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OPTIMIZATION OF SANDWICH PANELS WITH MULTIFUNCTIONAL APPLICATIONS

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Abstract: *The optimization of sandwich panels with multifunctional applications represents a challenge since it has often involved the solving of multiple and conflicting objectives. Within this work a fuzzy control loop system is used in order to determine the overall properties of the sandwich assembly and to identify and optimize its functional capabilities by choosing the most appropriate values for the properties of the individual components. An example is presented where nine input variables have been used to evaluate and optimize the flexural rigidity, shear rigidity and thermal resistance of a three layer composite sandwich assembly. However, when more accurate results are needed, analytical methods should be used in order to verify the results.*

Keywords: *sandwich structure, optimization, fuzzy system*

1. INTRODUCTION

The spread tendency of using sandwich structures in other industries and applications than aeronautics is mainly due to the recent developments of cost effective sandwich structures and also due to their multifunctional feature [1]. In the design stage of a sandwich panel, tools for exploiting this multifunctional potential are still not well established. The main problem is the optimization and it refers to the manner of adequately combining the specific properties of each of the sandwich structure components in such a way as to satisfy the requirements for given multiple load conditions and constraints, Figure 1.

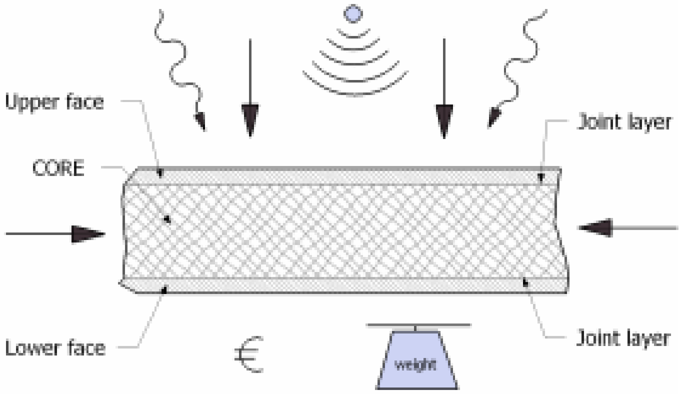

Figure 1: Sandwich panel and its component elements supporting multiple types of loads and constraints

The techniques which are nowadays used for optimizing sandwich panels can be classified in three categories: analytical [2], numerical [3], [4] and graphical [5], [6]. These procedures are applied, for example, in order to minimize structural weight or cost at given mechanical or acoustical constraints. Although these methods may lead to relatively precise solutions, they are hardly applied to a higher number of objectives and constraints which are often in a conflicting relation. Recent developments at Transilvania University of Brasov propose the use of fuzzy control systems for solving multiple and conflicting objectives during the first stage of designing a sandwich panel with multifunctional applications. This method will be briefly reviewed in the following.

2. DETERMINATION OF THE OVERALL SANDWICH PROPERTIES USING FUZZY SYSTEMS

Within this work, it is proposed the use of a fuzzy control system where the inputs, represented by the relevant material properties of each of the components of a sandwich composite assembly, are mapped to the outputs, represented by the overall properties of the sandwich assembly or by its functional capabilities, by following a set of If-Then rules collected from experience.

Considering the case of a single core sandwich panel, it consists of two faces, one core and two joint layers the first three components are coupled with in order to form a sandwich structure [8], Figure 1. The specific properties (physical, mechanical, acoustical, thermal, geometrical etc.) of each of the components are then identified. Figure 2 illustrates some examples of input and output variables that can be considered for a 3-layer-sandwich assembly; to simplify the-model, it is considered that the sandwich assembly is symmetrical and thus a single face and a single joint layer can be taken into account. Within the inference system, Figure 2, the output variables are assessed considering the input variables, through the defined set of rules.

