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GEOMETRICAL OPTIMIZATION OF AN EXTRUSION TOOL USED FOR AUTOMOTIVE DOOR'S SEALING SYSTEM USING CFD METHODS

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Abstract: *Purpose of modeling method with a CFD (Computational Fluid Dynamics) conducted in this paper is to study the internal geometry of the extrusion tool for the inner waist belt of the car door. Thus critical areas of material flow were identified and geometrically optimized before physical execution of the tool.*
The combination of materials used on the inner of the door parapet is made of polypropylene (TABOREN PC T30 33), for the rigid attachment to the door, and a vulcanized thermoplastic elastomer (Santoprene 121-67 W175), for the elastic contact areas with the interior panel and side window of the door.
XFlow choice of modeling software and working method has been shown to be correct, the results can be validated through practical testing.
Keywords: *TPV-E, PP, CFD, XFlow, extrusion die, material flow, geometrical optimisation*

1. GENERAL ASPECTS

In this paper the authors describe the ways for geometric optimization of the extrusion tool modeling method with CFD (Computational Fluid Dynamics) based on the theory of lattices of particles LBM (Lattice Boltzmann Method). The CFD software used was XFlow. The purpose of this simulation is to study viscous flow through an extrusion tool material combinations polypropylene (PP) and vulcanized thermoplastic elastomer (TPV-E).
By virtual optimisation of the geometry for the extrusion tool the target is to ensure its functionality before its physical execution. This reduces costs caused by a nonfunctional design and production batches of the necessary process optimization practice.

2. DESCRIBING THE EXTRUDING TOOL AND THE MATERIALS USED

The classical solution for the fabrication of automotive door sealing system is the use of EPDM (ethylene-propylene-diene-monomer) as a basic material. EPDM is a polymer enriched with additives and then vulcanized. Such connections arise irreversible chemical nature similar to those of natural rubber, because of this elastic properties of EPDM. To ensure geometric stability, required in mounting the door, sealing element can be reinforced using local insertion of metal band.
Figure 1 shows the inside of the door waist belt, made using the above technical solution.

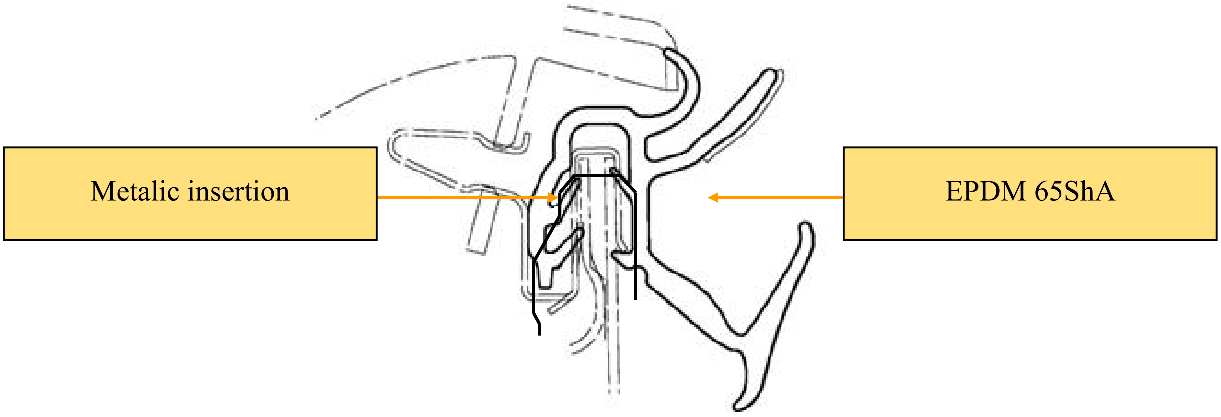

Figure 1: Automotive door's inner waist belt – EPDM stolution [1]

The need to reduce costs and thus the efficiency of production processes led to the use of new combinations of materials, designed to replace the classical solution of EPDM insert metal band. This combination is the use of PP for rigid attachment sites seals, and TPV-E, the elastic areas.
The concept for the door's inner waist belt using the combination PP / TPV-E is shown in Figure 2.

