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CONCEPTS OF REUSING WIND TURBINE BLADES IN CIVIL ENGINEERING CONSTRUCTIONS

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Abstract

Wind turbines have become an important source of renewable energy in recent years, but recycling them is difficult due to their material properties. The paper indicates the possibility of using turbine blades to produce elements that can be filled with concrete and used as members of small geotechnical structures: retaining walls, point and well foundations, foundations for railings, fences, road signs, etc., as well as excavation linings and shoring walls. In these solutions, concrete-filled elements of turbine blades constitute a form (formwork) for concrete, protecting it against environmental influences, and can also cooperate with concrete in transferring loads.

Keywords: wind turbine blades, recycling, upcycling, geotechnical structures, composite structures

1. INTRODUCTION

Wind turbines have become an important source of renewable energy in recent years. The most popular are turbines with a horizontal axis of rotation and three blades ranging from 20 to 80 metres in length. The main issue for users of this energy generation technology is the fact that after 20-25 years of use, the turbines must be dismantled due to wear. Moreover, the disassembly is carried out in order to replace older models with more efficient ones. Forecasts indicate [1] that in 2050, the mass of dismantled turbines will reach 2,000 tons per year. Disassembled turbine blades and columns are deposited in increasingly large landfills (Fig. 1). Turbine blade recycling is difficult due to their material properties. These materials are composites of glass or, less frequently, carbon fibres embedded in a polymer matrix (mainly epoxy resin). Fibres that could be reused are not easily extracted due to the strong covalent connections of the polymer chains. Mechanical decomposition (crushing, grinding) is most often used, and the obtained particles are used as a component of new thermosetting plastics [2] or concrete [3].

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Fig. 1. Wind turbine blades stored in a landfill (photo - Ł. Jabłoński)

Attempts are also made to extract fibres from crushed composite using vibration and aerodynamic separation [4, 5], but also chemical processes (pyrolysis, thermolysis, fluidised bed, solvolysis, hydrolysis, glycolysis and others]) [6, 7, 8, 9, 10] or combined methods (e.g. ultrasonic-assisted pyrolysis [11, 12]). These fibres are used to produce new polymer composites or fibre concrete [13].

A different approach constitutes upcycling, understood as giving wind turbine blades a "second life" by using blade fragments of various sizes as construction elements. Very small longitudinal fragments cut from turbine blades can be used as a kind of dispersed reinforcement in concrete [14, 15]. Fragments with dimensions ranging from several dozen centimetres can be used as panels for the production of furniture [16, 17] or floors. Larger elements constituting entire fragments of turbine blades are used to create urban relaxation infrastructure, e.g. benches [18], playgrounds or climbing walls [17]. In addition, they are also used as small elements of utility infrastructure (e.g. culverts and manholes, barriers and fences, road posts and cones) and agricultural infrastructure elements (e.g. flower pots, barriers separating animals in barns, barriers in grain warehouses, animal feeding troughs). The above applications are compiled in a catalogue prepared by an international team [19].

An undoubted challenge is the use of wind turbine blades to create larger structures; however, there are already known examples of such implementations. A concept of a building with walls and a roof made of fragments of turbine blades was developed [20, 21, 22], a pole for the power transmission of a tri phased electricity line was worked out in detail and tested [23], and bus stop shelters and acoustic screens were constructed [22, 19]. In addition, pedestrian bridges were also built, the structural element of which consisted of entire wind turbine blades [24, 25, 26, 27, 28]. Due to their resistance to corrosion, great hopes are associated with the use of turbine blades in maritime infrastructure - as vertical or horizontal buoys, structural elements of piers, and docks or supporting platforms for photovoltaic panels [19].

This article indicates the possibility of using turbine blades to produce elements that can be filled with concrete and used as members of small geotechnical structures: retaining walls, point and well foundations, foundations for railings, fences, road signs, etc., as well as excavation linings and shoring walls. In these solutions, concrete-filled elements of turbine blades constitute a form (formwork) for concrete, protecting it against environmental influences, and can also cooperate with concrete in transferring loads. Similar hybrid structural elements were created from new tubular composite elements [29, 30, 31, 32, 33], highlighting the positive features of composite tubes, such as corrosion resistance and ductility.

