MAGMA

UGM -2024_Steel

A case study on Steel and stress module

Investigating the Impact of Convection and Segregation on Stresses During Casting and Heat Treatment

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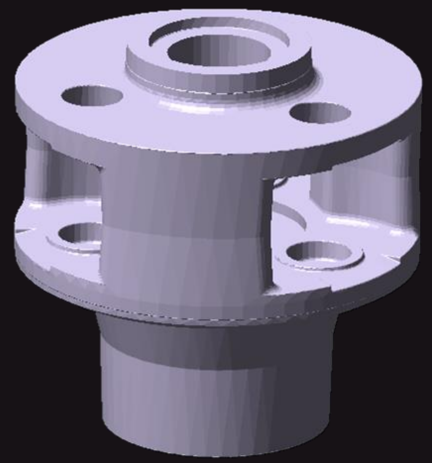


Case study of Planet Carrier

Simulations carried out with Steel and stress module

Modes of Heat Transfer

- **Conduction**: Conduction is the transfer of heat through a material without the movement of the material itself. It happens at the molecular or atomic level when fast-moving particles (molecules or atoms) collide with slower ones, transferring kinetic energy.

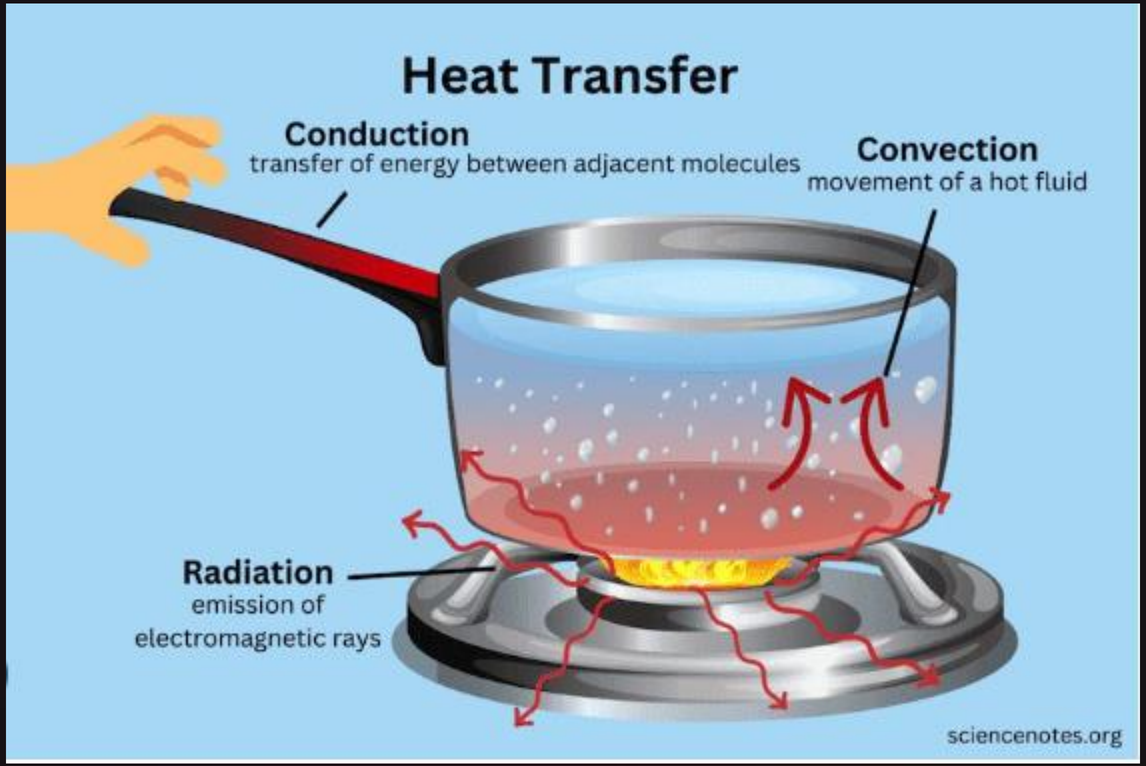
$$Q = \frac{kA(T_1 - T_2)}{d}$$

- **Convection**: Convection is the transfer of heat through a fluid (liquid or gas) due to the movement of the fluid itself.

$$Q = hA(T_s - T_\infty)$$

- **Radiation**: Radiation is the transfer of heat through electromagnetic waves (infrared radiation), and it does not require a medium (can occur in a vacuum). All objects emit radiation based on their temperature.

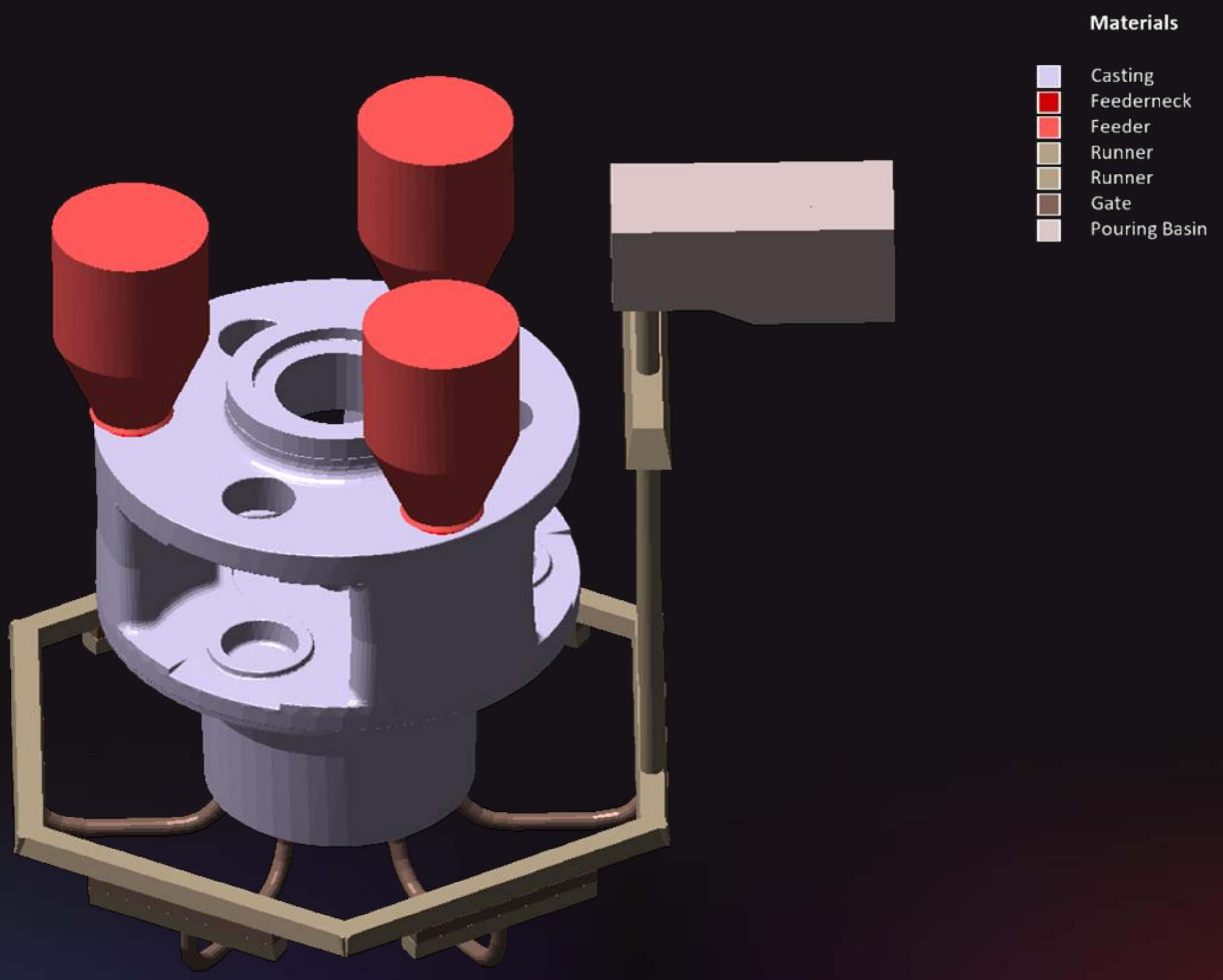
$$Q = \sigma \epsilon A(T^4 - T^4_{\text{surrounding}})$$



Convection in casting process

- During casting solidification, the large temperature differences in the melt cause the liquid density to also vary widely throughout the casting.
- Due to the action of gravity movement of metal happens.
- Movement of metal modifies the temperature field.
- This fluid flow, caused by density variations due to temperature differences, is called thermal convection. The current created by this movement is convective currents.
- As the casting solidifies, the thermal convection flow also interacts with the solidifying structure. At the tips of the solidifying dendrites where the solid fraction is low, the solid provides little resistance to the flow, i.e., the solid is still highly permeable an vise-a vise

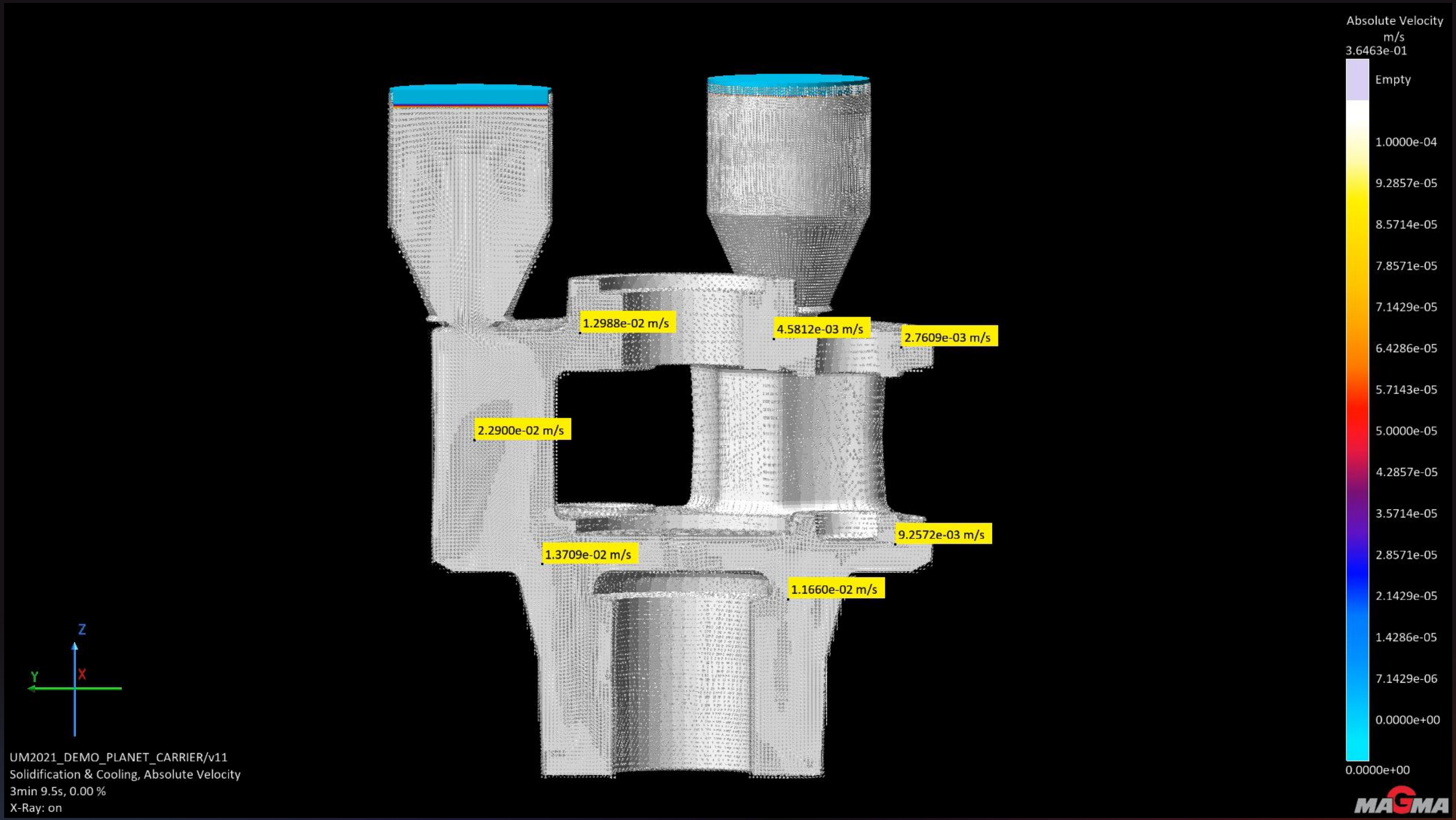
Method taken for experimentation



Inputs for simulation

- Material: GS30Mn5
- Initial Temperature: 1640ºC
- Core Sand: Furan
- Moulding Sand: Furan
- Sleeve: MAGMA Sleeve
- Chills: Steel

Convection result(Absolute velocity)



The MAGMA APPROACH(Think ahead to your targets)

SET UP YOUR OBJECTIVES

Describe the **current situation** - what are issues to resolve? (status, requirements)
What are the **expected/desired outcomes and benefits**? (optimum, robustness, knowledge)

DEFINE YOUR VARIABLES

What are the **relevant variables** (options, flexibility) that need to be changed or analyzed?
What are the **important constraints** (limitations, restrictions) that have to be considered?

SPECIFIY YOUR CRITERIA

Identify the **measurable quality criteria and their locations** (evaluation areas)?
Which quality criteria can (or have to) be combined and assessed quantitatively?

KEEP THE TASK EFFICIENT

Structure and **simplify** the complexity of your task!
Think about how to simplify the model, split into smaller tasks, reduce the number of influencing parameters, focus on a restricted number of variables.

CHOOSE YOUR METHOD

Which MAGMASOFT® **optimization tools are** most appropriate and effective to reach your objective?
Apply single simulations, Design of Experiments (DoE), autonomous optimization or a reasonable combination.

ACT & CHECK IMPROVEMENTS

Decide upon suitable **visualization tools** (clear, understandable) to **assess** and **communicate** the results!
Discuss and **decide** for actions and **measures** – who is important in that team?
Follow and track the **improvements**!

Defining the objective

- Understanding the effect convection in casting process and heat treatment.