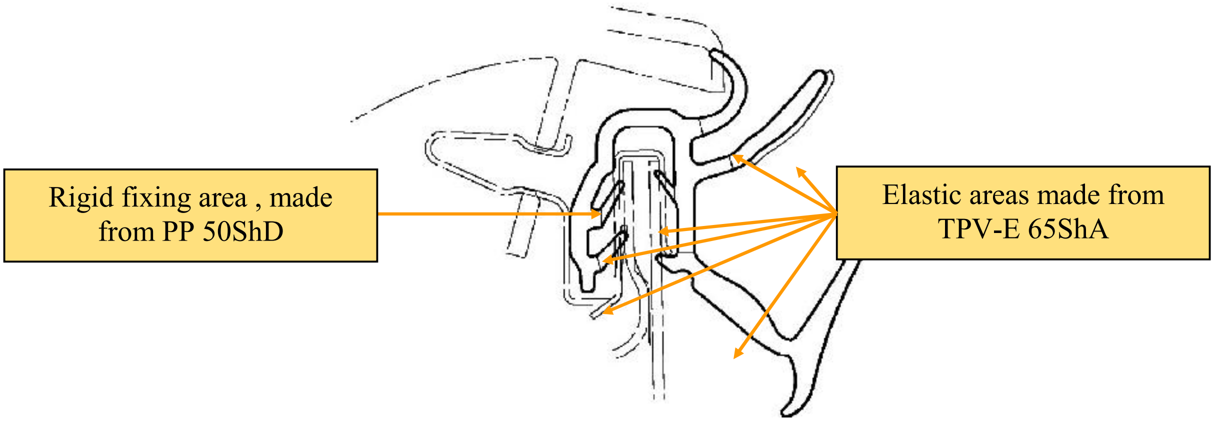

Figure 2: Door's inner waist belt – PP/TPV-E solution [1]

TPV-E is a thermoplastic elastomer with similar properties. In a thermoplastic matrix (eg PP) elastomer particles are added (eg EPDM). Full dynamic vulcanization of elastomer material generates high elasticity. Similar to thermoplasts, TPV-E becomes plastic under the influence of heat, elastic behavior returned after cooling. TPV-E bonds are physical, with reversible under the influence of heat, unlike pure elastomers, characterized by irreversible chemical bonds.
PP is a thermoplast characterized by long shaped macromolecules, which develops physical links. Under the influence of heat reaches a plastic state, in which remodeling is possible.
Upward trend to use combinations of PP / TPV-S elements to achieve the car door sealing system, is due to the advantages that these materials they bring with: simple processing technology (analog termoplastelor), ability to co-extrusion of different components , no vulcanization process (compared to EPDM), recyclable, free geometric design, low weight, high quality surface, geometric stability. [3]
The door's inner waist belt version PP / TPV-E (Figure 2) is subject CFD study described below. Specific package of materials is: [2]

- PP 50ShD = TABOREN PC 33 T30;
- TPV-E 65ShA = SANTOPRENE 121-67 W175.

3. MATHEMATICAL FRAME FOR CFD SIMULATION

The difficulty of results from CFD modeling the complexity of required extrusion PP extrusion tool, an essential element, and co-extrusion of TPV-E, as additional element.
To solve these problems Lattice Boltzmann method was chosen for modeling, based on particle kinetics. Reasons for this decision are:

- The method does not require the use of a mesh through which to simulate the flow. Thus there is no limit on the geometric complexity of the extrusion tool. Use of CFD software based on finite element analysis would have involved a very small Eulerian mesh. A direct consequence of using this would be a fine mesh analysis, whose run would have taken dozens of hours and would require very powerful hardware;
- Any change of geometrical configuration of the extrusion tool can be implemented easily because the model does not require recovery mesh;
- The method allows simulation of Multiphase / multicomponent flows, phenomenon particularly difficult to address by other methods.

