here lies in the competition with existing plastics of large volumes in terms of production, economics, and process equipment adaptation.

Another way is to make large volume monomers, such as ethylene (or other ethylene derivatives) from ethanol, obtained from renewable sources [21]. Then they can be used in existing polymerization units. In both cases, the chemistry is proven, but the key factor will be the amount of (non-renewable) energy used in the overall production chain.

Table 1 Estimated average corrosion cost per year due to maintenance, repairs, and downtime for each of the major types of ships [19]
Tablica 1. Procijenjeni godišnji prosječni trošak korozije zbog održavanja, popravaka i mirovanja za svaku od glavnih vrsta brodova

Type of ships	Num. of investigated ships	Average corrosion repair cost per ship ($)	Yearly repaircost (million $)	Average corrosion downtime cost per ship ($)	Yearly downtime cost (million $)
Oil	6,920	200,000	1,384	140,000	969
Chemical	2,421	300,000	741	140,000	346
Bulk Dry	6,252	50,000	313	56,000	350
Cargo	18,611	50,000	931	73,000	1,303
Fishing	23,711	25,000	593	20,000	474
Supply	12,954	50,000	648	50,000	648
Refrigerated	1,441	50,000	72	50,000	72
Cruise	337	200,000	67	1,000,000	337
Passenger	5,386	50,000	269	56,000	302
Others	7,724	50,000	386	56,000	433
WorldTotal			5,404		5,234

It is obvious that the use of polymers and polymer-based composites is currently dominant in the shipbuilding industry, as they significantly facilitate an increase in productivity and efficiency of materials due to their outstanding properties. At the same time, further investigations regarding the improvement of the properties of polymeric materials are relevant today to meet future challenges and to expand the spheres of their use.

3. VARIETIES OF PLASTIC PIPES FOR MARINE APPLICATIONS / *Vrste plastičnih cijevi za primjenu u pomorstvu*

Plastic pipes, due to their unique properties, are conquering the shipbuilding market more and more. The need to provide pure and high-quality drinking water for both the crew members and the passengers of the ship must not be neglected, as the comfort of their staying on the ship and, most importantly, their health depends on this, and therefore one of the most important pipelines on the ship is drinking water production and distribution system. Chemical and mechanical water purification systems are installed on big-sized and small ships. As a rule, they have a compact size and operate in automatic mode. For the manufacturing of such pipelines, plastic pipelines fit the best [22].

SeaDrain® White is the first tailored pipeline system, made of thermoplastics, specifically designed for marine applications [23]. In this case, fire-resistant polypropylene containing fire retardants, PPFR, is used as the pipe material [24].

Polypropylene is a plastic material which is distinguished by high impact strength and high flexing resistance, wear resistance, good electric insulation properties in a wide temperature range, high chemical resistance, low vapor and gas permeability. It is resistant to acids, alkalis, salt solutions, mineral and vegetable oils at high temperatures. At room temperature, it is insoluble and dissolves only at increased temperatures in strong solvents: chlorinated, aromatic hydrocarbons. Polypropylene mixes well with dyes, is easily processed, crystallized, and can be subject to chlorination [25].

At the same time, polypropylene, due to its chemical composition, is a combustible substance. Therewith, fire-resistant grades of polypropylene should be used for shipbuilding, specifically, with fire retardant (FR) additives. The main systems, which slow down combustion, consist of halogenated compounds, compounds of phosphorus, nitrogen, and a number of inorganic compounds [26]. Among the new directions in combustion retardation, the following can be noted: intumescent systems, polymer nanocomposites, low-melting glasses, different types of coke formers, as well as new types of eco-flame retardants based on natural renewable raw materials: lignin, starch [23].