Define your variable

- Simulation with and without convection and segregation

Specify your criterion

- Solidification results
- Stress results
- Mechanical properties (Heat Treatment)

Keep the task efficient

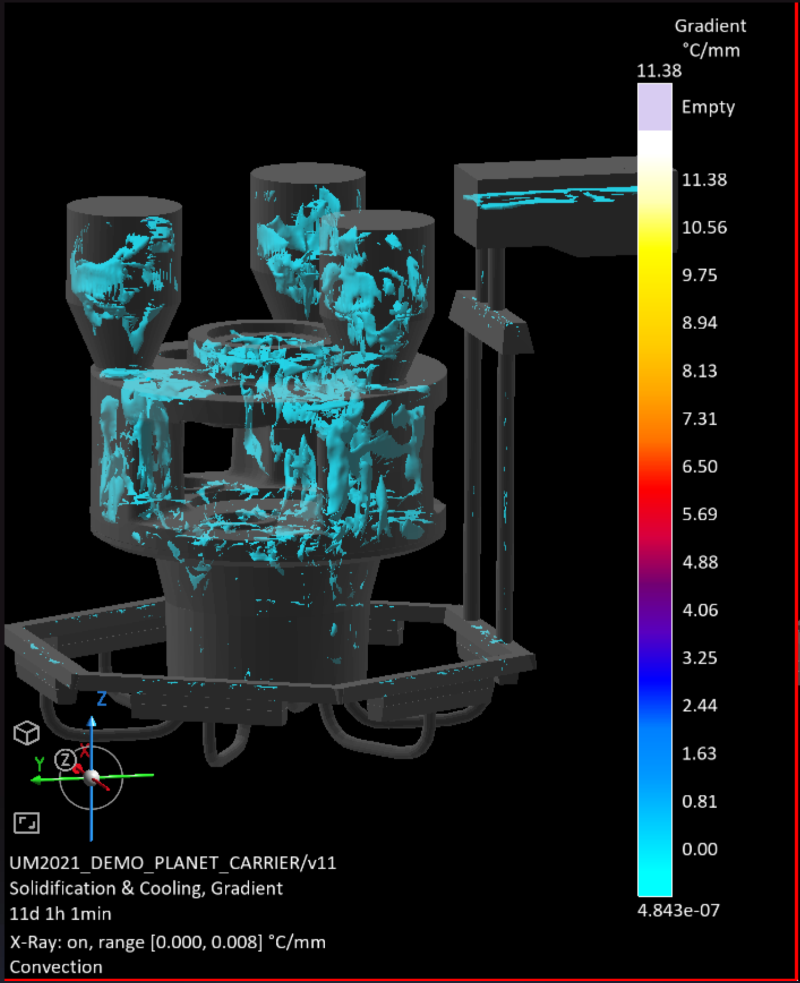
- Reduced mesh and higher core systems

Choose you method

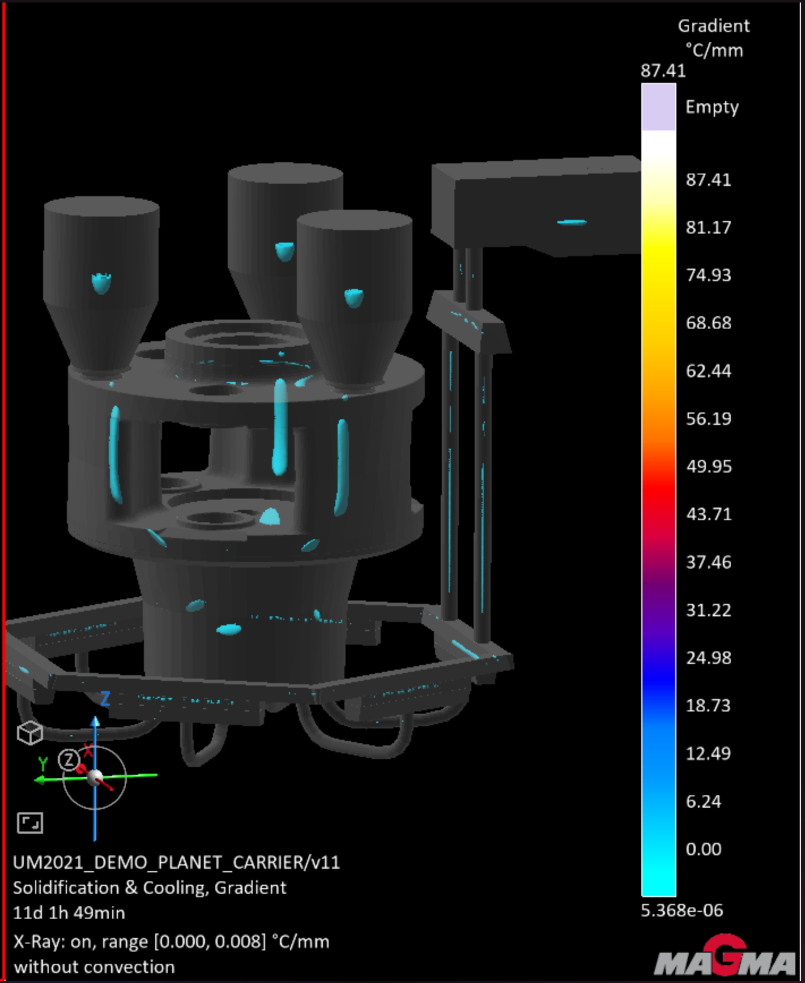
- Two separate single simulations

Act & check improvements(Solidification results)

Gradient result



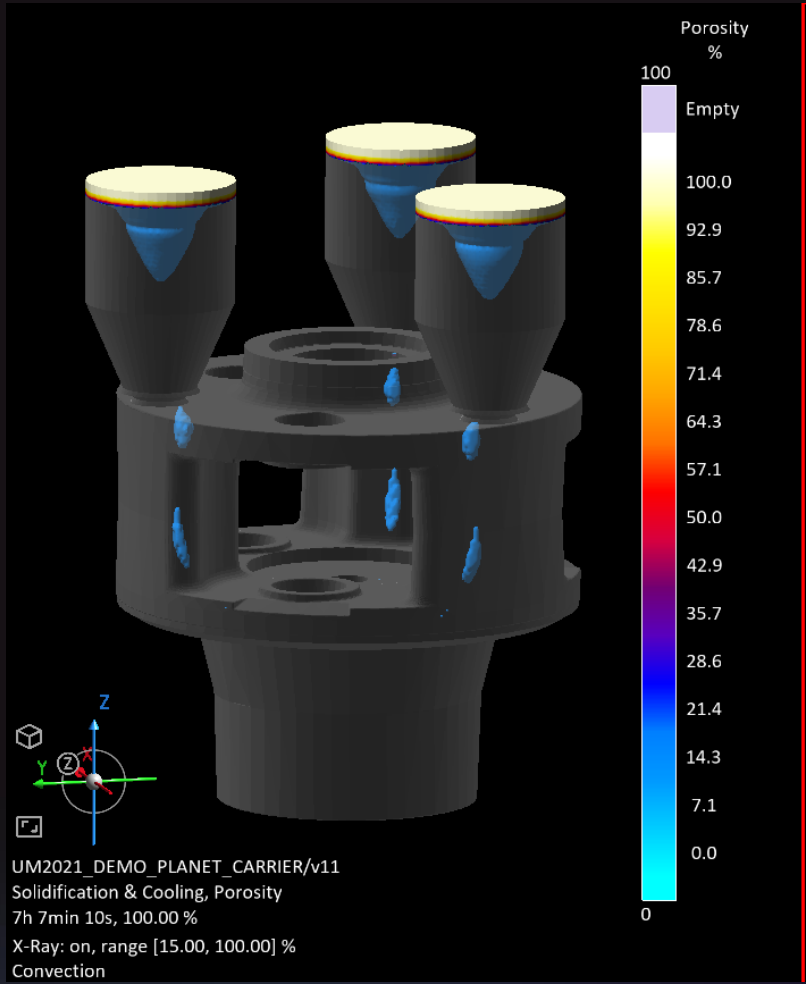
Convection

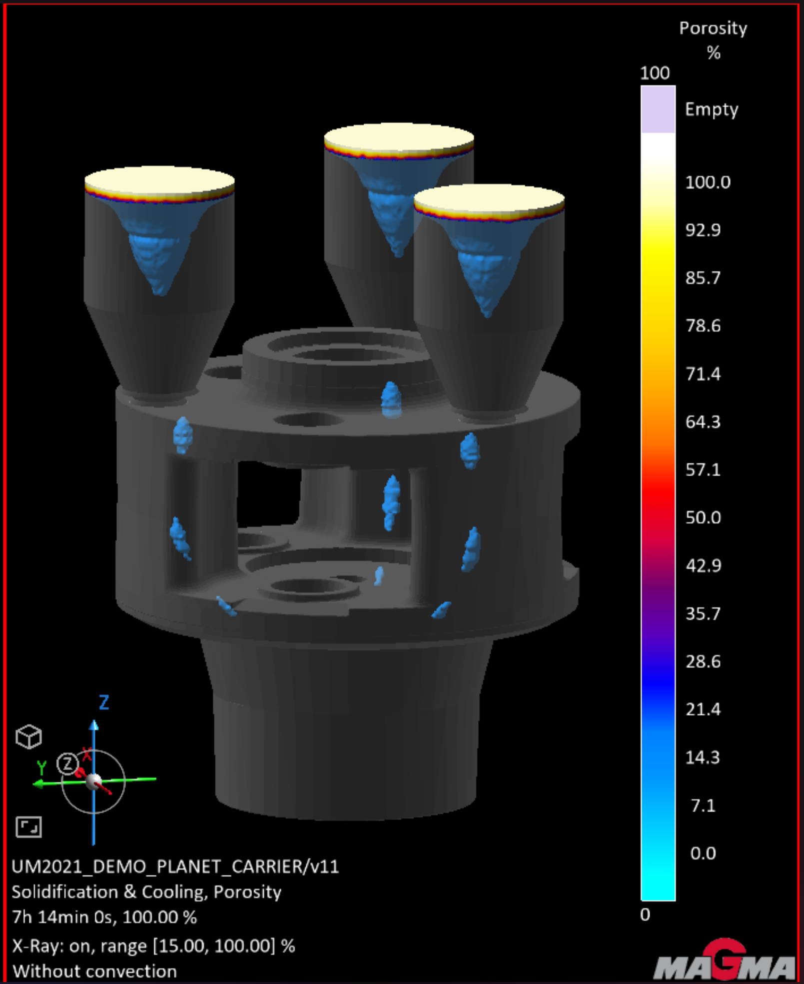


Without Convection

The gradient results show a significant difference when the simulation is carried out with convection. The convective currents cause changes in the temperature profile, resulting in a substantial variation.

Porosity



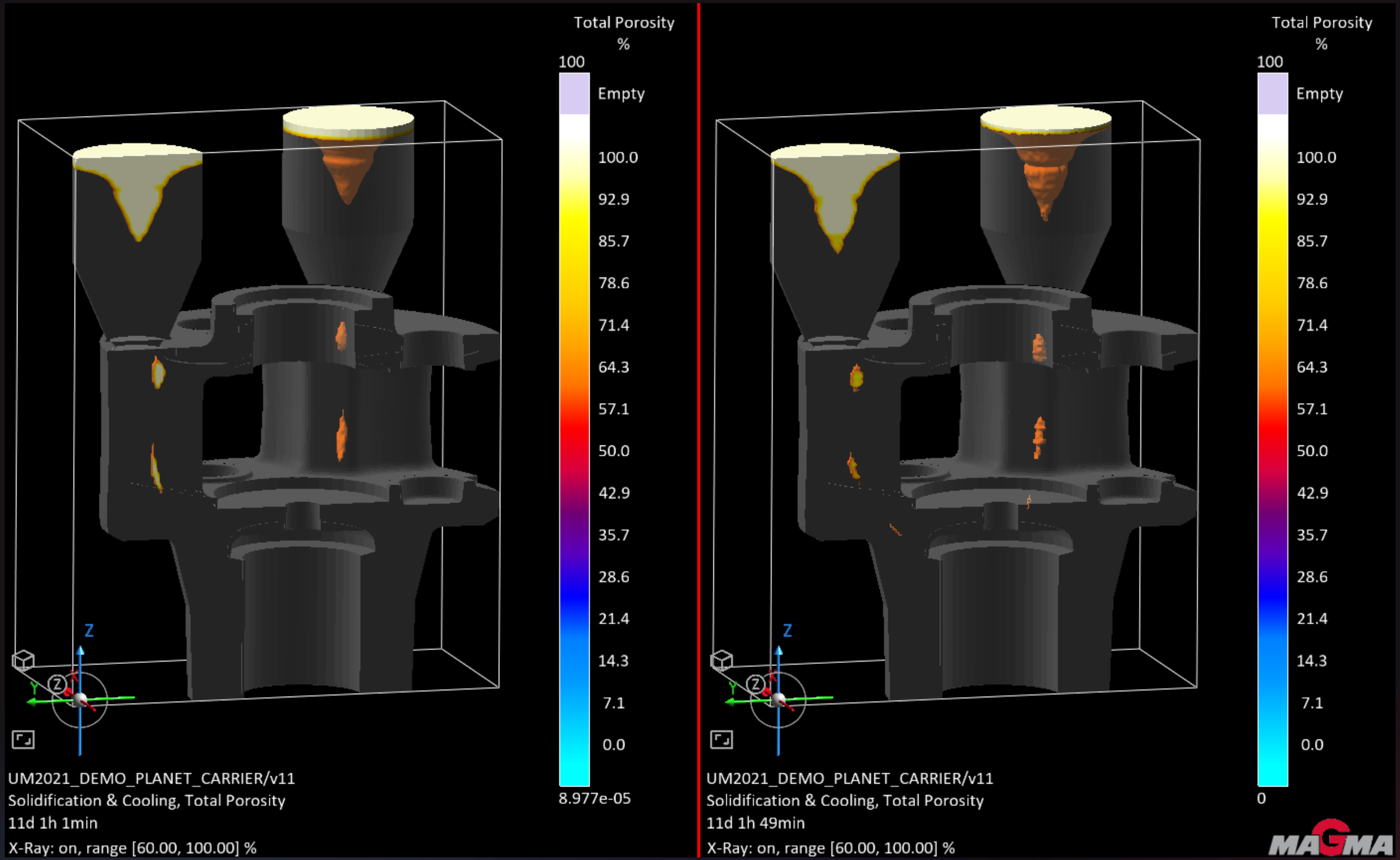


Convection

Without Convection

It was observed that in the simulation with convection, the porosity distribution differed compared to the simulation without the convection option.

