POSSIBILITY OF RECYCLING WIND TURBINE BLADES USING PLASMA TECHNOLOGY

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ABSTRACT

The energy produced in wind farms is considered as mostly clean and environmentally friendly. However, a more detailed analysis of the process shows that this notion is not fully conclusive. Problems start already in the early stages of the manufacturing phase of wind turbines and become even more pronounced when they are disposed of at the end of their life-cycle. A review of the worldwide scientific and technical literature on the recycling of wind turbine blades has shown that there are currently no viable treatment methods for this waste. Global science and practice focus on traditional incineration and flame treatment technologies, with fragment mentions of alternative methods. However, traditional incineration and thermal treatments have serious disadvantages, making them almost impossible to obtain a final product suitable for further application. Most importantly, however, the thermal treatment process is not environmentally friendly due to the organic binders in the blades. Plasma treatment could be the alternative technology that can be used for the effective decomposition of all organic and inorganic materials and impurities in wind turbine blades that do not produce secondary waste. The treatment takes place without any special preparation of the raw material, except mechanical comminution. The energy released during the process can be used for the plant's own needs, as well as for municipal needs. Despite the complexity of the method, plasma facilities also have more advantages. In this work, the possibility of using plasma technology for the utilization of used wind turbine blades was investigated. Low-temperature plasma jet was used to recycle blade composites into gas and fiber melt.

Keywords: plasma processing, wind turbine blades, waste, composite materials, recycling.

1 INTRODUCTION

According to the Global Wind Energy Council (GWEC), the global installed wind power capacity rises every year, and it was 93.6 GW in 2022 [1]. The wind as an energy source helps to reduce greenhouse gas emissions, but because of the extreme loads, the average life of a wind turbine is about 20 years. The large number of wind turbines installed in Europe and other world countries at the end of the 20th century is near the end of their service and used wind turbine blades will have to be liquidated in the next few years: it will be the dismantling or modernization of the first wind farms. One of the challenges in wind energy management is to find a solution to recycle disposed wind turbine blades.

2 END-OF-LIFE MANAGEMENT OF WIND TURBINE BLADES

The research of University of Cambridge scientists estimates that there will be 43 million tons of retired wind turbine blades waste on our planet by 2050 [2]. At the present time, they're likely to pile up in landfills. WindEurope has called on the European Commission to ban the use of landfills for blades by 2025 (four European countries: Germany, Austria, The Netherlands and Finland, have banned it already) with a reason to help accelerate the development of sustainable recycling technologies.

A typical three-blade wind turbine consists of a tower, a nacelle, and three rotor blades. The tower provides structural support and is made of tubular steel and concrete. The nacelle contains steel and copper predominantly. Wind blades are attached to the rotor and nacelle

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and are made from composite materials. While up to 90% of wind turbine components can now be recycled and reused (i.e. concrete and metal parts), the problem remains the blades, which are made of non-metallic components that are not easily recyclable. Wind turbine blades are made of a composite of glass or carbon fiber and various polymers. This combination of fibers and polymers, also known as glass- or carbon-fibre-reinforced polymer composites, accounts for the majority of the blade material (60–70% fiber and 30–40% resin by weight) [3].

The development of the recycling method for commonly used blade materials started at global cement producer LafargeHolcim company (now Holcim Group) already in 2005. After shredding the blade, finely grained crushed blade dust material was added to the especially prepared fuel mix to bind it together. Keeping a kiln temperature around 900°C the resin burns, transforming the blade material into ashes, which was used as a filler in composite in the cement industry [4]. It helped significantly (by 27%) reduce the CO_2 output of the cement manufacturing process [5].

Nowadays, there are a few possible ways for dismantled wind turbine blades processing: landfill, incineration, or recycling. The leading recycling technologies which could be used in the waste management of wind turbine blades are mentioned in Fig. 1. When selecting landfill disposal, no material recovery is possible. The blades are sectioned into smaller pieces and placed in a landfill. This option is no way out. World countries aim strategy to reduce the quantity of waste going into landfills.

