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Experimental Investigation and Analysis of Manufacturing Wind Turbine Blades Produced by Hydroforming of Aluminum Alloy AA5754

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Abstract
Development of new technologies and combined with creativity and innovation, plays the fundamental role in developing of any community′s value. Thus, in this research the design and production of hydroforming device was introduced. One of the best and most efficient technologies in the world of metal forming is wind turbine blade producing with hydroforming method which seems as an innovative manner in this field. The aim of this paper is design a small wind turbine blade. Application of this blade is for spaces with size limitation and building large-scale wind turbines. The first step of design process involves choosing and determining the airfoil blade wind turbine, distributing along the radius, angle of the airfoil and chording length distribution along the radius. Turbine blades modeled in CATIA software and transferred to finite element software, ABAQUS. Critical blades points under the hydrostatic pressure have been identified and outputs such as displacement, Von Misses stress obtained from hydroforming simulation process. In the final stage, after ensuring the software outputs blade has been modeled and produced.

Keywords
Wind energy, Hydroforming, Finite element method, Aluminum alloy, Argon welding

1. Introduction
Recently wind turbines electricity generation is introduced as renewable energy storage. Wind turbines can convert the kinetic energy of wind to other forms of energy. In the current situation regarding economic feasibility of wind energy comparison to the other new energy sources, wind energy is a vital issue. Islamic Republic of Iran is 1,648,195 square kilometers and it is located in the West Asia and considered as Middle East countries. Mountains and highlands, a quarter is deserts more than half of the areas and less than a quarter are fertilizing lands. Since different climate are exist in Iran widely various types of diversity are observed. The height of north, west and south Mountains is so high winds are so high that they prevent the impact of Caspian Sea, the Mediterranean and the Persian Gulf winds in inside of IRAN. That is why the outside slopes of these mountains have wet weather and the inside slopes have dry weather. Regarding to geographical location of Iran in Asia, wind flows between East and West, hot southern zone and mild northern zone.
Determining wind potential in Iran, in for zero phase of the project (wind potential in Iran) that was conducted by Department of Energy, for 26 regions of country which studied in 45 sites. Result of this study shows, Iran with average wind potential for generating power in some areas that is more appropriate and consistent. Iran, have an occasion capabilities and potentials for wind turbines installation and commissioning.

In Yogyakartaand Semarang, Indonesia, CFD models of wind turbines represented for 4 different of buildings with surrounding houses and in each of these cities models have been investigated [1].
Output power is the main aim during the design and optimization of wind turbine blades. By increasing the size of blade, some important parameters such as blade mass and generated noise must be considered. However, the International Electro-technical Commission (IEC) obtained maximum power output for small blades of wind turbines about 50 KW based on standard 61400-2. [2]. The Most small blades of wind turbines outside the network, means where a low-power wind that blows in a short period of time, are used. In addition, the blades are generally doesn't set to optimize the angle of attack in the wind. [3].
Numerical studies show main blade disadvantage in order to extracting maximum design performance is poor starting. Hampsey [4] produced an optimal blade which is not only appropriate in terms of performance but has a good result in starting time. In addition, studies on multi-dimensional analysis method (DE) by wood [5] and Clifton-Smith have been used. Improving small blades performance in low wind speed was the main purpose of these studies that it would be possible for improving blade startup time. The results of this simulation have considerable emphasis on the relationship between blades on set with output power changing [3]. In another hand, the effect of altitude on wind turbine blade performance at the height of 3,000 meters examined. The survey also indicated that redesigning blade is achieved due to reduction in air density and increase in height of kinematic viscosity, at an appropriate height by changing in generators characteristics and wind turbine performance [7].
The blade structure strength is another important factor that should be taken into account in designing. Based on which hollow blades have a minimum shell thickness, thereby optimizing the next few tiny blades for reducing amount of stress into blades. The blade is placed under static and dynamic loads. Fluctuating wind speed, wind direction deviation angle to turbine axis and random variation due to noise currents from entering are dynamic loads. In addition, the deviation of tip should not be dealt with the tower column [8].
Too many software which used for analyzing of entered tensions and diversion of wind turbine blades. Most of this software is using finite element method with high accuracy, but the analysis in the early blades design and optimization are very expensive and time-consuming. Hansen [9] and Capuzzi [10, 11], by replacing a turbine blade instead of a cantilever beam simulation, analyzed optimized structure of large wind turbines. Wood [12] considered a three-bladed turbine, with a diameter of 2 meters and a power output of 500(watts) under load. This research is performed by used of a simplified standard version IEC 61400-2.
According to Tavakoli et al. [13] by controlling blades angle in high wind speed, the speed of the rotor within the rated speed and productivity fixed in nominal value. In fact, power management settings will happen by used of blade angle control and some limitations due to limitations in scope and speed of blade response operator. The main object of this study is minimizing the amount of deviation from the optimum speed of rotor and also placing the operator.
A research has been done by Mojaveri et al [14] with regard to a typical turbine blade with two different speeds of wind power turbine in a state of constant $C_p$and C_p status and variable TSR. His research had a deeper look at some of the design factors such as wind turbine Blade Tip Speed, Tip Speed Ratio (TSR), the rotor power coefficient (C_p) and how to calculate the output power.

