Design And Analysis Of Split Blade Technology In Wind Turbine Industry

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Abstract

Transportation of long turbine blades from one place to another is a difficult process. Hence a feasibility study of split blade technique of wind turbine blade was taken from structural standpoint through finite element analysis. Initially, a non-segmented blade is modelled and its structural behaviour is evaluated to serve as reference. The resonant, static bending and buckling tests are simulated in accordance with IEC61400-23 standard for comparison purpose. The non-segmented test blade is separated at suitable location based on trade off studies. The developed blade model is analysed for its structural response through simulation.

Keywords: wind turbine blade, splitting technology, Modal analysis, Buckling analysis, Static analysis.

1. INTRODUCTION

The recent trend of increase in wind turbine blade sizes is an inevitable consequence Wind turbine industry is facing stern structural challenges along with increased difficulties in manufacturing, handling, haulage and assembly. Griffin in his work concludes that, increase in haulage costs is of most concern. Considering shipment, handling and assembly are of paramount importance, a concept of Segmented Blades is believed to be the feasible alternative. In recent past, many segmentation techniques have been proposed which shows that, developing innovative segmented blades is a tough challenge. Most of the work related to segmentation of wind turbine blades is found to be patented. However, published work does exist, which indicates that, an efficient design of segmented blade still remains to be an engineering problem. Literatures show that, the resonant characteristics and static displacement as a function of blade length can be considered as the primary parameters for selecting a suitable location for segmentation. The resonant, static, and buckling performances are identified to be the crucial parameters in the validation of a segmented blade concept. From the literature it is evident that, the aerodynamic loads which causes flap wise bending of the blade are critical from structural standpoint. Further, the developed segmented blade must conform to the performance of non-segmented blade for commercial utilization. Thus, development of a feasible segmentation technique and detail investigation of the structural performance is required. In the present work an attempt has been made to address this requirement by investigating the structural performances of a horizontal axis wind turbine blade subjected to static and buckling loading, to develop a prospective segmented wind turbine blade model.

2. LITERATURE REVIEW

Chandrashekhar Bhat [1] has discussed about Structural Performance Evaluation of Modularized Wind Turbine Blade through Finite Element Simulation. In this paper he study the feasibility of a segmentation concept for large (3 MW or higher) wind turbine blade by investigating its structural performance through finite element simulation. The results indicate that, the effect of segmentation on the overall structural performance is negligible. Developed segmented blade appears to be the feasible alternative considering its structural response specifically in fatigue within considered assumptions. The method adopted to locate the region for segmentation has found to be appropriate. Thus, the basic objective of developing a possible segmented wind turbine blade which shows similar performance as that of non-segmented blade is achieved.

National renewable energy laboratory [2] is discussed about Transportation and Logistics Challenges Affecting the Deployment of Larger Wind Turbines blade. The transportation of non segmented blade is a major problem in cross road and narrow passages roads and railways. Although alternate side roads can sometimes be used, the road weight limits on these side roads were cited by one industry member as limiting the effectiveness of these alternate routes. This challenge generally limits the length of blade that can be transported over roadways to between 53 m and 62 m depending on the design characteristics of the blade such as the amount of precurve and type of airfoils used.

Eric Loth and Michael Selig [3] has discussed about a morphing segmented concept is proposed here in for future extreme-scale wind turbine systems. The morphing may be accomplished by using segmented blades connected by screw sockets and a tension cable system. At low wind and rotor speeds, the segmented blades are fully tensioned and set at high pitch to ensure start-up and maximum power at low speeds. At high rotor rpm, the cable tension can be designed such that centrifugal forces drive the blade segments outward so as to unwind/feather the rotor and prevent over-speed.

Kun-Nan Chen and Pin-Yung Chen [4] has discussed about Structural Optimization of 3 MW Wind Turbine Blades Using a Two-Step Procedure. In this paper has presented a two-step procedure for the optimum design of composite wind turbine blades. A 3 MW, three-blade, horizontal-axis, upwind wind turbine with blades having cross sections of NREL S818, S825 and S826 airfoil types was demonstrated as the design example. The result of the first step is the optimum cord lengths and twist angles of airfoils of the blade cross-sections along the blade span wise direction. Generally, the aerodynamically optimized chord lengths and twist angles are larger near the blade root and sequentially diminish when approaching the blade tip. A parameterized finite element model of the aerodynamically optimized blade was created using the ANSYS software.

