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Optimal design of the rotor blade Gyroplanecarter copter

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***Abstract*— In this study, structural optimal design of rotorblades Gyroplane carter copter which is a type of gyroplane with high-tech, has been studied. The blade used infinite element of Abaqus software have been simulated and analyzed by using of design rules and standards. Toaccurate the feasibility of the design and analysis, one dissolved example, has been selected from the directory of Abaqus software and results achieved from solving the problem in several different types of meshing were compared with directory of software results in which have a very good correlation. The links of Finite Element of Abaqus and programming Matlab software were used for optimization. Optimization model in this study is the genetic algorithm. In this part, objective function is weight of blade, modalities of Tsai-Hill criteria and the maximum thickness of layers.**

***Index Terms*— carter copter, rotor, Abaqus, Matlab, genetic algorithm**

I. INTRODUCTION

An important part of any Gyroplane is its rotor, that provides the lifting force to pick up the bird at beginning of the flight. An advanced Gyroplane is Gyroplane carter copter. The rotor blade on this birdis made of composite material. The composite materials in engineering structures have been widely used. The widely used of Composite materials in various industries is influenced by the proper efficiency of resistance and hardness to density ratio of the material.

Composite materials essentially due to having a highratioof strength to weighthas been used inrotorblade that according to complexity of the design and simulation of advanced materials, finite element of Abaqus software canreduc th is problem to a large extent. Reduction of weight is a very important issueinaerial structures. The more reduction inweight of structure, could increase the authorized amount of carrying load or decrease the amount demand of fuel.Another benefitof decreasing weight in aerialstructures isthat causes to reduce driving force of the engineand leads to reducethe manufacturing cost.

Since early1985,introduction of the optimizating techniquesbegan for designinghelicopters[1]. In this field, the further investigation was performed for optimization in designingofrotor craftby Ganguli[2] and Celi[3].

Volovoi[4]in 2005,presenteda multi-level optimization ofcompositerotor blades. On the other hand, a multi-level optimization method for decreasing of weight and vibration and increasing strength of the blade was done by Kim and Sarigul with a modality to prevent the Resonancephenomenon [5, 6].

In 2008,LiHongLi[7] proposed new method for designing of a cross-sectional of the rotor blade. Ganguli and Kopra[8],to achievea hardness of cross-section for optimizing the aero elastic of helicopterrotor blades changed the shell thickness and fiber direction of cross-section of the two cells. Furthermore, in order to satisfy there quirements of cross-sectional hardness, Orr and Hajela[9], considered amulti-cell cross-sectional in which flanges are reinforced in amulti level design. Volovoi [10] in a D-shaped cross section beam to preserve the values of hardness and center section in the optimal range, assumed values of thickness, fiber direction and D-shaped beam locations are variables. According to the wide range of solutions in multi-layer composite optimization, genetic algorithm duo todeal with the solution set directly hasvery capabilitiesat this type of optimization.

Taheri Far in his thesisstudied design and optimization ofrotor blade Gyroplane ELA with the aim of minimizing the weight and changing of the position of blade.

II. BLADE MODELING

In this study, in order to Modeling and analysis of rotor blade Gyroplanecarter copteris used the Abaqus software. This software has nine parts in which all of steps for assuming bladehas mentioned at this section. In this case, type of problem analysis has been considered statically.

A. Structural geometry

In this Section, 6 modeling separately have been donein which all of them 3D model and Deformabletypeis used. To start the simulation, first the blade image in Autocad software calls and then knowing one of the parts dimensions (e.g. thickness rib) calculated scale value and dimensions of the other parts are obtained and finally modeling is done. The sixth section is modeled as follows: shell blade with shear ribs and webs figure(1), the weight adjust the blade figure(2), Article connectors spar to shell figure(3), Modeling core from stem blade to the first ribfigure(4), core in trailing edge (5), spar flanges figure(6).

B. Material properties

The blademodeled in this study is possess in gincreasinginertia weight(weight adjusted) of uranium, article bondingsparto the shell of silica, foamcoreand composite shellof glass-epoxy. According to the successful experience at selection material composite wings, in this study, spar flanges are considered from T6 6106 aluminum. Properties of these materials mentioned in Tables (1), (2), (3), (4) and (5).

