Advanced Electrode Melting for Highest-Purity Cast Parts

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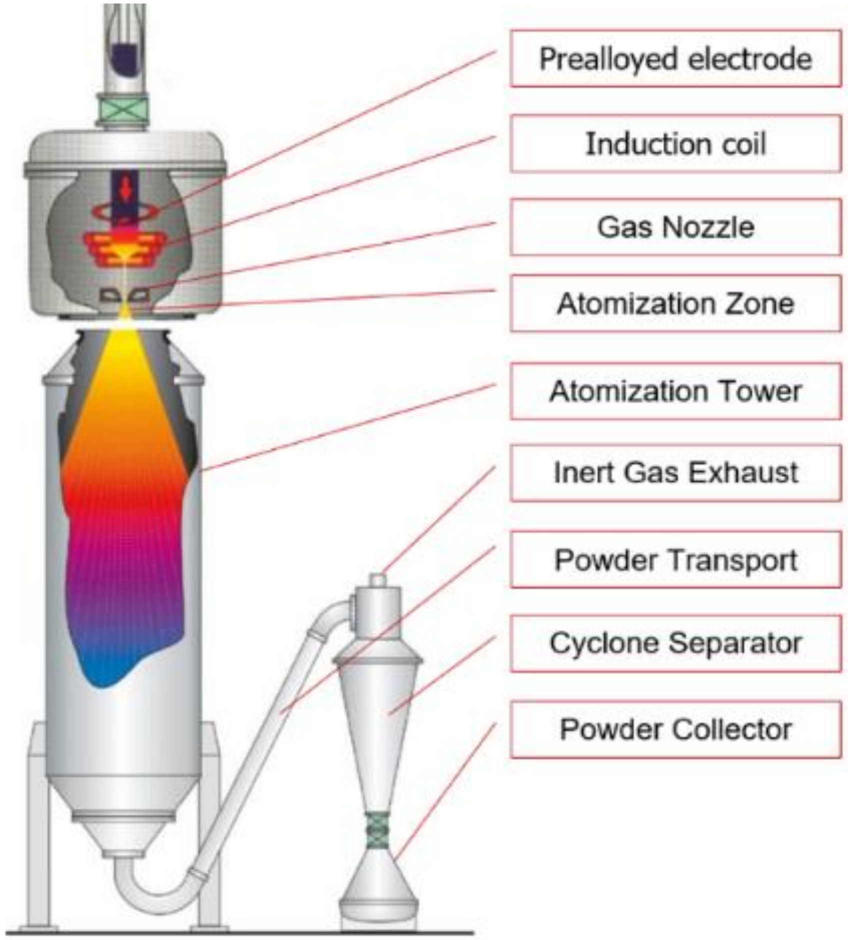
Outlook

- Presentation outline:
  - Electrode Induction Melting → Inert Gas Atomization (EIGA)Experimental Procedure
  - Electrode Induction Melting → Investment Casting | Advantages & Challenges
  - Modelling of EIGA-melting
  - Parameter impact on the superheat
    - Melt rate / Alloy / Number of coil windings / Total power
  - Validation
  - Conclusions

Electrode Induction Melting + Inert Gas Atomization (EIGA)

“state-of-the-art” metallic powder production



Feedstock

- Pre-alloyed electrodes < Ø150 mm and < 1 m length
  → Ti64 < 80 kg, IN718 < 150 kg

Process

- **Melting (crucible-free):**

  feeding the electrode into a conical coil and induction melting of the electrode tip

- **Atomization:**

  melt stream falls into a “free-fall” nozzle and is atomized by a high-pressure inert gas

