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BARRIERS TO SUSTAINABLE COMPOSITE POLES ADOPTION IN INFRASTRUCTURE

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ABSTRACT: Fiber-reinforced polymer (FRP) poles are, next to wooden poles, a more environmentally friendly solution than traditional steel or concrete poles. In addition to having a lower negative impact on the environment, they are characterised by durability, resiliency, and corrosion resistance. But, unfortunately, the range of their use, both in Poland and around the world, is limited. In this paper, the authors try to identify the most important barriers to the wide use of FRP poles in infrastructure construction. They also propose some actions to change this unfavourable situation from the sustainable development point of view.

KEYWORDS: composite poles, sustainability, barriers

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Introduction

Utility poles can be made of wood, steel, concrete or fibre-reinforced composite materials. Fibre-reinforced polymer (FRP) poles represent a modern engineering solution in which sustainability and ecology play a significant role. These poles consist of glass or carbon fibres arranged in various patterns enclosed in a resin, which generally consist of vinyl ester, polyester and other epoxy compounds. The most frequent method of manufacturing of composite poles is pultrusion, filament winding and vacuum infusion. Due to the main advantages of glass fibre-reinforced polymer (GFRP) poles, such as exceptional strength to weight ratios, resistance to corrosion and chemical attack, non-conductivity and long lifespans, the use of composite materials for poles is rapidly gaining acceptance throughout the utility industry.

Composite poles represent a new generation of poles that are becoming increasingly important in the lighting market. Concrete and metal poles still make up the vast majority of investments, but they are susceptible to the negative impact of environmental conditions. On the other hand, composite elements are characterised by greater durability. For this reason and potential economic benefits, significant interest from investors in composite poles has arisen.

According to research carried out by the Swedish Environmental Research Institute (Erlandsson, 2011), which evaluated the life cycle of lighting poles made of different materials, composite poles show one of the lowest environmental impacts, inferior only to wooden poles. In addition, they occupy first place in the category of human toxicity (they are the least toxic). The longest life cycle and high passive safety of the element are also important to avoid excessive damage to the vehicle during a collision.

Composite materials are versatile, durable and corrosion-resistant structural materials, relatively inexpensive, that can reduce the total outlays necessary compared to the cost of conventional structural materials. However, while introducing FRP composites into applications, barriers to the widespread use of these materials in infrastructure continue to exist. They occur at all levels, from regulation to fundamental material science (Sheridan et al., 2017). The paper aims to identify barriers to the broad introduction of fibreglass-reinforced composite poles to sustainable infrastructure and identify the environmental benefits and negative environmental impact of these poles.

Literature review concerning LCA of utility poles

Depending on the type of material the electricity poles are made, their negative impact on the environment throughout the entire life cycle is different. Thus, evaluating the environmental impact of product choices is increasingly important. Moreover, considering the substitution principle, which stipulates that, if possible, an environmentally harmful chemical or material shall be substituted with a less dangerous one, policy-makers or electric utilities faced up to the choice of the most sustainable pole material. By quantifying the environmental impacts of products, life cycle assessment (LCA) is a tool that can provide good insight to decision-makers (Nimpa et al., 2017). The existing literature on comparing the environmental impact of utility poles is not rich. Eight items are presented in which LCA has been applied directly – as a study by authors or indirectly – as a literature review. In general, all case studies concern four main materials from which utility poles are produced: wood, concrete, steel and composite materials.

In table 1, a summary of results from the literature on comparative LCAs of utility poles made from different materials is presented.