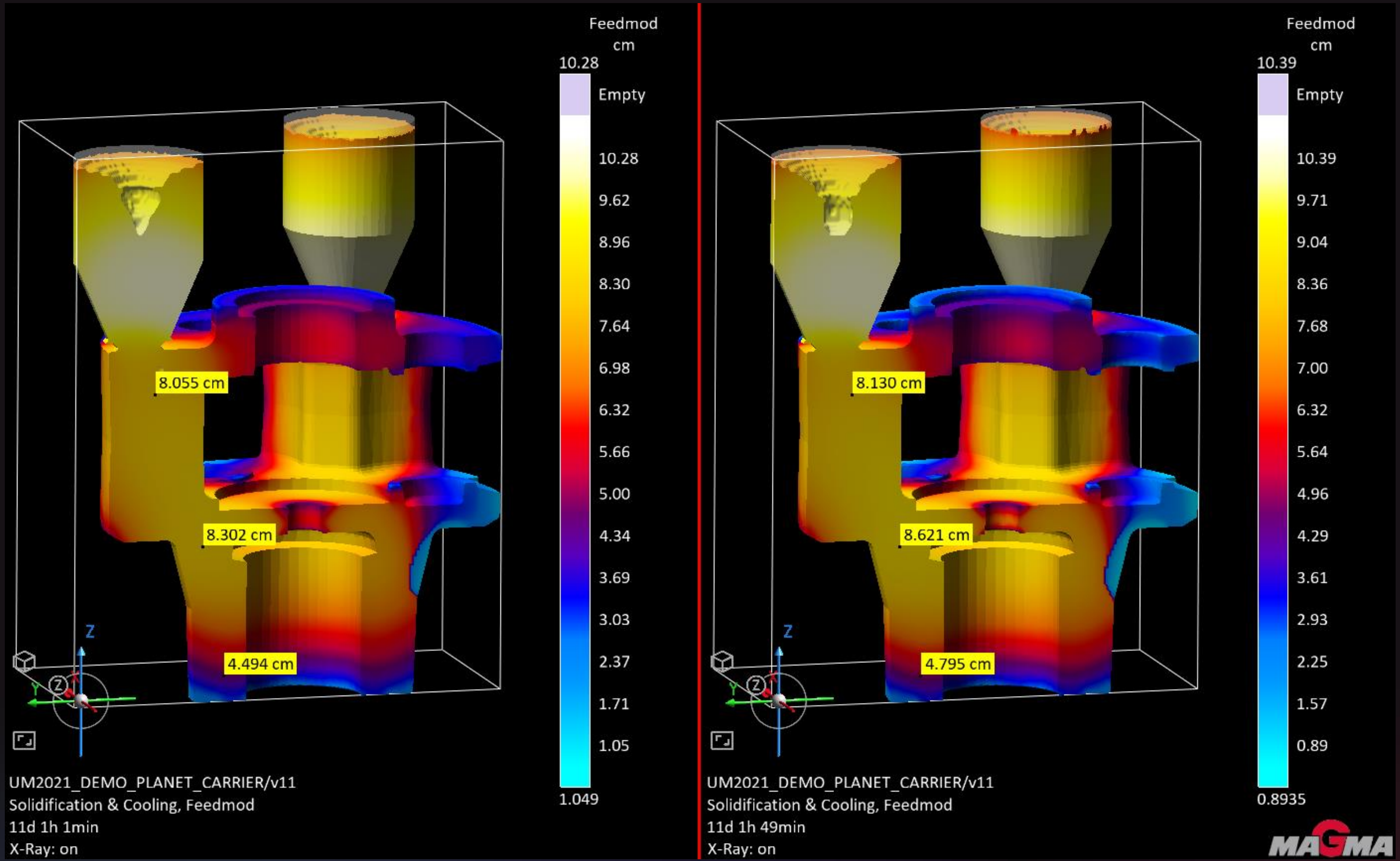
Porosity



Convection

Without Convection

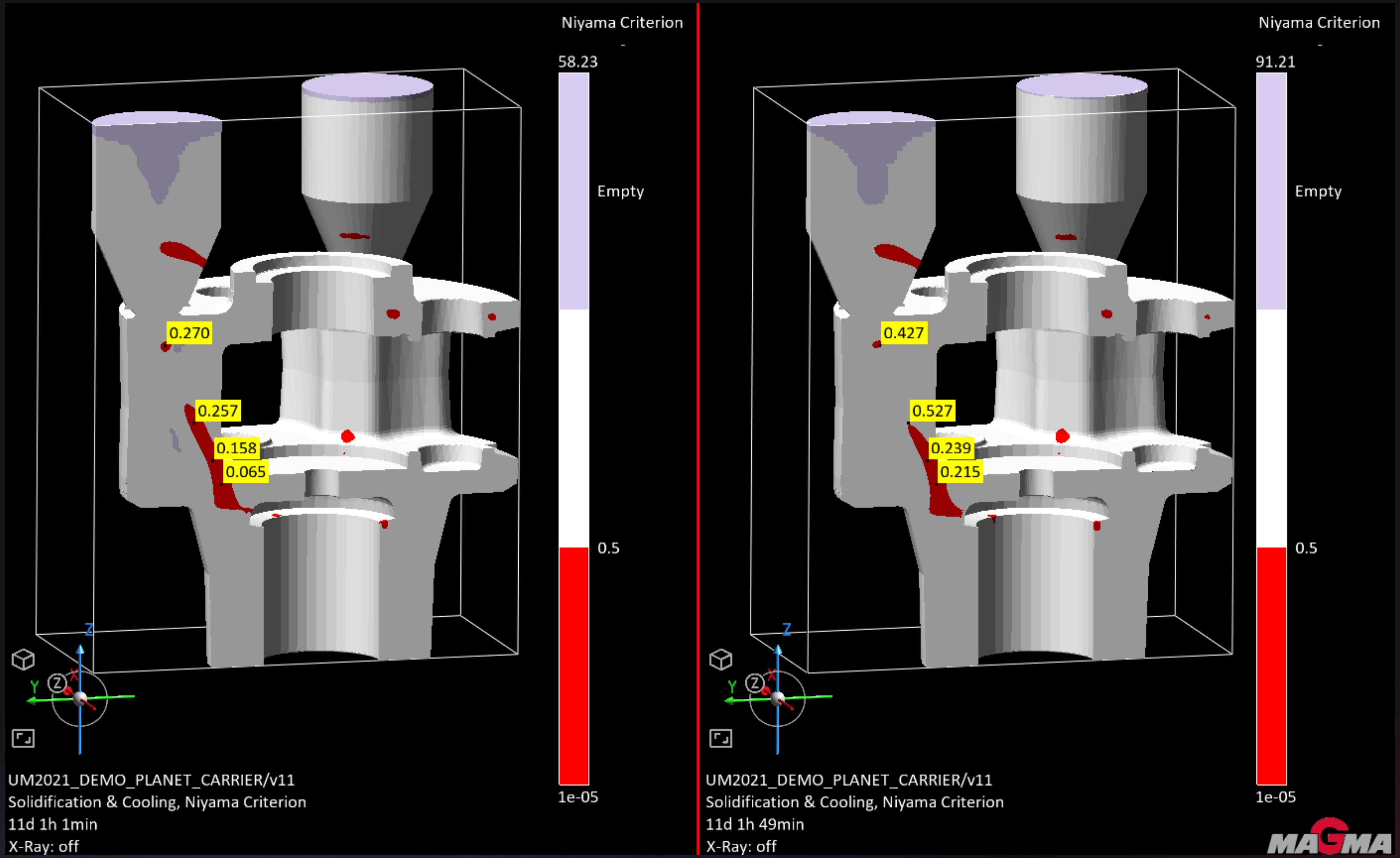
Feed mod



Convection Without Convection

The convection also changes the feedmod values which helps us in calculating the feeding aid requirements closer to realistic values such as feeder sizes , chills locations etc.

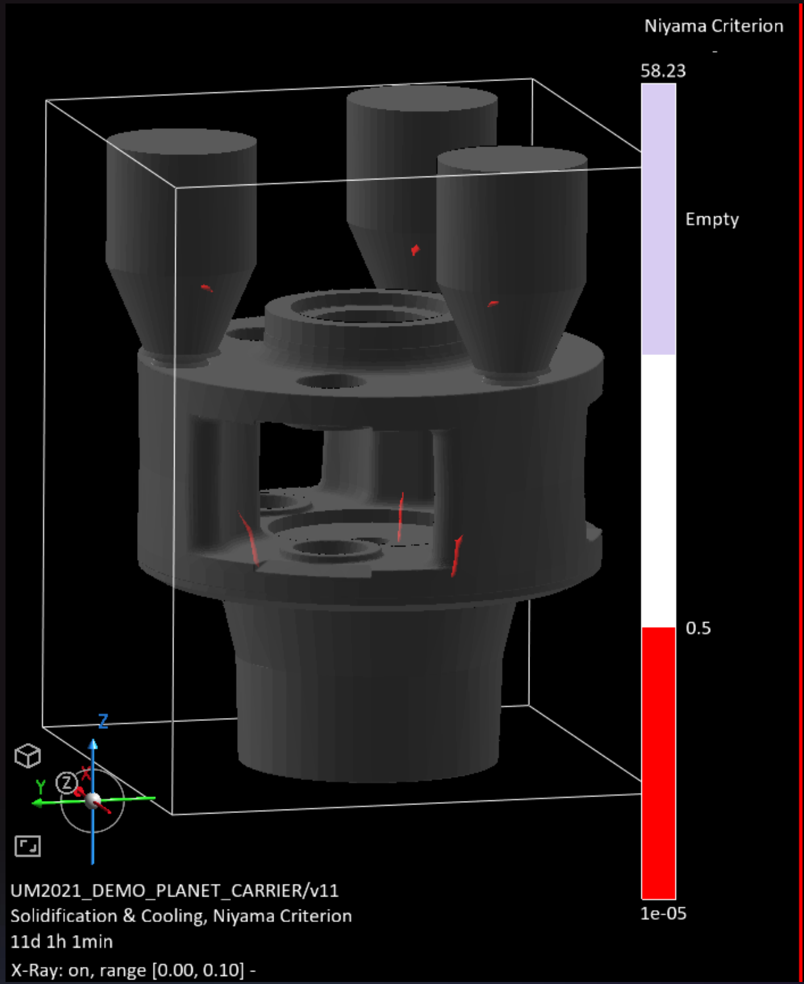
Niyama



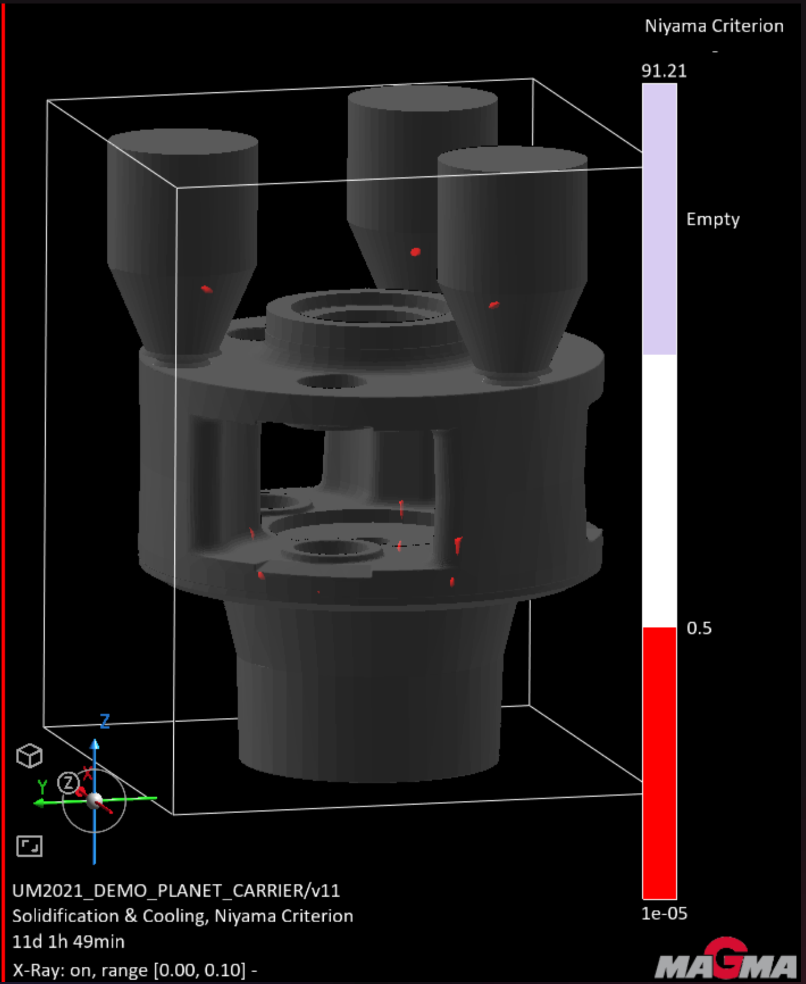
Convection Without Convection

It was observed that the Niyama criterion values varied. Therefore, the convection mode of heat transfer can also influence the evaluation criterion for the Niyama results. The Niyama values decrease when the simulation is performed with convection.

Niyama(X-ray)



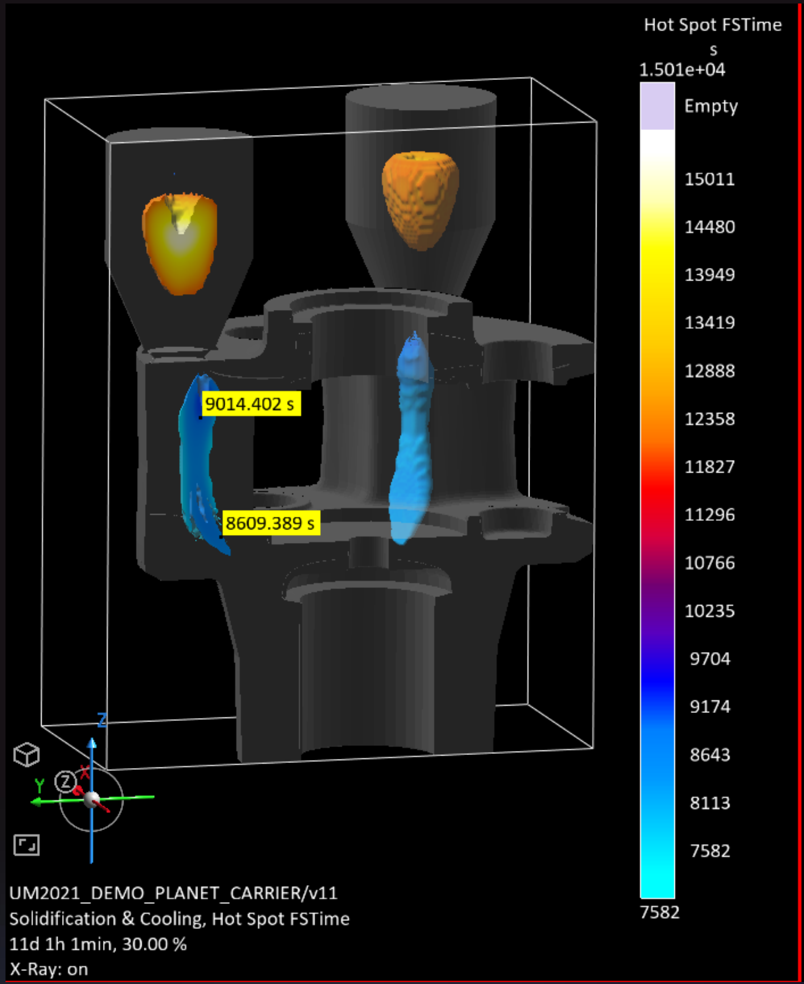
Convection



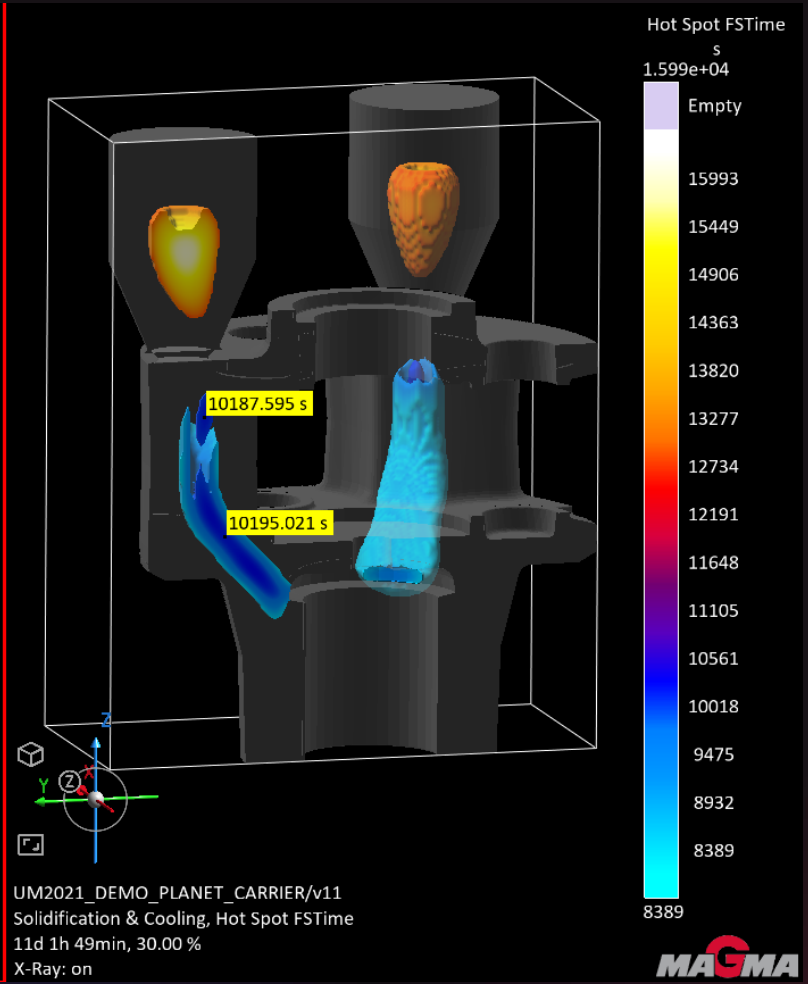
Without Convection

This results shows the clear indication of the niyama value distribution. Here the values are having lower values with convection even with X-ray (0 to 0.1). The probability of defect occurrence increases with the niyama values approaching 0.

