



Key partner in Design Process Innovation

ANALYSIS OF THE FACTORS CONTRIBUTING TO THE HEAT BALANCE

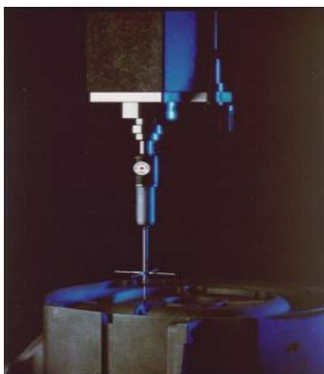
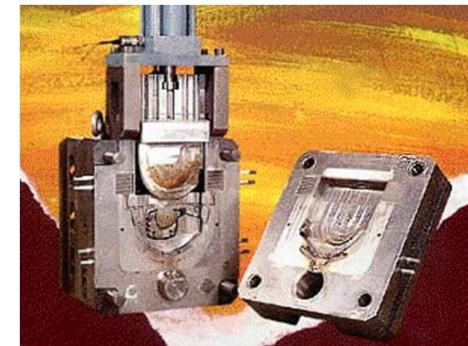
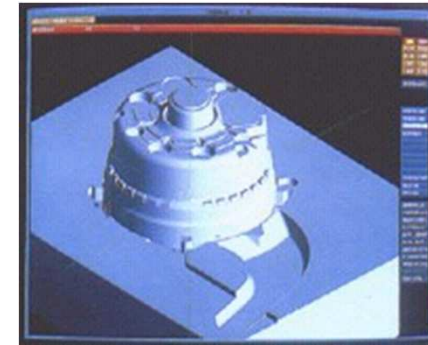
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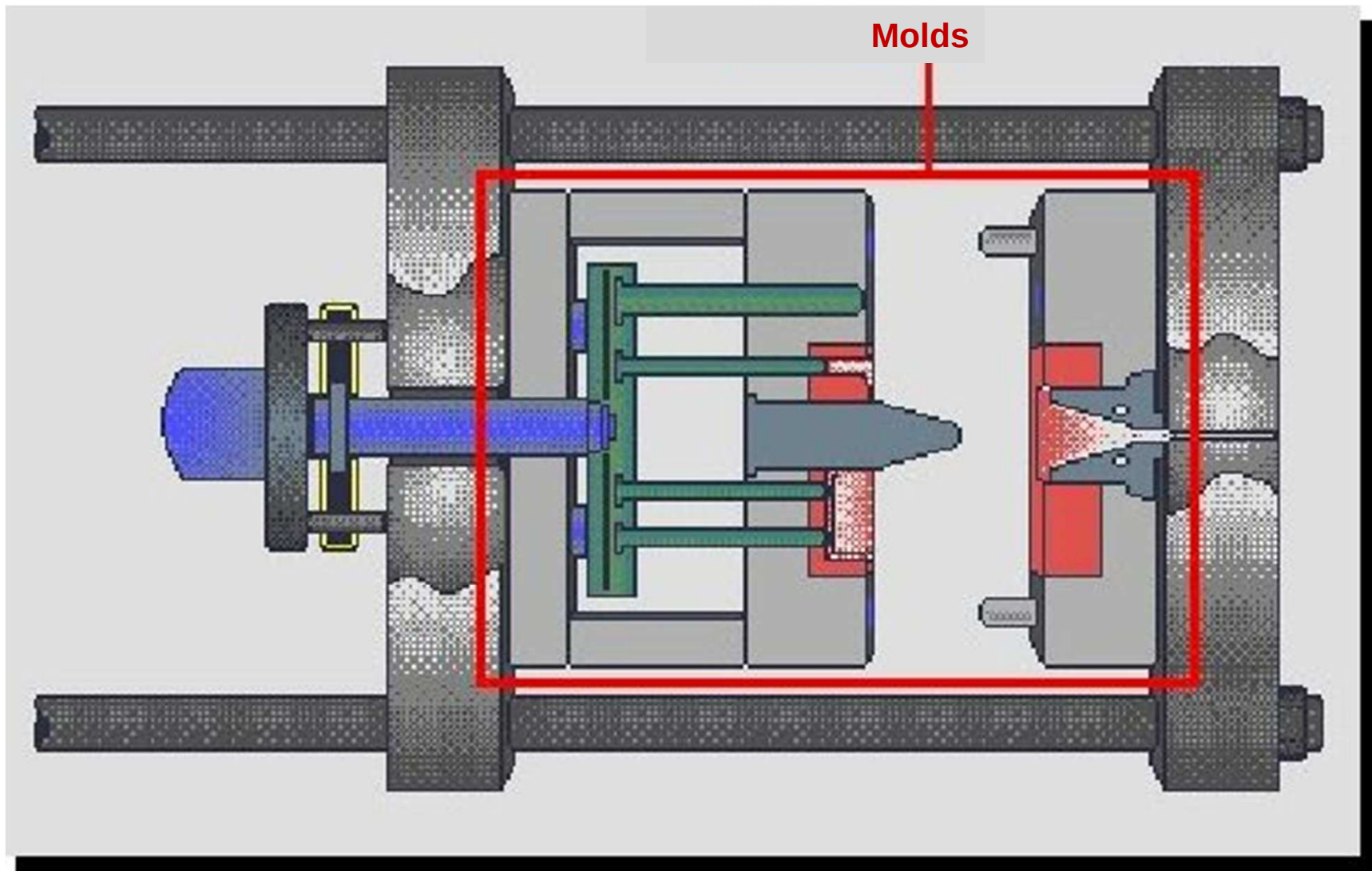
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The mold

- Concept and design of the Mold:
 - Orientation and position of the casts
 - Gating system design
 - Definition of the sliders
 - Colling channels design
 - Ejectors number and position
- Geometry CAD modeling for the dies and machining definition
- Molds construction
- Samples to verify/optimize the molds



The mold: layout

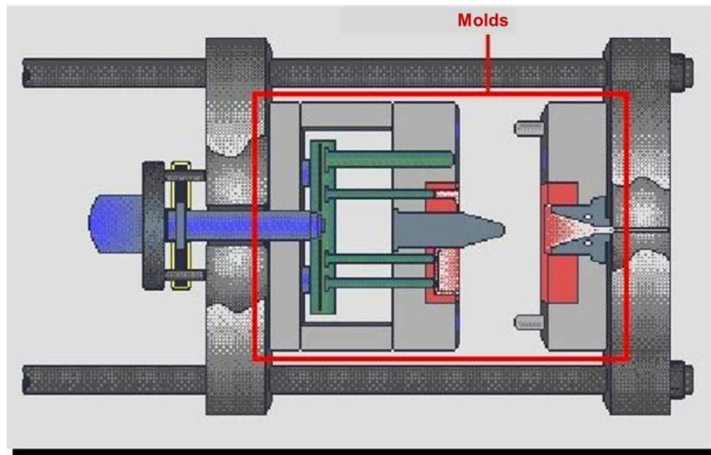


The mold: die material choice

- The choice of materials influence the yield / duration of the molds, in particular for the HPDC process where the conditions of use are extreme.
- There are a large number of steels types used according to the type of the mold considered. The table below shows the most used steels and treatments to which they are subjected.

<i>Designation</i>	<i>Material</i>	<i>Heat Treatment</i>
Dies holder	42CrMo4	Quenching e aging for HRC 35 (big molds)
Dies holder	C38	Quenching e aging for HRC 28-30 (small molds)
Dies (cover, ejector and slider)	X38CrMoVSi5	Quenching e aging for HRC 45-50 (for Al e Zn alloy)
Dies (cover, ejector and slider)	35NiCr16	For Zn alloy
Dies (cover, ejector and slider)	X35CoWCrMo5-4	For Cu based alloy (dies with cooling channel system)
Dies (cover, ejector and slider)	X30WCr9-3	For Cu based alloy (not cooling dies)
Spacers	42CrMo4	Quenching e aging for HRC 35
Pin	X38CrMoVSi5	Quenching e aging for HRC 50 + nitriding
Mold centering parts	40CrMnMo8	Quenching e aging for HRC 30-35 + sulfonitriding
Ejector pins	X38CrMoVSi5	Quenching, aging and nitriding
Ejector plates	C48	Annealing

The mold: die life



Zinc



1000000

Plastic



600000

Magnesium

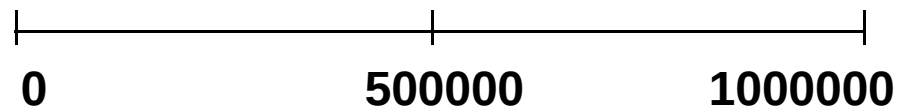


300000

Aluminum

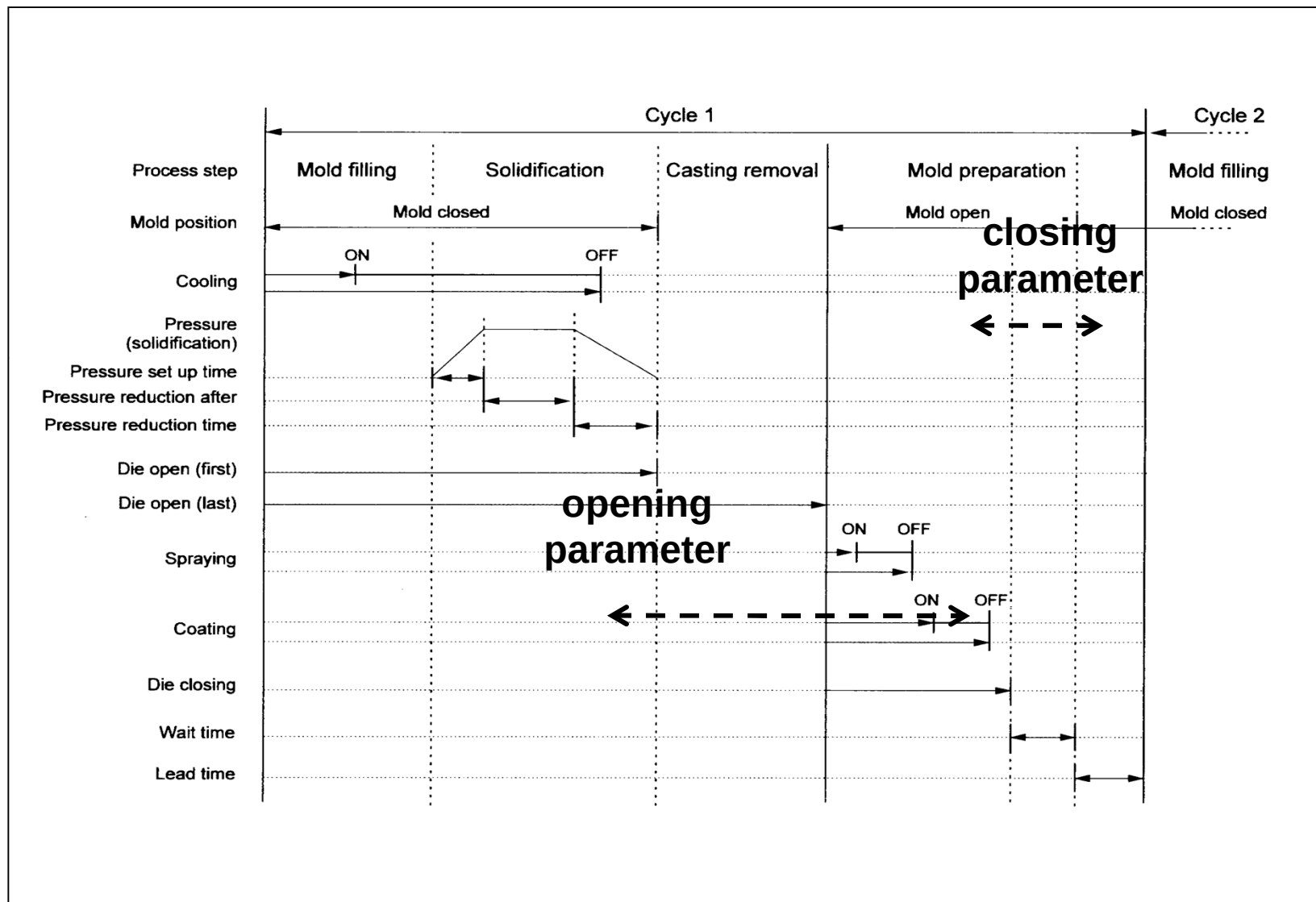


200000

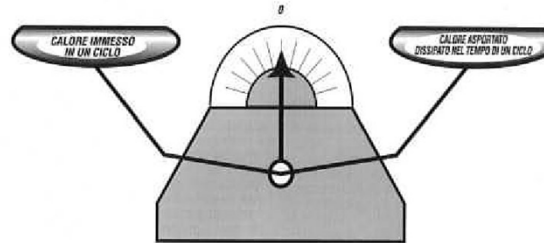


Total casts produced

Cycle Time



Thermal regime.



