INNOVATIVE COOLING SOLUTIONS OF HPDC TECHNOLOGY

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Abstract
In High Pressure Die Casting (HPDC), the so-called sliders are moving components of the mould, that can form cavities, holes, and undercuts. Sliders differ greatly from fixed- and moving mould halves regarding cooling and thermal balance. Typically, mould halves can range from a few hundred kilograms to several tonnes in size, whereas sliders have a significantly lower mass, and therefore their thermal balance changes much more drastically during casting cycles. Sliders can also be used to improve local heat dissipation in different areas. They are equipped with cooling holes through which the hole-forming cores, which penetrate deep into the mould cavity, can be tempered so that a significant amount of heat can be removed from the solidifying metal during the mould-filling process. As the industry produces increasingly complex castings, the cooling systems for the various moulds, inserts and cavities have evolved accordingly as the complexity of the castings has increased. This has resulted in innovative solutions and developments in the cooling of moulds and mould inserts, such as the use of 3D-printed metal inserts with improved heat dissipation. This article compares the cooling differences between traditionally cooled and 3D-printed sliders. We investigate cooling efficiency and tool temperatures at different cooling intensities through simulation experiments. Furthermore, at the end of the solidification phase, we examine the mold temperatures and the heat extracted for different molds and cooling intensities.

Keywords: *HPDC, 3D printed sliders, laser cusing, cooling technology*

1. Introduction

High pressure die casting is a rapidly developing industry where one of the most important development trends is to reduce the casting cycle time and the amount of lubricant applied. (ASM Metals Handbook, 1998; Butler, 2005; Andresen, 2005) By optimizing these, energy, auxiliary material, and time can be saved, resulting in significant cost savings and improving the competitiveness of the manufacturing company. One means of achieving these objectives is using various innovative cooling techniques for moulds to achieve more drastic cooling, i.e. to remove significantly more heat from the mould cavity and the solidified metal in a unit of time. (Cho et al., 2014; Jarfors et al., 2021)

2. Experimental work

The experimental geometry is a so-called single-cavity die-casting mould with two side sliders, one top slider and one fx side obliquely moving slider. The enclosing dimensions of the mould are 876 x 783 x 687 mm. The complexity of the casting under test is illustrated in Figure 1.

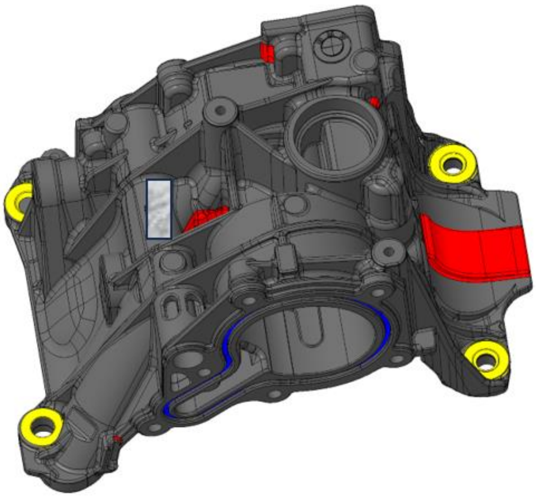


Figure 1. *Geometry of the tested casting*

Cooling of the mould was provided by oil and water cooling circuits. A Reglopast cooling and heating unit was used to maintain the heat balance. (www.regloplas.com) The experiments were carried out on two backdrops located on either side of the mould. The material of the sliders is 1.2343 (ESU HRC47) hot-worked steel. (uddenholm.com) In the original cast material sliders, the notched cooling holes, shown in blue and purple, are positioned as shown in Figure 2-3. Cooling holes are also located in the bore cores of the tool.

