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Techniques for rapid prototyping of scale models of blades for wind turbines

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Abstract. The paper presents techniques for the rapid prototyping of scale models of blades for wind turbines on a 3D printer using the FDM technology for the extrusion of filaments made of ABS polymers (Acrylonitrile Butadiene Styrene) and PLA (PolyLactic Acid). The following rapid prototyping techniques are described: printing by horizontal development across a negative substrate of single-component blades; printing by horizontal development of a two-component blade with longitudinal separation plan, assembled by gluing; printing by vertical development of a blade with 4 or 24 segments assembled by tie rods. Each of the above techniques has a number of advantages and drawbacks with respect to their use. The conditions for the occurrence of printing defects in the structure of these models were also investigated.

Keywords: rapid prototyping, 3D printing, wind blade turbine, polymer.

1. Introduction

The industrial prototype is the best way to verify the usefulness, functionality, reliability or performance of a future product [1].

The prototypes of the scale models of wind blades represent the concrete realization on a smaller scale of future blades as industrial products that will become components for wind power plants [2-4]. The checking of these blade models, with computer optimized profiles and geometries, is possible by testing them in wind tunnels.

For rapid prototyping of different plastic parts, such as scale models of blades for wind turbines, the most common technologies used today are the additive ones,

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polymer 3D printing either by curing [5-8], or by extrusion technology of polymer filaments, known as FDM (Fused Deposition Modelling) [9-12].
The research objectives were geared towards determining the best methods for making larger and larger blades, simpler in terms of construction, preferably single-component ones, with fewest defects and the lowest possible time and material consumption.

2. Equipment and materials used for experiments

Rapid prototyping was carried out on a 3D printer with a layer deposition of polymers (FDM) [13-15]. The 3D printer used was built by a team of researchers from “Dunarea de Jos” University of Galati (Fig. 1). The maximum print volume is 360x360x360 mm^3.
PLA or ABS filaments were used as material for printing, 1.75 mm in diameter. The extrusion temperatures provided by the manufacturers of filaments are 190-210 °C for PLA, and 225-245 °C for ABS.
The print parameters were: the print speed, 40 mm/s, the layer height, 0.2 mm, the fill density, 100% for horizontal developing and 20% for vertical developing and the bed temperature, 70 ºC for PLA and 90 ºC for ABS.

Fig. 1. 3D printer built at “Dunarea de Jos” University of Galati.

3. Techniques used for rapid prototyping of scale models of blades

In order to optimize the prototyping process, printing techniques were studied by horizontal development of the single-component and the two-component prototype and by vertical development of its 4 and 24 segment variant mechanically assembled by tie rods.

3.1. Printing of horizontally developed blades

3D printing by extrusion of polymeric materials is carried out by depositing the polymer layer by layer and the layer in work must cover almost the entire surface of the previous layer [16]. This techniques has, among others, the disadvantage that it does not allow the development of side surfaces with an inclination towards the outside of the volume greater than 45º to the normal to the surface of the deposited layer [17]. Since the blades of the wind turbines have curved side surfaces and cannot be set optimally on the horizontal of the surface of the development table, printing by horizontal development can be achieved in two ways: printing a single-component blade by horizontal development across a negative substrate, or printing by horizontal development of a two- component blade.

Printing a single-component blade by horizontal development across egative substrate

The procedure for the shaping of the substrate over which a single-component blade develops starts from the 3D model of the blade, created on a CAD platform. The substrate is created from a parallelepiped having the same length and width as the blade, and the thickness will be determined by the level of the maximum section of the blade. For models used for research purposes, the thickness of the substrate will be half the diameter of the blade root fixed in the hub of the wind turbine. The model of the blade is placed over the parallelepiped and the solid of the blade is cut off the solid of the parallelepiped by a SUBTRACT operation. This results in the uncut substrate comprising a surface which is the negative of the blade in Fig. 2.