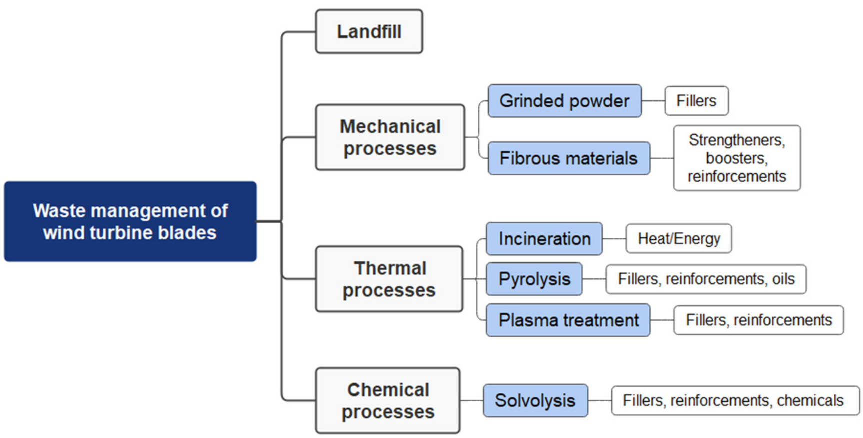

Figure 1: Recycling methods of wind turbine blades.

The development of alternative solutions and the creation of a recycling market are started already, either with an extended ban or with a sharp price increase for the landfill of the blades. The recycling technologies like mechanical shredding, chemical solvolysis (chemical reaction of solvent and solute that results in the formation of new compounds), and thermal decomposition are already being developed and improved.

When wind blades are recycled after the end of the work cycle by mechanical methods, they are only shredded and sorted. At the end of the process, the obtained milled mixture of composite pieces and powder is suitable for further application. However, due to their physical properties and chemical composition, the practical application of such wastes is limited [5], [6]. During mechanical blade treatment processes, a size reduction and separation into powder and fibrous fractions via cutting, crushing, shredding, grinding, or milling tools. Fine pieces are sieved out and used as fillers or reinforcements in building materials (cement, concrete) or as fuel for thermal waste processes. Theoretically, it has a wide range of potential applications for material recovery, but in addition, concrete made using shredded blades instead of crushed stones has unsatisfactory mechanical properties (lower stiffness and strength). The only solution is transforming fiberglass composites into small pellets, called EcoPoly (manufacturer Global Fibreglass Solutions). The pellets can be used as injectable plastics or highly waterproof panels that can be used in construction.

During the incineration (thermal process), the parts of the blades are incinerated at high temperatures – usually over 800°C. Organic substances are combusted and converted into ash and heat energy. This process is generally combined with energy production and heat recovery. The ash could be used as a recovering material as input for cement production or landfilled. The blades have high ash content, and burning composites create residues that can cause problems in the gas filtering systems. So, economically this treatment solution is not attractive.

During the pyrolysis (thermal process) method, the blades are cut into suitable pieces and decomposed using heating ovens in an inert atmosphere (450–700°C). Material is recovered in the form of fibers, which can be reused in other industries, such as glues, paints and concrete. Simultaneously, synthetic gas, which can later be combusted for electricity and heat recovery, and char products are gained during this process. The resin matrix can be transformed into pyrolysis oil. The disadvantage of this technology is that a significant amount of energy is needed to activate the pyrolysis process.

During solvolysis (chemical process), chemical solvents (usually water, alcohol, acid) are used to break the resin matrix bonds at elevated temperatures (300–650°C) and pressure conditions. After the treatment, fiber materials recovered have similar strength and could be reused in other applications, and the resins can be used for energy recovery. Regrettably, this technology focuses mainly on carbon fibers composites [7], [8].

All the technologies mentioned above allow to decompose wind turbine blades, but the final product is contaminated with impurities. Although these impurities could be easily removed, the possibilities for reusing the remaining fiber as an insulating material or producing other composites are limited. The main reason is that the glass crystallization process starts when exposed to temperatures higher than 500°C and fiberglass loses some of its physical and mechanical properties.

