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Optimization methodology of a product of white line by computational analysis using statistical approach and finite elements

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ABSTRACT

Purpose: The industry constantly seek reduction of production costs combined with improved product quality. The major challenge faced is to maintain the product quality. In this work, it is proposed an optimization methodology for a product of the white line. The objective is to study the behavior of some components after a reduction in sheet thickness and maintain the same original structural loads.

Design/methodology/approach: A two-dimensional mathematical model, obtained in CAD software, for numerical simulation of the effects of the reduction in thickness, is examined. Finally, it was developed an optimized methodology, based on mathematical and statistical analysis, in order to calculate the possible sheet thickness reduction from its original structure.

Findings: It was observed that it is possible by means of computer simulation and appropriate statistical analysis to decrease the thickness of assembled components in order to optimize costs and processes.

Research limitations/implications: Since this is an experimental research with numerical data, it would be fundamental for this technique of optimization a future research with physical products for comparison with the computational data.

Originality/value: The objective of experiment is maintain the product quality and because it is a job for optimization of processes and consequently costs, the great beneficiary will be the industry.

Keywords: Sheet metal; Thickness reduction; Numerical simulation

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The home appliance industry, automobiles and general machinery, constantly seek reduction of production costs combined with improved product quality. Some measures taken to reduce cost are to reduce the used volume of material - by reducing sheet thickness - and use alternative materials to the original steel. The major challenge faced is to employ one of these alternatives without compromising product quality. In the case of the automotive industry the main objective of sheet thickness reduction is to reduce weight and therefore fuel consumption. To do this, conventional steels have been gradually replaced by thinner sheets of advanced high-strength steels (AHSS, Advanced High Strength Steel) having much higher strength combined with acceptable ductility.

When the material can not be replaced the alternative is to optimize the design by reducing the material excess. The difficulty in the optimization of a project is to propose changes based on trial and error. This approach usually is costly and time consuming.

A technological tool that has gained ground in industrial applications is the computer simulation using Finite Element Methods (FEM) [1]. According to Andersson [2] MEF has been widely used in sheet forming helping to reduce time and stamping tools development costs. Makinouchi [3] examined a large number of simulation softwares and reported the great ability of these softwares to predict forming problems, such as wrinkle, deflection, determining blank geometry, breaking point condition, sheet metal thinning, residual stress and springback.

Tekkaya et al. [4] divides the industry objective with the sheet forming simulation in three main groups: (i) reduction of time: prior verification of manufacture ability of parts, reduction in development time, reduced time of try-out, rapid response to desired changes; (ii) cost reduction: cheaper products, reducing costs tools, die optimization, increased reliability and (iii) increased product quality, optimal selection of the work piece material, production of more complicated parts, know-how increase about new materials, process repeatability, optimization of process variables.

The computer simulation by finite element combined with a good experimental design and appropriate statistical analysis can help the industry to develop products with less time, cost and with higher quality. Lajarin and Marcondes [5] used the Abaqus to analyze the influence of some process and tool parameters in springback problem occurred after the forming of automotive steel parts. Through a statistical analysis the authors were able to observe the importance of the influence of these parameters on the formed component. Koc et al. [6] showed that a combination of experiment planning techniques and MEF can generate useful information on several variables in a process of hydroforming of metal parts. As a result of this investigation, the authors confirmed not only the expected effect of the trends of some parameters, but also interactions between them and the application of practical values that can be used. This information was obtained starting from a substantially reduced number of finite element analysis compared to the standard Response-Surface Methods (RSM), or technical factor, avoiding costly physical experiments. Acht et al. [7] combined design of experiments with MEF in order to identify the most important parameters that influence the distortion of parts subjected to hardening. In order to analyze the design of experiments, two different modes were used. At first, the factors influencing were identified by a probability plot and in the second an analysis of variance was performed.

This paper aims statistically analyze the grade of resistance of an appliance optimized by FEM. Commercial finite element software has been used to propose some reduction in the thickness of sheet metal components. The possibility of reducing the thickness of the assembled sheet components on a structure, with a cost optimization, and maintaining product safety with the standard requirements was observed.