CFD modeling software which uses mesoscopic grid and is based on algorithms LBM (Lattice Boltzmann Method) and LGA (Lattice Gas Automatic), is XFlow. Therefore analysis of material flow through the extrusion tool, presented in the present work was carried out using this software.

Briefly, LGA proposes computing schemes, which allows problem solving behavior of fluids. Based on these schemes, a fluid particle can move seamlessly between a d-dimensional lattice, in one of the predetermined directions at discrete times t = 0, 1, 2, ..., b, with speeds predetermined but, with i = 0, 1, 2, ..., b [6]

The simplest model is that in which particles can move in a two-dimensional rectangular grid in four directions, as shown in Figure 3. The state of a elementary lattice particle at time t is given by the value of occupation number ni (r, t), with i = 0, 1, 2, ..., b = 1 Here we are present, and $n_i = 0$ particle in the absence cell, moving in direction i.

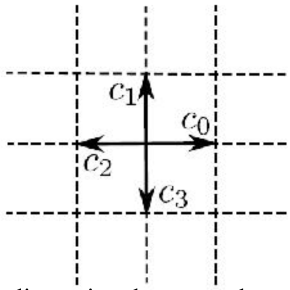

Figure 3: Two-dimensional rectangular grid in four directions

The equation which describes the system evolution (1) is: [6]

$$n_i(r + c_i\Delta t, t + \Delta t) = n_i(r, t) + \Omega_i(n_1, \dots, n_b), \qquad (1)$$

in which,
- r is position in lattice;
- Ω_i is the collision operator, which the previous state $(n_1, \dots, n_b)$ it computes a post-colition behavior $(n_1^C, \dots, n_b^C)$, conserving mass, kinetical momentum and also energy.

Based on these considerations, for a system consisting of a large number of particles, the resulting value of macroscopic density ρ (2) and kinetic momentum $\rho \mathbf{v}$ (3): [6]

$$\rho = \frac{1}{b}\sum_{i=1}^{b} n_i \, ; \qquad (2)$$

$$\rho v = \frac{1}{b}\sum_{i=1}^{b} n_i c_i \, . \qquad (3)$$

Similar to equation (1) can be developed the Boltzmann transport equation (4): [6]

$$f_i(r + c_i\Delta t, t + \Delta t) = f_i(r, t) + \Omega_i^B(f_1, \dots, f_b), \qquad (4)$$

where,
- f_i is the distribution function in the direction i;
- Ω_i^B is the colition operator.

LBM method is derived from LGA method. If LGA schemes use the discrete numbers to represent the state of molecules, LBM method uses statistical distribution functions with real variables, keeping by building mass conservation, kinetic momentum and energy.

4. DEFINING THE GEOMETRIC MODEL OF THE EXTRUSION TOOL

Based on experience, the authors have modeled in CATIA the extrusion tool for inner door wall, shown in Figure 2. As shown in Figure 4, the extrusion tool is composed of four disks. The reason for tool stalk is to enable its mechanical processing.

