# The structural optimum design of laminated slender beam section with arbitrary material distribution using a genetic algorithm

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**Abstract:** *In this paper, a study on optimum design methodology of a section structure of a composite material rotor blade using genetic algorithm is conducted, in order to calculate repetitive optimum design, analysis of strength, fatigue and vibration on blade section. In the analysis, the minimum mass of the rotor blade was defined as objective function; stress damage index, center of mass on blade section and fatigue life of blade were set as constraints. By applying genetic algorithm, laminate angle and thickness of skin, thickness, location and width of torsion box were established as design variables; the optimum design methodology on section structure of the composite material rotor blade was validated. The integrated design program of the section structure of the composite material rotor blade based on this study deals with designing the optimal rotor blade section which meets the design load and constraints given by the random position of rotor blade. By using blade's section design variables derived from this, it can be facilitated for basic information on detailed design of rotor blade.*

**Key Words:** *Genetic algorithm, Composite structure, Blade, High aspect ratio, Optimum design*

## NOMENCLATURE

| | |
|---|---|
| T | Three-dimensional strain components are expressed by the matrix. |
| $\kappa$ | Column matrix of elastic twist and curvature measures. |
| $\gamma$ | Column matrix of extensional and shear measures. |
| $\omega_{ij}$ | Warping vector. |
| D | Stiffness matrix of composite laminate. |
| $S_{ij}$ | Constants depending on initial twist and curvature. |

## 1. INTRODUCTION

Rotor blades are the core component of helicopters; to design rotor blades integrated design from multiple areas such as construction, vibration and elasticity, etc. are required. In case of analyzing the composite material of helicopter blades or wing structure of aircraft as a beam structure, it is required to adequately reflect the mutual movement direction of coupling effect based on material’s anisotropy and non-conventional effects, such as transverse shear deformation or warping deformation inside and outside of the section; restrain warping even its aspect ratio, becomes a very important analytical factor[1, 2]. In relation to studies on rotor blade modeling, Masfield and Sobey [3] conducted a study on coupling stiffness of bending, twist and tension of fiber reinforced composite material. Hong and Chopra [4] analytically assessed aspects of randomly laminated section as in box type with one-cell structure of rotor blade. Hodges and Dowell [5] explained the relation between strain and displacement by using Hamilton's principle in order to accurately calculate deflection. Hong and Chopra [6] idealized I-type section laminated with three composite material of bearing less rotor blade modeling and delineated behavior of flexible beam. Rehfield [7], Hodge et al. [8] and Rehfield and Atilgna [9] conducted a study on improving accuracy of structural model of composite material beam and presented a model based on the structural flexible aspect. Bauchau and Hong [10, 11] conducted a study on displacement, rotation and infinitesimal deformation rate of thin wall beam with the initial bending and twist through study on a structural dynamics and aerodynamics of rotor blade. Bauchau developed research analysis code, called “DYMORE” by using structural dynamics of rotor blade. Lee et al. [12] applied laminated composite material on box beam when designing rotor blade, using genetic algorithm to improve efficiency of optimization. They constructed modeling by removing leading and rear edge of air foil to improve accuracy of section aspect. After that, the box beam model was enhanced by applying laminated anisotropic composite material in design process.

Smith et al. [13] quantified Vlasov model and analytical beam model in an effort to expect effective elasticity and load behavior of mixed box beams. Ganguli et al. [14] applied Vlasov model to two-cell composite blades on optimal aerodynamics of rotor. Orr et al. [15] selected classical beam theory, thin-wall beam theory to calculate stiffness on twist , bending for tilt rotor blade design.

As a related research, Goldberg [16] has started designing mass spring dashpot with simple-GA (simple-genetic algorithm), and so far, many studies have begun. The optimal gas pipeline, robot behavioral evolution, nerve network learning, fuzzy membership function, etc. are the related studies and can be widely applied. Hajela [17] showed aspects of genetic algorithm when designing multidisciplinary composite blade with non-convex design variables by using aspects of genetic algorithm. Rodolphe Le Riche [18] optimized ply stacking sequence on stability condition. In this maximization, he proved the efficiency by suggesting permutation which is new genetic operator to genetic algorithm. The permutation (operator) was facilitated in maximizing stacking sequence by Boyang Liu [19]. In this paper, an algorithm which can satisfy various criteria has been developed by substantializing blade weight reduction by genetic algorithm.

Chen [20] described the characteristics of PreComp, VABS (Variational Asymptotical Beam Sectional Analysis), FAROB, CROSTAB and BPED based on the comparative study on sectional analysis program for dimension reducible modelling and compared performance of sectional analysis. Hu [21] conducted the study on VABS-IDE which optimizes the process of cross-sectional analysis and recovery utilizing GEBT [22] and VABS [23] which calculates one-dimensional beam’s movement by non-linear analysis. In this study, the mass of blades was minimized in early design phase of the rotor blade and the optimum design of the composite material rotor blade was implemented in order to decide the design variables disposition of the section blade which meet various constraints. As an optimal design tool, new search space instead of the transformation process is investigated and effective genetic algorithm was used to quickly find global optimal design points or design points close to the global optimal location with small entities.

The mechanical textile value of each composite material that constructs the rotor blade section has equivalent stiffness with laminated composite material; however, it applied the smeared properties method defined by single material to minimize the number of elements in blade section, trying to reduce the calculation time based on the structural optimization of the blade section.