2. Experimental Tests

Applied mechanical forces are justified after cutting the samples cut edge. The chamber pressure requires producing the parts into a seamless hydroforming, bending, welding by using a line across the edge of welded dumped into each other.

In the worst case, by assuming Non-isotropic of sheet cutting perpendicular to the rolling direction (along the visible traces sheets) was selected. Test sheets were made of alloy steel (AA5754) sheet with thickness of 1.5 mm. according to numerical analysis, Linear pattern of increased pressure in terms of time results on increasing pressure to 80 bar. As expected from the result of numerical analysis, the bursting of the piece under pressure from the weld seam in increasing pressure process applied to blade occurs (Figure 1).

Figure 1.View of bursting piece of the Seam welding

2.1. Final assembly of the mold

After completing the set and closing various components of the wind turbine blade mold making machine hydroforming is ready for testing. Hand pump injects oil through the conduit embedded into the blade. Sets of molds, pumps and emergency facilities in open and close conditions are shown in Figure 2.

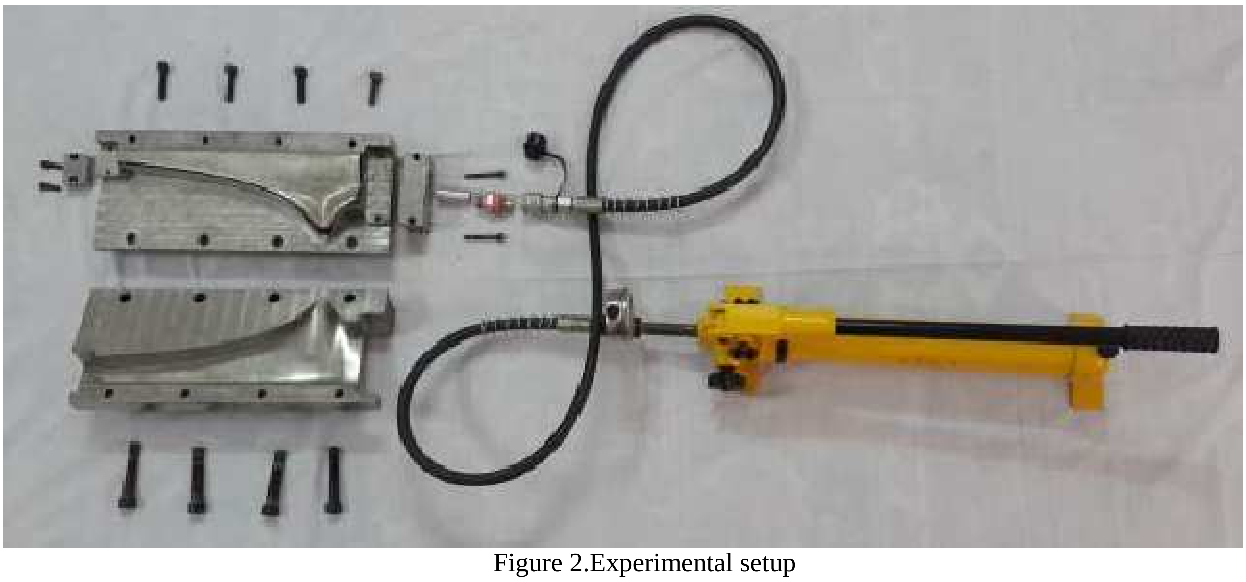


Figure 2.Experimental setup

2.2. The final piece