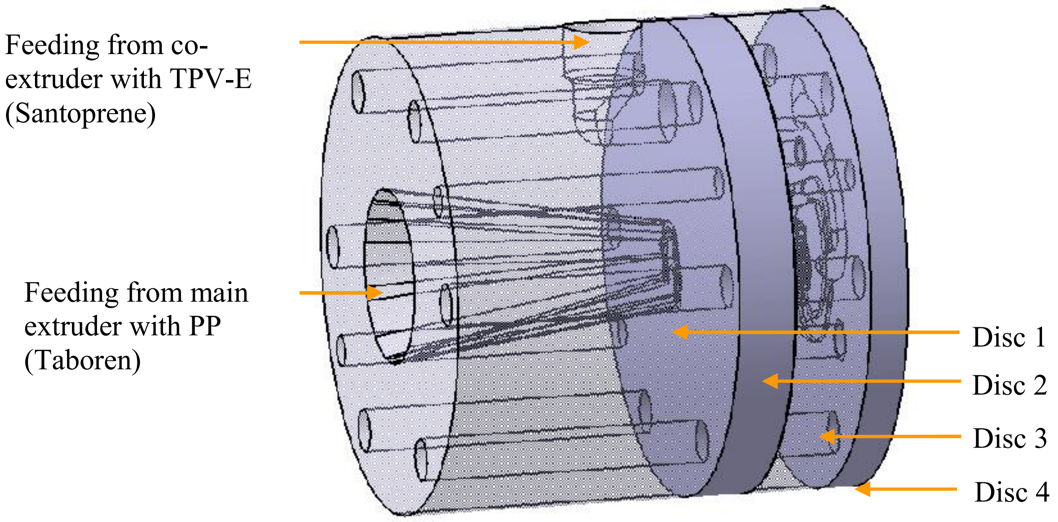

Figure 4: The extrution tool model for the inner waist belt [2]

For modeling flow inside the extrusion tool were performed, first of all, some geometrical changes CATIA model. Thus the four discs of the tool were merged into a single element (Figure 5) from which were extracted surfaces that describes the flow channels (Figure 6).

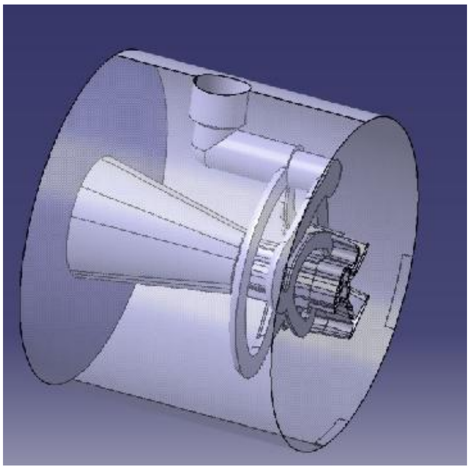

Figure 5: Modified CATIA model of the extrution tool

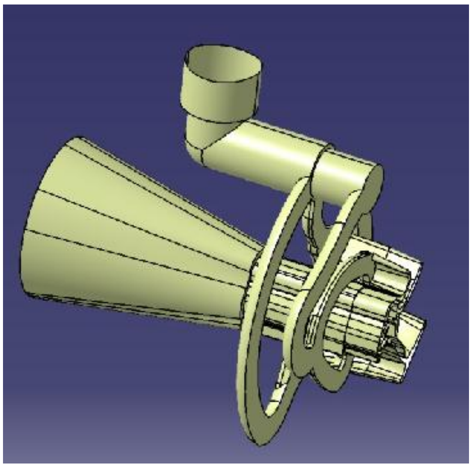

Figure 6: Flow channels derived from the extrusion tool model

5. MODEL VALIDATION OF EXTRUSION TOOL GEOMETRY

In this paper the authors give up the detailed description of CFD modeling steps of and they summarize in presentation of the input data and results.
An essential imput for modeling is made up of material data for the two components, as shown in Table 1..

Table 1: Material data needed for XFlow model [2]

Material	Density [kg/m^3]	Dinamic viscosity [Pa.s]	Fluid temperature [°C]	Flow [kg/s]
TABOREN PC 33 T30	1040	16	200	$4{,}997 \cdot 10^{-3}$

SANTOPRENE 121-67 W175	825	14	200	$7{,}561 \cdot 10^{-3}$

The second important input data consists of input and output speeds of the tool material. Starting from extrusion speed of 4.5 m / min (0.075 m / s) needed to produce the desired volume of parts and knowing the area for input and output sections of the material, input rates can be calculated for each component.
Thus, the set of physical parameters are presented in Table 2.