Heat input in one cycle = Heat output in one cycle

└ Latent heat of solidification
of the melt alloy (**A**)

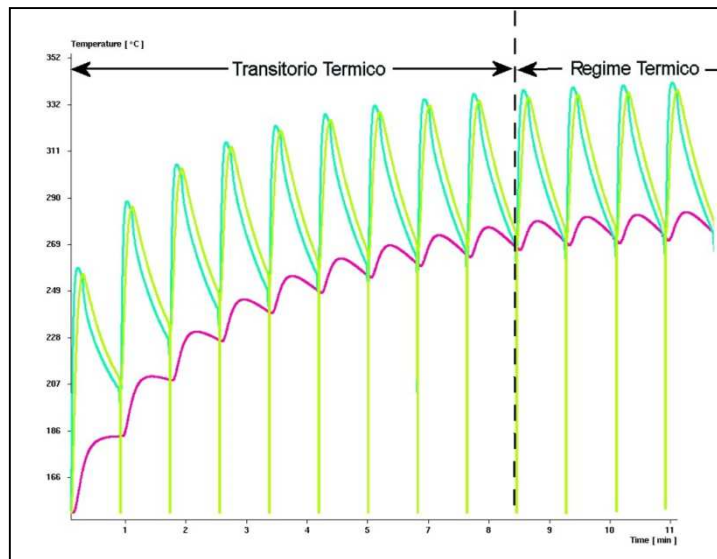
└ Thermoregulation (**P**)
└ Lubrication (**L**)
└ Dispersion to surroundings (**D**)

- all terms that affect the **heat balance (A,P,L,D)** depend on the average temperature of the die.
- the thermal equilibrium is obtained at different average temperatures of the die.
- after n production cycles the average temperature is reached which guarantees the thermal equilibrium for the die under examination.

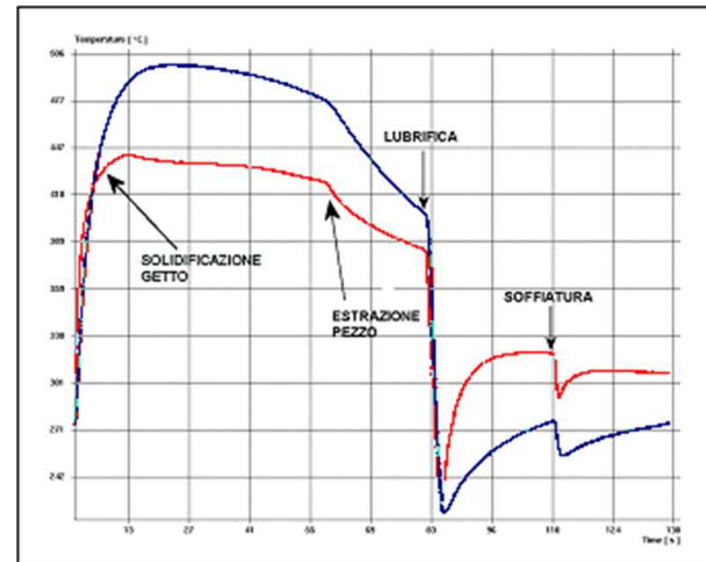


You have reached the condition of Thermal Regime.

Definition of thermal regime



Die Temperature evolution during 13 cycles



Die Temperature evolution in 1 cycle

In condition of the thermal regime, the contributions of heat that provide the heat balance remains constant in each cycle.



When is the thermal regime reached?

Die temperature end cycle = Die temperature start cycle

Thermal regime: condition of achievement.

One possible definition:

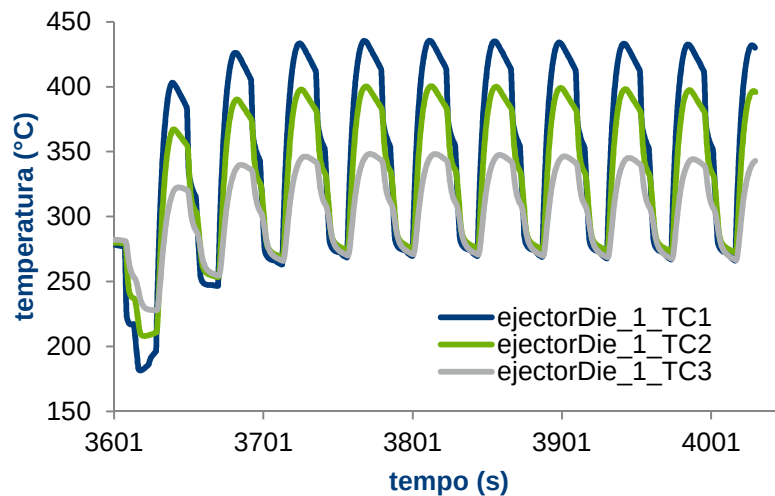
“The thermal regime is reached when at each point of the mold temperature is always the same at the same instant within each production cycle”.

The definition of the thermal regime introduced previously can be translated in quantitative terms exploiting the start-up ramp and setting a threshold value:

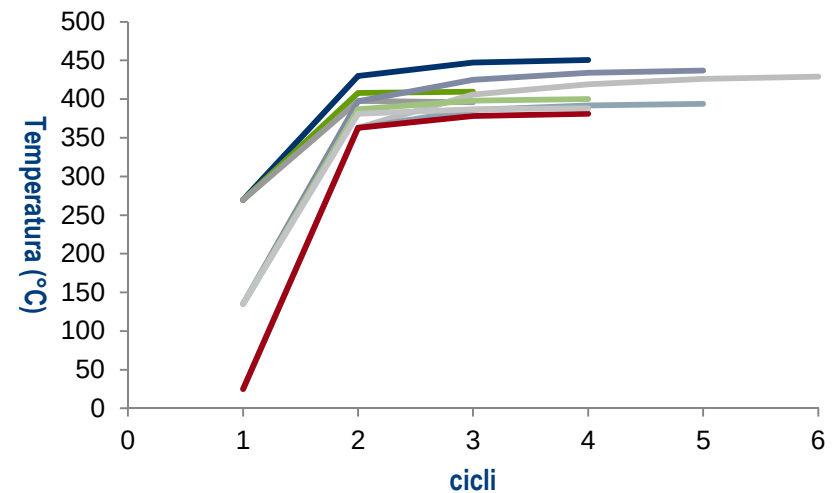
“when the temperature at a point varies from one cycle to the next to a value less than a threshold laid down (i.e. 1%) it can reasonably be said to have reached the thermal regime”.

Numerical simulations of the start-up phase.

The numerical simulation allows to obtain virtually the start-up ramp: for each point is possible to extract the temperature at the same time within successive cycles. This allows to define a quantitative and unambiguous criterion to define the achievement of steady state thermal condition.

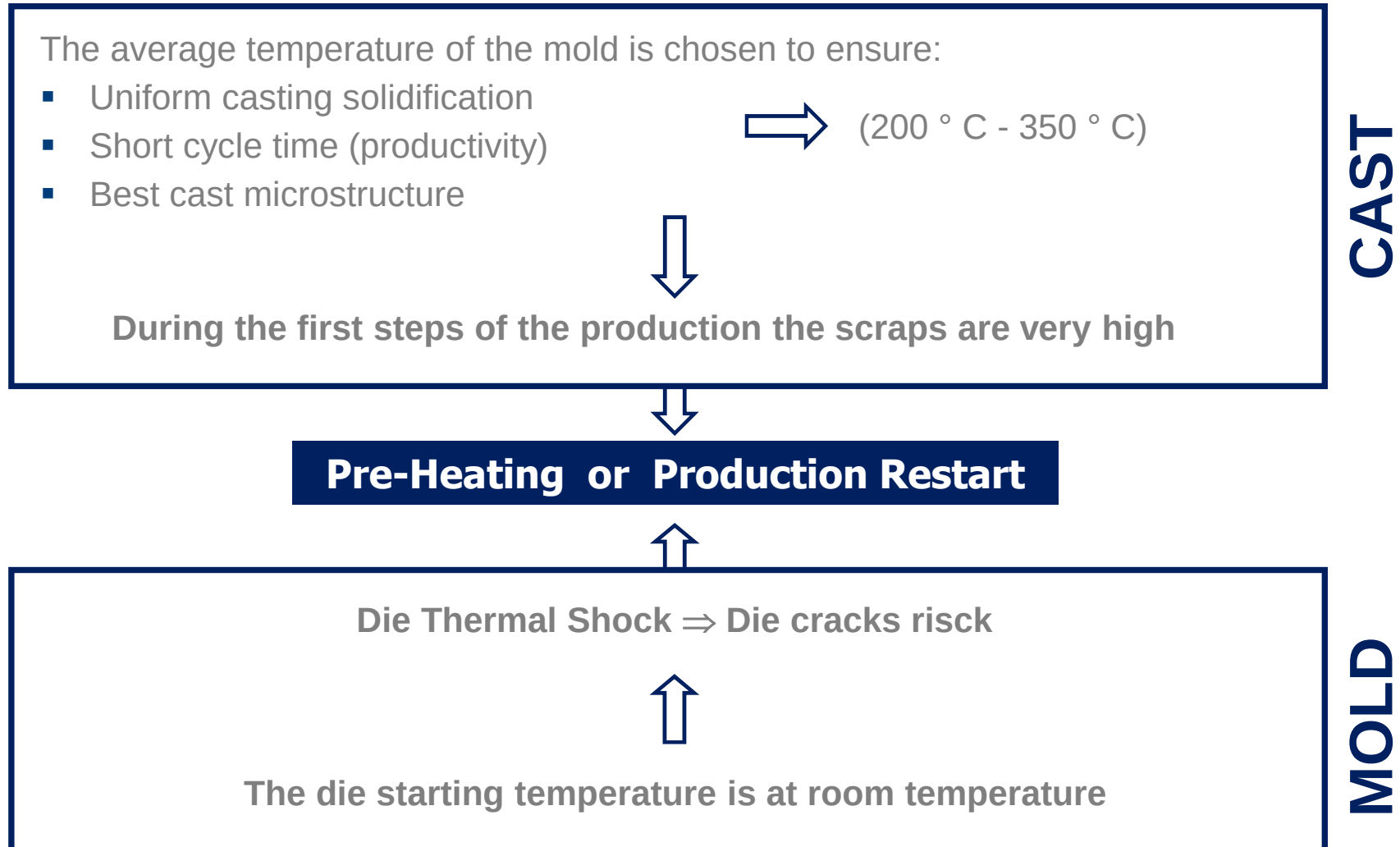


Die temperature evolution during the start-up phase.