2. Experimental procedure

The structure of a stove made up of eight components was modeled in a 3D CAD application and then imported into a commercial application of finite element (Ansys). The connections between the components was the rigid type, the material used in the model was the carbon steel described with Elastic Modulus of 2.1e5 MPa and Poisson coefficient of 0.3. Boundary conditions were defined in the components and applied diagonally towards the frame a force of 1.22 kN, between the highest and lowest region, Fig. 1.

The deflection measurements were made on the actual product by dial indicators as may be seen in Fig. 2 (b). In this study, via computer simulation, the measurement was made based on offset information reported directly in software.

According to the ANSI Z21.1-2005 a white line product, for the North American market, must support diagonal forces of 1.22 kN and may not exceed a deflection of 2.5 mm in the flat direction of the component - horizontal to the diagonal stress.

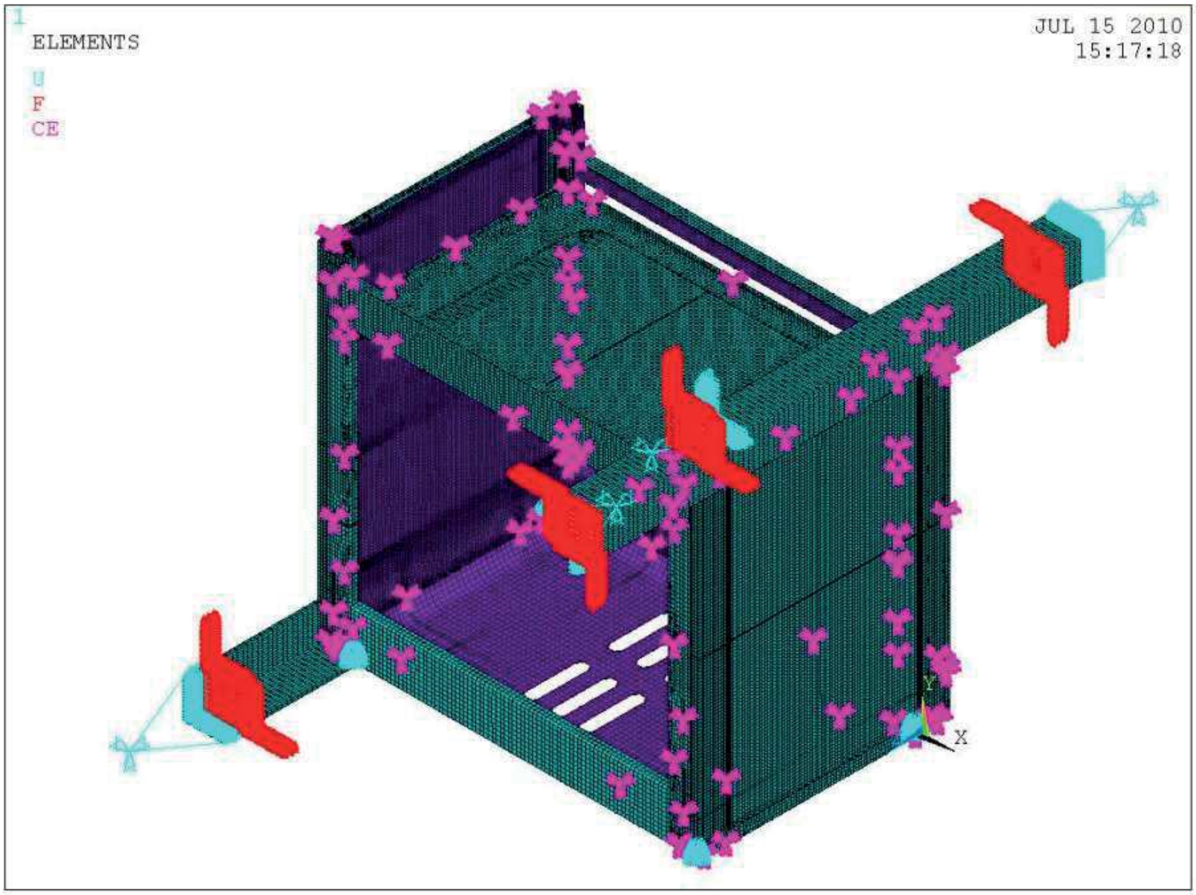


Fig. 1. Computational model of the stove with the defined boundary conditions and applied diagonal force