The mass of the structure is set as a final objective function for the structural optimization of the rotor blade section; in order to decide design factors in disposition of the inside of section of blade, thickness of skin, thickness, location and width of torsion box and ply angle of laminated skin were set as design variables.

By setting the stress damage index of various composite materials, center of mass, shear center, equivalent stiffness of section, minimum mass of blade per unit length and fatigue life as constraints, various constraints which should be considered in structural optimization of the rotor blade section were applied.

The integrated design program of the composite material rotor blade section developed by this study is to design the optimal rotor blade section which meets design load, boundary and constraints given by the random position of the rotor blade and by the section design variable derived from this process; it can be facilitated as basic information for detailed design of the rotor blade.

## 2. THEORY FOR LAMINATE SLENDER BEAM MODELINIG

### 2.1 Dimension Reduction and Stiffness Matrix through Sectional Analysis

To define the dimensional reduction model, we should demonstrate the material geometric properties through cross section analysis as a form of matrix. An one-dimensional energy function type is presented and its calculated matrix will be connected to a type of one-dimensional beam. First of all, the section analysis should take a precedence in order to reduce a three-dimensional analysis model into an one-dimensional analysis model. As in Fig.1, stiffness and mass matrix, moment of inertia and neutral point can be achieved by section analysis.

After selecting proper position on the cross-section of the configuration of use of airfoil having three-dimensional torsion or complex curvature similar to wing structure, the energy of strain per unit length should be calculated by section analysis on this exact position. The three-dimensional strain field can be arranged as below including elastic strain, warping vector and differential of warping vector.

$$
\begin{aligned}
\Gamma_{11} &= \gamma_{11} + x_3\kappa_2 - x_2\kappa_3 + w_1' \\
2\Gamma_{12} &= w_{1,2} - x_3\kappa_1 + w_2' \\
2\Gamma_{13} &= w_{1,3} + x_2\kappa_1 + w_3' \\
\Gamma_{22} &= w_{2,2} \\
2\Gamma_{23} &= w_{3,2} + w_{2,3}
\end{aligned}
\tag{1}
$$

where $\gamma$ is the classical extensional strain measure, $\kappa_i$ is the moment-strain. the $\omega_{ij}$ are warping vectors.

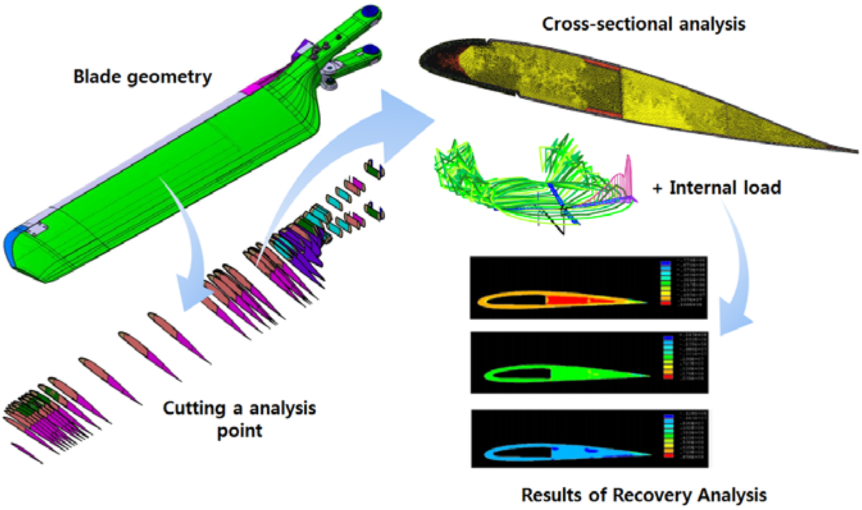


Fig. 1 - Reducible model & recovery analysis process for slender composite beam

The three-dimensional strain including term of warping function can be presented by facilitating Eq. (1). The energy of strain is as below.

$$U = \frac{1}{2}\left\langle\left\langle \Gamma^T D \Gamma \right\rangle\right\rangle \tag{2}$$

where the three-dimensional strain components are expressed by the matrix.

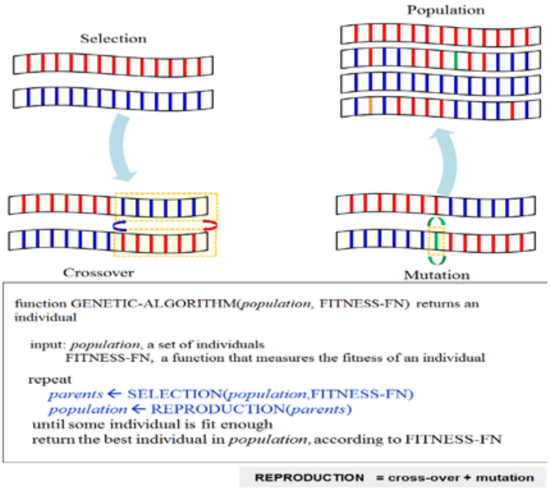
$$\Gamma = \lfloor \Gamma_{11} \quad 2\Gamma_{12} \quad 2\Gamma_{13} \quad \Gamma_{22} \quad 2\Gamma_{23} \quad \Gamma_{33} \rfloor^T \tag{3}$$