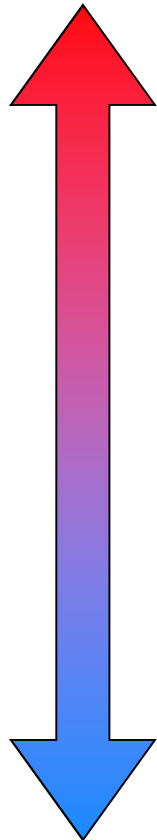
Different Die temperature evolution during the start-up in function of the different lubrication step

Pre Heating or Production Restart



Mean temperature.

Designed die mean temperature is selected to guarantee uniform solidification path and solidification time (200°C - 350°C).



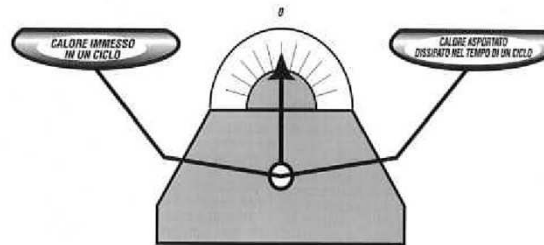
High temperature:

- Difficult cast ejection,
- Lubrication efficiency,
- Longer cycle time,
- Cast distortions/deviations,
- porosity,
- wear.

Low temperature:

- Thermal fatigue (high ΔT),
- Difficult cast ejection,
- Lubrication efficiency,
- Cold shuts,
- Dimensional instability,
- Incomplete filling.

Contributions to heat balance.



heat input in one cycle = heat output in one cycle

└ Latent heat of solidification
of the melt alloy (**A**)

└ Thermoregulation (**P**)
└ Lubrication (**L**)
└ Dispersion to surroundings (**D**)

The increase of temperature of the die is related to:

- Heat input (**A**)
- Die mass(**M**)
- Heat output:
 - Dispersion to surroundings(20%) (**D**)
 - lubrication (20%) (**L**)
 - Cooling channels (60%) (**P**)

Contributions to heat balance: heat input (A).

At each cycle the injected material solidifies and yields part of its heat to the mold

Example: 1kg aluminium alloy

Initial temperature = 680°C

liquidus temperature = 578°C

solidus temperature = 479°C

Final temperature = 300°C

$$Q_1 = C_p \Delta T = 1,10 \cdot (680 - 578) = 112.2 \text{ kJ/kg}$$

$$Q_2 = C_p \Delta T = 1,15 \cdot (578 - 479) = 113.8 \text{ kJ/kg}$$

+

Latent heat H=480 kJ/kg

$$Q_3 = C_p \Delta T = 1,10 \cdot (479 - 300) = 196.9 \text{ kJ/kg}$$

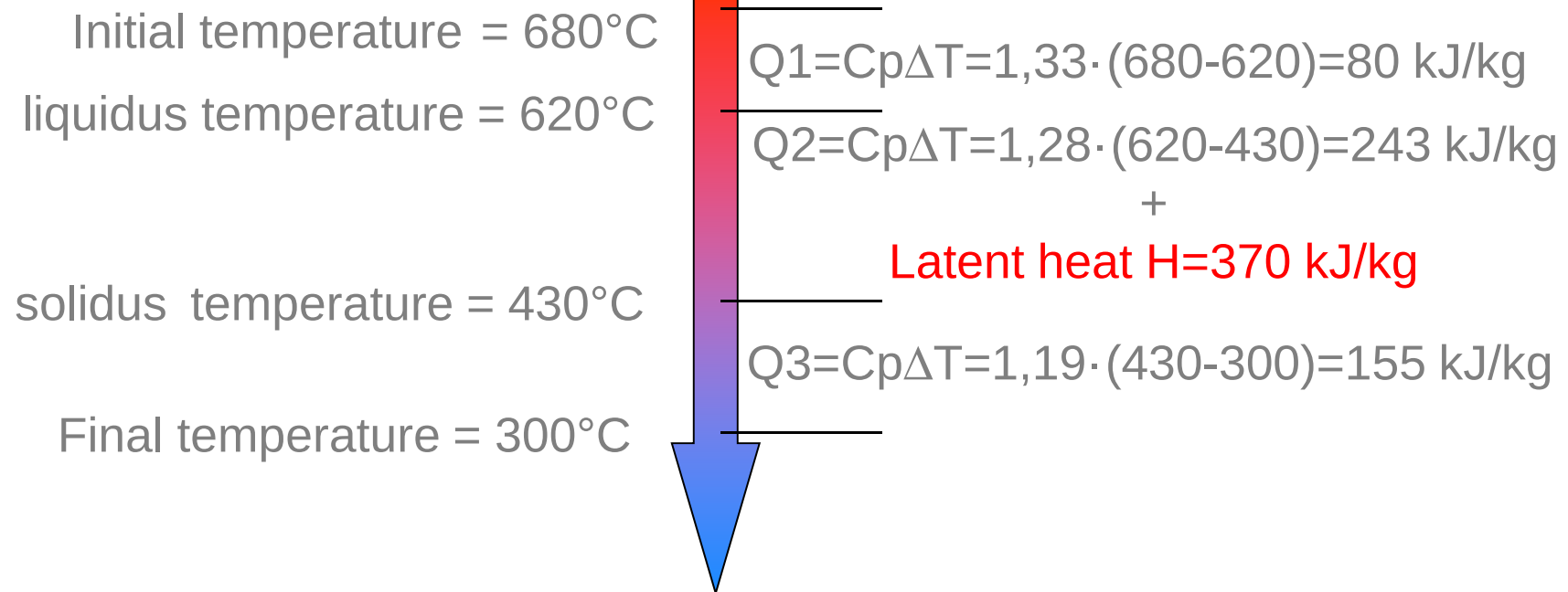
1kg aluminium alloy yields in each cycle to the mold about:

$$Q = Q_1 + Q_2 + H + Q_3 = 112.2 + 113.8 + 480 + 197 = 903 \text{ kJ/kg.}$$

Contributions to heat balance: heat input (A).

At each cycle the injected material solidifies and yields part of its heat to the mold

Example: 1kg magnesium alloy



1kg magnesium alloy yields in each cycle to the mold about :

$$Q = Q1 + Q2 + H + Q3 = 80.0 + 243.0 + 370.0 + 155.0 = \mathbf{848 \text{ kJ/kg.}}$$

Contributions to heat balance: heat input (A).

The heat that the mold receives in time is proportional to:

- Mass of the cast
- Number of injections/hour

$$M \cdot c_p \cdot (T_f - T_i) = A - D - L - P$$

C_p : specific heat of steel (0.5 kJ/kgK)

T_f : die mean temperature at the end of cycle

T_i : die mean temperature at the beginning of cycle

Die mass/cast mass = 500
D+L+P=0 no dissipation



1Kg aluminum alloy, every
cycle $500 \cdot 0.5 \cdot \Delta T = 903 \cdot 1$



Mean temperature
increase for cycle:
 $\Delta T = 3.6 \text{ } ^\circ\text{C}.$

Die mass/cast mass = 500
D+L+P=0 no dissipation



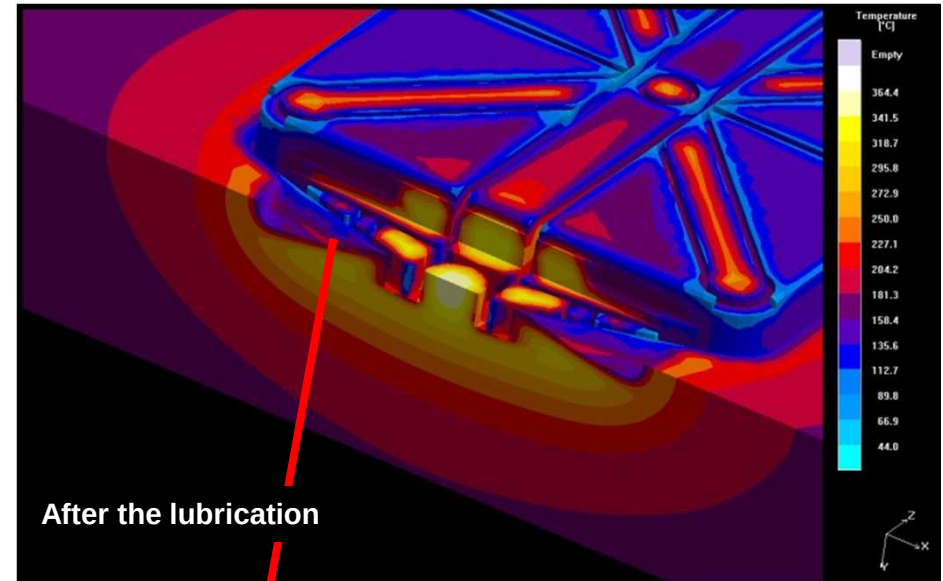
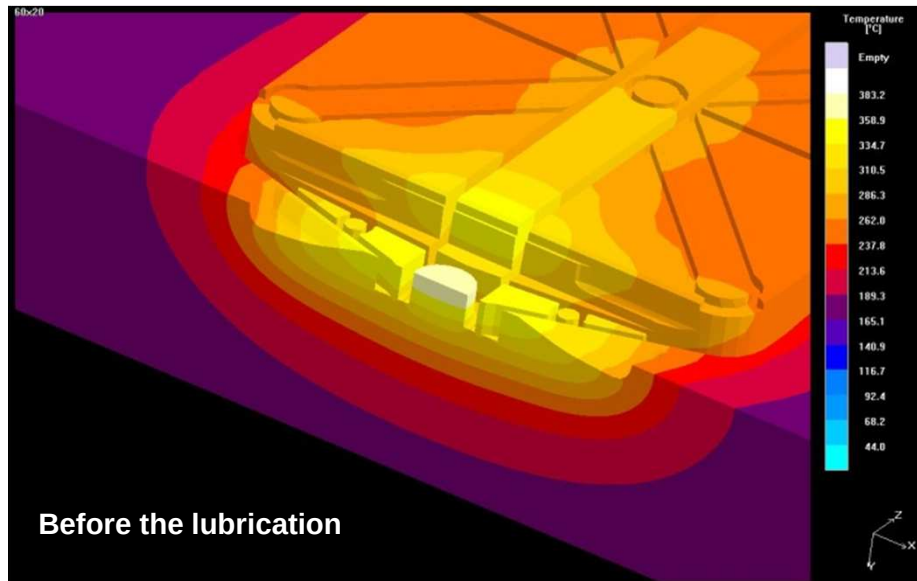
1Kg magnesium alloy, every
cycle: $500 \cdot 0.5 \cdot \Delta T = 848 \cdot 1$



Mean temperature
increase for cycle:
 $\Delta T = 3.4 \text{ } ^\circ\text{C}.$

Contributions to heat balance: spraying (L).

The spraying of the lubricant on the die surfaces causes a significant removal of heat due to temperature difference between die surfaces and lubricant's water content.