Since the pressure necessary for the formation of the simulation pressure (80 bar) was closed until the pressure inside the chamber increased the pressure after the pressure (load) and reaches to the desired pressure, the pressure exerted from the removed from inside of the blade (unloaded). It can be seen that the open template complete formation of aluminum alloy sheet (Figure 3) which corresponds to the upper and lower half has reached its final stage. Figure 4 shows different views of the blades forms obtained from experimental hydroforming process.

(B) (A)

Figure 3.The blades fit within (A) the upper half mold (B) the lower half mold

Figure 4.final form of blade obtained by hydroforming process

3. Research Methodology

Blade length of 332.5 mm from 20 sections, 17.5 mm each cross-section of the side sections, chord and chord angle with the horizon of each of these sections are shown in Figure 5. Numbered sections are carried out from the base of the blade (A) (section 1) to blade tip (B) (section 20) respectively.

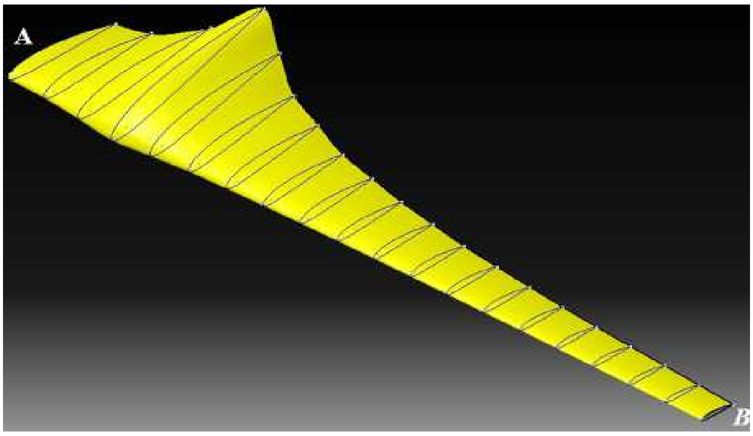


Figure 5. Selected section on the blade (20 sections)

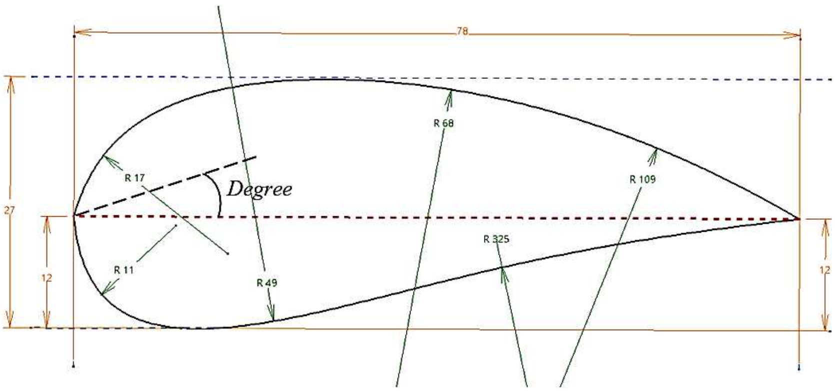


Figure 6. Angle and length in first chord degree

Parameters for each section reported in Table 1.

