mid Moulding Innovation Day 2025

Rubber - Synergy between the Shear Heating Parameter with the Filling & Curing CAE Simulations

Italian Gasket:
- Speaker: Ing. Mario Costardi (*Italian Gasket R&D Specialist*)
- Coworker: Mattia Ramini, PhD (*Italian Gasket Group R&D Director*)

Moldex3D

Synergy between the Shear Heating Parameter with the Filling & Curing CAE Simulations

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SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - OUTLINE

1. BACKGROUND INFORMATION / LITERATURE;

Literature References.

2. DESIGN OF EXPERIMENTS (DOE);

Moldex3D Simulation Study.

3. *Moldex3D* SIMULATION INVESTIGATION;

3 case studies with different rubber compound data, geometry & mold concept.

4. RESULTS & DISCUSSION;

CAE Simulations Runs Outputs.

5. FINAL REMARKS & IMPROVEMENT SUGGESTIONS.

Next steps.

About Us

ITALIAN GASKET

italian gasket group

Our Why

Giving value to the Individual,
in order to inspire Excellence
and contribute to a better World.

ITALIAN GASKET GROUP

ITALY

PARATICO (BS)

EMPLOYEES	TURNOVER 2024	INDOOR AREA
133	€ 26.500.000	13.000 sq.m.

HUNGARY

EMPLOYEES	TURNOVER 2024	INDOOR AREA
67	€ 3.900.000	6.000 sq.m.

ITALY

CORREGGIO (RE)

EMPLOYEES	TURNOVER 2024	INDOOR AREA
45	€ 11.200.000	8.000 sq.m.

ITALY

Costa Volpino (BG)

EMPLOYEES	TURNOVER 2024	INDOOR AREA
11	€ 1.300.000	1.200 sq.m.

PROCESSED RUBBER MATERIALS

EP(D)M	VMQ	AEM	NBR
FKM	HNBR	ACM	CR
LSR	FVMQ	ECO	NR

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RUBBER PRODUCTS

BELLOWS

SEALS

GROMMETS

CONNECTORS

SUCTION CUPS

O-RINGS

MEMBRANES

FRAMES

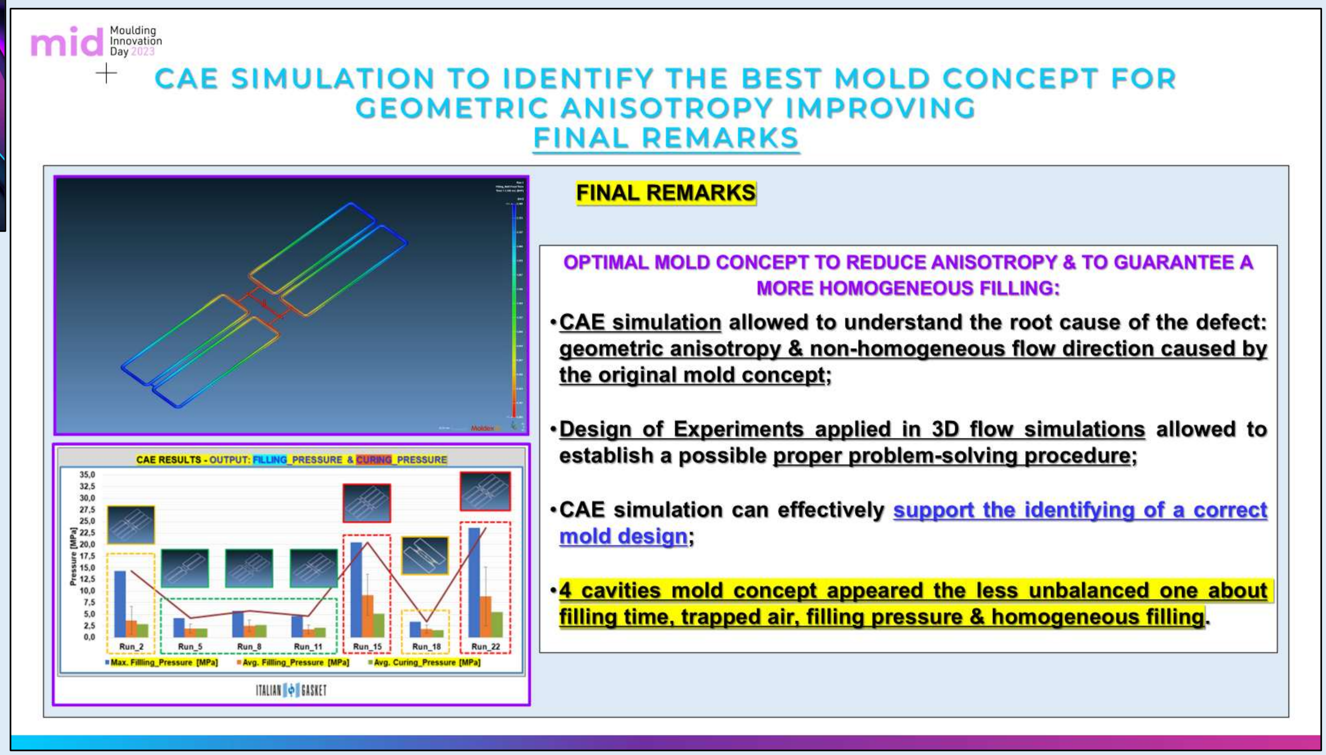
MANIFOLD GASKETS

TECHNICAL GASKETS

SPARK CAPS

ASSEMBLED PARTS METAL/PLASTIC/ RUBBER

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - BACKGROUNG INFORMATION



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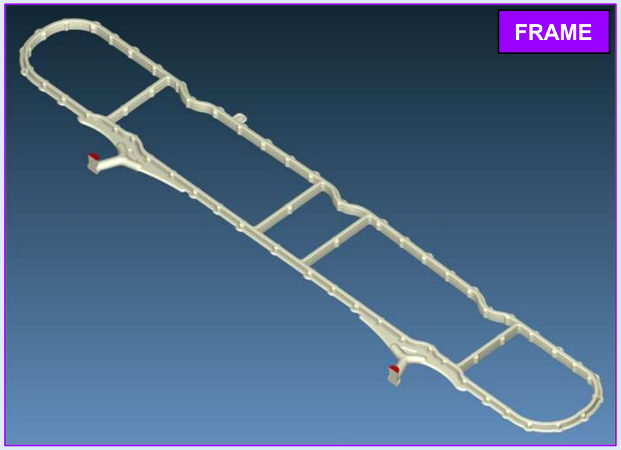
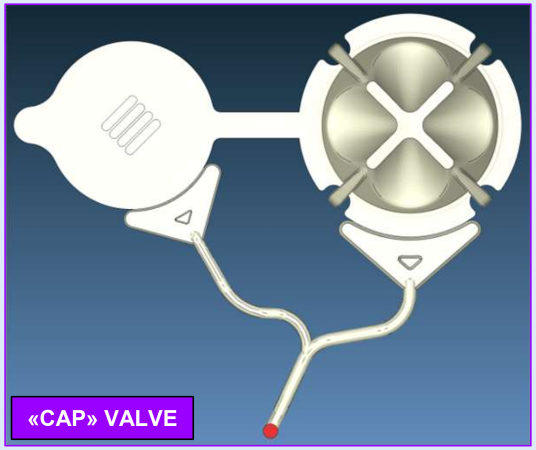
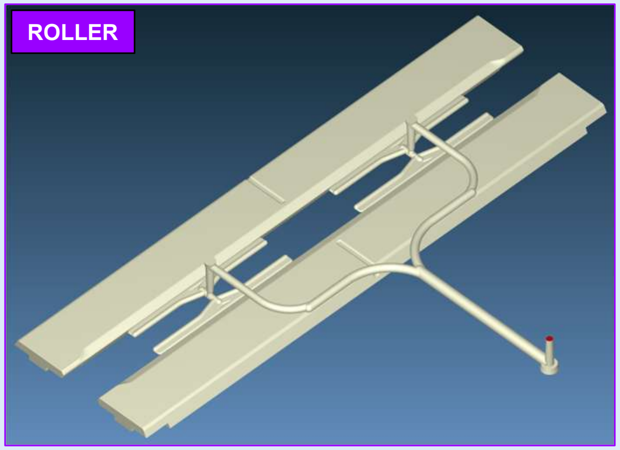
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - BACKGROUNG INFORMATION

