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THERMAL FINITE ELEMENT ANALYSIS OF A CAR REAR LAMP

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Abstract: *This paper presents the analysis of thermal behavior of the cavities of a car rear lamp during the operation of the bulbs. CAD model was developed using CATIA V5 software and the calculation was performed using ABAQUS FEM*

Keywords: FEM, car rear lamp, thermal analysis.

INTRODUCTION

The paper presents a preliminary analysis made in order to determine the radiation flow of the inner cavities of the car rear lamp, watching to verify the thermal behavior of the chosen materials and the heat risk assessment.

Cavity radiation can occur when the model surfaces can face each other and thus change the heat between them by radiation. Such exchanges depend on factors which measures the relative interaction between the surfaces making up the cavity. The analysis started from the CAD model of the rear lamp made in CATIA V5. Cavities were defined in ABAQUS as collections of surfaces composed of facets. In order to calculate the cavity radiation, every facet is assumed to be isothermal and have an uniform emission.

THEORETICAL CONSIDERATIONS ON HEAT CALCULATION

Our formulation is based on the 'gray body' theory of radiation which means that the monochromatic emission of the body is independent of the wavelength of radiation propagation. Only diffuse reflection it is considered. Radiation attenuation in the cavity environment it is not considered. Using these assumptions together with the assumption that the cavity facets are isothermal and have isoemittance, we can write the flow of radiation per unit area in a facet of the cavity as:

$$q_i^c = \frac{\sigma \cdot e_i}{A_i} \cdot \sum_j e_j \cdot \sum_k F_{ik} \cdot C_{kj}^{-1} \cdot \left(\left(\theta_j - \theta^Z\right)^4 - \left(\theta_i - \theta^Z\right)^4 \right) \tag{1}$$

with :

$$C_{ij} = \delta_{ij} - \frac{(1 - e_i)}{A_i} \cdot F_{ij};$$

A_i - area of facet i;

e_i, e_j - emissions of facets i, j;

σ - Stefan-Boltzmann constant;

F_{ij} - geometrical matrix of the factor;

θ_i, θ_j - temperatures of facets i, j;

θ^Z - zero absolute temperature on the utilized scale;

δ_{ij} - Kronecker delta.

In the particular case of 'blackbody' radiation, where no reflection occurs (emission = 1), the equation (1) will be reduced to:

$$q_i^c = \frac{\sigma}{A_i} \cdot \sum_j F_{ij} \cdot \left(\left(\theta_j - \theta^Z \right)^4 - \left(\theta_i - \theta^Z \right)^4 \right) \tag{2}$$

Variables used to solve the problem of discrete approximating of heat transfer with radiation in the cavity are the nodes temperatures on the surfaces of cavity. Since we assume that for radiation purposes in the cavity each facet is isotherm, it is necessary to calculate an average power of temperature radiation of the facets. To do this, we first define the radiation power of temperature as:

$$\eta_i = \left(\theta_i - \theta^Z \right)^4 ; \;\; \eta^N = \left(\theta^N - \theta^Z \right)^4 \tag{3}$$

where the index *i* refers to facets and the index *N* refers to the nodal quantities.
Then, we interpolate the average power radiation of facet temperature of the nodal temperatures of facets as:

$$\eta_i = \sum_N P_i^N \cdot \eta^N \tag{4}$$

where N is the number of nodes that compose the facet and P_i^N are the contributing nodal factors calculated from the integration area as:

$$P_i^N = \frac{1}{A_i} \cdot \int_{A_i} N_i^N \cdot dA_i \tag{5}$$

where N_i^N is the interpolation functions for the facet *i*.
The flow of radiation for the facet *i* may be written as:

$$Q_i = q_i^c \cdot A_i = \sum_j R_{ij} \cdot \left(\eta_j - \eta_i \right) \tag{6}$$

with $R_{ij} = \sigma \cdot e_i \cdot e_j \cdot D_{ij}$ and $D_{ij} = \sum_k F_{ik} \cdot C_{kj}^{-1}$.