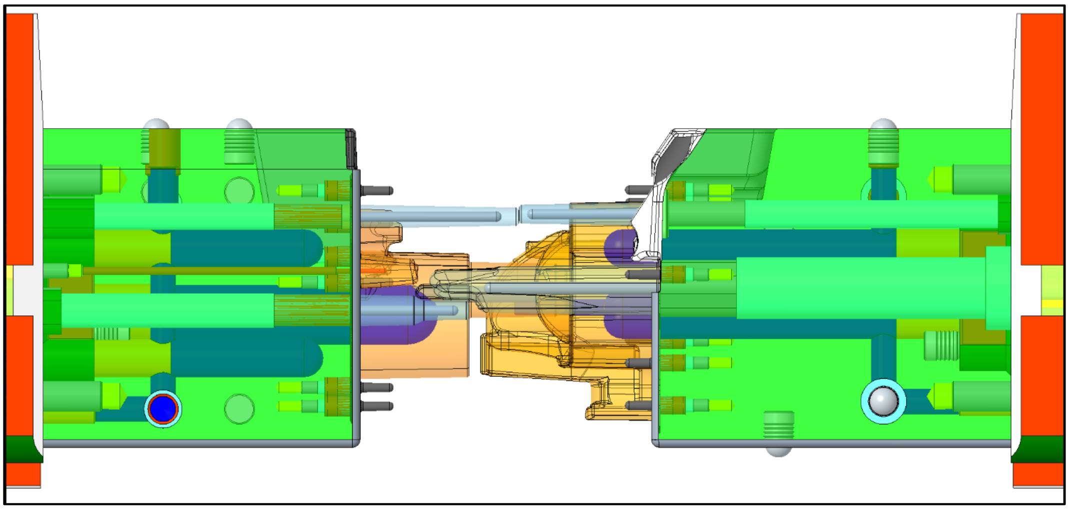


Figure 2. *Cooling system in the sliders*

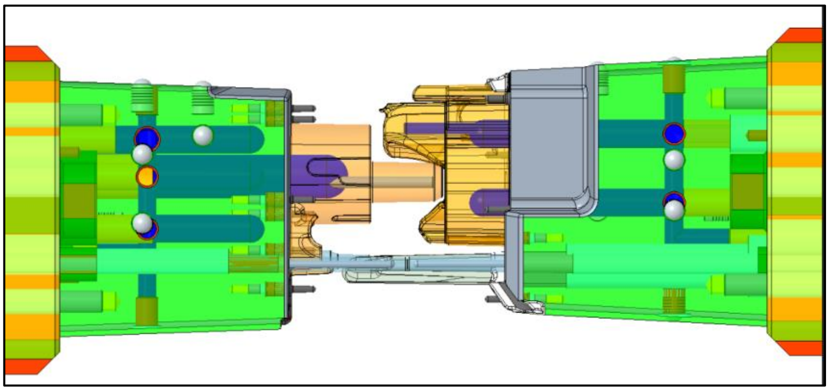
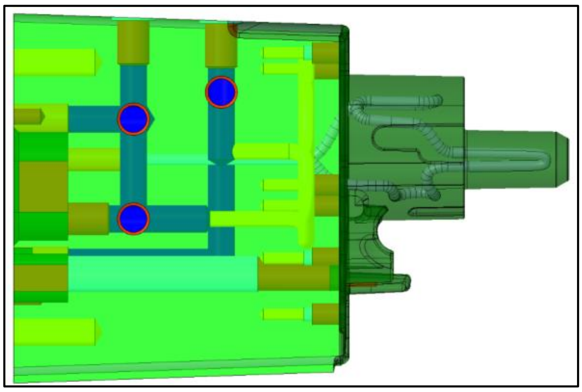
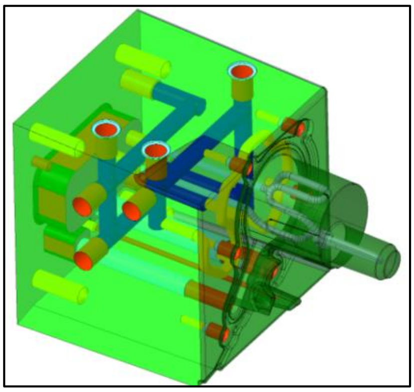


Figure 3. *Cooling system in the sliders*

The experiments involved modifications to the original cast material sliders. The experimentally optimized sliders are 3D printed. The quality of the 3D printed material is the same as the original cast sliders, i.e. 1.2343 (ESU HRC47). In contrast to the original solution, the sliders are made by laser cusing, i.e. metal 3D printing. Laser cusing is a laser three-dimensional metal melting process in which several 10-micron thick layers of a selected metal alloy are applied in powder form, and then each layer is laser melted together, layer by layer, to build up the three-dimensional geometry. The advantage of this method is that not only straight cooling holes can be formed inside the cores lining the inner cavities of the casting, but also channels of arbitrary shape and complexity. The big advantage of this is that the specific surface area of the cooling channel is significantly larger than that of a normal-shaped channel, i.e. it can draw significantly more heat from the mould in the moulding and solidification phase in a unit of time. (Gibson et al., 2021)

Figure 4-7. shows the cooling system of the 3D printed backdrop, where the cooling channels with high specific surface area are shown in grey and yellow. Since the heat dissipation capacity of 3D printed backdrops is significantly higher, the solidification time of the casting can be reduced and the lubrication cycle time and amount of material applied can be significantly reduced. This results in the fact that it is not necessary to remove large amounts of heat by emulsifying the lubricant, but it is possible to remove heat over a large surface area during the entire casting cycle.





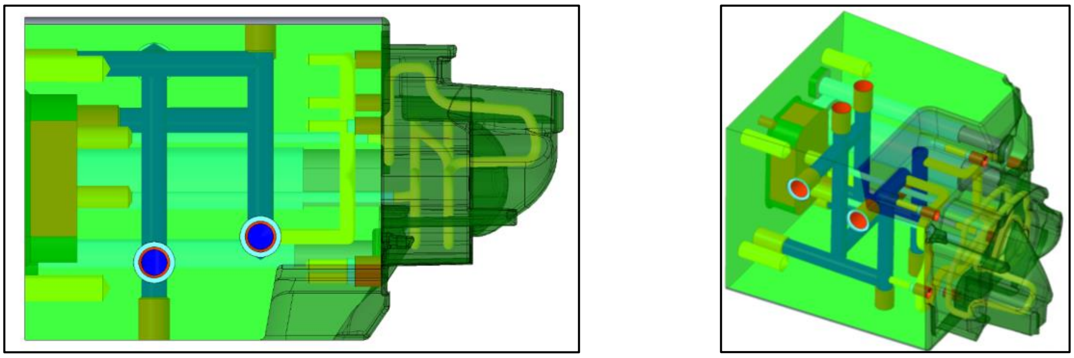


Figure 4-7. *Cooling system of the 3D printed sliders*

3. Results

Simulation tests were carried out to investigate the different ways in which each of the scenarios was designed:

1. The temperature conditions during filling and solidification.
2. The amount of heat dissipated during the solidification phase.
3. The position and morphology of the shrinkage cavities formed in the casting.

The simulation studies were carried out using the commercially available Magma casting simulation software. (www.magmasoft.de) For the simulation, the structure of each cooling system was imported from the 3D mould designs, which are shown in Figures 8-9.