- **The main topic of this presentation is to show the importance of the *Shear Heating Parameter* (η_{SH}) input data into MOLDEX3D® software to obtain outputs more "adherent to reality".**

- **The 3 proposed case studies have the following characteristics:**
  - **different main applications (automotive & industrial);**
  - **different rubber compound & geometry (both in shape & volume);**
  - **different mold concept & design.**







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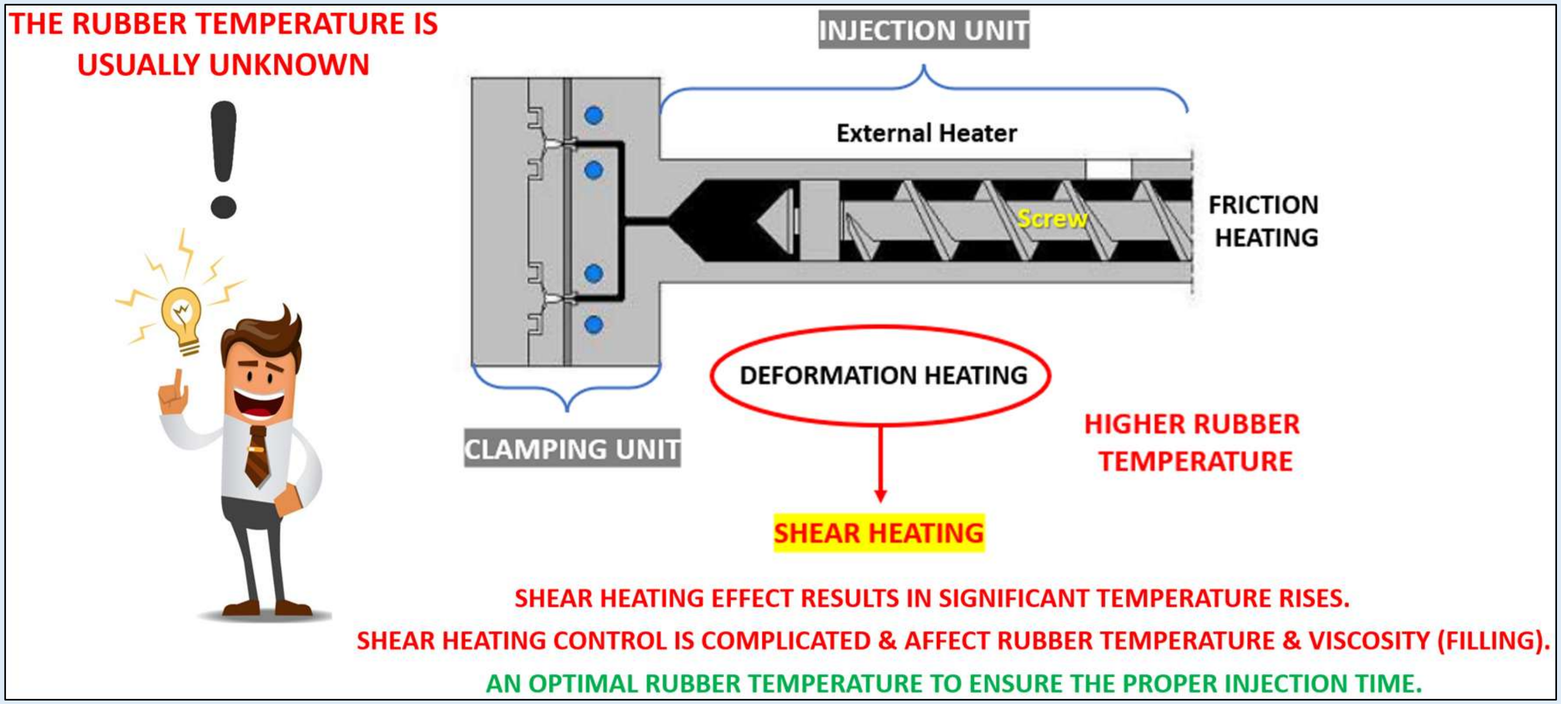
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - LITERATURE