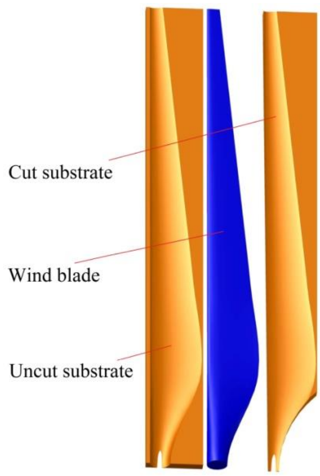

Fig. 2. Modelling of the blade and the substrate.

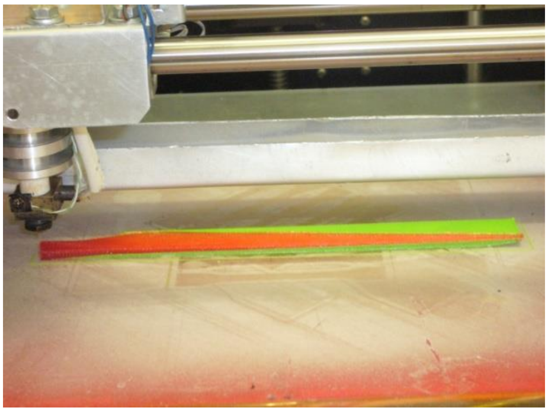

Fig. 3. Single-component blade horizontally developed.

As the development of the blade begins from the base of the substrate, conflict areas may occur during printing between the extrusion nozzle cone and the bottom wall of the substrate. For this reason, it is necessary to cut the substrate as shown in Fig. 2.
Fig. 3 presents the image during the rapid prototyping process of a horizontally developed blade.

Printing a two-component blade by horizontal development

The modelling of the two components of the blade is carried out in the CAD application by cutting the blade using a SLICE operation along a longitudinal cutting plane positioned on the level where the surface of the blade section is maximum.
After cutting, the two resulting solids are placed side by side (one of them needs to be rotated 180° about the Y-axis), as shown in Fig. 4.
If desired, the G code can be generated for simultaneous printing of both half-blades, as shown in Fig. 5. After printing of the two half-blades, they are assembled by gluing them in their plane of separation.

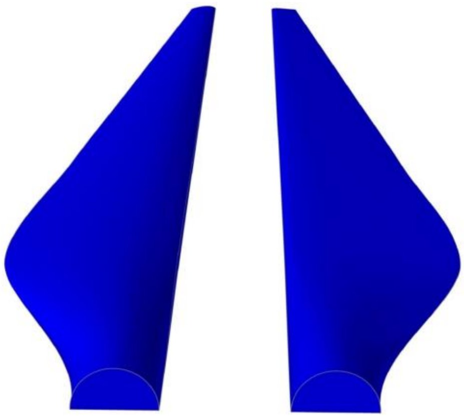

Fig. 4. Modelling of the blade for horizontal development with separation plan.

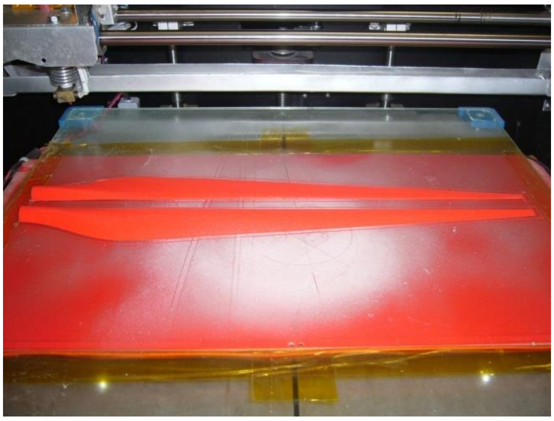

Fig. 5. Simultaneous modelling of the half-blades developed horizontally.