The use of SeaDrain® White pipeline system fundamentally changes the approach to installation and maintenance of a ship drainage system. In this case, corrosion is completely absent. The system of drain pipes for blackwater and greywater is lighter in weight, easier in requirements to maintenance, needs less time and labor costs for its installation than an analogical system of metal pipelines. The use of this system reduces the risk of bacterial contamination of a transported fluid. Particularly smooth inner surface of pipes reduces scale formation, while the arrangement of mechanical connection, which includes a special gate valve design, allows the installation worksto be executed up to five times faster than in alternative metal solutions.

SeaDrain® White system is a complete drainage piping in a range of sizes DN40 ... DN150 and includes all the components which are necessary for installation, including couplings, elbows, tees, transition fittings, drain tubes, etc. With that, the pipelines are designed for pressure up to 3.5 bar and operation temperature within the range of 0°C ... +100°C. The system components have a minimum operational life of 25 years compared to 5-10 years for alternative metal pipes. The bright white exterior paint coating includes additives for UV resistance against change in colour, so no external paint is needed. Such a polymer pipeline system is suitable for cruise liners, passenger ferries and luxurious yachts, both in the construction of new ships and in the upgrade of old ones. It is approved for use by ABS, DNV-GL, Lloyd's, registered in RINO, and alsocertified by NSF and ASTM D635-18 (HB).

The main connection method during the installation works is electrofusion. "Fast-Lock"mechanical connection is also quite effective for connecting the elements, for the completion of which only a screwdriver is needed. "Fast-Lock" mechanical connection is especially useful in confined roomslacking space to accommodate a welding machine, or when the power supply is not available. Considering the possibilities of various connection options, the system can be installed in the necessary areas of the ship: balconies, open decks, service lockers, cooking spaces (USPH), and fire-safe areas.

When performing erection works, during the installation of pipelines in a design solution, only 25% of typical fixing elements (supports and hangers) are needed. This system also makes provision for above-ground pipelining. A significant reduction in the number of fixing elements means a decrease in structure weight and costs.

Comparative technical characteristics of SeaDrain® White pipeline system and metal pipes are shown in Table 2.

Table 2 Technical characteristics of SeaDrain® White system and metal pipes [22, 27]

Tablica 2. Tehničke značajke SeaDrain® White sustava i metalnih cijevi

No.	Indicators	Metal pipes	SeaDrain® White
1	CO_2 emission	Higher	5 times lower
2	Weight	60% bigger	60% lighter
3	Installation time	50% longer	50% shorter
4	Labor costs	Higher	Lower
5	Relation to corrosion	Intensively subject to corrosion	Not subject to corrosion
6	Operational lifetime	5	25

Therefore, SeaDrain® White represents a unique marine pipeline system made of thermoplastics which can serve as a direct substitution for metal pipelines and opens a new direction in the use of plastics.

Another effective solution for marine applications is SeaCor™ pipeline system made by Georg Fischer company. This system is made of chlorinated polyvinyl chloride, CPVC, which has unique physical properties required for pipelines that are used in aggressive conditions of marine environment [28]. Chlorinated polyvinyl chloride is a thermoplastic obtained through chlorination of polyvinyl chloride (PVC) with the purpose of increasing its solubility and heat resistance. CPVC possesses the highest fire-resistance properties among thermoplastic materials: it does not melt and does not form burning drops, has the highest ignition temperature among thermoplastics – 482°C.

Pipes made of CPVC withstand significant pressure and are highly resistant to acids, alkalis, alcohols, and many other corrosive materials. They also have a high impact resistance, improved thermal and refractory properties, that is why they can be used in pipeline systems, including category A machine rooms, accommodation cabins, control segments, cofferdams, and pipe tunnels [29].

SeaCor™ piping system is available in the range of dimensions of metal pipes (IPS) and complies with more than three quarters of requirements to temperature/pressure ratios for modern typical programs. It is especially suitable for non-essential marine and offshore programs, including those for the transportation of fresh water, hot and cold drinking water, seawater, wastewater, blackwater and greywater, water treatment, arrangement of ventilation holes and vacuum applications.