3. METHODOLOGY

3.1 Types of wind turbine

- Horizontal axis wind turbine
- Vertical axis wind turbine

I. Horizontal axis wind turbine

These are the most common type of wind turbine uses in now a days. In fact all grid connected commercial wind turbines are today designed with propeller-type rotors mounted on a horizontal axis on top of a vertical tower. In contrast to the mode of operation of the vertical axis turbines, the horizontal axis turbines need to be aligned with the direction of the wind, thereby allowing the wind to flow parallel to the axis of rotation.

In so far as concerns horizontal axis wind turbines, a distinction is made between upwind and downwind rotors.

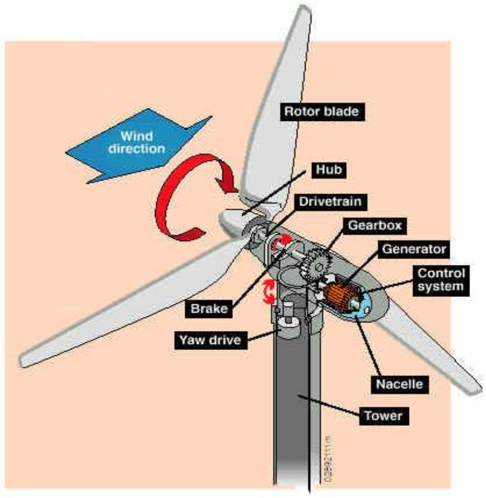


Fig. 1 Horizontal axis wind turbine

3.2 Advantages of horizontal axis wind turbine

1. Variable blade pitch which gives the turbines blade the optimum angle attack allowing the angle of attack to be remotely adjusted gives greater control, so the turbine collects the maximum amount of wind energy for the time of the day and season.
2. The tall tower base allows access to stronger wind in sites with wind shear. in some wind shear sites every ten meter up the wind speed can increase by 20% and the power output by 34%.
3. High efficiency since the blades always move perpendicular to the wind receiving power through the whole rotation.

3.3 Disadvantages of horizontal axis wind turbine

1. The tall towers and blades up to 90m long are difficult to transportation can now test 20% of equipments costs.
2. Tall HAWTs are difficult to install needing very tall and expensive cranes and skilled operators.

3.4 Wind turbine blades

The blades on the turbine catch the wind and use it to rotate the shaft of a generator. The spinning shaft of the generator converts mechanical energy into electricity.

Rotor blades are usually made of a matrix of fibreglass mats, which are impregnated with a material such as polyester, hence the term glass fibre reinforced polyester, GRP. The polyester is hardened after it has impregnated the fibre-glass. Epoxy is sometimes used instead of polyester. Likewise, the basic matrix is sometimes made wholly or partly of carbon fibres, which form a lighter, but more expensive material with a high strength. Wood-epoxy laminates are sometimes used in large rotor blades.

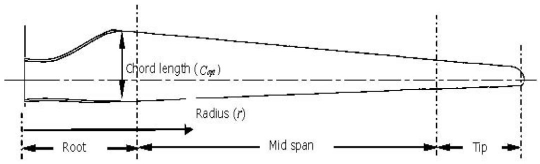


Fig. 2 Wind turbine blade

3.5 Industry problem with wind blades

- Size of the mould is too large very difficult to manufacture.
- Delamination problem.
- Transportation is a major problem in a unsplit blade.
- Require more space to manufacture a blade.
- Cracks occur any part of the blade whole blade should be replace.

3.6 Why split blade

- Very difficult to transport a blade in cross road and hilly reasons.
- It requires a huge truck to transport a blade.
- It creates traffic.
- Easy to manufacturing.
- Cost is very more to air lift a blade.
- Reducing manufacturing time, space and infrastructure requirements.
- Increasing production line flexibility.
- Existing production lines for medium size blades can easily accommodate the MW size machine blade parts.

Fig. 3 Truck is used carry the blade

Fig. 4 Problem facing while transporting a blade

3.7 Proposing the conceptual split blade design

Here I study the three conceptual split designs for a blade. Based on the result obtained from these three concepts I conclude that the best design concept.