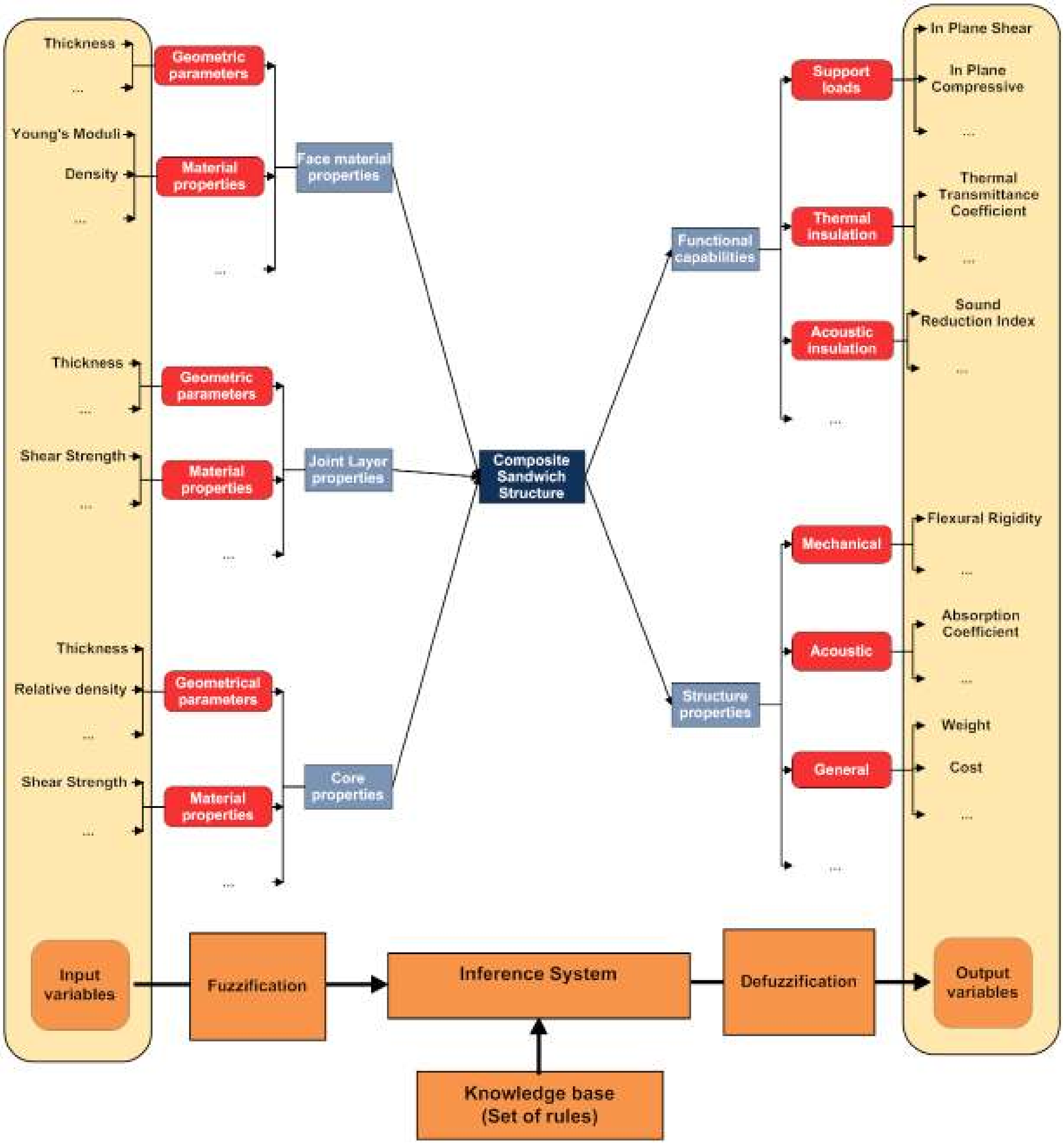

Figure 2: Examples of possible input and output variables for the proposed fuzzy control system

3. OPTIMIZATION OF THE SANDWICH PANEL

By adding a correction loop to the fuzzy system presented in Figure 2, the input variables can be modified in such a way as to obtain the desired output variables and thus making an optimization of the sandwich assembly for given load conditions and/or constraints. A block diagram of the optimization process using two fuzzy control systems is presented in Figure 3. The process starts with an initial set of input values that are multiplied by the initial correction coefficients, all having the unit value. The output values obtained from the fuzzy controller 2, Figure 3, are compared with the desired set values. The fuzzy controller 1, Figure 3, generates, as a function of the difference between the desired values (set values) and the resulted values, some correction coefficients the initial input values are again multiplied with. These correction coefficients take values between 0 and 2. The input properties of the individual components will change till the overall properties or the output functional capabilities fit the desired set values. The optimization process stops when the resulted values equal the desired ones or after a specified number of cycles.