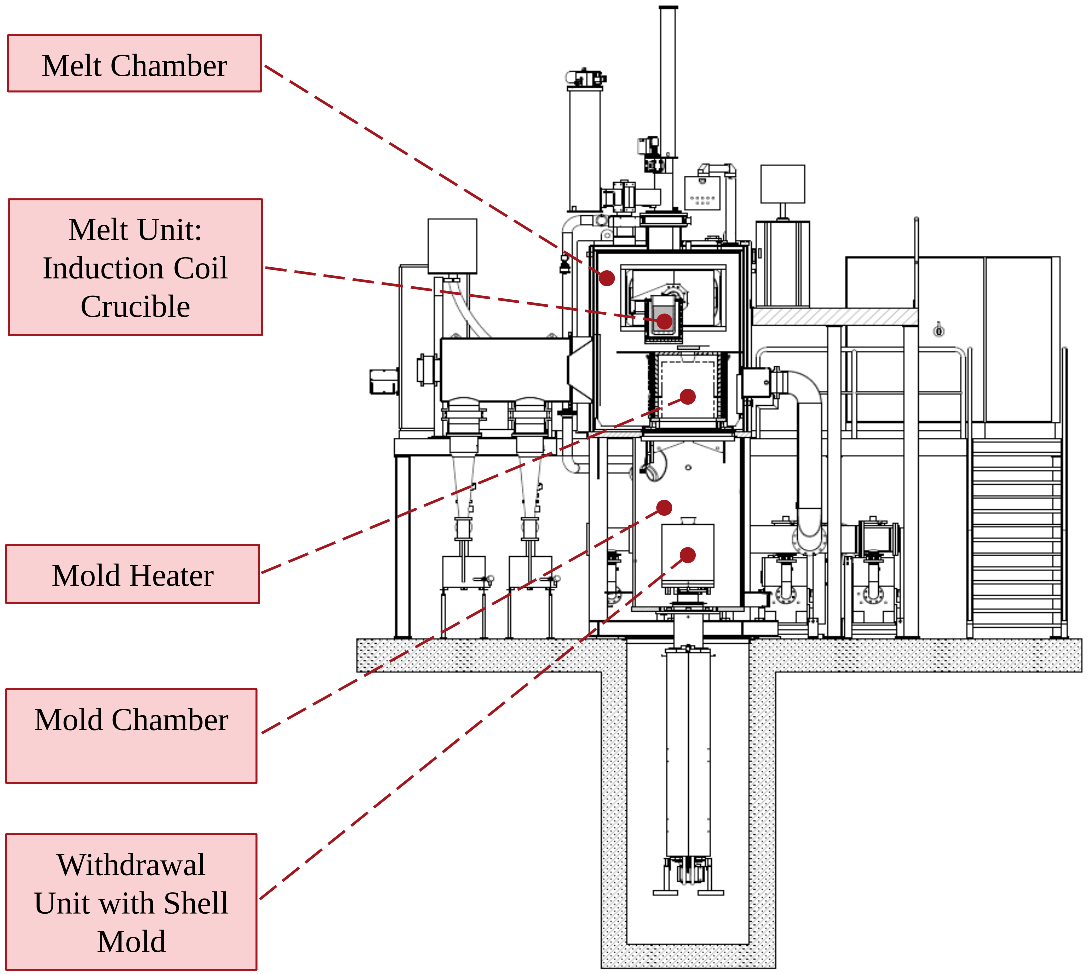
Features

- Spherical, super-clean powder
- Robust, reliable, reproducible
- Ceramics- and contact-free
  → reactive alloys (Ti-based)
  → high T_{liq} (refractory metals)

Vacuum Induction Melting + Investment Casting

"state-of-the-art" turbine blade production

VIM-IC DS/SC



Feedstock

- Pre-alloyed ingots or ingot between 15-150kg depending on the furnace size (additionally cut to fit the crucible)

Process

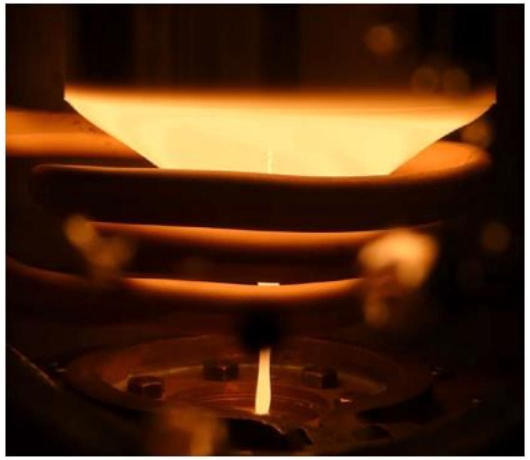
- **Melting (in back-up Crucible/one-shot Liner):**

  Material is heated up and melted in a permanent crucible or one-shot liner until casting temperature is reached.