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Table 1. Properties of glass-epoxy[12]

50GPa	E_1
15.2 GPa	E_2
0.254	$_{12}\nu$
4.7 GPa	G_{12}
4.7 GPa	G_{13}
3.28 GPa	G_{23}
1000 Mpa	X_t
-600Mpa	X_C
30Mpa	Y_t
-120Mpa	Y_C
70Mpa	S

Table 2. Properties of uranium [13]

208 GPa	E
0.23	ν
19100 kg/m^3	ρ

Table 3. Properties of silica [13]

73 GPa	E
0.165	ν
160 kg/m^3	ρ

Table 4. Properties of foam [14, 15]

350 MPa	E
0.3	ν
30 kg/m^3	ρ

Table 5. Properties of T6 6106 aluminum [13]

69.5 GPa	E
0.3	ν
2700 kg/m^3	ρ

C. *Interaction of models*

Incases where the two pieces haveinteract with each otherandminordents, with a choice oforiginal and sub-surface, sub-surface nodesby commandTie,withoutinitial stress createdonthe piecewill be transferred on the original surface. This will correct the geometry of the parts will be indented. Tie constraint in Abaqus software deal with task of closing the freedom degrees of nodes on the two pieces.This command is that can be determining the freedom degrees of rotational of movement which needs for clamping two pieces together.

D. *loading*

Since the aerodynamicloads are appliedon the blade length direction, the calculation and equation (1) in order to conversion the metric system on the blade was used, while It is related to the previous chapter and applied required coefficient. On the other hand, in order to applying the centrifugal force, the command Rotational body force is used, in which the angular velocity in radiansper second is equivalent to49/82.

$$L = (0/5) \times \rho \times CL\alpha \times C \times \Omega 2 \times R^2 \times \Delta r(\theta x^2 + \lambda x) \quad (1)$$

In this equation Δrisequal to1.6 blade length, and C is the average chord of the blade.

$$L = (0/5) \times 0/002377 \times 5/729 \times 0/861 \times 49/82^2 \times 16/75^2 \times 2/791\ (0/0349\ X^2 + 0/018\ X)$$

$$L = 423/76\ X^2 + 218/56X$$

In this equation, X is the distance of root from any desired point along the span. Also, to convert to the metric system, the above equation is multiplied by the number 4/45.

Also, in order to applying the boundary conditions of blade, rootisboundedon all directionsthataresh own in figure (7).

III. DISCRETIZATION OF PROBLEM

Operation of Discretization of problem at Mesh in gmoduleisdonethatso-called meshing. At this module appropriate to problem one element for each Section is selected and the entire model using appropriate elements is discrete. The meshing of weightconfiguration,the3DelementtypeC3D8Risused that it is8 nodes.

Also, at the meshing of blade composite shell is used of Shell element and type of S4R.Themeshing of foam core, article bonding the spar to shell and sparflanges, elements are 3D and of type ofC3D8R. Meshing size in the bladeshellisequivalent 0.05.Also, by this size of meshing that is not too small, time of the analysis and optimization is saved. Comparison between 3 meshing types mentioned can be seen in the Figure (8).

IV. ANALYSIS

After performing all necessary measures to define the model, entered into the module and addressed the analysismodel. After completion of the analysis, the output of thepre-specified, in this section can be seen that according to figure (9) values of von Misesstress and its distribution on the blade surface have been identified.

As shown in figure(9), contour of stress distributionontheblade surface is uniform. The maximumstress valuesare near thebladeroot which ismarkedby red color and duo toattachment the blade on the root, it isnatural.On theother hand,due to thelack ofscatteringstress distribution, stress concentration isnot creationon thesurface of theblade.

V. ROTOR BLADE OPTIMIZATION

Compositesduo to possessing remarkable abilities such ashigh strength and rigidity to weight ratio are concluded several design parameters in which that adjusted such orientation of fibers, thickness of layers, the arrangement of fibers and kind of achieve the best possible structures are involved applying appropriate optimization algorithms in which Due to the inherent complexity of the issues composite is necessary according to the structure of the model, great care is considered in selecting range of analysis and interest optimization. Implementation of a genetic algorithm is that first to encoding problem parameters, an initial population is determined and value of fitness function for all individual smeasured. Then Parentchromosomesare selected by using different methods and by applying genetic operatorson the chromosomes, anew generationis created. Then to satisfy the stopping criterions, the algorithm is terminated; otherwise the procedure of algorithm is repeated again.

