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CHARACTERIZATION OF THE "DETERMINATION BY DISPLACEMENT" APPROACH – DEFMOT WITH AN EMPHASIS ON THE ANALYSIS OF MULTIFACTORIAL MODELS

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Key words: *multiparameter analysis, automotive steels, properties, rational modes.*
Abstract: *The report discusses the possibilities of presenting graphical analysis related to a way of automated search for rational solutions. They are referred to the modern automotive industry. Cases of presentation with an odd and even number of factors are classified, and attention is focused on one, two, three and four factors. The analysis methods associated with this presentation clarify decision support with the DEFMOT automated system.*

1. INTRODUCTION AND STATEMENT OF THE PROBLEM

In modern product design systems of utmost importance in CAD-CAE simulations, a material defined by its material constants plays a role [1-6]. At the same time, it is always sought to invest in such a material that will ensure a sustainable and long-lasting mode of operation.

Let us focus our attention on a bidimensional plot, also known as a one-factor plot, involving a single goal function – for example, the relative elongation, which is a dependent quantity on a single factor – the tensile strength. The main task that the designer pursues when choosing a material from a specific area for a given construction is to select such a material that will fulfill its purpose in the most reliable and secure way. In this case, we choose three main groups of elements of the car body that perform different/certain functions. We tentatively call the first function "roof", the second – "ensuring security in the event of a collision" and the third – "carrying". In the figure, the elements for these functions of the car body are marked and the steels from which these elements can be made are recommended.

Due to the different application of the elements of these functions, different materials are used, characterized by different material constants used by the CAD system in the construction. Let us now concentrate our attention on the banana diagram and determine for each of the applications the strength and its corresponding ductility.

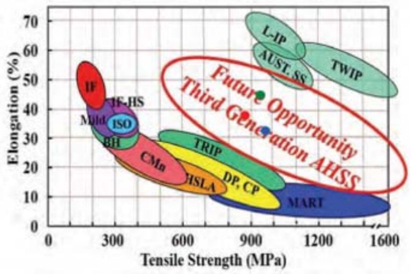


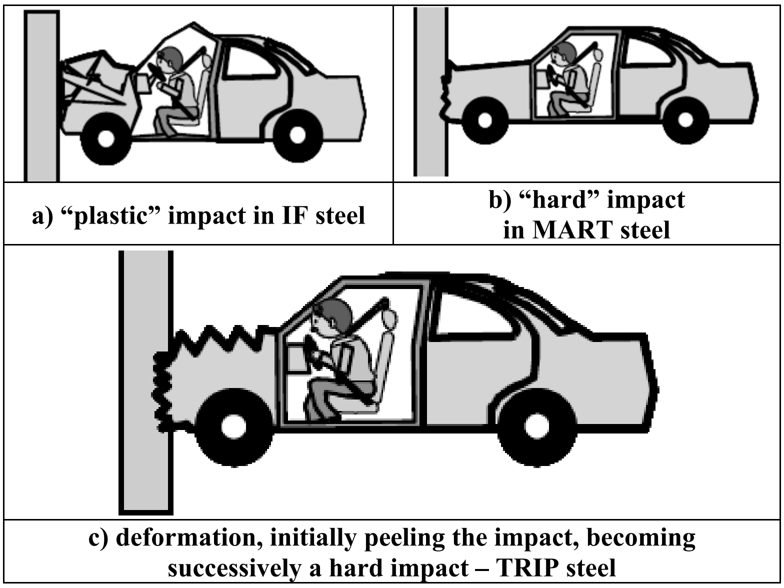
Fig. 1. Graphic representation of plasticity of automotive steels depending on the strength (the "banana" diagram)

IF steel with an average strength of 300 MPa; relative elongation 45%;
TRIP steel with an average strength of 850 MPa; relative elongation 25%;
MART steel with an average strength of 1100 MPa; relative elongation 10%.

IF	TRIP	MART

Fig. 2.