- **Investment Casting:**

  The melt unit is tilted and poured into a preheated mould at a typical casting rate of 60-120 kg/min (DS/SC process)

Electrode Induction Melting + Investment Casting



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Process

- **Melting (crucible-free):**

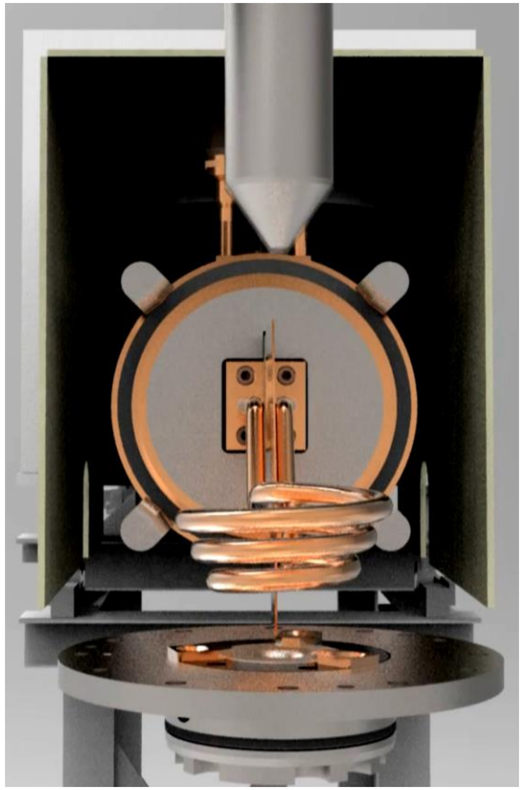
  feeding the electrode into a conical coil and induction melting of the electrode tip

- **Investment Casting:**

  melt stream fills a preheated mould at a typical casting rate of 60-120 kg/min (DS/SC process)

Can EIGA-melting be combined with Investment Casting in a new vacuum furnace design to make use of advantage of crucible-free melting?

Electrode Induction Melting + Investment Casting



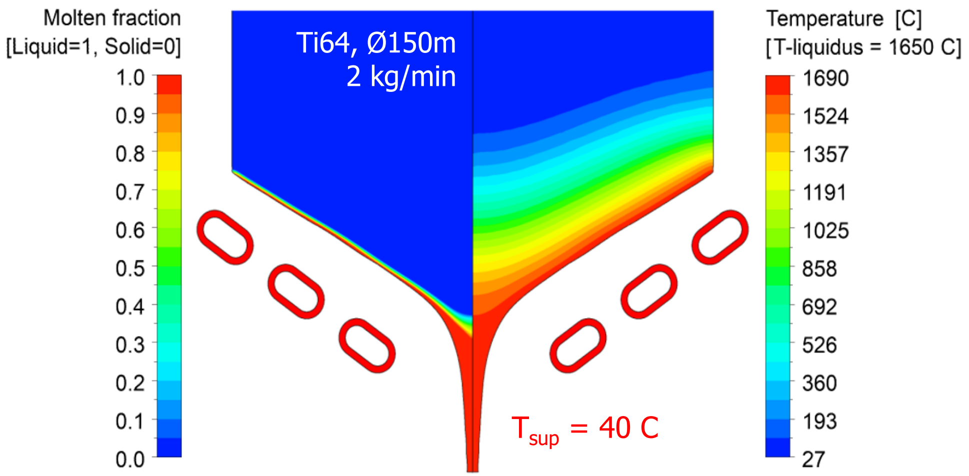
Is there a need from IC industry?

- ▶ Crucible-free (no wear/no consumables)
- ▶ Ultimate casting purity
- ▶ Easy to operate, reproducible, reliable
- ▶ Electrode:
  - → alloy supplied in form of electrode by alloy producer
  - → higher productivity & flexibility
  - → no need to cut the electrode

▶ Expensive high power generator for higher melt rates

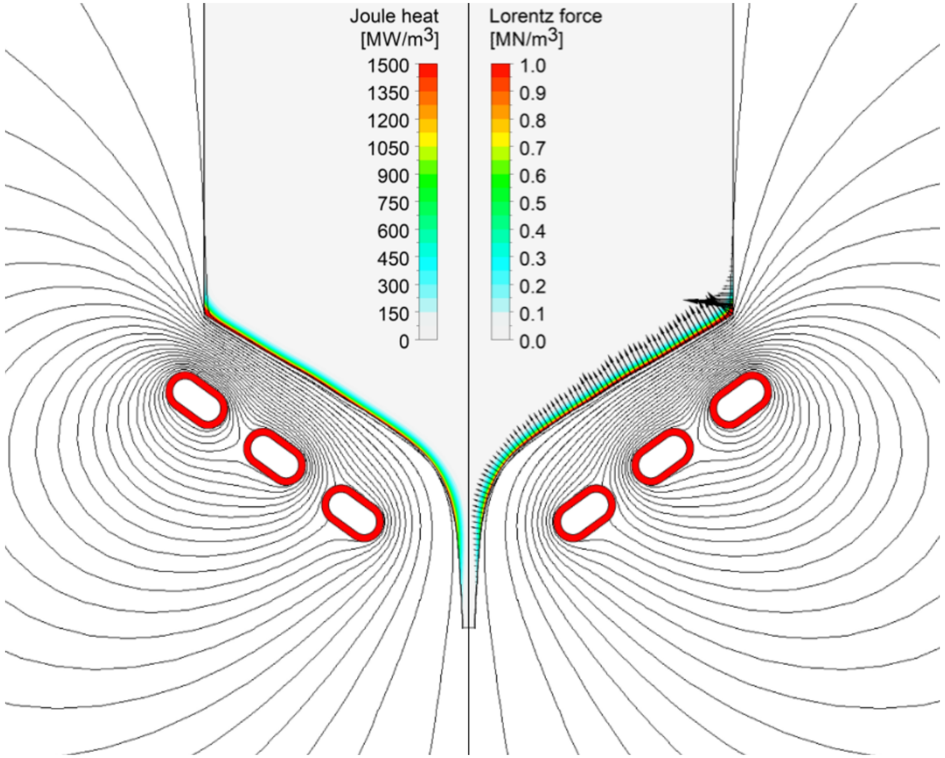
EIGA-melting – challenges to overcome:

- ▶ Well-established melt rates < 2.5 kg/min not sufficient
- ▶ Low melt superheat



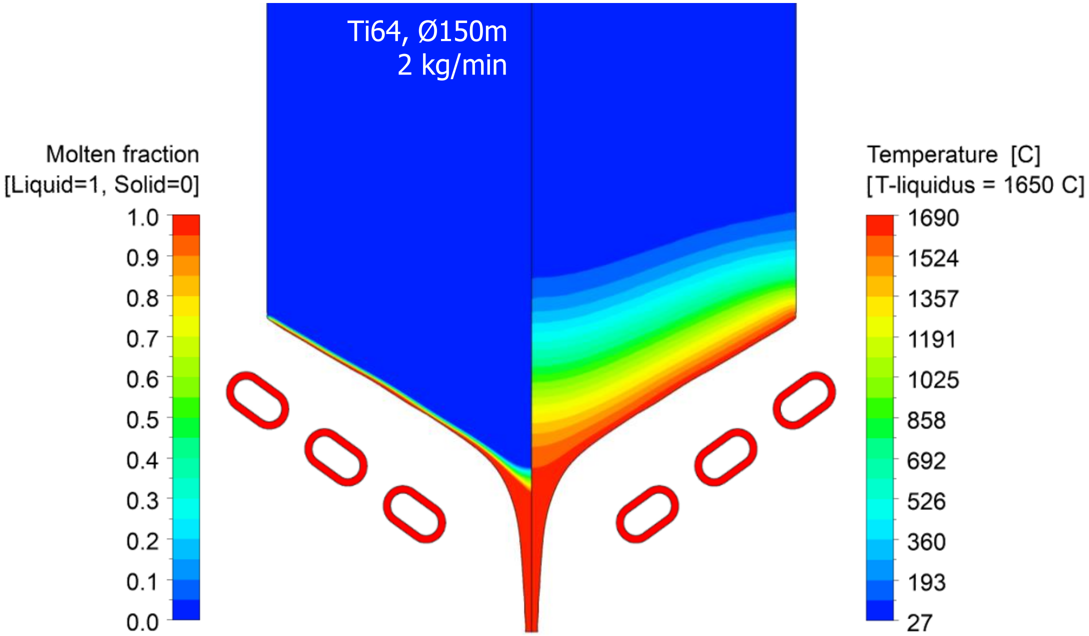
Simulation results

• Electromagnetic problem



- Joule heat and Lorentz force in the electrode
- Full description of the RLC-circuit
- AC current, voltage, frequency & power

