Research Journal of Recent Sciences ISSN 2277-2502
Vol. **3(1),** 50-56, January **(2014)** *Res.J.Recent Sci.*

The Correlation between Factor of Safety and Twist Angle in Axial Fan Blade

Zare Ali, Najafzadeh Ali, E. Ahmadi Naeim and Shahizare Behzad
[1]Department of Mechanical Engineering, Universiti Tenaga Nasional, Kajang, MALAYSIA

Available online at: www.isca.in, www.isca.me
Received 21th June 2013, revised 1st July 2013, accepted 1st August 2013

Abstract

These days, improving energy efficient systems is one of the most controversial and significant global focuses. However, this trend in the field of engineering researches concentrates on the optimization of the existing technologies more than implementing new ones. Meanwhile, fans are one of the potent devices to be more efficient. Improvement in fan's efficiency can be achieved by varying the twist angle of the blade. As the variation of twist angle affects the factor of safety, the present work focuses on the stress analysis of the axial fan blade with different twist angles, by the use of finite element method. Due to this, an axial fan blade with NACA5514 airfoil that is made by Aluminum 6061-T91 will be analyzed to find the correlation between the factor of safety and the twist angle in various pressure loadings.

Keywords: Finite element method, Factor of safety, Stress analysis, Twist angle.

Introduction

A revolution in the 19th century introduced a belt-driven fan in which wooden or metal blades were attached to the shaft. Fan isa type of turbo machinery used to move air with a slight increase in the static pressure[1]. Surely using fans for ventilation is important in providing healthy and comfortable places for human being work and life, from the view point of enhancing physical and mental efficiency of individuals, reducing diseases and reducing non-renewing polluting fuel consumption[2,3]. One of the first mechanical fans was built in 1832 and it was tested in coal mines. Further, developed fans have been utilized in diverse fields based on their applications[4]. These developments have been applied in various parts of the fan such as blades within which the twist angle and the shape of the cross section are of primary importance. In axial flow fans, it is desired to have an ideal axial flow within which there is no radial velocity component[5].

The shape of airfoil has a very important role in the performance of its applications. National Advisory Committee for Aeronautics (NACA) is the most famous one in developing airfoils since 1930[6].

The blade angle is the angle between the plane normal to the axis of rotation, and the blade's chord.The blade angle varies along the length of the blade. It decreases from root to tip of the blade due to its twist angle. To have a more efficient axial flow fan, its airflow should be distributedevenly over the working face of the fan wheel. To be more specific, we should have the same value for the axial air velocity from hub to tip. On the hand, the velocity of rotating blade does not have even distribution. Its value is low near the hub,while it increases toward the tip. This gradient should be compensated by a twist angle of the blade, which results in a larger blade angle near the hub and smaller blade angle toward the tip. However, some blades have the same blade angle from hub to tip.It leads to a loss in fan efficiency since most of the air is flowed by the outer portion of the blade, even at the low static pressures. At higher static pressures, the blade twist angle is very effective, as without it, the inner portion of the blade will stall and permit reversed airflow that affects the fan efficiency [7].

Figure-1 shows the Airfoil shape of the cross section with diverse twist angles. It presents one cross section in various angles of attack.