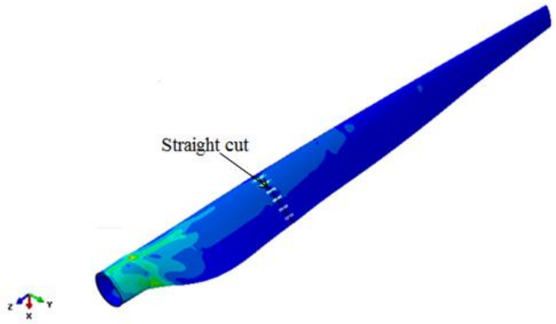


Fig. 5 Straight cut blade

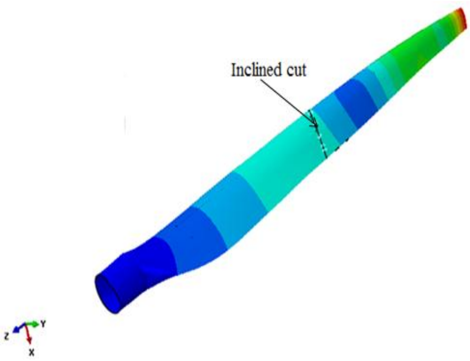


Fig. 6 Inclined cut blade

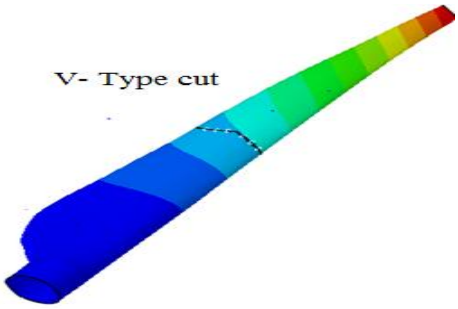
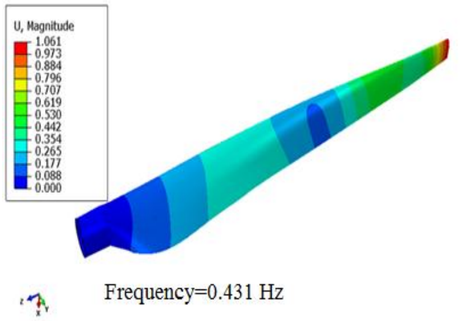


Fig. 7 V-cut blade

4. RESULT AND DISCUSSION

4.1 Modal analysis

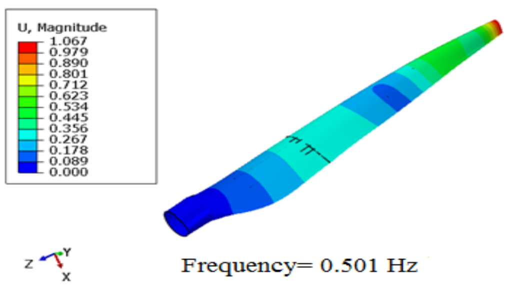
The modal analysis of the blade is solved by fixing the all Degree of Freedom at root end. Un-split blade frequency obtained from the ABAQUS is 0.431 Hz. The variation of frequency in the split blade is also minimum. So I conclude that splitting blade is not effect to blade efficiency. The theoretical calculation of the blade is complicated because very difficult to find out the area of aerofoil section. So for the validation of result I have taken the cantilever beam and applying the similar boundary condition, to check the behaviour of the beam, stress and deflection results. I observed that the behaviour of the blade is same as the cantilever beam and theoretical and FEA results are matched.