Except the Shell of Rotor bladecarter copter,other partshad Solid Modeling. According to Shell modeling in this study, optimization is done, only on shell of the composite blade. In optimizing composite blade, each individual has 2 chromosoms in which one of them contains angels of fibers and the other consists of thickness of layers. According present experiences in optimizing of blades and because of declining in duration of calculation and increase in answers, maximum no. of layers were considered 25 layers in this study. Minimum layers no. are 7, in order to maintaning Tessai- Hill.so each chromosom has 25 genes. Additionally, no. of primary population is equal 20. Chromosoms were selected competetively and quantitative coding was used for coding of prameters.

A. *design variables:*

Variables of design in this optimization include thickness and angle of the fibers which for each layer can be different. Based on mentioned already, maximum numbers of layers are equal with 25 considered layers and also, minimum and maximum thickness of each layer is measured 0.05 mm and 0.6 mm respectively. On the other hand, according to restriction in construction, it has been used from from applyable angles for fibers in this case: 0, +30, -30, +60, -60 and 90 degrees.

For calculating numbers of design variables, we used from following formula.

Numbers of design variables in optimization process: K*J*(P*E) (2)

In this equation K is equal with the number of chromosomes, the J= maximum number of genes on one chromosome, P= number of parts of a blade in order to optimization and E= ceramic layer of longitudinal sections. If K=2, J=25, p=1, E=1 then Numbers of design variables in optimization process will be equal 50.

B. *objective function:*

objective function is defined as F= (w/ w*)+ R*(0 & T_H-1) which w= weight of structure, w*= coefficient without weight dimention, T_H= Tsai- hill criteria and R= constant value, which is multiplied by the maximum value between 0 and amount Tsai - hill subtracted from 1(R*(0 & T_H-1)) and is considered equal with 10. Aim of optimization of rotor blade in this study is minimizing of its weight.

C. *modalities and qualifications:*

One of applied modalities in the optimization program of considering rotor is scattering criteria of the Tsai – hill and another modality is maximum thickness of layers. So in order to go under (bear) cutting straining pressures by the shell, maximum thickness of layers has been calculated equal to 4.5 mm.

For prevention of surcharge in modalities, the objective function is used, in this way (surcharging of the objective function is used for satisfaction of modality problem), if the qualification of the problem is not well done surplusing of objective function causes a reduction in amount of function (if the aim maximizing). In this situation capability of human decreases or even is destroyed in participation for producing future generation.

D. *planning inputs:*

Planning inputs contain following parameters:
Size of population= 20
Number of genes in each chromosome: 25
Rate of mutation:0.08
Rate of crossing: 0.7
Minimum no. of layers: 7
Maximum no. of layer: 25
Maximum no. of generation: 30

VI. DISCUSSION AND RESULTS:

After performing optimization activities, linking of corresponding softwares and abaquse (which was lasting about 140 hours, a result graft of optimization has been developed according figure (10), which the weight of composite shell drastically declines from -126/802 Kg to 78/7 Kg and total weight of blade diminished by 37/9 %.

Tsai- hill criteria and ceramic layer before and after optimization are existing in figures (11), (12), (13) and shows the thickness of whole layers decreases from 7 to 4/4 mm. Also, amount of calculating Tsai- hill is 0/65 that indicates modality of the problem has well done and there is no damage to the structure. Thereby it can be said that:

1- In abaquse software, the meshing of designed models are so important for modeling of considered blade. Since in the absence of proper meshing, volumes of calculations have elevated and in optimizing of the problem, time also increases.

2- With decreasing no. of layers and their thickness, which is due to problem optimization (solving problems), the cost of design and production of structure declines.

3- In optimization section, velocity of algorithm decreases with increasing no. of chromosomes and the optimization is taking a longer time. Thus, for reaching for better answers should use from a population with bigger sizes, since, although duration of solving problems increases but accuracy of answers will have better convergence.