Table 2: Section areas and input and output speeds of extrusion tool material

Material	Output speed [m/s]	Output section area [m^2]	Input speed [m/s]	Input section area [m^2]
TABOREN PC 33 T30	0,075	$6{,}381\text{x}10^{-5}$	$2{,}393\text{x}10^{-3}$	0,002
SANTOPRENE 121-67 W175	0,075	$1{,}222\text{x}10^{-4}$	0,027	$3{,}433\text{x}10^{-4}$

Overlapping output speed of components from the extrusion tool and the study rate of coverage for tool internal geometry are required to ensure the quality of adhesion between the two materials.
Running simulation of material flow through channels, starting from the data above, it was found that the flow is interrupted for Santoprene component, a phenomenon shown in Figure 7.

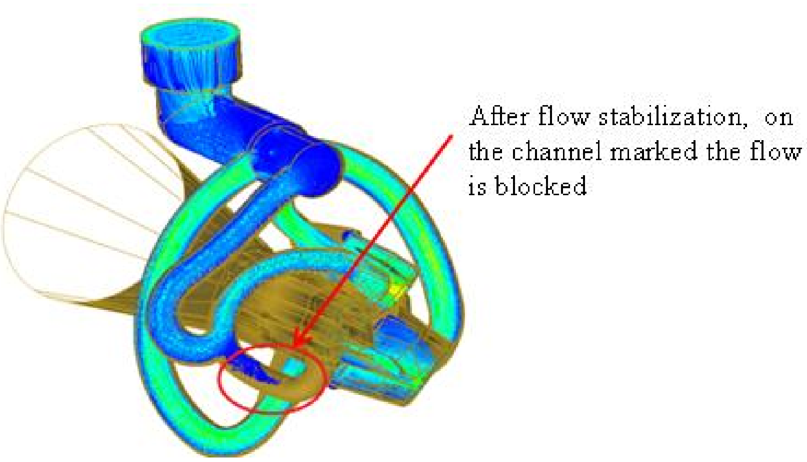

Figure 7: View interruption of Santoprene channel material flow

The geometrical model in CATIA analysis leads immediately to identify the stagnation area of the material (Figure 8).

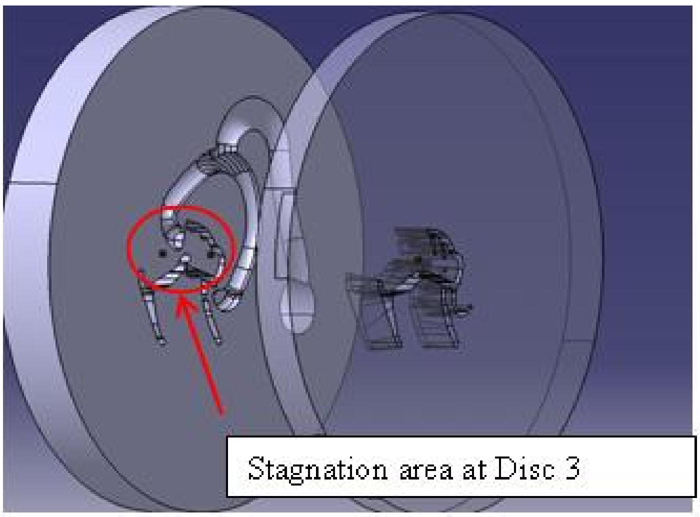

Figure 8: Stagnation area of Santoprene component near the disc 3

By overlapping discs 3 and 4 (Figure 9) is observed a mismatch between channels of the two disc material. Thus transfer of material between the discs is interrupted.