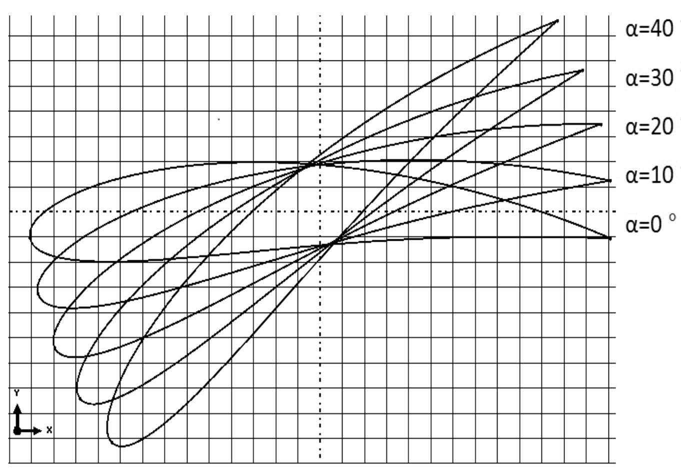

Figure-1
Airfoil shape of cross section with diverse twist angles

Nowadays axial flow fans are mainly utilized for cooling and ventilation purposes. In order to have more efficient cooling and ventilation applications, the fan structure and its performance under certain conditions are very critical. Due to this, changing the twist angle to find the best value is recommendable. This variation may cause a failure in the blade; therefore, it must be controlled by the factor of safety (FOS). FOS can be achieved by usage of the maximum of Von Mises stress in the whole blade. It can be expressed as a proportion of the maximum of Von Mises stress over the tensile strength of the material. In the axial fan blades,by changing the twist angle, Von Mises stress will change, and FOS varies consequently.

Several scholarly research has been done in the area of designing the axial fan blade. Furthermore, several researches have been conducted to optimize the twist angle by utilizing various techniques of optimization. Some works that form this research'sbackground for are as follows:

In 1957, a static bending of pre-twist blade was examined. The blade was pre-twisted linearly about the center of its cross section to a maximum angle of (π/2) radius, and it was fixed at the root[8].

In 1980, the dynamic stress analysis of rotating twisted and tapered blades were studied. The FEM was utilized to calculate the deformations and stresses. Three-dimensional, twenty-node isoparametric elements were utilized for the analysis. Further analysis was done on different blade twist angles. The numerical results were verified by experimental results[9].

In 1992, the steady state dynamic stress and deformation analysis of the twisted blade was studiedby the usage of a triangular shell element with six degrees of freedom per node [10].

In 2000, an efficient implementation of the Blade Element and Momentum theory was utilized to optimize the twist angle due to its reasonable and accurate estimation of performance. As the BEM theory had presented an acceptable accuracy with regard to time cost, it can be considered as a suitable theory for blade geometry optimization[11,12].

In 2006,a method was presented to findthe optimal twist angle in wind turbine blades. The method used genetic algorithms. Itdid not considerthe assumptions about optimal attack angle related to the ratio between the lift to drag coefficients[13].

In 2008, the dynamic stresses of a twisted blade was calculated. The blade was designed using the blade element theory. The dynamic analysis was made using the beam theory and the modal analysis was made using the finite element modeling and also using the blade motion equation[14].

In 2009, the performance of an axial fan blade with various angles of attack was predicted. The prediction result was verified by experimental results. This study improved the conventional CFD approaches for the prediction of fan performance[15].

In 2012, a study has been conducted on estimating the optimal shape of an axial fan blade, such as chord length and twist angle. At first, numerical calculations were implemented to design and analyze the optimal shapes of fan blades with NACA 4-digit series airfoil. The experimental test validated the accuracy of its estimations[16] . In addition, in the same year, the similar optimization of the chord length on the axial fan blade and wind turbine blade was done[17,18].

In 2013, the correlation between chord length of fan blades with NACA 4-digit series airfoil and the factor of safety was investigated by the usage of Von Mises stress[19].

Fans have several applications in modern life; therefore, saving energy and material play crucial roles in their design and manufacturing. Reaching the global goal of saving energy and material necessitates a close analysis of various variables in fans. Meanwhile, changing the blade twist angle may lead to improve the performance of fans. This variation affects the factor of safety (FOS). However, FOS is a very important criterion in designing and manufacturing of the fan. The objective of this study is analyzing the FOS in various twist angles to find their correlation.

Material and Methods

In this study, an axial fan blade with the following specifications will be examined. Model Number of the fan is 1250-350-12 (30deg) with the Impeller Diameter of 1245 mm. Inlet and Outlet Areas of the fan are 1.2272 m^2 and 1.2272 m^2. The fan blade length is 446.5 mm with the cross section of NACA5514. The primary blade chord length is 130 mm.

The blade is made of Aluminum 6061-T91 with the Modulus of Elasticity of 69.0 GPA, a density of 2.7 g/cc, Poisson's Ratio of 0.330, and Tensile Strength of 395 MPa. The pressure load is applied to the lower surface of the blade.