In this work, the possibility of using plasma technology to utilize used wind turbine blades was investigated. Low-temperature plasma jet was used to recycle blade composite into gas and fiber melt. This is a relatively expensive process, but it allows the complete decomposition of organic and inorganic substances present in the blades to a level that does not contain any toxic or other environmentally hazardous substances or compounds. A high density and non-equilibrium plasma jet was generated using 100 kW plasma torch. The glass melt formed during wind blade waste processing was leaching into new fibre employing a plasma-chemical reactor using the dynamic energy of the plasma jet. The whole process runs at atmospheric pressure and is friendly to the environment.

3 PLASMA WASTE TREATMENT TECHNOLOGY

The plasma waste treatment process can be a new alternative method for the recycling of wind turbine blades. It is related to intensive heat transfer between high-temperature plasma flow, dispersive heating particles and the environment. The experiments on fiber and granules production from different materials (sand, glass, zeolite, basalt, aluminum oxide, etc.) as well as the blades of dismantled wind turbine blades were performed by a direct current plasma-chemical reactor (Fig. 2) specially constructed for fiberization of raw ceramic and composite materials at Lithuanian Energy Institute [9].

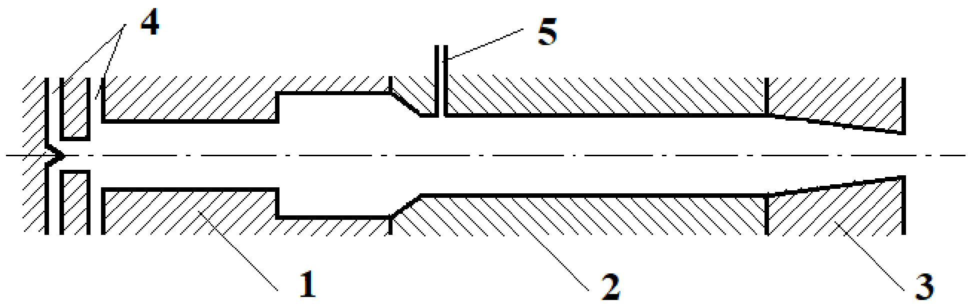

Figure 2: Experimental set-up of cylindrical plasma chemical reactor. 1 = Plasma torch; 2 = Reactor section; 3 = Outlet section; 4 = Working air feeding; 5 = Waste material feeding.

The electric arc ignited in the plasma torch heats up and ionizes the gas flow flowing through the reactor. When the powder of raw material is injected into the plasma flow, part of its energy is used to heat up the particles and melt them. The liquid melt mass flows along the plasma flow direction until it reaches the outlet of the reactor. As the final products, fibers and droplets are formed from the melt by the high-speed gas flow before they are cooled and solidified. The principal scheme of the waste recycling process by the plasma-chemical reactor is presented in Fig. 3.

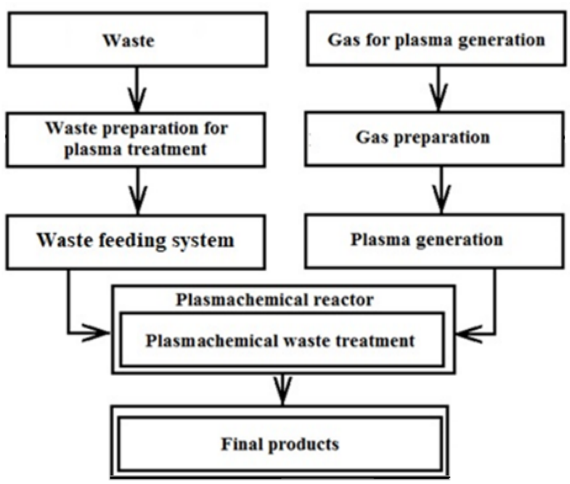

Figure 3: Scheme of blades waste treatment by the plasma torch.

