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# PARAMETRICAL OPTIMIZATION OF EXTRUSION PROCESS FOR AUTOMOTIVE COMPONENTS MADE FROM PP/TPV-E USING CFD METHODS

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***Abstract:*** *For a sealing component of the vehicles door, made by extruding plastics PP (polypropylene) and TPV-E (vulcanized thermoplastic elastomer), the optimal set of extrusion parameters can be virtualy determined. Suitable for this type of studies is the simulation software Xflow.*
*The studied component in this paper is the vehicles inner door waist belt. In the fabrication process of this component the productivity can be increased, by increasing the extrusion speed. The consequence is the need to increase the dynamic viscosity of the material, which can be achieved by lowering the temperature and increasing the material pressure inside the extrusion die. The correlation between extrusion speed – material pressure – die temperature, determined with the XFlow simulation program was confirmed through practical tests.*
***Keywords:*** *TPV-E, PP,CFD, XFlow, extrusion, material flow, parametrical optimisation*

## 1. GENERAL ASPECTS

For a sealing component for vehicles, made using extrusion, a virtual optimization of the flow channels geometry, inside the extrusion die, can be made, applying CFD methods (Computational Fluid Dynamics). Thus design risks and mistakes can be identified. The question that the authors ask in this paper is, in which measure the CFD simulation methods of visous flow can help to define the optimal extrusion parametres.
The answer is given through using the XFlow simulation program, which is based on the lattices theory of particles LBM (Lattice Boltzmann Method). The simulation aim is to virtually determine, for the inner door waist belt of the vehicle, the optimum parameters of the extrusion process: extrusion speed, temperature inside the die and material pressure. Also their dependency is studied.

## 2. DESCRIPTION OF THE VEHICLES INNER DOOR WAIST BELT

The inner door waist belt (Figure 1), studied in this paper, is a vehicle component realized by extrusion of two materials: Polipropylene (PP) and a vulcanized thermoplastic elastomer (TPV-E).

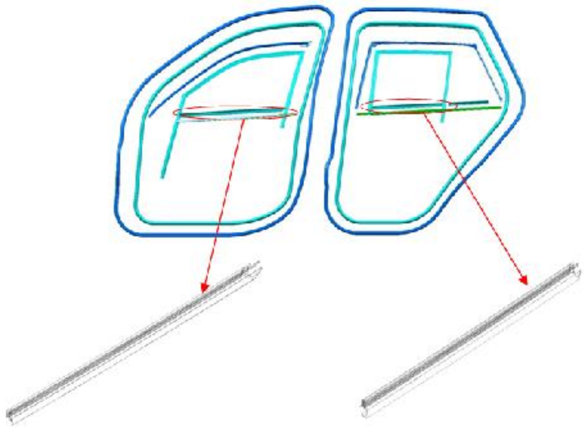

**Figure 1:** Vehicle door sealing system – Inner door waist belt [1]

The blank extruded profile is stamped on the ends, obtaining the necessary geometry and dimension for the integration in the vehicles door. (Figure 2).