This could be rewrite as:

$$Q_i = \sum_j \overline{R}_{ij} \cdot \eta_j \tag{7}$$

with $\overline{R}_{ij} = R_{ij} - \left(\sum_k R_{ik} \right) \cdot \delta_{ij}$.

The nodal contributions of the radiation flow on each facet could be written as:

$$Q_i^N = \int_{A_i} q_i^c \cdot N_i^N \cdot dA_i = P_i^N \cdot Q_i \tag{8}$$

and the total radiation flow for the node *N* is:

$$Q^N = \sum_i Q_i^N = \sum_i P_i^N \cdot Q_i \tag{9}$$

Replacing the equations (4) and (7) in the above equation, results:

$$Q^N = \sum_M \overline{R}^{NM} \cdot \eta^M \qquad (10)$$

with $\overline{R}^{NM} = \sum_i \sum_j P_i^N \cdot \overline{R}_{ij} \cdot P_j^M$.

The q_i^e flow of radiation is evaluated based on the temperatures at the end of the increment, on the coordinates of the end of the increment and on the emissions at the beginning of the increment. Any time variation of the coordinates during the heat transfer analysis is defined as a movement of translation and / or rotation.

The Jacobean contribution resulting from the radiations flow in the cavity it is written:

$$J^{NM} = \frac{\partial Q^N}{\partial \theta^M} = 4 \cdot \overline{R}^{NM} \cdot \left(\theta^M - \theta^Z\right)^3 \qquad (11)$$

THE CALCULATION MODEL UTILISED

Figure 1 shows the CAD model of the lamp used for thermal calculation. The mesh model was done using ANSA software, the elements being of type shell, trias and quad.

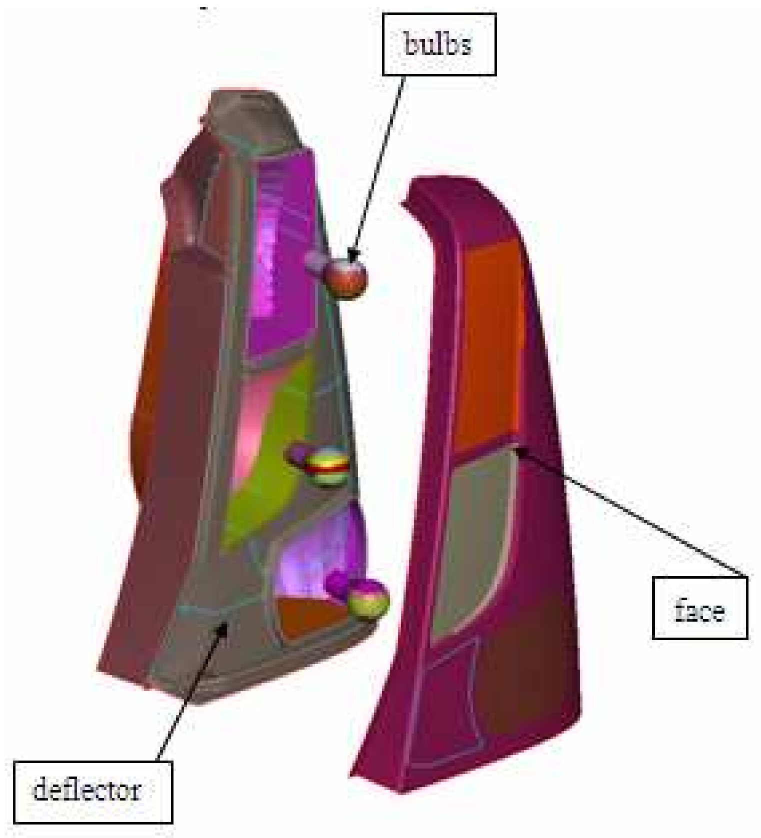


Fig. 1. Exploded view of the rear lamp.