Figures

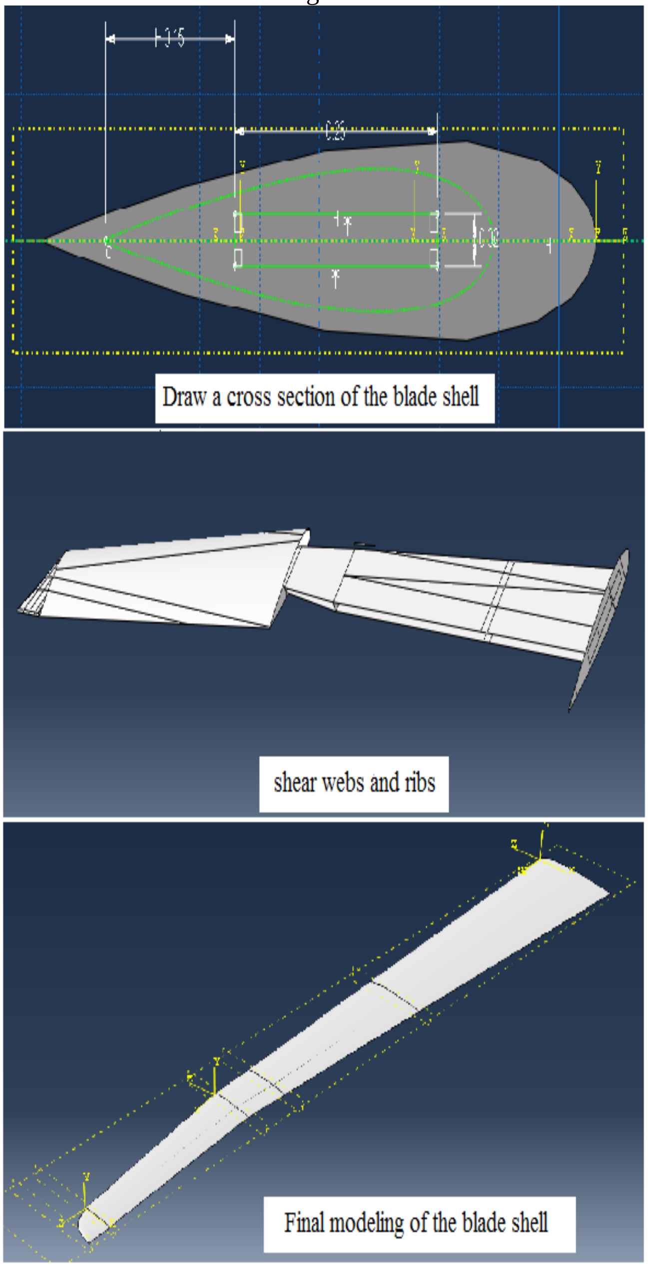

Fig 1. Shell Blade withshearwebs andribs

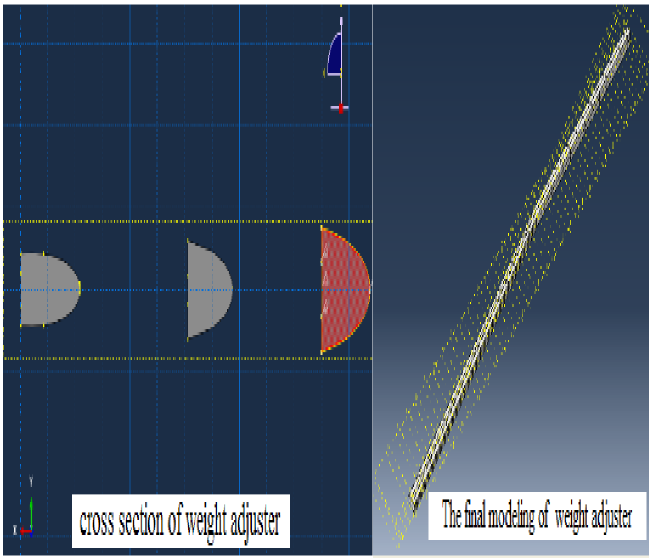

Fig 2. Weight adjuster of blade

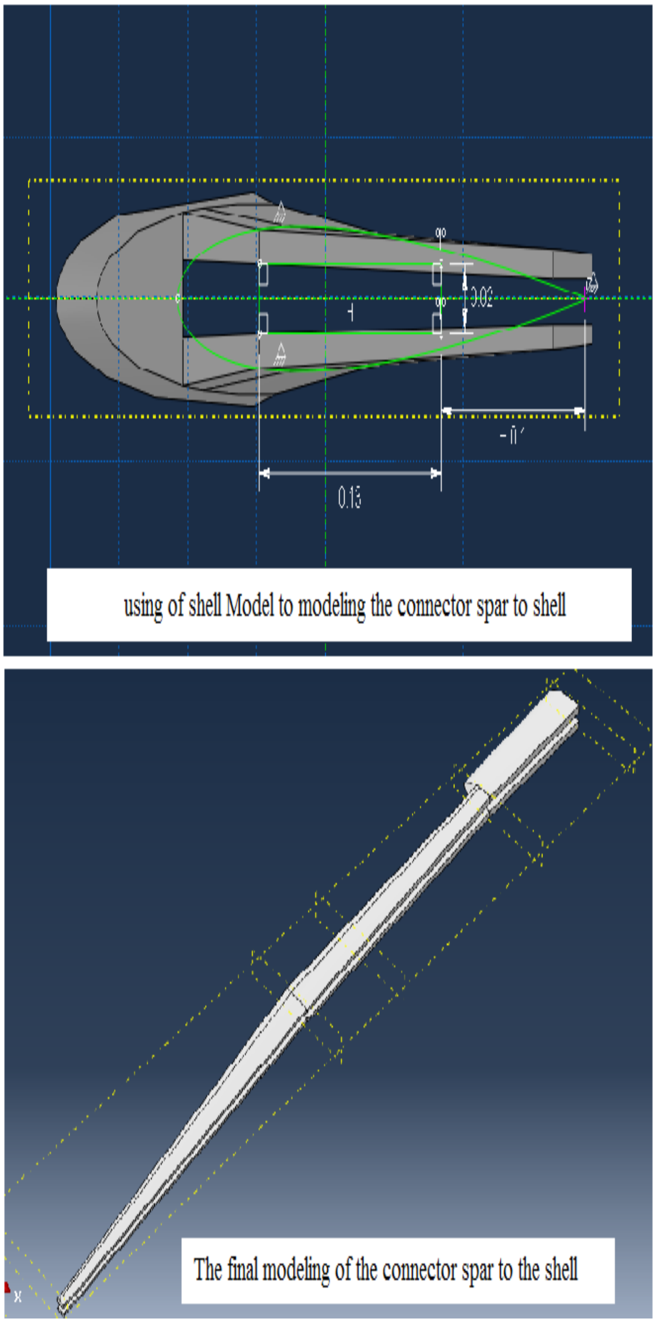

Fig 3. Matter bonding spar to the shell