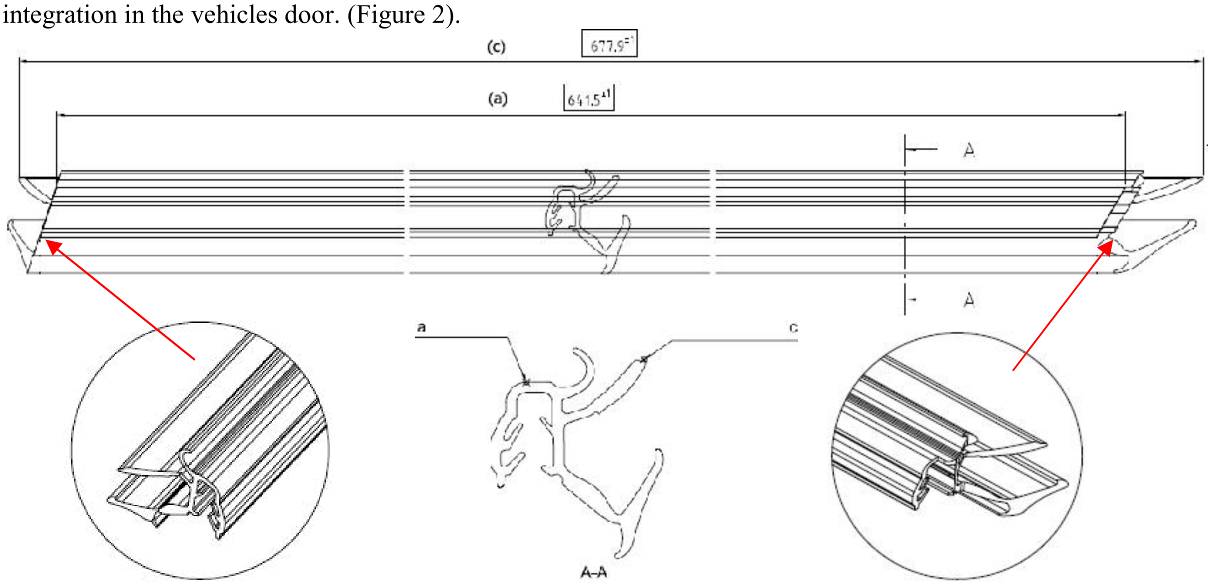


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**Figure 2:** Extract from technical drawing of the vehicles inner door waist belt [2]

The repartition of the PP and TPV-E materials is presented in Figure 3.

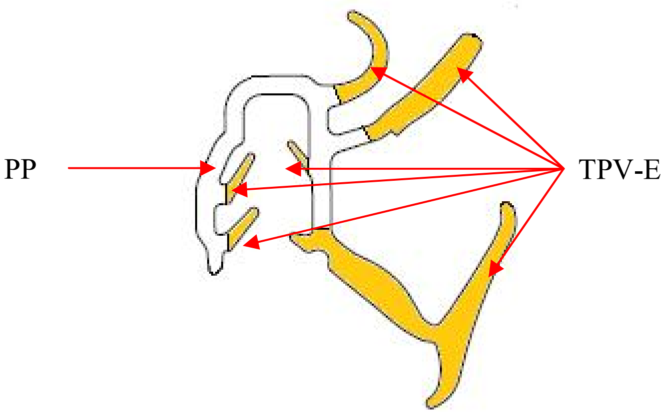


**Figure 3:** Section through inner door waist belt and material repartition

Specifically, the materials used for the vehicles inner door waist belt are:

- o PP - Taboren PC 33 T30;
- o TPV-E - Santoprene 121-67 W175.

## 3. CONCEPT OF THE EXTRUSION DIE

The working principle of the extrusion die is simple. The die is connected with the extruders and supplied with heated material, which has a viscous state. The material is transported inside of the die through a channels system.
The inner door waist belt, which is studied in this paper, uses a concept die with four discs (Figure 4). The die was sectioned in order to make possible the mechanical processings needed.