2. STRUCTURAL CHARACTERISTICS OF THE ANALYSED WIND TURBINE BLADES

Wind turbine blades, as mentioned above, are from 20 to even 80 metres long. They have a box cross-section, as shown in Fig. 2. The cross-sectional shape of the blades is determined by aerodynamic requirements, just like the shape of an aircraft airfoil. The function of load bearing is performed by the strengthened central part of the cross-section (‘spar cap’).

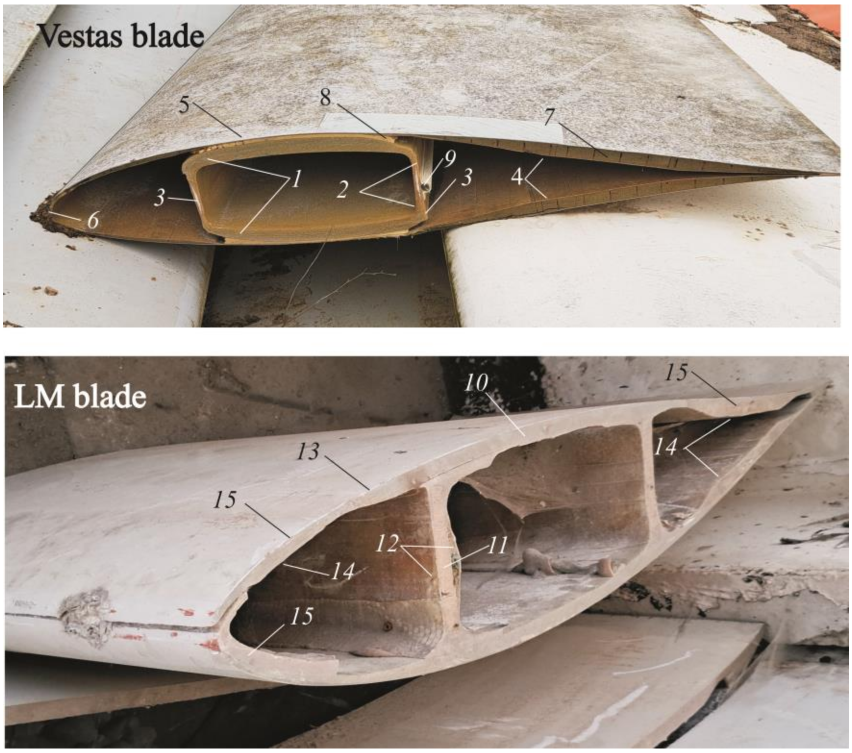

Fig. 2. Structure of wind turbine blades (photo - Ł. Jabłoński): a) Vestas-type blade; b) LM-type blade, 1 - load-bearing beam made of multi-layer composite, 2 - internal and external laminate veneers of the load-bearing beam, 3 – balsa spacer, 4 – internal laminate veneer of the aerodynamic shell, 5 – external laminate veneer of the aerodynamic shell, 6 - composite strengthening the aerodynamic coating, 7 - polyurethane foam filling, 8 - adhesive, 9 - lightning conductor, 10 - load-bearing element made of multi-layer composite, 11 - balsa core of the cross wall, 12 - internal and external laminate veneers of the cross-wall, 13 - balsa external veneer, 14 – inner laminate of the aerodynamic shell, 15 – multi-layer composite strengthening the aerodynamic shell

The material from which the turbine blades are made is a multi-layer composite of glass or, less often, carbon fibres embedded in a polymer matrix, combined with layers of wood and polyurethane foam. The wood is obtained from the outer part of the balsa (Ochroma pyramidale) trunk. This tree is found in the forests of North and Central America and is also cultivated. The feature that determined the use of balsa in aviation and sailing is its lightness (density 40-180 kg/m^3) and high elasticity.

Two types of blade design solutions are used in Europe, shown in Figure 2. Vestas-type blades (Fig. 2a) have a bearing beam (spar cap) in the form of a box made of a multi-layer composite (with the transverse walls having a wooden spacer), the external and internal surfaces of which are covered with laminate. The aerodynamic shell is shaped of internal and external laminate layers with polyurethane foam between them. In LM-type blades (Fig. 2b), the load-bearing part (spar cap) constitutes the thickening of the outer walls of the aerodynamic profile made of a multi-layer composite, fastened with wooden cross walls. The aerodynamic shell is formed by a composite layer finished with balsa wood veneer on the outside and with a laminate on the inside. The surfaces of the cross walls are also covered with laminate.