The weight savings during the use of polymer pipes compared to metal pipes (table 3) are significant, ranging from 36 percent savings for 12" pipe to 57 percent savings for 6" pipe. Costs for SeaCor™ pipes are competitive compared to copper pipes, but thermoplastic systems have a longer operational life – 25 years, which is a considerable investment in the product lifecycle.

Table 3 Plastic to metal weight comparison (per 100 m of pipe) [23]

Tablica 3. Usporedba težine plastike i metala (na 100 m cijevi)

No.	Indicators	¾ in.	1½ in.	4 in.	6 in.
1	Plastic	35	117	547	1,212
2	Carbon steel	262	514	1,625	2,410
3	Stainless steel	174	434	1,113	3,400
4	Copper	130	644	1,625	-
5	Savings, plastic to steel	227	527	1,078	2,187

Pipelines are connected by way of chemical welding, which involves the use of a solvent and a special cement material. Welding ensures a quick, strong and tight connection. A considerable advantage of this connection technique is the ability to perform it in cold weather.

SeaCor systems comply with the International Code for Application of Fire Test Procedures (presence of smoke, toxicity, and surface flammability) and are approved by the US Coast Guard and Transport Canada.

The next group for the use in marine applications is high-density polyethylene pipes, which are considered to be a perfect choice for use in a variety of ship systems and other marine industries because of many advantages, including light weight, extraordinary corrosion resistance. Fire-retardant polyethylene is used for ship pipeline systems. In this case, fire retardant agents interfere with the combustion reaction or block the source of incoming oxygen. The most common fire retardants for polyethylene are phosphorus-containing compounds, bromine-containing compounds, and bromine-containing compounds along with antimony trioxide. Ways of manufacturing fire-resistant polyethylene pipes are adding fire retardants during pipe production or coating the pipe surface with fire retardants. Adding is the easiest, the cheapest method and does not change the properties of the material [30].

The use of polyethylene pipes and fittings in different parts of water supply system during the construction and reconstruction of ships, tourist leisure motorboats, marine vessels, marine structures increase productivity and efficiency of the systems [31].

Light weight of high-density polyethylene pipes and extreme flexibility, corrosion resistance, low economic maintenance costs, as well as high resistance to tension and vibrations are properties that have made these pipes the leading solution for marine structures, platforms, and the shipping industry, with the minimum service life of 50 years.

The main applications of high-density polyethylene pipes are:

- plumbing cold and hot water systems;
- systems (ventilation);
- sea water systems;
- water disposal systems - washing waste waters.

Since its invention in 1955, a polyethylene pipe has been successfully used in many pipeline installations around the world. Such pipes were also used for underwater pipelines, including drain siphons across rivers, lakes and seas, as well as in municipal and industrial water intakes (fresh and sea water) and waste water spillways. Plastic pipes are also used in the repair and sanitization of underwater pipelines [32].

Just recently, with the purpose of prevention of the expected difficulties with water in Istanbul and for the well-balanced satisfaction of water demand in Asian and European parts of the city, a project of pipework routing under the Bosphorus strait has been developed. According to this project, drinking water from Melenriver (MelenÇayı) is supplied via a pipeline laid across the sea bottom in the area between Salacak – Sarayburnu with the help of PE100 pipes of 1200 mm diameter and 16 bar working pressure. Due to the project implementation, 300,000 m^3 of additional water volume per day is pumped to the European part of the megapolis [33].

The Bosphorus strait, due to a difference in the seawater density between the Black Sea and the Marmara Sea, has a two-way current with quite a high speed. Due to this feature, the Bosphorus is one of the most hardly passable straits in the world. Such difficult conditions cause a need in the use of highly flexible pipes in order to prevent the influence of marine phenomena, such as turbulence, resonance, and vibration. A very important feature of PE100 material is its resistance to the effect of seawater and the absence of corrosion.