Table 1. Angle Classification and chord length of blade sections

angle with horizon (degrees)	chord length (mm)	Section	angle with horizon (degrees)	chord length (mm)	section	angle with horizon (degrees)	chord length (mm)	section	angle with horizon (degrees)	chord length (mm)	section
0.8	28	**16**	3.9	43	**11**	11.6	78	**6**	0	78	**1**
0.4	27	**17**	3	39	**12**	9.5	68	**7**	4.874	78	**2**
0	26	**18**	2.35	36	**13**	7.4	58	**8**	9.75	97	**3**
-0.3	24	**19**	1.7	33	**14**	6.1	53	**9**	19.5	117	**4**
-0.6	23	**20**	1.25	31	**15**	4.8	47	**10**	15.55	97	**5**

3.1 Material properties

Material used for designed blade is aluminum alloy sheet AA5754. Important specifications for this material are given in table2.

Table 2.Material properties

Density	Modulus of Elasticity	Yield Strength	Tensile Strength	Hardness
2.66 gr/cm^3	68 GPa	Min 130 MPa	Min 220 MPa	63HB

3.2. Load

Hydrostatic internal pressure which supplied for blade analysis is under 8 Mpa from the hydraulic manual pump.

3.3. Meshing

The meshes created and converged in an appropriate type and size respectively. The improper selection can cause instability or lack of proper convergence mesh in the calculations. Grid mesh was investigated in order to independency and verified simulation and analysis with initial phase. Grid independence was obtained by changing the number of element from 500 to 20,000 and finally 9896 elements were selected for blade as an appropriate grid.

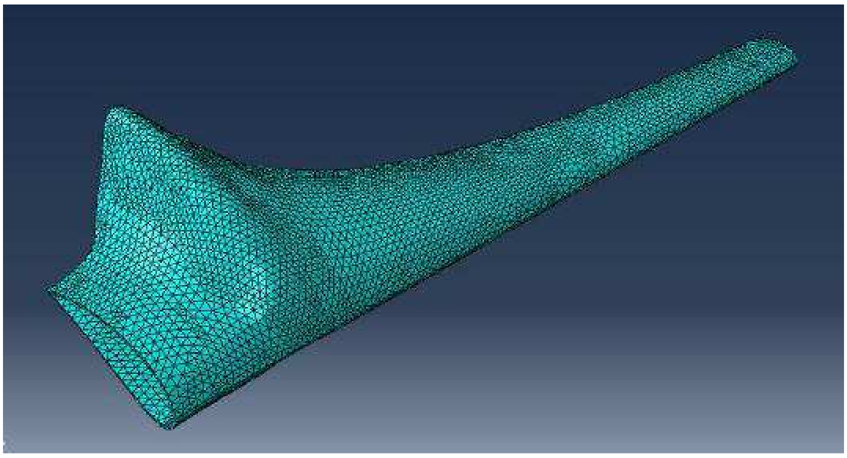


Figure7. A sample finite element mesh generated for blade

3.4. Analysis of hydroforming blade

Blade surface (inner surface of the model) with 9.0 scale real size in CATIA was modeled for calculating the effect of hydroforming analysis. The hydroforming process analysis using the concept hydrostatic pressure inside the chamber (blade) applied to the mold to obtain an initial pressure for forming and pressure authority approximated to obtain the desired pressure causes different pressures, re-loading and then the problem solved several times [15, 16,17].

3.5. Displacement

One of the most important parameters in the finite element analysis is deformation (displacement). The vertical displacement contour is shown in Figure 8.In the analysis, displacement along two axes (x,y) is approximately zero and displacement is possible only in z-axis (inflation direction). According to Fig.8 most of displacements are occurred near the base and gradually elements movement toward tip of blade reduced.