Hotspot FStime



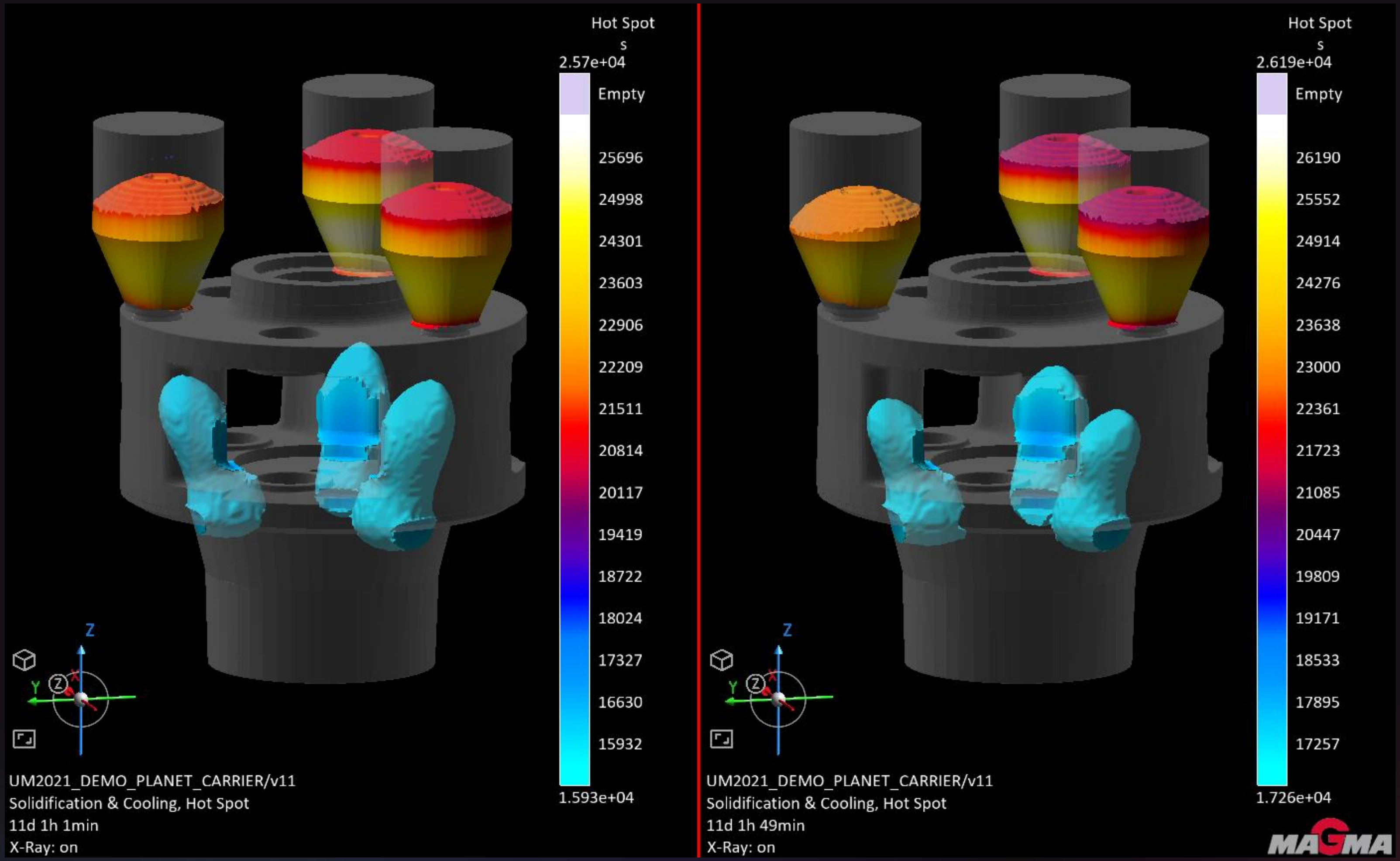
Convection



Without Convection

The hotspot FSTime value decreases when the simulation is conducted with convection. In the current case, the difference is not significant, but if critical profiles are present, this difference may increase, potentially leading to major defects that may not be accurately indicated in simulations conducted without convection.

Hotspot

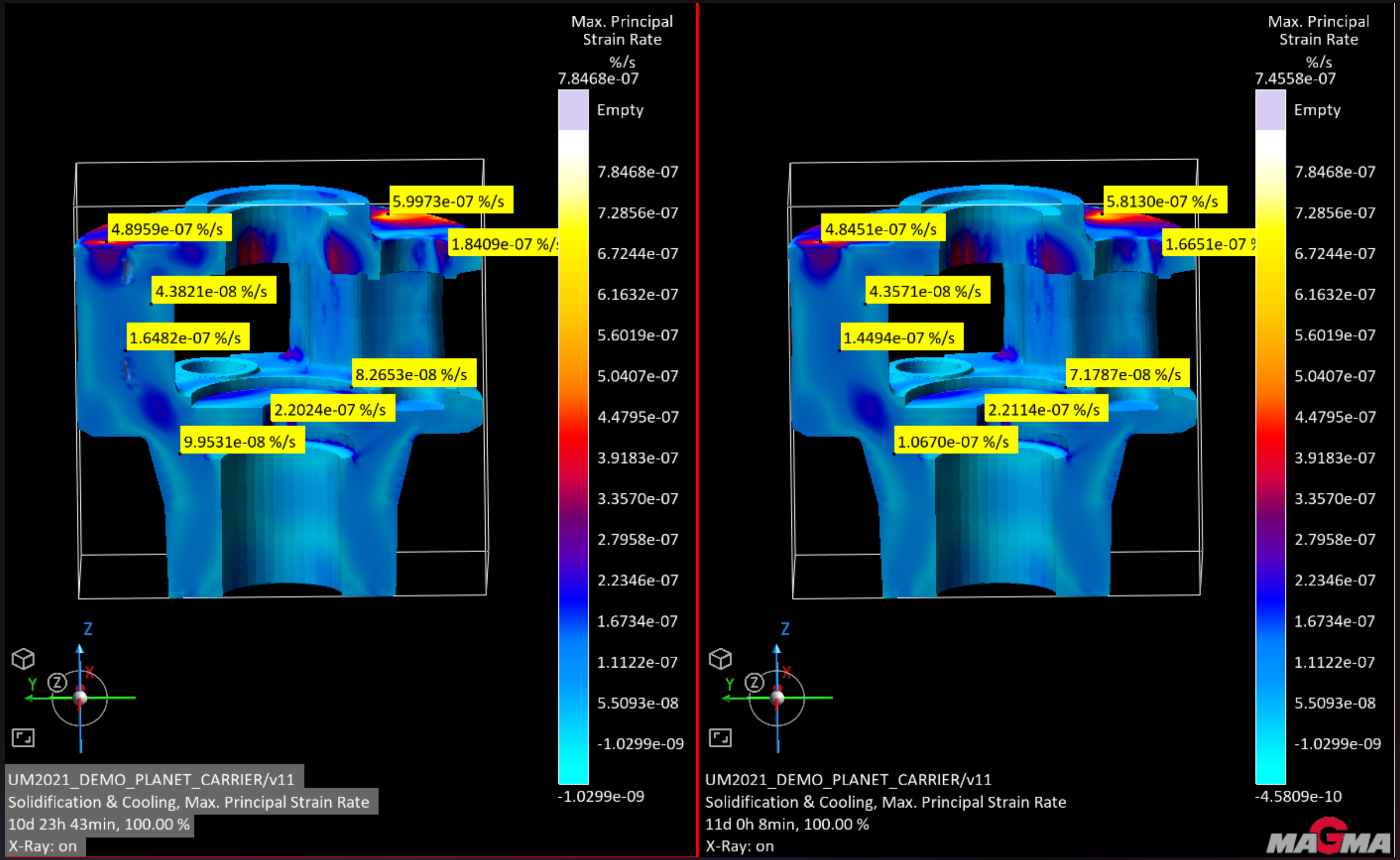


Convection

Without Convection

Act & check improvements(Stress results)

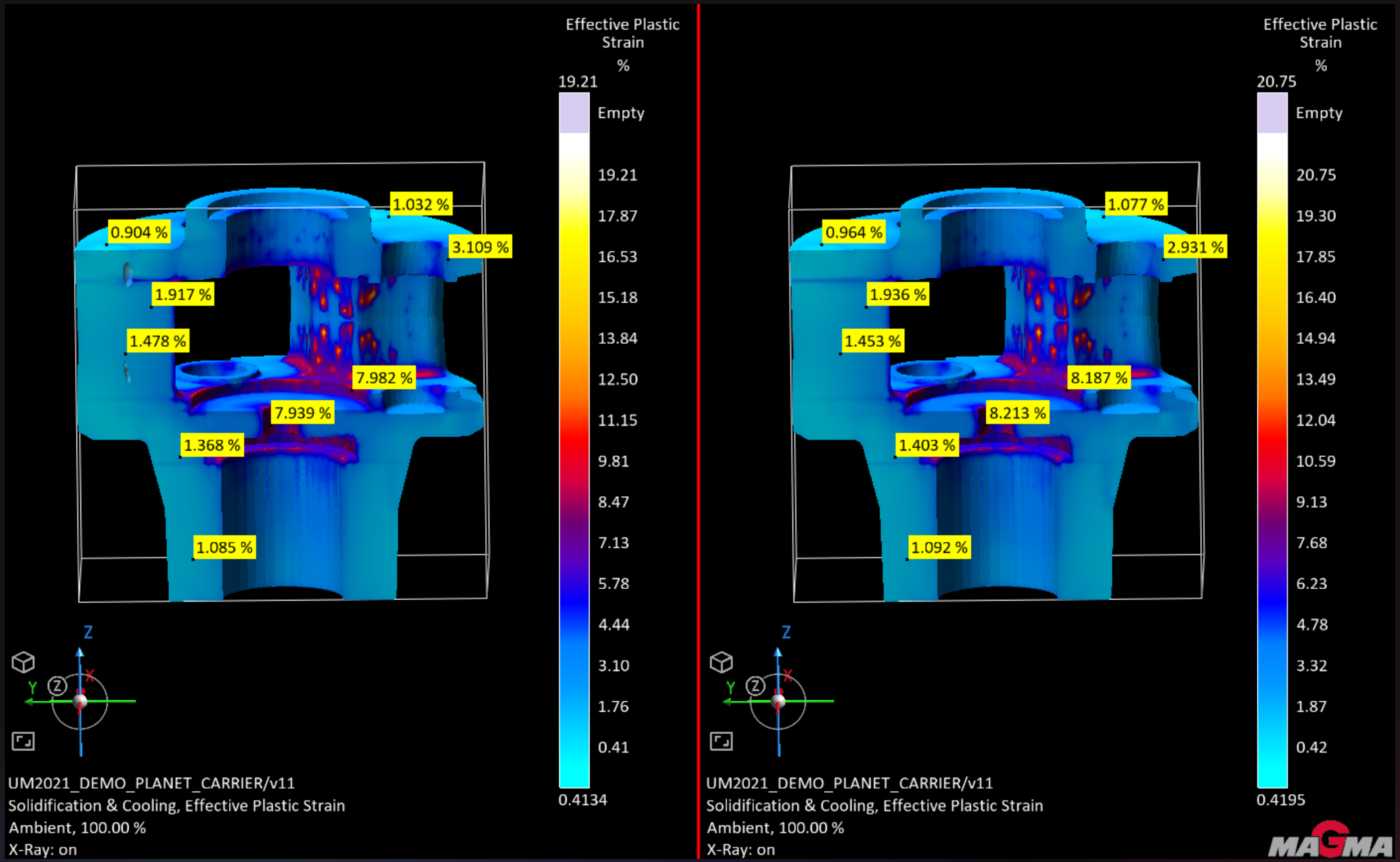
Mechanical strain rate



Convection   Without Convection

The maximum principal strain rates differ when the simulation is conducted with convection. Variations in the value were observed.

Effective plastic strain

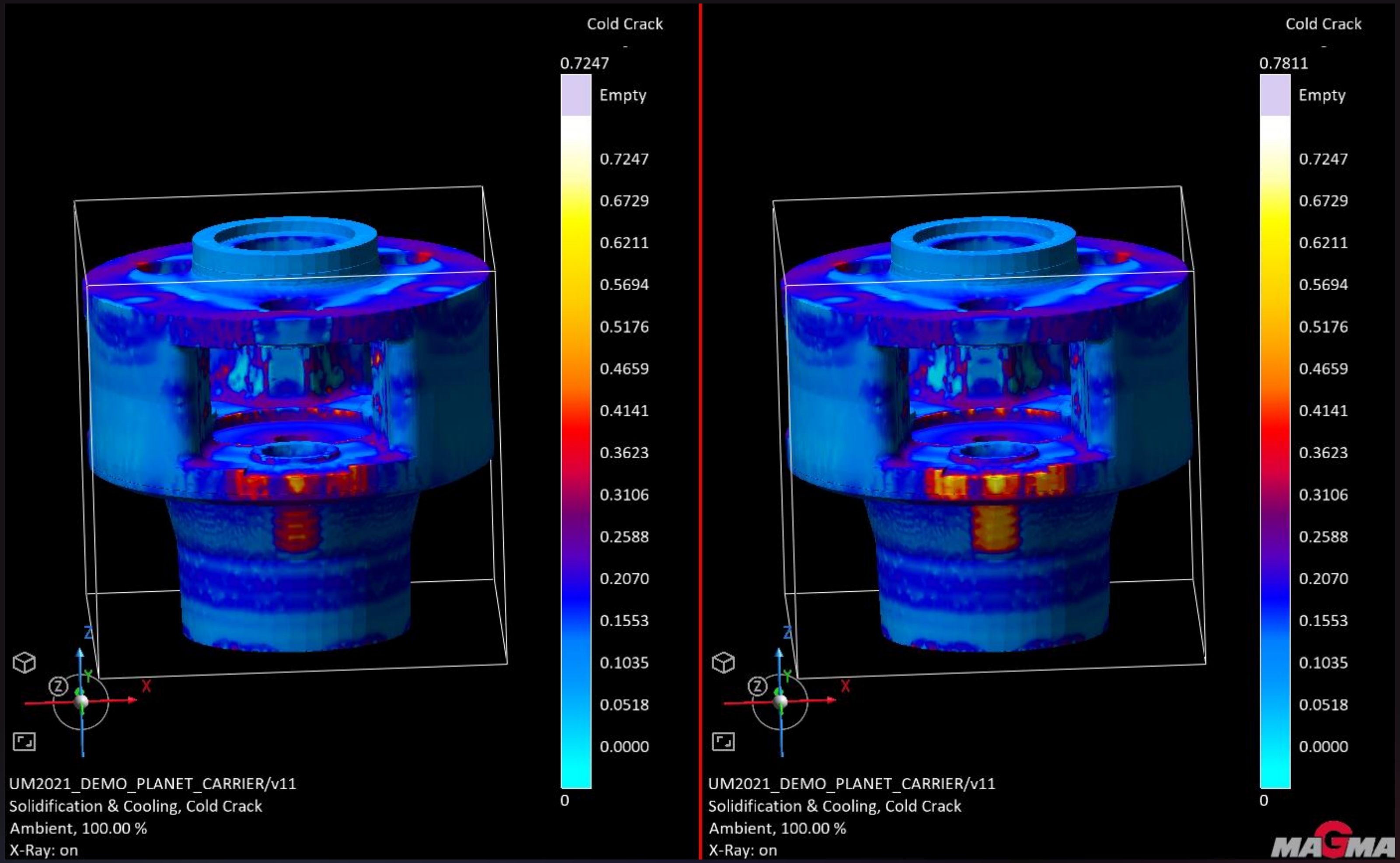


Convection

Without Convection

The effective plastic strain is used as the hardening parameter and is directly calculated from the plastic strain tensor at the end of each increment. The differences observed were minimal.