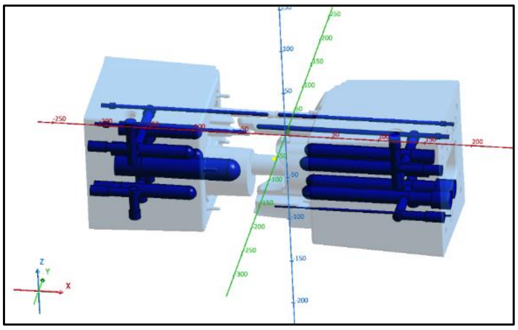


Figure 8. *Cooling system of the conventional sliders*

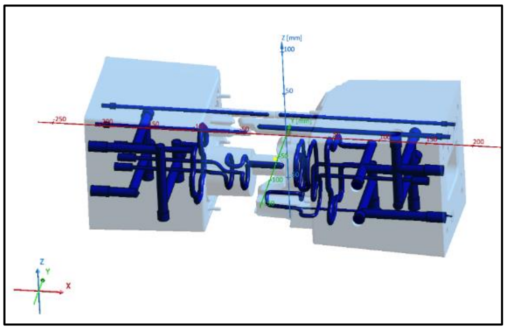


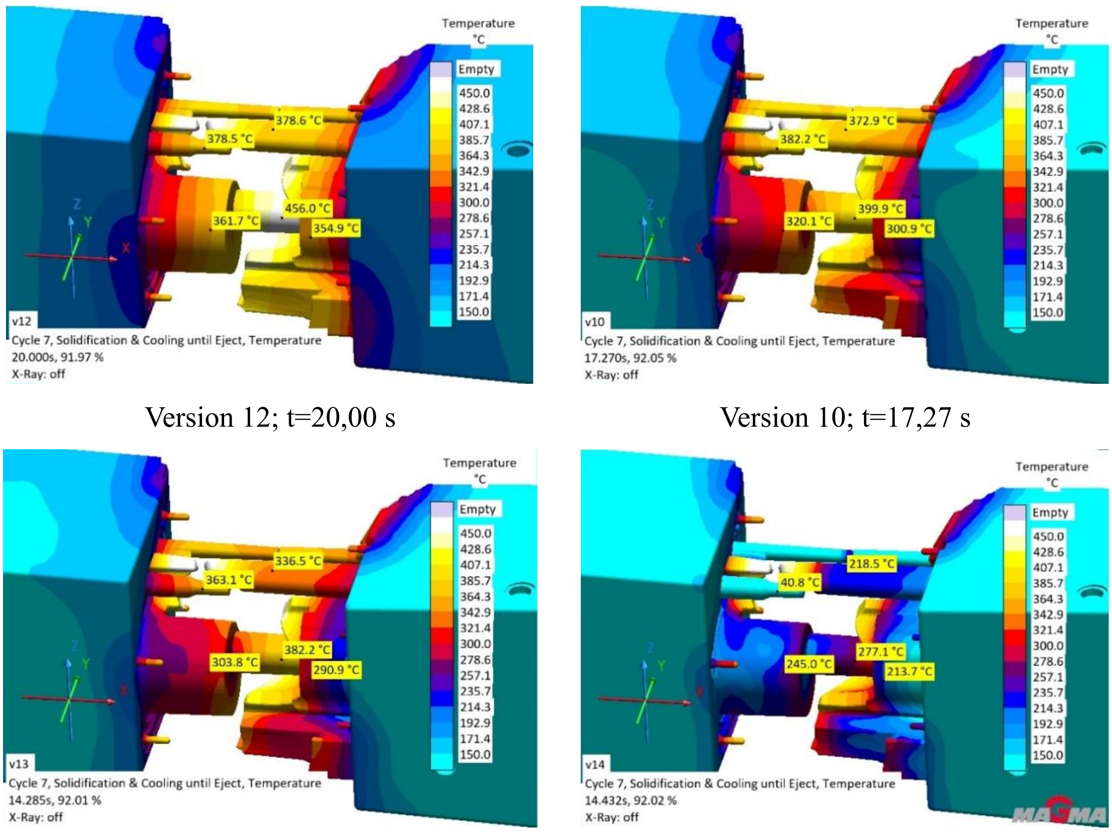
Figure 9. *Cooling system of the 3D printed sliders*

The material properties and the initial and boundary conditions used in each simulation experiment corresponded to real production conditions. Table 1. illustrates the main parameters of the four simulation calculations performed. For the cooling types, SLM stands for 3D printed backstage cooling, and Conv. for conventional cooling. By changing the value of the heat transfer coefficient, we simulated the change in the cooling effect.

Table 1. *Description of experiments*

Version	**Cooling type**	**Cooling time [s]**	**Heat Transfer Coefficient [W/m²K]**
10	SLM	6 sec	9500
12	Conv.	Perm	2660
13	SLM	6 sec	20000
14	SLM	20 sec	9500

Figure 10. shows the slider temperatures for the different simulated versions at the time points under study. In all cases, the temperature range is 150.0-450.0°C.



Version 12; t=20,00 s

Version 10; t=17,27 s

Version 13; t=14, 28 s

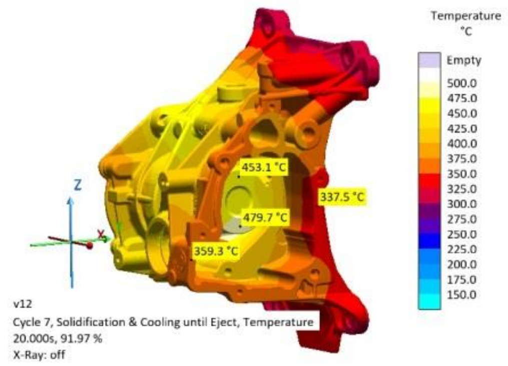
Version 14; t=14,43 s

Figure 10. *Calculated slider temperatures for each version at the time points studied scale: T=150,0-450,0°C*

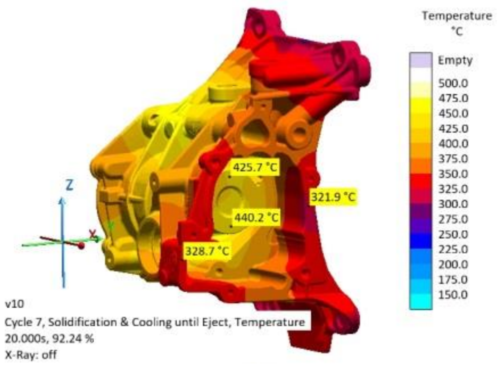
For each version, the slider temperatures were tested at five identical points, and the results show that the conventional slider temperatures are 40-50°C higher than the 3D printed slider temperatures.