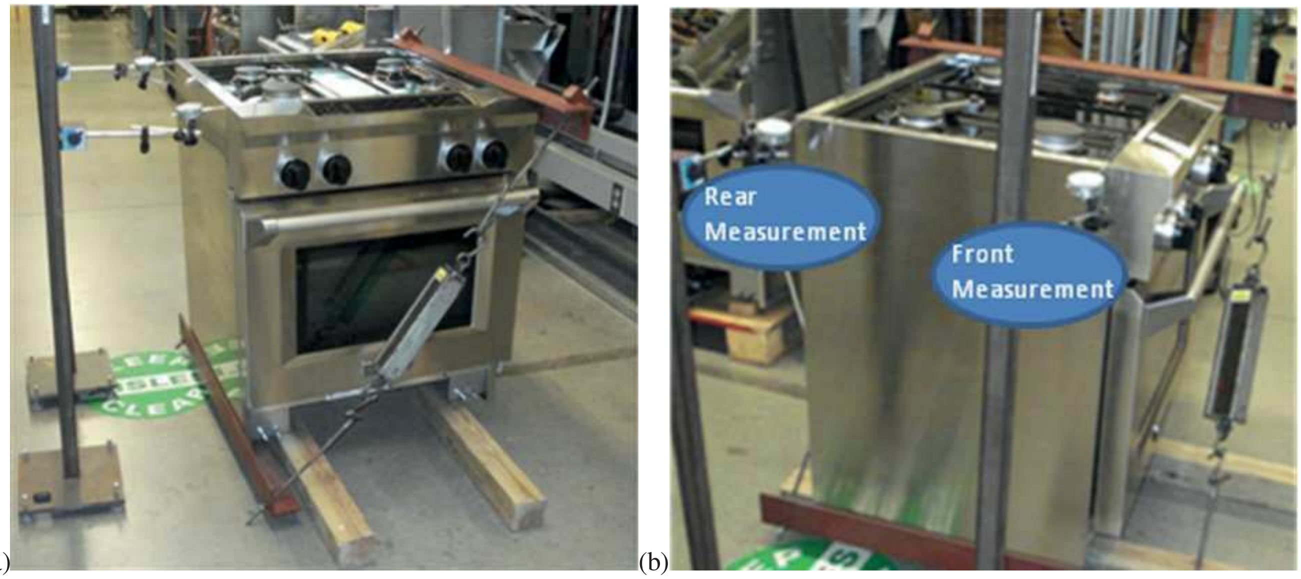
(a)  (b)

Fig. 2. Product: (a) assembling of diagonal stress test and (b) front and rear deflection measurements