Cold crack Tendency

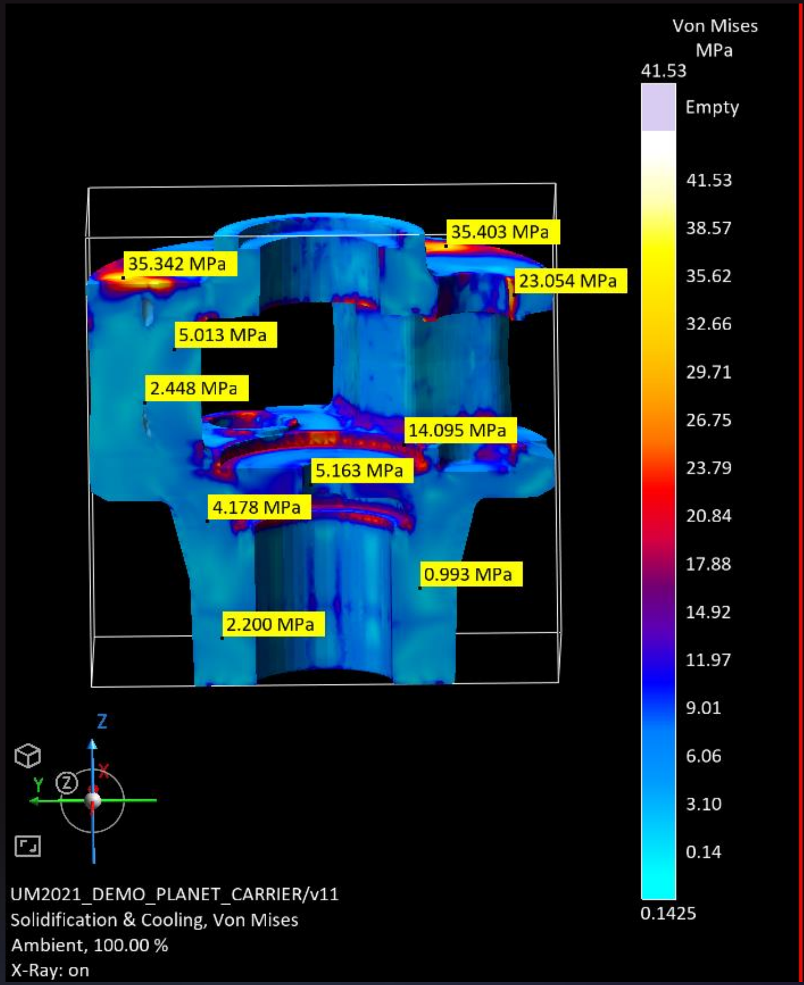


Convection

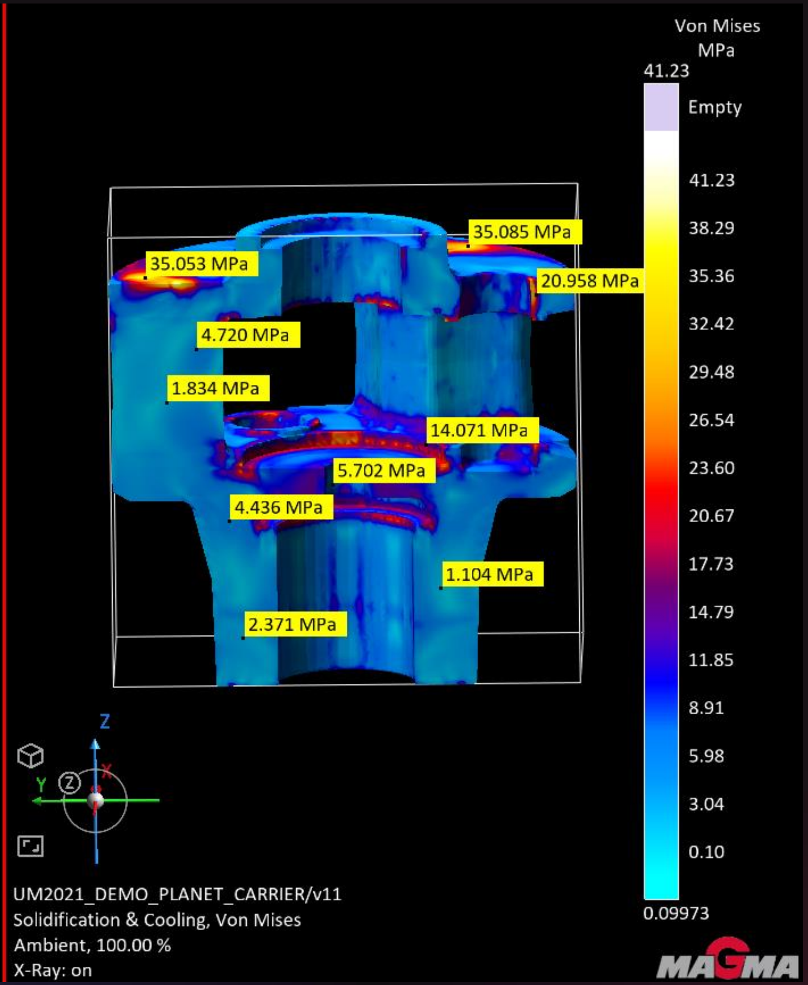
Without Convection

The final 'Cold Crack' result (at ambient temperature or after a machining step) highlights areas where a high crack tendency develops due to tensile loads during solidification and cooling of the casting.
It was observed that the cold crack values decreased, indicating a lower likelihood of cold crack occurrence. In contrast, without convection, the values were higher.

Von mises



Convection

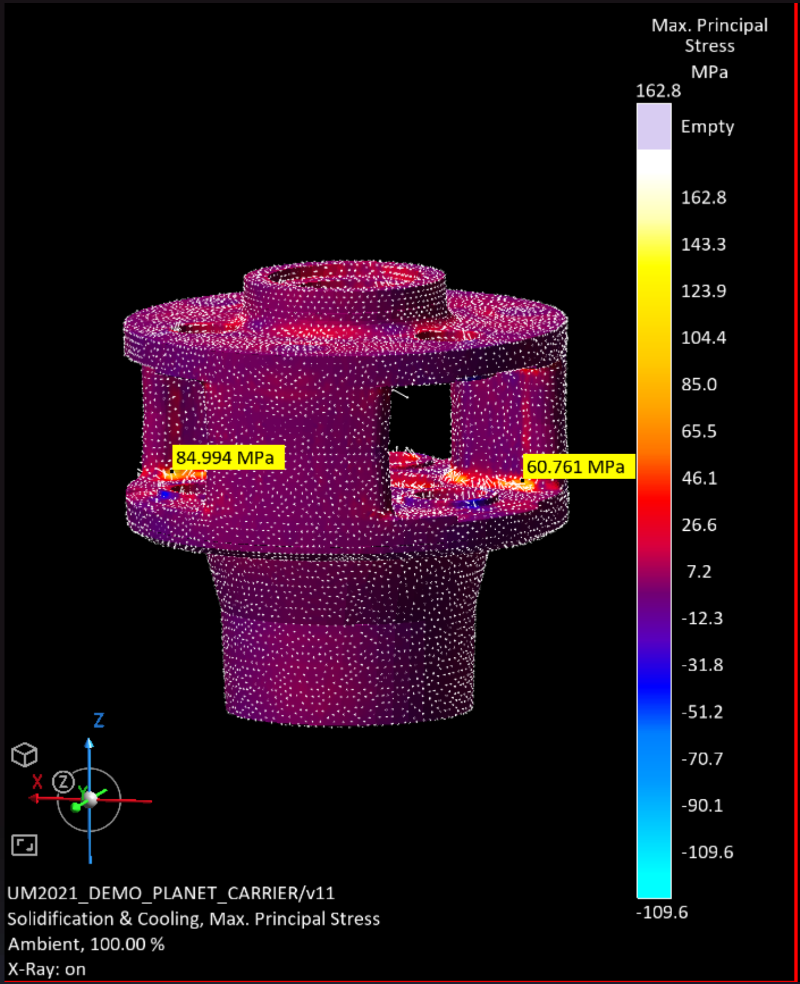


Without Convection

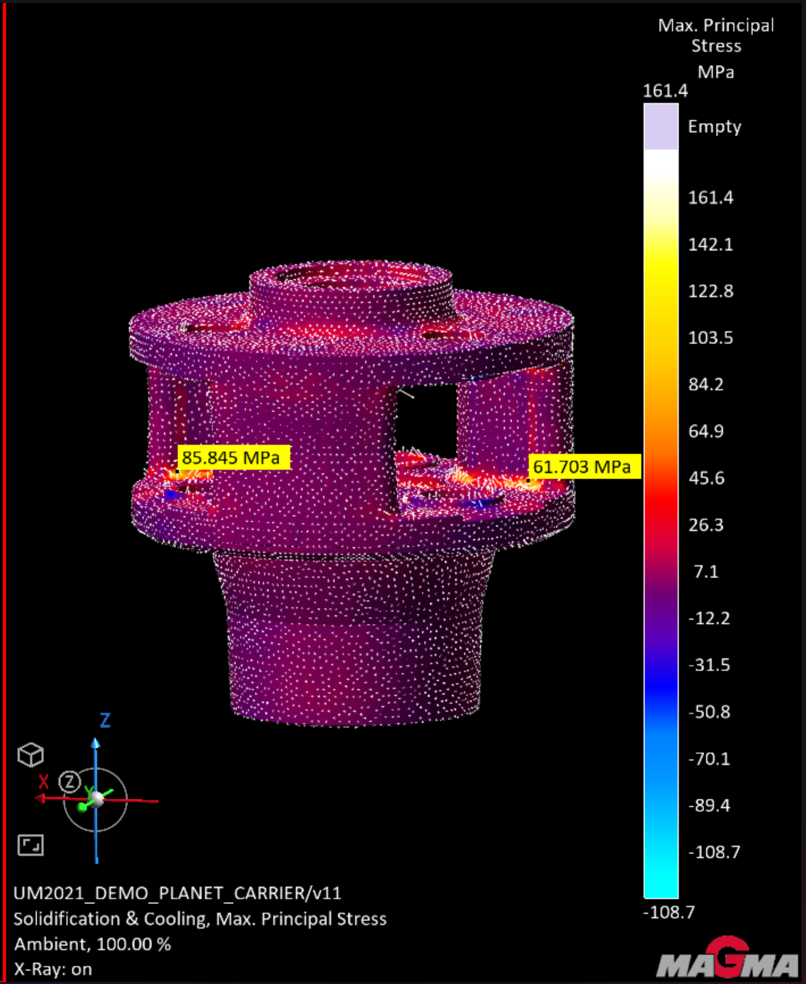
To detect the crack tendency of a casting during solidification, cooling, or subsequent machining steps, the von Mises stress can be compared to the tensile or compressive strength of the material. The stress and strain states change as a function of time during the process, while tensile strength is a temperature-dependent property.
The von Mises stress distributions vary, and with convection, these results may appear more effective.

The residual stresses can be evaluated in the same way as the crack tendency. First of all, you should have a look on the von Mises stress at ambient temperature. In a second step, you should evaluate the maximum principal stress and the minimum principal stress in order to see if the von Mises stress is based on tensile or compressive stresses. The principal stress vectors visualize the direction of the principal stresses.

Max Principles Stresses



Convection



Without Convection

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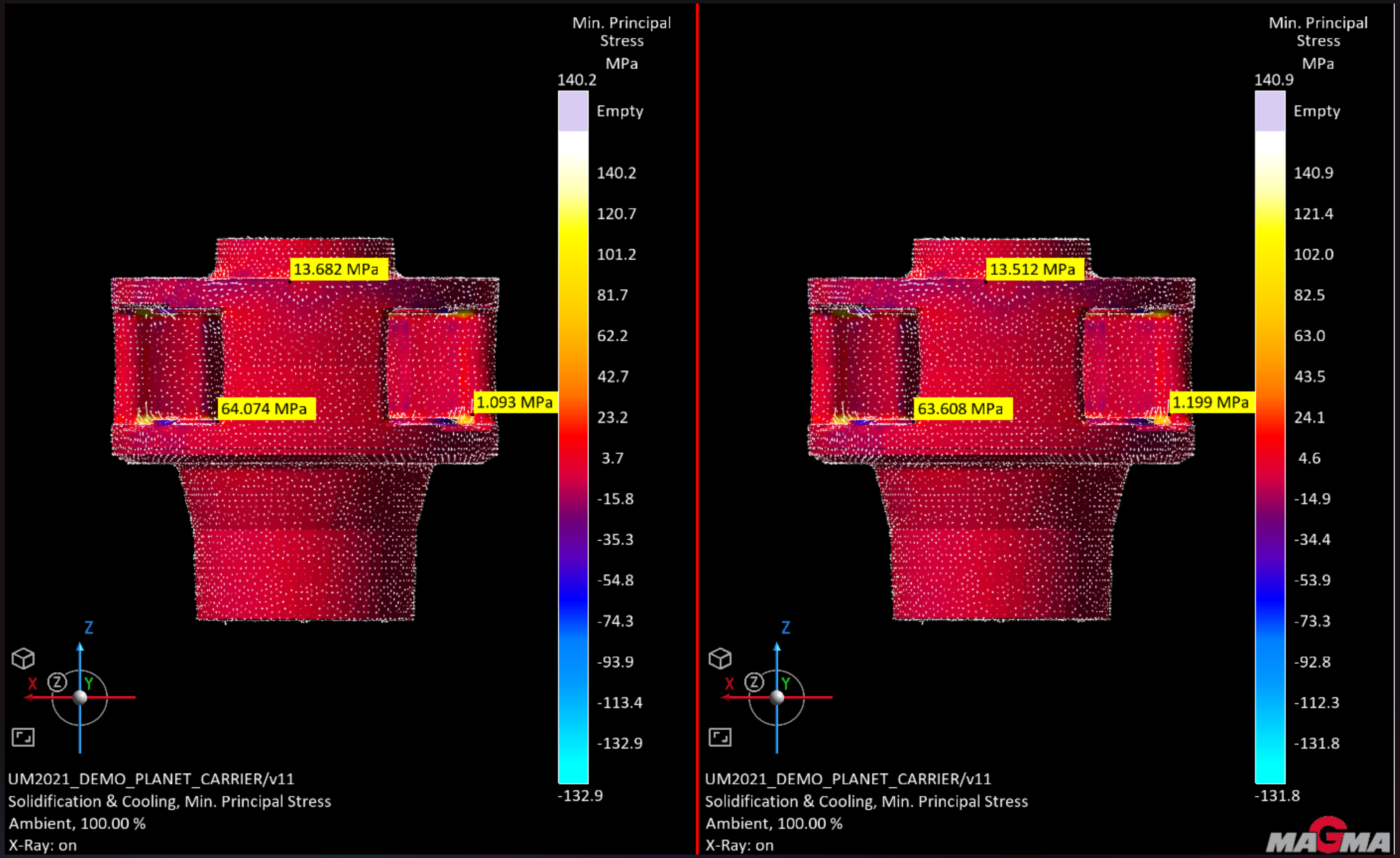
Min Principles Stresses