With 3D printed sliders, as the cooling volume increases, the amount of heat extracted increases, so that slider temperatures can vary by more than 100°C in some places compared to conventional sliders. It is important to point out that for version 14 (20 sec cooling volume), both the sliders and the thicker moulding parts of the sliders show more uniformly lower temperatures.

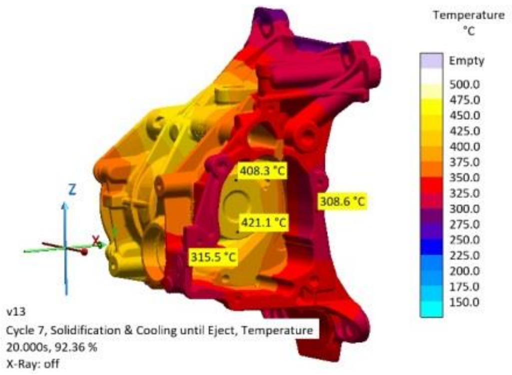
It can be pointed out that the 3D printed sliders have lower temperatures in all cases, which means that the amount of heat extracted is higher and therefore the cooling efficiency is better. The implication is that if the slider temperatures are lower before the lubrication phase, less lubricant needs to be applied during the lubrication phase to ensure thermal equilibrium. Figures 11-12. show the mould temperatures simulated with each version in different views at the moment of the complete design filling. For each version, the temperatures were evaluated at four identical positions. The temperature range in all cases is 150.0-500.0°C. It is noticeable that, as in the case of the mould temperature presented above, higher temperatures characterize the moulds in the case of conventional cooling, the mould temperatures at the end of the moulding show the same trends. At the temperature points investigated, the mould temperatures for conventional cooling and 3D printed sliders show a difference of 20-40°C. For the most intense cooling, the temperature differences range from 40-80°C.



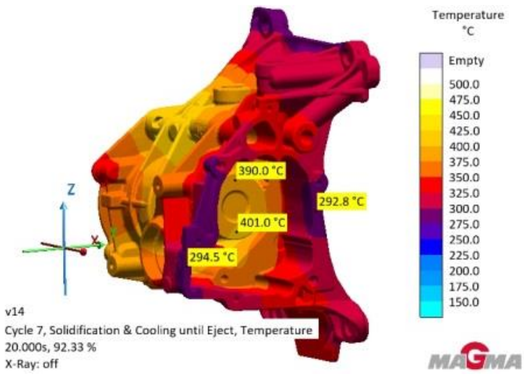
Version 12; t=20,00 s



Version 10; t=20,00 s

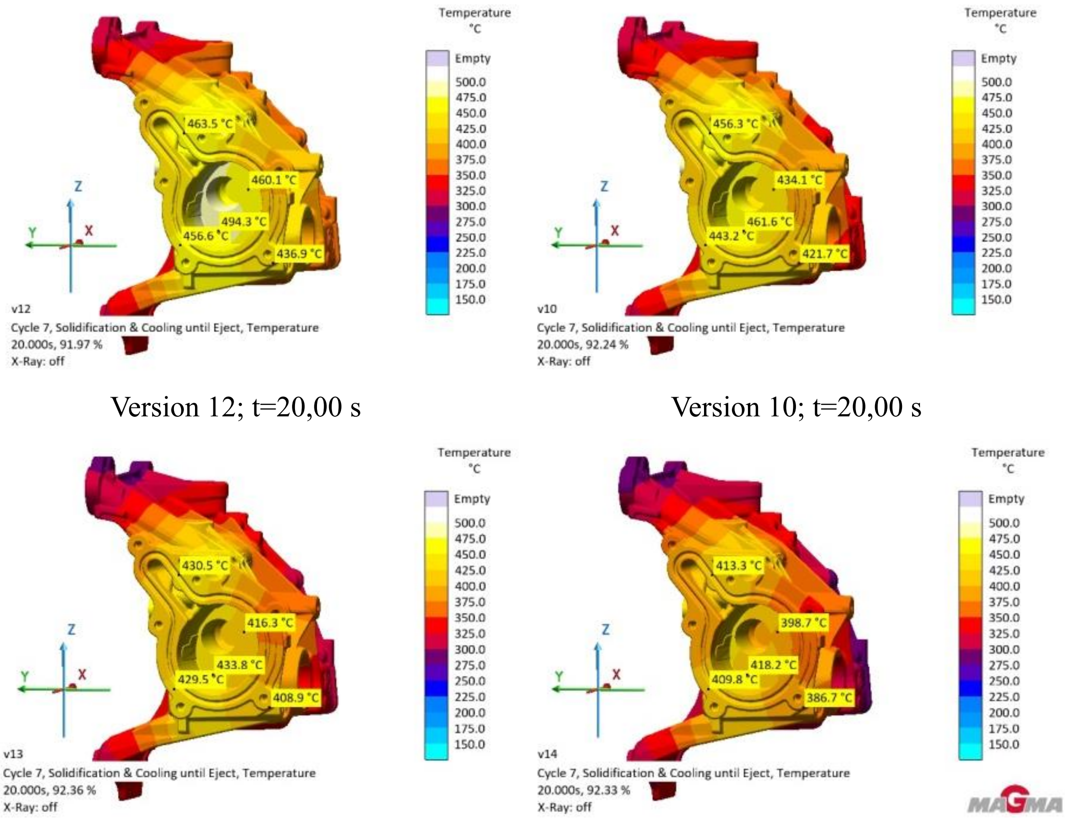


Version 13; t=20,0 s



Version 14; t=20,0 s

Figure 11. *Calculated casting temperatures for each version at the time points considered, view A, Scale: T=150.0-500.0°C*