If we have to summarize the example of the banana diagram as the most elementary way of representing a goal parameter of one factor, we should note that, as a rule, the goal function is located on the ordinate, and in this case, it is the relative elongation, and on the abscissa is located the factor itself, in this case the strength.



a) "plastic" impact in IF steel

b) "hard" impact in MART steel

c) deformation, initially peeling the impact, becoming successively a hard impact – TRIP steel

Fig. 3.

This example was chosen because it best expresses the main contradiction in materials science – the contradiction between strength and plasticity. The greater the strength, as with MART steels, the less ductility. With IF steels, it is exactly the opposite. They are characterized by high plasticity and low strength. Most interesting, however, is the case of TRIP steels. Their typical average strength is 850 MPa. It is noteworthy that the DP-CP steels have the same average strength of 850 MPa, and the abbreviations are “dual phase – complex phase”. Nevertheless, from the “banana diagram” DP-CP steels have about 10% less ductility than TRIP steels. The explanation for this lies in the microstructure of the steel.

The materials technologist can advise the designer that behind the combination of each value from the database for a particular material that will be used in product calculations, there are two main groups of effects. They are the chemical composition determined by the alloying elements of the steel and the applied heat treatment mode. These two main effects form the values in the embedded CAD system material constants. As we have already explained, the material constants are selected according to the function or purpose of the product/part.

And after these material science explanations, let us now discuss how the dependence of the banana diagram can be analyzed by the "DEFMOT" approach at nine discretization nodes in the interval of [–1; +1]. Of course, for one factor this approach is a little workable, but we have taken the liberty of including it here so that it is possible to clarify the approach when starting it from a more elementary level.

The DEFMOT approach works with coded factors and normed criteria in research. In order to code the factors, the maximal and minimal values of both the changing factor and the examined criterion must be known. In the case of investigating the relative elongation depending on the tensile strength on the data of the “banana diagram”, by discretizing the definition area in the interval [–1; +1] with a step of 0.25.

A normalized graphical representation of the banana diagram at a given level of displacement constraints using DEFMOT is presented in Fig. 4.

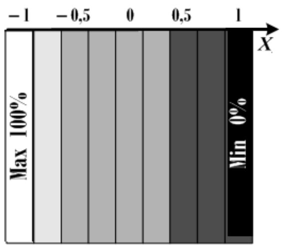


Fig. 4. Graphical representation of plasticity from the "banana" diagram using DEFMOT

It shows that the largest relative elongation (100%) is at the lowest strength value and this is for IF steel, and the smallest is for MART steels (0%) at the highest strength value. The percentages quoted are normalized to Amax = 50 % and Amin = 10 %. In the graph, these values are colored in different colors, and for the remaining sectors, the coloring depends on the moving constraints set by the decision maker. There is no way to evaluate this possibility within this small example, but You will see its advantage when considering more factors. The three figures depicted in Fig. 5 show what other application this representation can have in the field of materials science.

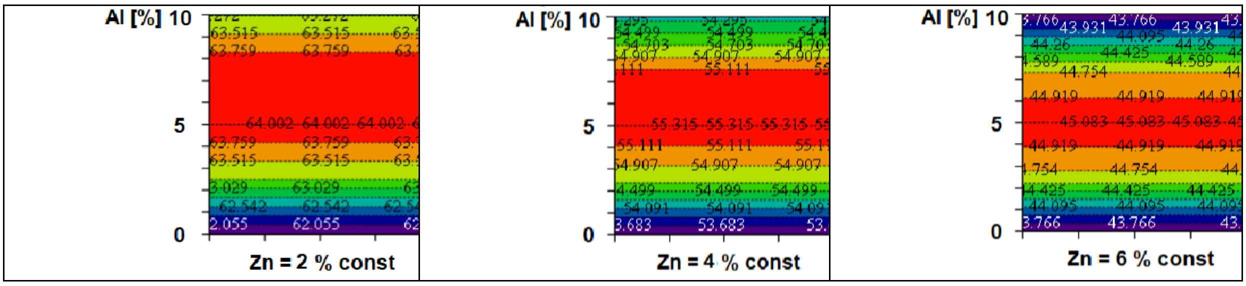


Fig. 5. Graphical representation of the tensile strength of an aluminum alloy using DEFMOT at different zinc contents