• Heat transfer & fluid flow problem

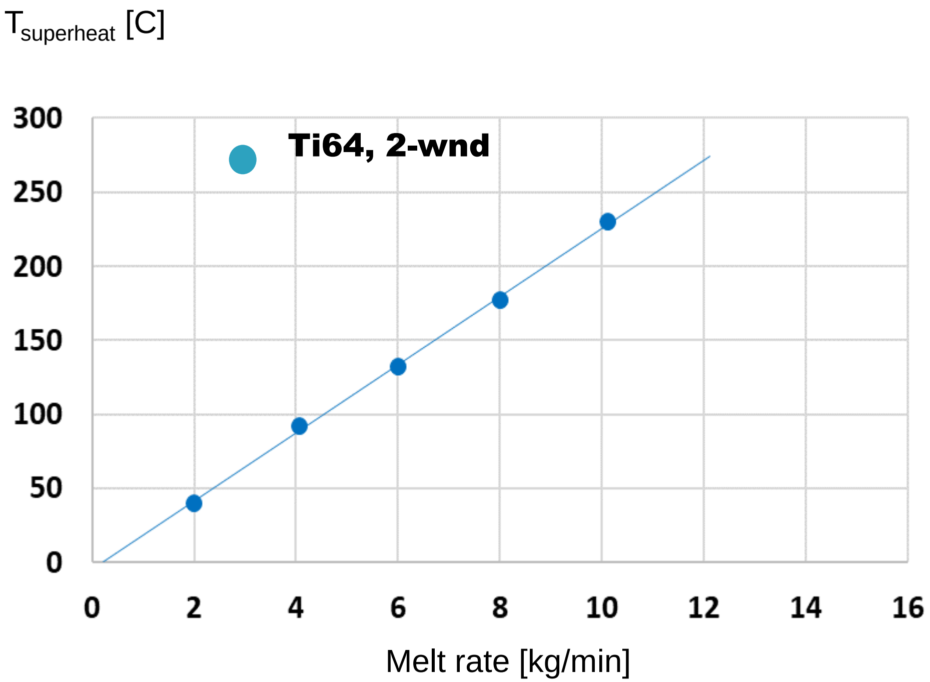


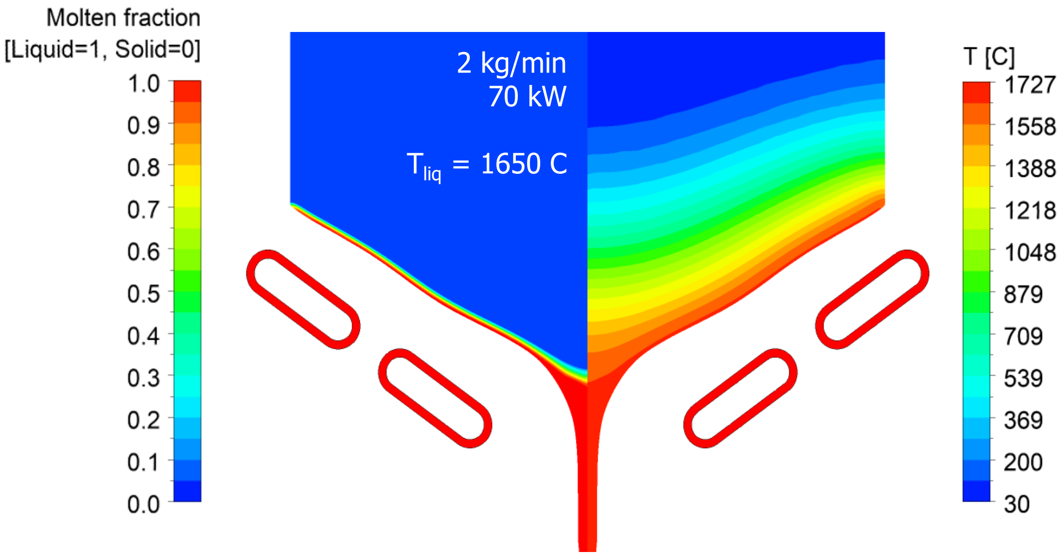
- Melting front shape & molten layer thickness
- Melt flow & surface tension effects
- Melt stream instability & break-up in droplets
- Radiation losses & **melt superheat**

Parameter study – melt rate

If the gap between the coil and conical electrode tip (system inductance) is kept the same:

The superheat is directly proportional to the melt rate





- Truly interesting results – low superheat expected!
- Material instantly leaks out of the zone of EM heating via thin melt layer at the electrode tip (low residence time unlike crucible melting)
- Due to small thickness and high thermal conductivity the layer is hard to superheat
- Why faster melting increases superheat?