In here, D is the stiffness matrix of the composite laminate. The section analysis can be calculated, and it can be presented as a form of Eq. (2) by definition of strain energy then, the stiffness matrix can be achieved in the same way of classic composite material dynamics. When the strain energy for 1-D beam model allows the transverse shear, deformation is presented as an energy function form; thus it will be same as Eq. (4). where the $S_{ij}$ constants depend on initial twist and curvature as well as on the geometry and materials of the cross-section.

$$2U = \begin{Bmatrix} \bar{\gamma}_{11} \\ 2\gamma_{12} \\ 2\gamma_{13} \\ \bar{\kappa}_1 \\ \bar{\kappa}_2 \\ \bar{\kappa}_3 \end{Bmatrix}^T \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} \\ S_{12} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26} \\ S_{13} & S_{23} & S_{33} & S_{34} & S_{35} & S_{36} \\ S_{14} & S_{24} & S_{34} & S_{44} & S_{45} & S_{46} \\ S_{15} & S_{25} & S_{35} & S_{45} & S_{55} & S_{56} \\ S_{16} & S_{26} & S_{36} & S_{46} & S_{56} & S_{66} \end{bmatrix} \begin{Bmatrix} \bar{\gamma}_{11} \\ 2\gamma_{12} \\ 2\gamma_{13} \\ \bar{\kappa}_1 \\ \bar{\kappa}_2 \\ \bar{\kappa}_3 \end{Bmatrix} \tag{4}$$

## 3. GENETIC ALGORITHM FOR COMPOSITE BEAM STRUCTURE

Genetic algorithms follow the law of the natural world allowing a highly viable individual to adapt to the natural world and evolve into a superior offspring. They are built on the genetics and follow the principles of biological evolution.



```
function GENETIC-ALGORITHM(population, FITNESS-FN) returns an
individual

  input: population, a set of individuals
         FITNESS-FN, a function that measures the fitness of an individual

  repeat
     parents ← SELECTION(population,FITNESS-FN)
     population ← REPRODUCTION(parents)
  until some individual is fit enough
  return the best individual in population, according to FITNESS-FN
```

Fig. 2 - General structure of genetic algorithm

Previous optimum methodologies facilitated a derived function and selected the way of sequentially exploring objective functions or securing starting point and then starting to explore. Therefore, traditional methodologies were effective in narrow areas but, there is a limitation to show greater performance on broader areas. Genetic algorithms do not use the differential concept of target function but, execute probability and directional exploration, which can solve an optimization problem. As in Fig. 2, Genetic Algorithms are algorithms having an entity-group that executes optimization by selecting, distributing and mutating as in order of biological evolution.

### 3.1 Encoding

As for the laminate sequence in table 1, it gives the biggest benefit since it only uses $SST_{lam}$ and $SST_{ins}$ resulting in small and effective enciphering type for genetic algorithm. SST defines the thickest laminated sequence and enumerates angles of fabric. $SST_{lam}$ designates the order to enter into $SST_{ins}$, not the part of the thinnest ply laminate and "0" of $SST_{ins}$ shows the ply that already included in the thinnest play laminate, it became to exist in all other laminate order. A chromosome is perfectly shown in table 1. The third chromosome $N_{str}$ shown in table 2 defines column of SST which attribute to four (4) panels to be mixed.

These three chromosomes are combined and formed a genotype. As a result of symmetry requirements, the genotype can be simplified considering to be listed in table 2.

Table 1. Genotype, including of three chromosomes to calculate sequence table

| | |
|---|---|
| $SST_{lam}$ | [45 0 0 -45 0 45 90 45 90 90 45 90 45 0 -45 0 0-45 ] |
| $SST_{ins}$ | [ 0 0 1 7 3 0 0 5 0 0 6 0 0 4 8 2 0 0 ] |
| $N_{str}$ | [ 19 16 17 9 ] |

Table 2. SST genotype, abusing symmetry

| | |
|---|---|
| $SST_{lam}$ | [ 45 0 0 45 0 -45 90 -45 90 ] |
| $SST_{ins}$ | [ 0 0 1 7 3 0 0 5 0 ] |
| $N_{str}$ | [ 19 16 17 9 ] |

### 3.2 Initialization

As shown in Fig. 3, genetic algorithms are executed sequentially to perform optimization. The initialization on the laminates of the composite material, it can be started to create stacks which have $N_{min}$ laminate. A random position of the inside stack in the adjacent ply can select all executable set of ply angles which meet the design requirements. In the set, the angle is randomly selected and added to the laminate sequence table. To restore symmetry, the same ply is added to the corresponding matching position in the next step, creating a different heat on SST. Table 3 is a process that initializes and adds laminate sequence. The laminate process continues until it reaches the maximum ply $N_{max}$