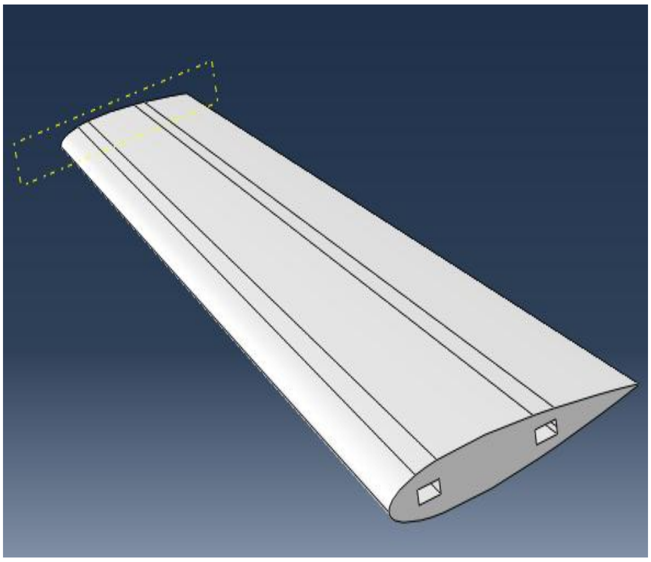

Fig 4. Modeling of core from blade root to first rib

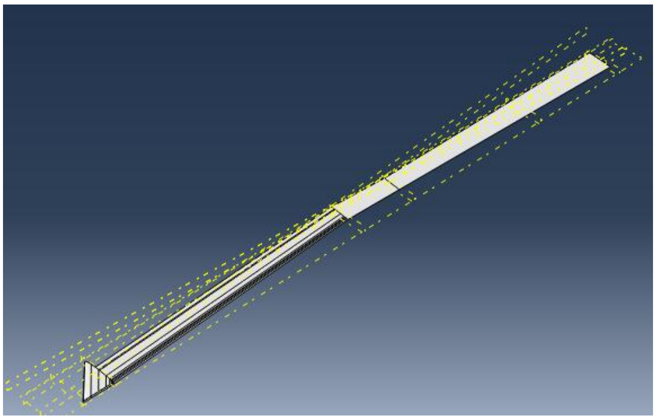

Fig 5. Final modeling of core at the trailing edge

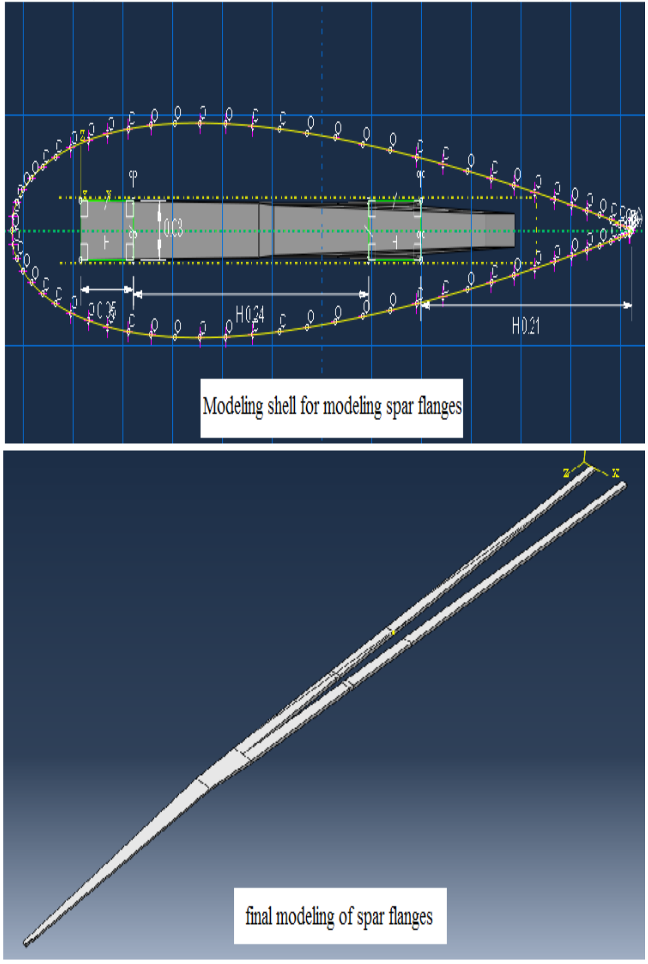