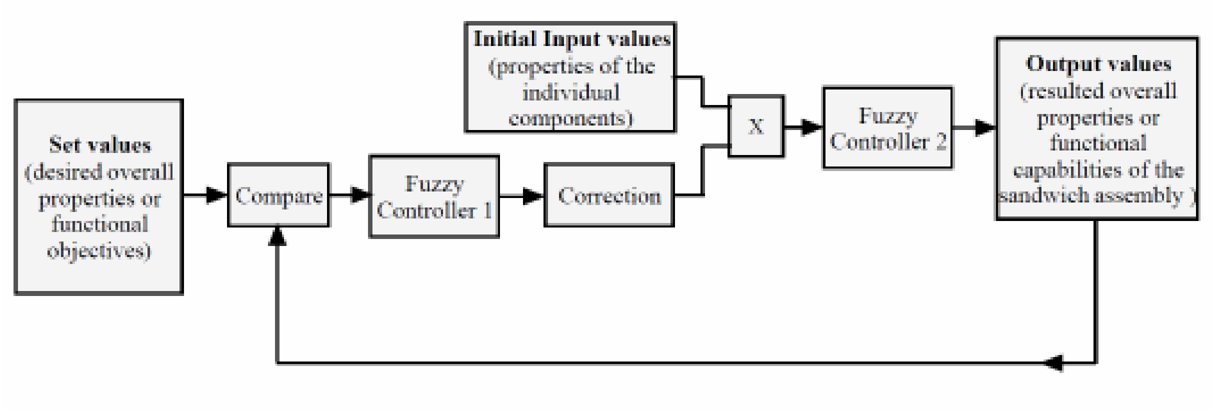

Figure 3: Block diagram of the optimization process

Based on the final properties of the individual components that offer the desired overall properties or functional capabilities of the sandwich assembly, the material of each component may be selected from catalogues of the producers, from engineering handbooks or from a particular material database.

4. APPLICATION

For the presented composite assembly, Figure 1, in order to exemplify the method, a set of input and output variables is proposed, Table 1.

Table 1: Proposed input and output variables

Variables		**Meaning**
Input variables	**CThick**	Core thickness
	FThick	Face thickness
	FEmodulus	Face E modulus
	CGmodulus	Core G modulus
	FLambda	Face thermal conductivity coefficient
	CLambda	Core thermal conductivity coefficient
Output variables	**D**	Flexural Rigidity
	S	Shear Rigidity
	R	Thermal Resistance of the Panel

For each of the inputs, there are considered 3 fuzzy sets, Figure 4, having the membership functions described by Gaussian curves [9] and 5 fuzzy sets for each of the outputs, Figure 5, having the membership functions described by triangular shapes [9].

The input and output universes of discourse are expressed in percentages, Figure 4 and Figure 5. The real input crisp values u_i(R), mentioned over a specific universe of discourse, with the boundary limits defined by [a, b], are transformed in percentage u_i(%), Figure 6, using Equation 1. Inversely, the resulted output values y_i(%) are transformed from percentage in real crisp values y_i(R) over a specific universe of discourse, using Equation 2. This will allow the change of the boundary values of the universes of discourse over a [min, max] interval, Figure 6, without modifying membership functions and in correlation with a class of materials the user wants to work with, for each of the material property. In addition, this will also allow the tuning via scaling universes of discourse in order to improve the performance of the fuzzy control system [8].

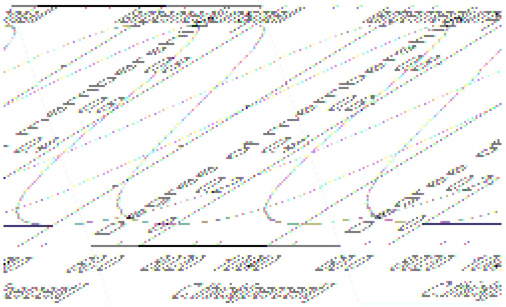

Figure 4: Input membership functions

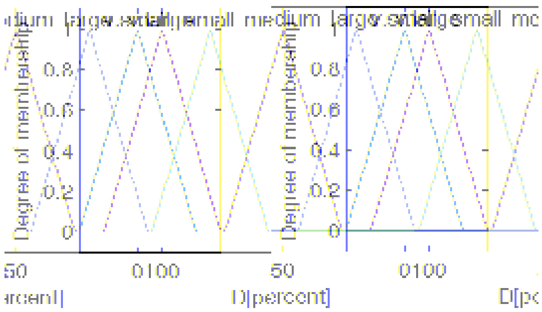

Figure 5: Output membership functions

$$u_i(\%) = \frac{(u_i(R) - a) \times 100}{b - a} \tag{1}$$

$$y_i(R) = a + \frac{(b - a) \times y_i(\%)}{100} \tag{2}$$

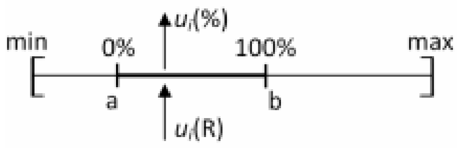

Figure 6: Boundary limits for the universes of discourse of an input variable.