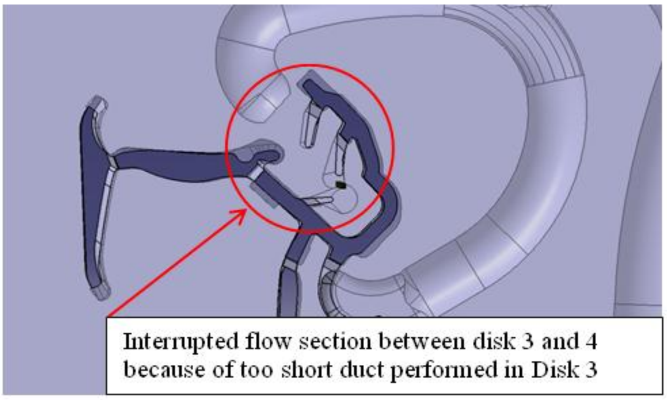

Figure 9: Misscorelation of flow channels of the component Santoprene between discs 3 and 4

Geometry optimization was performed by the authors in Santoprene material extending from the disc channel 3, thus ensuring its communication with approved material from the disc channel 4. This is due to interruption of transfer of material removed. Modification resulted in CATIA model is presented in Figure 10.

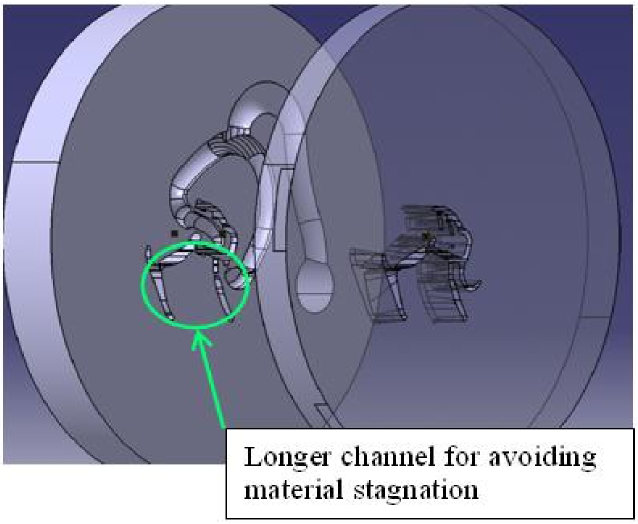

Figure 10: Geometrical optimisation of material channel in disc 3

Overlapping again after geometry optimization, between discs 3 and 4 can be seen in detail the correspondence between flow channels of Santoprene component from the two discs. This correspondence is captured in Figure 11.

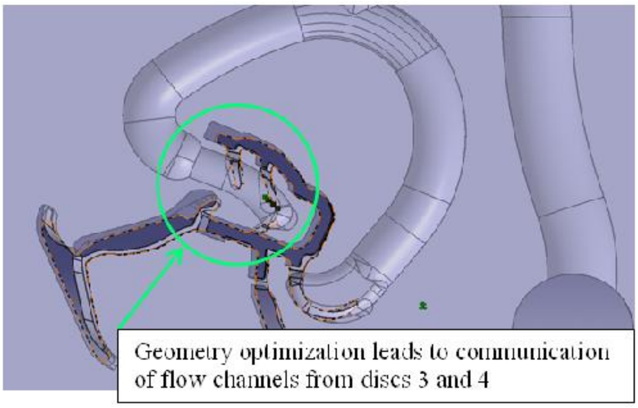

Figure 11: Correspondence of Santoprene material flow through channels from discs 3 and 4 after geometrical optimization

After geometrical optimization of the tool and after removing the stagnation area of material flow the simulation through the extrusion tool was resumed. Results that highlights the evolution of fluid within the tool are summarized in Figure 12.