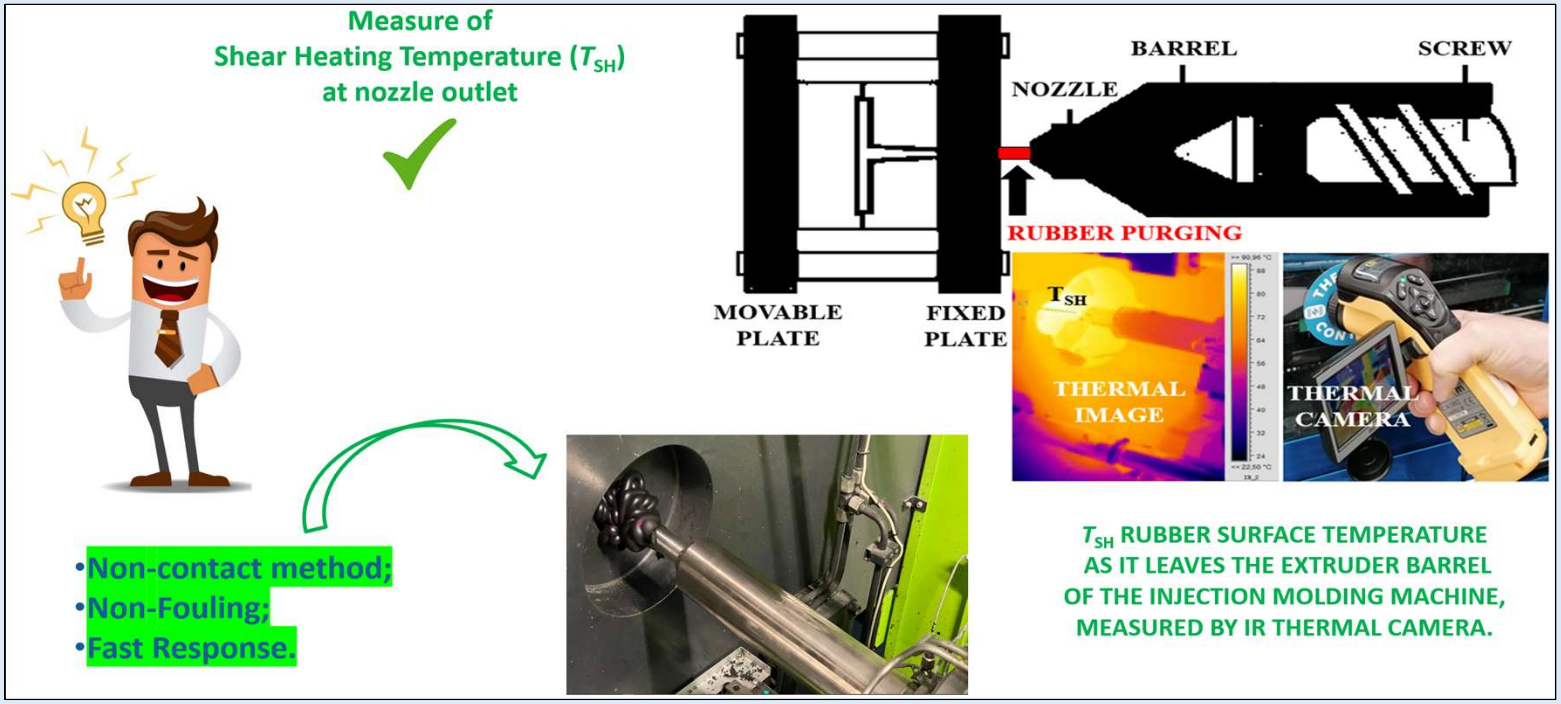
TEMPERATURE CONTROL IN RUBBER INJECTION MOLDING



References:
1. Ramini, M., Agnelli, S.: Shear heating parameter of rubber compounds useful for process control in injection molding machine, Rubber Chemistry & Technology, 93, 729–737 (2020).
2. Ramini, M., Agnelli, S.: Monitoring of shear heating effects during injection molding of rubber to improve the process control, Polym. Bull. (2022).

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - LITERATURE

TEMPERATURE CONTROL IN RUBBER INJECTION MOLDING



References:

1. Ramini, M., Agnelli, S.: Shear heating parameter of rubber compounds useful for process control in injection molding machine, Rubber Chemistry & Technology, 93, 729–737 (2020).
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SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - LITERATURE

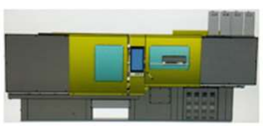
SHEAR HEATING PARAMETER FOR RUBBER INJECTION MOLDING

Theoretically, the increase of temperature (ΔT) due to shear heating in a channel for a Newtonian fluid & adiabatic flow, without wall slip, can be related to viscosity η by:

(1) $$\Delta T = \eta \cdot \frac{4\dot{\gamma}L}{\rho C_p D}$$

L & D: channel length and diameter
C_p: specific heat capacity [J/kg/°C]
ρ: density [kg/m^3]
$\dot{\gamma}$: wall shear rate [s^{-1}]

Most of these conditions do not apply to rubber, **however we derived from Equation (1) the definition of shear heating parameter, η_{SH}, a technological parameter** having dimension of viscosity [Pa·s], as follows:

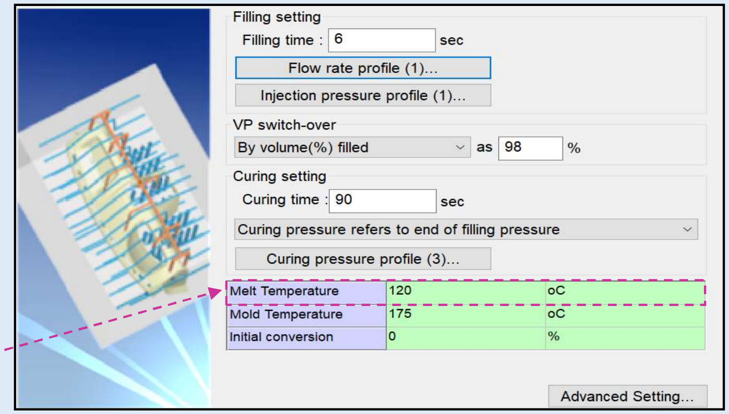


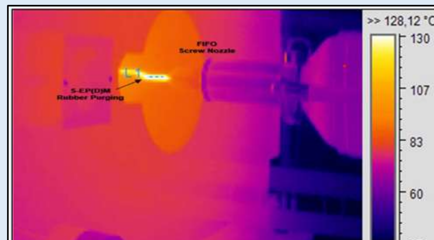
(2) $$\eta_{SH} = \Delta T_{SH} \frac{\rho C_p}{4v} \alpha$$

ΔT_{SH} = T_{SH} - RT
v: flow rate parameter (10 s^{-1})
α: screw D/L (to a first approximation)

Equation proposed to provide the proper process parameter setup

η_{SH} values from online measurements are correlated to Minimum Torque (M_L) values, from MDR measurements.





Screw Nozzle Outlet Extruding S-EPDM60 EXTRUDATE Thermal image

Accuracy: ±2°C
Sensitivity: 0.08°C

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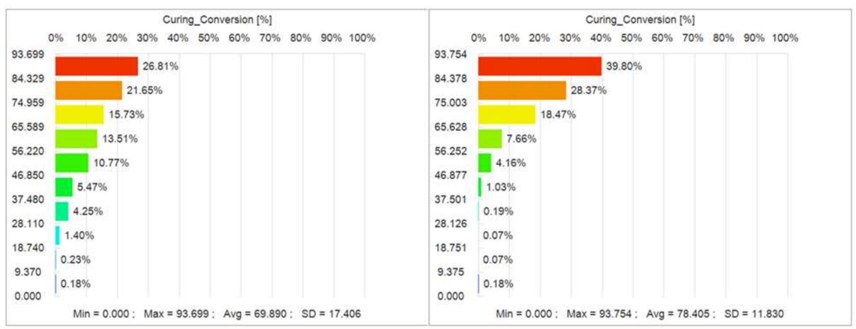
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - LITERATURE

- T_{SH} is an indicator of the **thermal history undergone by rubber till the injection point**.
- **It's a very fast on-line process control of injection molding of rubber.**
- **The use of T_{SH} as an input parameter does not significantly affect the simulation of the filling phase, probably due to the small sensitivity of the viscosity characteristics to temperature, compared to plastics.**
- **The use of T_{SH} impacts mostly the simulation of the curing phase, in particular the average curing conversion is higher and more homogeneous than the result obtained with T_{barrel}.**

T_{barrel} (80°C) | T_{SH} (110°C)

Average curing conversion: **70 ±17 %**



Average curing conversion: **78 ±12 %**

References:

3. **Agnelli, S., Ramini, M., Ramorino, G.: (July 2022) Injection molding process of rubber components: improving the process design with the shear heating parameter, 15th International Conference on Advance Computation Engineering, 3-7 J.**

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - DOE

DESIGN OF EXPERIMENTS (DOE)

ITALIAN GASKET + Moldex3D MOLDING INNOVATION

MOLDEX3D CAE SIMULATION: 3D MODELS & MESH

- 3D Model + Meshes of the Actual Mold Concepts;
- Mesh Technical Support.

SIMULATED MATERIAL (RUBBER COMPOUNDS)

- Characterized material directly from IG database;
- Material characterization & data collecting under IG-R&D internal method.