Experimental results: Different pressure load values were applied to the blades. These values achieved from experimental tests, which were done by GT-Gulf (M) SdnBhd company under AMCA standards on January 10, 2011. The data were achieved from experimental results of Test No. 27353-A2, which was named as CONTRACT TESTING – MODEL No. TFA 1250-350-12. The chord length of the blade in this test was 130mm. The fan was tested in a wind tunnel. Based on the experimental data, the pressure load values were measured in different regions; from free delivery to stall. The results show that the pressure load values on the surface of the blade varied from 0 kPa to 800 kPa. This pressure applies load on the lower surface of the blade, which can be considered as a surface pressure in the software simulations.

Finite element method: Finite element analysis (FEM) has become commonplace in recent years, and is now the basis of a multibillion dollar per year industry[20]. The FEM are technique utilized for approximating differential equations to continuous algebraic equations by a finite number of variables[21]. This method is one of the most practical ways for analyzing structures with a large number of degrees of freedom. To get a more accurate result from FEM, it is recommended to use some software in order to carry out the numerical computation part. In addition, saving time is another factor which motivates specialists to use software instead of solving problems manually[22]. The general process of FEAis divided into three main phases, preprocessor, solution, and postprocessor[23].Various FEM based software such as ABAQU are utilized to solve engineering problems. In this study, ABAQUS software is used to analyze Von Mises stress in the axial fan blade.

Mesh convergence study: A mesh convergence study was done to choose the optimum mesh number from the computational accuracy point of view. Meanwhile, Von Mises stress was computed for different types of meshing. In these types of finite element analysis, Three-Dimensional with HEX type of element are more suitable than rectangular or triangular flat elements[24].

In order to get better result in different analysis with ABAQUS software, a mesh convergence study was done in the sample simulations. As it is shown in Fig. 3, by increasing the number of elements, Von Mises stress goes up sharply and then approximately remains steady. The mesh convergence study was started with 88 elements that increase until 356005 elements. In the first test, Von Mises stress is 1.157 MPa, which goes up until 1.657MPa in the last test at 356005 elements. As it is shown, in 106148 elements, Von Mises stress stops its sharp increase at 1.637 MPa and keeps its very slight rise until the last point. As it is shown in the figure-2, the point with 106148 elements is a proper point to be utilized in all simulations.

Due to this, in this study all the meshing will be done by these numbers of elements. Figure-3demonstrates a meshed blade with 106148 elements.