Polyethylene pipes of 1200 m diameter and 16 bar working pressure were manufactured from the third generation LS class PE100 polyethylene raw materials developed especially for the project of pipework routing under the Bosphorus strait. In view of big benefits provided by the structure of this material, it was the exact material given preference in the project of pipeline laying under the Bosphorus. The wall thickness of the pipes constitutes 110 mm and is the biggest thickness in the world for the pipes of this diameter. The operational life of the pipes is not less than 100 years. Pipe material starts to wear after 100 years [33].

Due to these characteristics, PE100 pipes have been reliably used for many years, for their laying in the sea straits and in the areas that require resistance to seismic events which occur in a seismically active belt. PE100 pipes are joined by way of butt welding and electrofusion welding. Both methods ensure 100% tightness and compressive strength.

The manufacturing of ship pipeline systems from fiberglass is quite promising. Demonstrating excellent corrosion properties, glass-reinforced plastic pipelines extend the operational life of marine facilities [1, 34]. Typically, steel piping systems must be replaced 2-3 times within the entire operational life of a marine facility, while glass-reinforced plastic ones last the full lifetime of the embedded resource, decreasing the total cost of the facility (Fig. 1). Fiberglass pipeline systems are also environmentally friendly and do not pose a threat to the environment [35]. The joining of glass-reinforced plastic pipes is done by way of gluing.

Glued joints are more and more frequently used in marine construction, as they also offer a possibility of joining together different materials with the advantages brought by the glue process itself, which is cost-effective and ensures ease of maintenance and repair.

Thus, the use of polymer pipelines allows to improve the efficiency of pipeline systems of a ship due to superb corrosion resistance, reduced maintenance frequency, reduced total operational costs, and opens up a new direction in the use of plastics. The weight of plastic pipelines is about significantly less than that of metal ones, which allows to reduce the weight of the vessel by several tons, and thus to increase its maneuverability, reduce fuel consumption, decrease polluting emissions, ensure easier passing of all the necessary weight regulations, as well vessel operation optimization. At the same time, it should be mentioned that the matter of plastic pipeline introduction in the sphere of shipbuilding and marine construction is at an initial stage and requires further scientific investigations.

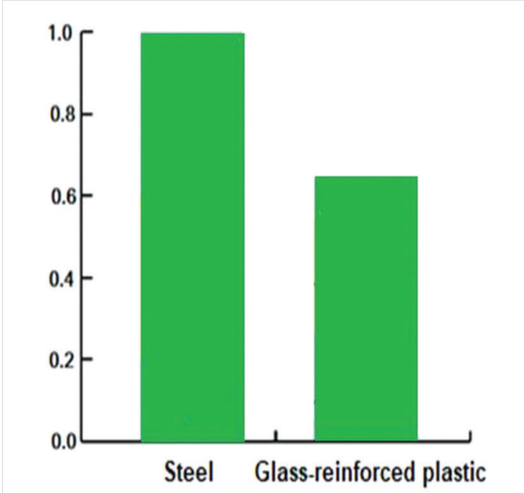

Figure 1 Comparison of operational costs for glass-reinforced plastic pipes and metal pipes [34]

Slika 1. Usporedba operativnih troškova za staklom ojačane plastične i metalne cijevi

4. EFFICIENCY OF PLASTIC PIPE CONNECTION TECHNIQUES / *Učinkovitost tehnika spajanja plastičnih cijevi*

Based on the analysis of the materials that are being used, one can make a conclusion that the connection technique plays a key role in the selection and efficient work of pipeline systems. It should be mentioned that the efficiency of new structural materials application strongly depends on the availability of relevant connection technologies [2, 36]. In order to join plastic pipes, welding methods are used: electrofusion, butt-fusion, butt welding, socket fusion, gluing; also, mechanical and flanged connections can be used. It should be noted that the mentioned connection technologies belong to flameless (easily welded with a flameless technology that produces no volatile emissions), which is a clear advantage, especially during the execution of erection works.