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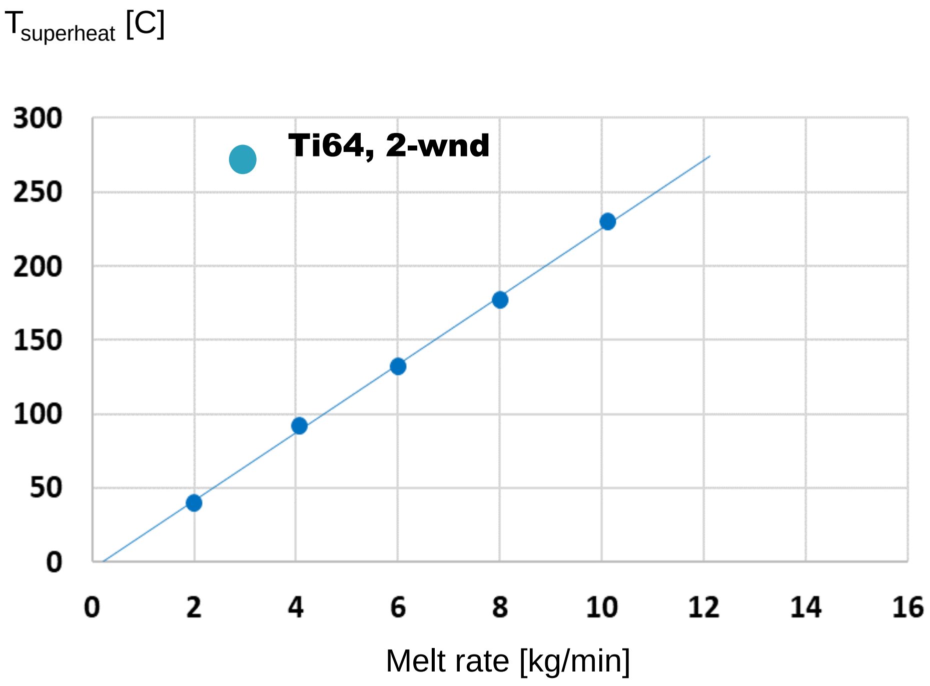