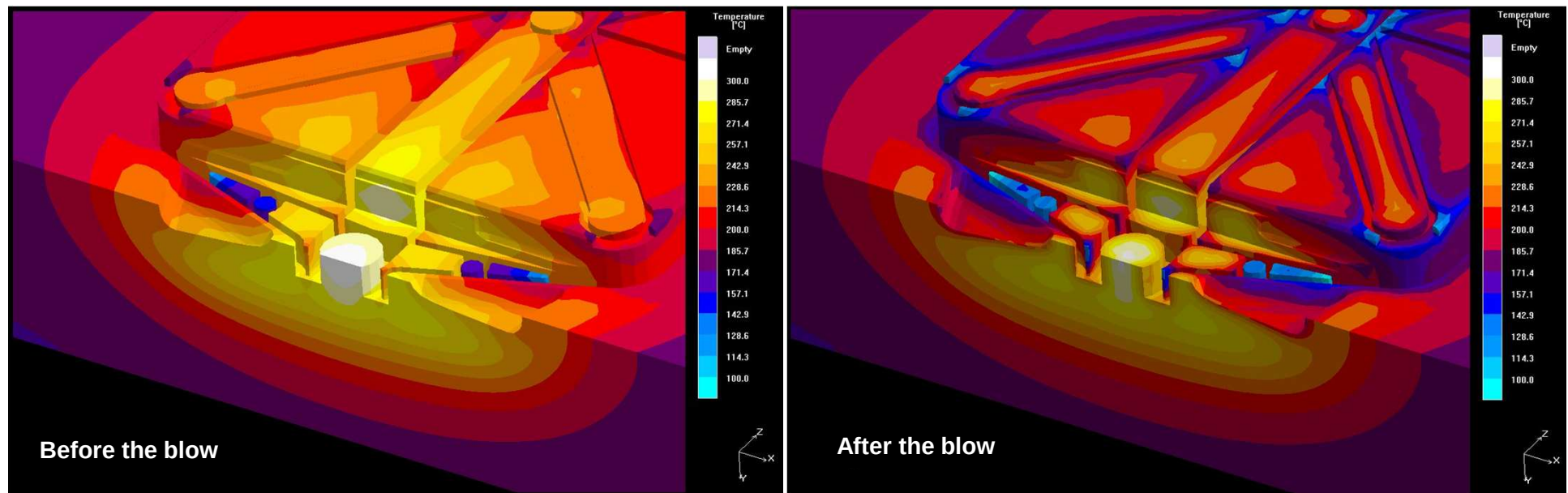


The effect of lubrication is superficial

Contributions to heat balance: blowing (L).

The eventual phase of the blowing, following the lubrication, involves a removal of heat by forced convection.

This amount of heat is lower than that removed during lubrication.



Contributions to heat balance: lubrication (L).

In a generic cycle in steady thermal state :
**heat transferred from the casting to the die =
dispersion from the die to the environment +
heat removed by cooling channels + heat removed by lubrication.**

The heat loss to environment (4-6%) and heat removed by cooling channels (58-80%) can be considered a fairly uniform amount during the cycle.

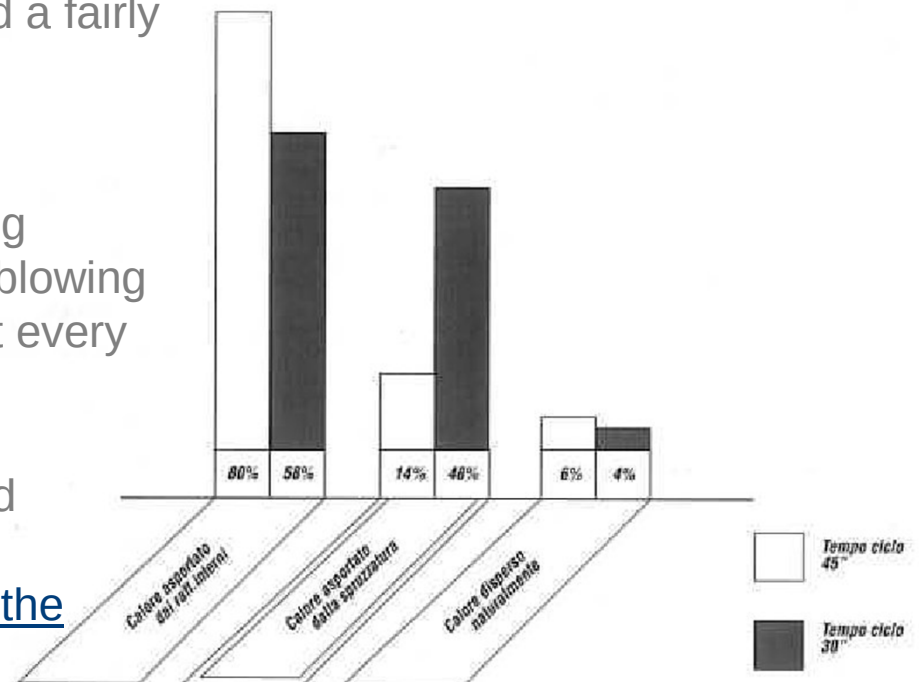


heat transferred from the casting to the die during solidification and heat removed by lubrication & blowing (14-48%) are regular pulses that are repeated at every cycle.



The heat transferred from the casting to the mold during solidification and the heat removed by lubrication & blowing are strongly dependent on the rate of injection.

Accelerando la cadenza di stampaggio la quantità di calore asportato dalla spruzzatura deve essere aumentata.



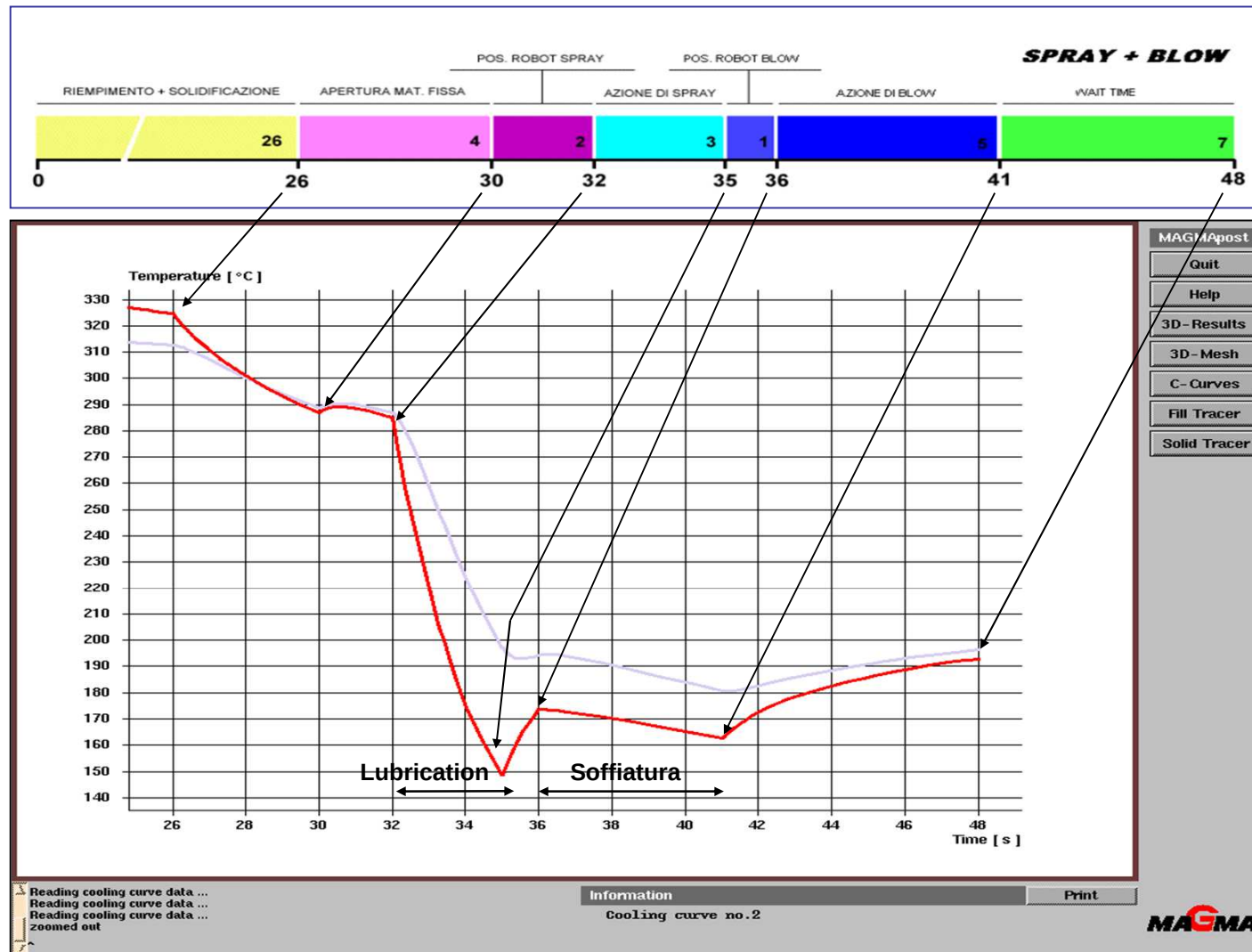
Blowing Phase

The blowing phase function is to dry the molds and to remove humidity

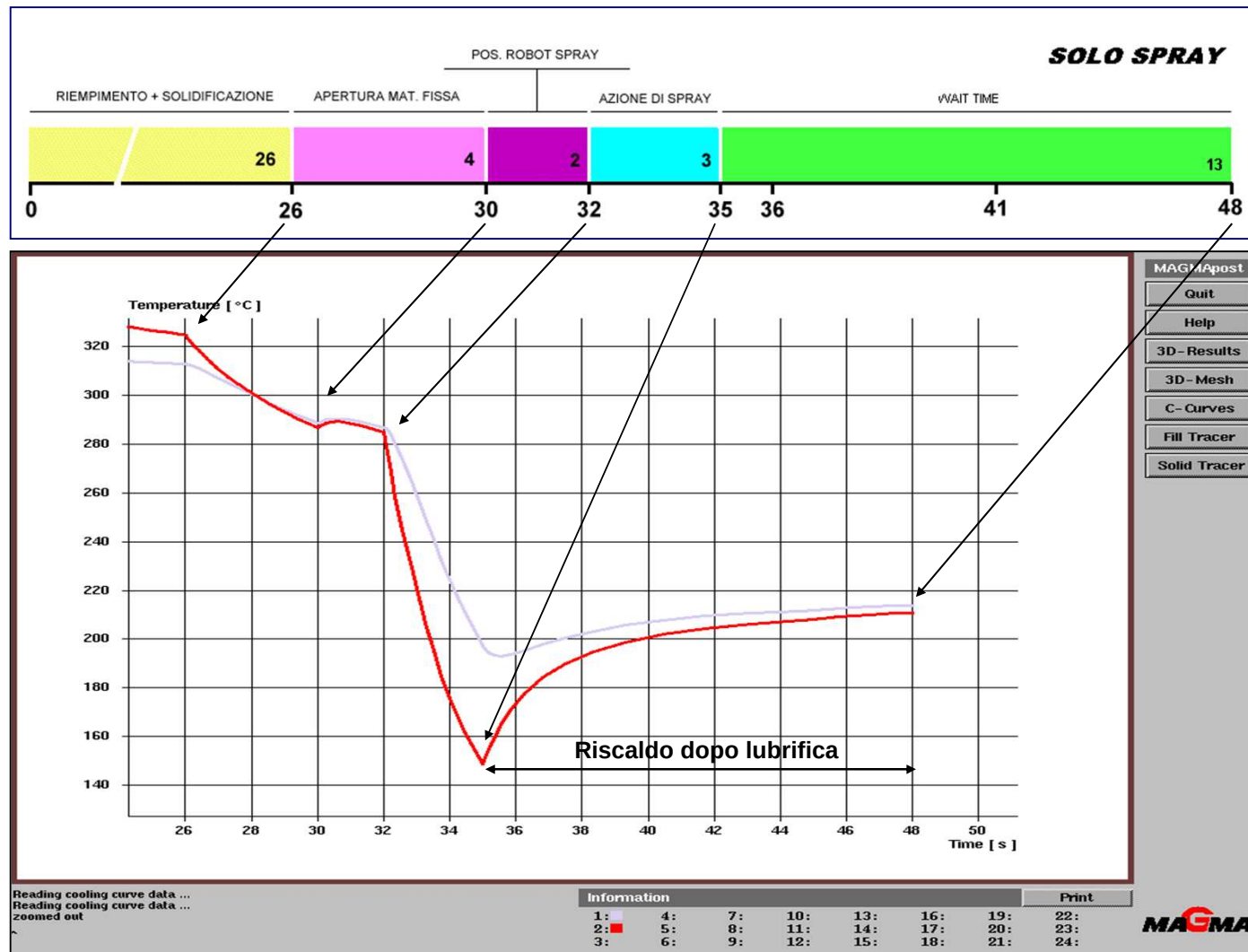
The possible phase of the blowing, following the lubricates, involves a heat removal by forced convection.