The model has 21514 elements (20329 quad and 1185 trias) and an average dimension of mesh of 5.5 mm, as could be seen in Figure 2.

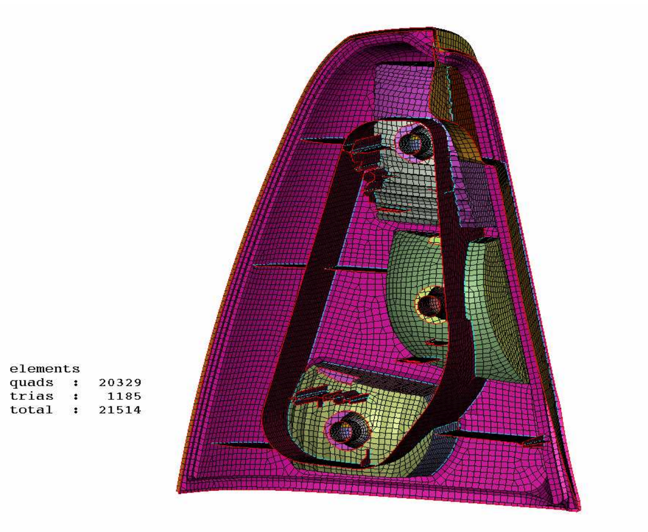


Fig. 2. The mesh of the rear lamp.

The properties of the materials used for the numerical calculation are presented in Table 1:

Table.1. The properties of the materials.

PLEXIGLAS (density = 1190 $kg.m^{-3}$)		
The expansion coefficient (K^{-1})	Ambient temperature (°C)	Conductivity ($W\ m^{-1}\ K^{-1}$)
50*10-6	23	0.15
Polycarbonate-Styrene Acrylonitrile Acrylic (density = 1050 $kg.m^{-3}$)		
The expansion coefficient (K^{-1})	Ambient temperature (°C)	Conductivity ($W\ m^{-1}\ K^{-1}$)
40*10-6	23	0.2
GLASS (density = 1190 $kg.m^{-3}$)		
The expansion coefficient (K^{-1})	Ambient temperature (°C)	Conductivity ($W\ m^{-1}\ K^{-1}$)
0.8*10-4	23	10

The admissible temperatures for these materials are presented in Table 2:

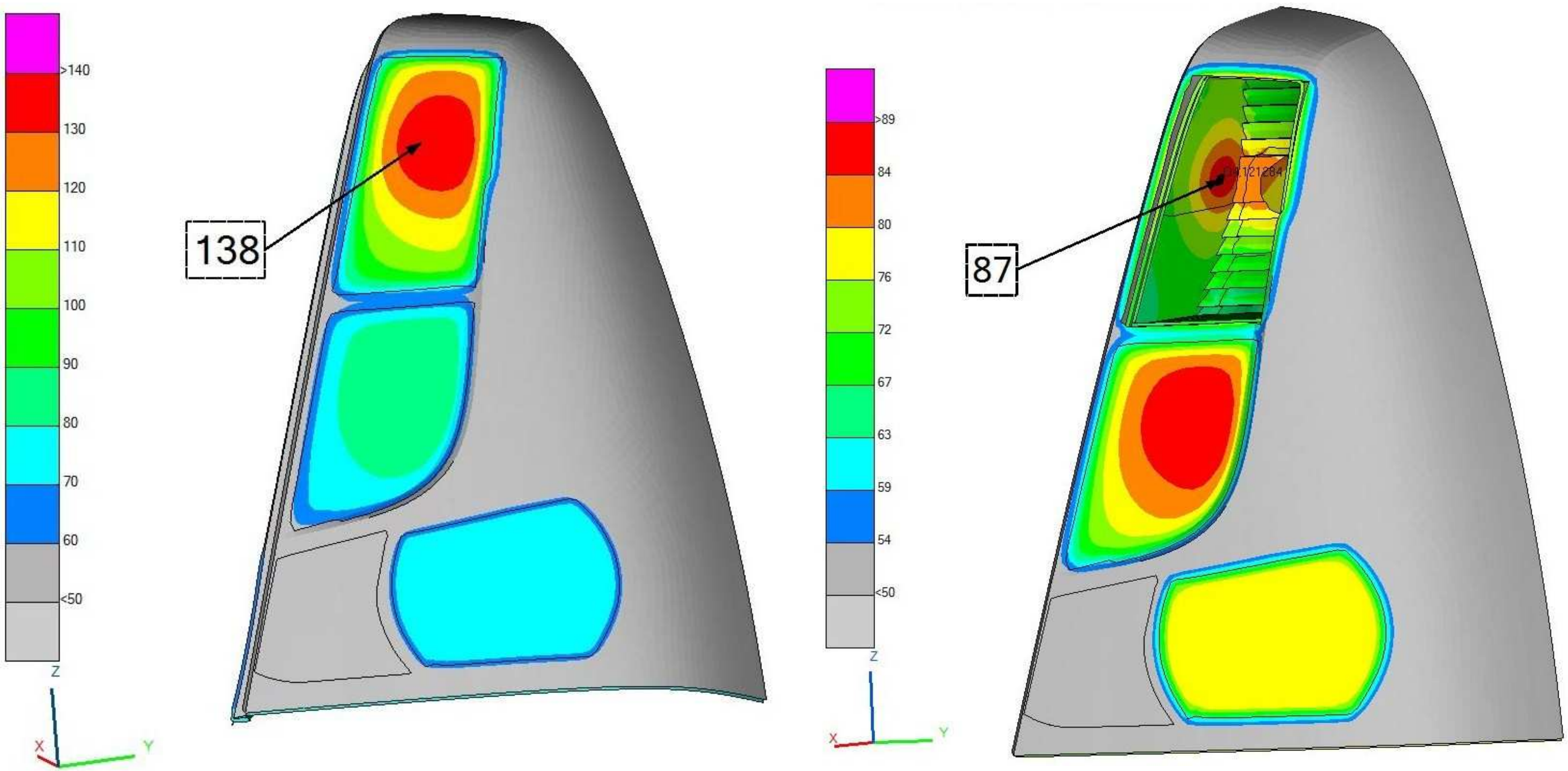
Table 2. The admissible temperatures.

Materials	Deflection temperature at 1.8 MPa	Viscous transition temperature
PLEXIGLAS	98	110
POLYCARBONATE - ASA	140	160

The convection coefficients used for calculation are:
4 $W/m^2/K$ for the interior surfaces;
10 $W/m^2/K$ for the exterior surfaces.
The emission coefficients of the cavities interior surfaces have the following values:
0.8 for the surfaces of bulbs and the exterior of the lamp;
0.123 for the deflector interior surface.

RESULTS AND CONCLUSIONS

Figures 3, 4 and 5 presents the distribution of the temperatures obtained by calculation for each element. The confidence level of the results is ± 5°C.



FACE DEFLECTOR

Fig. 3. Temperatures cartography for the first cavity.

