THE SYSTEM FOR ANALYSING THE FIGURES OF MERIT IN MATERIALS SELECTION

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ABSTRACT

The method for selection of optimum structural materials is shown in this work. Whole set of figures of merit is included in the system for evaluating materials (OPTIMAT). A computer program for defining the figures of merit, the weighting factor, by digital -logic method, and for normalizing the value of the merit parameters is developed. The system serves as a tool for examining and comparing the quantitative methods for materials selection, and being also applicable for other ways of deciding.

KEY WORDS: Figures of Merit, Materials Selection, Optimization

1. INTRODUCTION

Materials selection today is a rising engineering problem. The number of available technical materials today is very large (about 70 000), and every one of them can be described with about 200 numerical characteristics. Each day we are witnessing the acquisition of new data about the characteristics of either already existing or new materials. Thus the group of structural materials is not at all static, on the contrary, it changes rapidly both quantitatively and qualitatively. The time the engineer could rely upon some catalog or manual for materials selection is gone forever. The development of computers and their global linking, as well as the development of specialized data bases and information services about materials, enable the users' quick access to data. Because of the huge number of materials that come into account for preselection, and because of the growing number of construction requirements and their complexity, the use of computer systems and tools for selection of optimum materials is nowadays necessary.

Based on literature about existing methods and systems it can be affirmed that they enable to put two or more requirements.

Miaw and Wilsons' system (1981) also enables to define the kind of load and geometry of the part upon which the functions of evaluating the structural requirements are dependant. Moreover, the problem of establishing the importance (weighting) factor of some requirement in relation to the others and the problem of normalizing the obtained values of the merit parameters, are widely present.

The proprietary system - OPTIMAT, which is described here, contains most of the options of the mentioned systems, because the primary intention during the development of OPTIMAT was the verification and the estimation of validity of existing methods for materials selection, as well as the evaluation of new ideas (free requirements setting, the method of acquiring the weighting factor with correction, different models of normalizing the values of merit parameters, etc.).
2. FIGURES OF MERIT IN MATERIALS SELECTION

The figure of merit is a mathematical description of the relevant requirements or group of demands. It is the mathematical expression the input data of which are the values of the characteristics of certain material, and the output data is the value which shows the validity of the examined material with respect to the given requirement. By comparing that value with the values calculated for other materials it can be concluded which material is better according to the given requirements.

Materials can be evaluated on the bases of:
1. certain characteristics,
2. figures of merit which are directly calculated from the relevant characteristics
3. general figures of merit.

The simplest way of materials comparison is through the values of certain characteristics.

With more complex requirements on materials greater number of properties characterise some relevant behavior.

Figures of merit are combinations of characteristics. Some of these merit parameters are dependant upon external influencing factors (e.g. geometry, kind of load ...). Here are several examples:

\[
\begin{align*}
\frac{R_e}{R_m}, \frac{R_{p0.2}}{R_m} & \text{ - notch sensitivity or the ability of bearing overload} \\
R_{p0.2}\cdot K_{IC} & \text{ - resistance to crack propagation} \\
R_m\cdot A & \text{ - resistance to brittle fracture} \\
\sqrt{\frac{E}{\rho}} & \text{ - minimum mass along with maximal stiffness (for the bending stressed beam)} \\
\frac{E}{\rho^2} & \text{ - minimum mass along with constant deflection (bending stress for round cross-section)} \\
\frac{R_{p0.2}}{\rho} & \text{ - resistance of the plate to the centrifugal forces} \\
\sqrt{\frac{E}{\rho}} & \text{ - resistance to vibrations} \\
\frac{\rho}{E} + \frac{\sqrt{E}}{\rho} & \text{ - behavior in resonance} \\
\left(1-\nu^2\right)^2\cdot \frac{R_{p0.2}}{E^2} & \text{ - resistance to surface pressures} \\
\lambda/\alpha & \text{ or } \lambda/(\rho\cdot\alpha\cdot C_p) & \text{ - resistance to heat dilatations} \\
\frac{E}{\rho} & \text{ - minimal mass along with constant resistance at temperature differences} \\
\left(1+(E/\rho)+(1-\nu)(1+\lambda)/\alpha\right)R_{p0.2} & \text{ - maximal strength along with the ability of bearing } \Delta T \\
\frac{R_m\cdot \lambda}{E \cdot \alpha} & \text{ - resistance to thermal fatigue.}
\end{align*}
\]

Some characteristic general figures of merit from the literature are mentioned in table I.

OPTIMAT works with all mentioned kinds of merit parameters, and also very simple is adding of new ones.

3. DEFINING THE WEIGHTING FACTORS

In product development and materials selection several requirements are usually set - there exist several comparison criteria. Each of them has certain importance comparing it to the other or to the rest of them.

Establishing of single weighting is very often of subjective nature. In this computer work the so-called DIGITAL-LOGIC method (Farag, 1989) of defining the weighting factors, is shaped which is also generally applicable for setting any kind of evaluation criteria. Instead of
defining all weighting factors at once OPTIMAT sets a row of questions in which it confronts each requirement (merit parameter) with each other. For n requirements there will be n·(n–1)/2 questions (combinations). Questions are very simple: is it in the concrete case more important the requirement Z₁ or the requirement Z₂. With positive answer it is associated 1, with the negative 0. This kind of requirements comparison is very close to the human approach to the problem: the complex problem is separated into a row of single problems that are solvable.

