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Procedia CIRP 66 (2017) 79 – 84

www.elsevier.com/locate/procedia

1st Cirp Conference on Composite Materials Parts Manufacturing, cirp-ccmpm2017

Optimization of variable stiffness composites in Automated Fiber Placement Process Using Evolutionary Algorithms

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Abstract

Stiffness variety in composite parts is performed by local improvement in directions which are more favorable to carry loads in Automated Fiber Placement (AFP) technology. An approach to find the optimum position and the best length of layup dropping in AFP technology is introduced. Since, the objectives are minimum weight and maximum stiffness, problem is considered as a multi-objective optimization. Fiber failure, matrix cracking, and onset of delamination take into account as the constraints for objective function. A comparative study is introduced to evaluate the performance of Genetic algorithm and Firefly algorithm in finding the global optimum result.

Peer-review under responsibility of the scientific committee of the 1st Cirp Conference on Composite Materials Parts Manufacturing

Keywords: Optimization, Variable stiffness Composite, AFP process, Genetic Algorithm, Firefly algorithm

1. Introduction

Composite materials because of the high ratio of strength to the weight have been widely used in aerospace. Addition to this reason, automotive industry because of the necessity of reducing the fuel consumption and increasing the safety has been interested to bring light weight material in automotive structure during the recent years. Essentially, the existing fiber direction of unidirectional composite materials lead to create constant stiffness through the length. However, multiplicity and variety of applied loads on a structure, perform different load distribution in different region of parts. It means that, some regions may need more amount of stiffness regards to the higher distributed load. Generating different stiffness by using different orientation and position of fiber patches leads to variable stiffness laminate (VSL). Automated fiber placement technology provides the ability of locating predefined dimension and orientation of patches. Finding the optimum place and suitable angle of patches which caused to increase the overall strength without considerably increasing the weight and/or cost of part has been studied by different approaches.

"Curvilinear fiber method" is an effective approach to generate and enhance the stiffness of a composite structure which is performed by placing the proper specification in load trajectories. Akhavan et al. [2] studied on natural frequencies of a variable stiffness composite with regards to manufacturing constraints. They showed that using curvilinear fiber method instead of straight fiber approach has greater degree of freedom to adjust the frequencies and mode shapes.

Despite the advantages of curvilinear method, some studies have remarked that because of a minimum allowable radius for bending of straight path, generating the exact curvature routs which obtained from optimization results might be not applicable. Alhajahmad at al. [3] with consider to the minimum operation radius of AFP process found the optimum patch to maximization of bearing the buckling load of a composite plate.

"Gradient-based method" deals with objective function and/or approximation model of objectives and constraints. Both approaches need to run a sensitivity analysis to calculate the gradient of objectives and constraints respect to all design variables. Jorgenson [14] used an analytical expression and

Peer-review under responsibility of the scientific committee of the 1st Cirp Conference on Composite Materials Parts Manufacturing
doi:10.1016/j.procir.2017.03.302

consider the material orientation for each element of a cantilever plate as the single design variable. As the exact expression of objectives and constraints may not be available in stacking sequence problem, the objective function method could be replaced by some approximated sub-problems. Setoodeh [15] used lamination design parameters instead of fiber angle and thicknesses. He modeled the bending behavior of composite plate with only four lamination parameters. Similar to approximation method, response surface approach generate an approximated model by using of a set of variables over the whole design space. Vandervelde [19] used a quadratic response method to find the optimum lamina sequence for each zone in a multi-zone composite wing. Gradient-based methods essentially need to calculate the gradients however they require fewer number of iteration than the evolutionary algorithms [9] but they normally experience the risk of finding local optimum.

"Optimality criteria method" iteratively finds the optimum value of a criterion for requested objectives of the structure. Usually, the common criteria in this method consist of fully stress, uniform strain energy density, and constant interval force distribution [11]. Khosravi at al. used strain energy method in two levels. In first level by minimizing the strain energy found the optimum fiber angle and in second level obtained the optimum thickness [11]. Optimality criteria approach is able to optimize only the objectives depend to the used criterion such as energy, weight, and stiffness not a combination or any others.