MATLAB Fuzzy Logic Toolbox and Simulink environment was used to create the model, where the flexural rigidity *D*, shear rigidity *S* and thermal resistance *R* of a three layer sandwich panel were evaluated considering a set of 54 rules for the fuzzy controller 2, and 36 rules for the fuzzy controller 1, Figure 3. Mamdani inference method was used as it is a rule-based implication method and thus more intuitive and well suited to human input [9].

The way in which the inputs are mapped to the outputs of a fuzzy inference system can be visualized by generating output surfaces [9]. Such an output surface is illustrated in Figure 7, where it may be observed the way in which the output variable *D* depends on the *FThick* and *CThick* input variables, based on the defined rules.

The closed-loop control system is created by adding separate fuzzy control systems for each of the output variables *D*, *S* and *R*, which will use the difference between the desired output value and the measured output value as a feedback to generate correction coefficients for the specific input variables (core thickness, etc.), based on a set of rules.

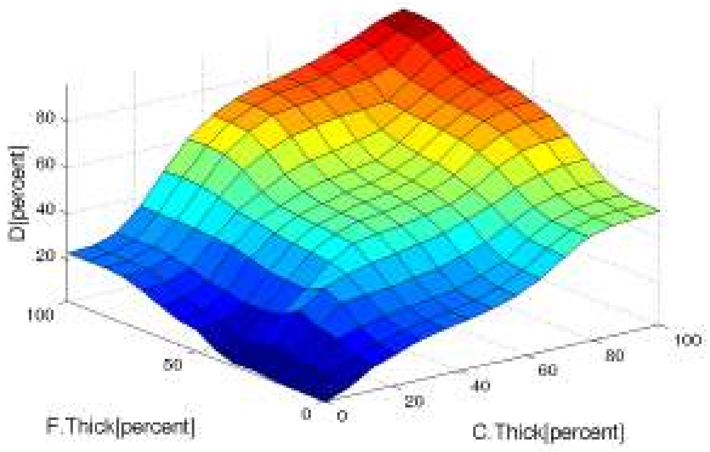

Figure 7: Output control surface

The optimization process starts by setting the desired output values, respectively *D*, *S* and *R* and by defining some initial values for the input variables. In this example, they were randomly selected: *D_desired*=75%, *S_desired*=65%, *R_desired*=55%. All of the input variables were considered to have an initial value of 50%.

5. RESULTS

In order to satisfy the imposed *D* value (75%), it may be observed in Figure 8 that the correction coefficients generate, within 20 iteration steps, a high final value for *CThick* input variable (around 94%), while for the imposed *S* (65%) and *R* (55%) output variables, the *CThick* needs to be smaller, and thus, the correction coefficients yield to values between 30%-40% for *CthickS* and *CThickR*. This type of conflict in the design of a multifunctional sandwich panel is solved within this method by using, at each calculation step, an average value of the respective variable. These changes will have an effect on the other input variables, Figure 9, by applying specific correction coefficients in such a way as to obtain the desired output set values.

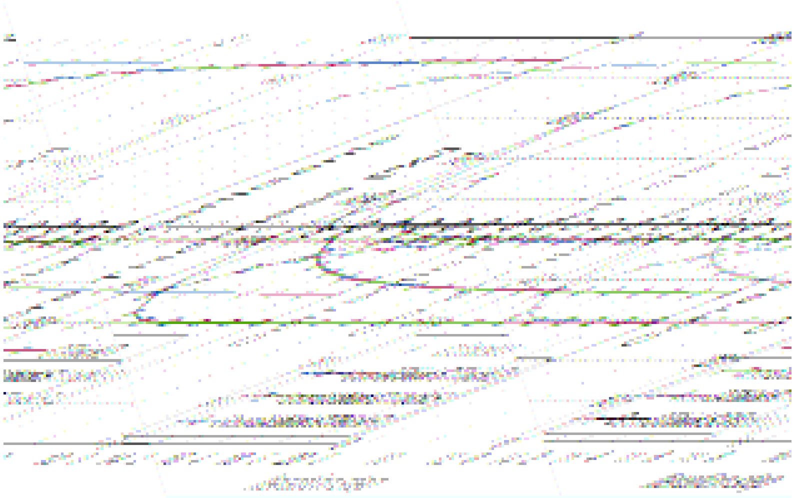

Figure 8: Multiple core thickness values with applied corresponding correction coefficients and the resulted average