SIMULATED INPUTS → OUTPUTS

- Simulation runs based on input data directly from IM processes;
- Filling Data Inputs: Filling Time & Melt Temperature (T_{SH});
- Curing Data Inputs: Mold Temperature & Curing Time.

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SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

DESIGN OF EXPERIMENTS (DOE) - COLLECTING DATA FOR CAE SIMULATION

Property	*Method*
Density (Densimeter)	ASTM D297
Viscosity / Shear Rate	Internal / ASTM D4440
Heat Capacity (DSC / Differential Scanning Calorimeter)	ASTM E1269
Thermal Conductivity (TCi / Thermal Conductivity Analyzer)	ASTM D7984
Curing Kinetics (DSC / Differential Scanning Calorimeter)	Internal
Specific Volume With Curing (PVTC by Dilatometer)	PVTC Model: Tait-C Model
Hardness (Hardness tester)	DIN ISO 7619-1
Tensile Strength (Dynamometer)	DIN 53504
Elongation at break (Dynamometer)	DIN 53504
100% modulus (Dynamometer)	DIN 53504
Poisson’s Ratio	N/A

1. CAE is used to simulate the compound flow & curing behavior inside the mold;
2. As accurate is the rubber compound characterization as effectively will be the simulation outcome;
3. Laboratory measurements, with process data from industrial injection molding test, enable for the most reliable results.

References:

2. Ramini, M., Agnelli, S.: Monitoring of shear heating effects during injection molding of rubber to improve the process control, Polym. Bull. (2022).
3. Agnelli, S., Ramini, M., Ramorino, G.: Injection molding process of rubber components: improving the process design with the shear heating parameter, 15th International Conference on Advance Computation Engineering, 3-7 J (July 2022).
4. Ramini, M., Agnelli, S.: (May 6, 2021) Process control in injection molding machine by using shear heating parameter of rubber compounds. All about rubber compounding, (virtual event), knowhow webinars forum by Technobiz.

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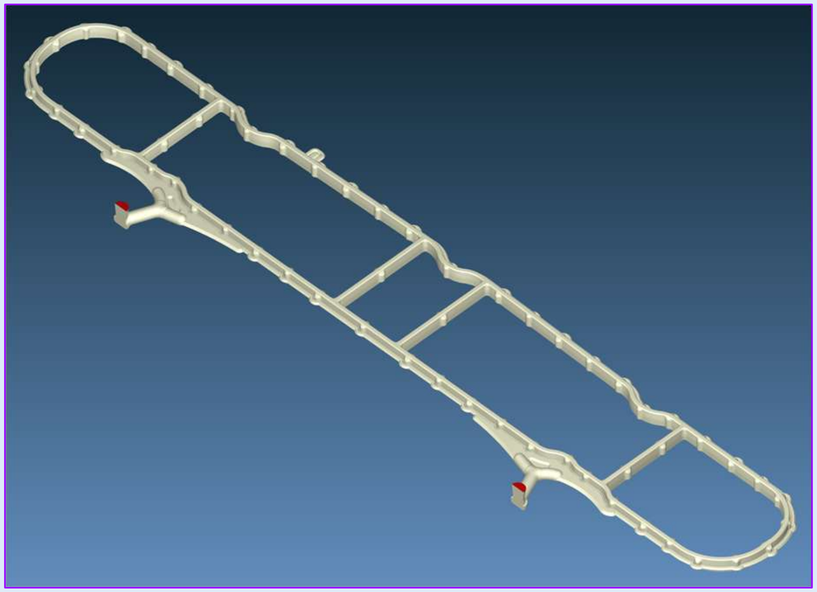
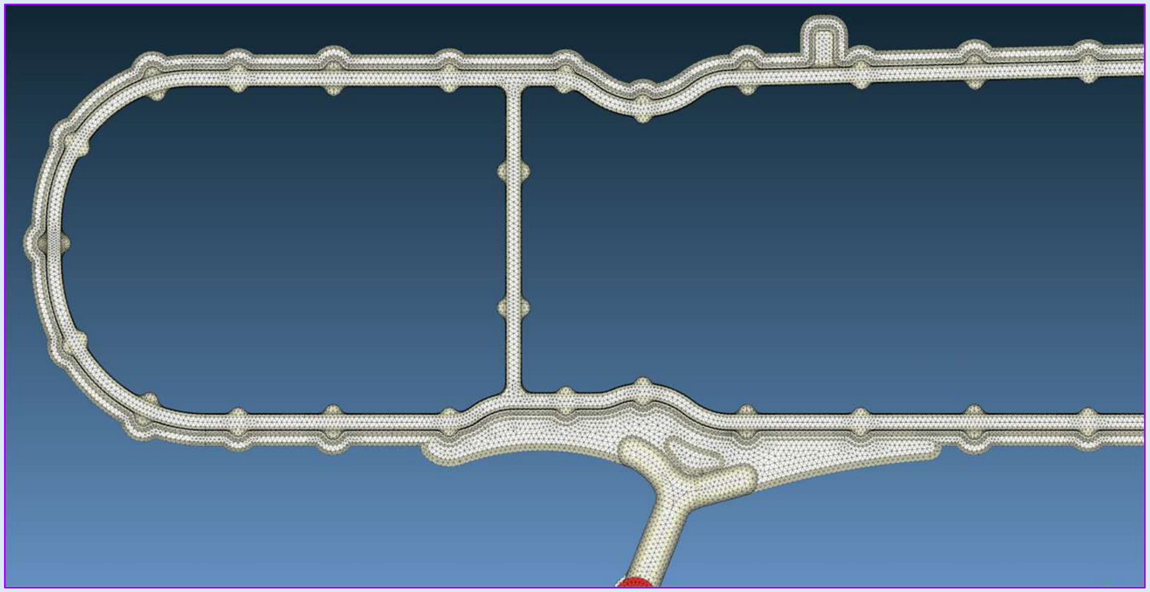
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

RUBBER FRAME - MOLDEX3D ITALIA TECHNICAL SUPPORT => 3D MODELS + MESHES



1 CAVITY FRAME - 3D MODEL

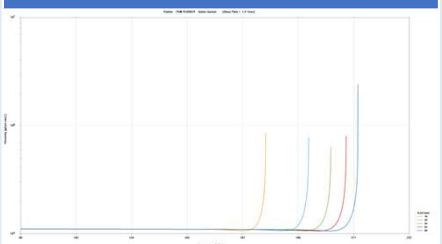


1 CAVITY FRAME - MESH DETAIL

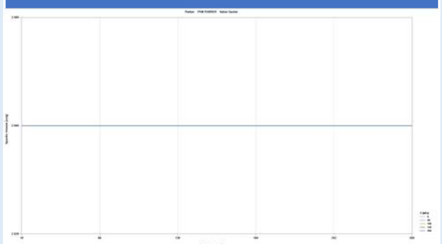
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