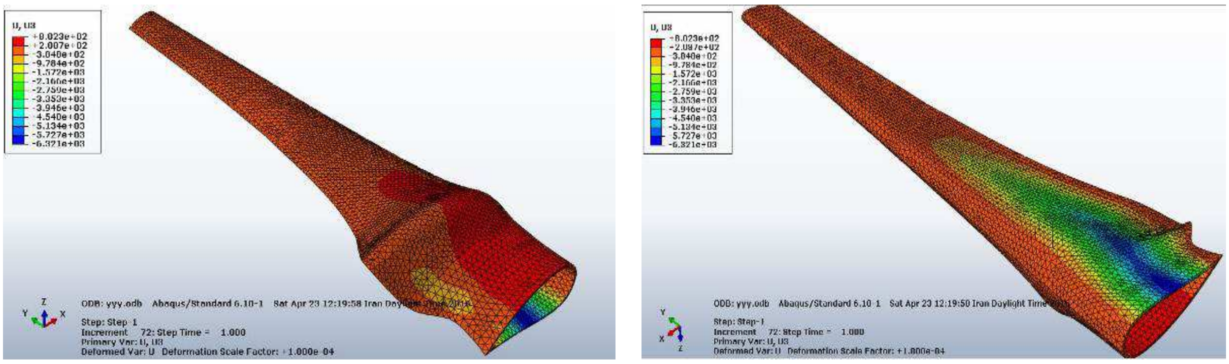
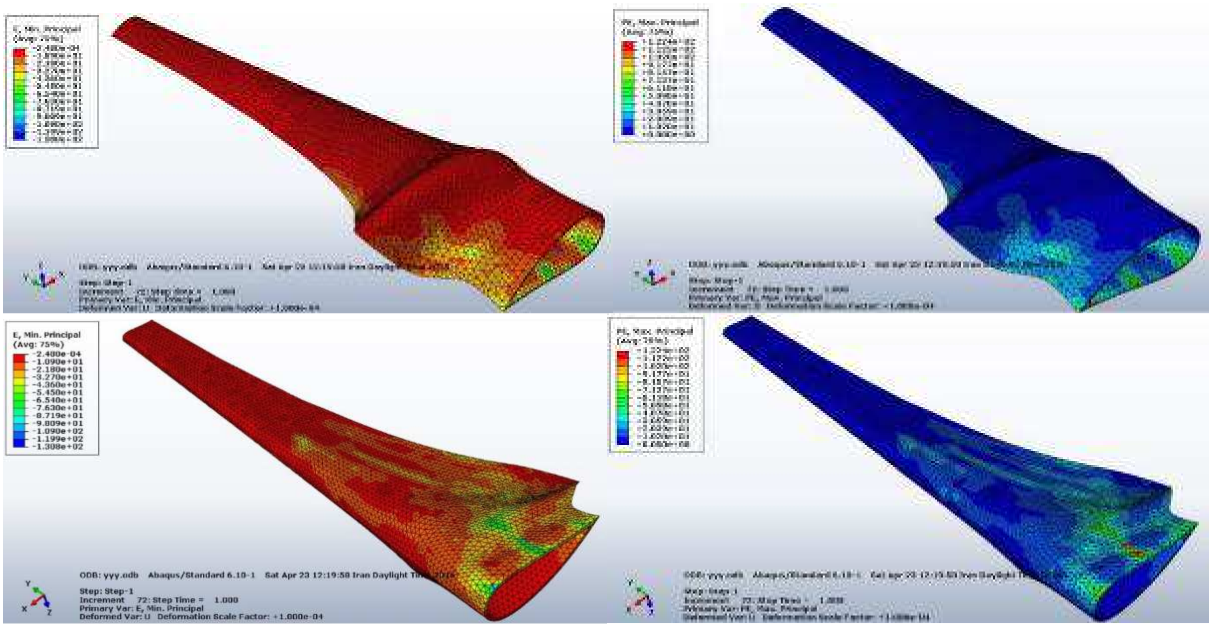


Figure 8.Vertical displacement contours

3.6. The maximum and minimum principal strain

The main strains (minimum and maximum ($\varepsilon_1$andε_3)) created from deformation hydroforming shows in Figure 9.



(B) (A)

Figure 9. (A) Minimum strain and (B) maximum of two facades curving blade

Figure 10 shows strain in the thickness direction along the 20 points of length with same distance from the central axis at upper and lower of blade. Result shows, this parameter on the underside of intensity greater than a high level and it causes differences in surface curvature.