Un-split blade

Fig. 8 Modal analysis of un-split blade

Conceptual Design -1



Straight cut

Fig. 9 Modal analysis of straight cut blade

Conceptual Design -2

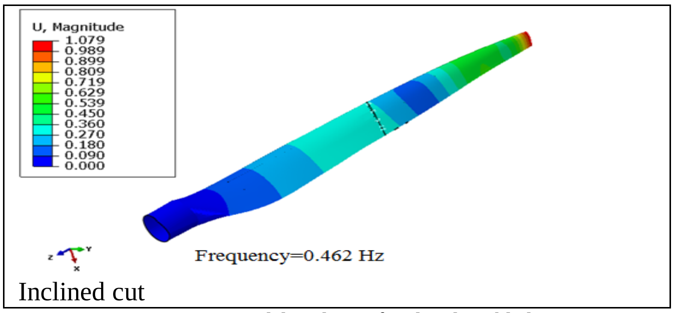


Fig. 10 Modal analysis of inclined cut blade

Conceptual Design -3

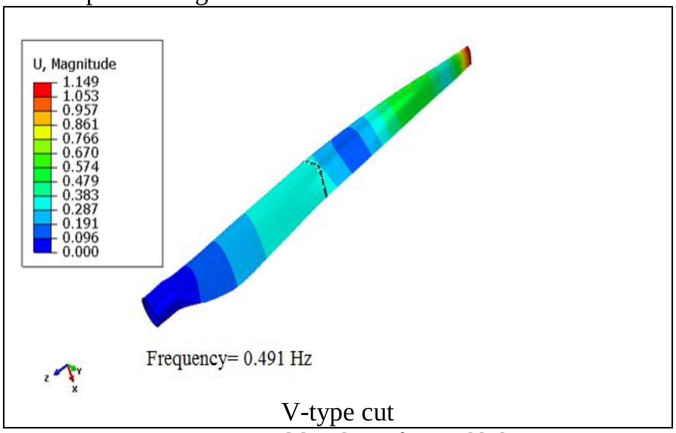


Fig.11 Modal analysis of V- cut blade

4.2 Buckling analysis

The buckling is a state failure due to instability of the material by applying the compressive load. The blade is also fails due to buckling load so we need to study the buckling analysis of wind blade. Here I analyze the critical buckling load with the use of FEA tool ABAQUS. By constraining the all degrees of freedom at the root and applying load to overall surface on the aerofoil cross section. Obtained critical buckling load is 9822N .The critical load indicates that maximum amount of load it can withstand without failure. The critical buckling load of split blade is approximately same as the un-split it is indicates that split is not affect the result.