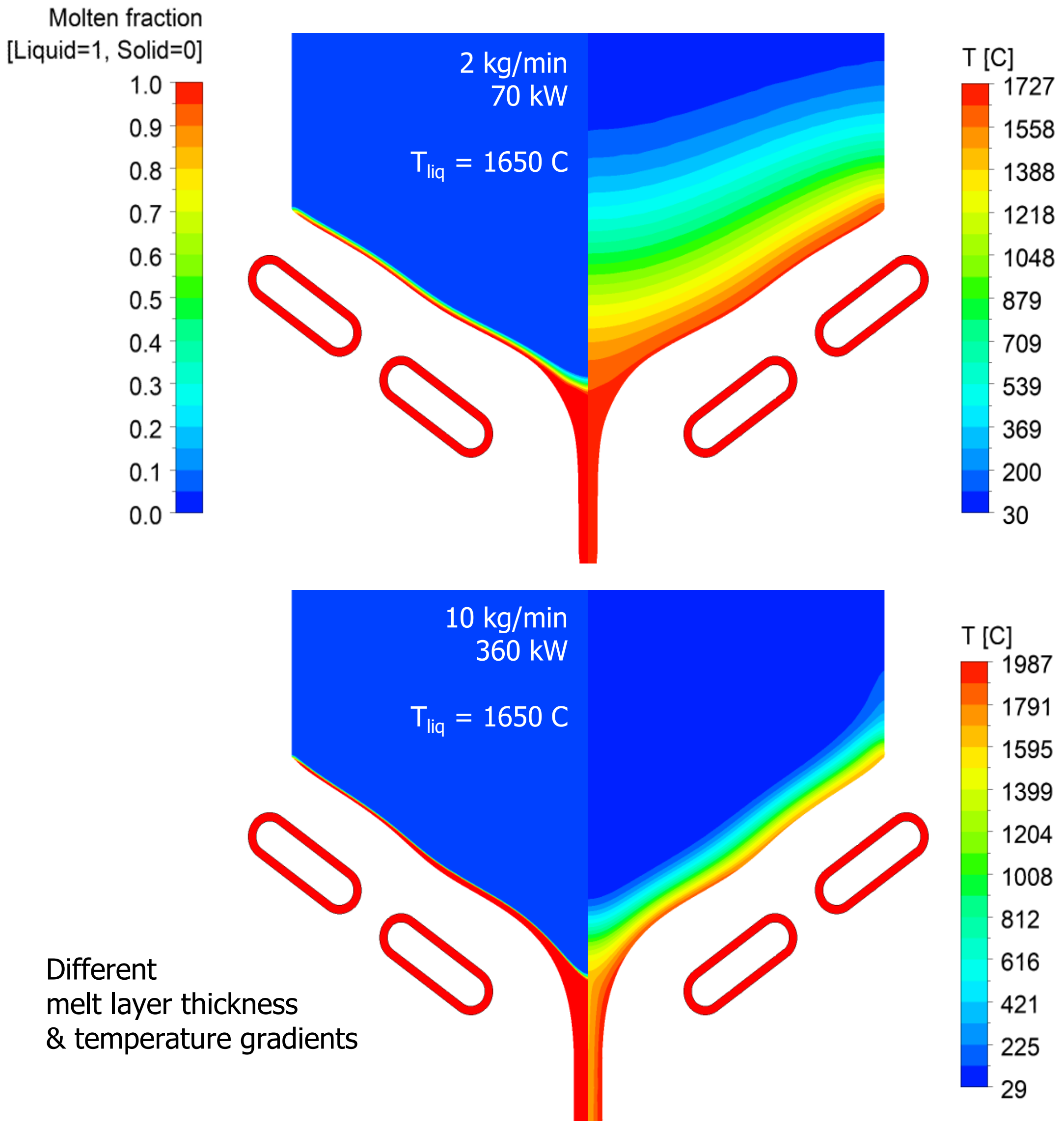

Different
melt layer thickness
& temperature gradients

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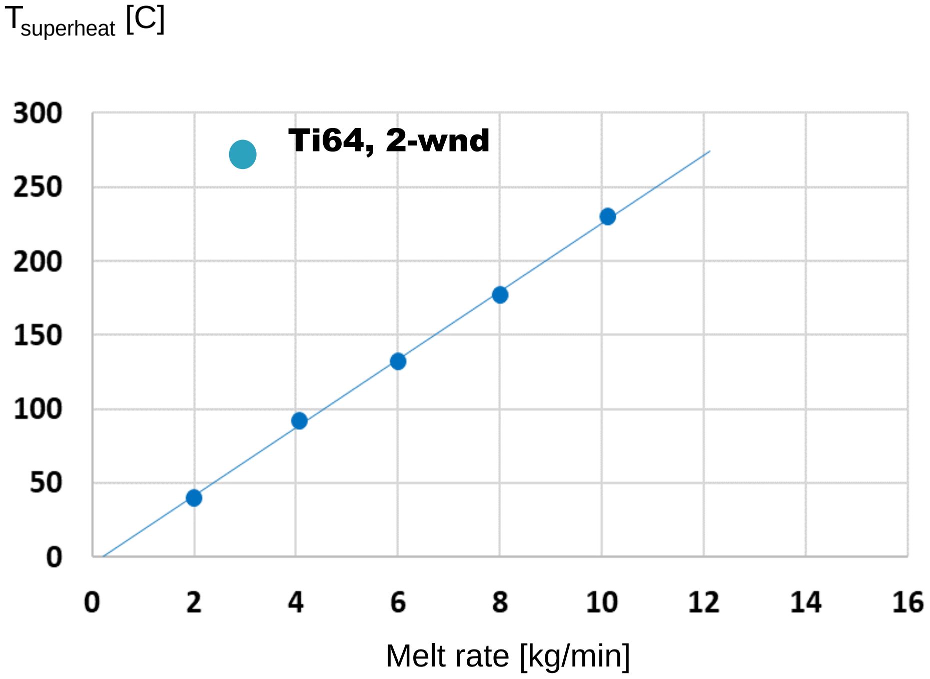