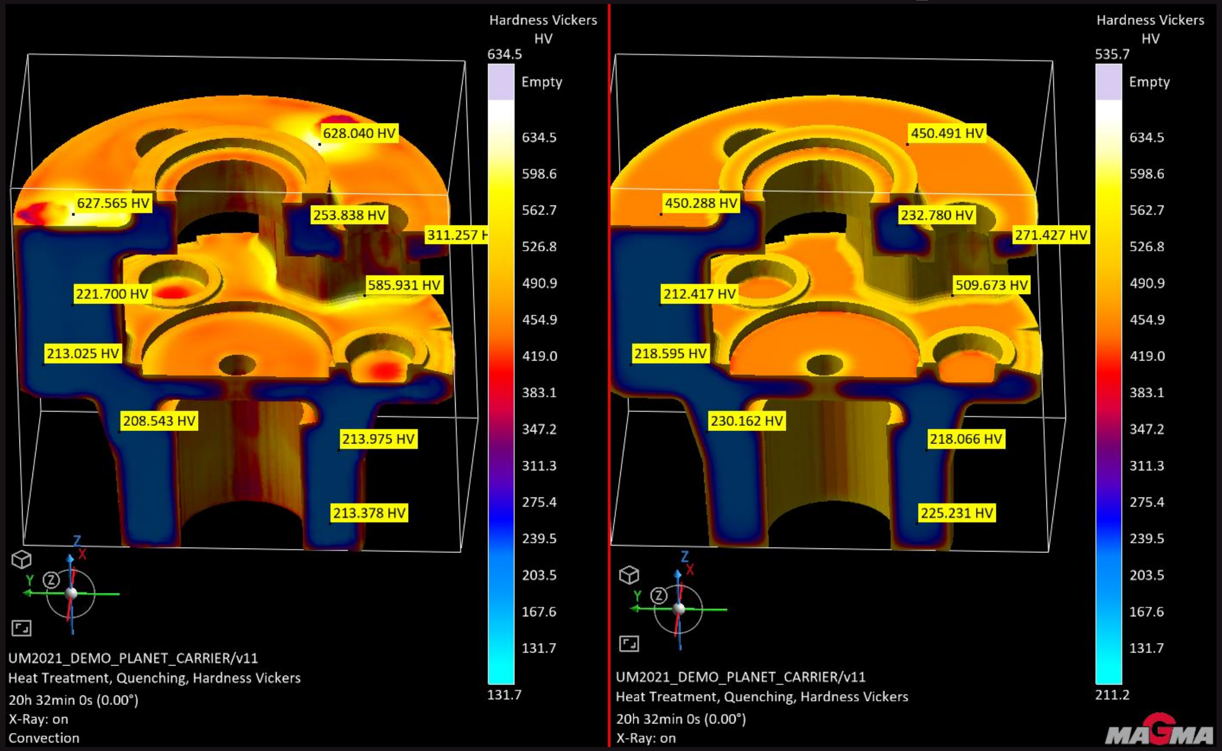


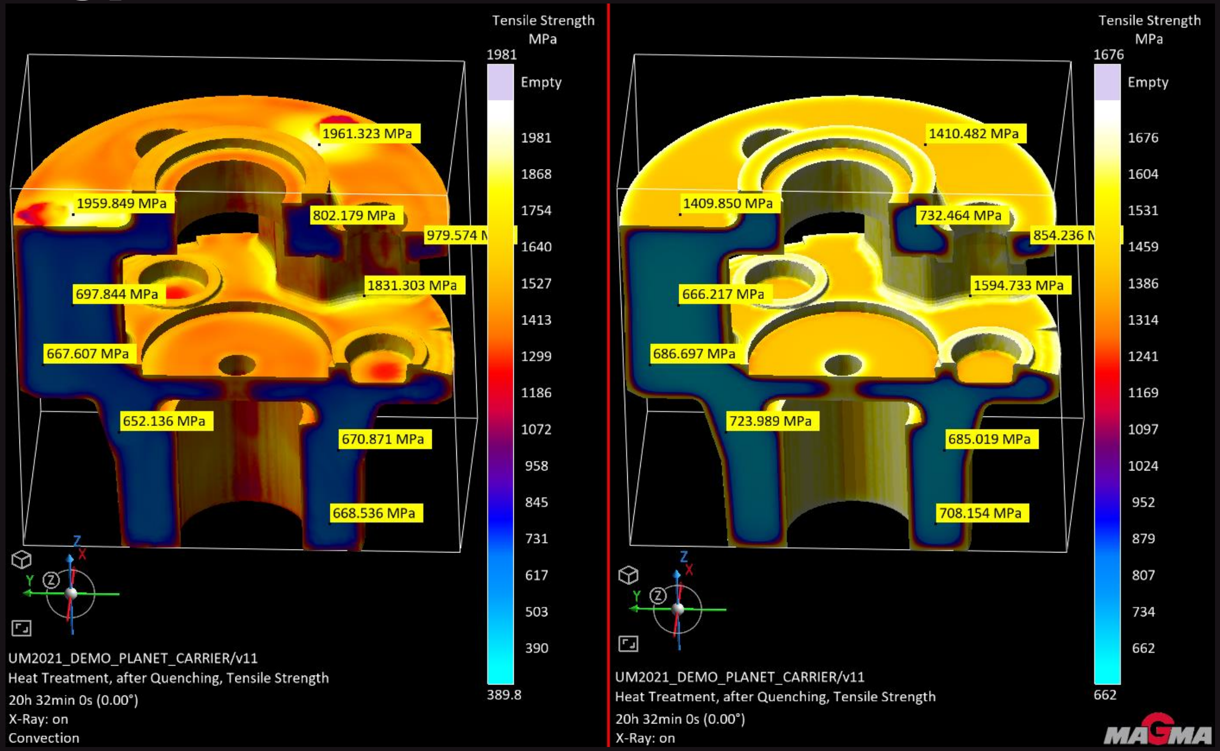
Convection

Without Convection

Act & check improvements(Mechanical properties)

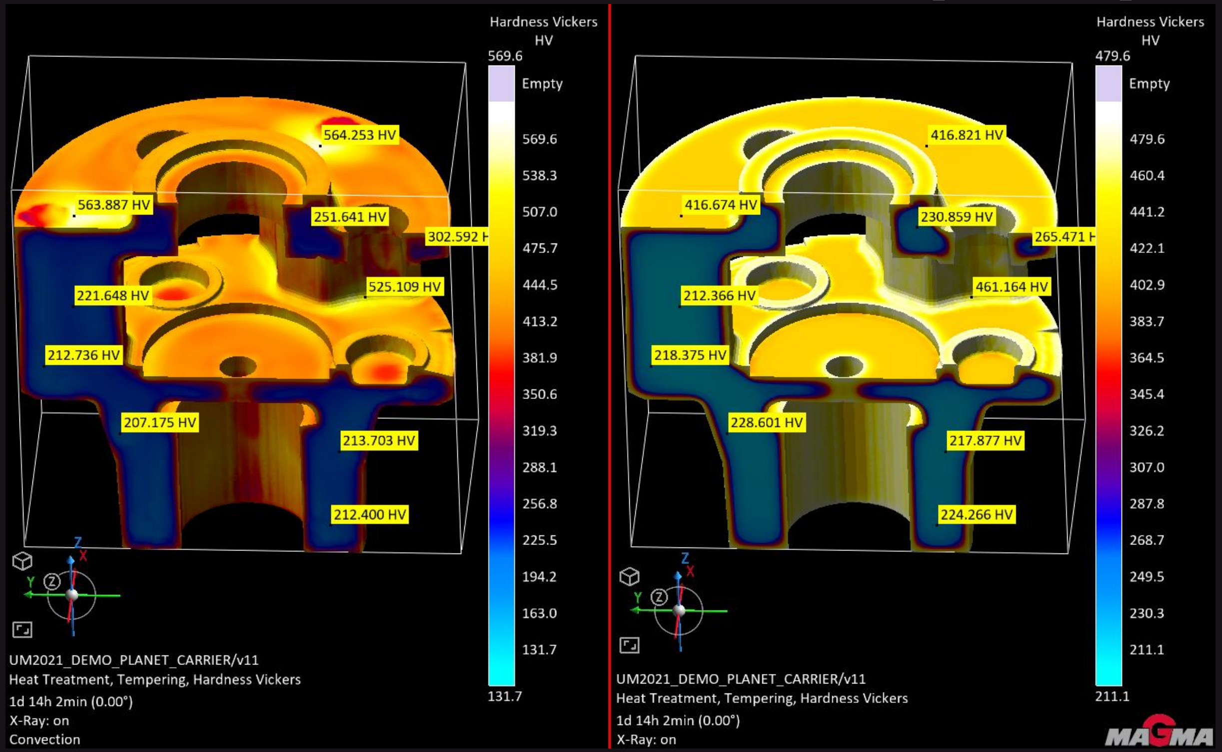
Hardness & tensile(Quenching)

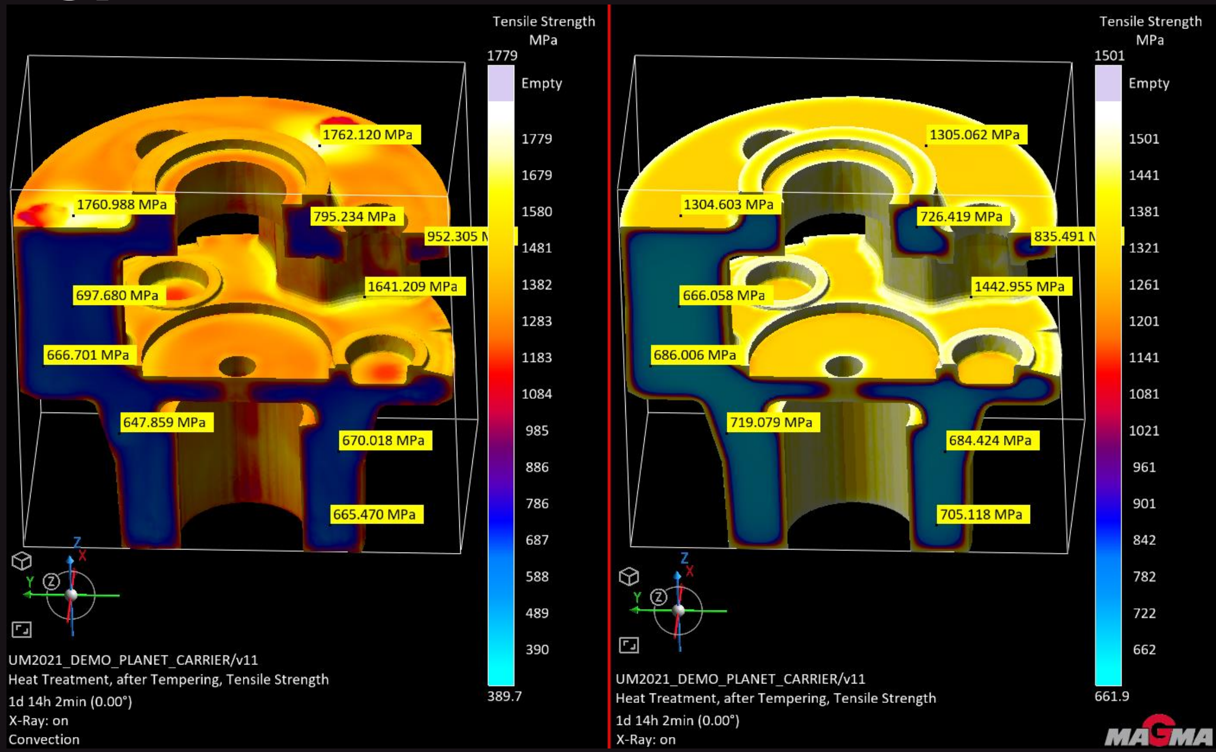




It was observed that the mechanical properties vary, and the distribution within the casting is different when the simulation is carried out with convection.

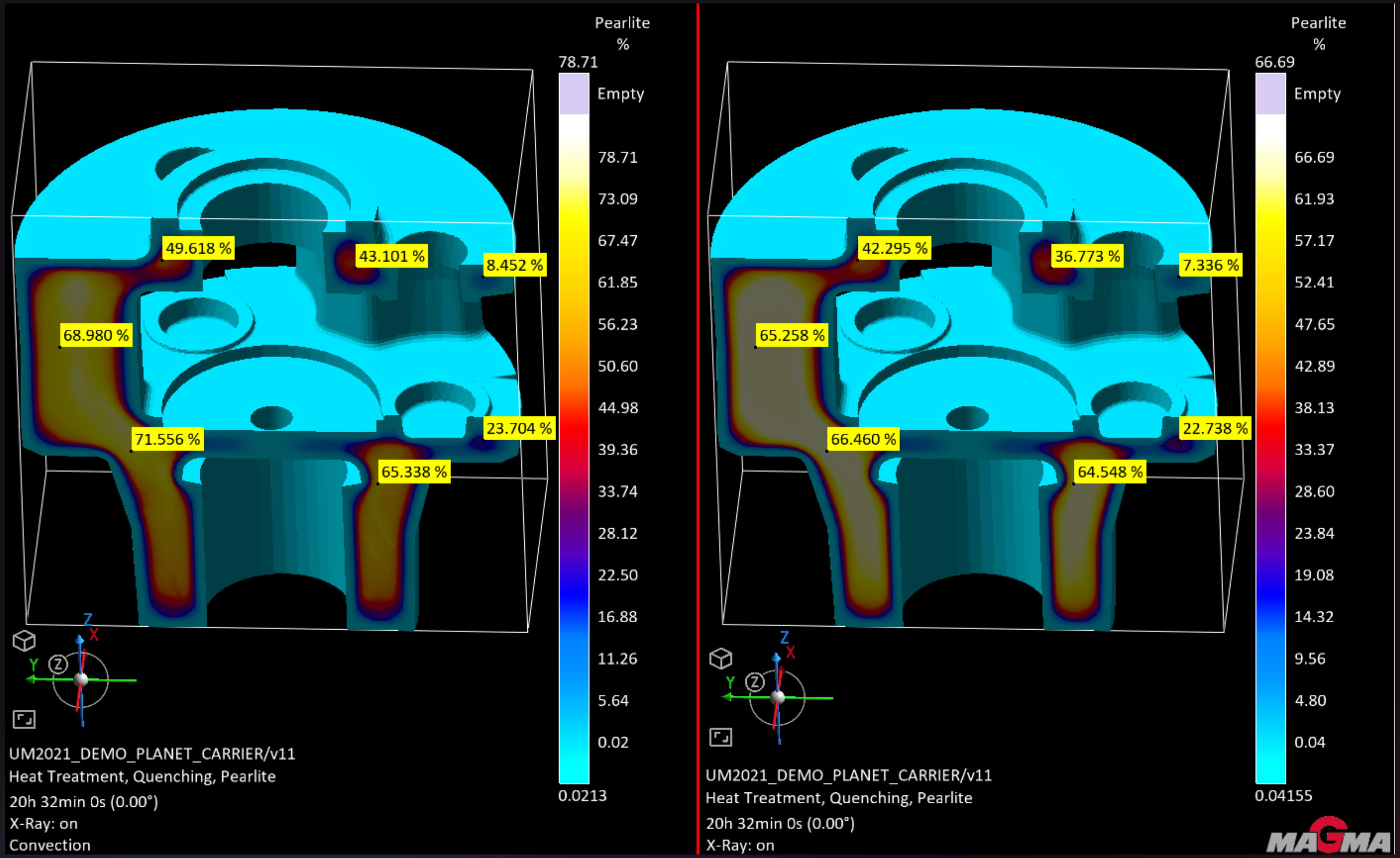
Hardness & Tensile(Tempering)



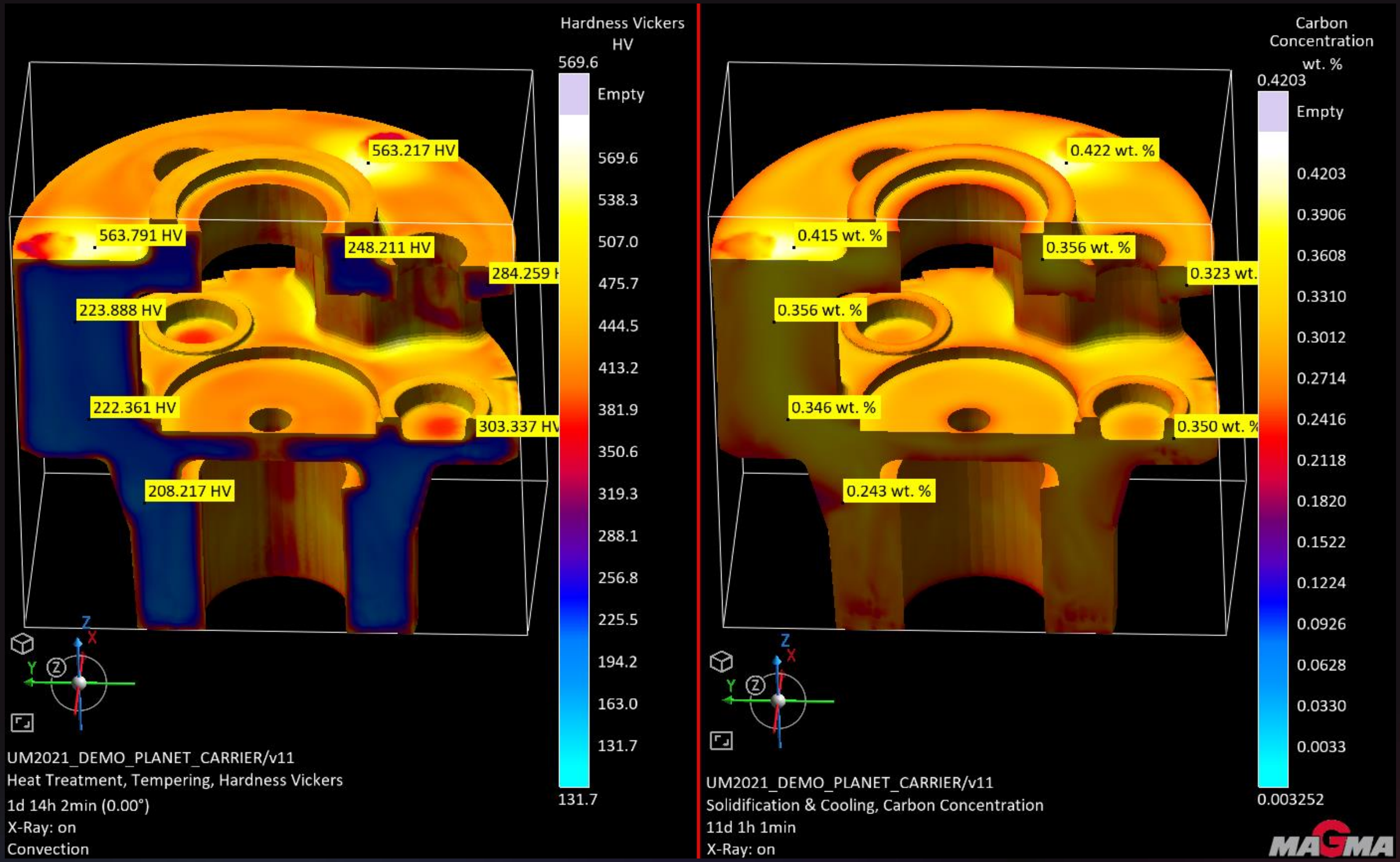


It was observed that the mechanical properties vary, and the distribution within the casting is different when the simulation is carried out with convection.