DESIGN OF EXPERIMENTS (DOE) - INPUT: MATERIAL FIGURES

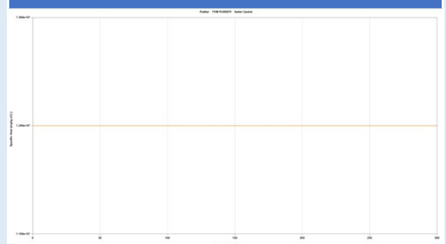
Material_*Viscosity*



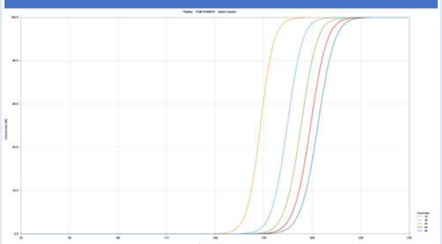
Material_*PvT*



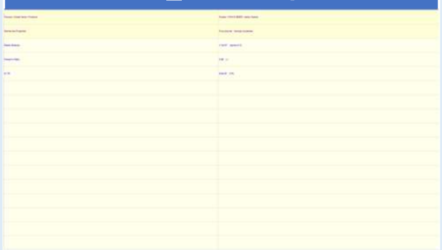
Material_*Specific Heat*



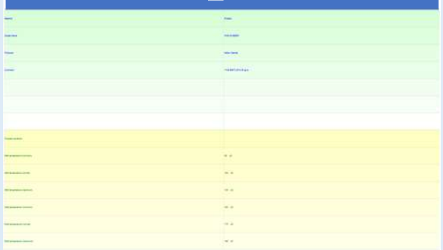
Material_*Curing Kinetics*



Material_*Mec. Properties*



Material_*Contents*



CAE *MOLDEX3D* RUBBER COMPOUND:

Rubber_FKM_FKM Perox Green 60 Shore A.mtx

Material characterized under IG-R&D method.

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

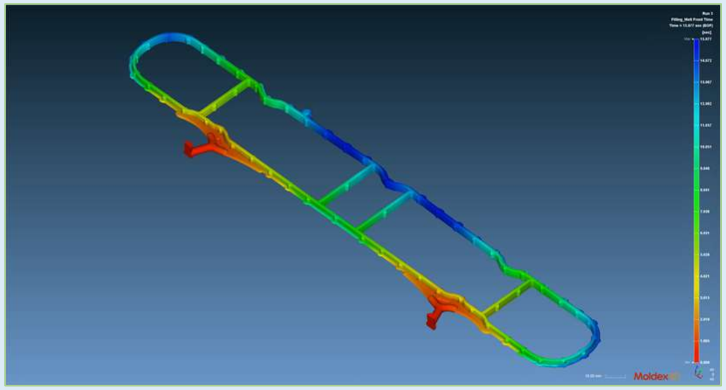
DESIGN OF EXPERIMENTS DOE - INPUT: PROCESS PARAMETERS (RUBBER FRAME)

Filling	Item Data	Unit
Filling Time	15	s
Melt Temperature	120	°C
Mold Temperature	175	°C
Max Injection Pressure	250.00	MPa
Injection Volume	10.7719	cm^3
Curing		
Curing Time	120	s
Max Curing Pressure	250	MPa

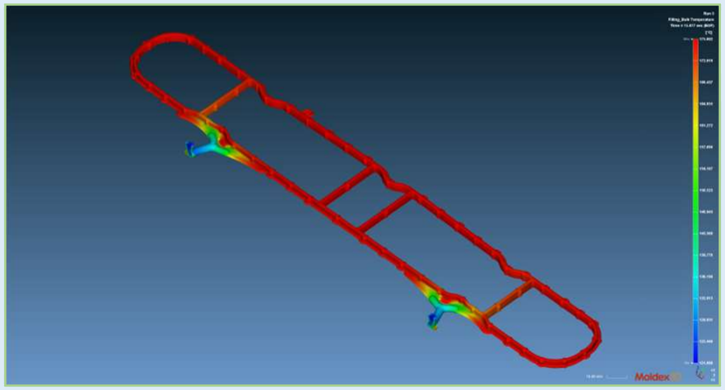
T_{SH}

The input data (*Filling Time*, *Melt Temperature*, *Mold Temperature* & *Curing Time*) were set-up based on IG know-how & by considering a similar injection moulding production.

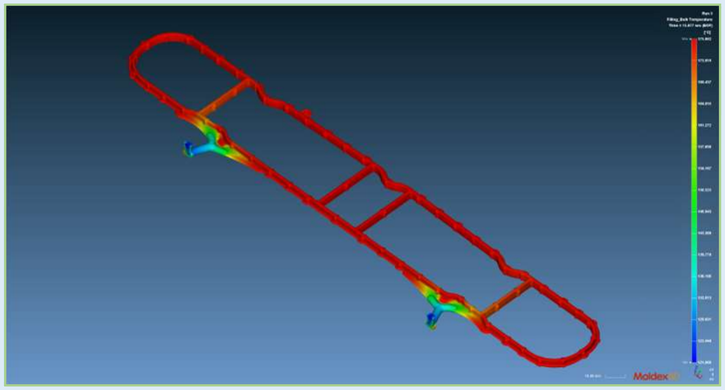
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D