The cross-section of the blade varies along its length. At the column, it is circular to allow symmetrical mounting on the column, and then changes smoothly to an aerodynamic ‘teardrop’ shape with a rounded leading edge and a ‘sharpened’ runoff edge. The length of the section chord decreases as it moves away from the base column. For example, in a blade approximately 43 m long, reconstructed from a point cloud obtained from a 3D scan [34], the longest chord dimension is 3.70 m, and this reduces to approximately 1.3 m.

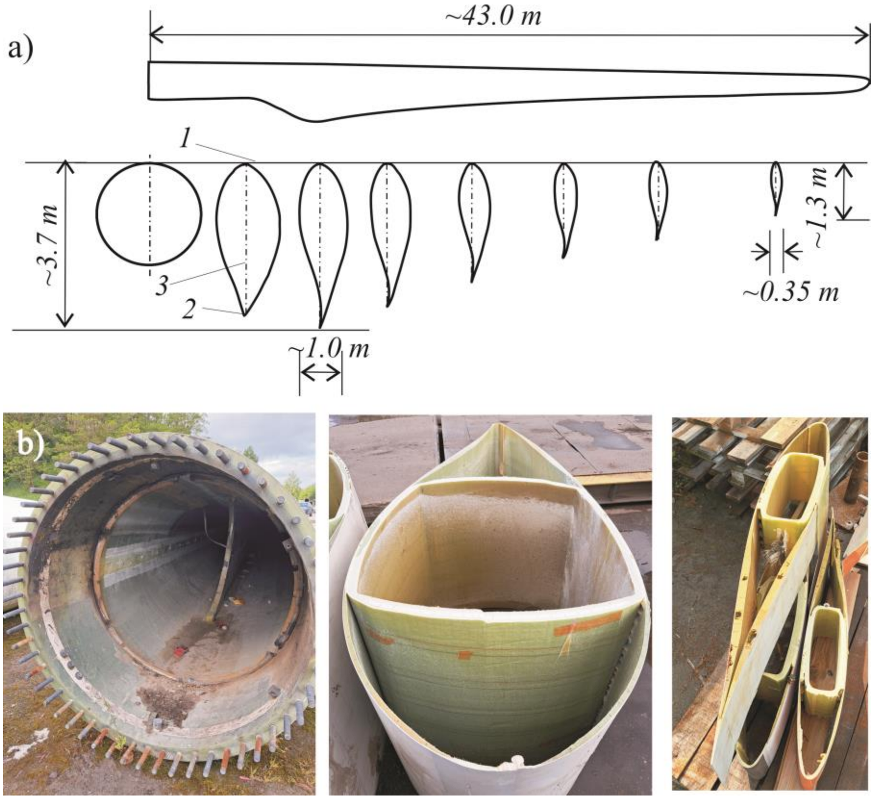

Fig. 3. Cross-sections of wind turbine blades: a) change of cross-section along the blade (figure made on the basis of [34], b) blade cross-sections: circular cross-section near the column, “wide teardrop” transient section, “teardrop” section (photo - Ł. Jabłoński)

3. PROPOSALS FOR THE USE OF WIND TURBINE BLADES TO CREATE STRUCTURAL ELEMENTS IN CIVIL ENGINEERING

Proposals for the use of elements cut from wind turbine blades, when bonded to concrete, as structural elements for specific geotechnical applications are presented below.

As a result of the analysis of the blade materials and geometry, it was found that Vestas-type blades and LM blades may be used for structural applications in construction in different scopes. Considering the Vestas blades, the spar cap may be used as a strong structural element due to its stiff closed box section and high bearing capacity, which is determined by its multi-layered composite material. The structural use of the aerodynamic shell is limited however, because of its composition of polyurethane foam with laminate veneers. Regarding the LM blades, the most useful is the semi-flat multilayered composite central part of the aerodynamic shell; however, all cross-sections that include more composite layers than Vestas-type blades show promise.

However, despite its significant compressive and bending capacity, use of the above listed blades parts is limited with changes of dimensions along the length of the blades. Therefore, the following proposals are limited to relatively short elements (maximum 3.0 m).