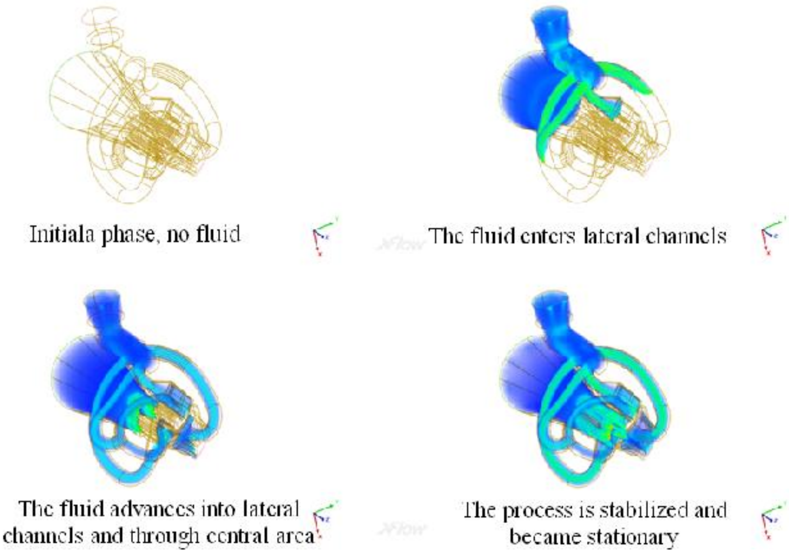

Figure 12: Fluid evolution inside the extrusion tool after geometrical optimization

The final result of CFD modeling is that the optimized model of extrusion tool for interior wall of the door is functional, so Taboren component, as well as component Santoprene covering the entire output section of the tool geometry.

6. PRACTICAL VERIFICATION OF FLOW MODELING RESULTS

Previously optimized model was developed practically, the extrusion tool thus obtained was verified in the manufacturing process. Section increased to scale 10:1 of the extruded obtained with the extrusion speed of 4.5 m/min and a tool temperature of 200° C, is shown in Figure 13.

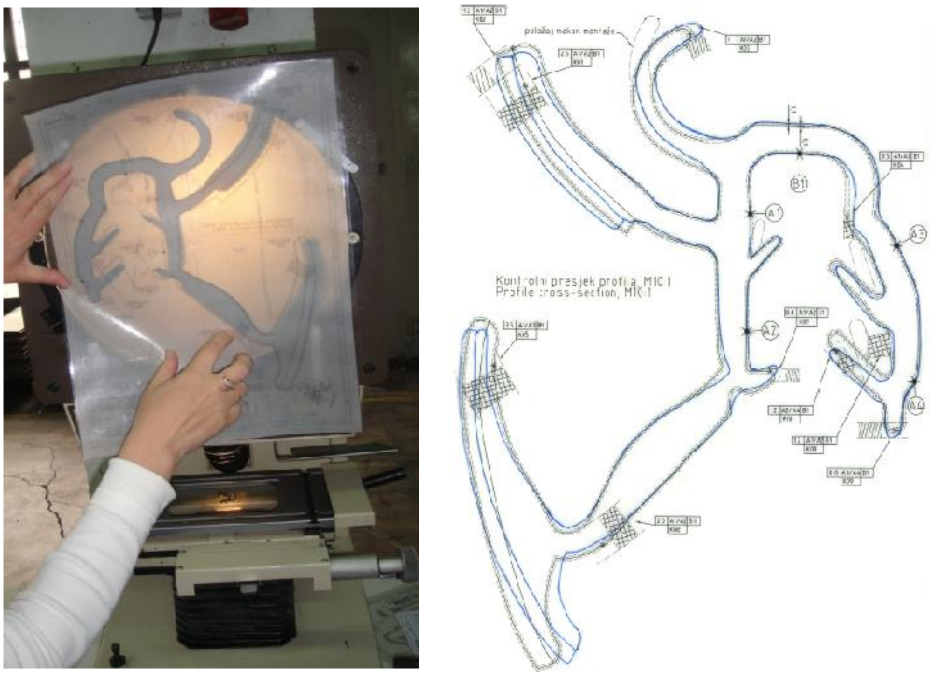

Figure 13: Extruded obtained by practical testing using optimized tool with XFlow [2]

Comparing asked outline drawing (black line) with real contour (blue line) concludes that meets geometrical demandings profile obtained. Further we see, on the image section on the projector, that the whole geometry is covered by material, as there are unoccupied spaces, such gas inclusions.
Therefore the profile obtained confirms the functionality of the extrusion tool.