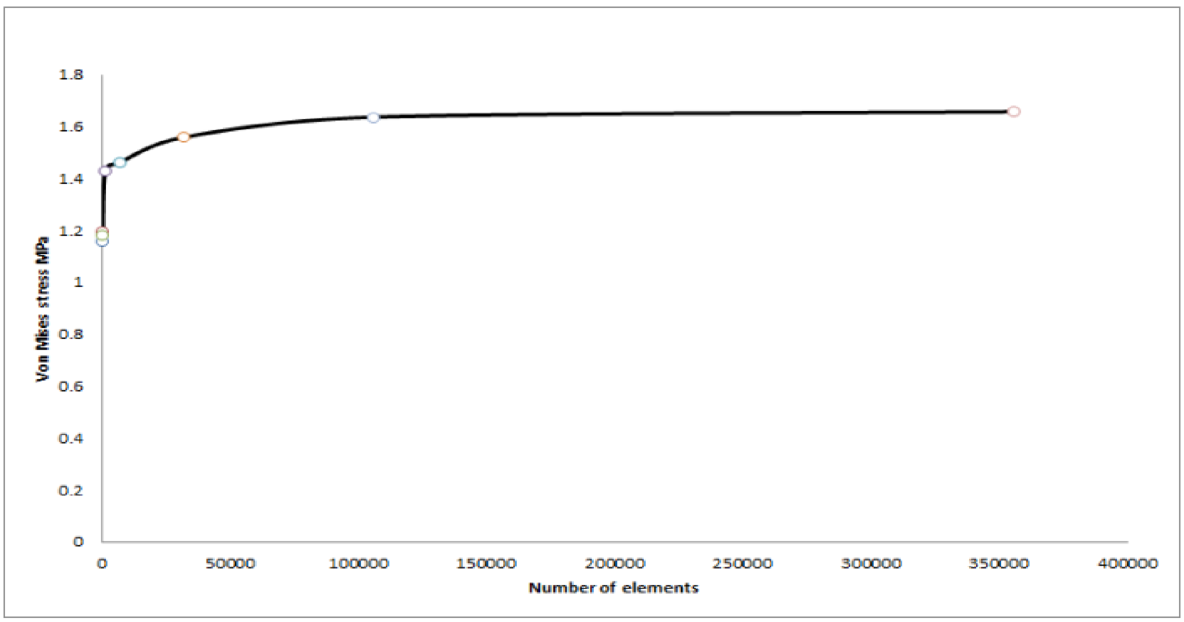

Figure-2
Trend line of mesh convergence study

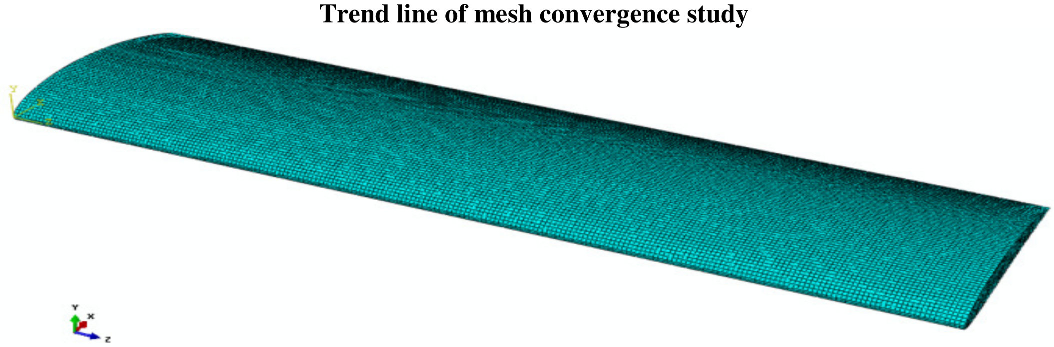

Figure-3
Meshed blade with 106148 elements

Result and Discussion

In this section, the axial fan blade with various twist anglesis analyzed. Von Mises stress value is achieved by the result of the simulation. Consequently, factor of safety is calculated for all twist angles to find their correlation. The simulation is done in various twist angles from 0° to 45° for different pressure loads that varies from 100 kPa to 800 kPa. Von Mises stress is a very important value in the result of ABAQUS software.

Figure-4 shows the simulation result of the blade with 20° of twist angle under 500kPa pressure loads. The maximum of Von Mises stress is 1.6MPa at the root of the blade that is shown with red color. The Von Mises stress at the tip of the blade has a low value.

Each series of data that were achieved from ABAQUS simulation can be plotted separately. The graph inFigure-5shows that by increasing the twist angle, Von Mises stress has a quick rise until α=5°, then it reduces gradually and the trend line of all graphs has a negative slope. By ascending the pressure load, the slope increases in the negative direction. The maximum slope in a negative direction relates to 800kPa.However, the minimum slope refers to 100 kPa loading value that its graph starts at 0.33MPa and ends at 0.284MPa. The 0.284MPa is the minimum point of all graphs. In addition, the maximum point of the graph is 2.637MPa relates to α=5° and 800 kPa.

