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Composite Lamina Optimization Using Genetic Algorithm

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Abstract: *Composite materials are widely used in aerospace, automotive, and structural applications due to their high strength-to-weight ratio, corrosion resistance, and customizable mechanical properties. However, optimizing the fiber orientation, stacking sequence, and material composition to achieve the best performance is a complex challenge. This study explores the application of genetic algorithms (GA) for the optimization of composite lamina, focusing on maximizing mechanical strength, minimizing weight, and enhancing overall structural performance.*

A multi-objective optimization approach is employed, where genetic algorithms are used to determine the optimal ply sequence and fiber orientation for composite laminates subjected to various loading conditions. The analysis is conducted using finite element modeling (FEM) and numerical simulations to evaluate key parameters such as stiffness, stress distribution, and failure criteria (Tsai-Wu and Hashin failure theories).

The results demonstrate that GA-driven optimization significantly improves the mechanical efficiency of composite laminates, reducing material wastage while enhancing durability and performance. This research contributes to the development of intelligent material design methodologies, paving the way for next-generation composite structures with optimized properties for advanced engineering applications.

Index Terms— Composite lamina, GA, Ansys Parametric Design Language, Composite box wing

I. INTRODUCTION

Composites are highly-used on several industrial domains like spacecraft, civil or aircraft design. Their popularity is due to their excellent mechanical properties as well as their available freedom to tailor material properties. Most practical laminate designs require combinatorial optimizations because the ply orientations are usually restricted to small set of discrete values. In spite of this discretization, composite optimizations often have multiple solutions with similar performance. This kind of problems are one of the most complex and expensive to solve. Moreover, its large number of design variables contributes to having multiple local optima. This optimization process is also hardened with the addition of several structural constraints. In order to check some of these constraints (i.e. maximum strain values), a finite element simulation is usually executed. This simulation is highly time-consuming and therefore its number of executions should be reduced to a minimum.

During the last years, Genetic Algorithms (GAs) have been used for a variety of optimization problems. One of their main advantages is the capability to treat multimodal functions, finding its multiple optima and giving the possibility chooses one solution (design) or another. Also, GAs does not use any gradient information during the searching process, in contrast to numerical optimization procedures. Hence, GAs are a compromise between expensive brute force search strategies and numerical approaches**.**

II. GENETIC ALGORITHMS

The idea of a genetic algorithm was thought to have been conceived by John Holland at the University of Michigan in the 1970s. Holland was interested in applying the laws of natural selection towards the development of artificial systems rather than systems that are based on some reasoning process. These artificial systems could be constructed using computer software and applied to various disciplines which emphasize design, optimization and machine learning. Gas represent potential solutions for the problem as chromosomes. Chromosomes can be sequences of bits (bit streams), of other types of data (e.g. real numbers) or even more complex structures (sometimes referred as Genetic Programming or GP). Each chromosome encodes one individual. The set of chromosomes (individuals) under evaluation by the algorithm is called population. A GA performs a heuristic search over the vast solution space of possible chromosomes to find the most appropriate individual.

A GA starts from an initial population of chromosomes and evolves it in an iterative procedure with the following steps: (i) computing the quality (fitness function) of the individuals in the present population, (ii) selecting the best individuals from this population, (iii) mating pairs of individuals to generate new ones, (iv) performing random mutations (changes) on some of the new individuals, and finally (v) all the new individual and the individuals from the previous generation (iteration) conform the population for the next generation, selecting them based on fitness or similar criteria.

2.1 Basic structure of genetic algorithms

GAs are probabilistic algorithms that utilize the processes of natural selection by mimicking the concept of survival of the test. The main element of a GA is the organism which usually consists of a fixed number of chromosomes.

In turn, each chromosome may consist of one or many genes. Typically, each gene of a chromosome is coded using a binary alphabet, showing whether a gene is active (represented by a 1) or inactive (represented by a 0). Other representation has used general alphabets with many more elements or multiple gene alphabets for different types of genes. The complexity of an organism can be controlled by the length and number of chromosome and gene strings, and the size and number of gene alphabets. A genetic algorithm is usually made up of a group of organisms commonly referred to as a sub-population or population of organisms. If more than one group of organisms exist, then each group is called a sub-population. A group of sub-populations is called a population. Such terminology is often used when discussing parallel genetic algorithms. A parallel GA invokes several sub-another to improve the performance

III. 3.APPLICATIONS OF GENETIC ALGORITHM IN AEROSPACE

Genetic algorithm are used in the following fields

- Airfoil pressures
- Genetic Algorithms in Aerodynamics
- Genetic Algorithms in Multidisciplinary Design

