THE USE OF GENETIC ALGORITHMS FOR STRUCTURAL OPTIMIZATION OF HYBRID SANDWICH PANELS

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Abstract
This paper describes the procedures followed to develop an optimization method for the design of a sandwich panel to be used in flooring applications. This sandwich panel is composed of polyurethane foam core, fibre reinforced polymer bottom layer and webs, and a fibre reinforced mortar top layer. The possibility of adopting additional internal ribs to increase the flexural and shear stiffness was also considered. The panel was described using a standard stacking sequence, coded as a string, using continuous variables to describe the geometric, economic and environmental parameters, and discrete variables to describe the laminate stack architecture. The optimization procedure was based on a global approach strategy, divided into two steps: (i) firstly, the features of each individual panel solution were assessed by analytical procedures and a fitness was assigned using a ranking function; (ii) secondly, the multi-objective optimization problem was solved by using a genetic algorithm, which performs a random search from generation to generation and keeps the "best individuals". Penalty criteria were also considered when any panel solution was not satisfying the restrictions and design requirements. Different solutions were obtained by imposing different restrictions to the design of the sandwich panel, namely considering: (i) the length; (ii) the width; and, (iii) the use of one or two types of fibres (carbon and glass). This paper discusses the results obtained, both regarding the performance of the optimization procedure developed and the optimal solutions obtained for each case studied.

1. Introduction

The Genetic Algorithms (GAs) are a metaheuristic approach that can be used to solve optimization problems based on the natural selection and genetics found in nature [1]. The GAs were mainly introduced by Holland [2], and quickly spread to many engineering fields to solve decision problems, to carry out genetic programming and to deal with design problems, among others. Examples of applications of GAs to the design of composite structures can be found in the literature. Martín *et al.* [3] used a GA to perform the geometric design of the composite materials of a stiffened panel, using static analysis and considering hydrothermal effects. Nagendra *et al.* [4] used GAs to reduce the computational cost involved in the design of composite panels. In general, GAs were shown to be one of most reliable tools in optimization problems. The present study is focused on the design of a hybrid sandwich panel to be used in flooring applications, mainly in rehabilitation of old buildings, using GAs. The optimization problem is based on the use of a GA to find the optimal geometry of the hybrid sandwich panel by minimizing the self-weight, the panel price and environmental footprint, using both classical laminate theory and sandwich panels theory.

2. The Genetic Algorithm

In this optimization problem, a steady-state concept of the GA was adopted [1], as presented in Figure **1**. The evolutionary process to search for the problem solution starts by creating a random population with high diversity, preferably within the limitations and restrictions of the problem. The number of individuals (NI) to be created depends on the complexity of the problem, and it should be noted: (i) a low NI can lead to a spurious solution, and (ii) a large NI can severely increase the computing time. After one particular population is created, a fitness evaluation function is used to classify each individual according to desired objective functions and boundary conditions. Subsequently, the population stack is sorted by classification where, by using an “Elitist” selection, the best individuals are chosen to create a new offspring of individuals, using the genetic operators, namely: (i) crossover and; (ii) mutations. Finally, the fitness of the new offspring is evaluated and then the stopping criteria is tested. Normally, if the population presents high fitness and low diversity, the GA is close to the solution set. Otherwise, it has to return to the “Elitist” selection of individuals and repeat the process again.

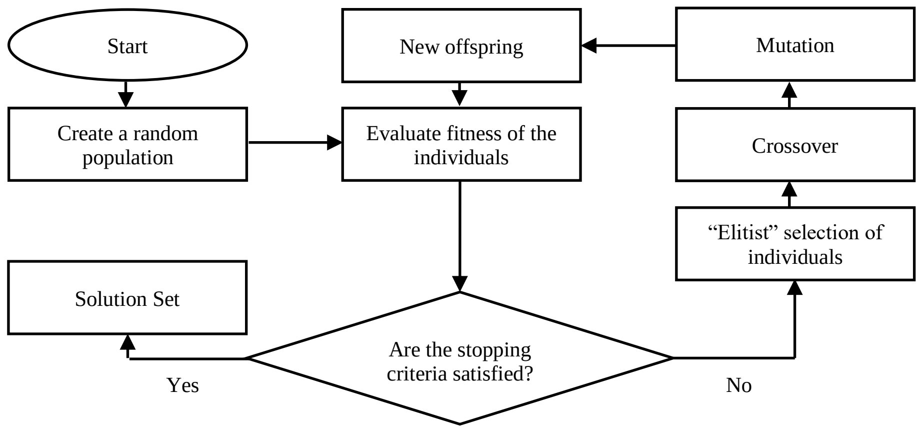

Figure 1. The genetic algorithm flowchart.