The choice of a welding technique for specific conditions of pipeline manufacturing is a timely task at present, which includes the possibility of performing works with this technique, equipment selection, welders' qualification, and economic factors. The operational life of plastic pipelines can constitute fifty years and more, therefore high requirements are put on the weld seams. Taking into consideration the mentioned factors, we carried out the research of technical characteristics of the main methods of plastic pipe welding: electrofusion, butt-fusion, socket fusion. Research data are shown in Table 4.

One of the main factors of weld seam reliability is the strength of the monolithic material in the weld seam area. According to data [37], for butt-fusion welding this indicator constitutes 0.8 of the strength of the pipe body, while for electrofusion and socket fusion welding no weakening happens, as in this case the wall thickness increases due to the coupling. It is also worth mentioning that for butt-fusion welding most national standards make provision for the elimination of external weld flash, which can be an additional factor in the weld seam weakening due to tension stresses. Therefore, the presence of internal flash during butt-fusion welding decreases the pipe diameter at the point of the weld seam and, at the same time, the productivity of the pipeline as a whole.

As an important indicator of electrofusion and socket fusion welding, the ability to carry out erection works on complex two-dimensional and three-dimensional pipeline systems can be considered. Butt welding, in this regard, is only used in one plane.

For butt-fusion welding, as a rule, technically complex installations are used, for certain typical sizes, with special pads for specific diameters, that is why the obtainment of a high-quality weld seam is limited by the availability of a highly qualified operator, while electrofusion welding can take place in a fully automatic mode, and technological equipment is distinguished by simplicity, therefore the operator's qualification requires a minimal, sufficient skill level. What concerns socket fusion welding, although in this case manual operations are used, they are simple and not difficult for the operator.

To this we should add that the weight of butt-fusion machines ranges within 150 - 300 kilograms, and their price is within 5000 € - 30,000 €; for electrofusion, the weight constitutes approximately 20 kilograms, and the price is 2500 €. At the same time, the weight of socket fusion machines is within the range of 1 - 3 kilograms, and their price is about 300 €. In terms of productivity, socket fusion method clearly dominates the opponents: its performance is 80 joints per shift, while for electrofusion this indicator is 40, and for butt-fusion it is 16 joints per shift. To this we should add that the cost of a coupling in case of socket fusion welding is almost ten times cheaper than the coupling cost in electrofusion welding.

Glued joints become more and more frequently used in marine construction, as they also offer a possibility to join different materials, together with the advantages brought by the glue process itself, which is cost-effective and ensures ease of maintenance and repair [2].

The use of a glued joint enables an effective replacement of welding in some cases, a decrease of deformations, an elimination of residual stresses, and an improvement of fatigue characteristics, compared to a welded joint [39]. Avoidance of high temperature treatment allows to use safe construction practices in difficult conditions. At present, polyester, polystyrene and epoxy types of glues, which are also applied in other industrial programs, are mainly used for shipbuilding [40].

For connecting the pipelines, mechanical connection, in particular, "Fast-Lock", is effective. Such a connection can be made with a screwdriver. This connection is quite effective in the rooms where there is no space to place welding equipment and where there is no power supply.

Based on the analysis of the used materials, it can be concluded that the connection technique plays a key role in pipeline system selection and efficient performance. The selection of a welding method for the specific conditions of pipeline manufacturing is a timely task at present, which includes the possibility of work execution with this method, equipment selection, welders' qualification, and economic factors.

5. CONCLUSIONS / *Zaključci*

1. The use of polymer pipelines allows to increase the efficiency of pipeline systems of a ship due to their extraordinary corrosion resistance, a decrease of maintenance frequency, a reduction of total operational costs.
2. The weight of plastic pipelines is considerably less than that of metal ones, which allows to decrease the vessel weight by several tons, to increase, due to this, its maneuverability, to reduce fuel consumption, to decrease polluting emissions, to ensure easier passing of all the necessary weight regulations, and to optimize vessel operation.
3. The use of pipes made of polymer materials enables a 50% decrease of time of their installation in the designed position.

