DESIGN, DEVELOPMENT AND TESTING OF MODEL WIND TURBINE BLADES USING ADDITIVE MANUFACTURING PROCESS

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Abstract— The increase in global demand for energy and environmental concerns has made a shift to renewable energy sources. Wind turbines blades are usually made up of composite material. The latest trend of designing and manufacturing of blade are through designing software and Additive Manufacturing Technique. Blade design softwares like QBLADE have given the opportunities to enhance the design capabilities and development of more efficient blades that can also reduce cost and time considerably. Enhancement of structural properties at the root sections using wortman's series airfoils is the primary objective. FX84-W175 section is inculcated in root section and NACA4412 for rest of the blade length. Two blade specimens of different t/c ratio are manufactured using ABS plastic by FDM 3D printing technology. The two point bending tests on UTM indicated a failure load of 6KN for the t/c 17.5% specimen and 6.5KN for the t/c 20% specimen. The same failure loads are used in the simulation. The maximum bending stress induced are 64.95MPa and 70.42MPa for t/c 17.5% and t/c 20% respectively. The feasibility of using 3D printed blades in roof-top power generation units seems to be reality in near future.

Index Terms—QBLADE,ABS plastic, FDM, 3D printing,

I. INTRODUCTION

Renewable energy is the term used to cover those energy flows that occur naturally and repeatedly in the environment and can be harnessed for human benefit human benefit. The time of cheap oil and gas is over. Mankind can survive without globalization, financial crises and flights to the moon or Mars but not without adequate and affordable energy availability. Renewable energy offers our planet a chance to reduce carbon emissions, clean the air, and put our civilization on a more sustainable footing. Renewable sources of energy are an essential part of an overall strategy of sustainable development. Renewable energies will provide a more diversified, balanced, and stable pool of energy sources. Renewable energy sources derive their energy from existing flows of energy from ongoing natural processes, such as sunshine, wind, flowing water, biological processes, and geothermal heat flows. The most promising alternative energy sources include wind power, solar power, and hydroelectric power. The need for power generation from renewable energy sources has been increasing over the years with faster rate of depletion in fossil fuel and crude oils. Solar energy, wind energy and hydro energy has been the area under current focus in research. Current trend is dominated by wind energy as a result there is an increase in the number of turbines installation and as well as the increasing diameter of turbine rotors with the corresponding energy output per turbine. The performance of the model turbines fabricated using the AM technique has been noticeably better than that of models produced by hand, the previous method. Introducing the AM method has also given an extra educational dimension to this design-build-test project. Utilizing fused-deposition modeling (FDM) additive- manufacturing (AM) technology, it is possible to produce the turbine blades by additive manufacturing, which has provided an opportunity to greatly improve the accuracy and finish of the model airfoils that can be produced, as well as ensuring geometric repeatability of blades on the same hub. It also allows to produce concave surfaces on the underside of their blades, which was almost impossible when producing the blades by hand methods. This work gives introduction to testing and measurement methods, as well as to the advantages and limitations of the particular AM technology used.