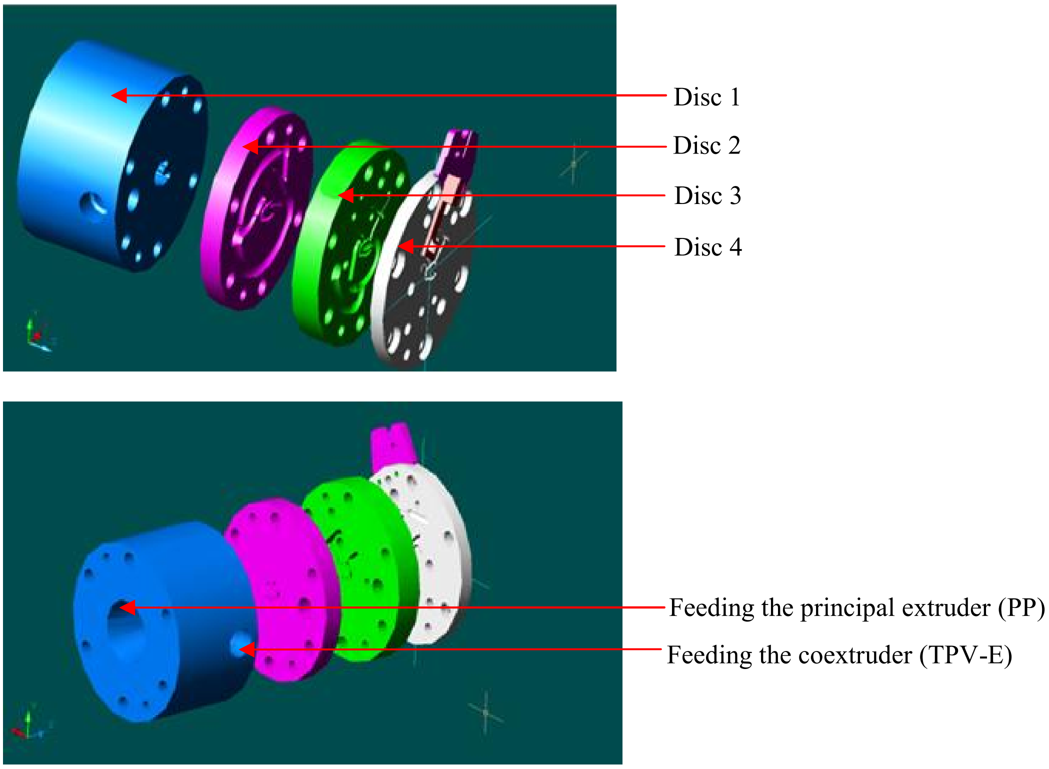


**Figure 4:** Concept with 4 discs for the extrusion die [2]

Disc 1 is mounted on the top of the principal extruder, which feeds the extrusion die with PP. The feeding with TPV-E is made also through the disc 1, where is connected the coextruder, too. The geometry of the central channel defines the final section shape of the extruded profile.

## 4. VIRTUAL DETERMINATION OF THE OPTIMAL EXTRUSION PARAMETERS

As mentioned already, analyzes and previous studies, conducted by the authors for similar car parts, have shown that, by using the simulation software XFlow the geometry of the material flow channels in the extrusion die can be virtually optimized. The benefit is, that using this method, the functionality of the die is assured before building it, thereby eliminating costs for testing and practical optimization.
The material flow channels have to be virtually optimized, so that:
- fluid volume, that flows out of the extrusion die must occupy the whole exit hole;
- output speeds of different components (for example: Santoprene 121-67 W175 and Taboren PC 33 T30) are the same at the exit hole, thus achieving material cohesion;
- material pressure in the extrusion die is in technological limits, demanded by the equipment.

Productivity of the extrusion process is given by the extrusion speed. Otherwise stated, productivity increases with the increase of extrusion speed. In the present study, this speed was increased and based on the simulations, made using the XFlow software, the adjacent necessary parameters were determined (temperature inside the die and material pressure). Initial extrusion speed has a value of 4.5 m/min.
This study was made with an unchanged configuration of the extrusion die. This means, keeping constant the invariants Reynolds and Euler, which correspond to the framework, used for the calculation and validation of the die. Reynolds invariant is given by the relation: [5]

$$Re = \frac{\rho . V . L}{\mu}, \quad (1)$$

where,

- $\rho$ - density;
- $V$ - speed;
- $L$–characteristic lenght;
- $\mu$ - dynamic viscuozity.

Maintaining constant in relation (1) Rynolds invariant, density, speed, characteristic length and dynamic viscuozity, results:

$$\frac{V}{\mu} = ct \quad \text{or} \quad V = ct\,\mu \; . \quad (2)$$

From relation (2) it is concluded that, for keeping constant the Reynolds value, the dynamic viscosity of the material should be increased, in order to increase the extrusion speed. Dynamic viscuozity of the material is a function of temperature. This physical law is the base of the optimization made for increasing the productivity of the extrusion process.

The consequence of increasing the dynamic viscuozity of the fluid is the increase of the pressure in the extrusion die. This dependency can not be detected only by preserving the value of Reynolds. For this reason it should be considered another invariant. Dependency between dynamic viscuozity and pressure $(\Delta \mathbf{p})$ is given through Euler invariant:[5]

$$Eu = \frac{\Delta p}{\rho V^2}. \quad (3)$$

By squaring the Reynolds invariant and carrying out adequate substitution, it is obtained:

$$Re^2 = \frac{\rho V^2 L^2 \rho}{\mu^2} = \frac{\Delta p L^2 \rho}{Eu \cdot \mu^2} \; . \quad (4)$$

Maintaining unchanged the characteristic length, density, Reynolds and Euler invariants results:

$$\frac{\Delta p}{\mu^2} = ct \quad \text{or} \quad \Delta p = ct\,\mu^2 \; . \quad (5)$$

It is noted that the relation (5) is not an absolute pressure, but a pressure variation from the reference value. The considered reference value is, actually, the pressure used for geometric validation of the extrusion die. In our case the pressure has a value of 155 bar.