Fig 6. Modeling of spar flanges

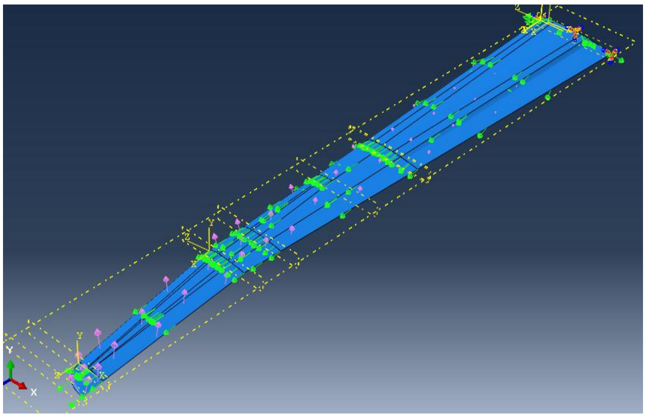

Fig 7. Applying all of the loading on the blade

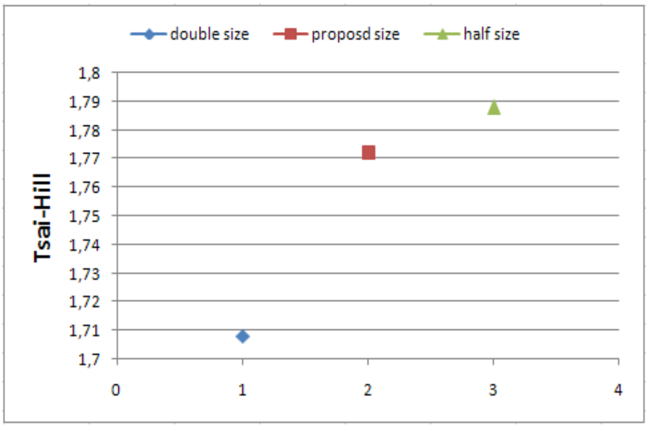

Fig 8. Variation of Tsai-Hill with meshing size

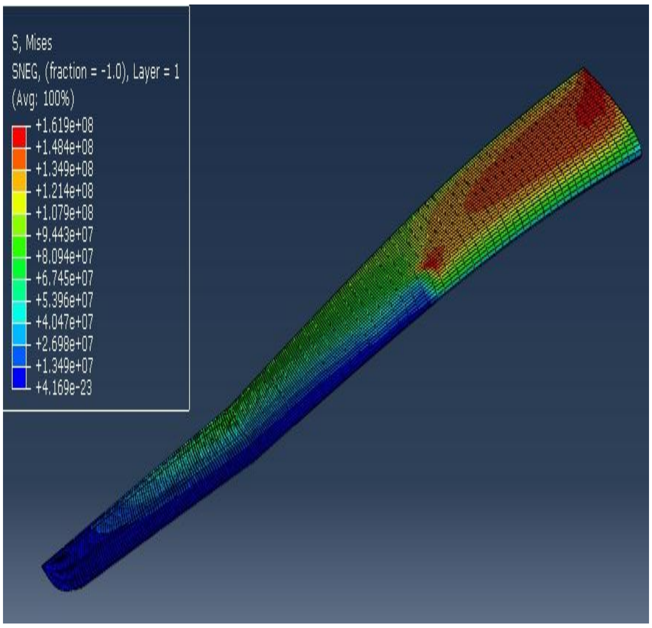