Table 4 Comparative characteristics of butt and electrofusion welding [37, 38]
Tablica 4. Komparativne značajke sučeonog i elektrofuzijskog zavarivanja

No.	General criteria	Electrofusion	Butt-fusion	Socket fusion
1	Decrease of a pipe internal diameter	Decrease of a pipe internal diameter does not happen	The pipe internal diameter decreases by the value of weld flash	Decrease of a pipe internal diameter does not happen
2	Material strength in the welding area	Weakening of material in the welding area does not happen	Material in the welding area becomes weaker, with a coefficient of 0.8	Weakening of material in the welding area does not happen
3	Need in additional welding materials	Electrofusion coupling is needed	No need in welding units	Common coupling is needed
4	Flexibility of equipment use	A welding machine can be used for all pipe diameters	A welding machine can be used for a certain range of pipe diameters	A welding machine can be used for a certain range of pipe diameters
5	Execution of works without a possibility of pipe movement along the axis	Can be used	Is not used by operating principle	Can be used
6	Execution of welding and erection works on 3-dimensional pipeline systems	Can be used	Is not used by operating principle	Can be used
7	Operator's qualification	Minimum level of knowledge	Maximum qualification of the operator	Maximum qualification of the operator
8	Productivity	50 weld joints per shift	16 weld joints per shift	80 weld joints per shift
9	Possibility of welding the reinforced pipes	Can be used	Inadequate strength of a weld seam	Can be used
10	Equipment price	Price of a standard set of equipment 2500 €	Price of a standard set of equipment 5000 €-30000 €	Price of a standard set of equipment 300 €
11	Weight of a set of equipment, kg	20	150-300	1-3

4. The system of polymer pipelines makes provision for both welded and mechanical joints, while installation works can be done using a minimum set of tools in a small space.
5. Therefore, in the cases where it is technically possible, plastic pipelines can be used as a direct substitution of metal pipelines.
6. The matter of introduction of plastic pipelines in the shipbuilding and marine construction spheres is at an initial stage and requires further scientific research.

REFERENCES / *Literatura*

[1] Hossain K.A., Golam Zakaria N.M. (2017) A study on global shipbuilding growth, trend and future forecast. 10th International Conference on Marine Technology, MARTEC 2016. Published by Elsevier Ltd. Procedia Engineering. Vol. 194. 247-253. https://doi.org/10.1016/j.proeng.2017.08.142

[2] Panchuk M., Kryshtopa S., Sladkowski A., Kryshtopa L., Klochko N., Romanushyn T., Panchuk A., Mandryk I. (2019) Efficiency of production of motor biofuls for water and land transport. Naše more. Vol. 66. No. 3. 6-12.

[3] Dlugokecki V., Hepinstall L. (2014) Optimizing design processes to drive down total ownership cost. Marine Technology. Vol. 30. 31-37.

[4] Jang M-S, Nam J-H. (2020) Determination and application of installation seguence of pipping system in cramped spaces of ships and offshore structures considering geometric relationship of pipe elements. Internacional. Journal of Naval Architecture and Ocean Enginiring. Vol 12. 60 -70. https://doi.org/10.1016/j.ijnaoe.2019.07.001

[5] Jang M-S, Nam J-H. (2018) VR Application to Installation Order of Piping System in Narrow Space by Checking Geometric Interference of Neighboring Pipe Structures. Paper presented at the The Thirteenth ISOPE Pacific/Asia Offshore Mechanics Symposium, Jeju, Korea, October 2018.

[6] Park J.G., Kim H.J., Woo J.H. (2020) Development of Entering Order and Work-Volume Assignment Algorithms for the Management of Piping Components in Offshore Structure Construction. Journal of Marine Science and Engineering. Vol. 8, No. 894. 1-21. https://doi.org/10.3390/jmse8110894

[7] Gokdeniz N. (2017) Polimer based composites in marine use: history and future trends. Procedia Engineering. Vol. 194.19-24. https://doi.org/10.1016/j.proeng.2017.08.111

[8] Rubino F., Nisticò A., Tucci F., Carlone P. (2020) Marine application of fiber reinforced composites: a review. Journal of Marine Science and Engineering. Vol. 8. No. 26. 1-28. https://doi.org/10.3390/jmse8010026

[9] Evolution of supply, employment and skills in the European maritime technology sector. Final Report of the EU-Funded Project "Creating a European Skills Council for the Maritime Technology Sector" (2014- 2016).