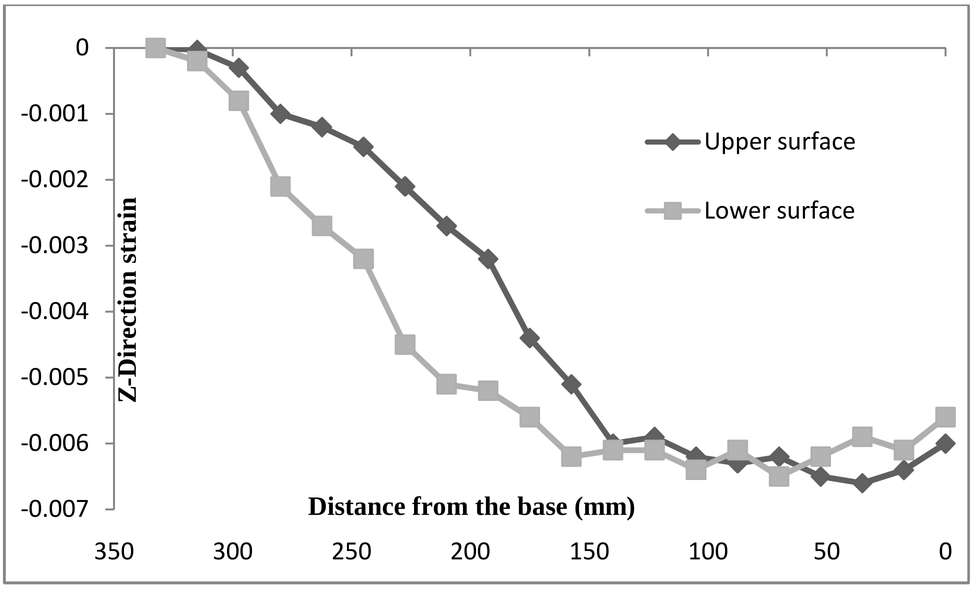


Figure 10. Z- Strain distribution on length

3.7. Determination the most critical point

After bending and reaching double-edged sheets, seam welding with two edges of the form (7-A) seam apart as shown in Figures 11 and 12.