II. LITERATURE REVIEW

Martin Widden, et. al[1],worked on design, development and testing of a scale-model wind turbine. Authors used fused-deposition modelling (FDM) additive manufacturing (AM) technology to produce turbine blades. AM technique gave freedom to design blades according to their desired parameters which was difficult to achieve by hand method. The work exposes testing and measurement methods, advantages and limitations of AM technology. The model was tested at different torque magnitudes and varying of air speeds. Dimensionless performances curves of power coefficient against blade-tip-speed ratio were plotted. The performance of a full-size rotor with similar geometry could be predicted with the above curves. **A Mun˜oz, et.al [2],** investigated and demonstrated innovative designs for offshore wind turbines. From the structural point of view, the root is the region in charge of transmitting all the loads of the blade to the hub. Therefore it is very important to include airfoils with adequate structural properties in this region. At the root, airfoils used were of high-thickness and blunt trailing edge to improve the structural characteristics of the blade. The airfoil profiles which can be used as the root the G¨ottingen (GOE), Wortmann (FX), Delft University (DU) and ¨ NREL-SANDIA (FB) airfoils. Out of these the Delft University and the Wortmann airfoils were chosen due to their fitness to the objectives and to the technical specification. DU airfoils are relatively thick but they keep the trailing edge gap below 2% and the FX family exhibits quite large trailing edge. From the DU series of airfoils DU 95-W-180 and from the FX series FX84-W-175 were chosen for comparing. **Richard E. Stamper and Don L. Dekker [3**], discussed the use of rapid prototyping. The FDM process uses a layer-wise building process to create the part. The FDM rapid prototyping process was used for design methodology concept of parametric design. An airfoil with a Clark Y cross section was constructed from the ABS. A wing from ABS (Acylonitrile Butadiene Styrene) material in order to compare it with an aluminum one of the same cross-section. The rough wing didn't correspond very well to the aluminum wing but after the ABS wing was smoothed, the lift and drag curves approached the curves obtained from the aluminum wing. Further tensile and torsion test were performed on the modeled specimens. **Peter J. Schubel and Richard J. Crossley [4],** reviewed wind turbine blade design, theoretical maximum efficiency, propulsion, practical efficiency and blade loads. A complete picture of wind turbine blade design and the modern horizontal axis rotors was demonstrated. The aerodynamic design principles blade plan shape, aerofoil selection and optimum angle of attack were included in the review. The study also described aerodynamic, gravitational, centrifugal, gyroscopic and operational conditions. Both Horizontal Axis Wind turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) were tested for above given parameters. It was concluded that HAWT dominated design configuration and manufacture in large scale. Study also compared performance of slender airfoils with thicker airfoils. **N.Manikandan, B.Stalin,[5],** worked with the objective to increase reliability of wind turbine blades through airfoil structure and to reduce the noise level of the wind turbine during its running period. Pro/E, Hypermesh software was used to design blades. NACA 63-215 airfoil profile was considered for the analysis. The wind turbine blade was modeled and several sections were created from root to tip for improving the efficiency. The efficiency was to be increased and reduce the noise produced from the blades in working condition by introducing winglet at the tip of the blade. The conventional blades and modified blades with winglet were compared for results. The aerodynamic performance was made using computational techniques and the computations were predicted using clean and soiled surface. Generic model was developed for different shapes and sizes with associated parameters and was used in the pre-design stage of winglets, where spending more time in the design process was minimized. All the winglets developed were designed according to the design criteria provided by the respective research papers and so there were no need for designing a specific type of winglet from the base, when this model was used. **F.W Perkins and D.E Cromack[6],** worked on blade stress analysis, design, aerodynamic, natural frequency and cost. The main problems encountered were aerodynamic performance, structural integrity and cost. The problems of the aerodynamic and structural integrity were studied by NASTRAN programming. The characteristics were computed using programs, the overall cost of the design was reduced as repetitive codes were used. The Rayleigh Ritz method was used for the solution of the natural frequencies. The object of the study was the development of computer programs useful to the wind turbine designer. Codes were developed which allowed the resolution of bending stress and natural frequencies of wind turbine blades. Good agreement between the predicted and observed flexural deflections was showed along with natural frequencies. The strong evidence for the application of Rayleigh's method to the problem of free beam vibration, allowing coupling between deflections in two directions, was valid.