This amount of heat is lower than the lubrication.

Lubrication and Blowing Phase



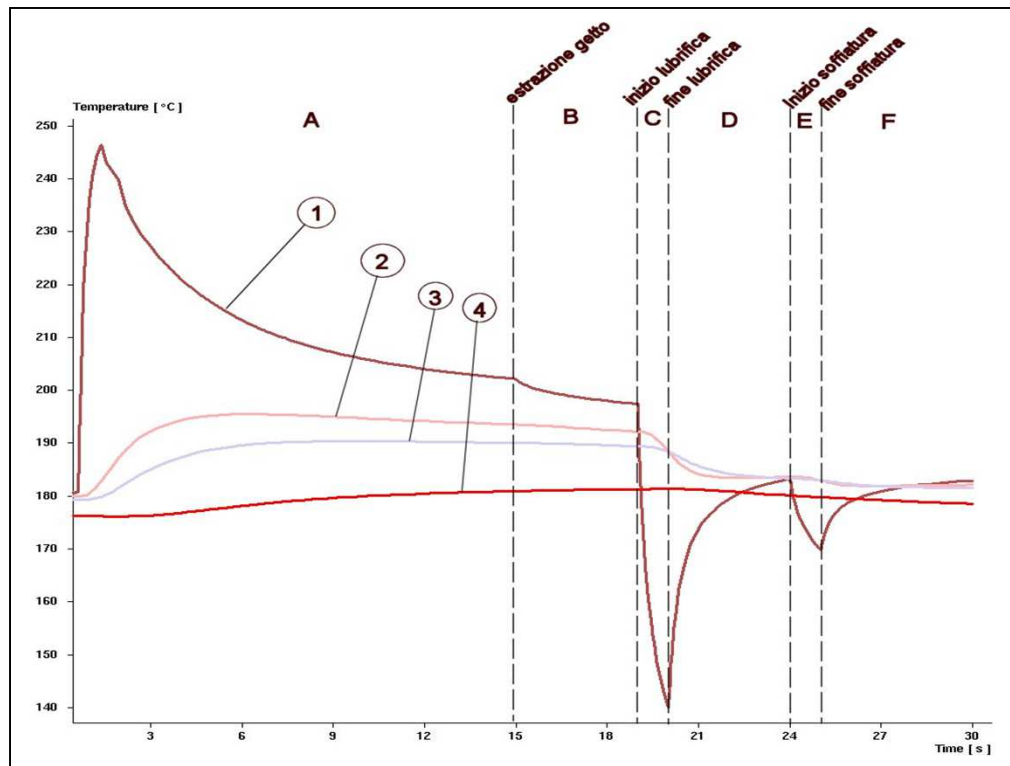
Lubrication Phase



Surface thermal shocks.

Thermal shocks translate in surface stresses.

The area subjected to higher thermal shocks is the surface of the mold; it is in direct contact with the melt alloy during injection and undergoes the greater drops in temperature during lubrication phases.



Trend of temperature at some points of the mold during casting cycle.

Points position:

1. Cast-mold interface,
2. 5 mm from interface inside mold,
3. 10 mm from interface inside mold,
4. 15 mm from interface inside mold.

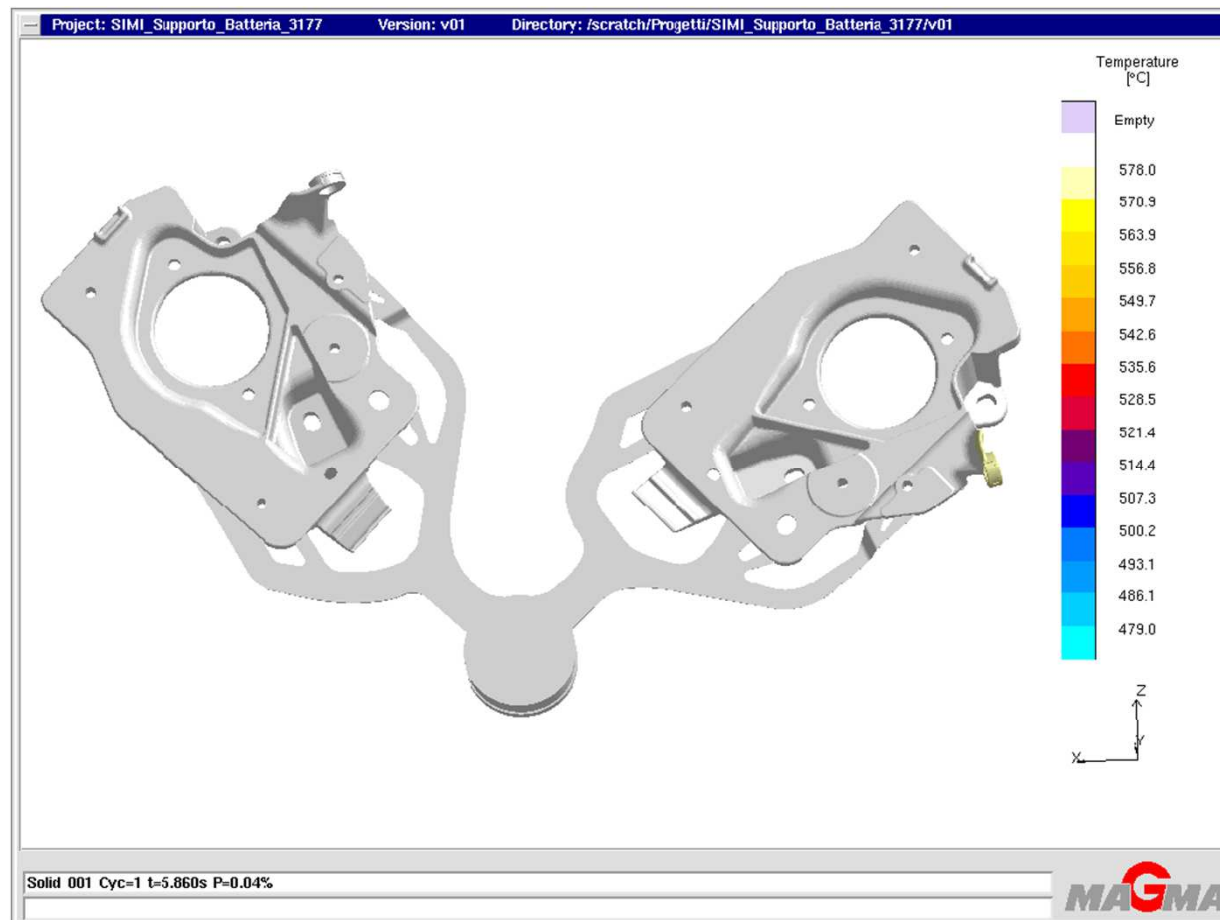
Thermoregulation system design

Steps to design a thermoregulation system

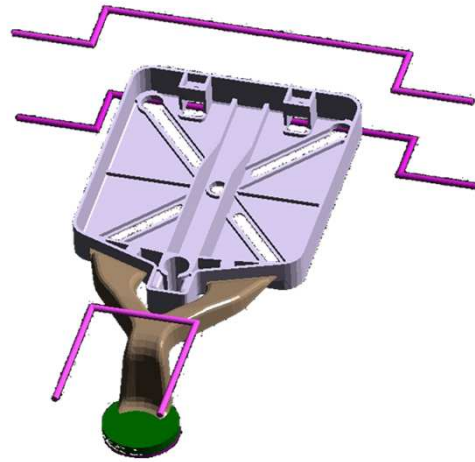
- Cast hot spots evaluation to defin where to put the cooling channels
- Evaluation of the heat flow through the molds
- Medium choice (water or oil)
- Flux evaluation
- Geometry evaluation
- Cooling channel distance from the surface

Thermoregulation system design: preliminary solidification

The preliminary solidification allows to verify the last solidified areas, evaluating also the critical time



Contributions to heat balance: cooling channels (P).



The medium in the cooling channels can be:

- Water
- Oil

Heat removed by the cooling channels depends on:

- fluid,
- Volume flow,
- Thermal gradient between fluid and die,
- Cooling channel exchange surface.

There are experimental and analytical relationships to determine the heat transfer coefficient of the cooling channels as a function of these parameters.

Specific heat of water:

$$C_p = 1 \text{ kCal}/(^{\circ}\text{C} \cdot \text{kg})$$

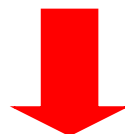
Specific heat of oil:

$$C_p = 0.5 \text{ kCal}/(^{\circ}\text{C} \cdot \text{kg})$$

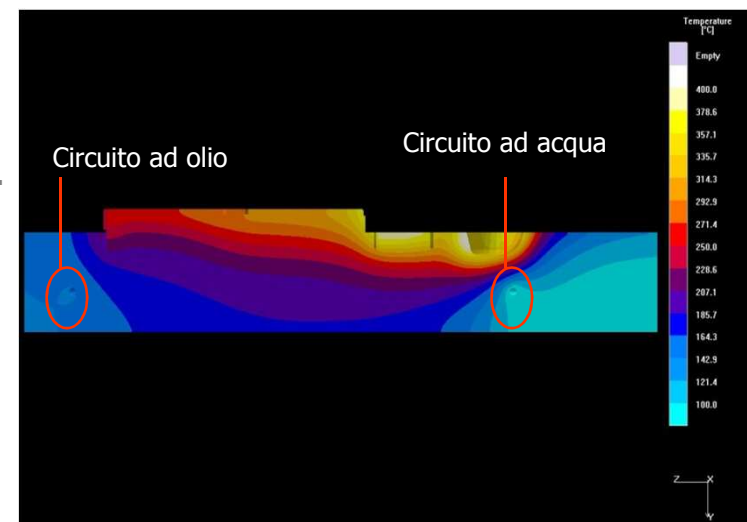


Cooling channels with water have greater heat removal capacity.

$$\text{HTC water} > \text{HTC oil}$$

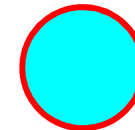


$$\text{water heat flux} > \text{oli heat flux}$$

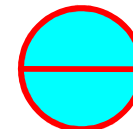


Typical cooling systems

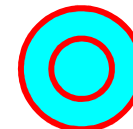
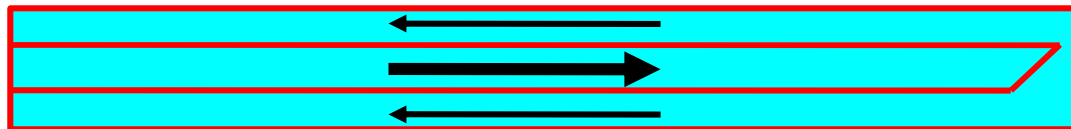
- Cooling channel



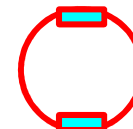
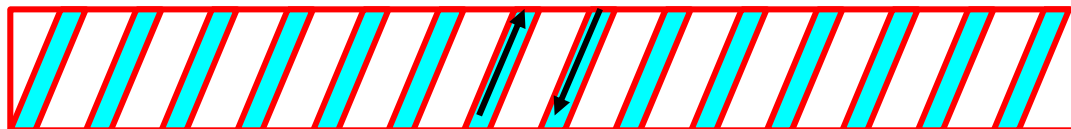
- Cooling pin with flow separator



