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Efficient distribution of materials in multi-component systems design

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Abstract

In this paper we propose a method for materials selection, conceived to be applied to multi-component systems design, which has the following main characteristics: it takes into account various aspects of optimization in the choice of material, from conventional ones (minimization of the masses and costs), to those aimed to meet the functional performances required; for each component constituting the system, it matches the choice of material with sizing, by defining free geometrical variables of the problem; it takes account of the constraints to be imposed on the distribution of materials in a multi-component system. As a further peculiarity, the optimal choice of materials and component sizing are guided by an efficiency principle, which presupposes a choice of material calibrated on real performance needs. After presenting the formalization of the problem of choice of materials in multi-component systems, such as to contemplate the features specified above, an application in the case of a widely diffused plant component is outlined.

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1. Introduction

Design activity in the product development process can be divided in some key stages, that from an early stage of requirements definition and formulation of the problem, provide for the development of the design according to the

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following levels, as concordantly specified by many scholars such as Pahl and Beitz (1996), Dieter (2000), Ullman (2003): concept, system, details. The last two levels are the ones through which design requirements take shape in concrete design solution.

Although already at the level of system design preliminary studies of the shapes of the components, and a basic choice of materials are conducted, it is in the detail design phase that geometric variable dimensioning, and the combination of the most suitable materials become central.

In this context, the wide variety of available materials for engineering applications expands the design possibilities, but combined with the complexity of the set of requirements that affect the choice of the most appropriate materials, usually involves a multi-criteria optimization problem of considerable difficulty.

To support the designer in addressing this problem, in the last decades systematic methods for optimal selection of materials have been proposed, with the aim of providing tools that enable a rational choice of the most appropriate materials. Chiner (1988) proposed five stages for materials selection process: definition of design problem, analysis of material properties, screening of candidate materials, evaluation and identifying of the optimal solution, and final verification. Farag (1989) ascribed the various activities of material choice to the different phases of design process, and defined three stages of selection: initial screening, comparing alternatives, and selecting the optimal solution. According to Ashby (1992) four fundamental steps should be considered in the selection process: translating design requirements into specifications for material; screening out those materials that cannot meet the specifications; ranking the surviving materials, identifying those that have the best potential; searching for supporting information about the top-ranked candidates, to refine the final choice.

Similarities between the suggested approaches outline a basic materials selection activity as constituted by formulating material requirements, making a set of candidate materials, comparing and ranking them to obtain best solution. A wide variety of quantitative models also have been developed by Farag (2002), Ashby et al. (2004), Rao (2006), Raman (2007), Jahan et al. (2010), to allow systematic evaluations in these basic steps of the selection process. Multi-criteria decision making techniques have been applied in this regard, to strengthen final ranking process and search for optimal solution, by Jee and Kang (2000), Sirisalee et al. (2004), Shanian and Savadogo (2006), Chatterjee et al. (2009), Athawale and Chakraborty (2012), Jahan and Edwards (2015), to mention a few significant examples.

The analytical and graphical tools provided by these quantitative methods enable rational choice of materials according to the different types of performance required, but are all characterized by the feature of focusing on individual components without taking into account the systemic context which they belong to, and isolating the choice of material from the definition of other design variables, delegating to other activity the sizing of significant geometric variables.

The method proposed here looks at a detail design of components that takes into account the systemic dimension that must have the optimal choice of material for each component, and its close connection with the sizing of geometric variables that define its shape, and must ensure that the required performance is met. The method therefore presents the following peculiarities:

- for each component of the system, combines the choice of material with the components dimensioning, by defining the free geometric variables of the problem;
- takes into account the systemic constraints imposed on the distribution of materials, constraints stemming from the various types of interaction between the components of the system;
- the optimal distribution of materials between components, and their sizing, are guided by applying an efficiency principle, which presupposes a choice of material and the sizing of components calibrated on real needs.

After presenting the formalization of the problem of choice of materials in multi-component systems, such as to implement the features specified above, an application in the case of a plant component will be outlined.

2. Approach and methodological framework

To structure the process of material selection and sizing of the components of a system, a procedure is proposed according to the steps outlined in Fig. 1. The procedure is based on the specification of the design requirements,