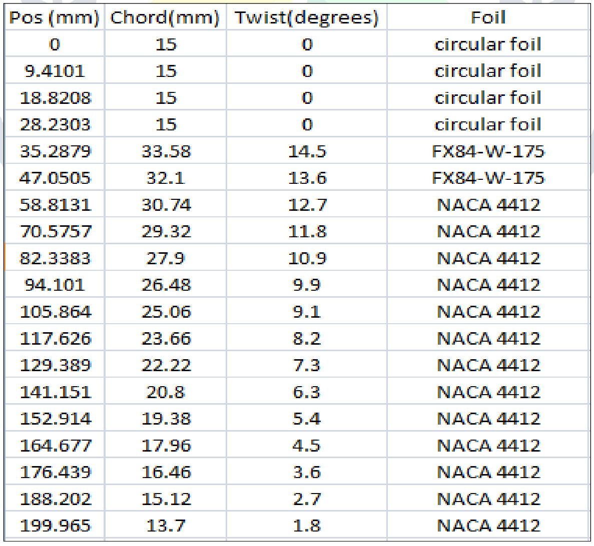
III. BLADE DESIGN AND MANUFACTURING

This work investigates the flexural stress withstanding capability of model ABS plastic wind mill blades manufactured using FDM 3D printing technology. FX-84-W175 airfoil section was inculcated in two consecutive root sections of the blade to enhance the structural properties (cross sectional area and second moment of area). NACA 4412 airfoil section is used for the remaining sections along the length.

Blade design

From the literature [2] two airfoil sections were selected.FX-84-W175 at the root section for structural strength and NACA4412 for remaining span of the blade for aerodynamic performance. For the model blade length of 200 mm the optimum chord length, twist distribution, and location of each section along the length is determined by using Wind Blade Calculator software (using Betz's limit). The calculated values were input into QBLADE open source software to generate the 3D model of the blade and saved in .STL format. There are two blade specimens with slight variation in thickness to chord ratio.

Table 1: Span wise location of sections, chord length, twist distribution



Pos (mm)	Chord(mm)	Twist(degrees)	Foil
0	15	0	circular foil
9.4101	15	0	circular foil
18.8208	15	0	circular foil
28.2303	15	0	circular foil
35.2879	33.58	14.5	FX84-W-175
47.0505	32.1	13.6	FX84-W-175
58.8131	30.74	12.7	NACA 4412
70.5757	29.32	11.8	NACA 4412
82.3383	27.9	10.9	NACA 4412
94.101	26.48	9.9	NACA 4412
105.864	25.06	9.1	NACA 4412
117.626	23.66	8.2	NACA 4412
129.389	22.22	7.3	NACA 4412
141.151	20.8	6.3	NACA 4412
152.914	19.38	5.4	NACA 4412
164.677	17.96	4.5	NACA 4412
176.439	16.46	3.6	NACA 4412
188.202	15.12	2.7	NACA 4412
199.965	13.7	1.8	NACA 4412