Let's imagine that we need to determine the influence of zinc on the strength of an aluminum alloy for which we have derived a model. Five more alloying elements are involved in the composition of the alloy, which are considered by the model. We plot aluminum along one axis varying in the interval [0, 10%] through 1% and analyze for three discrete values of zinc when examining the strength of the alloy. From the attached graph in all three graphs the maximal strength occurs at 5 % aluminum. But the maximal strength of the order of 64.0 MPa is highest at Al = 5%, Zn = 2%, while at Al = 5%, Zn = 6 it is significantly lower: 45.08 MPa. The last decision may be reviewed by the decision maker; in this case, not one property will be considered, but a complex of properties Fig. 6, where – in addition to strength – there must also be a requirement for plasticity. Now it may turn out that Zn = 4 is the final solution, but it all depends on the specification. We include this question for consideration because for another level of the main alloying elements when considering strength and ductility together, we obtained the following conflicting distributions.

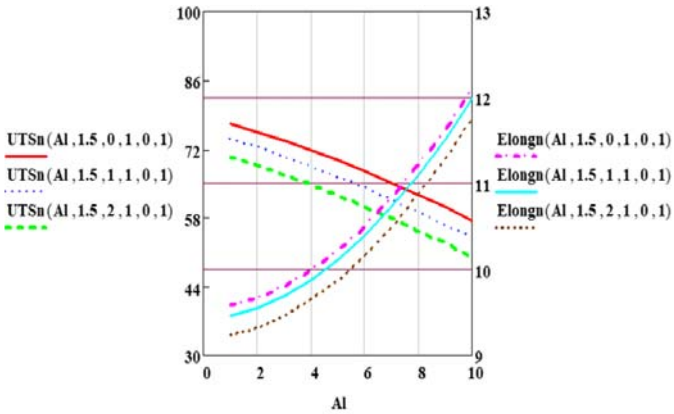


Fig. 6. Graphical representation of the tensile strength and elongation of an aluminum alloy using DEFMOT for freely varying two of the alloying elements

If other than the fixed alloying elements are released, the strength and ductility values will change, but generally the character of the graph will be preserved.

2. ANALYZING TWO, THREE AND FOUR FACTOR MODELS

If DEFMOT is to be applied to two factors, in this case the factor X_1 as an odd parameter occupies the horizontal axis and X_2 the ordinate axis. Discretization is thus performed on both factors according to the following statement. Fig. 7 shows an example response surface for changing the quality indicator depending on the values of the technological (input) parameters.

It is customary to analyze such surfaces graphically by means of contour plots defined by the lines of constant level as noted at right. Thus, it is possible graphically to determine the coordinates of the values of the technological parameters at which local or global maxima and minima of the goal parameter occur.

To perform this analysis automatically [1] in the plane of the technological parameters, it is necessary to discretize the variables in this plane – Fig. 8.

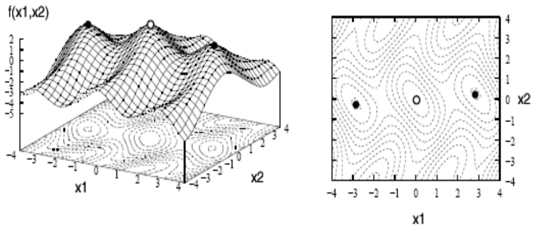


Fig. 7. Graphical interpretation of a one-criteria optimization problem with two variation factors