IV. IMPLEMENTATION OF GENETIC ALGORITHM TO COMPOSITE LAMINATE STRCTURES

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Procedure of GA algorithm

For example two materials (M1,M2), two
i) Algorithm need following inputs thickness(5mm,10mm) and two angles (0,45) were taken for

crossover operation

a) No of layer
The best sequence1 (parent 1)

b) No of Materials
Total no layer = 5

c) No of thickness
Position 1 2 3 4 5

d) No of Layer Orientation
Material = M1 M2 M1 M2 M1

e) Enter the material properties
Sequence

[Young’s modulus poisons ratio, shear modulus, density]
Thickness = 5 5 10 10 5

ii) Enter the Thickness in mm
Sequence

iii) Enter the Layer Angle
Angle = 45 0 0 0 45

a) Reproduction (iteration 1)
Sequence

In this process laminate design variables are randomly
generated and results were stored for different combinations. The best sequence 2 (parent 2)

Total no layer = 5

b) Crossover (iteration 2)

The best sequence from previous iteration was selected based on high fitness Optimization

- Genetic Algorithms in Propulsion
- Genetic Algorithms in Structures

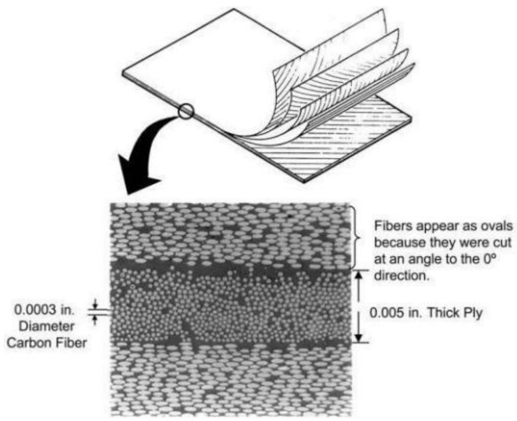

Fig. 1 Cross section of a cross-plied carbon/epoxy laminate

Fitness[i] =1-stress[i]/stress [max]

or

Fitness[i] =1-volume[i]/volume [max]

In this iteration, laminate sequence were randomly changed from one sequence (parent1) to another sequence (parent2) for producing new sequences (child1 and child2).This concept is applicable for material, angle and thickness sequences.

Sequence1 Sequence2

Before crossover

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Position 1 2 3 4 5

Material = M2 M2 M1 M1 M1

Sequence

Thickness = 5 5 10 5 5

Sequence

Angle = 45 0 45 0 0

Sequence

After cross over (child 1)

Total no layer = 5

Position 1 2 3 4 5

Material = M1 M2 M1 M1 M1

Sequence

Thickness = 5 5 10 5 5

Sequence

Angle = 45 0 0 0 0

Sequence

After cross over (child 2)

Total no layer = 5

Position 1 2 3 4 5

Material = M2 M2 M1 M2 M1

Sequence

Thickness = 5 10 10 10 5

Sequence

Angle = 45 0 45 0 45

Sequence

The above process is called single point crossover with right side shifting

Crossover operations are classified into

1. Single crossover with right shifting
2. Single crossover with left shifting
3. Single crossover with left to right cross shifting
4. Single crossover with right to left cross shifting

The best results from above four operations were stored.

c) Mutation (iteration 3)

The best sequence from previous iteration was selected based on high fitness. In this process variables are randomly exchange in between the single sequence itself. It is shown in below.

Sequence1

Before Mutation After Mutation

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The above process is repeated for all best sequences and result was stored.

d) Addition (iteration 4)

The best sequence from previous iteration was selected based on high fitness. In this process variables are added randomly in the best sequence .It is shown below

Sequence1

Before Addition After Addition

134251342523

The above process is repeated for all best sequences and result was stored.

e) Deletion(iteration 5)

The best sequence from previous iteration was selected based on high fitness. In this process variables are deleted randomly in the best sequence. It is shown in below

Sequence1

Before Deletion After Deletion

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The above process is repeated for all best sequences and result was stored.

f) Alteration (iteration 6)

The best sequence from previous iteration was selected based on high fitness. In this process variables are altered randomly in the best sequence. It is shown in below

Sequence1

Before Alteration After Alteration

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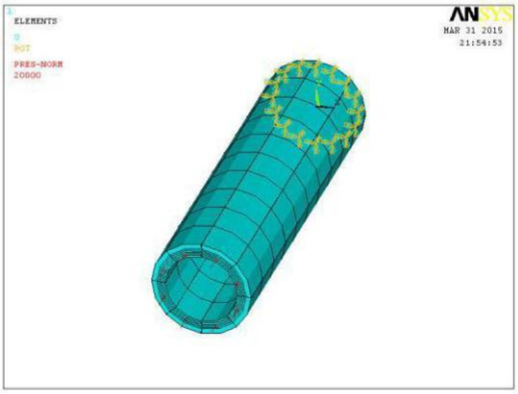
The above process is repeated for all the high fitness sequences and result was stored. This is called generation. Finally the overall best result from above six operations was plotted and stored. The same process was repeated for 50 numbers of generations. .