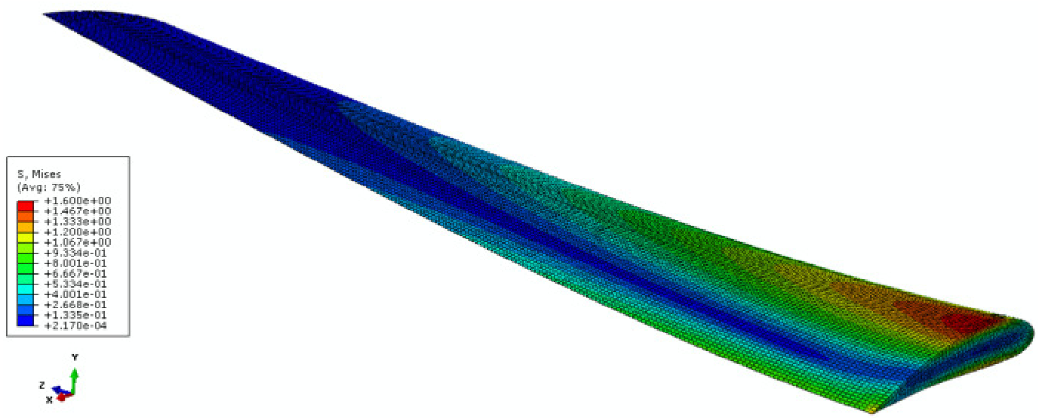

Figure-4
Von Mises stress (MPa) with twist angle of 20°, deformed shape under 500kPa

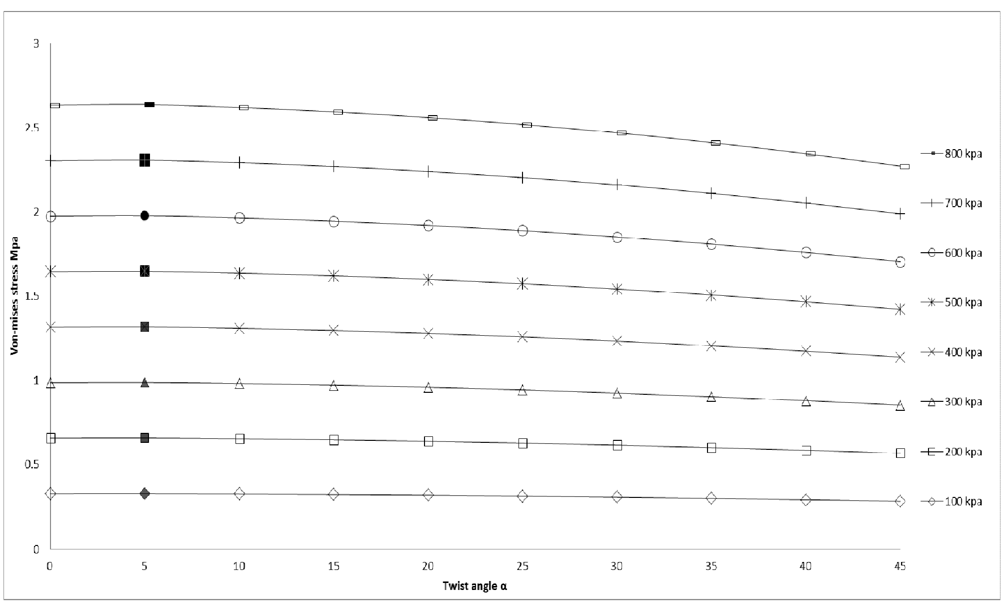

Figure-5
Von Mises stress vs.twist angle in various pressure loads

The graph in figure-6 presents that by increasing the pressure load, Von Mises stress goes up. The trend lines for all graphs illustrate that the minimum slope of the trend lines relates to α=45° and the maximum of them relates to α=5° .The trend line of α=45° has the lowest value of Von Mises stress, 0.284MPa, and the highest value of 2.556Mpa. The graph refers to α=5° has the highest value of 2.636MPa within all twist angles with the pressure load of 800kPa.

Finally, factor of safetyis calculated for all simulations and the trend of changing this value is shown in the figure-7.