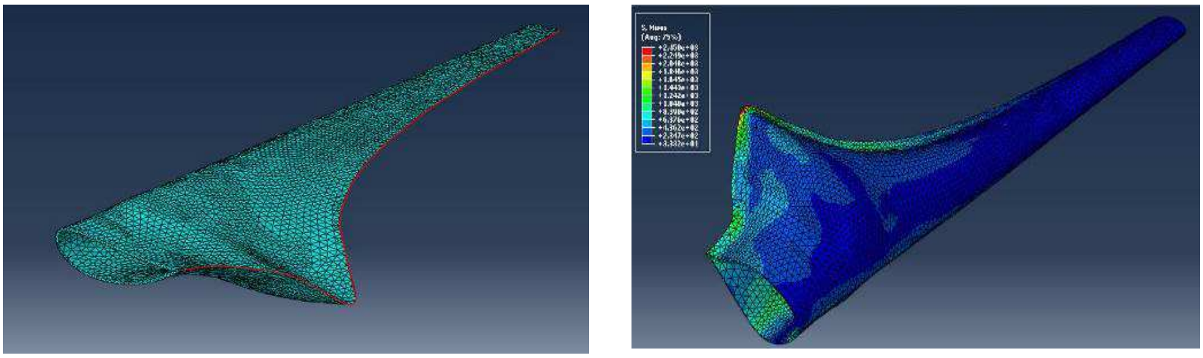


Figure 11.critical design points

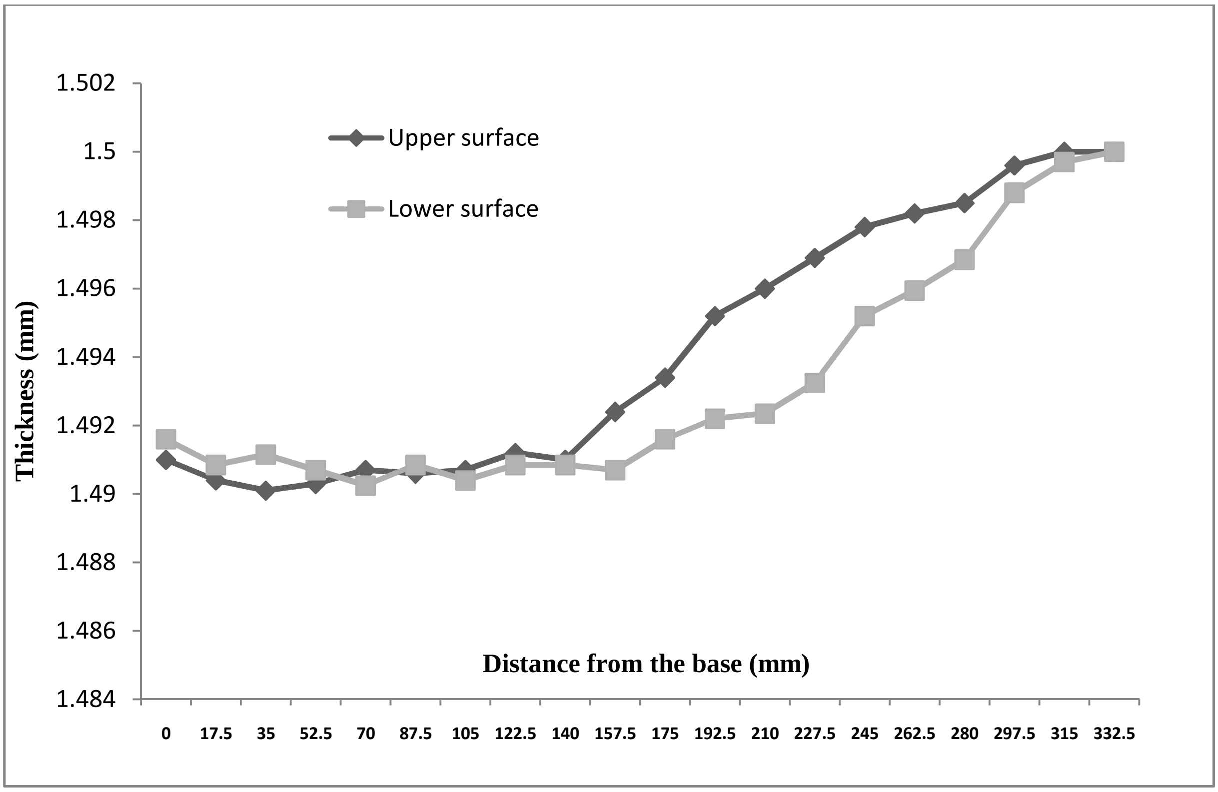


Figure 12. Thickness distribution on length

Thickness values at 20 points with the same distance are given in Figure 12. As can be seen from the tip to base as we move that this is because larger sections. The thickness reduction rate in underside of upper level is greater than justified as shown in Figure 10.

Hydrostatic pressure applied to blade weld seam is critical point of design. Due to nature of displacement and plastic strain in blade protrusion that is greater than other regions and according to this analysis, critical point displayed in (7-B).

3.8. Stresses (von Misses and Tresca*)*

Contour changes between maximum and minimum principal stress shown in Figure 13. Results of this analysis shows that uses von Misses criterion points detected for endure more stress.