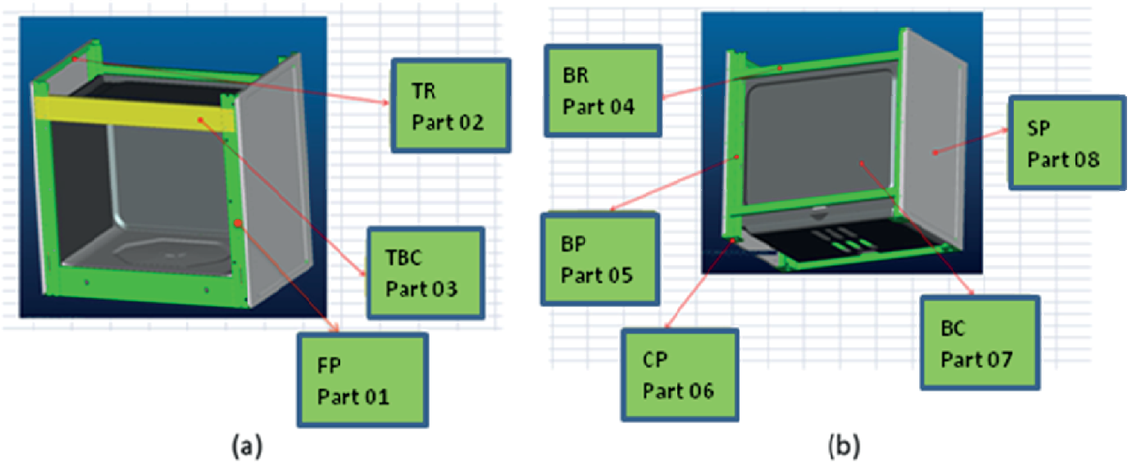


Fig. 3. Components of the structure: (a) 1, 2 and 3 and (b) 4, 5, 6, 7 and 8

Of the eight structural components studied six were analyzed with two options of thicknesses (thicknesses higher and lower) and the other two components were analyzed under the original conditions or removed from the structure (with or without), as shown in Table 1 and Fig. 3.

Table 1.
Stove components

Peace	Name	Thickness, mm	
		+	-
1	BC	0.61	0.45
2	CP	1.14	0.75
3	FP	1.21	0.75
4	SP	0.61	0.45
5	TBC	WITH	WITHOUT
6	BP	1.14	0.75
7	BR	0.584	0.45
8	TR	WITH	WITHOUT

A fractional experimental design was carried out with 16 simulations factors according to the relationship diagram, Fig. 4. The fractional factorial analyzes only a part of all possible combinations contained in a full factorial. This is useful to determine guidelines and prioritize factors. With these factors a relationship diagram can be obtained combining all the possible options of materials, with more or less thickness and with or without the component, Table 1. These combinations were analyzed statistically by Jump® software that indicates which are the best combinations to be assembled to the frame.

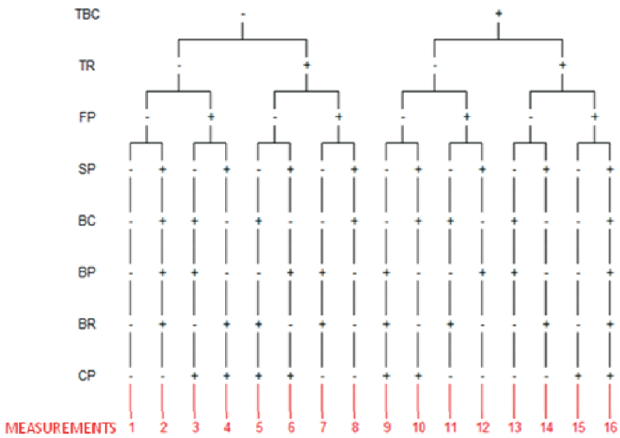


Fig. 4. Relationship diagram of the factors

3. Results and discussions

The values of the sixteen deflections of the computational trials are presented in Fig. 5. It can be seen that the smaller average of values of deflection occurred in cases 3, 6, 12 and 16. In these cases the parts showing the thicknesses of the best combinations of force were applied in the structure. Furthermore, the combinations that supported the lower stresses were the cases 1, 5, 10 and 14.

Fig. 6 (a) determines the relative importance of the factors to establish the study of priorities. The priorities are used to choose a starting point for solving the problem. In Figure 6 (b) is illustrated, with normal probability, the significant effects of frontal measurements.