Table 3. Laminate process, $N_{min}$=10 to 12, symmetry returning step

| 10 | 11 | 12 | | 10 | | 12 |
|---|---|---|---|---|---|---|
| | -45 | -45 | | -45 | -45 | -45 |
| -45 | 0 | 0 | | 0 | 0 | 0 |
| 0 | +1: 0 | 0 | | | 0 | 0 |
| 45 | 45 | 45 | | 45 | 45 | 45 |
| 90 | 90 | 90 | | 90 | 90 | 90 |
| 90 | 90 | 90 | | 90 | 90 | 90 |
| 90 | 90 | 90 | | 90 | 90 | 90 |
| 90 | 90 | 90 | | 90 | 90 | 90 |
| 45 | 45 | 45 | | 45 | 45 | 45 |
| 0 | 0 | +1: 0 | | | | 0 |
| -45 | -45 | 0 | | 0 | 0 | 0 |
| | | -45 | | -45 | -45 | -45 |

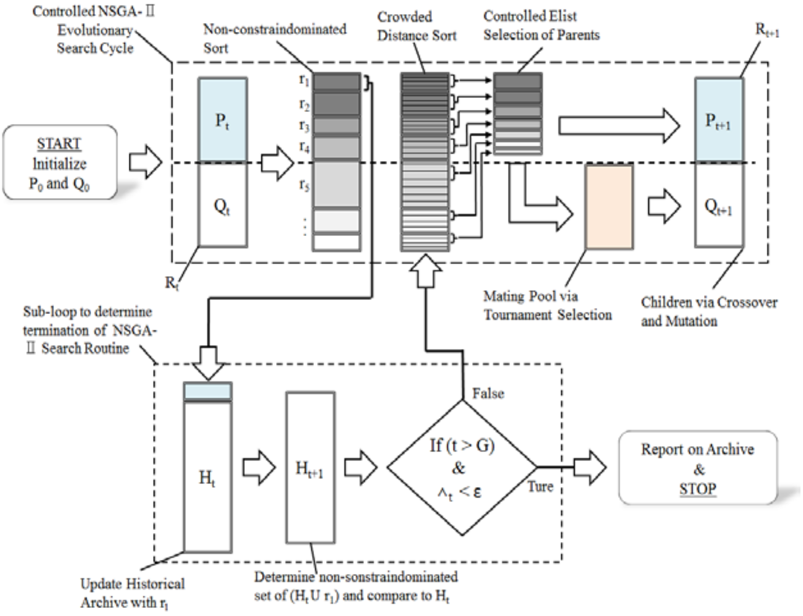


Fig. 3 - Schematic of the NSGA-II genetic algorithm [20]

### 3.3 Reproduction

In principle, both intersection and mutation can be utilized on SST and thickness definition $N_{str}$. The mutation of chromosome, $SST_{lan}$ builds the variances of ply ±θ (balance) inside of laminate sequence by randomly selecting among the ply angle group which allowed in that position. The chromosome's mutation, $SST_{ins}$ basically belongs to random exchange of two SB-cycle. While the order of ply is not affected, the only guidance when it creates in SST is to replace the ply drop. The only guidance is △n-rule in which the single component is replaced during mutation with randomly created numbers between $N_{min}$ and $N_{max}$.

Since the SST intersect operation consists of selecting same length of ply, in $SST_{ins}$, the same number is selected between two types and then this subtype is replaced. This type of wok can easily generate defects, it is required to apply follow-up repairs based on the technique described in population initialization due to the fact that it violates the guidance of directional loss. The cross over on $N_{str}$ consists of randomly selecting two groups with same length and the exchange afterward between two configurations. In this case, SST can be measured after confirmed based △n-rule.

1. The population is divided into feasible and not feasible designs.
2. Divide into feasible designs based on suitability and not feasible design based on constraints.
3. Reintegrate classified, feasible, and not feasible designs into a single population.
4. Select first genotype $n_{best}$ for reproduction (including not feasible designs).
5. Randomly select two of the $n_{best}$ genotypes and place them in a new pool $n_{repro}$.
   (a) both feasible: Genotypes with better suitability for $n_{repro}$,
   (b) one feasible: genetic form that can be placed in $n_{repro}$,
   (c) not feasible: Genotype with lowest failure margin in $n_{repro}$,

Among $n_{repro}$, many cross-operations obtained by arbitrarily selecting two contributing factors are achieved as necessary to create a complete population. As a result, the mutation is performed at a specified percentage and complete the new creation.

## 4. OPTIMIZATION DESIGN STRATEGY FOR COMPOSITE BEAM

### 4.1 Global structural optimization of composite beam

The design variables required in the initial design phase of composite material blade can be determined by the value of stiffness after performing equivalent modelling. In order to perform composite blade 1-D modeling, node and element points of finite element model must be sufficiently divided to show the curvature. Decrease in the number of elements is a prerequisite for reducing the calculation time, but sufficient elements required to decide accurate coupled characteristics of equivalent modelling. After allocating each mass matrix and coupling-stiffness matrix in the direction of blade axis-direction, a pre-vibration analysis is conducted. For frequency confirmation, a modal analysis is performed in a vacuum state. The purpose of the modal analysis is to confirm whether n/rev frequencies in fan plot sufficiently separated. The coupling-stiffness matrix can be controlled to ensure dynamic stability by adding or reducing design variables. Finally, the design variables set in an early stage were optimized and conducted the design of lightweight, composite material blade.