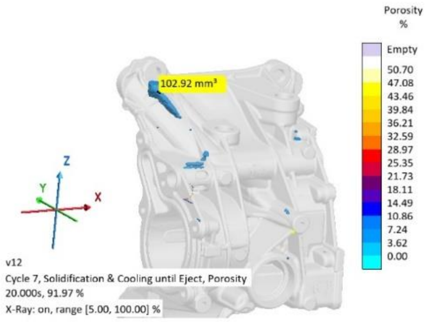


Version 12; t=20,00 s   Version 10; t=20,00 s

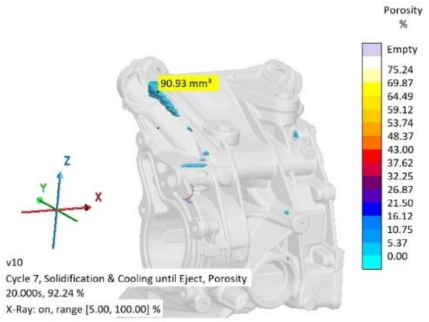
Version 13; t=20,0 s   Version 14; t=20,0 s

Figure 12. *Casting temperatures calculated for each version at the time points under investigation, view B, Scale: T=150.0-500.0°C*

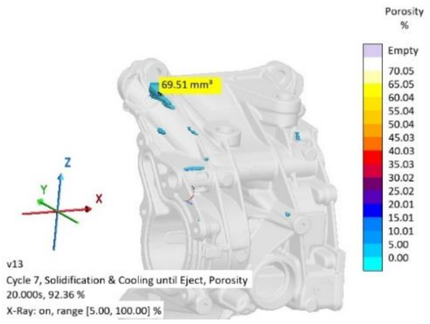
Figure 13. shows the location and extent of the shrinkage cavities formed for different versions of the cooling parameters. It can be seen that the location is the same for all versions, with a difference in the extent of shrinkage. The volume of the shrinkage cavities due to volume change is ~103 mm^3 for the use of conventionally cooled sliders, while for 3D printed sliders it is ~90; ~70, and ~50 mm^3. In these cases, the difference is due to the different cooling time and heat transfer coefficient values. The smallest size shrinkage occurs for version 14, which has the highest cooling time. The shrinkage cavities are formed furthest away from the cut-out, and the feeding pressure after the end of the moulding process is the least effective. Figure 14 shows the scale shrinkage: 0.0-100.0%.



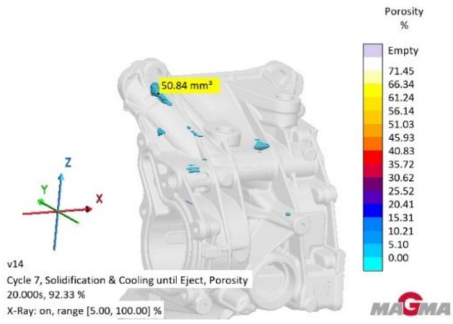
Version 12; t=20,00 s



Version 10; t=20,00 s



Version 13; t=20,00 s



Version 14; t=20,00 s

Figure 13. *Shrinkages calculated for each version shrinkage scale: 0.0-100.0%*

Figures 14-17. show the heat balances of the different simulated versions, i.e. the energy input and the energy output. Our study focused on the comparison of the energy extracted by the tempering circuits since we aimed to increase the cooling and the amount of thermal energy extracted by the innovative cooling process. For each version, it can be seen that the energy extracted by the tempering circuits when using the conventional sliders is 413.71 kJ. This is the lowest energy extraction from the system of all the calculated versions. With the 3D printed sliders, the system can extract 548.19 kJ, 637.79 kJ, and 807.37 kJ of energy, respectively, based on the simulations. The difference between the results of the 3D printed sliders with the most powerful cooling and the conventional sliders is 49%.