[10] Fraga-Lamas P., Noceda D., Fernández-Caramés T.M., Díaz-Bouza M.A., Vilar-Montesinos M. (2016) Smart pipe system for a shipyard 4.0. Sensors. Vol. 16. No. 2186. 1-43. https://doi.org/10.3390/s16122186

[11] Suriani M.J., Wan Nik W.B. (2017) Hybrid-biocomposite material for corrosion prevention in pipeline: a review. Corrosion Science and Technology. Vol. 16. No. 2. 85-89.

[12] Malick P.K. (2008) Fiber reinforced composites-materials, 3rd ed. CRC Press and Taylor & Francis Group, Bota Racon. 1-26.

[13] Davies P. (2016) Environmental degradation of composites for marine structures: new materials and new applications. Philosophical Transactions of the Royal Society A - Mathematical Physical and Engineering Sciences. Vol. 374. No. 2071. Paper 20150272. https://doi.org/10.1098/rsta.2015.0272

[14] Mouritz A.P., Gellert E., Burchill P., Challis, K. (2001) Review of advanced composite structures for naval ships and submarines. Composite Structures. Vol. 53. No. 1. 21-42. https://doi.org/10.1016/S0263-8223(00)00175-6

[15] Oladele I.O., Omotosho T.F., Adediran A.A. (2020) Polymer-based composites: an indispensable material for present and future applications. International Journal of Polymer Science, Vol. 2020. No. 8834518. 1-12. https://doi.org/10.1155/2020/8834518

[16] Rajak D., Pagar D, Menezes P., Linul E. (2019) Fiber-reinforced polymer composites: manufacturing, properties, and applications. Polymers. Vol. 11. No. 1667. 1-37. https://doi.org/10.3390/polym11101667

[17] Muralidhar Singh M., Nagesha K.V., Gurubasavaraju T.M., Kumar H., Ajay K.M., Vijaya G. (2018) Evaluation of mechanical properties of polymer composites profiles for marine applications. Grenze International Journal of Engineering and Technology. Grenze ID: 01.GIJET.4.3.67. 344-347.

[18] Davies P. (2016) Environmental degradation of composites for marine structures: new materials and new applications. Philosophical Transactions of the Royal Society A - Mathematical Physical and Engineering Sciences. Vol. 374. No. 2071. Paper 20150272. 1-13. https://doi.org/10.1098/rsta.2015.0272

[19] Kutz M. ed. (2018) Handbook of Environmental Degradation of Materials. 3rd Edition. Elsevier.

[20] Panchuk M.V., Shlapak L.C., Panchuk A.M. et al. (2016) Perspectives of use of nanocellulose in oil and gas industry. Journal of Hydrocarbon Power Engineering. Vol. 3. No. 2. 79-84.

[21] Panchuk M., Kryshtopa S., Sładkowski A., Panchuk A. (2020) Environmental aspects of the production and use of biofuels in transport. In: Sładkowski A. ed. Ecology in Transport: Problem and solution, Lecture Notes on Networks and System 124. Springer Nature Switzerland AG. 115-168. https://doi.org/10.1007/978-3-030-42323-0_3

[22] Makris K.F., Langeveld J., Clemens F.H.L.R. (2020). A review on the durability of PVC sewer pipes: research vs. practice. Structure and Infrastructure Engineering. Vol. 16. No. 6. 880-897. https://doi.org/10.1080/15732479.2019.1673442

[23] GF Piping System. Marine Product Range 2016. [Online]. Available: https://www.georgefischer.cz/data/katalog_files/547.pdf