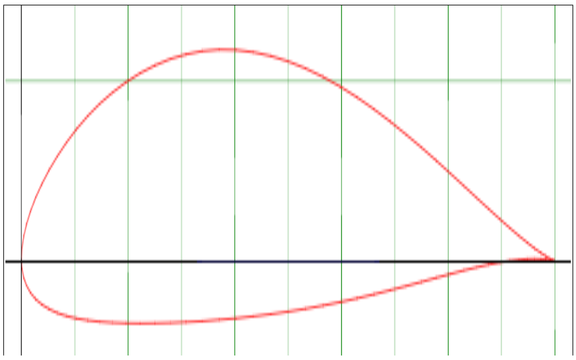


Fig 1: FX-84-W175 airfoil section

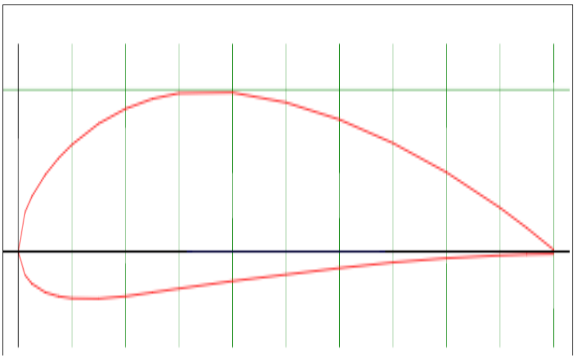


Fig 2: NACA4412 airfoil section

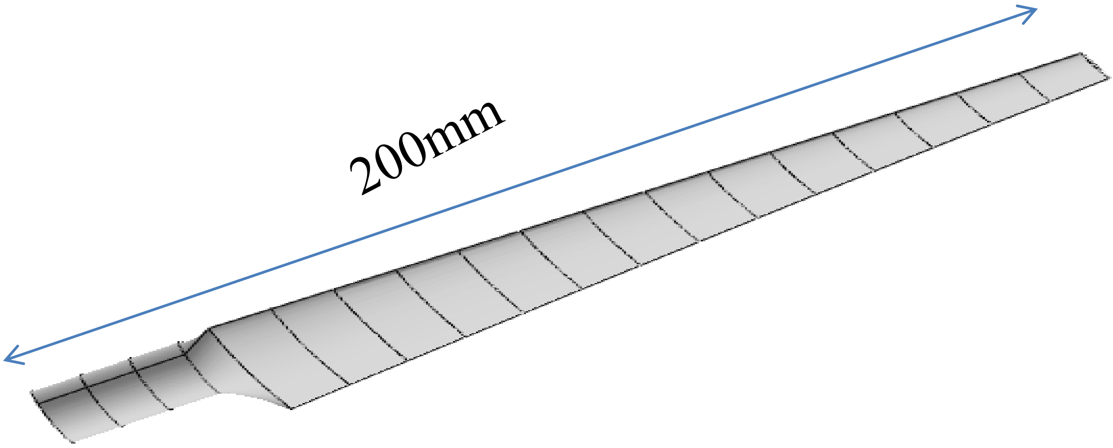


Fig 3:Wind turbine Blade t/c=17.5%,

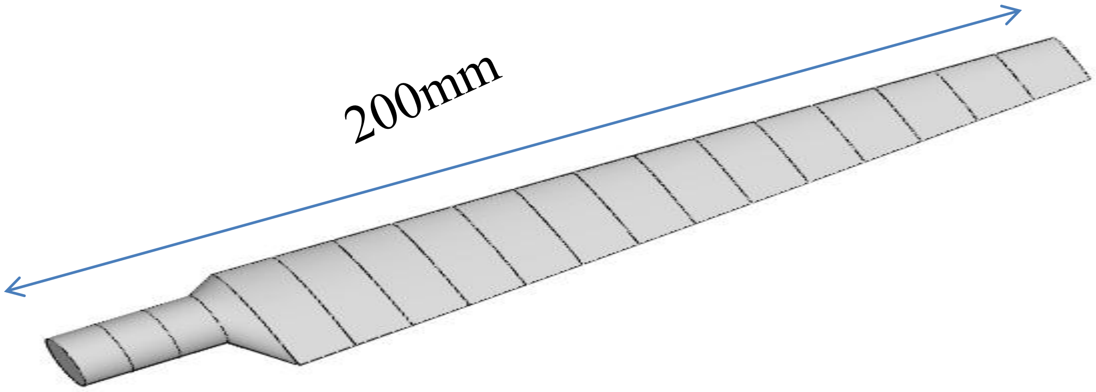


Fig 4:Wind turbine Blade t/c=20%

Blade manufacturing by 3D printing process

The blades were manufactured using ABS plastic by 3D printing with the help of fused deposition modeling process. The blades were imported into computer in .STL format. The computer divides the model into number of layers. Each layer is of 0.1778 mm. The tool path was generated to manufacture the blade. Since the minimum thickness required for 3D printing was 1mm, the trailing edge of the blade was altered to blunt shape by 0.01% of chord length. The printing time was 3 hours and 16 minutes.

Fig 5:Wind turbine Blade t/c=17.5%,

Fig 6:Wind turbine Blade t/c=20%

IV. TESTING AND SIMULATION

The wind turbine blades are subjected to maximum load at the tip. Therefore two point bending test was carried out on UTM machine. The fixtures for the testing were such that under incremental loading at the tip, the stress is taken by the root sections.
The load was incremented gradually until the specimens either developed a crack or failed.