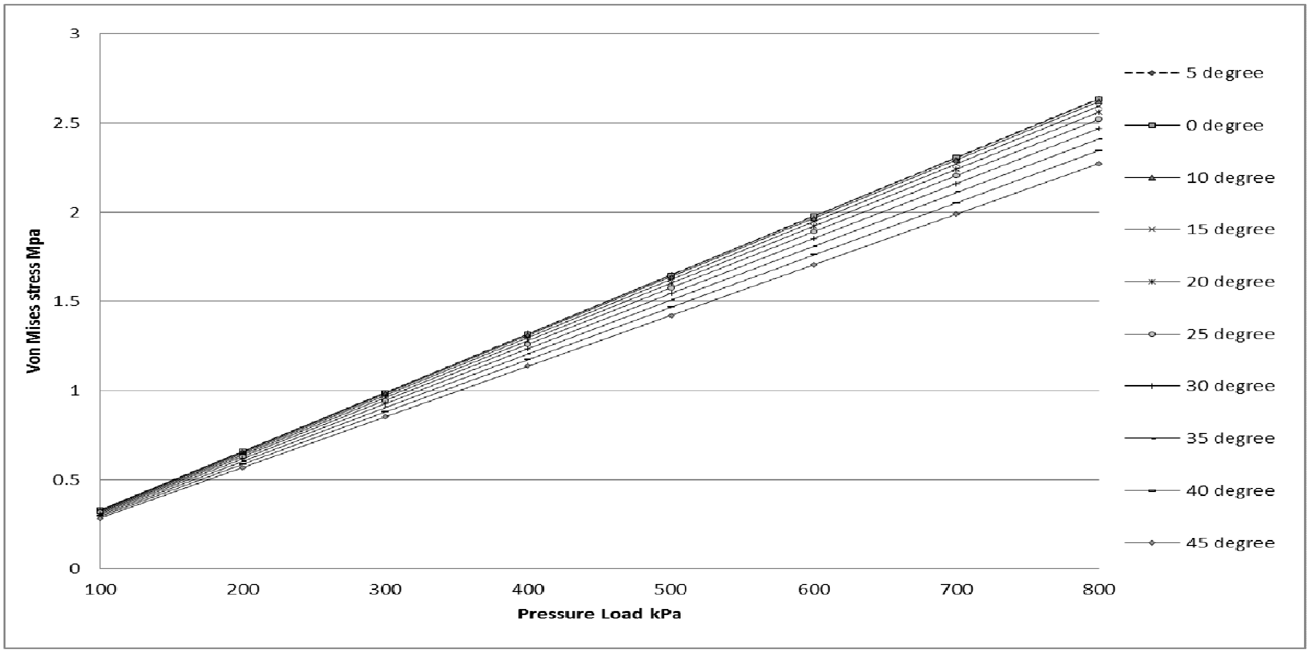

Figure-6
Von Mises stress (MPa) vs. load (kPa) for different twist angles

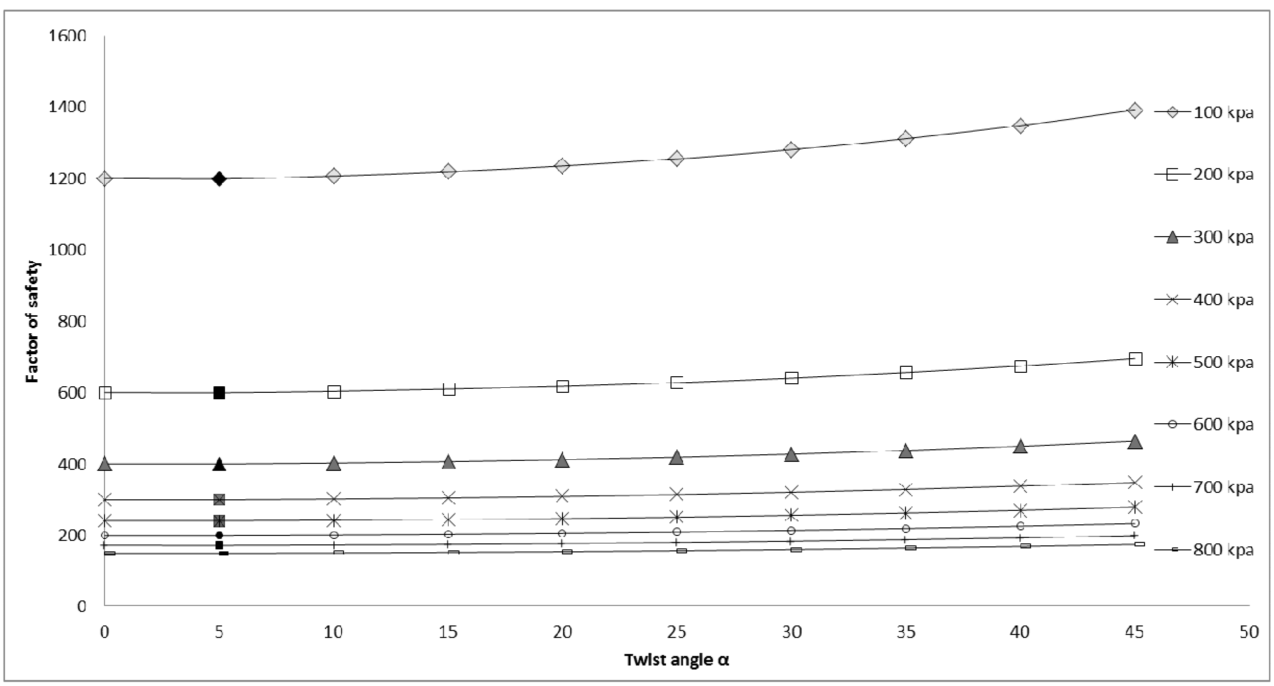

Figure-7
Factor of safety vs. twist angle for different pressure loads

As it is shown in Figure-7, by increasing the twist angle, FOS will rise. Pressure load increment leads to the reduction in FOS. The highest values of the FOS relate to 100 kPa pressure load which vary from 1198.61 at α=5° to the highest value, 1234.46, at α=45° among all values. The lowest values of FOS relate to 800 kPa. The minimum value of FOS among all values is 149.83 at α=5° and 800 kPa. The maximum value in 800 kPa series is 137.162 at α=45°.

Conclusion

As the objective of this paper was finding the correlation of the twist angle and FOS in the NACA5514 airfoil fan blade, it examined the mentioned variables by the use of FEM. The length of the utilized blade in this study was 446.5 mm. The material of the blade is Aluminum 6061-T9. In order to complete this study, the basic concepts related to the axial fan field were elaborated. Furthermore, a close investigation of the previous studies was done. Then, ABAQUS software was adopted to simulate the airfoil blade with different characteristics. The Pressure loads, which were achieved by the experimental tests, were applied on the lower surface of the blade. They varied from 100 kPa to 800 kPa. Finally, Von Mises stress was achieved from the simulation's result. This value was utilized to find the factor of safety. The analysis was performed on different twist angles that vary from 0° to 45°, in various pressure loads and constant chord length of the blade. The simulations' results indicate that by increasing the pressure load in a constant twist angle, Von Mises stress goes up, while the factor of safety falls. In addition, for a constant loading value, by ascending the twist angle, Von Mises stress declines gradually after a quick rise. Factor of safety has a counter trend that goes up gradually right after a short fall. The best factor of safety related to the maximum of twist angle and the minimum pressure load. However, selecting the best twist angle confined with some other factors in the fluid flow field such as CFM, pressure, BHP.

Recommendation for future work: Selecting a proper twist angle is confined with some other factors in the fluid flow field such as CFM, pressure, BHP. According to this, it is recommended to study these factors in the fluid flow field by CFD method to analyze the best performance of the fan. In addition, the material of the blade can be changed. In order to reduce the weight of the fan blade and increase the mechanical properties of the fan, composite materials such as FRP can be utilized. This goal can be obtained by finding the value of these factors and comparing them with the factor of safety to find the optimized geometry and the best material.

Acknowledgement

The author is grateful to Universiti Tenaga Nasional, MOHE, and GTG Industries Sdn. Bhd. for supporting this research.In addition thanks to Dr. Kannan for his cooperation.