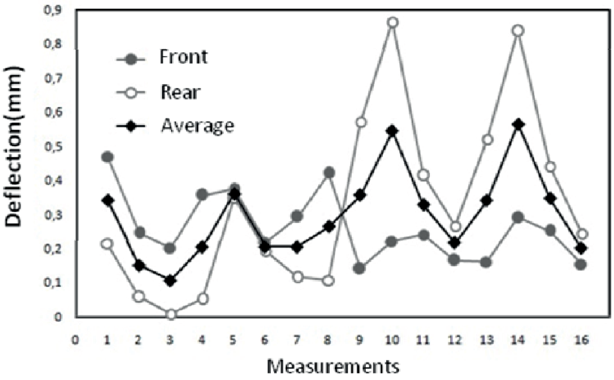


Fig. 5. Results of the deflection measurements

In Figure 6 (a) it can be seen that the TBC, FP and BP parts are the most significant for the experiment and 88.7% of the experimental variation is due to them. Thus, one can ignore the other factors to be little or with no influence on the result. The thickness of the piece of 0.19 mm for TBC acts on the final result of the deflection. The same trend for FP of 0.24 mm and BP of 0.16 mm were observed. In Figure 6 (c) is shown the result to the back measurements. It can be seen that the BP, CP and TBC parts had the most significant effect, accounting for 91.8% of the variations. The result of 0.06 mm (half, is multiplied by 2) of the BP components acted on the end of the deflection. It can be seen that, in the same way, it was found the value of 0.1 mm for TBC and 0.04mm for CP. Fig. 6 (e) shows the result with the average values and can be observed that the BP, FP and TBC parts were the most influential in the results with 88.1% of the variation. The BP component with 0.07 mm acted on the average of the end result, the same way 0.12 mm for the TBC and FP.

The deflection measurement results were used to equate the thickness reduction for a structure with eight components. Equation 1 predicts frontal deflection. The value of 0.263 is the average deflection of the front and the values presented in equation 1, in front each component, corresponds to the deflection value of the component in the front region. These components used in equation are the significant ones and exemplified in the Pareto and probability charts (Fig. 6). They match the variation of 91.8% in the region of the experiment.

$$\text{Deflection (front)} = 0.263 + (-0.065 * BP) + (-0.059 * TBC) + (-0023 * CP) \quad (1)$$

In equation 2 can be calculated the back deflection. The value of 0.328 is the average deflection of the rear and the values present in front of each component, equation 2, correspond to the amount of deflection of the rear part. These components values used in the equation 2 are the significant ones exemplified in Pareto and probability plots (Fig. 6) and match 88.7% of the variations of the experiment in the region.

$$\text{Deflection (back)} = 0.328 + (0.192 * TBC) + (FP * -0.122) + (-0.081 * BP) \quad (2)$$

In equation 3 can be calculated the average of deflection. The value of 0.297 is the average deflection and the values in front of each component, in the equation 3, correspond to the mean deflection value at the respective component. These components utilized in the equation are the significant ones and exemplified in Pareto and probability charts (Fig. 6), which corresponds to 88.1% of the experiment changes in the product structure.

$$\text{Deflection (average)} = 0.297 + (-0.073 * BP) + (0.066 * TBC) + (-0.062 * FP) \quad (3)$$

As a final proposition the deflection equation can be rewritten as:

$$\text{Deflection} = A0average + (A1X1) + (A2X2) + (A3X3) \quad (4)$$

where:
A0 = Effect coefficient (average inputs);
Ai = Effect / 2 (slope of the line);
Xi = Significant Factor (level)

In this work, it was proposed a method to optimize the sheet thickness of a white line structure. The presented methodology still requires practical experimentation to obtain an indication of the error that should be used in the equation in order to achieve the lowest noise in the experiment.

4. Conclusions

The paper proposes an experimental procedure to evaluate the influence of the changes in thickness of structural components of a product of the white line. It has been observed that through an appropriate experimental design and computer simulation is possible to optimize a product still in the design stage without the need for construction of the physical product for the empirical modifications. Furthermore, the study shows that the appropriate choice of factors and efficient statistical analysis is important for the reliability of the results.