Microstructure- Pearlite



Effect of C segregation on Mechanical properties(HT)



Can the sand system affect the stresses and convection?

Defining the objective

- Understanding the effect of Sand system on convection & stresses

Define your variable

- Simulation with different sand system(Cera-bead, Chromite, Silica & Zircon

Specify your criterion

- Solidification results
- Stress results

Keep the task efficient

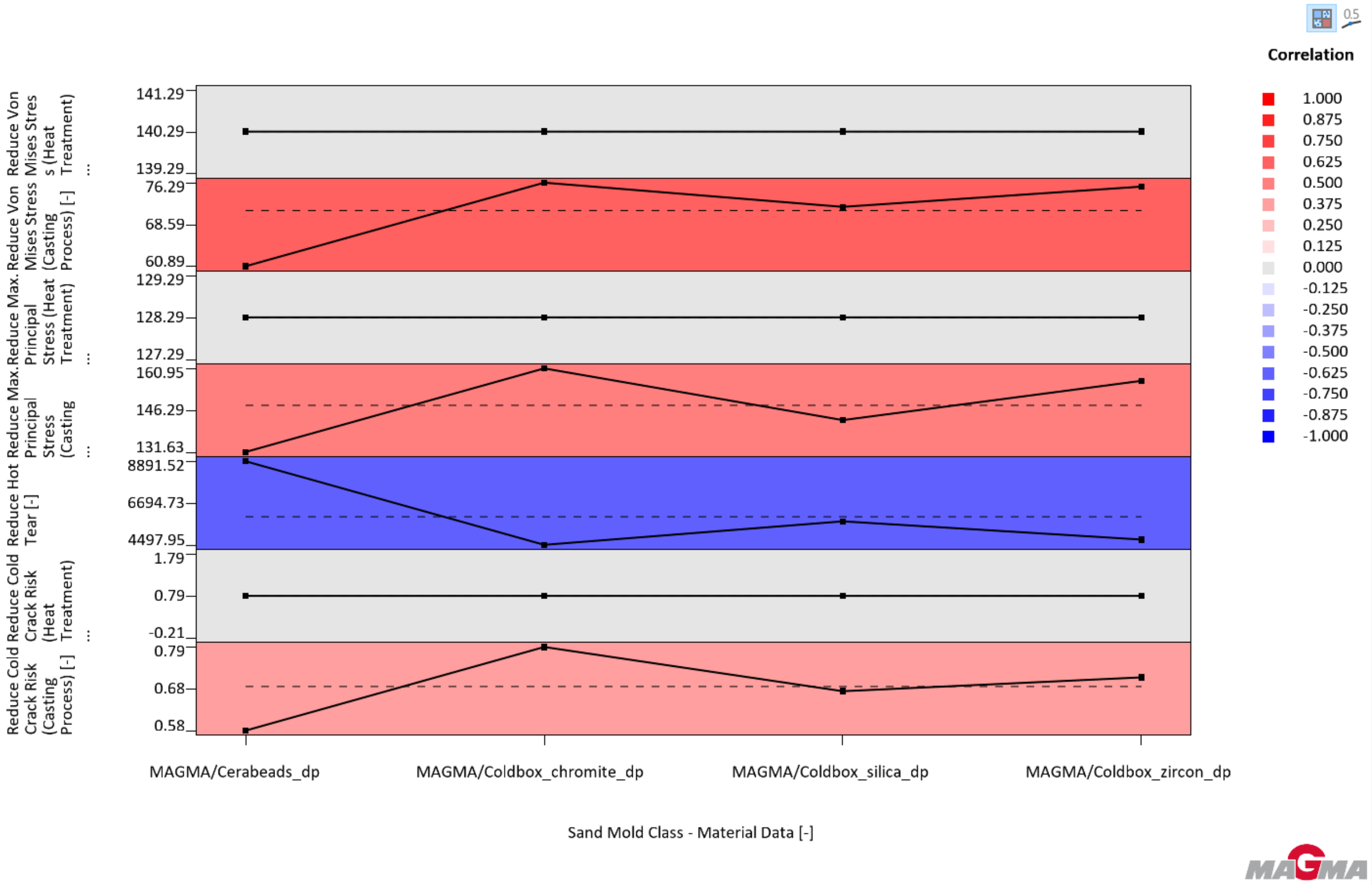
- Reduced mesh

Choose you method

- Start sequence

Act & check improvements(Solidification & Stress results)

Correlation Matrix



Effect of sand on Solidification results

Rank	Design	Sand Mold Class - Material Data (-)	Gradient (-)
Rank 1	Design 1	MAGMA/Cerabeads_dp	3.09944e-07
Rank 2	Design 4	MAGMA/Coldbox_zircon_dp	4.61936e-07
Rank 3	Design 3	MAGMA/Coldbox_silica_dp	8.09187e-07
Rank 4	Design 2	MAGMA/Coldbox_chromite_dp	1.55568e-06

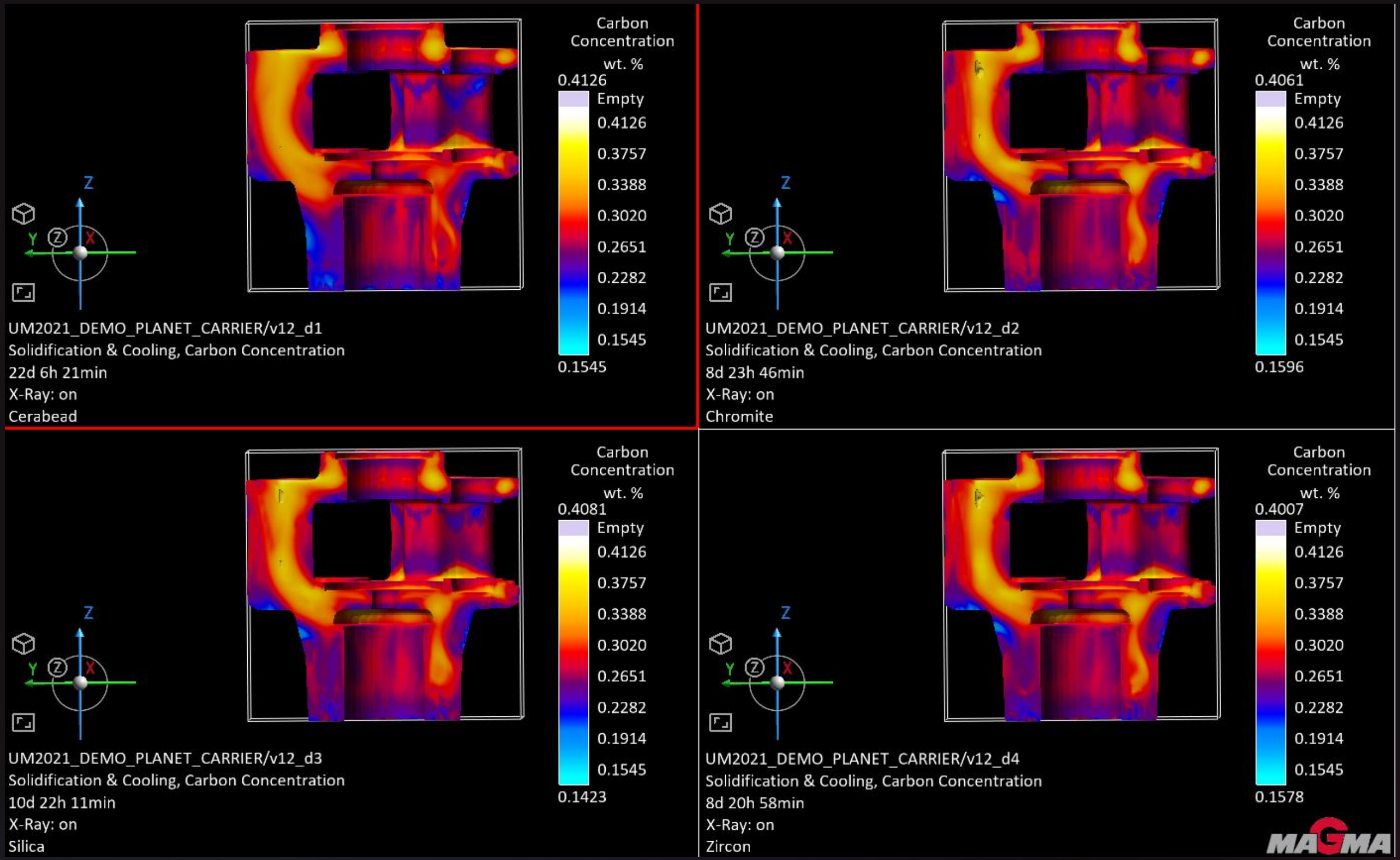
Rank	Design	Sand Mold Class - Material Data (-)	Feedmod (-)
Rank 1	Design 1	MAGMA/Cerabeads_dp	0.522
Rank 2	Design 3	MAGMA/Coldbox_silica_dp	0.626
Rank 3	Design 4	MAGMA/Coldbox_zircon_dp	0.694
Rank 4	Design 2	MAGMA/Coldbox_chromite_dp	0.717

Rank	Design	Sand Mold Class - Material Data (-)	Reduce Porosity (-)
Rank 1	Design 1	MAGMA/Cerabeads_dp	244.57
Rank 2	Design 3	MAGMA/Coldbox_silica_dp	374.29
Rank 3	Design 4	MAGMA/Coldbox_zircon_dp	654.45
Rank 4	Design 2	MAGMA/Coldbox_chromite_dp	728.22

Rank	Design	Sand Mold Class - Material Data (-)	Carbon Concentration (-)
Rank 1	Design 4	MAGMA/Coldbox_zircon_dp	0.401
Rank 2	Design 2	MAGMA/Coldbox_chromite_dp	0.406
Rank 3	Design 3	MAGMA/Coldbox_silica_dp	0.408
Rank 4	Design 1	MAGMA/Cerabeads_dp	0.413

Observation: With Cerabead sand, the convection effect is more pronounced, which improves feeding but also leads to increased segregation.

Effect of sand on segregation



Observation: The variation in carbon percentages inside the casting is greater with the Cerabead sand system.

Effect of sand on Stresses results

	Rank	Design	Sand Mold Class - Material Data (-)	Reduce Von Mises Stress (Casting Process) (-)
	Rank 1	Design 1	MAGMA/Cerabeads_dp	60.89
	Rank 2	Design 3	MAGMA/Coldbox_silica_dp	71.83
	Rank 3	Design 4	MAGMA/Coldbox_zircon_dp	75.56
	Rank 4	Design 2	MAGMA/Coldbox_chromite_dp	76.29

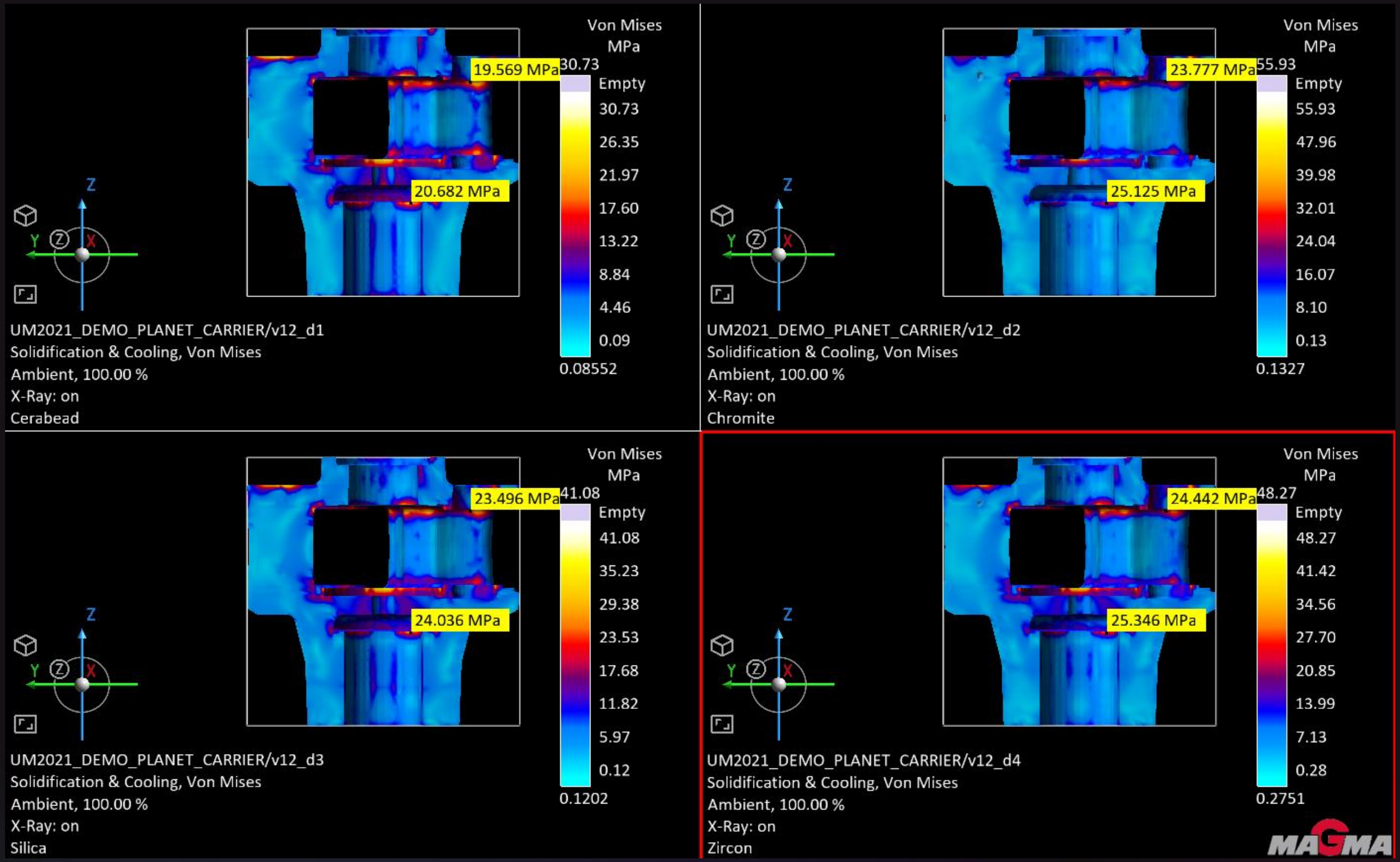
	Rank	Design	Sand Mold Class - Material Data (-)	Reduce Cold Crack Risk (Casting Process) (-)
	Rank 1	Design 1	MAGMA/Cerabeads_dp	0.576
	Rank 2	Design 3	MAGMA/Coldbox_silica_dp	0.677
	Rank 3	Design 4	MAGMA/Coldbox_zircon_dp	0.712
	Rank 4	Design 2	MAGMA/Coldbox_chromite_dp	0.79

	Rank	Design	Sand Mold Class - Material Data (-)	Reduce Max. Principal Stress (Casting Process) ...
	Rank 1	Design 1	MAGMA/Cerabeads_dp	131.63
	Rank 2	Design 3	MAGMA/Coldbox_silica_dp	142.81
	Rank 3	Design 4	MAGMA/Coldbox_zircon_dp	156.58
	Rank 4	Design 2	MAGMA/Coldbox_chromite_dp	160.95

	Rank	Design	Sand Mold Class - Material Data (-)	Reduce Hot Tear (-)
	Rank 1	Design 2	MAGMA/Coldbox_chromite_dp	4497.95
	Rank 2	Design 4	MAGMA/Coldbox_zircon_dp	4776.15
	Rank 3	Design 3	MAGMA/Coldbox_silica_dp	5733.53
	Rank 4	Design 1	MAGMA/Cerabeads_dp	8891.52

Observation: Sand system also have effect on the stress distributions

Effect of sand on Stresses



Observation: The von Mises distribution is also different for each sand. Higher von Mises values were observed with the Chromite sand system.
Why do the hot tear and cold crack results show opposite trends?