References

1. Atre Pranav C., and Thundil Karuppa Raj R., Numerical Design and Parametric Optimization of Centrifugal Fans with Airfoil Blade Impellers, *Res. J. Recent Sci.,***1(10)**, 7-11 **(2012)**
2. Magarajan U, Thundil karuppa Raj R., and Elango T., Numerical Study on Heat Transfer of Internal Combustion Engine Cooling by Extended Fins Using Cfd, *Res. J. Recent Sci.,***1(6)**, 32-37 **(2012)**
3. Amooie M., Hooshmand Aini A., Hassanpanah M., and Tasdighi S., Investigating Flow Patterns in Wind Catchers with Underground Tunnels Using Computational Fluid Dynamics, *Res. J. Recent Sci.,***1(11)**, 64-69 **(2012)**
4. Desai D. J., 'Optimization Design of a Low Speed Axial Flow Fan Used for Local Ventilation in the Mining Industry', Lamar University-Beaumont, **(2012)**
5. Özgen C., Design of an Axial Flow Fan for a Vertical Wind Tunnel for Paratroopers, Middle East Technical University, **(2010)**
6. Jacobs E. N., Ward K. E., and Pinkerton R. M., The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel, **(1933)**
7. Bleier F. P., Fan Handbook: Selection, Application, and Design, **(1998)**
8. Carnegie W., Static Bending of Pre-Twisted Cantilever Blading, *Proceedings of the Institution of Mechanical Engineers,***171(1)**, 873-94 **(1957)**
9. Ramamurti V., and Sreenivasamurthy S., Dynamic Stress Analysis of Rotating Twisted and Tapered Blades, *The Journal of Strain Analysis for Engineering Design,***15(3)**, 117-26 **(1980)**
10. Omprakash V., and Ramamurti V., A Cyclic Symmetry Approach to the Structural Dynamic Analysis of Bladed Discs, *Communications in applied numerical methods,* **8(2)**, 81-91 **(1992)**
11. Martin O., Hansen: Aerodynamics of Wind Turbines, Rotors, Loads and Structure, **(2000)**
12. Burton T., Sharpe D., Jenkins N., and Bossanyi E., Wind Energy Handbook, *Closed-loop Control: Issues and Objectives", excerpt*475 **(2001)**
13. Méndez J., and Greiner D., Wind Blade Chord and Twist Angle Optimization Using Genetic Algorithms, *Fifth International Conference on Engineering Computational Technology, Las Palmas de Gran Canaria, Spain*12-15 **(2006)**
14. Mahri Z., and Rouabah M., Calculation of Dynamic Stresses Using Finite Element Method and Prediction of Fatigue Failure for Wind Turbine Rotor, *power,* **15** **(2008)**

15. Liu S. H., Huang R. F., and Chen L. J., Performance and Inter-Blade Flow of Axial Flow Fans with Different Blade Angles of Attack, *Journal of the Chinese Institute of Engineers,* **34(1**), 141-53 **(2011)**

16. Huang C. H., and Gau C. W., An Optimal Design for Axial-Flow Fan Blade: Theoretical and Experimental Studies, *Journal of mechanical science and technology,* **26(2)**, 427-36 **(2012)**

17. Abdullah O. I., and Schlattmann J., Stress Analysis of Axial Flow Fan, *Adv. Theor. Appl. Mech,***5(2012)**

18. Jeong J., Park K., Jun S., Song K., and Lee D. H., Design Optimization of a Wind Turbine Blade to Reduce the Fluctuating Unsteady Aerodynamic Load in Turbulent Wind, *Journal of mechanical science and technology,***26(3)**, 827-38 **(2012)**

19. Zare A., Munisamy K. M., Najafzadeh A., Shahizare B., Ahmadi A., and Jaafari A. A., Finite Element Analysis of Axial Fan Blade with Different Chord Lengths, *Indian Journal of Science and Technology,* **6(5)**, 4403-09 **(2013)**

20. Sanjay P. T., and Sunil P., Aspect of Finite Element Analysis Methods for Prediction of Fatigue Crack Growth Rate, *Res. J. Recent Sci.,* **1(2)**, 85-91 **(2012)**

21. Foroni F., Filho L., and Menezes M., Blade Design and Forming for Fans Using Finite Elements, *Innovative Algorithms and Techniques in Automation, Industrial Electronics and Telecommunications*135-40 **(2007)**

22. Zienkiewicz O. C., Taylor R. L., and Zhu J. Z., The Finite Element Method: Its Basis and Fundamentals. Vol. **(1)**, **(2005)**

23. M.L. K. K. a. A., A Finite Element Approach for Analysis of a Multi Leaf Spring Using Cae Tools, *Res. J. Recent Sci.,* **1(2)**, 92-96 **(2012)**

24. Zienkiewicz O. C., and Taylor R. L., The Finite Element Method: Solid Mechanics. Vol. **(2)**, **(2000)**