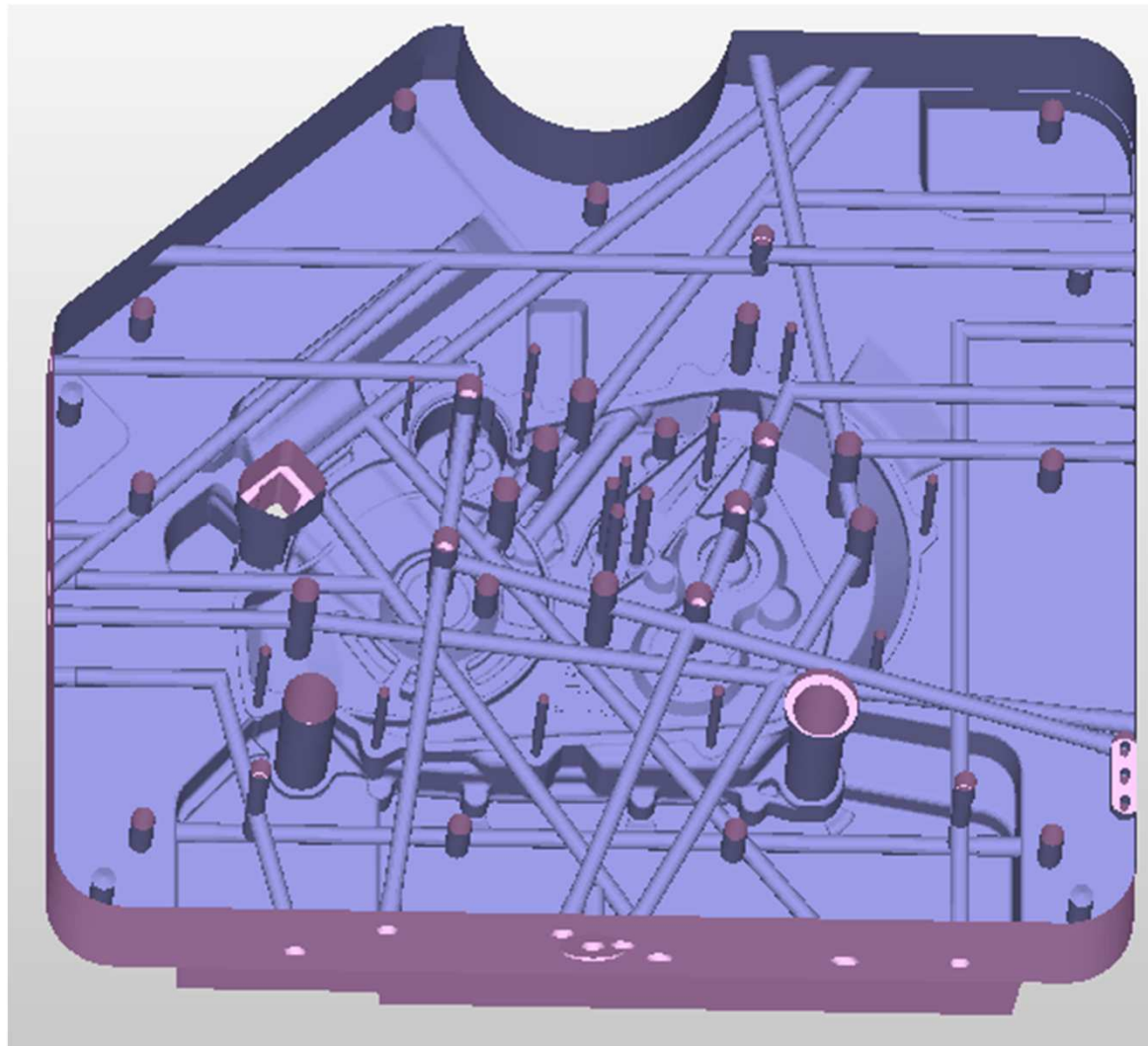
- Concentric tubes cooling pin



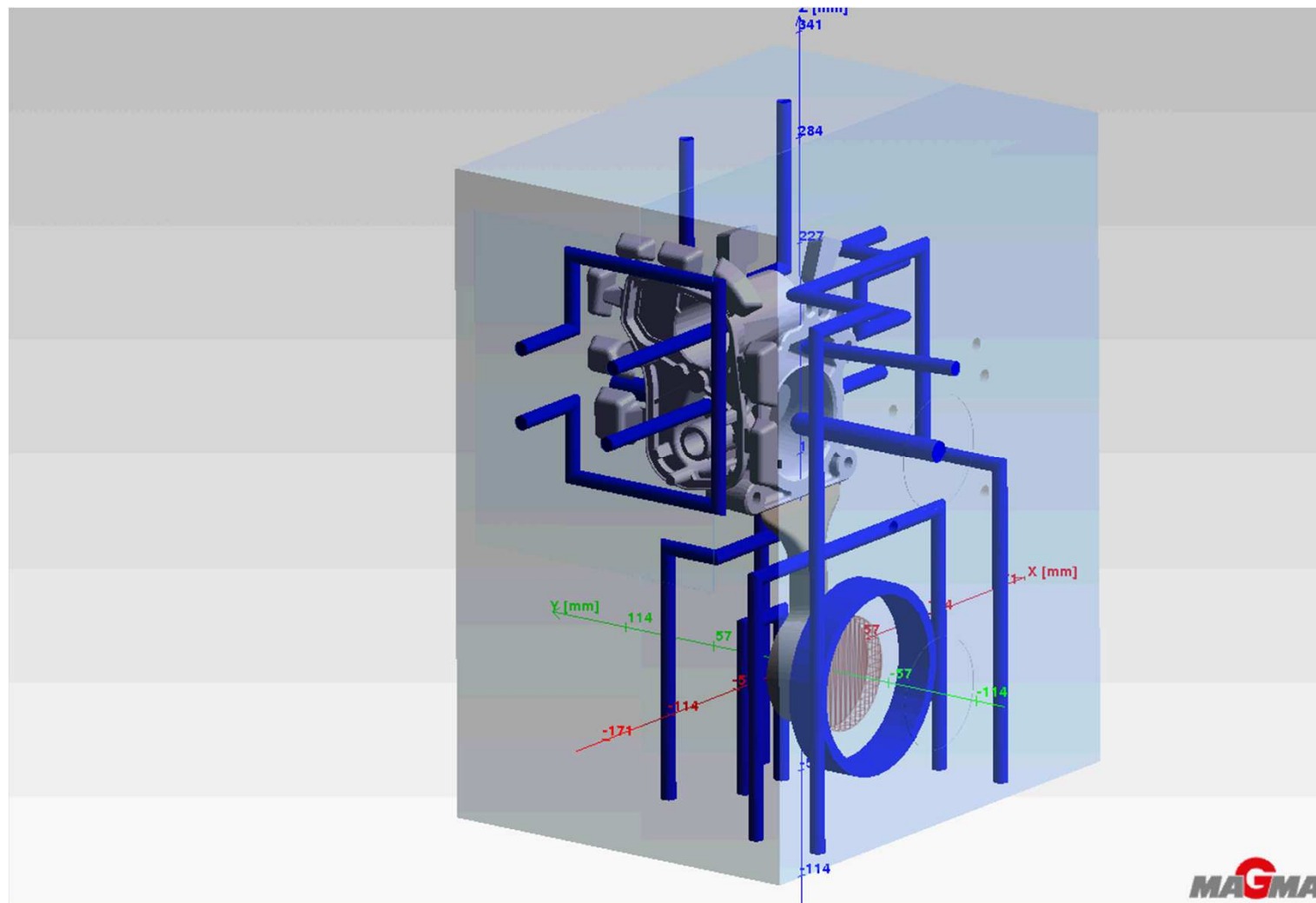
- Helical cooling pin



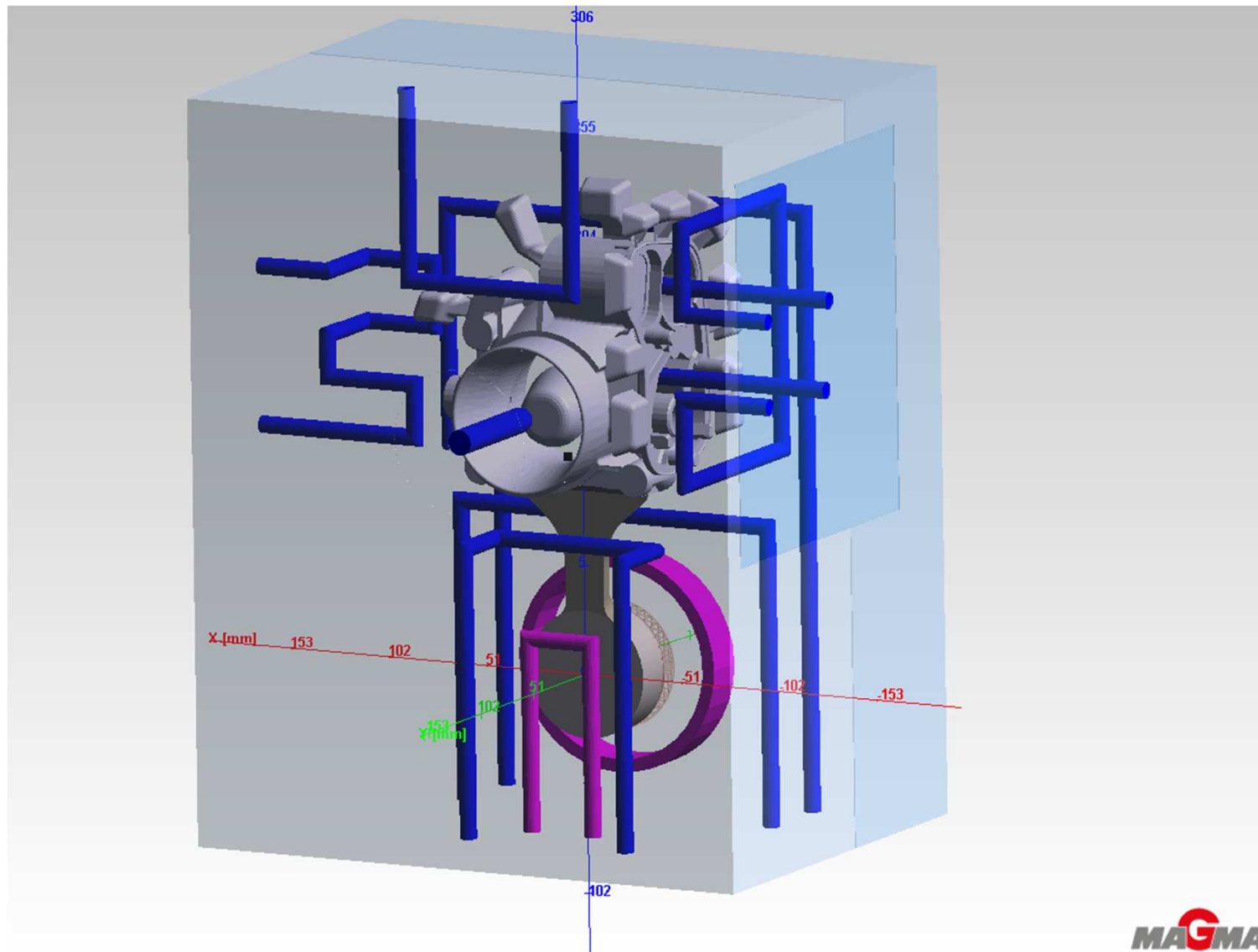
Typical cooling systems: example



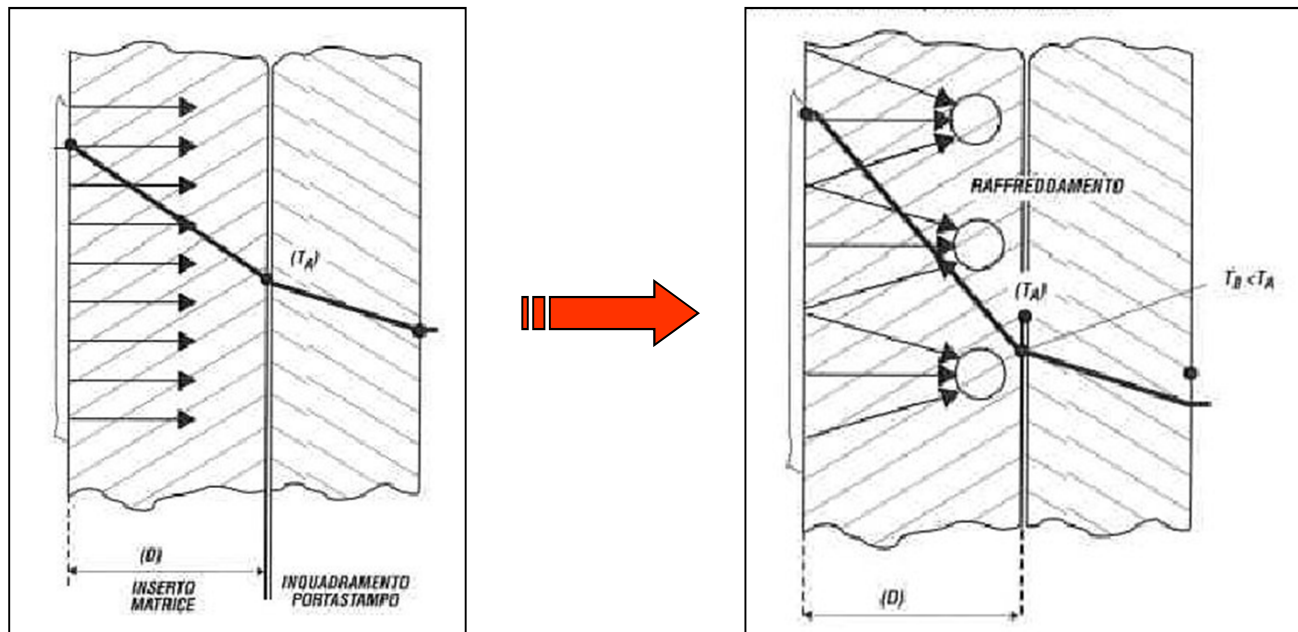
Typical cooling systems: example



Typical cooling systems: example



Heat flow in the mold



The presence of cooling channels leads to an increase of the temperature gradient and therefore the thermal flow from the cast to the mold

$$\dot{q} = \lambda \cdot \Delta T$$

$$\Delta T_A < \Delta T_B$$

$$\dot{q}_A < \dot{q}_B$$

Heat flow in the mold

The surface channel temperature is proportional to temperatura della superficie dello stampo

- Mold surface temperature
- Cooling channel distance from the mold surface
- Mold conductivity (steel conductivity)