### 4.2 Local structural optimization of composite beam

Composite material blade can be divided into three parts of geometry. It is divided into upper and lower arms which carry the counterfoil section and transition section in which the configuration rapidly changes, and finally the air foil section. It determines the size of glass UD, form and thickness of the skin receiving the centrifugal force. Fig. 4 shows the configuration of section of composite blade. In the optimum design of section, composite material blade can be assumed to consist of multi torsion boxes and skin and form. On the front of the torsion, a uni-directional glass is allocated which can carry the main load of the blade. In case of skin, it is possible to optimize the ply sequence of composite materials based on the load, but the thickness is relatively thin so, following the general ply sequence for manufacturing convenience. Design variables for optimization were set to the thickness of the thin wall, and the position of the form, the thickness of the skin, the width of the uni-directional glass.

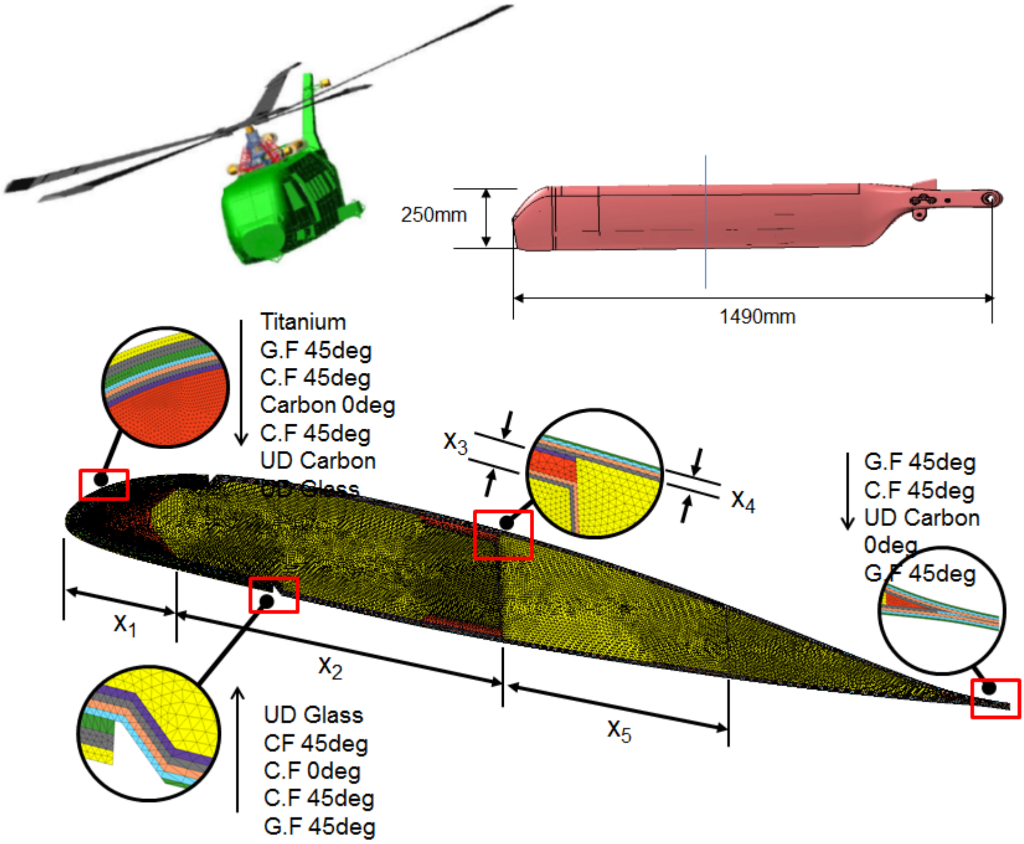


Fig. 4 - Design variables, ply sequence configuration of composite blade

### 4.3 Design objective

In general, aircraft like helicopters is required to minimize mass of components in order to enhance carrying capacity. Therefore, in this paper the mass of blade is set as objective function which intended to be obtained through the optimum design of rotor blade section as shown in Eq. (5)

$$Minimize\ F = Blade\ mass \tag{5}$$

As for design variables for reducing mass of rotor blade, thickness of skin ($x_3$, $x_4$), thickness of torsion box ($x_1$), position of torsion box ($x_2$), width of torsion box ($x_5$) and ply angle of skin ($t_5$) were set accordingly.

In Fig. 4, design variables for section of rotor blades were defined. By using design variables for section of rotor blades, the sectional area is calculated, and the mass of blade section is calculated by density value of each material. Since the configuration of section is uniform in blade span direction, when multiplying the mass and length, the mass of entire blade can be calculated. To simplify analysis, it was assumed that the thickness of skin and torsion box were uniform across the blade section. In this paper, as for the thickness of skin, thickness of torsion box and laminated angle of skin, it is considered both continuous design variables and discrete design variables. As for the discrete design variables, it was intended to reflect productivity so, 0.25 was applied for the thickness of one ply, for the ply angle of skin, it was set to have optimized laminated angle out of discretized laminated angles. Continuous design variables were applied to the position and width of torsion box.