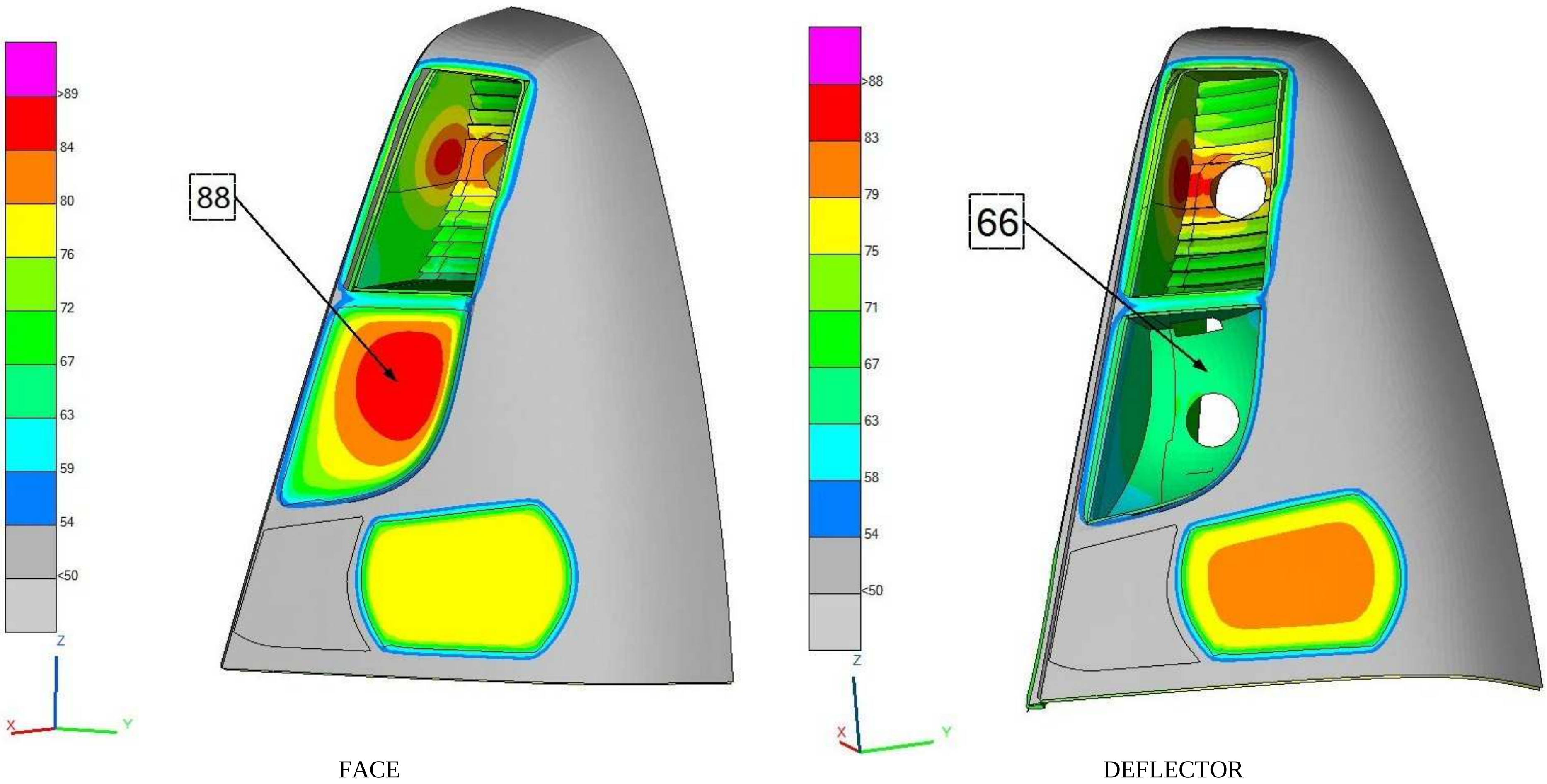


Fig. 4. Temperatures cartography for the second cavity.