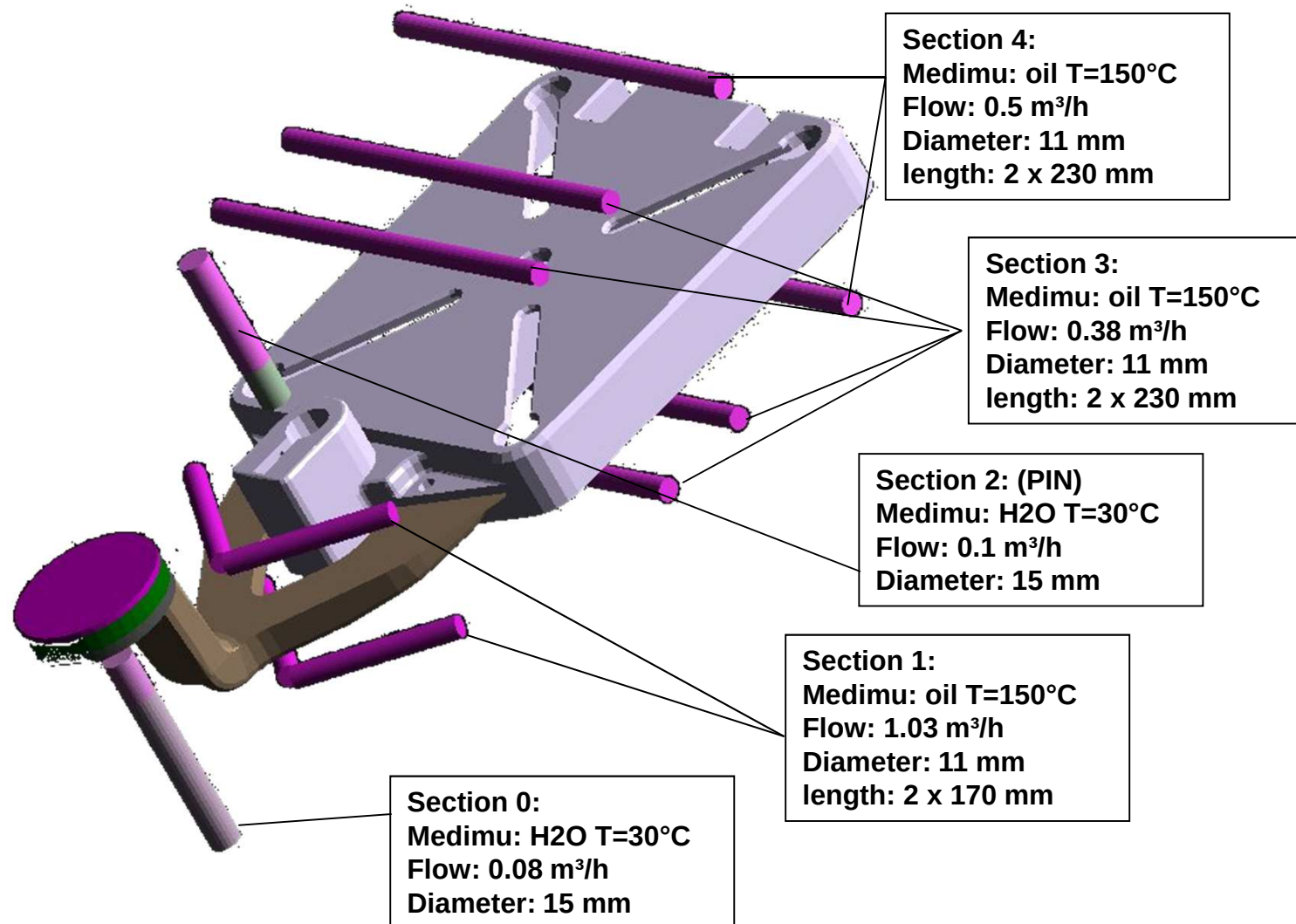
The heat removed from the mold is determined by:

- Medium temperature difference between the inlet and outlet of the circuit
- quantity of fluid passing through the circuit
- specific heat of the fluid

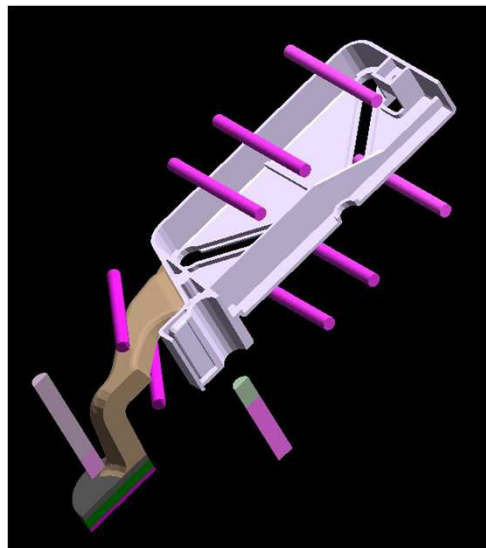
The medium temperature increasing depends on:

- velocity of the medium in the channel
- length of the channel

Example



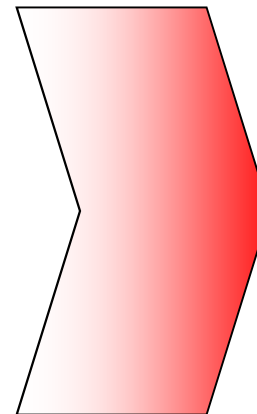
Example



Magnesium alloy
AM60B:
5.6% - 6.4% Al
0.26% - 0.25% Mn

T liquidus = 619 °C
T solidus = 433 °C
T initial = 680 °C

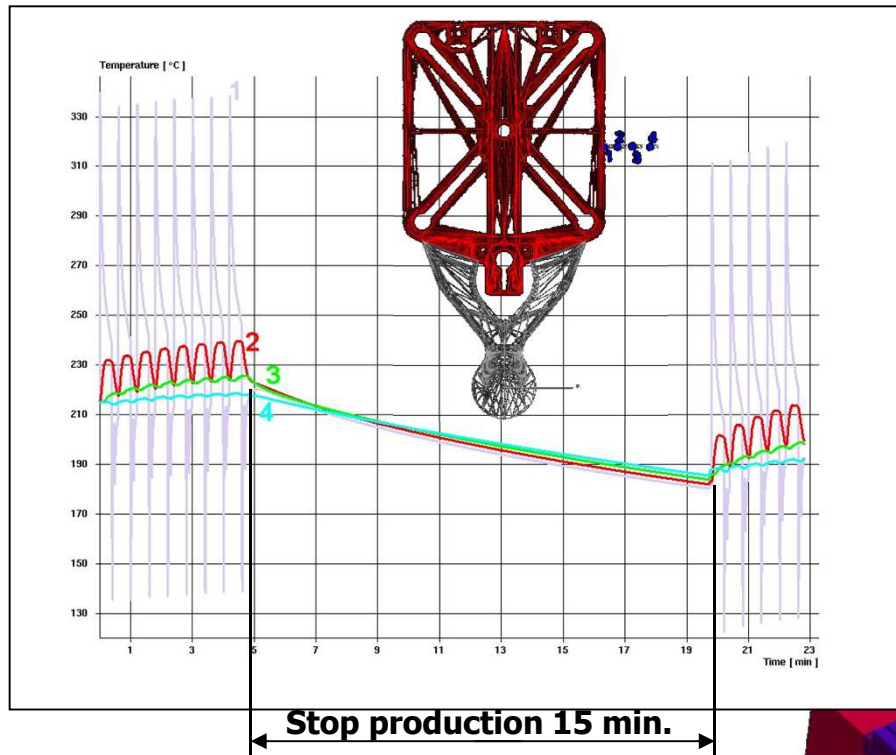
Action	Time
Filling	0.6 s
Overpressure	6 s
Dies open	18 s
Cast ejection	20 s
Start Lubrication	24 s
End Lubrication	25 s
Start blowing	29 s
End blowing	30 s
Mold closed	32 s
End Cycle	36 s