[24] Nazir R., Gooneie A., Lehner S., Jovic M., Rupper P., Ott N., Hufenus R., Gaan S. (2021) Alkyl sulfone bridged phosphorus flame-retardants for polypropylene. Materials and Design. Vol. 200. No. 109459. 1-29. https://doi.org/10.1016/j.matdes.2021.109459

[25] Arvidson S.A., Wong K.C., Gorga R.E., Khan S.A. (2012) Structure, molecular orientation, and resultant mechanical properties in core / sheath poly (lactic acid) / polypropylene composites. Polymer. Vol. 53(3). 791-800. https://doi.org/10.1016/j.polymer.2011.12.042

[26] Nazir R., Gaan S. (2020) Recent developments in P(O/S)-N containing flame retardants. Journal of Applied Polymer Science. Vol. 137(1). No. 47910. 218-244. https://doi.org/10.1002/app.47910

[27] Marine Manufacturer Says Thermoplastic Pipes Eco-friendly. Press Release April 3, 2012 (2021) [Online]. Available: https://www.marinelink.com/news/thermoplastic-ecofriendly343542

[28] SeaCor™ Piping Systems Solutions No. 164.141/36/0 for Marine Applications. [Online]. Available: file:///C:/Users/a/Downloads/seacor-mts-houston.pdf

[29] A Whole New Age in Marine Piping Systems. (2015) [Online]. Available: https://cdn1.shipserv.com/ShipServ/pages/profiles/221001/documents/33.-SeaCor-Brochure_2015.pdf

[30] Ghomi E.R., Khosravi F., Mossayebi Z., et al. (2020) The flame retardancy of polyethylene composites: from fundamental concepts to nanocomposites. Molecules. Vol. 25. No. 5157. 1-28. https://doi.org/10.3390/molecules25215157

[31] Application of Polyethylene Pipe in Ships. [Online]. Available: http://www.parsethylene-kish.com/separsekish/default.aspx?page=Document&app=Documents&docId=12386&docParId=11465

[32] Piping system for shipbuilding end offshore applications. [Online]. Available: https://www.ipexna.com/media/6051/shipbuilding_offshore_brochure_cdn.pdf

[33] Bosphorus Crossing Project. [Online]. Available: https://www.firat.com/en-us/success-stories/bosphorus-crossing-project

[34] Glassfiber Reinforced Epoxy Pipe Systems (GRE). [Online]. Available: http://cinnaval.com/wp-content/uploads/Glassfiber-Reinforced-Epoxy.pdf

[35] Panchuk M., Sładkowski A., Panchuk A., Semianyk I. (2021) New technologies for full assemble in shipbuilding. Naše More. Vol. 68. No. 1. 48-57. https://doi.org/10.17818/NM/2021/1.6

[36] Yousefpour A., Hojjati M., Immarigeon J.-P. (2004) Fusion bonding/welding of thermoplastic composites. Journal of Thermoplastic Composite Materials. Vol. 17(4). 303-341.https://doi.org/10.1177/0892705704045187

[37] Akkurt A. (2013) An analysis of electro-melting and hot element welding metods' safety used to join PE natural gas pipes. International Journal of Electronics, Mechanical and Mechatronics Engineering. Vol. 3. 493-504.

[38] Panchuk M.V., Shlapak L.S., Theremko N., Szkodo M., Kiełczynski W., Kishka S.O. (2017) Study of the influence of thermal factors on the welding process of polyethylene gas pipelines. Journal of Hydrocarbon Power Engineering. Vol. 4. No. 2. 88-92.

[39] Luo G.M., Lin Y. (2018) Study on structural adhesive applied to the bulkhead joints subjected to non-contact underwater explosion. Journal of Marine Science and Technology. Vol. 26(3). 421-430.

[40] Hashim S.A., Knoch E.M. (2004) Aspects of ioint design and evaluation in thick-adherend application. The Journal of Adhesion. Vol. 80(7). 569-583. https://doi.org/10.1080/00218460490476964