FILLING_MELT FRONT TIME



FILLING_BULK TEMPERATURE



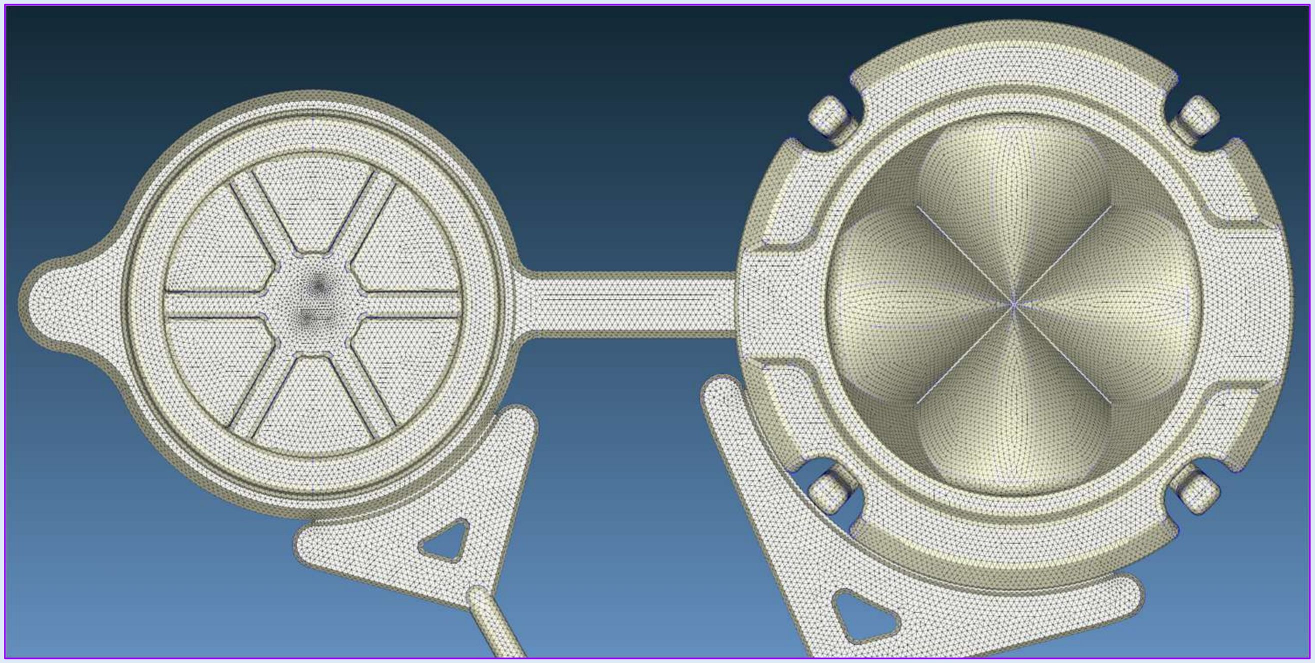
FILLING_PRESSURE

CURING_CONVERSION

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

"CAP" VALVE - *MOLDEX3D ITALIA* TECHNICAL SUPPORT => 3D MODELS + MESHES

1 CAVITY - 3D MODEL



1 CAVITY - MESH DETAIL

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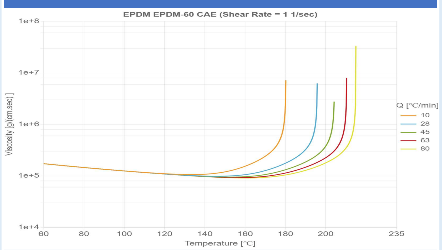
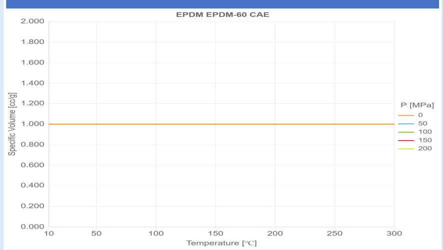
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

DESIGN OF EXPERIMENTS (DOE) - INPUT: MATERIAL FIGURES

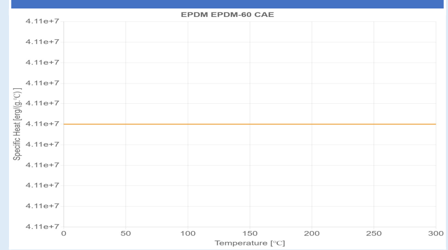
Material_*Viscosity*



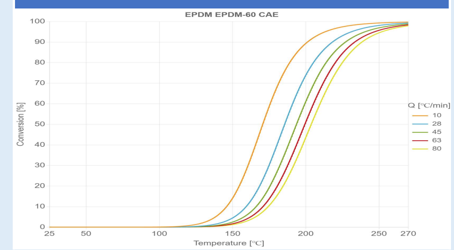
Material_*PvT*



Material_*Specific Heat*



Material_*Curing Kinetics*



Material_*Mec. Properties*

Type	EPDM
Grade Name	EPDM-60
Producer	CAE
Mechanical Properties	Isotropic Pure Polymer
Elastic Modulus	2.2e+7 (dyne/cm²)
Poisson's Ratio	0.38 (-)
CLTE	8.59e-5 (1/K)

Material_*Contents*

Type	EPDM
Grade Name	EPDM-60
Producer	CAE
Melt Temperature (Minimum)	60 ℃
Melt Temperature (Normal)	70 ℃
Melt Temperature (Maximum)	80 ℃
Mold Temperature (Minimum)	140 ℃
Mold Temperature (Normal)	155 ℃
Mold Temperature (Maximum)	170 ℃

CAE *MOLDEX3D* RUBBER COMPOUND:

Rubber_EPDM_EPDM Sulphur Green 60 Shore A.mtx

Material characterized under IG-R&D method.

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

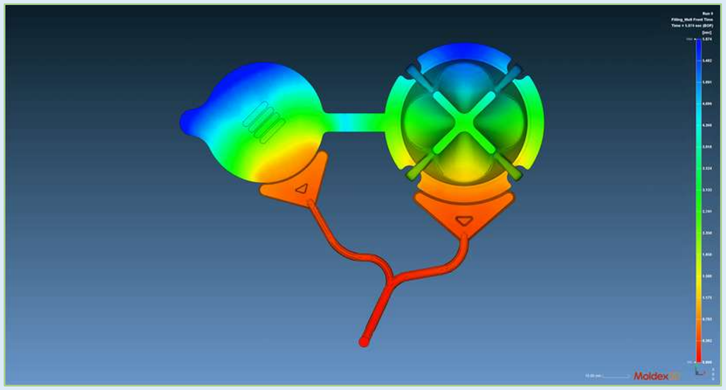
DESIGN OF EXPERIMENTS DOE - INPUT: PROCESS PARAMETERS («CAP» VALVE)

Filling	Item Data	Unit
Filling Time	6	s
Melt Temperature	150	°C
Mold Temperature	190	°C
Max Injection Pressure	250	MPa
Injection Volume	23.3172	cm^3
Curing		
Curing Time	90	s
Max Curing Pressure	250	MPa

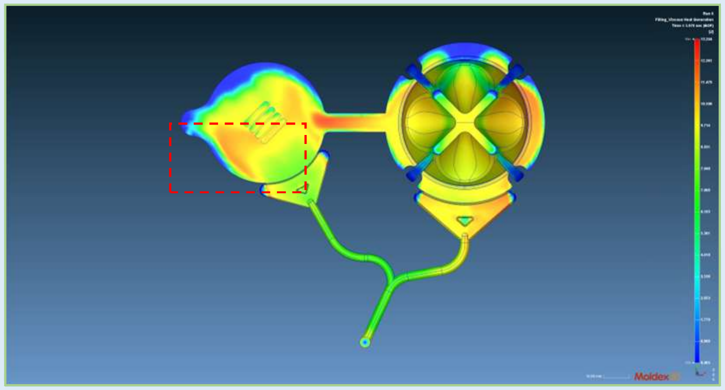
T_{SH}

The input data (*Filling Time*, *Melt Temperature*, *Mold Temperature* & *Curing Time*) were set-up based on IG-know how & by considering a similar injection moulding production.

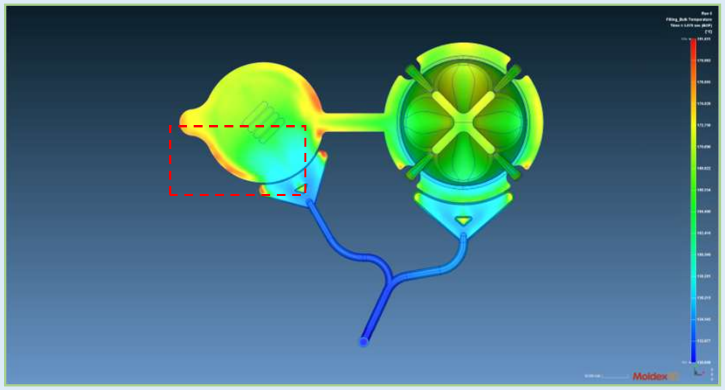
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D