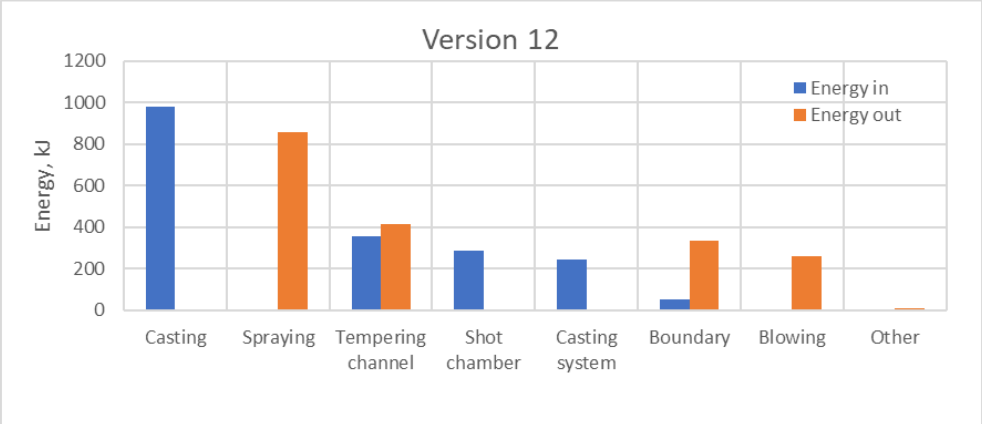


Figure 14. *The heat balance of version 12*

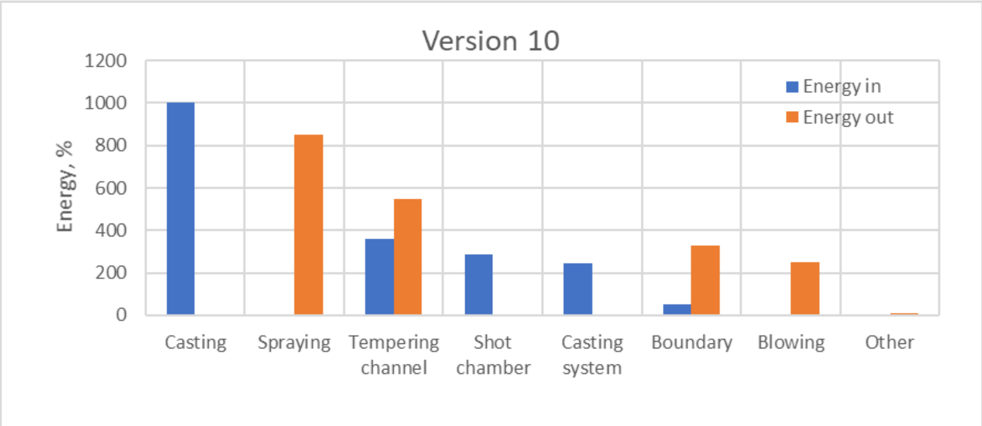


Figure 15. *The heat balance of version 10*

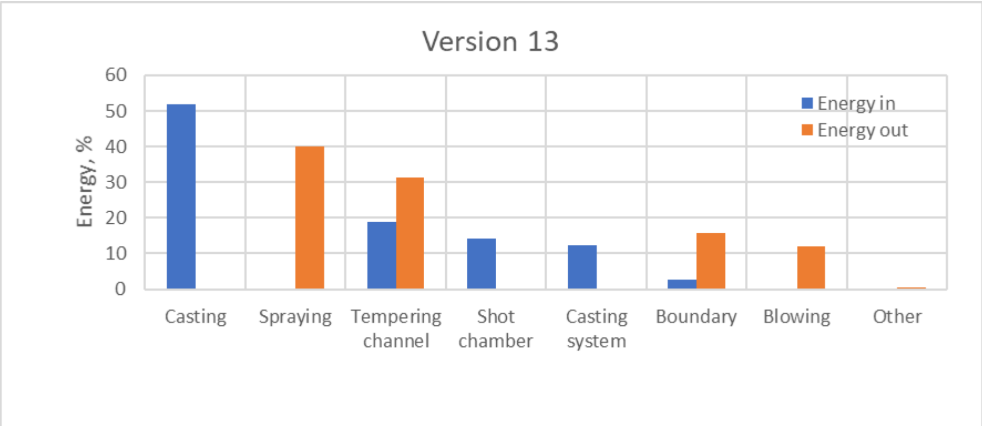


Figure 16. *The heat balance of version 13*

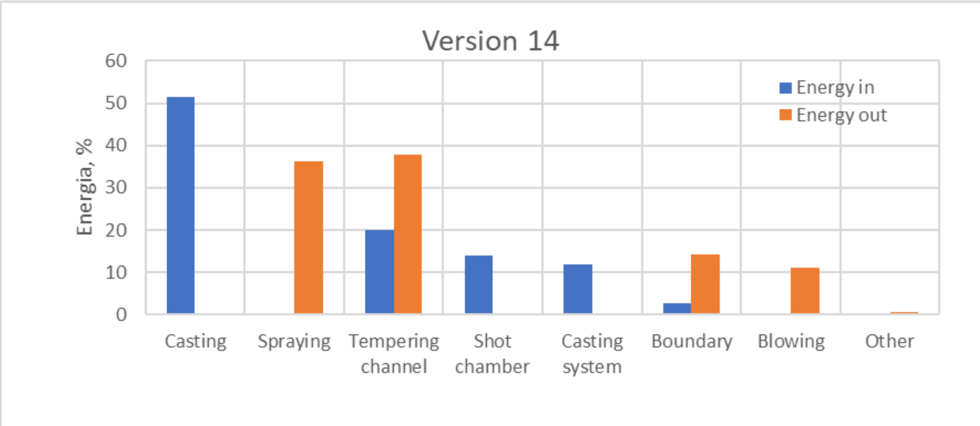


Figure 17. *The heat balance of version 14*

Figures 18-21. show the thermal scales of the simulated versions tested, classified by each cooling channel of the mould. The energy dissipated by the unconventional sliders is shown in Figure 19., for the simulated results of version 12. The left conventional slider extracts 64.30 kJ, while the right conventional slider extracts 61.30 kJ during the casting process. For the 3D printed sliders, the energy dissipated varies from 145.98 kJ for the left 3D printed sliders to 216.98 kJ for the right 3D printed sliders, with increasing cooling intensity. For the right side sliders, the energy dissipated varies from 122.17 kJ to 193.87 kJ. The amount of energy extracted increases with increasing cooling intensity.