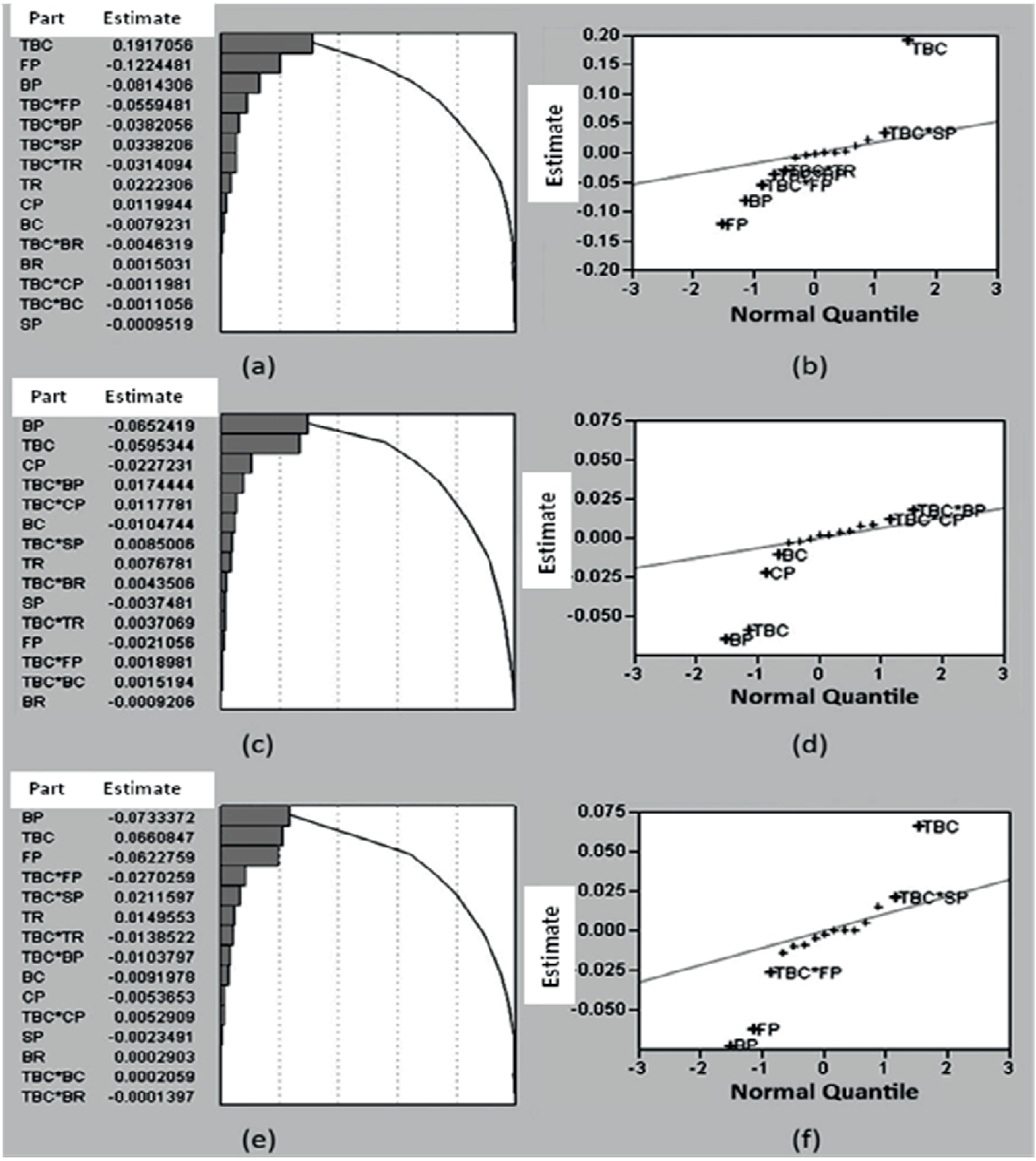


Fig. 6. Deflection results: (a) of the front Pareto chart deflections, (b) Normal Probability front deflection, (c) Pareto chart of the rear deflections, (d) Normal Probability rear deflection, (e) Graph medium deflections and (f) Normal Probability of middle deflections

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