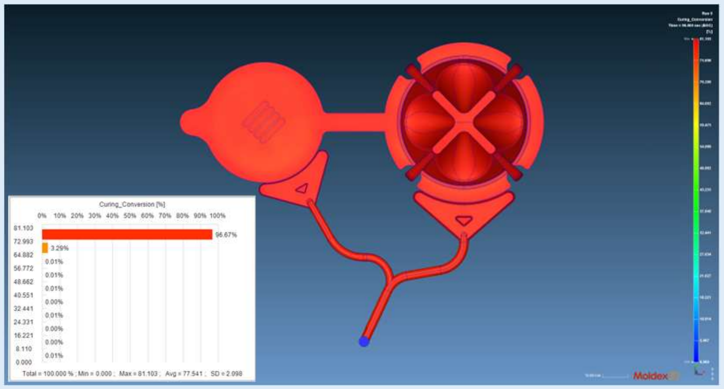
FILLING_MELT FRONT TIME



FILLING_VISCOUS HEAT GENERATION



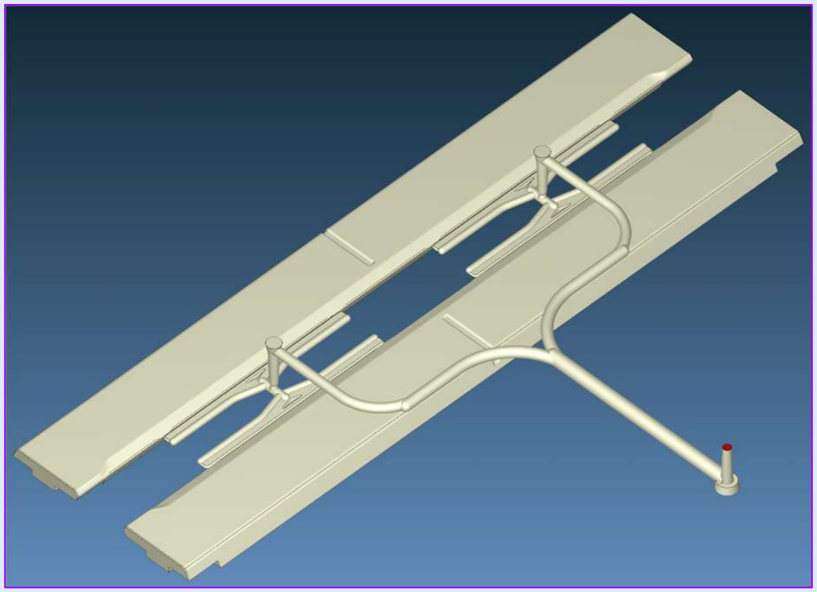
FILLING_BULK TEMPERATURE



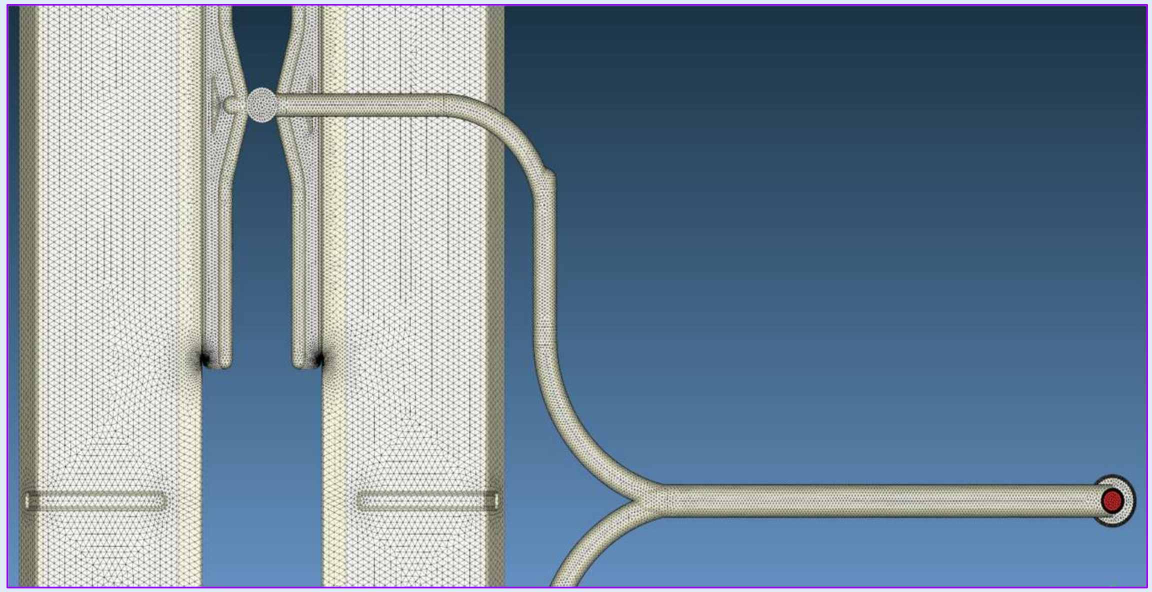
CURING_CONVERSION

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

***ROLLER* - *MOLDEX3D ITALIA* TECHNICAL SUPPORT => 3D MODELS + MESHES**



2 CAVITIES - 3D MODEL



2 CAVITIES - MESH DETAIL

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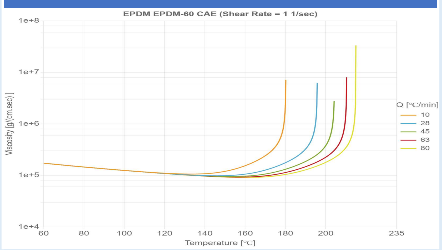
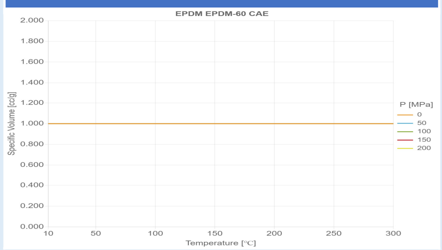
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

DESIGN OF EXPERIMENTS (DOE) - INPUT: MATERIAL FIGURES

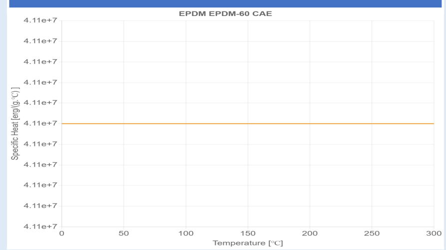
Material_*Viscosity*



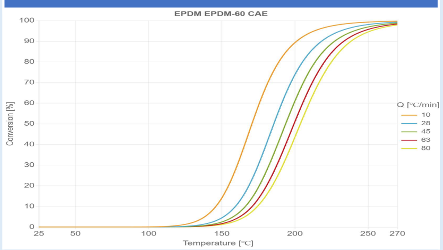
Material_*PvT*



Material_*Specific Heat*



Material_*Curing Kinetics*



Material_*Mec. Properties*

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Grade Name	EPDM-60
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Material_*Contents*

Type	EPDM
Grade Name	EPDM-60
Producer	CAE
Melt Temperature (Minimum)	60 °C
Melt Temperature (Normal)	70 °C
Melt Temperature (Maximum)	80 °C
Mold Temperature (Minimum)	140 °C
Mold Temperature (Normal)	155 °C
Mold Temperature (Maximum)	170 °C

CAE *MOLDEX3D* RUBBER COMPOUND:

Rubber_EPDM_EPDM Sulphur Black 60 Shore A.mtx

Material characterized under IG-R&D method.

SAME RUBBER COMPOUND OF THE PREVIOUS ARTICLE

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D

DESIGN OF EXPERIMENTS DOE - INPUT: PROCESS PARAMETERS (ROLLER)

Filling	Item Data	Unit
Filling Time	24	s
Melt Temperature	140	°C
Mold Temperature	185	°C
Max Injection Pressure	153	MPa
Injection Volume	638.797	cm^3
Curing		
Curing Time	300	s
Max Curing Pressure	153	MPa

T_{SH}

The input data (*Filling Time*, *Melt Temperature*, *Mold Temperature* & *Curing Time*) were set-up based on IG-know how & by considering a similar injection moulding production.