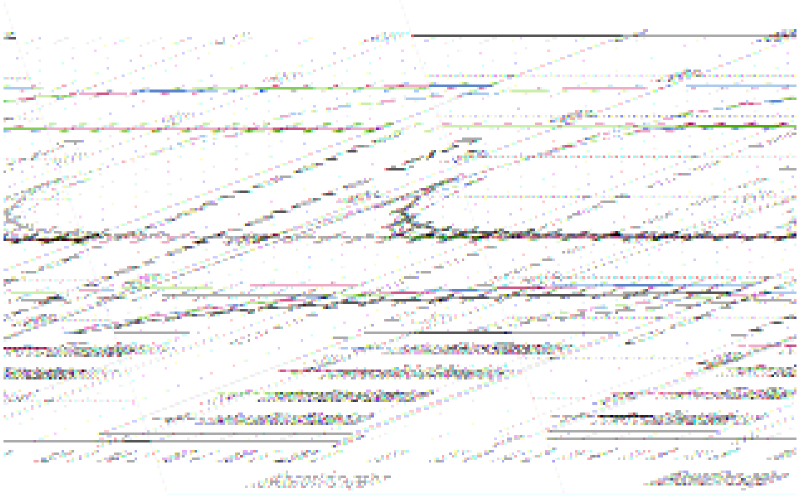

Figure 9: Input parameters with single values and the applied corresponding correction coefficients

Figure 10 illustrates the evolution of the resulted *D*, *S*, *R* output variables. It may be observed that within 20 steps, the reached values correspond to the desired set values respectively *D* = (75%), *S* = (65%) and *R* = (55%).

Acording to Figure 8, Figure 9 and Figure 10, in order to obtain a sandwich assembly having the imposed *D*, *S* and *R* overall properties, the individual components should have the following properties: *CThick*=53%, *FThick*=58%, *FEmodulus*=89%, *CGmodulus*=78%, *FLambda*=36%, *CLambda*=39%. The percentages are then transformed in real crisp values using Equations 1 and 2, in terms of the input and output defined universes of discourse.

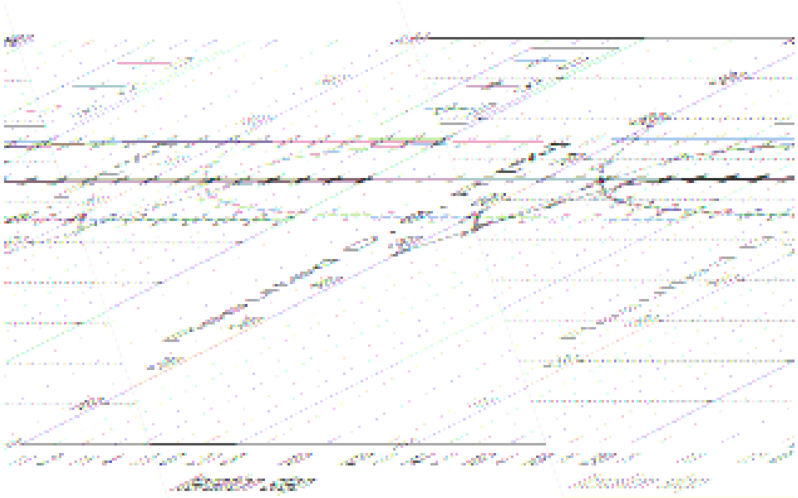

Figure 10: Resulted output variables

6. CONCLUSIONS

The proposed method represents a fast way for solving multiple and conflicting objectives in designing a sandwich panel. The number of input and output variables can be extended in terms of the applications. The method allows a reduction of the design time and cost during the first stage of the project developement, providing useful information for further analysis, when more accurate results are needed. Still, the necessary number of rules for evaluating an output will increase exponentially with the number of inputs or membership functions, which may lead to the increase of the computational time. Further research should be carried on in order to verify the stability of the control system and also to improve its accuracy.

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