- Opposite trend indicates due to the heat transfer rates are different , cera-bead is having insulating properties which may increase the hot tear chances as the metal solidification takes more time. Cold crack chances in Cerabead sand will be less due to slow cooling in solid contraction stage. Which is opposite with Chromite sand

Can the chemistry change affect the stresses and convection?

Defining the objective

- Understanding the variation in chemical composition on segregations & Mechanical composition

Define your variable

- Composition of Carbon 0.24 % to 0.34% with Interval 0.05%

Specify your criterion

- Solidification results
- Heat Treatment Results

Keep the task efficient

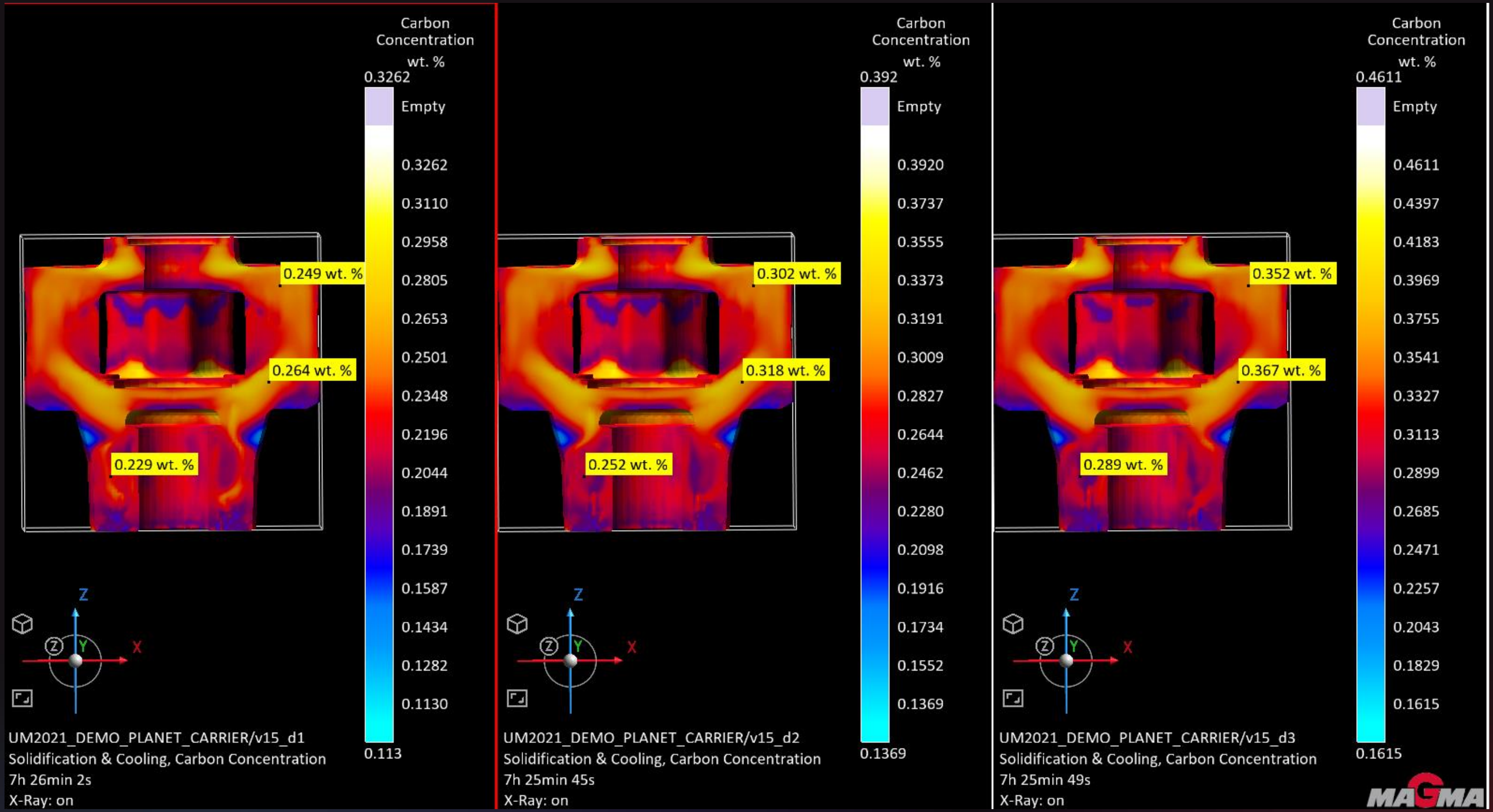
- Reduced mesh

Choose you method

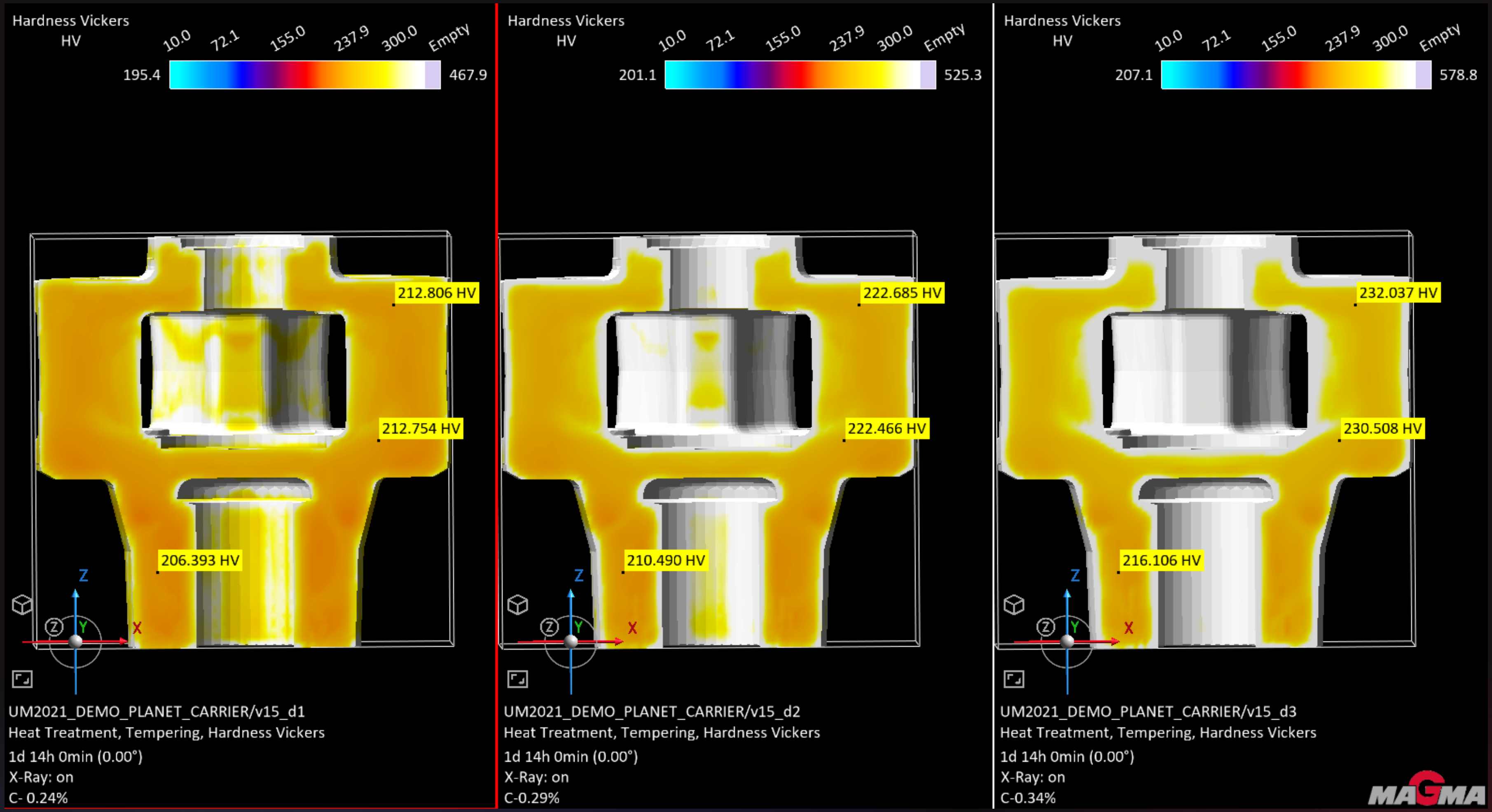
- Start sequence

Act & check improvements

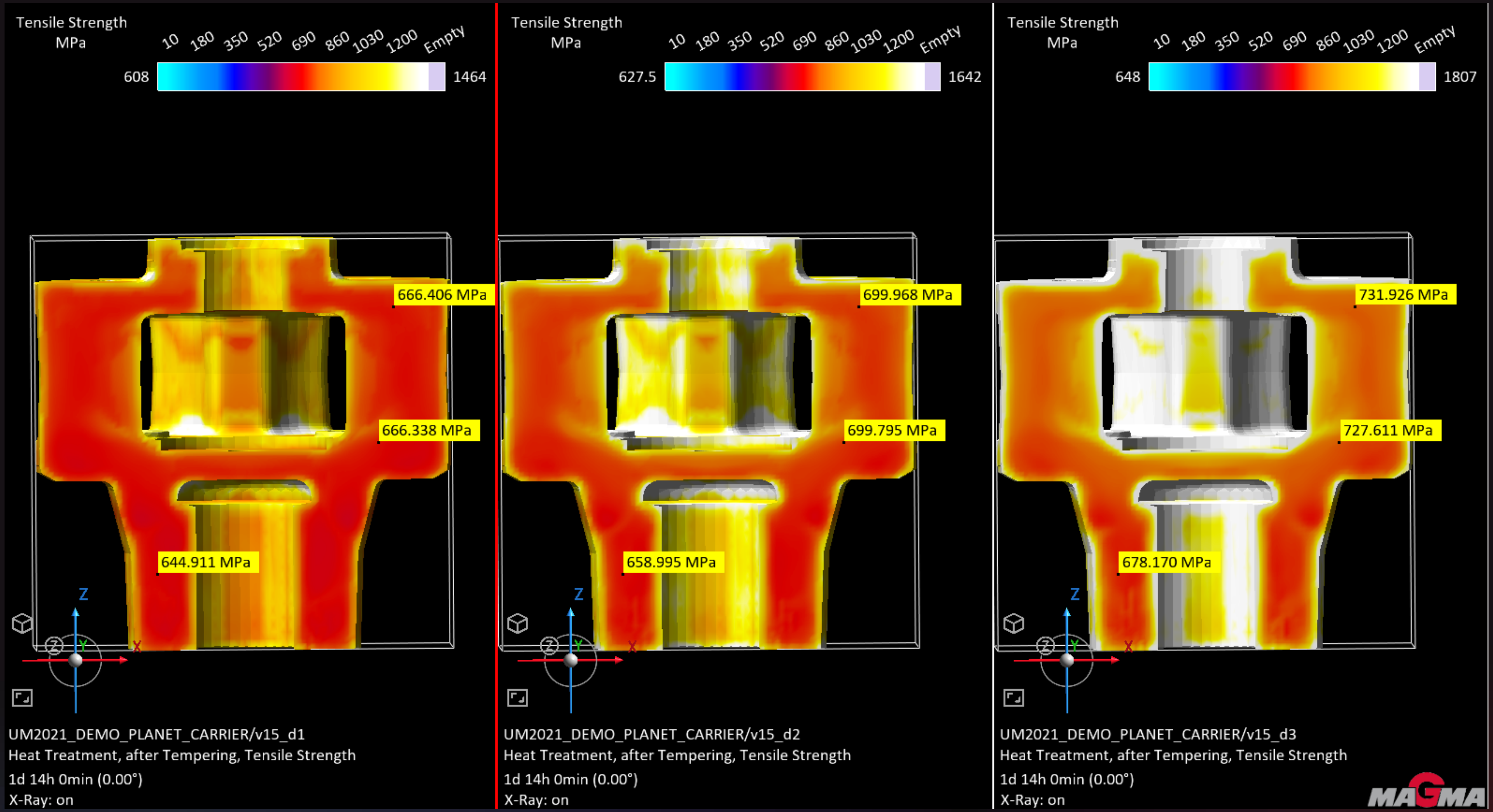
Carbon percentage distribution in casting



Mechanical Properties: Hardness



Mechanical Properties: Tensile

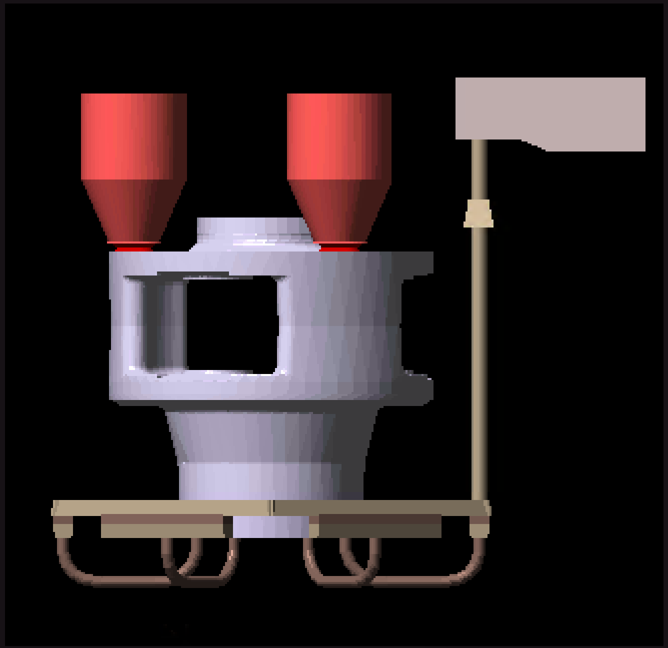


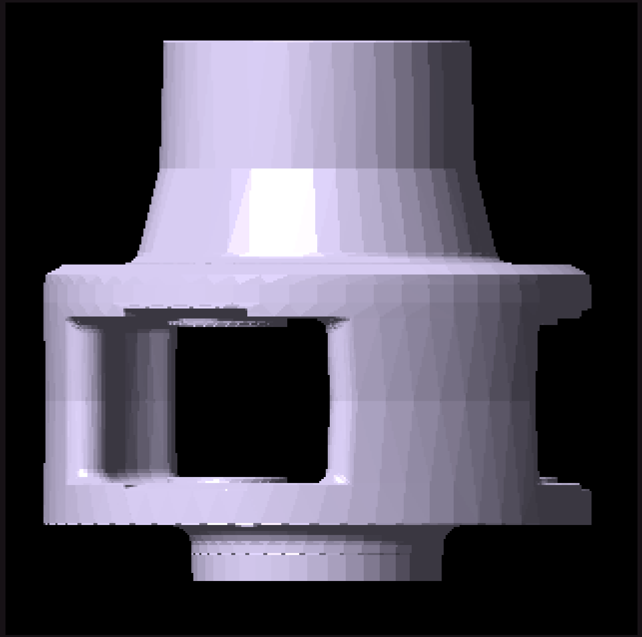
Summary

- Effect of convection was observed to some significant value in solidification stress and heat treatment as well.
- Changes in chemical composition MAGMASOFT® effects the segregation distribution and Mechanical properties.
- Sand have major influence over stresses as well as segregations. Less segregations in Chromite sand system.

Thank you

Running heat Treatment with opposite orientation





Can we do the stress simulation for the heat treatment with orientation ?

Utilising the Result mapping feature

1. Export model from results with scale1 (saved as M1 or any other name)
2. Create New version or project and import M1
3. Change the orientation of M1 for heat treatment
4. Tools>Result mapping
5. Locate the base version with casting process stresses
6. Update the geometry and map as per the current orientations
7. Select the results required from base version
8. Now HT stress simulation runs considering the stresses from base version

Thank you