In the present study, the limitation criteria for increasing the material viscosity is a maximal pressure in the die of 175bar.

In order to determine the optimal parameters, it will be considered only the component Santoprene 121-67 W175. The reason is the high degree of complexity and the small size of flow channels in the extrusion die. Thereby increase of the pressure will be much higher than the Taboren 33 PC T30 component.

The analysis of possibilities for increasing the productivity of the extrusion process starts from the initial simulation, where the geometry of the flow channels was optimized. This was made on a similar model, due to the numerical necessity required by the software, which needs low values for the dynamic vioscuozity. From the results of the initial simulation run are extracted, as a time dependence, the data, which correspond to the total pressure flow through the material inlet in the die.

According to the definition in the simulation software, the total pressure flow is given by the formula: [6]

$$\Phi_{pres} = \iint_{A\,inlet} (p_{static} + p_{dynamic}) V_n \, dA \; , \quad (6)$$

where,

- $V_n$ – normal speed;
- $p$ – pressure;
- $A$ – sectional area ;
- $dA$ – infinitesimal surface element.

The average pressure through the inlet is obtained form the integral relation (6):

$$p_{inlet} = \frac{\Phi_{pres}}{V_{n\,average} A_{inlet}} \; . \quad (7)$$

Next, the value of the pressure obtained for the similar model, used for simulation run, can be corrected with relation (5), written as:

$$\frac{\Delta p_{real}}{\mu^2_{real}} = ct. = \frac{\Delta p_{model}}{\mu^2_{model}} \; .$$

Therby results the correlation between dynamic viscosity and pressures for the actual model and the similar one:

(8)

$$\Delta p_{real} = \frac{\mu^2_{real}}{\mu^2_{model}} \Delta p_{model} \,. \quad (9)$$

In a concrete way, the steps competetd for analysing the possibility of increasing the extrusion speed and the productivity are:

- increase the output speed with 10 % for the Santoprene 121-67W175 component;
- running a new simulation in XFlow for the new parameters;
- extraction, out of the simulation, of the temporal variation law for the pressure flow through the inlet surface;
- calculating the average pressure with relation (7) and correcting with relation (8), to obtain real pressure;
- check if the pressure exceeds the limit imposed by the technological equipment;
- increase of output speed with an additional 10% for the Santoprene 121-67 W175 and repeat the previous steps.

When the limit pressure 175bar is reached, the optimization algorithm is stoped and the corresponding parameters for the Taboren PC 33 T30 component are calculated, so that the output speed is identical with the one of Santoprene 121-67 W175.

Obtained results after the virtual process optimization and the dependency between extrusion speed, average material pressure at the die inlet and fluid temperature are presented in the Table 1.

**Table 1:** Virtual optimization of the extrusion process using XFlow software

| | Average pressure at die inlet after flow stabilisation [bar] | Dynamic viscuozity corresponding to speed increase and constant perpetuation of Reynolds and Euler criteria [Pa·s] | Corresponding temperature to the fluid vscuozity [°C] |
|---|---|---|---|
| Initial run with extrusion speed of 4,5m/min | 155 | 14 | 200 |
| Run with increased speed of 10% | 172 | 15,4 | 180 |
| Run with increased speed of 20% | 175 (limit pressure) | 16,8 | 165 |

Figure 5 shows the variation of the pressure at the die inlet hole, as a time dependency of the flow stabilisation for Santoprene 121-67 W175.