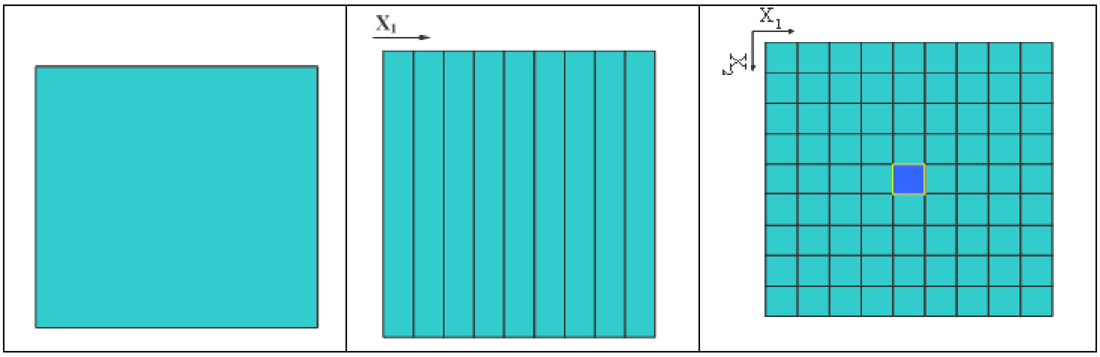


Fig. 8. Graphic representation by DEFMOT of the division of the global multiparameter definition space

The discretization is performed in the interval of variation of each variable with a certain step. The accuracy of the determined solutions depends on the size of the step.

With the performed discretization, it is possible to calculate the values of the quality indicator and through this sequence a discrete (digital) contour diagram is constructed.

Discretized contour plots can present the model in a user-friendly manner to the decision maker. Thus, the decision support person analyzes the model after its single-criteria optimization. The representation is related to coloring in different colors the different areas bounded by the contour lines. The different colors are projected onto the analysis plane by scanning the response surface with multiple (up to five) planes. An essential feature of this representation is the different range of variation with respect to certain values of the goal parameter. Therefore, the geometric representation of the discretized image will depend on the location of the planes along the axis of the criterion (quality indicator). The corresponding color on the discrete contour plot is directly related to the value of the quality indicator.

For the depicted model of the analog contour diagram with DEFMOT, four digital images examining the minimum and four – the maximum – Fig. 9.

The tool used to traverse the discretized plane of technological parameters in DEFMOT is called "zoom".

The zoom movement in the plane of the technological parameters determines the relationship between them and the value of the investigated quality parameter.

The peculiarity of this representation is that the discretization along X_1 and X_2 changes globally, and along X_3 and X_4 – locally.

Thus, preparations (Fig. 10) were made to create conditions for rendering the 5D- space. In this case, the n-th space turns out to be an arrangement in a specific way of the bidimensional space.

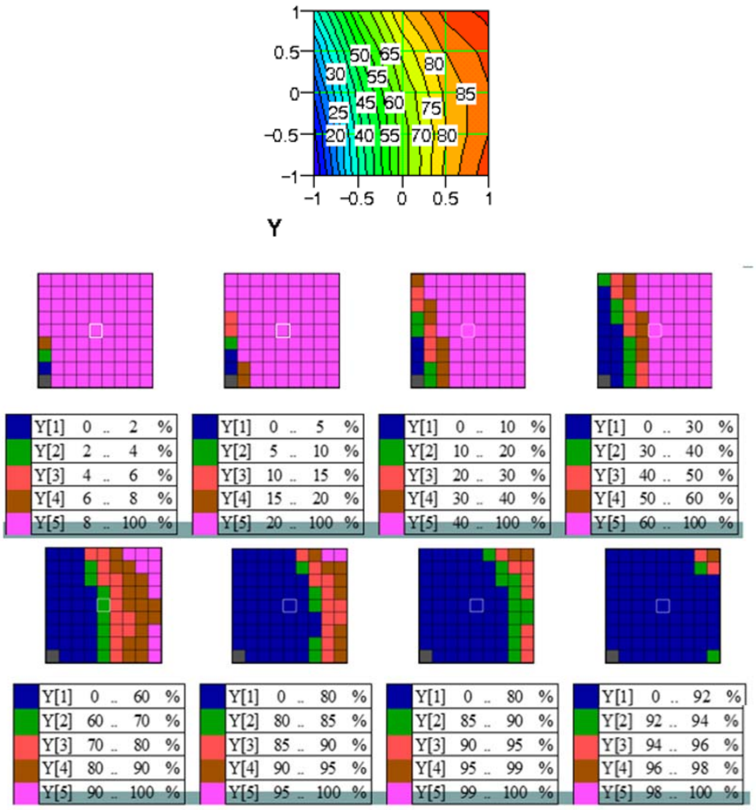


Fig. 9. Graphical digital representation by DEFMOT of the minima and maxima of a two-dimensional model originally represented as analog