Fig 9. Value and distributionof von-mises stress

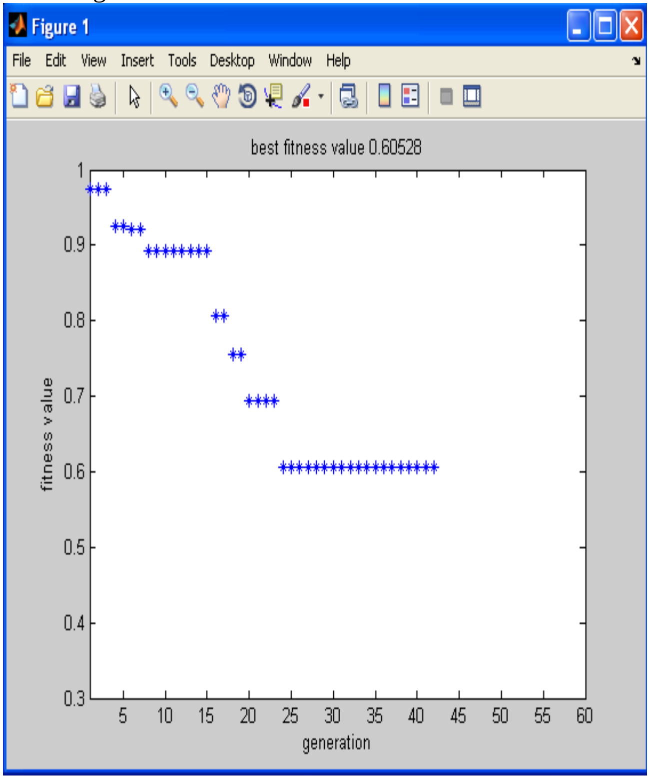

Fig 10. Diagram obtained of optimization

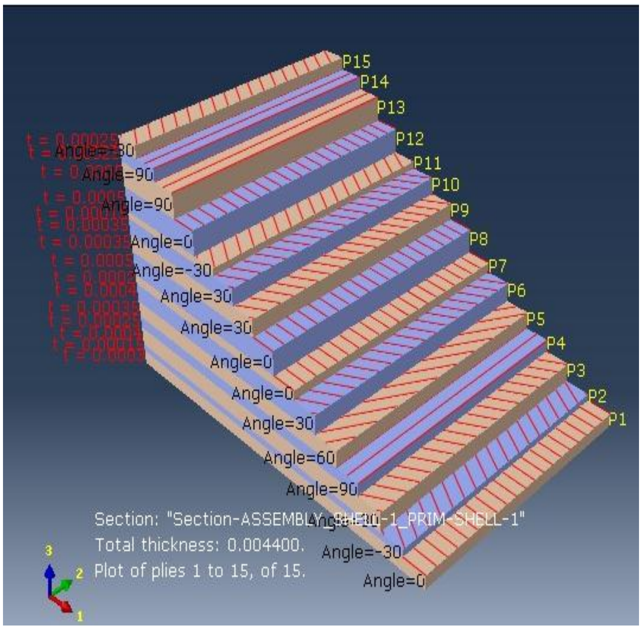

Fig 11. Number of layers and thickness after optimization