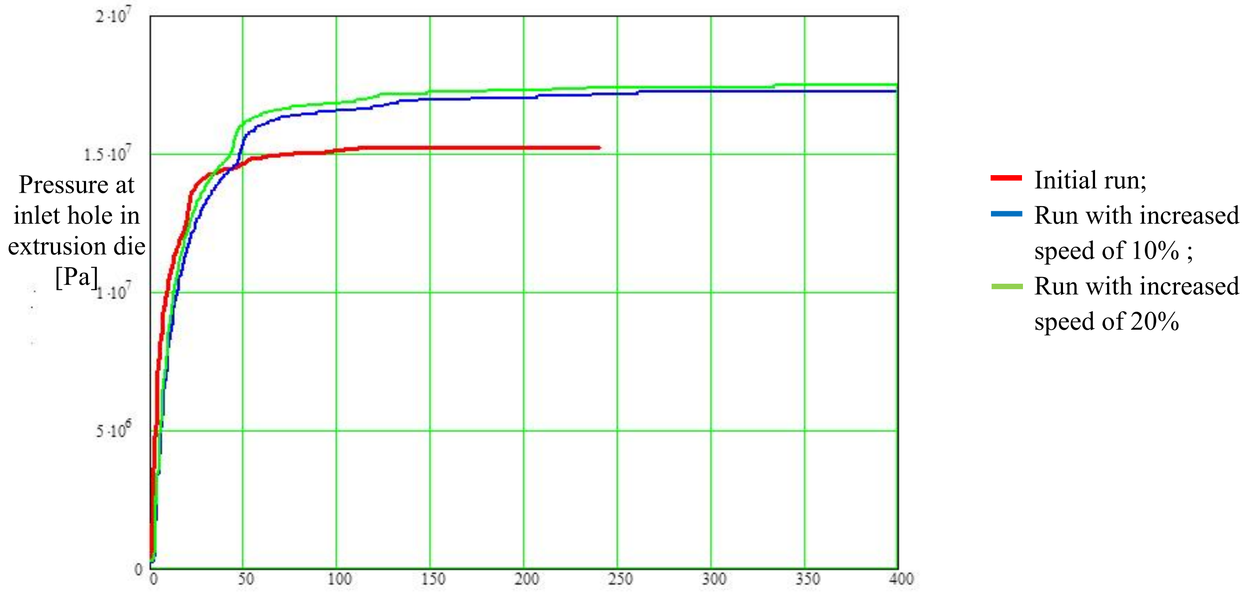


**Figure 5:** Pressure variation through the inlet hole for Santoprene 121-67 W175

The obtained results show that, the extrusion process can be optimized by increasing the extrusion speed, which imply lowering the material temperature. The consequence out of these results is the necessity to create a technical solution for temperature controlling and regulation in the extrusion die.

## 5. PRACTICAL VERIFICATION OF THE FLOW SIMULATION RESULTS

Using the same extrusion die, products were phisicaly realized in all three parameter sets, shown in Tabel 1. These were analyzed and compared, according the main evaluation criteria:

- filling degree of the form;
- concour accuracy of the section.

For all three parameters sets similar results were obtained.

## 6. CONCLUSIONS, RECOMMENDATIONS AND PERSPECTIVES FOR RESEARCH

Applying the flow simulation program XFlow for an extrusion die, different optimization can be made. Besides the optimal design of the channels geometry, the most favourable extrusion parameter set can be found: extrusion speed, material pressure and temperature in die.

Extrusion speed is dependent of the level of productivity required. Thereby, if a higher volume of products is needed, the extrusion speed can be increased. The new values of the main process parameters can be virtually determined using the XFlow program. This saves time and eliminates the testing cost and practical optimization of the parameters.

To increas the extrusion speed, the dynamic viscosity of the material should be increased. Increased viscosity involves a temperature reduction and a higher material pressure in the extrusion die. The extrusion speed can be increased up to the maximum pressure of material permited in the die. In order to regulate the die temperature, a themical adjustment of the extrusion die is needed.

Considering these findings, the authors recommendation is to apply the flow simulation software Xflow, in ordner to find the most advantageus parameters for the extrusion processes. By the variation of important technological parameters with the program Xflow, the optimal setting for the productivity requirements can be virtually defined.

In the automotive industry, there are already constructive solutions for the inner door waist belt, which uses more than two plastic components. There are also available technical solutions that use elastomers (EPDM - ethylene propylene diene monomer). The Xflow simulations could be extended and adapted to these cases, in order to virtualy optimize the extrusion process.

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