### 4.4 Constraints

To facilitate the design variable derived from optimum design of composite blade section at the early development phase as a useful design input at the critical design phase, various constraints which are required for design of rotor blade in actual process should be reflected in an optimum design of the rotor blade section. To determine damages of each composite material that forming composite material rotor blade, the stress break index using the Tsi-Wu break criteria was set as the constraints and is defined as in Eq. (6).

$$\text{Failure Index}_i,\ i=1,2,3\cdots,n \tag{6}$$

In designing rotor blades, one of major concerns is the dynamic coupling of twist and bending, when the load of bending by lift force created in rotor blades is applied, the twist created due to the distance between center of shear and center of aerodynamic and in result, this twist changes lift force by changing the angle of attack of blade. These iterated interaction reaches over to some extent, it creates dynamic instability such as flutter. In worst case, the wings or the blade can be damaged. In most recent cases, composite materials are applied to rotor blade so, from the early design phase, it is required to reflect bending-twist ductility of section of blades by anisotropy of composite material. Therefore, in many of optimum design studies on blade section, the distance between the center of shear and the center of aerodynamic are set as objective function or constraints in order to minimize twist moment. In this paper, it was supposed that the center of aerodynamic is located at 25% of the length of the code from the leading edge and then, the center of shear located within ± 10 based on the center of aerodynamic to reflect constraints as in Eq. (7).

$$0.85\times chord/4 \le Shear\ center \le 1.20\times chord/4 \tag{7}$$

By referencing the equivalent stiffness of section rotor blade air foil, the constraints for the section of torsion/flap/lag equivalent stiffness were set as Eq. (8)

$$\begin{aligned}
&0.85\times GJ_{refer} \le GJ \le 1.15\times GJ_{refer}, GJ_{refer}=1.0\times 10^{11}\\
&0.85\times EI_{Flap,refer} \le EI_2 \le 1.15\times EI_{Flap,refer}, EI_{Flap,refer}=7.1\times 10^{10}\\
&0.85\times EI_{Lag,refer} \le EI_3 \le 1.15\times EI_{Lag,refer}, EI_{Lag,refer}=5.1\times 10^{12}
\end{aligned} \tag{8}$$

First, the breakage index is the constraints related to strength, and the centre of mass and shear are constraints related to the location of characteristics of section. The torsion/flap/lag equivalent stiffness of the section of blade show the aspect of constraints associated with the strain. In addition, the minimum mass of blade per unit length is the constraints related to mass and lastly; it is classified as fatigue restraints as in Eq. (9).

$$\frac{S}{S_{endurance\lim it}}=\frac{A}{N^{\gamma}},\ D_i=n_i/N_i\le 1,\ \text{Required life} > 15{,}000 \tag{9}$$

### 4.5 Material properties for composite blade

Skin and torsion box are made of flat carbon fiber fabric. The laminated angle of torsion box is set to 45° and the spar is set to 0° uni-directional glass. Material properties of skin, torsion box, spar and form filled in torsion box are as in Table 4.

Table 4. Material properties of composite blade[21]

| Material | $E_{11}$, $E_{22}$, $G_{12}$ (Mpa) | ν | Thick(mm) |
|---|---|---|---|
| Carbon Fabric | 54000, 37800, 3730 | 0.3 | 0.36 |
| Carbon UD Tape | 131000, 19650, 4800 | 0.42 | 0.13 |
| Glass Fabric | 19600, 13720, 3040 | 0.3 | 0.31 |
| Glass UD Tape | 54690, 8190, 5870 | 0.31 | 0.25 |
| Steel | 200000, 200000, 76900 | 0.31 | 0.55 |
| Titanium | 190000, 190000, 73400 | 0.3 | 0.6 |
| Nickel | 16300, 16300, 62000 | 0.31 | 0.6 |

## 5. OPTIMUM DESIGN INTEGRATION PROCESS FOR COMPOSITE BLADE SECTION

Genetic algorithms were used for the optimum analysis of the composite material blade structure. Modified method of feature analysis is the most popular but it is difficult to apply if there are many design variables as in this study.

Therefore, in this study, genetic algorithms were used for the optimum analysis of the composite material blade structure. In the optimal design of composite blade, the process can have more advantages which can easily apply to design variables for instance the ply angle and ply number. The weight of blade is set as final objective function for optimization of cross section of blade. The design variables were set as thickness of the torsion box, the position and constraints were set as mass center, static strength, fatigue life (15,000 hours).

Fig. 5 shows the process of optimum design of this study. When initial design value is inputted then, sectional analysis will be completed depending on the span wise location of the composite material blade. In order to conduct this process, pre-processing has to be executed for the finite element analysis on each section. By using the program, the equivalent properties of blade can be calculated. At early phase of the rotor blade development, sizing is performed for the design of section of blades. This means that the main design variables such as thickness, location, width and ply angles of composite material can be determined for the main components of the section of blades such as skin, torsion box and spar. As for the rule of reducing weight of blades, it requires to determine optimal design variables and iterated design/analysis of rotor blades. The design variables of repetitive section of blades based on the optimization of section of rotor blades are set, and material properties are calculated while changing design variables. The equivalent material properties set at the initial include the stiffness matrix and the mass matrix. Genetic algorithms research the disposition and material properties in design variables initially set. As for the local optimization, it means that the load applied to each section must meet the strength requirement of the composite material and fatigue life. As for the global optimization, it requires to meet vibration condition of blades and stiffness & section area would be controlled to achieve weight reduction. In order to perform the optimal results collected, gene algorithm should be replaced with a positive loop. In this paper, 140 loops were iterated to assess the convergence and it was evaluated by extracting the values from diagonal values of stiffness matrix.