Closing parameter = 12 s

13 cycle simulated with a stop production between the 5° and 6° cycle

Example

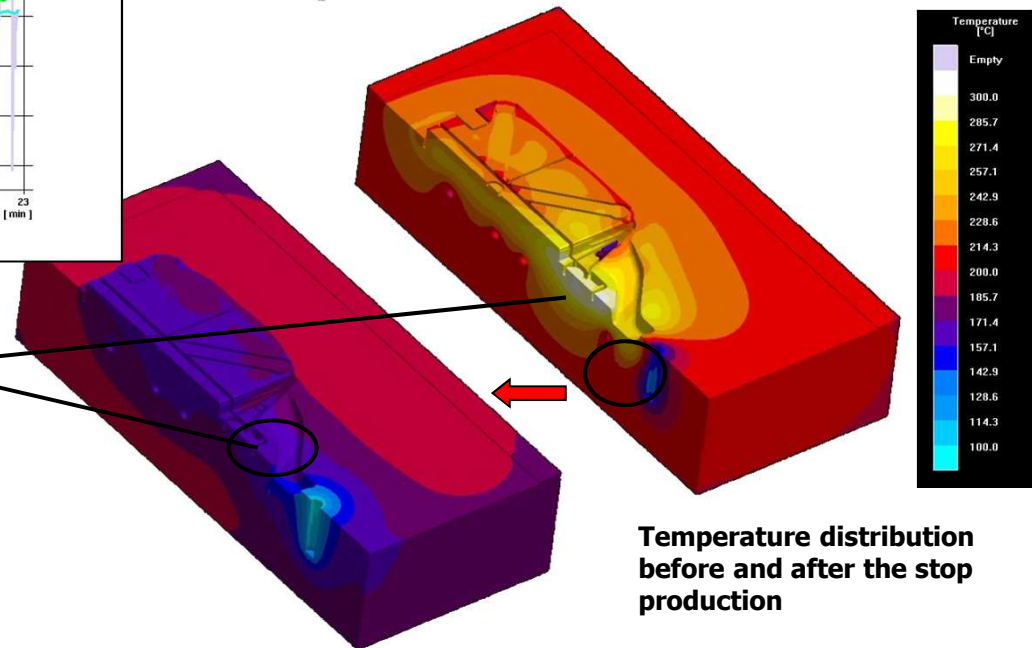


During the stop production the cooling channels are active

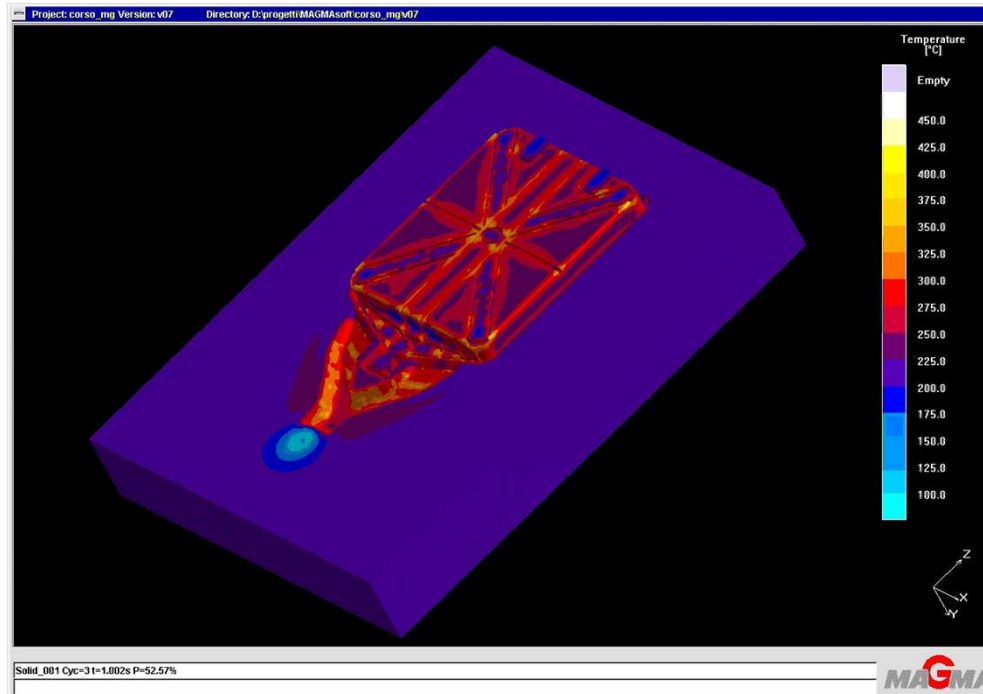


The temperature decrease depends on:
Wait time
Mold dimension
Cooling channels powerful

High $\Delta T \Rightarrow$ Die life



Example: long lubrication time

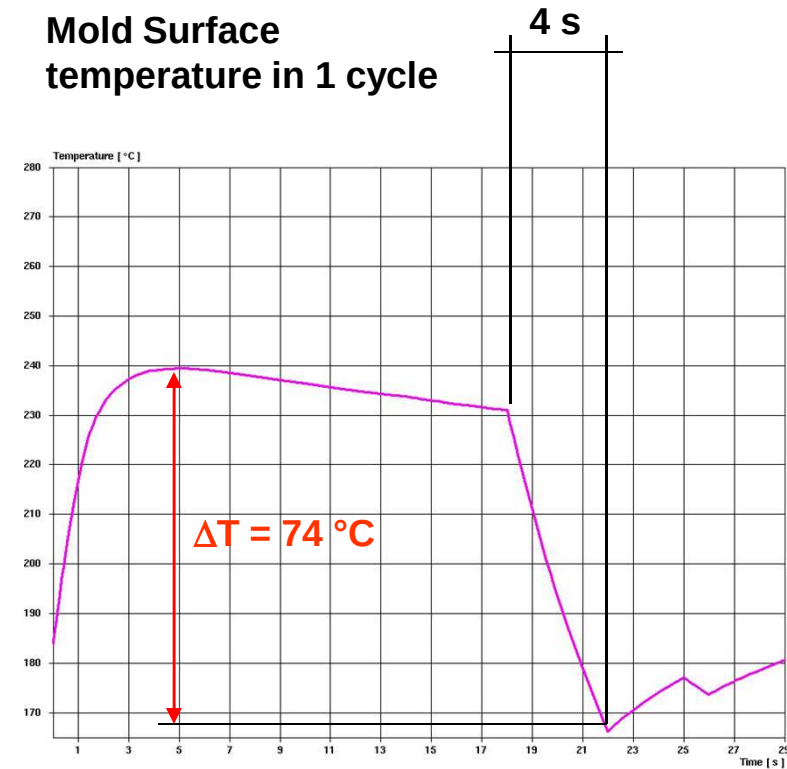


A long lubrication phase leads to a deep mold cooling

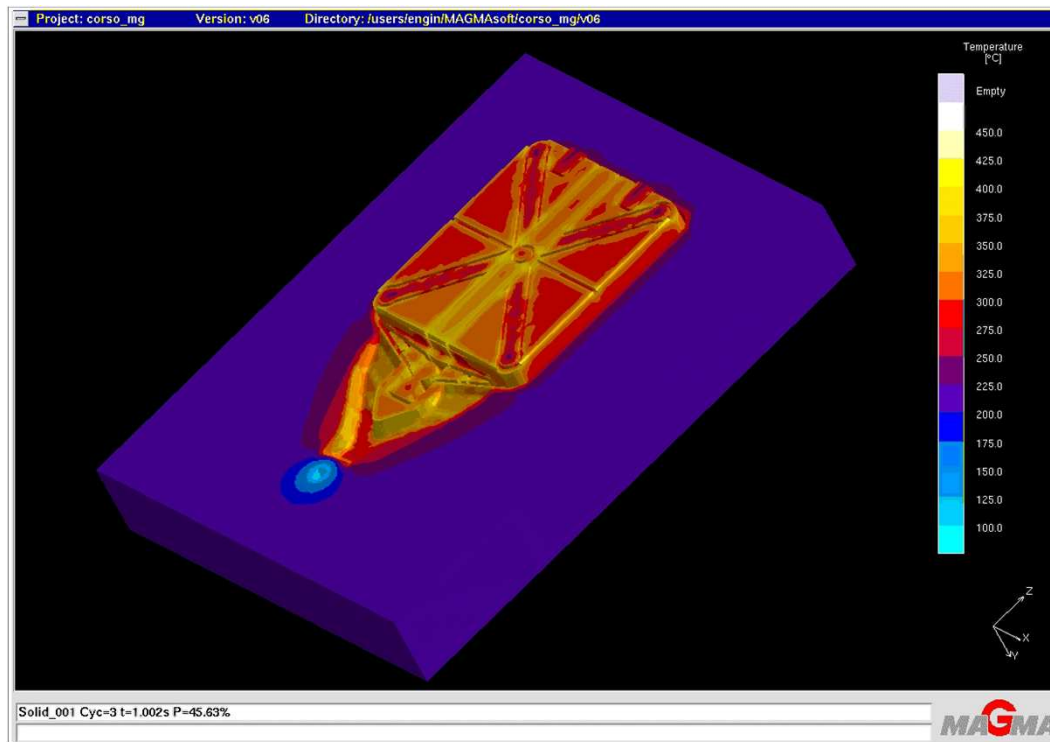


- Die life reduction
- Cold shot risk

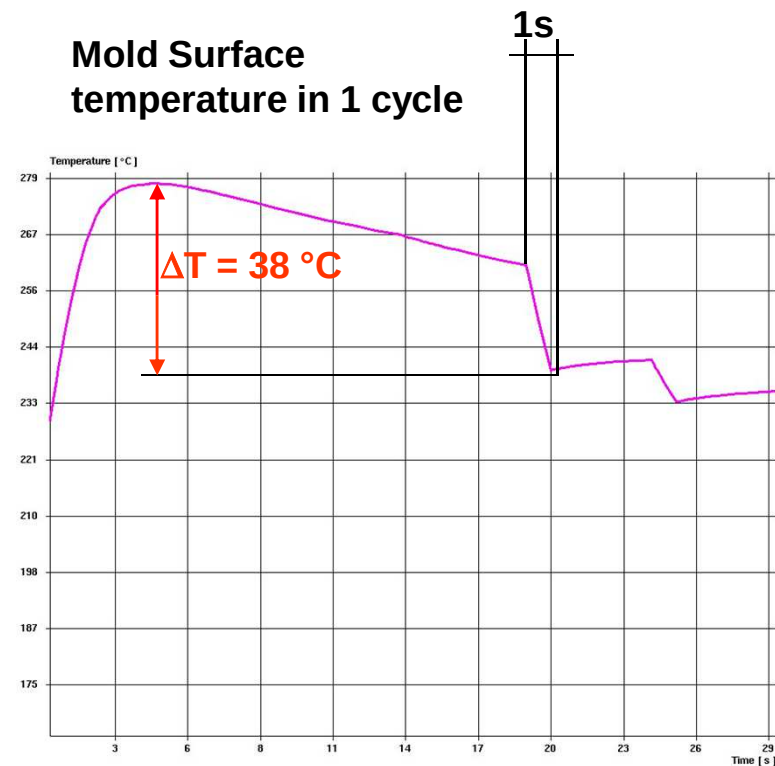
Mold Surface temperature in 1 cycle



Example: short lubrication time



The average molds temperature is greater than the previous case $\Rightarrow$ less cooling of the metal during the filling



Andamento di temperatura registrata dalla termocoppia posta nell'interfaccia getto-matrice durante un ciclo

Information on the heat balance

materials		internal	external	heat balance
cast alloy	1	2507.227	1802.904	4310.131
cooling	1	-153.338	-10.152	-163.490
cooling	2	-270.715	-21.302	-292.017
inlet	1	106.819	44.753	151.573
surrounding	1	0.000	0.000	0.000
gating	1	270.203	168.392	438.595
ingate	1	555.663	376.256	931.919
ejector die	1	-1373.948	1900.697	526.749
cover die	1	-1775.934	2465.885	689.951
biscuit	1	134.024	1.879	135.902
process		heat balance		

Material List

energy exchanged between materials

energy released into the environment

Total energy Absorbed/lost

CONTACTS

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