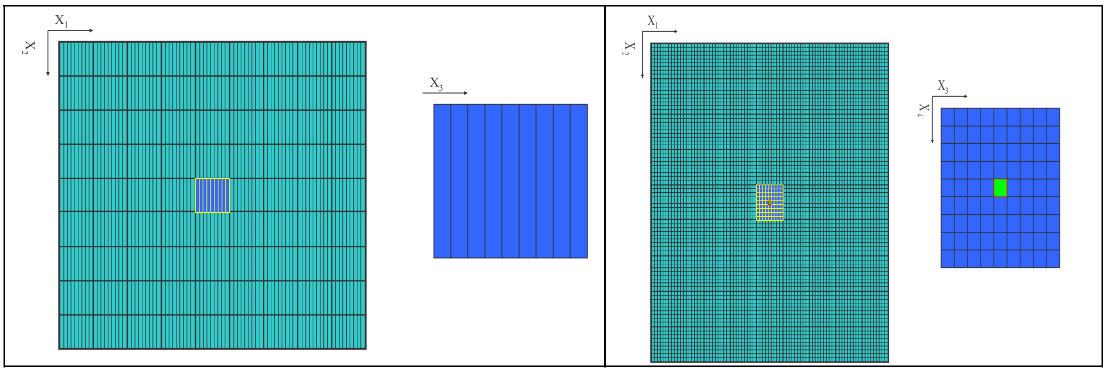


Fig. 10. Graphic representation by DEFMOT of formation of the global multiparameter definition spaces of the third and fourth parameters

In this case, the most important thing in the analysis of all models and all factors using DEFMOT is that by means of different moving planes with a selectable step, the response surface is intersected – Fig. 11. The planes move along the *y*-axis, and the range between them is colored with a certain color. This color is projected onto the corresponding square of the definition area. Thus, the user analyzes the area and determines the maximal and minimal values. The value of the examined quantity is a corresponding color.

Here is an example (Fig. 12) describing the situation with three factors. With two global factors fixed, nine steps of local variation can be assigned to the third and fourth factors, respectively.

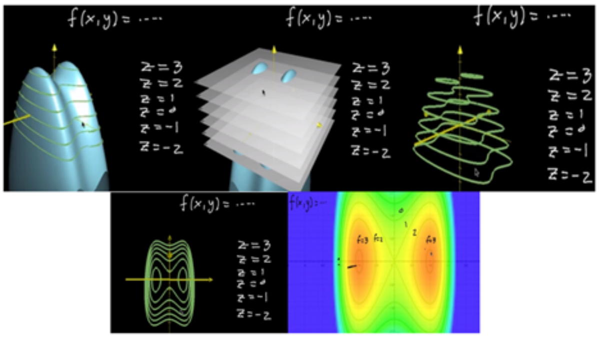


Fig. 11. Graphic representation of the tensile strength of an aluminum alloy using DEFMOT at different zinc contents

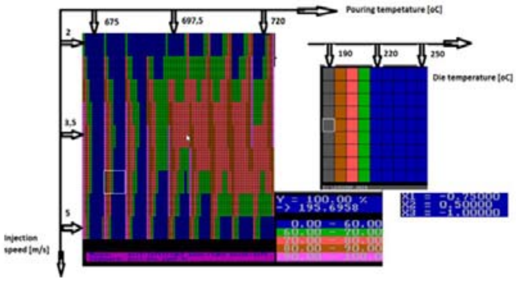


Fig. 12. Graphical representation of the tensile strength of an aluminum alloy using DEFMOT at different zinc contents

CONCLUSION

The considered capabilities of graphical analysis are related to a way of automated search for rational solutions. They refer to the field of design. The analysis methods associated with this presentation clarify decision support with the DEFMOT automated system. This graphical approach has been adapted to solve analysis and optimization problems from the field of materials science for three and four change factors. The paper presented the method of discretization and how the value of the multiparameter model is calculated for fixed parameters. The odd factor is also placed on the horizontal axis, and if there is an even factor, it is placed on the ordinate. Thus, the scheme used can visualize models with more than 4 factors.

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