"Direct search method" is used in variable stacking sequence which has been made of continues and integer variable and practically sensitivity approaches doesn't work to find the structure behavior related to the design variables. Since, direct search approaches such as genetic algorithm (GA) not take into account as gradient-based algorithms, they introduce more flexibility in combinatory variables problems. However, they are costly than the gradient-based method but simplicity of implementation of direct search methods compensates this shortcoming. Legrand et al. [13] found the optimum fiber orientation in a unidirectional lamina which allowed the fiber to vary its angle through the length. They divided the 2D search space into the elements with anisotropic property and considered the orientation of each element as an input variable for GA. Mathias et al. [12] optimized the ply orientation, shape, and patch location simultaneously to reinforce an aluminium plate using GA. They also considered the area of patches and forbidden locations as a manufacturing constraints.

A comparative study on existing methods has been introduced in optimization of variable stiffness structures by Ghiasi [9]. As a simple out coming, direct search methods present more robustness and simplicity to implement hence need more time to find the optimum result than the other approaches.

This study uses direct search method and two evolutionary algorithms; genetic algorithm and firefly algorithm in structural optimization problem. Finding the optimum location and orientation of patches in AFP process with the aim of reinforcement a composite structure under multi-axial load case is performed. The abilities of mentioned algorithms to find the optimum configuration of patches is compared at the end.

2. Proposed methodology

As mentioned in introduction section, local patch reinforcement is able to increase the mechanical abilities of structures using AFP process. Figure 1 shows the schematic of AFP process which drops tapes on predicted paths and specific feed rate and temperature to joint patch into the ground part.

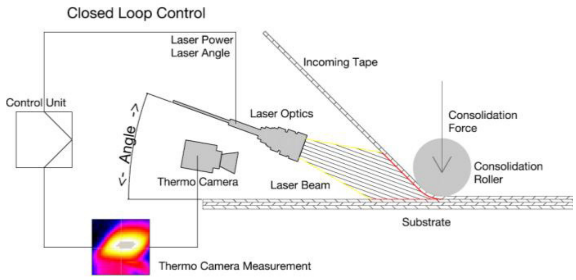
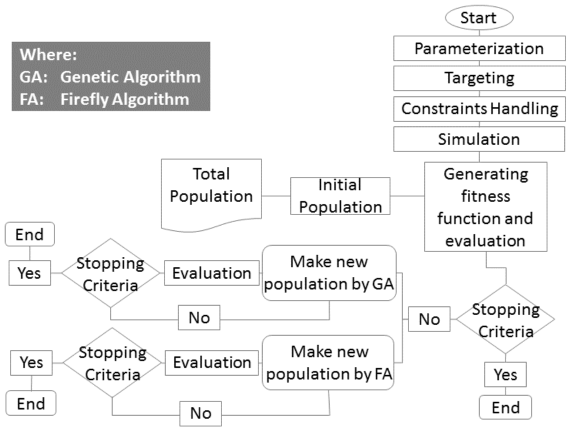


Fig. 1. Schematic of AFPT's closed loop control during AFP process [4]

This paper is going to introduce a comprehensive scheme to find the location and orientation of patches in problems which are complex to solve and/or might have the risk of finding the local optima with gradient-based or optimality approaches. Flowchart 1 shows circumstances of design space definition, objectives generation, and handling the limitations. In continue, optimum values of requested variable will be iteratively find through evolutionary algorithms.



Flowchart 1. Process of proposed methodology in this study

Regardless of the type of optimization algorithm, improvement of structure will be continued until requested objectives obtain. Then, algorithm will be stopped and generates the configuration of patches positions and length on the ground parts. This study uses two evolutionary algorithms in parallel; Genetic Algorithm (GA) and Firefly Algorithm (FA). First one exchanges genes between strong individuals and cause to improve the fitness of chromosomes and second