3.2. Printing of vertically developed blades

Because the blades of the wind turbine are slender structures, they have very low stiffness [18]. On the other hand, during the printing process, tangential forces T are generated parallel to the printing planes (Fig. 6) which are caused by the friction between the extrusion nozzle and the surface in work of the prototype. Due to this phenomenon, instead of relative motion of the extrusion nozzle to the working surface of the layer, there is a motion of the surface of the layer in work with the extrusion nozzle. Under these circumstances, the added polymer material will be deposited in the same place causing print defects to occur.

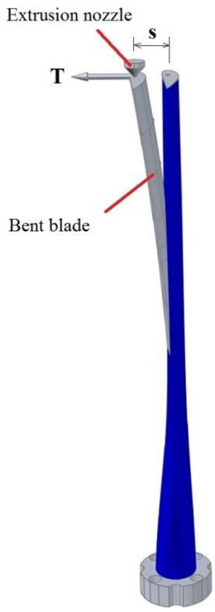

Fig. 6. Bending of slender component during 3D printing.

For the reasons stated above, vertical printing of the blades in one piece is not recommended; it is preferable that they be divided into segments and, after printing, blade segments be mechanically assembled by means of tie rods.
This technique can be applied either by dividing the blade in a small number of (4 ÷ 8) segments or by dividing the blade in a large number (16 ÷ 40) of segments. For each case, different CAD modelling techniques apply.

Printing a 4-segment blade by vertical development

Printing by vertical development of a blade with 4 segments also requires printing slender structures, but more rigid than one-piece blades.
When modelling segments, one must keep in mind that these structures can overturn during printing due to their detachment off the development table; also, they can bend in the normal direction to the face/back surface of the blade segment. The overturning of the blade segment during printing can be prevented by addition of a substrate to the base of the structure, which improves the adherence to the development table. The bending of the segments during printing can be prevented by addition of grates to the structure, as shown in Fig. 7, which significantly increases the rigidity of the blade segments during printing.

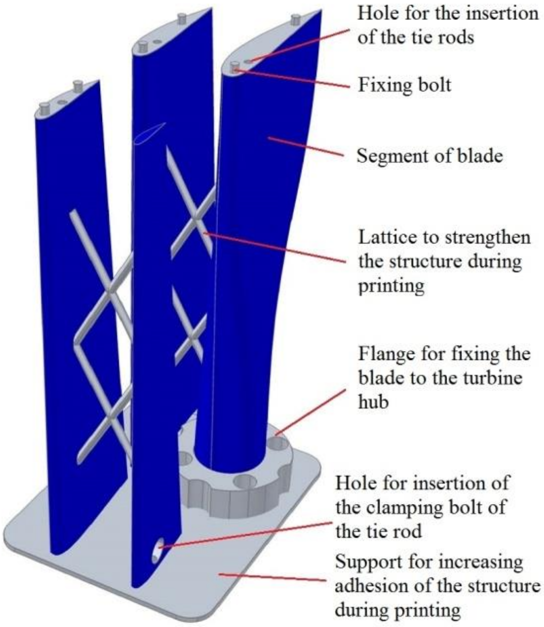

Fig. 7. Modelling of the 4-segment blade by vertical development.

During the CAD modelling of the blade segments, the holes for the insertion of the tie rods, of the fastening bolt of the tie rods and of the plugs will be created. Also, the plugs/bolts for fastening and rigidization of the segments in the whole structure of the blade will be added. After printing, it is necessary to remove the grates from the blade segments surface.