3. Problem Statement

3.1. The sandwich panel variables and considerations

The presented optimization procedure was described using 22 different input variables stored in a two-dimensional array with a length and width equal to the number of individuals and input variables, respectively. In addition, the input variables were stored with different datatypes, namely: (i) as float numbers; (ii) as integers, and; (iii) as strings. The input variables formed a chromosome-like structure with 5 genes, as shown in Figure 2, where each gene defined a major property of the hybrid sandwich panel.

3.2. Objective functions and boundary conditions

In the present work, the optimization procedure aims at finding design solutions for the sandwich panel with minimized self-weight, price and environmental footprint. Thus, a multi-objective optimization function, as presented in equation (Eq. 1), was followed. Also, a number of 100 individuals were established in this exercise.

$$\min[\,Weight(x_1,x_2,\dots,x_{22}),Cost(x_1,x_2,\dots,x_{22}),Footprint(x_1,x_2,\dots,x_{22})] \quad (1)$$

In order to create the random population and to continuously exclude the individuals outside the boundaries of the problem statement, a set of boundary conditions (BC) had to be established initially to avoid “cripple” solutions. Some of the BC were set according to the requirements of the manufacturer, while others were established in order to guarantee the fulfillment of the European standards, Eurocode 1 [5] and the Italian recommendation CNR DT 205 [6]. In Table 1 all BC considered for the design and optimization of this problem are presented. In addition, different solutions were evaluated by changing the BC of the problem, namely: (i) using only GFRP in the laminate stack architecture; and, (ii) using carbon fibre roving and glass fibre for chopped and woven fabrics. In total, four solutions were evaluated as shown in Figure 3.

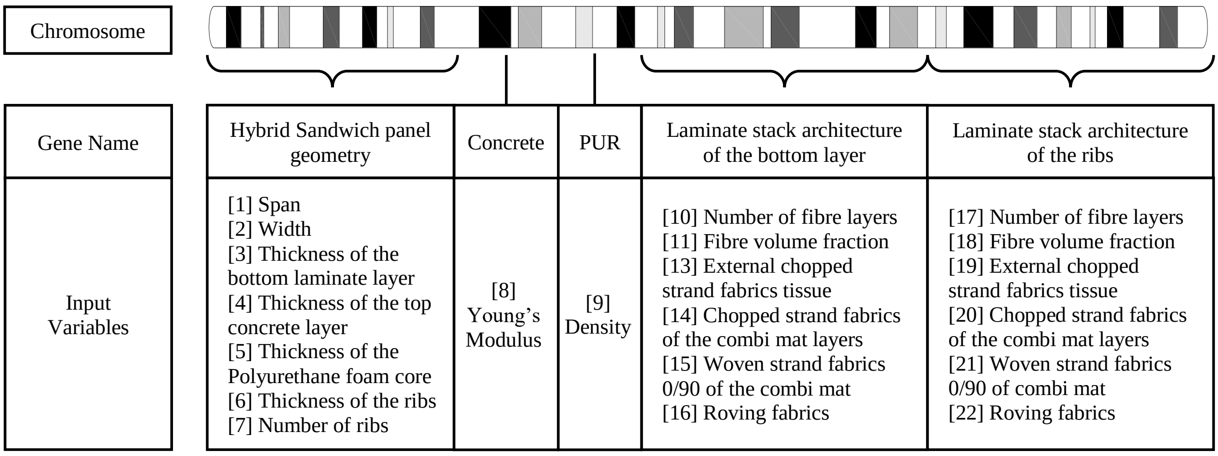

Figure 2. Input variables of the GA chromosome.

Table 1. Boundary conditions.