Fig 7:Testing set up

Fig 8:Deflected blade under loading

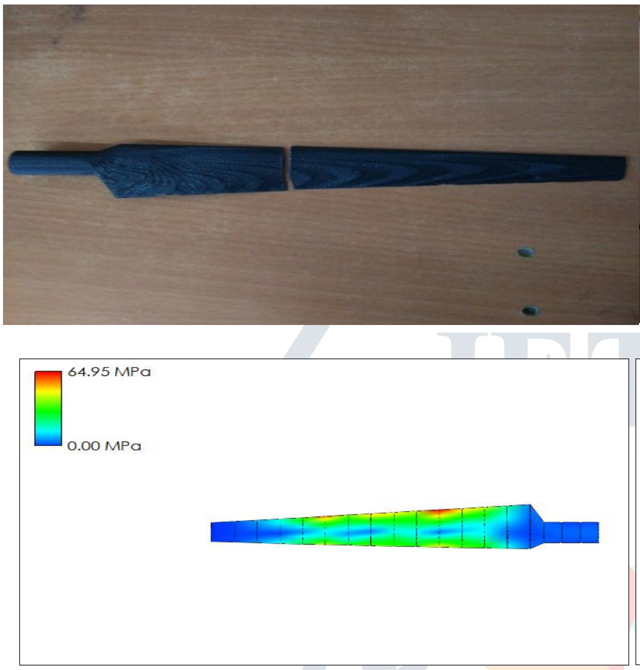
V. RESULTS AND DISCUSSIONS

Under two point bending test the specimens failed at a load of 6KN and 6.5KN respectively. The same failure loads were used to determine the maximum bending stresses induced in the specimens using QFEM software. The 3D models of the blades were applied flap wise transverse load and static structural analysis was carried out. The table shows the maximum flexural stress values for both the specimens.

Table 2 : ABS plastic material properties

Material	Young's modulus	Density	Poisson's ratio
ABS Plastic	1.86 GPa	1040 kg/m^3	0.35

Failed specimens and simulations



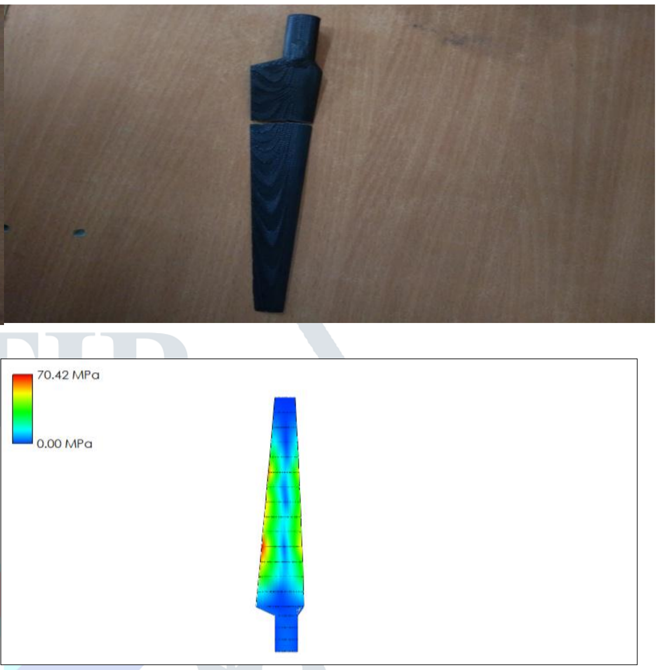


Fig 9:Failed wind turbine Blade t/c=17.5%, **Fig 10:Failed wind turbine Blade t/c=20%**

Table 3: Results of UTM test and QFEM simulations

S.No	t/c ratio	Root section	Section for remaining span	UTM failure load	QFEM Flexural stress MPa
Specimen 1	17.5%	FX84W175	NACA4412	6	64.95
Specimen 2	20%	FX84W175	NACA4412	6.5	70.42

VI. CONCLUSIONS

- The 3D printed model blades manufactured using ABS plastic showed promising load carrying capability in order to be used in household roof-top applications. The role of FX-84-W175 airfoil section was trustworthy. The blades of up to a meter length can withstand much higher loads and are feasible to be used for low cost full scale power generation units on roof-tops.
- Alternative materials or technologies in 3D printing can be investigated for more strength carrying capability in blades. Also advanced airfoil sections developed specifically customized for wind turbine blade root sections can be inculcated in design.

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