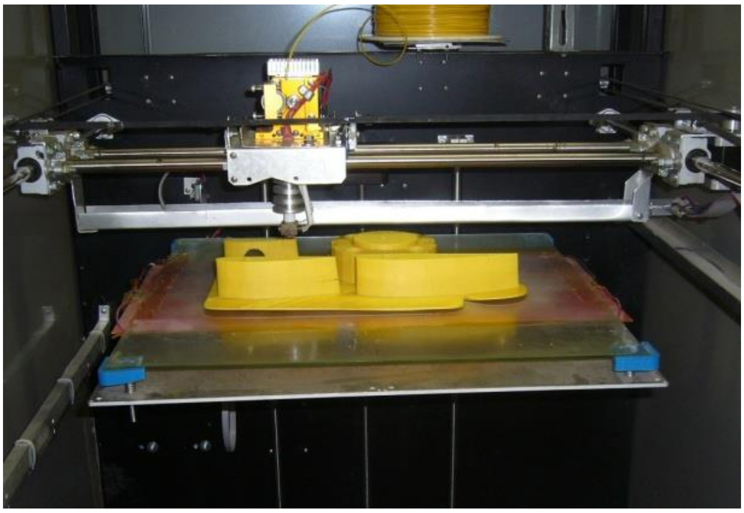

Fig. 8. Printing of 4-segment blade vertically developed.

Printing a 24-segment blade by vertical development

CAD modelling for printing by vertical development of a 24-segment blade is simpler because it does not require props which are then removed. It is necessary that after the segmentation of the blade into the 24 segments, as shown in Fig. 9, the fastening plugs be added and the corresponding holes be made in the structure of the segments for tie rods, bolts and plugs.

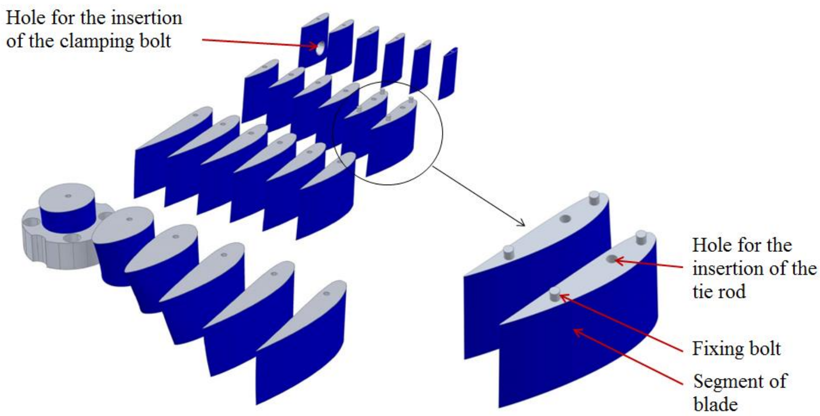

Fig. 9. 24-segment blade developed vertically.

3.3. Results of blade printing using the two techniques

Using the horizontal development technique, PLA mono-component blades, 180 mm each, and PLA and ABS bi-component blades, 360 mm each, could be, as shown in Fig. 10.
Using the vertical development technique, 4-segment blades (Fig. 11) and 24-segment blades (Fig. 12) with a total length of 1440 mm were printed. In the case of 24-segment blade, each segment could be printed separately and no significant defects in their structure were found.

Fig. 10. Wind Blades – horizontal development.

Fig. 11. 4-segment blade.

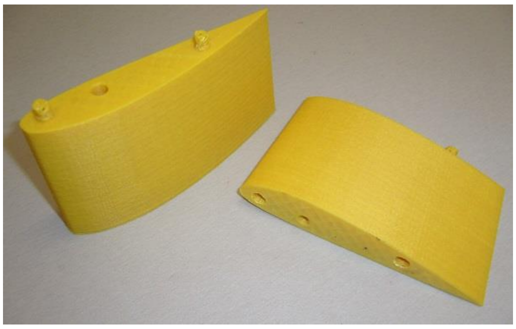

Fig. 12. 24-segment blade.

4. Conclusions

(I) There is still no blade printing technique showing only advantages and simultaneously achieve all initial objectives.
(II) The most advantageous method for rapid prototyping of blades is the one in which they are developed vertically and have more than 16 segments.
(III) The method showing most disadvantages for rapid blade prototyping is the one by which the blades are made up of four segments vertically developed, as it results in excessive consumption of material and time. Even more than that, this printing method resulted in most defects in the form of cracks caused by delamination of the layers. Delamination occurs because of the shearing between the layers caused by the thermal contraction of the material due to the high temperature gradient during printing by vertical development.

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