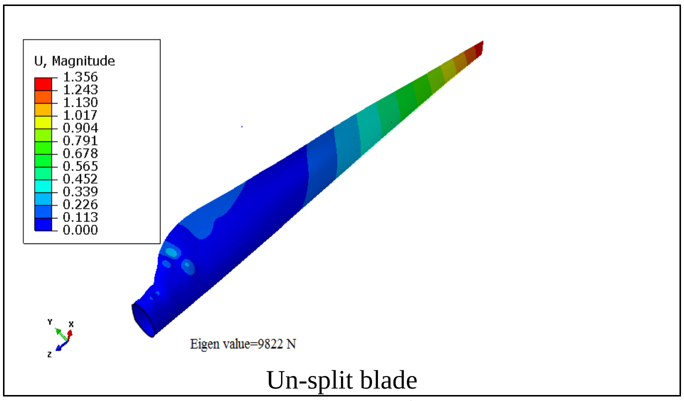


Fig. 12 Buckling analysis of un-split blade

Conceptual Design-1

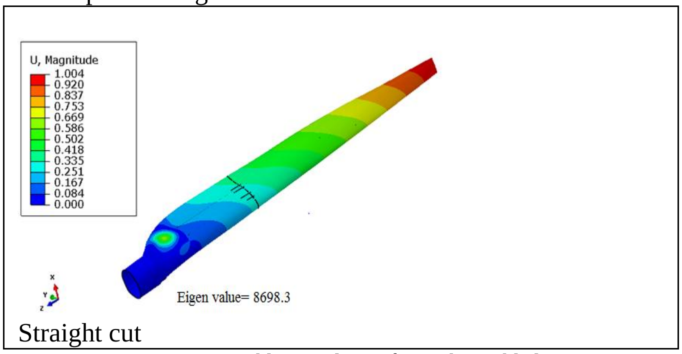


Fig. 13 Buckling analysis of straight cut blade

Conceptual Design-2

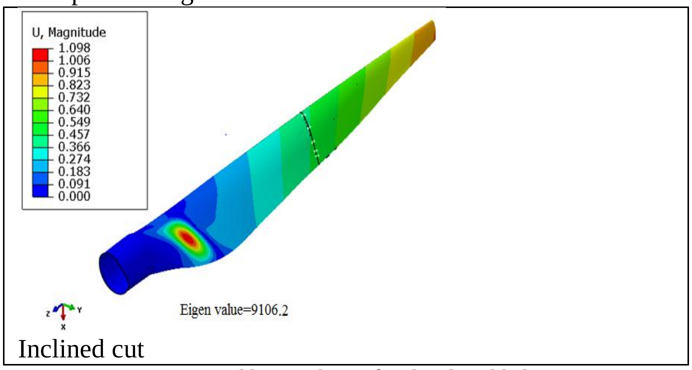


Fig. 14 Buckling analysis of inclined cut blade

Conceptual Design-3

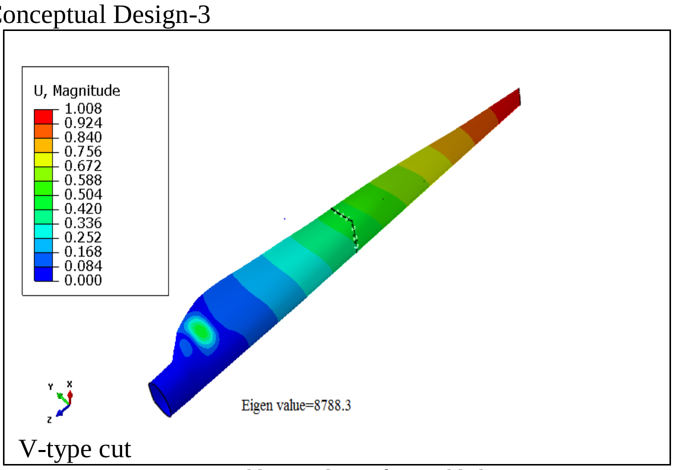


Fig. 15 Buckling analysis of V-cut blade

4.3 Static test results

With the applied bending load the suction and pressure face of blade is causes tension and compression correspondingly. In the case of bending it is common behaviour subjected to bending. For the analysis I observed that the region near the root occurs the maximum stress both the split and un-split blade due to the bending moment. It is the common behaviour of the cantilever beam. For the better performance of the blade we need to check the stress and deflection result by constraining all degree of freedom at the root side. I observed that the stress developed in the blade model is 230MPa and also the developed stress is less than the yield strength so I conclude that design is safe. In the region nearer the root both split blade and un-split blade developed maximum stress approximately similar. So I conclude that splitting is not affecting the performance of the blade.