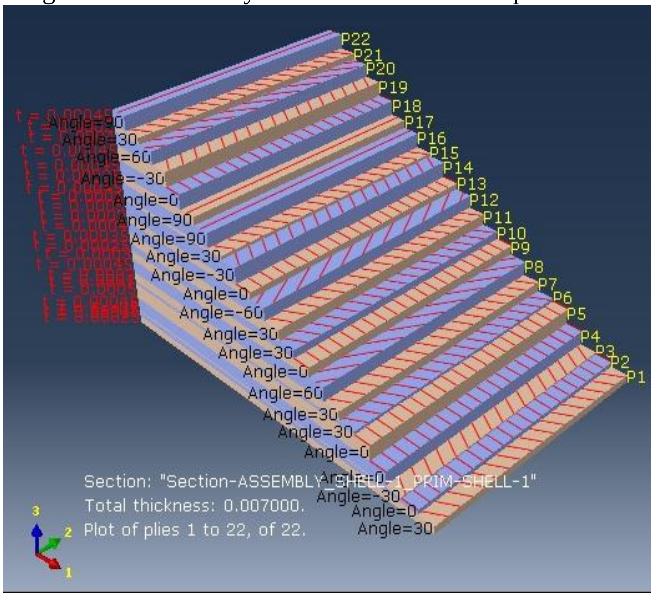

Fig 12. Number and thickness of layers before optimization

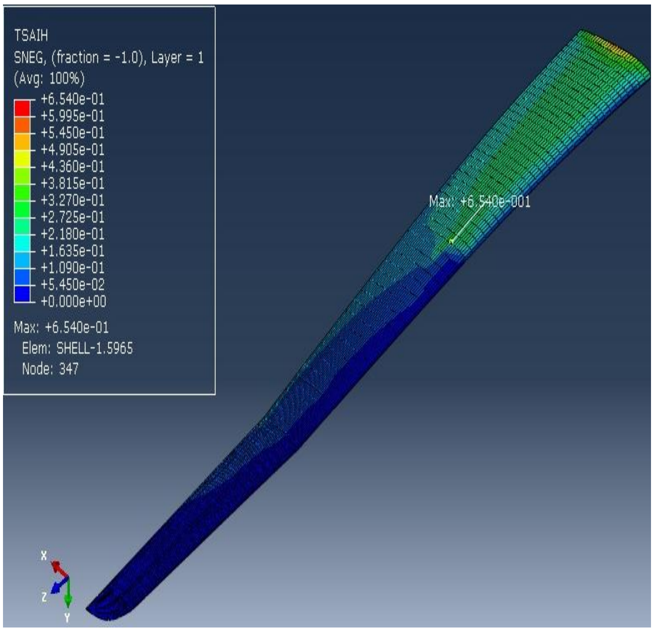

Fig 13. Tsai-Hill criteria

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