Table 1. Results from the literature on comparative LCAs of utility poles made from different materials

Name, year	Comparison	Methods of analysis	Factors	Ranking
Petersen and Solberg, 2005	Construction materials and poles: wood, steel, concrete	Literature review	energy, emissions to air, waste, global warming, acidification, eutrophication, human toxicity	1. wood 2. steel 3. concrete
Wood et al., 2008	Utility poles: wood, concrete, steel, high-density polyethylene (HDPE)	LCA	greenhouse gas (GHG) emissions, use of energy, toxic relases	1. high-density polyethylene (HDPE), wood 2. concrete 3. steel
Erlandsson, 2011	Utility poles: concrete, creosote impregnated wood, steel, composite – fibreglass	LCA	climate change, eutrophication, acidification, ground level ozone, ecological toxicity, human toxicity	1. creosote impregnated wood 2. concrete, composite – fibreglass 3. steel
AquAeTer Inc., 2012	Utility poles: wood, concrete, steel and fibre-reinforced composite	LCA	energy & resource use, anthropogenic greenhouse gas, total greenhouse gas, acid rain, Eco toxicity and eutrophication causing emissions	1. treated wood 2. fibre-reinforced composite 3. steel 4. concrete

Name, year	Comparison	Methods of analysis	Factors	Ranking
Maxineasa, Țăranu, 2013	Construction materials: concrete, steel, timber, fibre reinforced polymeric (FRP) composite materials	Describing	life span of a structure	1. FRP composite materials 2. others
Emeryville CA, 2013	Utility poles: wood, galvanised steel	LCA	energy resource depletion, water use, metals and minerals resource depletion, land use ecological impact, global climate change, acidification, ecotoxitcity, human health impact, risk from untreated hazardous waste	1. steel 2. wood
Nimpa et al., 2017	Utility poles: wood, steel, concrete, and fibre-reincorced composite	Literature review	global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), ecological toxicity (ET), smog potential (SP)	1. wood 2. steel, FRC 3. concrete
Lu, Hanandeh, 2017	Veneer-based composite (VBC), concrete, steel	LCA, LCC	global warming, acidification, eutrophication, fossil depletion and human toxicity	1. VBC 2. steel 3. concrete

Source: author's work.

There is a large discrepancy in the results of the presented analyses. Wood appears most often as the material with the least environmental impact. However, many of the authors emphasise that impregnates used for wood cause significant environmental damage. The United States Environmental Protection Agency has labelled creosote a potential carcinogen and sharply limited its use. For this reason, the vast majority of new utility poles are treated with CCA. CCA has its problems, however, as arsenic is a heavy metal that can contaminate air and water with very low concentrations (Wood et al., 2008, p. 4).

Outside the USA, wooden poles were also popular in Australia. However, due to the growing demand for utility poles and the ban on native logging in Australia, it is necessary to find sustainable alternatives to round utility poles made of wood. Currently, steel and concrete are the most common alternatives (Lu and El Hanandeh, 2017), and these are also the most common poles in Europe.

According to LCA analyses, the first or second place in the ranking is often occupied by composite poles. In fact, if the wood is not taken into account, composites are better material for building electric poles than steel or concrete.

A composite material is a combination of two or more materials: reinforcing elements (such as fibres) and binders (such as polymer resins), differing in form or composition. The combination of these materials can be designed to result in a material that maximises specific performance properties. The resin is primarily attributed to the following favourable FRP material properties (Liang and Hota, 2013):

- higher specific strength and stiffness than steel or wood;
- higher fatigue strength and impact energy absorption capacity;
- better resistance to corrosion, rust, fire, hurricane, ice storm, acids, water, intrusion, temperature changes, attacks from micro-organisms, insects and woodpeckers;
- longer service life (over 80 years);
- lower installation, operation and maintenance costs;
- non-conductivity;
- non-toxicity;
- reduced magnetic, acoustic and infrared interferences;
- design flexibility, including ease of modular construction;
- consistent batch-to-batch performance.

The environmental benefits of FRP composites can be discussed in terms of (Liang and Hota, 2013):

- better durability;
- lightweight;
- lower transportation costs;
- superior corrosion resistance and thus longer service life;
- ease of installation;
- free of maintenance.