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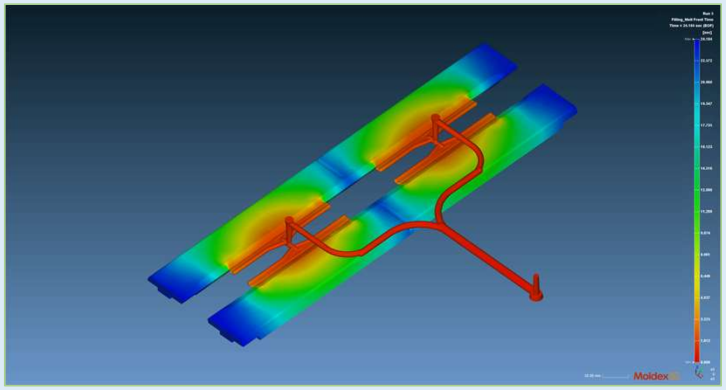
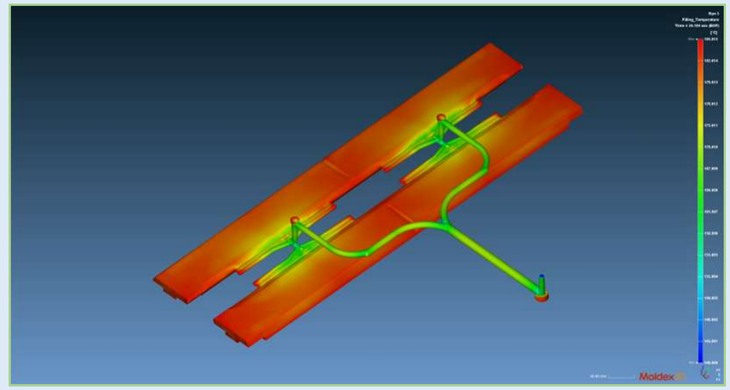
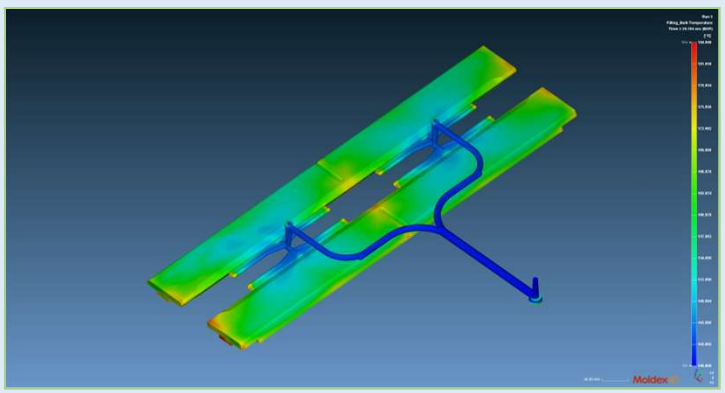
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - MOLDEX 3D



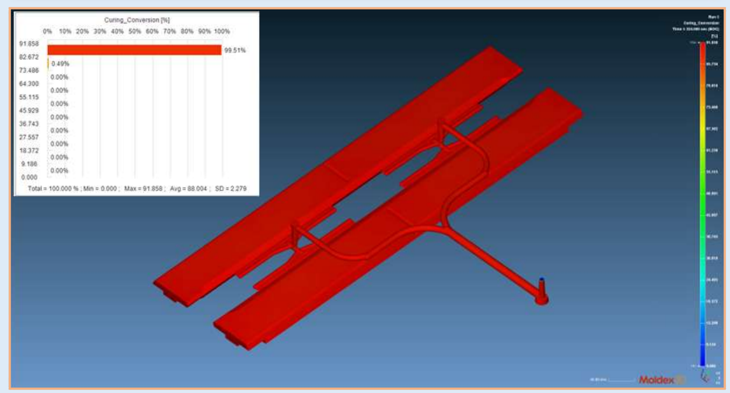
FILLING_MELT FRONT TIME



FILLING_TEMPERATURE



FILLING_BULK TEMPERATURE



CURING_CONVERSION

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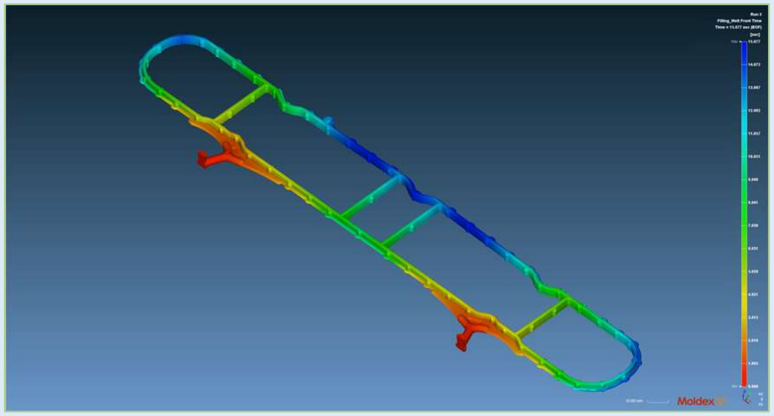
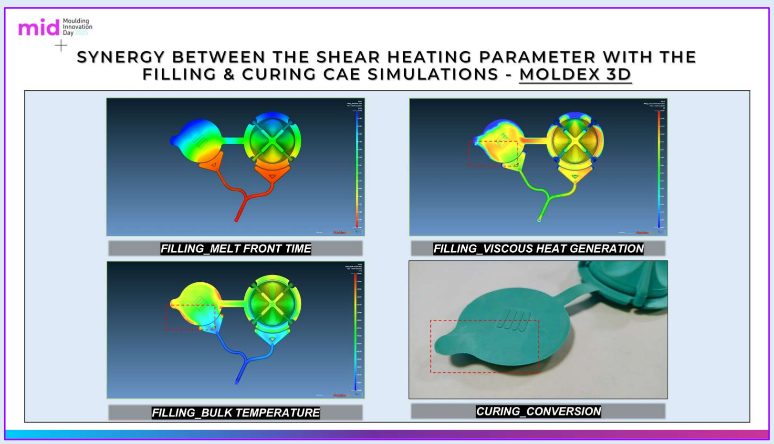
SYNERGY BETWEEN THE SHEAR HEATING PARAMETER WITH THE FILLING & CURING CAE SIMULATIONS - FINAL REMARKS





FINAL REMARKS

SYNERGY BETWEEN THE SHEAR HEATING PARAMETER & MOLDEX3D®:

- **The implementation of T_{SH} as an input data allowed to properly set-up the simulation & to obtain outputs more "adherent to reality";**
- **Design of Experiments (DoE) applied in 3D flow simulations allowed to identify the correct mold design, by considering multiple aspect of the injection moulding process;**
- **CAE simulation can effectively support the identifying of a correct mold design;**
- **Moreover, by using real injection moulding data for the set-up of the simulations, it was possible to detect defects present on technical articles & take action to reduce/eliminate them.**

AKNOWLEDGEMENTS & REFERENCES

ITALIAN GASKET RESEARCH & DEVELOPMENT STUDY

AUTHORS:

Italian Gasket R&D Dept: Ing. Mario Costardi & Mattia Ramini, PhD

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Thank you