Plasma torch, generating non-equilibrium plasma jet at atmospheric pressure, and supplying equipment necessary for high temperature jet generation are described in detail in

[9], [10]. The main operational parameters of the plasma torch used for experiments are: power supply (P) 70–120 kW, arc current (I) 150–300 A, arc voltage (U) 250–400 V, total airflow rate (G) 15–30 $g \cdot s^{-1}$, the average outlet temperature (T) 2500–3500 K, the average outlet velocity (v) 650–1250 $m \cdot s^{-1}$. The plasma chemical reactor was built of several separate sections 0.015 m in diameter from stainless steel with a length of 0.25 m (Fig. 2). The last section's exit diameter was 0.013 m. This allows to increase the outflow jet velocity and results in better melting process. All sections, as well as the plasma torch, were cooled with water. The wind turbine blades were shredded and milled down to 0.25 mm in size. Injected into the reactor, this powder was melted and fiberized in a reaction chamber connected to a plasma torch. The clogging at the outlet section during the recycling process was avoided regarding the high fluidity of the melt. Part of the melt was fiberized – pure and thin fiber was obtained (Fig. 4(a) and (b)). Part of the melt was also carried in the form of vitreous slag (Fig. 4(c) and (d)).

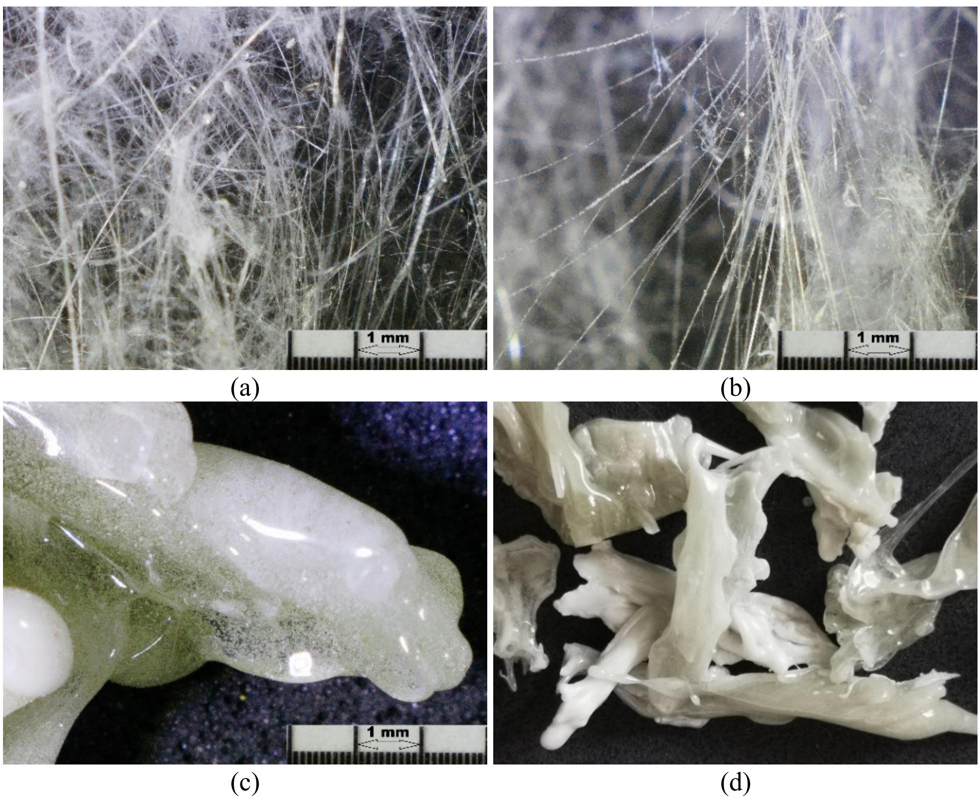

Figure 4: The morphology of fiber (a) and (b) and glassy slag (c) and (d), obtained from recycled wind turbine blades by plasma technology.