Identification of the impact on the environment

The negative environmental impact can be expressed in commonly used indicators such as global warming, acidification, eutrophication, ozone layer depletion, toxicity and resource depletion. The key environmental concerns in composite structures can be categorised as follows: energy use in production (embodied energy), energy use in service (operational energy), transportation, use of raw materials and water, emission of harmful substances, recycling and reuse, waste treatment and land use, indoor environment.

The negative environmental impact of composite poles may occur throughout the entire life cycle:

- the extraction of raw materials,
- transportation from suppliers to composites manufacturers,
- manufacturing process,
- installation,
- operation and maintenance,
- transport to a disposal site,
- disposal process.

Kara and Manmek (Kara S., Manmek S., 2009) assessed the environmental impact of a 2.5 m long column cross made of composite fiber. They analysed the entire product life cycle (cradle-to-grave analysis). They compared the environmental impact of power-pole cross-arm made from fiber composite and the sawn hardwood. The life cycle analysis of these products consisted of four stages:

1) the materials stage is the total raw materials that are used in making the power-pole cross-arms;
2) the manufacturing process stage comprises the processes involved in making the power-pole cross-arms;
3) the use phase covers activities that follow after the manufacture of the power pole cross member, i.e. assembly and maintenance activities, up to the disposal of the product. In this case, the useful life was assumed to be 40 years;
4) the end-of-life stage is the disposal scenario which includes the transportation of the power-pole cross-arms to the disposal site and the disposal process.

Comparative life cycle analysis studies were conducted by using literature reviews and the libraries from the database of the LCA software, SimaPro 7.1.8. The research results are presented in three indicators: embodied energy consumption, greenhouse gas emissions and Eco-Indicator 99 H/A version 2.03 method[1]. The results of Eco-Indicator 99 are presented in figure 1.

The environmental impact of the power-pole cross-arm at the material life stage is 7 points per power-pole cross-arm for the hardwood and 2 points per power-pole cross-arm from the fibre composite. This 68% increase for the hardwood power-pole cross-arm is due to the fact that the hardwood was based on a forest transformation scenario and cutting wood from the forest. Therefore, it is associated with a high environmental impact in terms of land use and reducing biodiversity. In addition, a large amount of fuel is required to cut forests. Another advantage of the fibre composite power-pole cross-arm is the use phase, where the environmental impact is reduced by 99.7%

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1 This index is calculated as a single score, expressed in points. It is a comprehensive life cycle assessment analysis that considers human health, ecosystem quality and the impact of resource use.

during installation and replacement operations. This is due to the weight of the fibre composite power-pole cross-arm, which is lighter than the hardwood timber power-pole cross-arm. As a result, the truck will consume less fuel while transporting to the chosen destination.

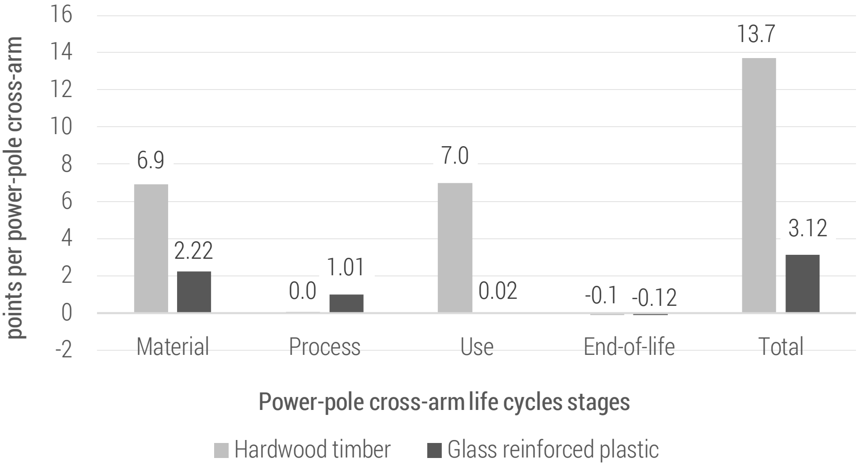

Figure 1. Comparison of environmental impact two kinds of power-pole cross-arm [in a unit of points]

Source: (Kara S., Manmek S., 2009, p. 163).