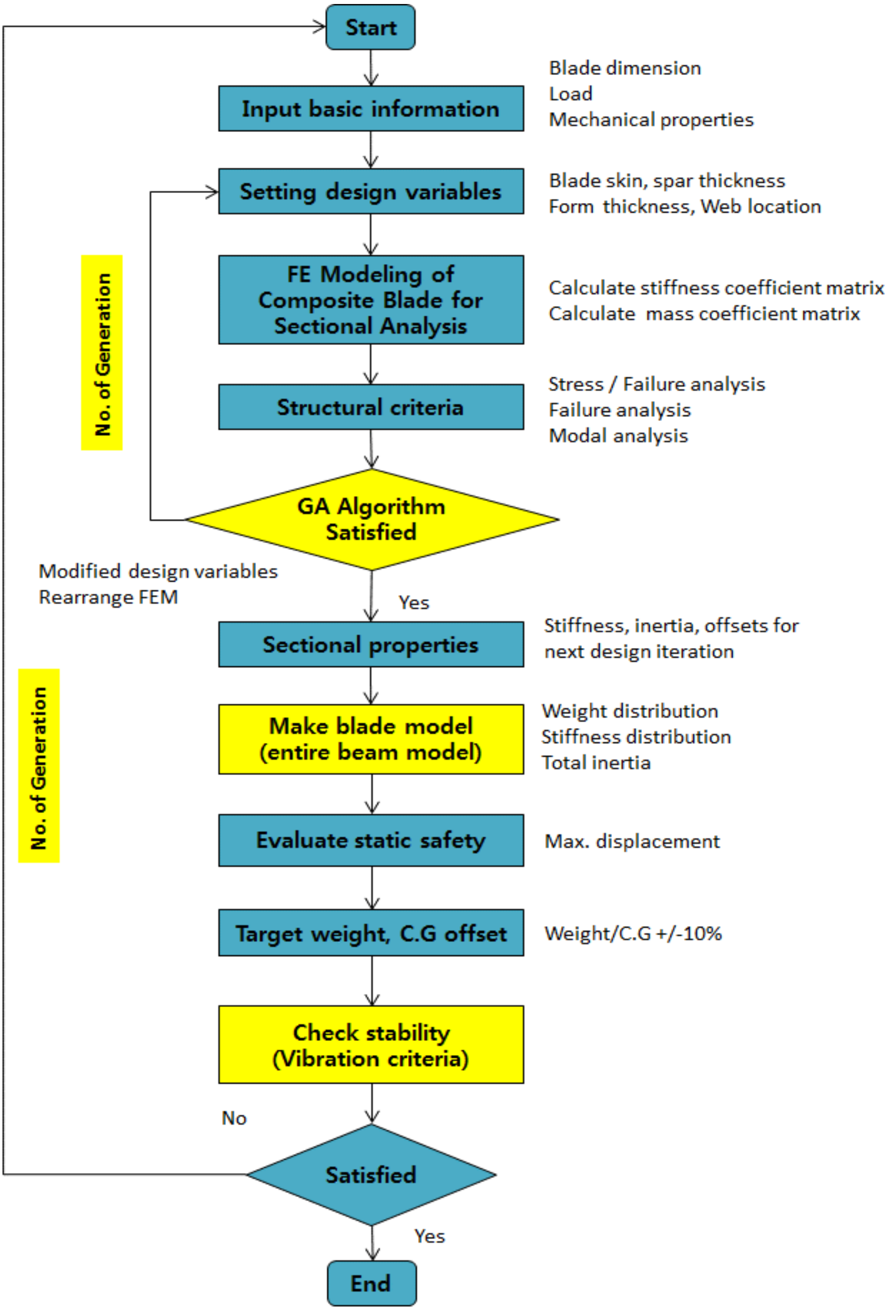


Fig. 5 - Flowchart for the structural optimization design procedure

## 6. RESULTS OF OPTIMIZED DESIGN USING GENETIC ALGORITHM

While locally searching at one design space, it could be possible to search at the other design spaces. There is a problem to depend on gradient on one point, but since the genetic algorithms are searching for population of design points, it is not sensitive about the problem created in complex design space.

Genetic algorithm produces a group of solutions that cannot be a single solution to a problem. Initial section configuration for optimization of section blade is the same as in Fig. 5 Constraints for optimum defined at the position of 1.0 smaller than of failure index and 25% of the 1/4 position of string of mass center.

Fig. 6 shows the optimal design results of blade section configuration using genetic algorithm.

Through optimum design framework, the preliminary weight of blade was reduced from 7.55 kg to 6.35 kg.