V. MESHED MODELS



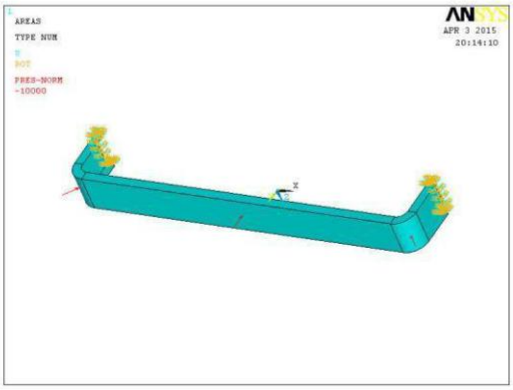


Fig.3 Meshed model of multi panel hollow cylinder

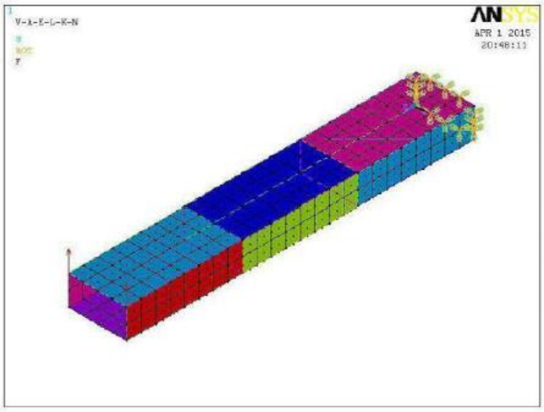


Fig. 5 Meshed model of multi panel wing box structure

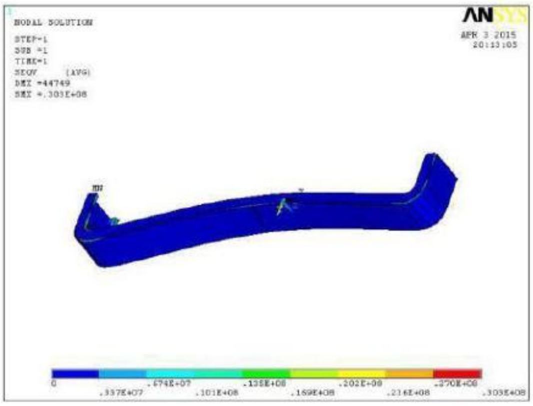


Fig 6 Stress distribution over a bumper

VI. RESULT & DISCUSSION

The APDL programme is written for the optimization of following components using composites. For the given load all the possible ply angle combinations are analyzed and the best combinations are selected after over 100 iterations. The result is explained below.

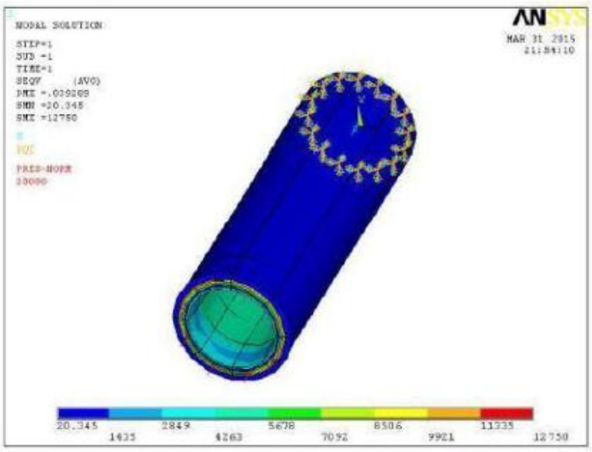


Fig. 7 Stress distribution over a hollow cylinder

Panel No.	No. of layer	Angle sequence (degree)	Material sequence	Thickness sequence	Volume (mm^3)	Vonmises stress (N/mm^2)
1	4	45 -45 45 90	2 1 2 1	10 5 5 10	76547845.33	21809
2	5	0 -45 45 0 -45	1 1 2 2 2	10 10 10 5 5		
3	3	45 0 45	2 1 2	5 10 5		
4	2	-45 0	1 2	10 5		
5	5	90 -45 0 45 -45	2 1	5 10		
6	4	90 45 0 -45	1 1 1 2	5 5 5 10		
7	3	90 -45 0	2 2 1	5 5 10		
8	3	-45 0 90	1 2 1	5 10 5		
9	4	0 45 0 90	1 2 1 2	10 10 5		
10	4	0 45 -45 45	2 2 2 1	10 10 10 5		

Table 1 Optimum stress of the fittest Box Wing laminas

VII. CONCLUSION

This work presents the results obtained applying genetic algorithms to the configuration of composite material of panels design. The problem is defined by several manufacturing and design constraints (layer symmetry, maximum number of layers, fixed number of possible orientations and some parameters of certain structural components, such as horizontal and vertical frames). The performance and characteristics of the proposed configurations are evaluated via nonlinear finite element simulation. The algorithm is controlled by a programmable state machine which selects among two different representation schemes and two finite element simulation model (linear vs. nonlinear).

8 FEATURE WORKS

The global optimized genetic algorithm plays major role in multi panel composite laminate optimization. The above algorithm can applicable for any type of problems with known loading and boundary conditions. Further the computation time will be reduced by using cluster based optimization i.e many computers simultaneously involved in optimization

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