By digital - logic method the weighting factor (Bᵢ) is calculated in this way:

\[ Bᵢ = \frac{\text{number of positive answers for the given requirement}}{\text{total number of questions}} \]

To enable completely free factor calculation OPTIMAT offers an additional graphical way of weighting factors correction (Fig. 1). The results of digital - logic method are of initial value, and if needed can be revised; the computer helps it: when correcting one weighting factor it adequately corrects others, so that the sum of all weighting factors is always 1.

It is interesting that the digital - logic method gives good results - the results get better as the number of requirements rises. With other methods, situation is exactly opposite.

Table 1: The Figures of Merit from Literature /10/

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<tr>
<td>( F_j = \frac{C_j}{X_j} ) ( \rightarrow \min )</td>
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<td>( F_j = \frac{\sum_{i=1}^{n} \sum_{i=1}^{n} X_{ij} \cdot B_i \cdot B_{ij}}{\sum_{i=1}^{n} C_i} ) ( \rightarrow \max )</td>
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<tr>
<td>( F_j = \sum_{i=1}^{n} B_i \cdot \frac{X_i}{C_i} ) ( \rightarrow \max )</td>
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<td>( F_j = \left( 1 - B_j \right)^2 + O_j^2 ) ( \rightarrow \min )</td>
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<td>( P_j = \frac{\sum_{i=1}^{n} X_{ij}}{\sum_{i=1}^{n} B_i} ) ( \rightarrow 1 )</td>
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<td>( O_j = \frac{\left( \sum_{i=1}^{n} \left( \frac{X_i}{Y_i} - P_i \right) \right)^2}{\sum_{i=1}^{n} \left( \frac{X_i}{Y_i} - P_i \right)} ) ( \rightarrow \emptyset )</td>
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\( F_j \) - Figure of merit for j-material
\( B_i \) - Weighting factor
\( X_i \) - Candidate material value of properties "i"
\( Y_i \) - Specified values of properties "i"
\( C_j \) - Total cost of material
\( \varphi \) - Density of material "j"
\( n \) - Number of characteristics (materials properties)

4. NORMALIZING THE FIGURES OF MERIT

Normalizing of the merit parameters is transferring the absolute values into relative ones in relationship with maximum, medium or minimum value of such figure of merit or, generally, in
relationship with any number. Normalizing is necessary to annul the influence of the value of the evaluation function itself. Choosing a referent value for normalizing is not an easy task, because this choice has a direct influence on materials ranking.

Field and Neufville (1988) emphasise that it isn't possible to make such a general model that would be acceptable for solving every problem. In other systems for materials preselection normalizing is used quite often according to some characteristic values of the merit parameter: minimum, maximal or medium. Except for these possibilities, OPTIMAT also maintains two new ones:

- normalizing according to the merit values for some material,
- normalizing according to aimed (wanted) values.
5. COMPUTER PROGRAM OPTIMAT

Computer program OPTIMAT leads the user to the selection of the optimum materials step by step following the logic of the system. Of total 10 steps, 5 of them are always present, and the rest appears depending on the choice within the permanent steps.

The steps are, as appearing in the program:

1. Data bases selection - materials and figures of merit;
2. Defining the external influencing factors;
3. Relevant requirements selection;
4. Weighting factor establishing - digital-logic method;
5. Weighting factor establishing - factor correction;
6. Establishing of needed requirement values and figures of merit;
7. Setting the interval of good values of the characteristics;
8. Normalizing the calculated values;
9. Results print-out - materials ranking;
10. Analysis of the obtained results and print-out of the materials characteristics.

6. CONCLUSION

Existing formalized methods for materials selection have been studied, and their advantages and disadvantages commented. Several important problems are solved in a new and better way. Finally, a computer aided system for materials preselection is developed.

Now, it is being compared with many other systems, which will lead to the verification of the applied solutions. Simultaneously, data about materials for an own data basis are being collected.
Perhaps even more interesting part is the verification of the merit parameters, in the first place those that were 'freely' set. OPTIMAT's requirements basis with figures of merit is gradually increasing in size. Along with it rises, the applicability of the system because with many requirements different problems can be described.

Particularly challenging is the further experimenting with the normalizing models. Latest analyses have shown that normalizing according to the most favourable values gives most often satisfying results. Still, with well chosen wanted values, the normalizing model according to aimed values is certainly more favourable.

OPTIMAT as a tool for investigating the problem of the selection of optimum material fills the gap which disabled more serious researches of that problem.

REFERENCES:

/1/ ...Basic Material Studies (1982), "Material Properties Comparisons", p. 122-137
/2/ Mohwald, K., Kern, H., Hartung, F. (1991), "WEKEB - Ein Werkstoffkernberatersystem zur Werkstoffeinsatzbewertung", VDI Berichte Nr. 936, s. 105-121