Variable name	Units	Symbol	Minimum	Maximum
Self-weight	kg/m^2	w	-	75
Height of the panel	mm	h	-	140
Thickness of the concrete layer	mm	t_{conc}	18.5	-
Thickness of the FRP bottom layer	mm	t_{bot}	3	6
Thickness of the FRP ribs	mm	t_{ribs}	3	6
Density of the polyurethane	kg/m^3	ρ_{pur}	35	120
Maximum deflection after 50 years (*SLS*)[1]	mm	δ_{50}	-	10
Shear stress in the polyurethane	MPa	τ_{pur}	-	0.30
Shear stress in the ribs	MPa	τ_{ribs}	-	27.5
Compressive stress in the concrete layer	MPa	σ_{conc}	-	30
Tensile stress in the FRP bottom layer	MPa	σ_{bot}	-	200
Fibre volume fraction in the laminates	%	v_f	-	50
Thermal conductivity	W/m^2	U	-	0.30
Longitudinal axial stiffness	MN/m	EA_L	550	-
Transverse axial stiffness	MN/m	EA_T	110	-
Acoustic insulation to aerial sounds	dB	D_{ntw}	35	-
Acoustic insulation to impact sounds	dB	L_{ntw}	95	-

[1]The design working life was set to 50 years and the deflection was estimated using the quasi-permanent load combination [5].

4. Results and discussion

The results obtained are shown in Table 2 and Figure 4, where the individuals that achieved the highest fitness in the stop verification criteria are presented. In these solutions (S1 to S4), the obtained deflection at *SLS* was always equal to 10 mm, meaning that this criterion is restrictive. Besides, solutions S1 and S2 presented total heights that exceeded the limitation imposed of 140 mm. This result can be explained by the steady-state nature of the GA used, which maintains the number of individuals constant from generation to generation. This concept allows the GA to continue to search for the best individuals, even if the population is "crippled". In terms of fitness, the best solution was the S1, but this solution did not fulfil the criterion of maximum height of the sandwich panel. Also, all solutions exhibited similar results of weight and price, with exception for the environmental footprint, due to the high environmental footprint presented by the use of the carbon roving.

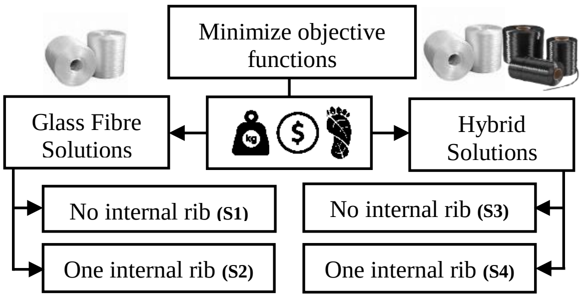

Figure 3. Evaluated solutions.

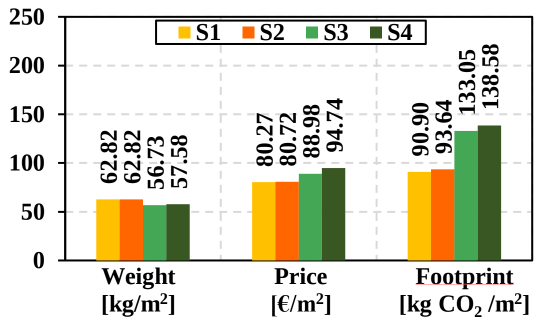

Figure 4. Objective function values for each solution.

Table 2. Results in terms of the physical and geometrical parameters obtained.

Solution	L [m]	b [m]	h [mm]	t_{conc} [mm]	t_{bot} [mm]	t_{ribs} [mm]	ρ_{pur} [kg/m^3]	D_{ntw} [dB]	L_{ntw} [dB]	U [W/m^2]
S1	5	0.5	191.6	18.8	5.0	4.9	35	36.1	87.0	0.13
S2	5	0.5	187.0	18.9	4.9	3.9	35	36.1	86.8	0.14
S3	5	0.5	128.0	20.0	4.0	4.0	35	35.4	88.5	0.21
S4	5	0.5	126.7	20.0	4.0	4.0	35	35.5	88.3	0.22

Finally, S3 presented the best fitness and, at the same time, complied with all the imposed boundary conditions. Therefore, this solution was the one selected for the geometry/architecture of the sandwich panel to be produced by pultrusion, in the scope of the EasyFloor R&D project.

5. Conclusions

This manuscript presents the results of a design optimization procedure implemented for finding the optimal geometry of a hybrid sandwich panel for flooring applications. This procedure was based on a steady-state GA. In total, four solutions of the optimization problem were analysed. Solution S1 showed the best performance in terms of fitness, even if some of the boundary conditions were not satisfied, such as the ones related to the total height of the panel. Based on the obtained solutions, solution S3 was selected as the geometry/architecture of the panel to be produced by pultrusion in the scope of the EasyFloor R&D project.

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