7. CONCLUSIONS

From the study performed the following conclusions can be formulated:
- XFlow choice of modeling software was correct, being able to discover noncompliance design of extrusion tool;
- The results of modeling the flow of two components, Santoprene and Taboren, through the extrusion tool were confirmed by practical tests;
- Imposed technological parameters and used in modeling, extrusion speed of 4.5 m / min and temperature in the extrusion tool 200 ° C, can be picked up in the manufacturing process.

Based on these findings, the authors recommendation is to use for similar components, XFlow modeling method, described above. Thus can be optimized the geometry of extrusion tool before its physical execution. Extra parameters can be varied by Processing XFlow, obtaining the set of parameterization process to ensure optimum flow of material through the tool.
These results obtained virtual reduce costs caused by a broken design of a tool or inappropriate parameter setting, phenomena that would otherwise be discovered only through trial and optimized manufacturing practice.

8. RESEARCH DIRECTIONS

Figure 14 illustrates the calculation extracted from FEM (Finite Element Method) for the inner waist belt of the door in the free state (a) and in situ (b). As you can see, in mounted position the parapet interacts permanently with side window of the door. By lowering and raising the window, sill lip contact area of TPV-E is subjected to high wear demands.

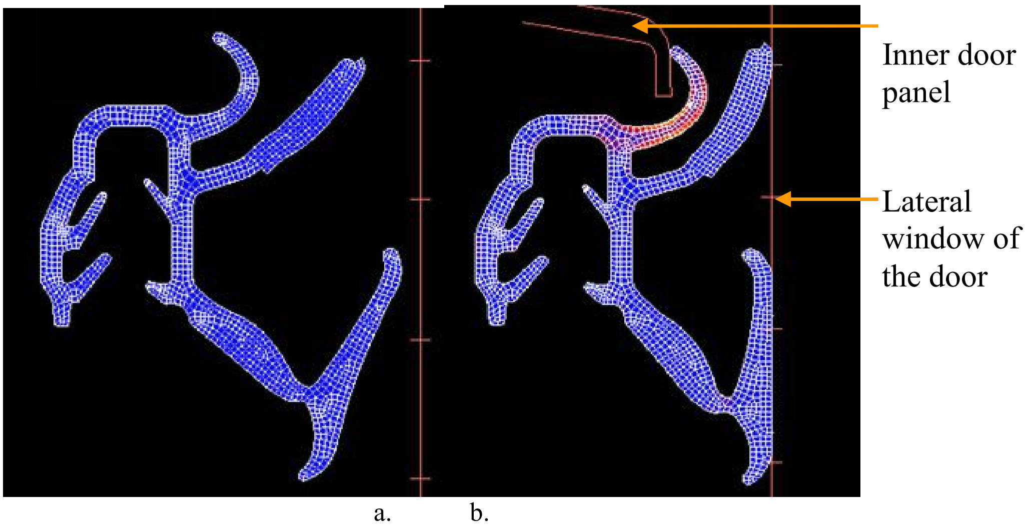

Figure 14: Geometrical comparison between free standing parapet (a) and tensioned mounted parapet (b) [2]

As mentioned already, a great advantage of using TPV-E, to achieve the car door sealing elements, consists in the possibility of co-extrusion technology of auxiliary components. Such contact areas of the lips with the window can be covered with a layer of co-extruded TPV filigree-E sliding properties (eg Lubmer TM 80).
In case of such technological solutions, modeling flow in XFlow be extended and adapted for the study of three different materials flow through an extrusion tool.

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