3.1 Blade fragments as foundations or parts thereof

Proposal 1: Point foundations

The following uses for the blade elements are proposed:

- Spar cap sections of Vestas-type blades filled with concrete can be used as ‘prefabricated’ point foundations (Fig. 4a) for the support of the foundation beams, e.g. timber houses (Fig. 4b);
- The concrete-filled spar cap sections of the Vestas can be used for the support of foundation slabs when the thickness of the weak soil layer is relatively small, and the execution is possible in an open excavation (Fig. 4c). The possibility of driving into the ground without excavation (driven pile form) will be investigated by the authors in further research.

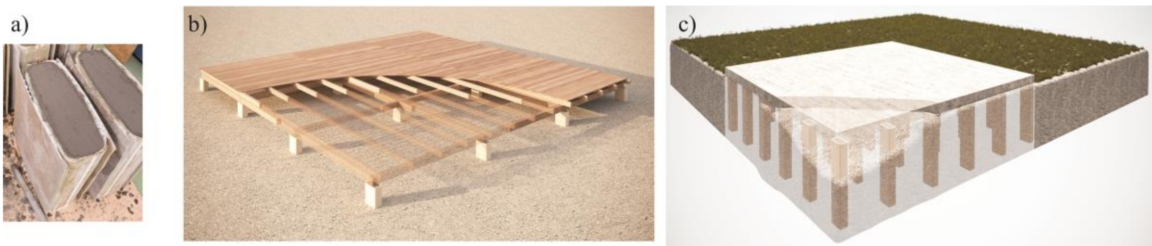

Fig. 4. Proposal 1: Point foundations made of concrete-filled Vestas-type spar caps sections (visualisation - N.Jakubiak, W.Jabłoński): a) ‘prefabricated’ foundation, b) timber house foundation beams supported on point foundations, c) point foundations under a bottom slab

Proposal 2: Foundation wells

The circular sections of blades obtained from the vicinity of the base column can be used as well as foundations for the support of house bottom slabs (Fig. 5). The well compound of one or more sections is sunk by undermining and then filled with concrete. The use is limited to cases where the thickness of the weak soil layer (e.g. peat) is relatively small, and the diameter allows human labour for excavation. The possibility of undermining is conditioned by ‘fitting’ the lower edge of the caved section with a steel knife and applying load onto the upper edge (the weight of the caved section must be greater than the friction of the side against the soil).

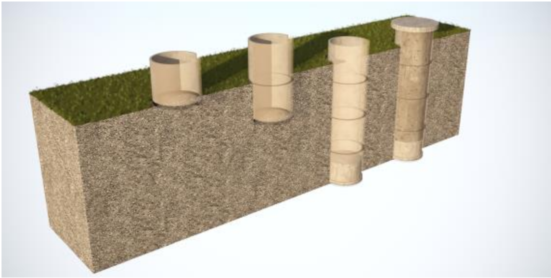

Fig. 5. Proposal 2: Foundation well made of Vestas or LM blade circular sections (visualisation - N.Jakubiak, W.Jabłoński):

Fig. 6. Proposal 3: Foundations for railings and fences made of LM blades (visualisation - N.Jakubiak, W.Jabłoński)

Proposal 3: Foundations for railings, fences, road signs, and photovoltaics

The whole ‘teardrop’ sections of LM-type blades, filled with concrete, can be used as foundations for railings, fences, road signs or photovoltaics (Fig. 6). The height of the blade sections used should be determined by the depth of ground freezing and, in the case of railings, ensuring stability when loaded with a horizontal force of the value specified in the relevant standard. The fence posts or railings are embedded after the ‘formwork’ made of the blade fragments has been laid on the ground, while concreting.

Proposal 4: Foundations for billboards and lamp posts

Circular blade fragments from the vicinity of the base column and transition sections, filled with concrete, can be used as foundations or ballast elements for billboards and lamp posts. The dimensions of the blade sections used should be determined by the stability of the billboard under wind load. Such foundations may be made as ‘prefabricated’, where the steel frame of the billboard or lamp post is attached to concrete with anchors. The second possibility is filling the blade fragments with concrete on site, and embedding the billboard frame or posts at the same time.