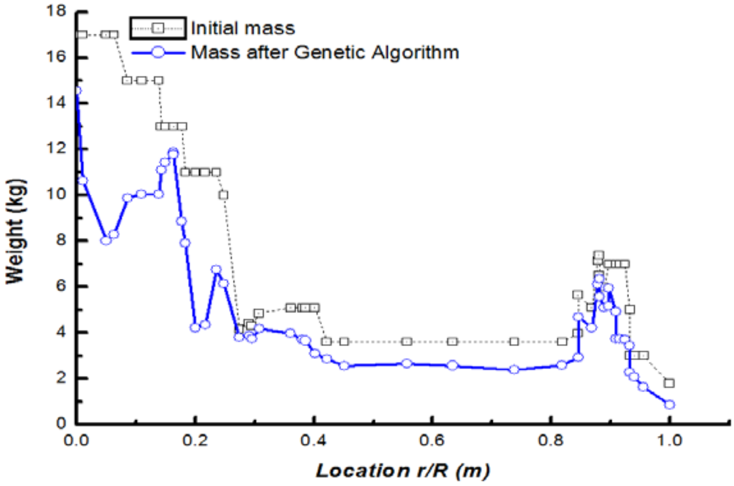


Fig. 6 - GA optimization results on weight reduction

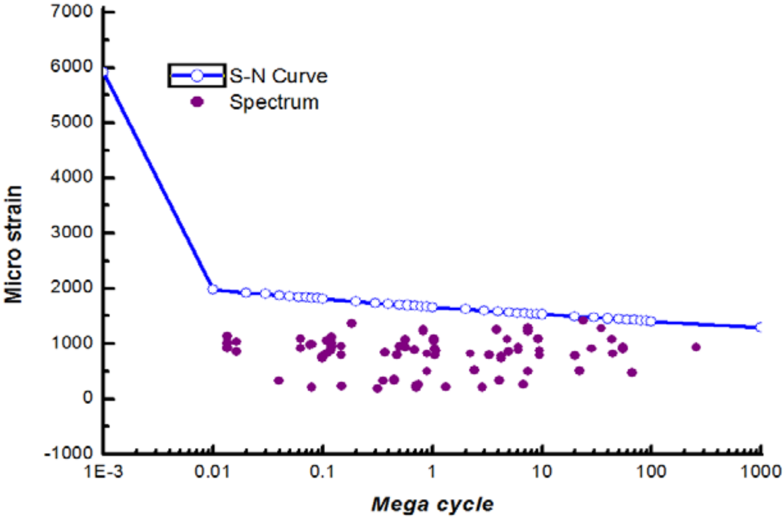


Fig. 7 - Optimization results on fatigue life at r/R = 0.654

As for the evaluation of fatigue life on composite material blade, the load created in Camrad II was facilitated and calculated e-n curve which constructs blades. Life evaluation of rotor craft is executed by safe-life method.

In Fig. 7 the result of using load spectrum was set to meet 20,000 hours but, the infinite lifetime calculated from all areas except the areas of r/R=0.654. Figure 8 shows the blade section configuration before and after optimization. From the result of optimization of blade, the thickness of skin became thin, the size of front and back of torsion box became small and also its thickness became thin.

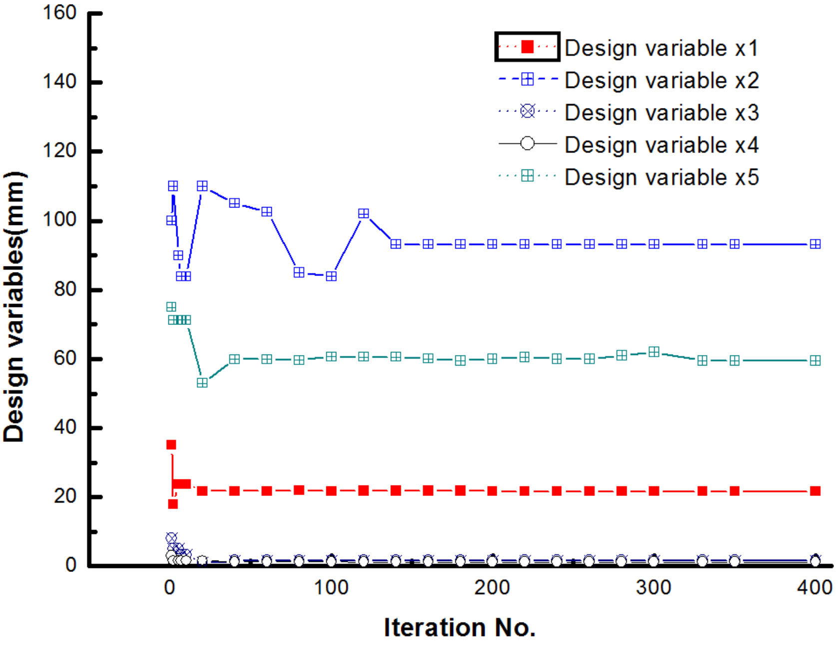


Fig. 8 - Optimization results on variation of design variables

Through optimization process, the mass of blade remained unchanged from 7.55kg to 6.35kg, and the thickness of skin and thickness of torsion box was compact by r/R=0.654. The size of the front torsion box became large and the size of the rear torsion box became small.

## 7. CONCLUSIONS

In this paper, the process of optimum design for composite material blade is described by dividing into the local and global area using the genetic algorithm. The stiffness was controlled to locally meet the structural requirements and globally meet the vibration requirements. The stacking sequence in outer ply of given geometry was not considered, it was because the parts that support the main load are the uni-directional glass, uni-directional carbon and carbon fabric, the thin thickness of outer ply skin was not considered.

To calculate the section modulus of coupled stiffness matrix, Variational Asymptotic Bram Sectional Analysis was used. Rapid design changing external configuration and internal materials, 1-D beam model can be used. In addition, the S-N Curve for each composite blade was used as the constraints condition. The optimization of section, through the optimization of the configuration of section, leads to the weight reduction by 15.8% of the blade.

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