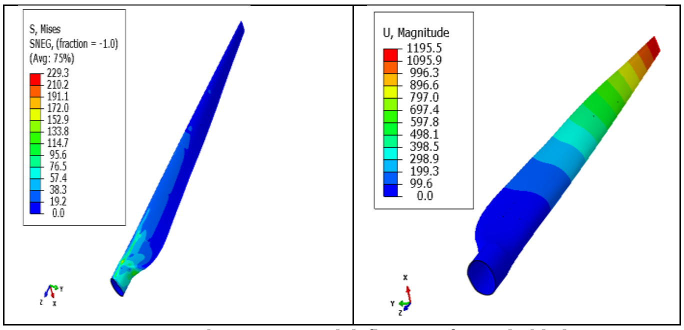


Fig. 16 Shows stress and deflection of un-split blade

Conceptual design -1

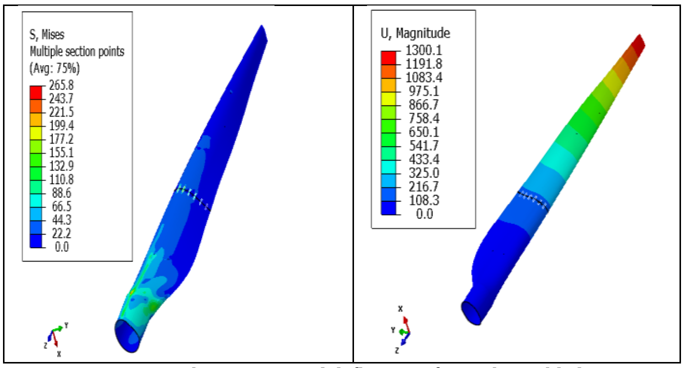


Fig. 17 Shows stress and deflection of straight cut blade

Conceptual design -2

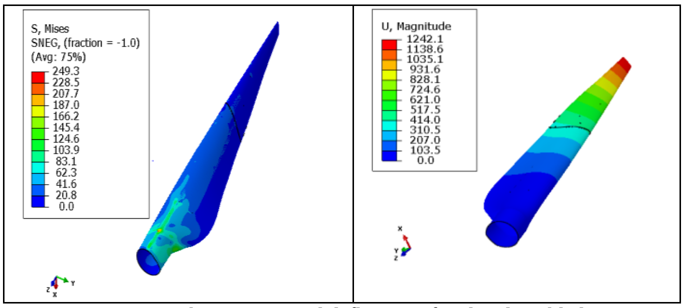
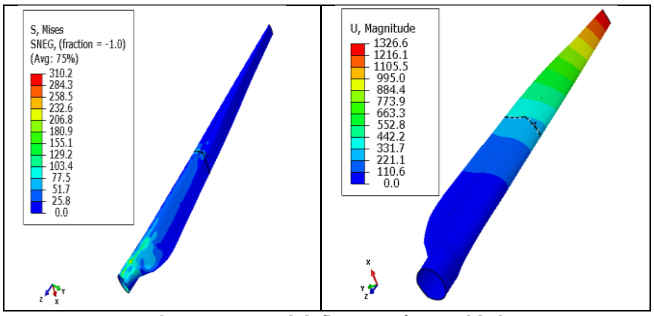


Fig. 18 Shows stress and deflection of inclined cut blade

Conceptual design -3



Fig,19 Shows stress and deflection of V-cut blade

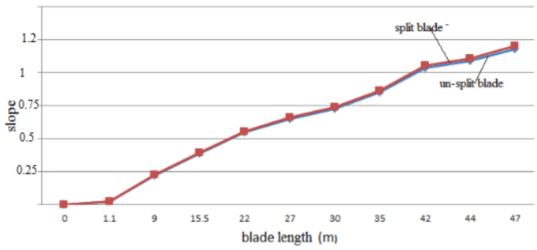


Fig.20 Comparison of deflection in un-split and split blade

4.4 Decide the suitable location for split a blade based on the above results

The efficiency of the split blade depends on the location selected for introducing a separation. Hence I worked on to find the suitable location to split a blade. The factor considers to deciding the splitting location are mode shapes of the un-split blade and analyze the slop pattern of un-split blade under the static analysis and buckling analysis. Analyze the mode shape to decide the less deflection in the blade and extract the mode shapes showed region of less deflection in the blade. Near the tip larger deflection it indicates that splitting is not possible in that regions. This gives a rough idea about to decide a splitting region then we go to static bending result and buckling result to decide the exact location. However inside the blade have shear webs so not able to cut the blade in the same location. This reduces the stress concentration it may affect the blade strength. The joint areas are distributed over the area therefore the stress concentration is reduced and efficiency of the joint is increased. So I did the three conceptual design modes to cut the blade and identify the stress and deflection variation on these modes. Based on the results I conclude the suitable conceptual design modes to split a blade. Among the three modes I observed that inclined cut is the better conceptual design.

Table. 1 The location choose to split

Component	Leading edge side	Trailing edge side
Distance from root	24500 [mm]	23000 [mm]

5.CONCLUSION

In this work I study the suitable location of split based on the modal analysis, buckling analysis and static analysis. Based on the obtained result from these three analysis I conclude that the suitable splitting region. The obtained modal analysis results are

Table.2 Frequency values of wind turbine blade

Model	Frequency in Hz
Un-split blade	0.413 Hz
Straight cut blade	0.501 Hz
Inclined cut blade	0.462 Hz
V-cut blade	0.491 Hz

Based on the above result we can easily understand that frequency of inclined cut blade is 0.462 Hz is less compare to other two conceptual designs. Based on this result I conclude that inclined cut design is more efficient than others two.

From the buckling analysis we get buckling factor based on that we get the critical load carrying capacity of the wind turbine blade. The critical buckling factor for different conceptual designs as shown in the table

Table.3 Buckling factor of wind turbine blade

Model	Buckling factor(Eigen value)
Un-split blade	9822
Straight cut blade	8698
Inclined cut blade	9106
V-cut blade	8788

From the above result we understand that critical load carrying capacity of inclined cut blade is more compare two other two conceptual designs. Based on this analysis I conclude that inclined cut blade is more efficient than other two.

From the static analysis I get stress and deflection of wind turbine blade. Based on that result I decide the suitable splitting region. The stress and deflection results of different conceptual design as shown in table below

Table.4 Stress and deflection of wind turbine blade

Model	Stress in MPa	Deflection in mm
Un-split blade	229	1195
Straight cut blade	265	1300
Inclined cut blade	249	1242
V-cut blade	310	1326

Based on the above result we understand that stress and deflection of inclined cut blade is less as compare to other two conceptual designs. So I can easily say that inclined cut blade is a more efficient than other two conceptual designs.

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