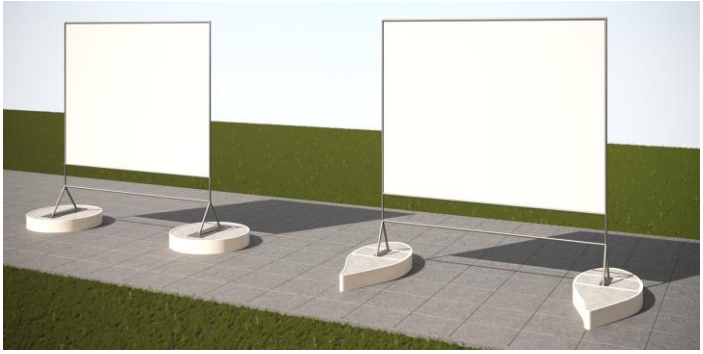

Fig. 7. Proposal 4: Foundations for billboards (visualisation - N.Jakubiak, W.Jabłoński):

Fig. 8. Proposal 5: Low decorative retaining wall made of LM blade sections (visualisation - N.Jakubiak, W.Jabłoński):

3.2 Retaining walls

Proposal 5: Decorative retaining walls

LM-type turbine blade fragments of 'teardrop' cross-sections of 1.0-1.5 m in length and 40-50 cm in height can be used as members of decorative retaining walls. The elements are laid in layers, alternating the runoff ends between the left and right sides (Fig. 8). The central part of cross sections (between cross walls) overlaps in individual layers. This part is filled with concrete, creating the bearing column. It is also reinforced, and reinforcing bars are anchored in the concrete footing. The remaining parts of the blade sections are filled with soil and can serve as plant pots. The height of the wall is limited by stability conditions. The wall should be insulated from the ground and covered with a drainage layer. It is also possible to use the wall as a facing layer for a reinforced soil structure.

Proposal 6: Cantilevered retaining walls, excavation linings and shoring walls

The final proposal is the concept of repurposing wind turbine blade waste for protecting slopes and excavation edges (Fig. 9). Cantilevered retaining walls can be used for temporary and permanent support systems, retaining backfill material along with carrying backfill and earth pressure. These walls can also be used to strengthen the seaboards, which is suitable because a significant number of wind farms are located in coastal and offshore areas.

The concept involves the use of two types of elements. Vertically set spar caps of Vestas-type blades, 3.0-4.0 m in length, filled with concrete, are used as the main structural elements of the walls. Their performance is simulated by the cantilevers, spaced 1.5 – 2.0 m, embedded in earth and loaded with earth pressure. The infill between the vertical elements is made up of horizontal composite planks cut from the aerodynamic shells of LM-type blades, working as the beams supported by the cantilevers. This type of retaining wall may carry the relatively high ground's downcast due to specifity of composite structure (the tensile stress occurred in a cantilever is carried by the composite spar cap, whereas compressive stress by concrete). Detailed solutions are currently being studied by the authors.

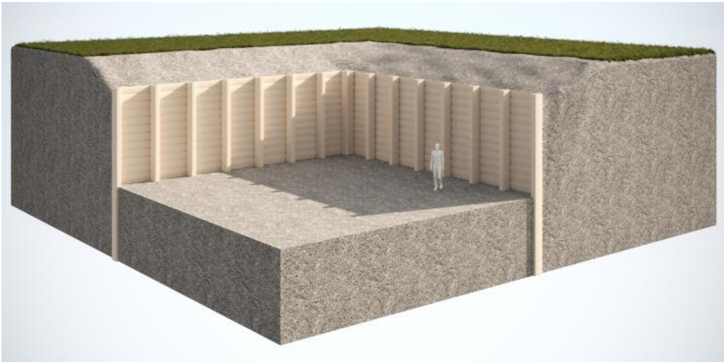

Fig. 9. Proposal 6: Cantilever retaining wall: cantilever beams made of Vestas-type spar caps and plating made of fragments of LM blades (visualisation - N.Jakubiak, W.Jabłoński)

4. CONCLUSIONS

The increasing amount of used wind turbine blades that are difficult to dispose of forces the necessity of research focusing on their recycling and upcycling. The solutions proposed in this article make it possible to take advantage of the positive mechanical characteristics of the blade parts by using them as the elements of civil engineering structures, especially geotechnical ones. The proposed solutions involve utilising the structural potential of upcycled blades, in particular the beam elements obtained from them (additionally filled with concrete), cladding elements (as a type of formwork) and solid profiles with concrete filling. The applications presented in the article are innovative ones. They have been analysed and preliminarily tested in terms of strength, and the structural details are being worked out. The authors hope they have a high application and economic potential.

ADDITIONAL INFORMATION

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