Moreover, due to the long service life of the composite material, there is no need to replace the power-pole cross-arm during use. This significantly reduces the amount of materials and energy compared to the power-pole cross-arm made of hardwood. However, a disadvantage of a fibre composite power-pole cross-arm is the manufacturing process, where its overall environmental impact is 99.97% higher than a hardwood timber power-pole cross-arm.

In general, the life cycle of composite items has much lower embodied energy than traditional products (steel, concrete, wood, aluminium) in a cradle-to-grave analysis. This is important because typical materials require a significant amount of energy during their extraction. During the production process, the majority of composite items have a higher embodied energy than traditional products. At the stage of use, composite products outperform traditional items significantly. This is mainly due to its small weight and resistance to corrosion. Maintenance tasks, for example, can save up to 35 percent on fuel consumption. Despite their many benefits, composite materials have a drawback at the end-of-life stage, when they are now 100%

garbage. In contrast, traditional products such as steel and aluminium are 65 to 70% recyclable. The composites sector may face a future challenge in improving the recyclability of composite products. This will help composite products improve not only their embodied energy efficiency but also their competitiveness.

In conclusion, composite products are anticipated to perform better than traditional products in terms of embodied energy incurred over their life cycle stages. They are the most effective in the material stage. Their superior material features, including strength and lightness, provide them with a distinct advantage over traditional materials.

Main barriers and their overcoming

Stand-alone FRP composite products, like utility poles, represent a small portion of the overall FRP composite infrastructure market and face specific barriers to increasing their market share. Owners, designers, and contractors are familiar with traditional materials and construction processes, so they are reluctant to use FRP composites even though they promise increased safety, lower life-cycle costs, and greater durability.

The main barriers for stand-alone FRP composite structures are identified as follows (Sheridan et al., 2017, p. 11):

1) predicting service life;
2) codes, specifications, and standards;
3) first-cost paradigm;
4) training and education.

Infrastructure structures typically have a service lifetime of 75 to 125 years. The major engineering assessed design properties are stiffness, failure strength, creep and creep rupture, damage tolerance, bearing strength, fatigue life, and environmental resistance because UV radiation, wetness/moisture, saltwater, cyclic and persistent loads (fatigue), and large temperature changes are all common service conditions of infrastructure structures. Composite materials' higher durability in severe settings is well acknowledged. The capacity to quantify the remaining life for asset management needs is the key difficulty. The rate of corrosion or fatigue-crack propagation in steel, for example, is well established and can be used to estimate the chance of a pipeline failing. However, there may be no apparent symptoms of degradation or propagating cracks in an FRP composite material that allow precise forecast of remaining service life.

Currently, FRP structures are designed conservatively for safety, which raises costs and inhibits structural innovation. Due to a lack of understanding of FRP materials (particularly their long-term durability), a lack of approved design standards, and a lack of thorough property characterisation of the material, high safety factors are frequently applied. Because many original applications have not reached their projected lifetime, material property data acquired from realistic exposures is not readily available. Furthermore, no systematic attempt has been made to collect publicly available in-service data on material property changes resulting from exposure. Non-destructive monitoring approaches must be combined with statistical predictive modelling to make correct asset management decisions.

The short term amortisation of the purchase cost of composite columns does not accurately reflect the cost benefits of FRP composites. However, in the US, overall installation costs have been observed as FRP utility pole cross-arms became widely used (Sheridan et al., 2017).

Customers believe that FRP composite materials require cumbersome training and safety equipment for installation and maintenance. For example, trained installers are needed to repair infrastructure in the event of a natural disaster, which further complicates the implementation of FRP composites outside of niche applications.