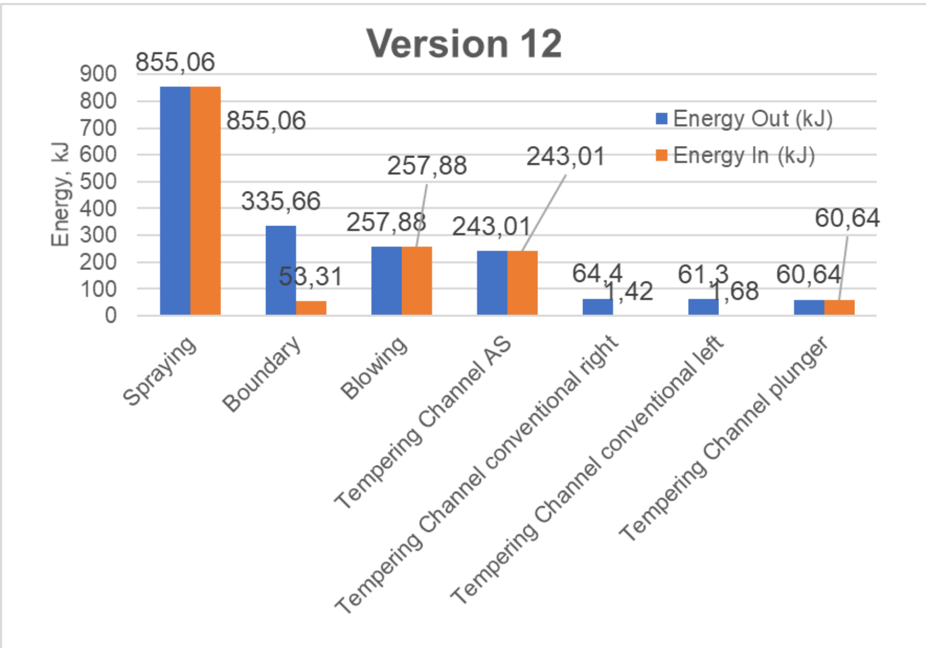


Figure 18. *Heat balance of version 12 broken down by cooling channels*

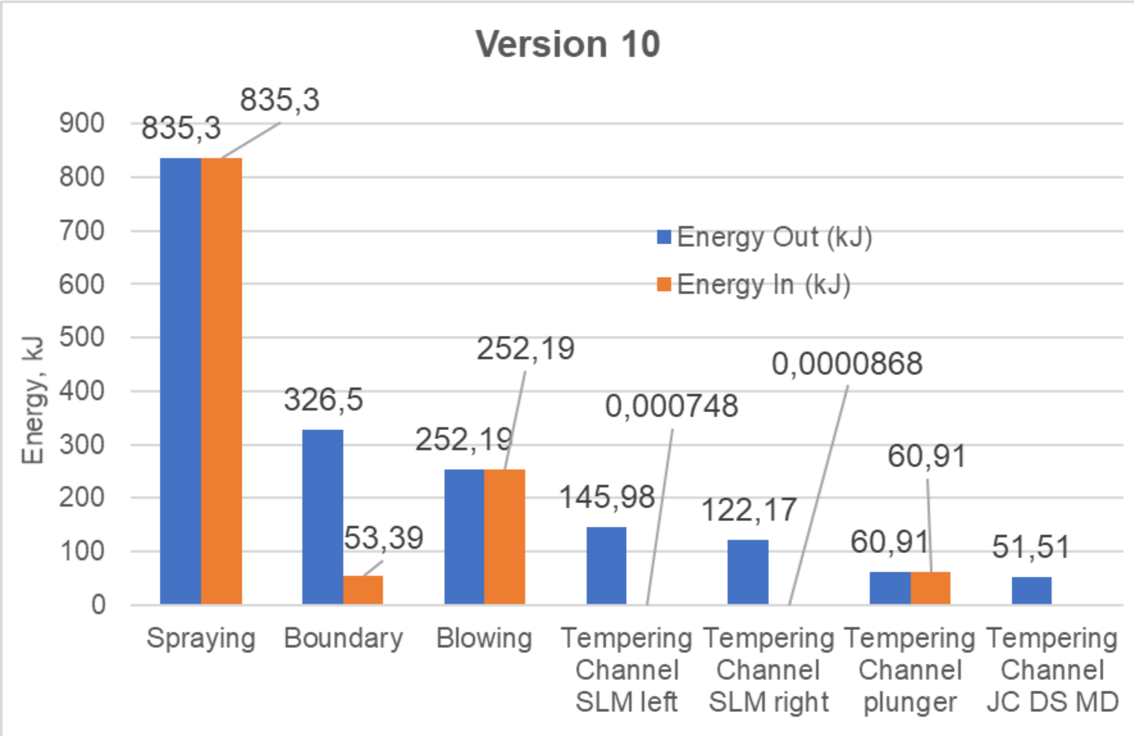


Figure 19. *Heat balance of version 10 broken down by cooling channels*

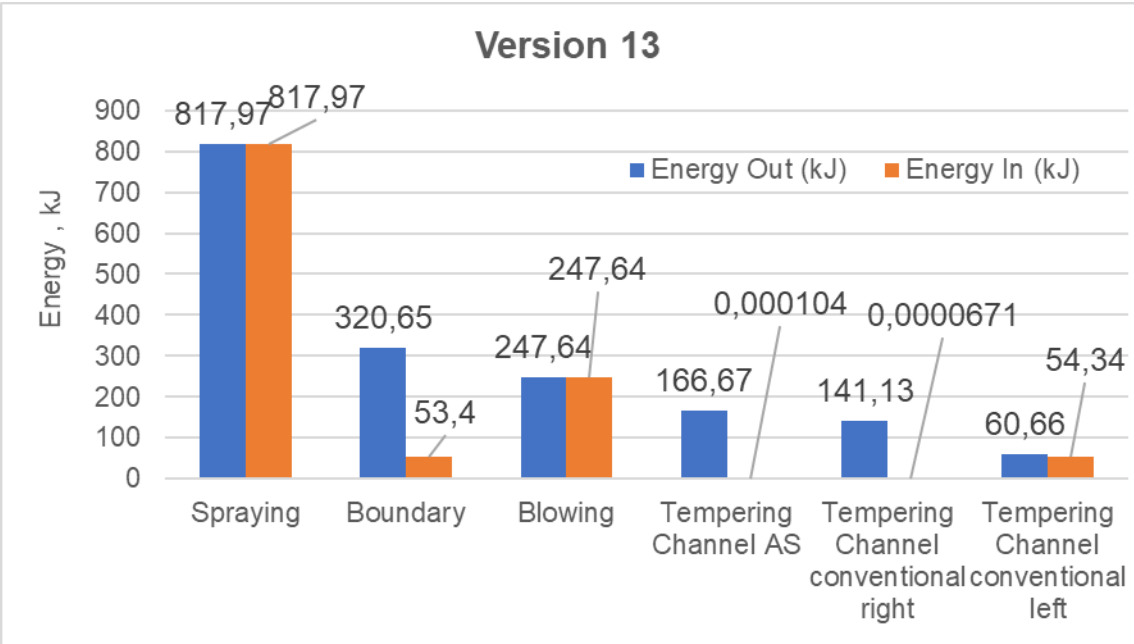


Figure 20. *Heat balance of version 13 broken down by cooling channels*

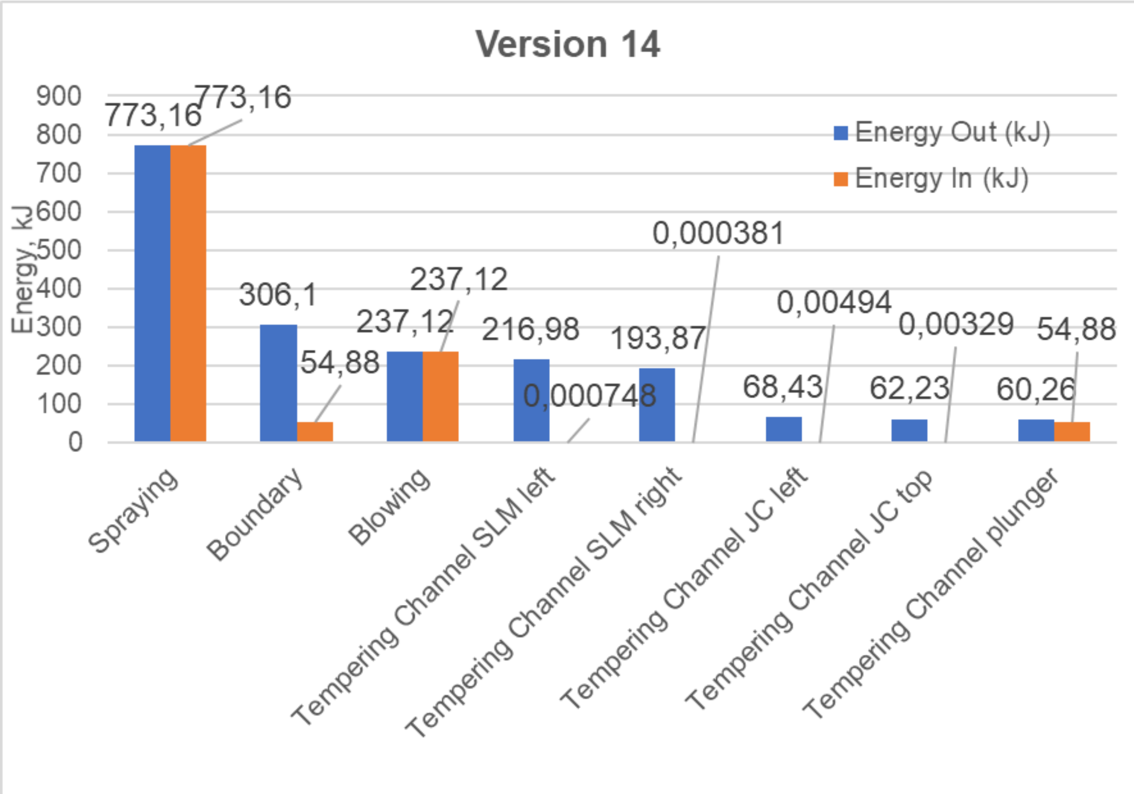


Figure 21. *Heat balance of version 14 broken down by cooling channels*

4. Summary

In the experiment, the cooling technology of traditional, i.e. conventional sliders, was compared with the cooling technology of 3D printed sliders. The 3D printed sliders with a larger specific surface area can dissipate more heat compared to the conventional one, which is illustrated by the simulated mould temperatures. Conventional sliders have temperatures 40-50°C higher than 3D-printed sliders. For 3D printed sliders, as the cooling volume increases, the amount of heat extracted increases, so that slider temperatures can vary by more than 100°C in places compared to conventional sliders. It can be shown that the temperatures of 3D printed sliders are lower in all cases, which means that the amount of heat extracted is higher and therefore the cooling efficiency is better. The same can be observed at the end of the design process, with the mould temperatures showing the same trends. At the temperature points examined, the mould temperatures for conventional cooling and 3D printed sliders show a difference of 20-40°C. For the most intense cooling, the temperature differences range from 40-80°C.

The rate of shrinkage cavity formation due to volume change is the highest for conventionally cooled sliders at 103 mm^3. As the cooling intensity increases, the rate of shrinkage cavities decreases for 3D-printed sliders.

The calculated heat dissipation of the sliders is the lowest for conventional sliders as the cooling intensity is increased so is the amount of heat dissipated. There is a difference of nearly 49% in the heat removed between conventional and 3D-printed sliders.

5. Acknowledgments

Thanks to Christian Walter, Simulation Engineer of the Wolf Industries Group, for his support during the experiment.

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