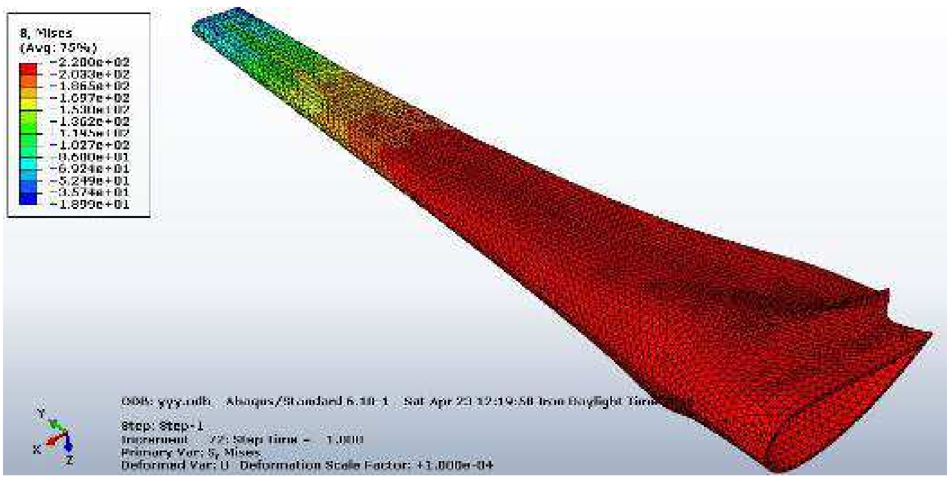


Figure 13.Von Mises stresscontour

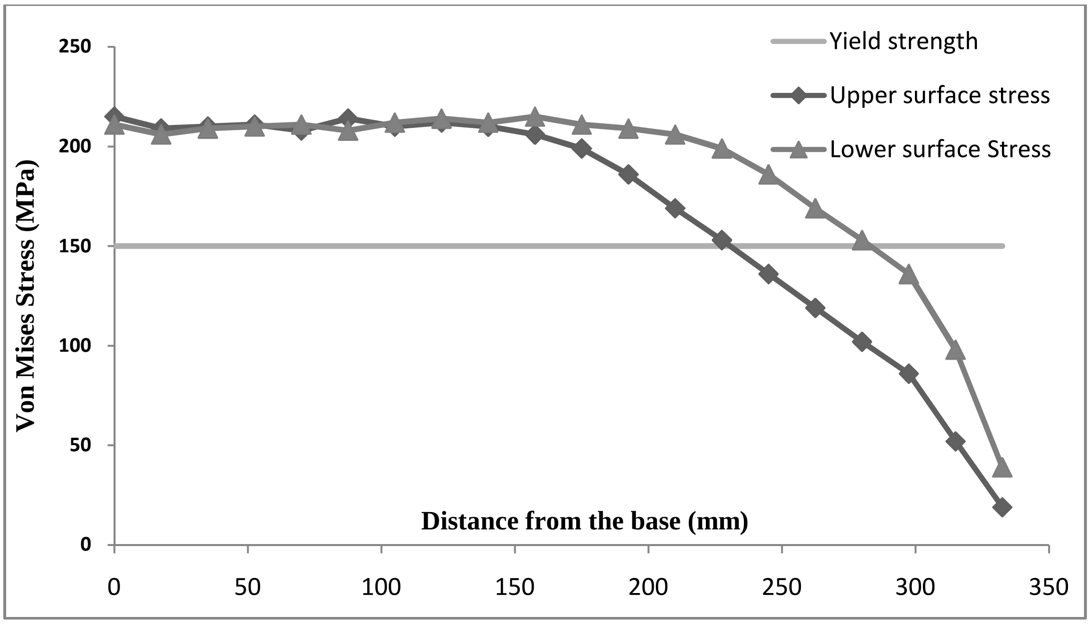


Figure. 14. Von Mises stress distribution on length

Von Mises stress at 20 points with the same distance on the central axis at the top and bottom blades as well as the yield strength of material as shown in Figure 14. According to Figure 14, we can see an average of 230 mm from the upper surface and 280 mm from underside of plastic zone entered.

4. Conclusion

Undoubtedly development of new technologies and the world and combine it with creativity and innovation play a fundamental role in the development and growth of any society values is stopped. Hence in the present study, design and build devices that one of the best and most efficient technologies hydroforming shaping the world in numerous metals used. In this study, a novel wind turbine blade was introduced. The advantage of this design of processes that have produced mentioned in following:

- Ease of construction
- Lighter weight.
- Integrated structure.
- High production rate and possibility of industrial production Blades.

Forming sheet with conventional methods can easily damage to the pieces during the process, at same hydroforming process for applying pressure to pieces will build with high quality is final product. Finite element simulation for aluminum alloy sheet hydroforming process AA5754, according to the material properties and stress-strain diagram drawn. Continuing with the design requirements set Molds and hydraulic system of the hydroforming process is used for manufacturing highly efficient and modern Forming hydroforming method. Laboratory samples made by machine represent full compliance between numerical simulation and samples, respectively.

5. Reference

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