Extensive research and testing are required regarding the properties of composite materials. These would provide the necessary data for an accurate estimate of the remaining service life and would serve as a basis for changing the existing safety factors in the existing standards. This, in turn, would reduce costs. Modelling methods should be performed with solid scientific support. The development of existing standards for the use of FRP composites in infrastructure applications will help owners feel more comfortable with the specification of FRP composites. The standards will help engineers to use FRP composites in their designs properly, and also provide a more consistent approach to design using these materials. The development of standards related to the use of FRP composites in infrastructure provides the opportunity to address many of the identified barriers related to the adoption of FRP composites. However, it is a complex task that requires considerable time and commitment from various stakeholders (Sheridan et al., 2017).

To create and implement such standards to be successful, collaboration between industry, government, and academia is essential. A framework is needed that includes guidelines for manufacturing, quality control, and repair processes. Standards should include 1) certification, 2) design and manufacturing process, 3) quality control, maintenance methods to ensure durability.

It is suggested that a program be developed to set up testbeds, collect data, and generate models from accelerated testing to produce a set of dependable design tools. This empirical method should be supplemented by an a priori program aimed at developing tools that can predict service life solely based on the particular structure and material combinations. The resulting models and data would be made broadly available to industry, end-users, engineers, architects, and designers through an online tool. Because industry participation is critical to ensuring that the research program is commercially relevant, a public-private partnership is desirable. This collaboration should focus on gathering data on composite durability and service life as a function of environmental and material characteristics (ultraviolet, moisture, mechanical fatigue/creep, salt spray, freeze/thaw cycle, temperature exposure, chemical structure). Case studies and laboratory testing could be used to validate the forecasts to be able to predict more than 100 years of service life. The Durability Testing program should include: identification of critical data and modelling needs, accelerated ageing methods for FRP composites, fundamental durability and lifetime models (Sheridan et al., 2017).

Design guides and trustworthy data tables for infrastructure applications should be collected, curated, and disseminated. In the short term, it would produce valuable data by categorising and storing existing data to make it broadly available for infrastructure applications and accessible to all.

The activities should aim at:

- facilitate end-user communication and education,
- widespread availability of guides and standards for FRP composites,
- ensure traceability and harmonisation of standards and norms.

Such activities should give the first steps in harmonising design rules and standards, allowing for a more comprehensive view of the design space and verification test techniques. This standardisation should be expanded to a worldwide endeavour to provide a broad and consistent market, allowing for widespread use of composites in infrastructure.

Durability testing and design data information must be transmitted to designers, practising engineers, and end-users so that it may be used in infrastructure applications.

As data and information created by these activities become public and recognised, curriculum development may include them. Once such programs are established and approved, they may be used to teach qualified technicians and designers, who can then instruct others to provide direct, decentralised, and individualised education.

Conclusions

Scientific research has repeatedly confirmed the sustainable nature of composite materials. Environmental impact analyses and life cycle analyses conducted by scientists confirm the lower negative environmental impact of structural elements made of fibre-reinforced polymer. The main advantages of composite materials are their strength, corrosion resistance and longevity. However, because composites are a relatively new material in civil engineering, they are not well understood. This is the main barrier to their wide application. Insufficient knowledge of the strength, construction techniques, a real lifetime of FRP composites is a barrier for designers. It is necessary to conduct extensive research on composites' properties and then establish standards for FRP composites. These should include the stages of design, production, maintenance, quality assurance and certification. Another problem is the lack of skilled labour for field installation. For many engineers and workers, the procedural knowledge of, e.g. fixing and anchoring FRP composites to existing structures is insufficient. Education in the correct technique of installing the structure is necessary.

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Mirosław Broniewicz: conception – 60%, literature review – 10%, writing 30%
Elżbieta Broniewicz: conception – 40%, literature review – 60%, writing 30%
Karolina Dec: literature review – 10%, writing 20%
Szymon Lubas: literature review – 20%, writing 20%

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