The plasma spray technology enables to join the processes of raw material melting, melt homogenization and formation of required material (fiber, nano-, micro-sized particles, or spherical ceramic granules) in a very short duration (0.1–0.5 ms) [10]. Produced fiber can be used as an insulation wool, a filter for ultrafine particles, or a concrete additive for strengthening building materials.

4 CONCLUSION

The global installed wind power capacity rises every year. The current and typical wind turbine blade life-cycle is about 20 years of service, and the waste stream after this time is dominated by the end-of-life blades, which becomes an urgent problem. The main ways of disposal are landfill, incineration or recycling. Currently, disposed wind turbine blades recycling and reuse technologies are limited, and most of them are still in the laboratory stage. A new plasma treatment method for recycling this type of waste is provided. Plasma spray technology demonstrates the ability to recycle wind turbine blades and gain products (fiber, vitreous slag) suitable for environmental, construction and insulating applications. The final products (fiber, vitreous slag) do not contain any additives or impurities. The process was realized by employing a specific plasma-chemical facility with a stream reactor and a linear DC plasma torch with up to 100 kW of power. The steady operating regime of the equipment is reached immediately after the start of the plasma torch. It was demonstrated that the final product's structure depends on the high viscosity of melted mass.

The results showed that plasma technology is an excellent tool for processing of wind turbine blades and allows to be optimistic for further tasks.

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REFERENCES

[1] The Global Wind Energy Council, Global Wind Report 2022. https://gwec.net/global-wind-report-2022. Accessed on: 12 Apr. 2022.

[2] Liu, P. & Barlow, C., Wind turbine blade waste in 2050. *Waste Management*, **62**, pp. 229–240, 2017.

[3] Mishnaevsky, L., Branner, K., Petersen, H.N., Beauson, J., McGugan, M. & Sørensen, B.F., Materials for wind turbine blades: An overview. *Materials*, **10**, p. 1285, 2017.

[4] Miceli, F., Circular economy: Use of wind turbine blades as combustible and mix material for cement production. Windfarmbop. https://www.windfarmbop.com. Accessed on: 12 Apr. 2022.

[5] Pickering, S.J., Recycling technologies for thermoset composite materials: Current status. *Composites Part A: Applied Science and Manufacturing*, **37**(8), pp. 1206–1215, 2006.

[6] Pławecka, K., Przybyła, J., Korniejenko, K., Lin, W.-T., Cheng, A. & Łach, M., Recycling of mechanically ground wind turbine blades as filler in geopolymer composite. *Materials*, **14**, p. 6539, 2021.

[7] Mattsson, C., André, A., Juntikka, M., Tränkle, T. & Sott, R., Chemical recycling of end-of-life wind turbine blades by solvolysis/HTL. *IOP Conference Series: Materials Science and Engineering. Proceedings of the 41st Riso International Symposium on Materials Science: Materials and Design for Next Generation Wind Turbine Blades*, Roskilde, Denmark, 7–10 Sep. 2020.

[8] Piñero-Hernanz, R., García-Serna, J., Dodds, C., Hyde, J., Poliakoff, M., Cocero, M.J., Kingman, S., Pickering, S. & Lester, E., Chemical recycling of carbon fibre composites using alcohols under subcritical and supercritical conditions. *J. Supercrit. Fluids*, **46**, pp. 83–92, 2008.
[9] Milieška, M., Kėželis, R., Valinčius, V., Grigaitienė, V. & Valatkevičius, P., Effect of outlet nozzle design on the morphology and microstructure of micro-and nanostructure fibre formed by means of plasma technology. *Radiation Interaction with Material and its Use in Technologies: 3rd International Conference*, Kaunas, Lithuania, 20–23 Sep. 2010. Kaunas: Technologija, pp. 371–374, 2010.
[10] Valinčius, V., Snapkauskiene, V., Kezelis, R., Valinciute, V. & Mecius, V., Preparation of insulating refractory materials by plasma spray technology. *J. of High. Temp. Mat. Proc.*,**10**, pp. 365–375, 2006.