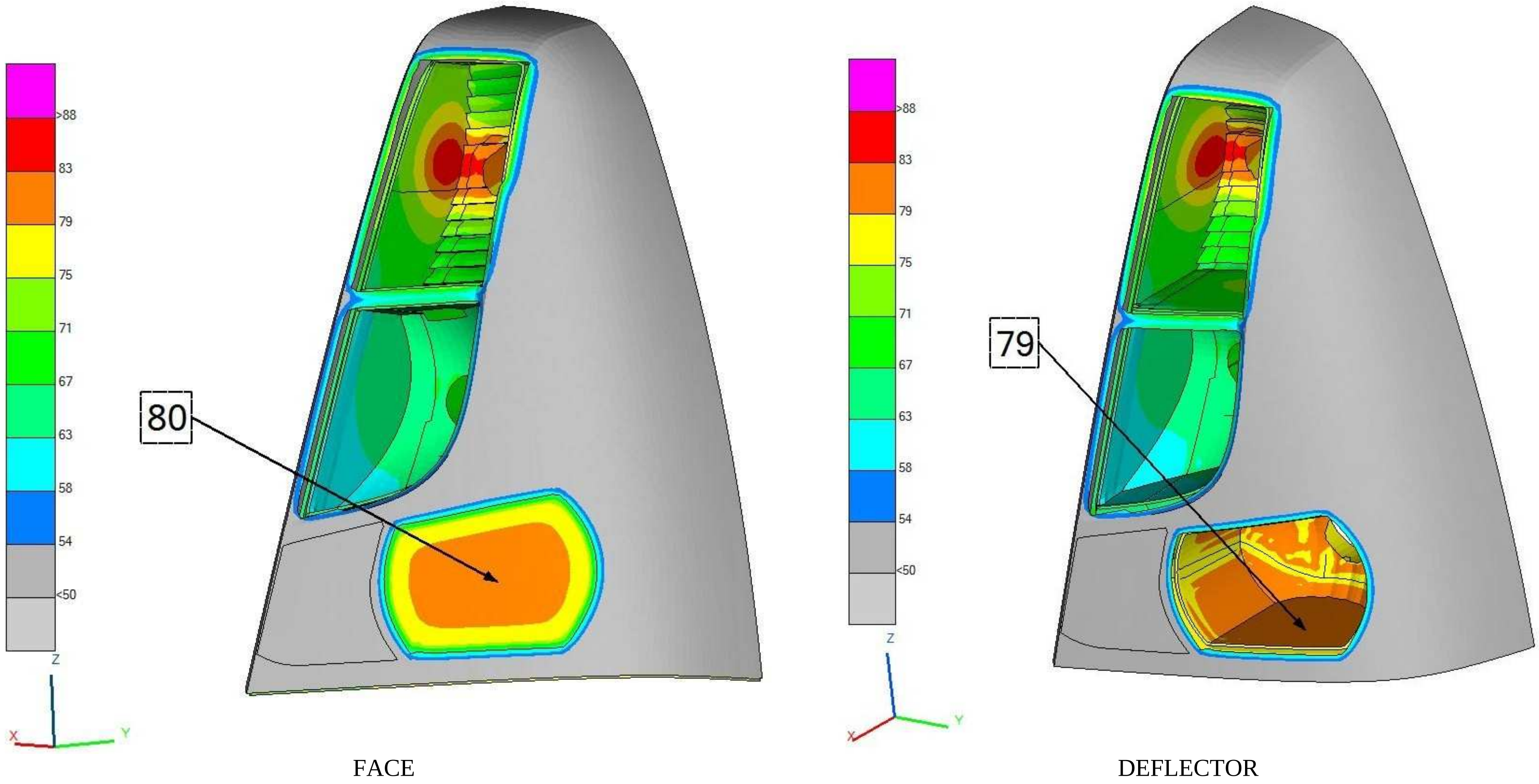


Fig. 5. Temperatures cartography for the third cavity.

Table 3 presents the synthesis of the extreme results obtained.

Table 3. The synthesis of the extreme values.

Parts	Material	Calculated temperature [°C]	Admissible temperature [°C]
DEFLECTOR	POLYCARBONATE - ASA	80 ± 5°C	140
FACE	PLEXIGLAS	138 ± 5°C	98

It could be noticed that for the "DEFLECTOR" part, made of "polycarbonate-ASA" material, the calculated maximum temperature is of 80°C, lower to the allowable inferior temperature for this material which is of 140°C.
For the "FACE" part, made of "Plexiglas" material, it was obtained a temperature of 138°C, exceeding thus the permissible temperature of 98°C.
Next, the authors aim to determine by experiments on the test bench the temperatures and their correlation with calculations done; the solutions can be sought in increasing the thickness of the material or even its replacement with another material with superior properties.

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