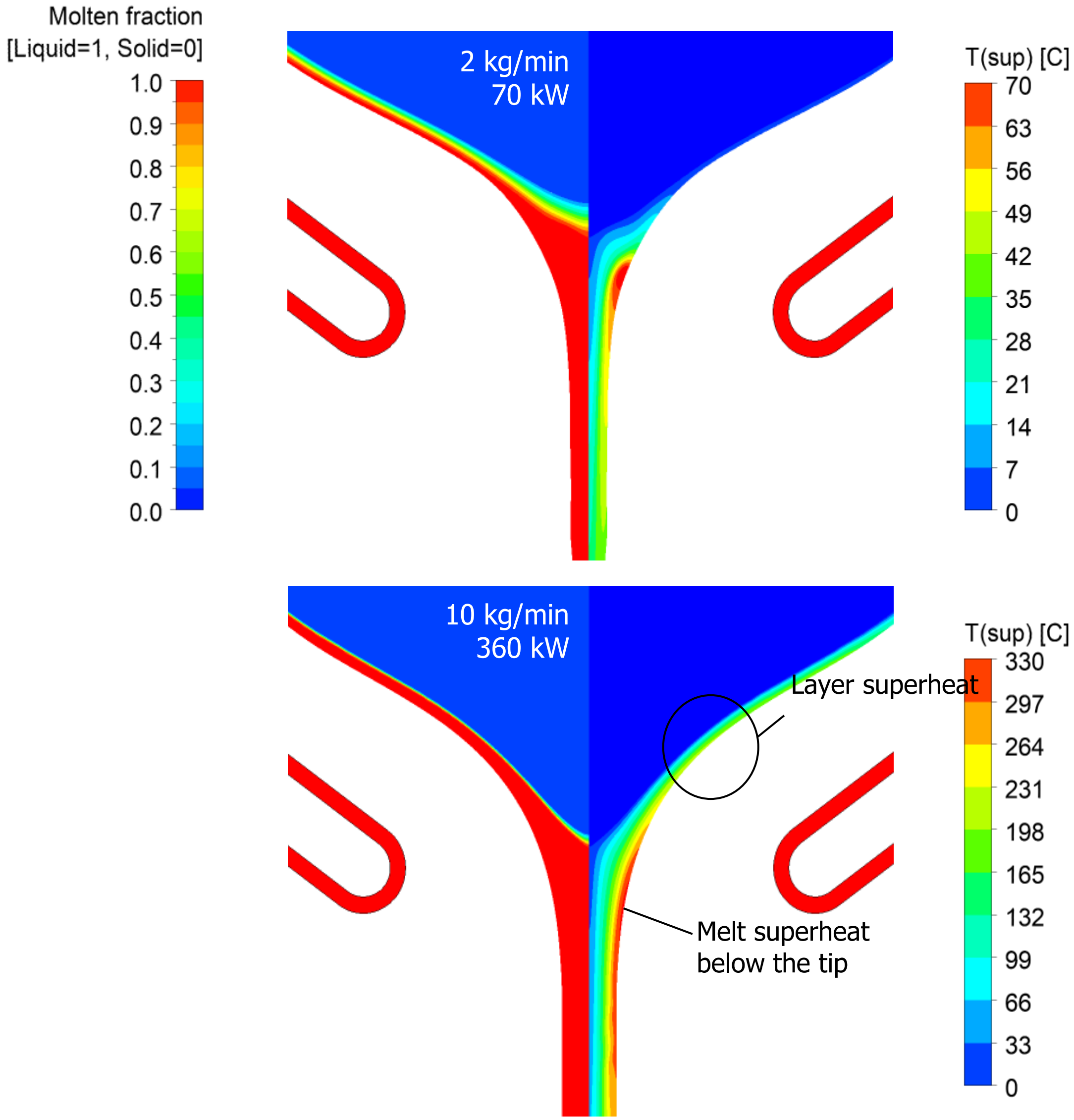

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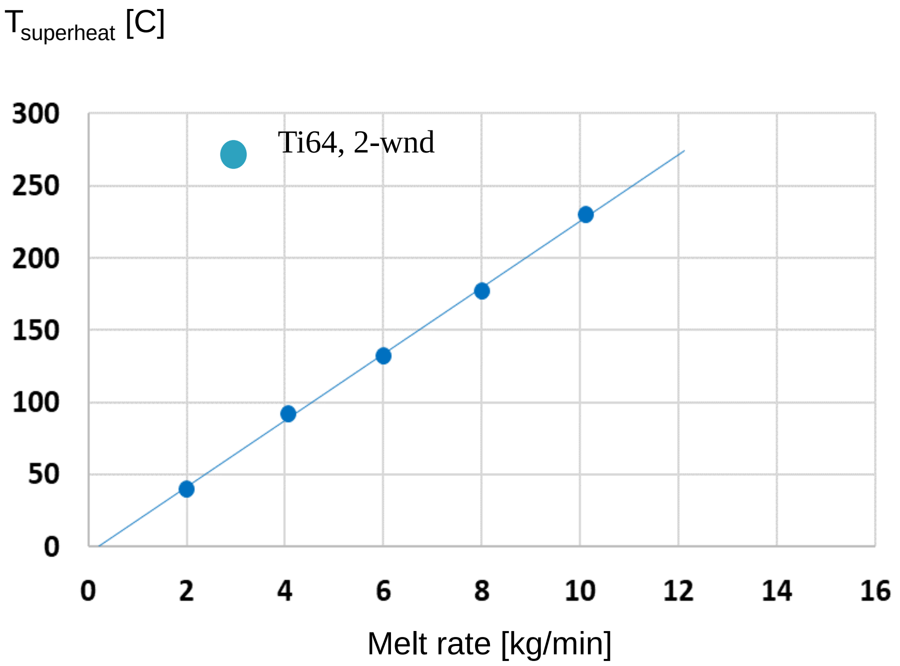

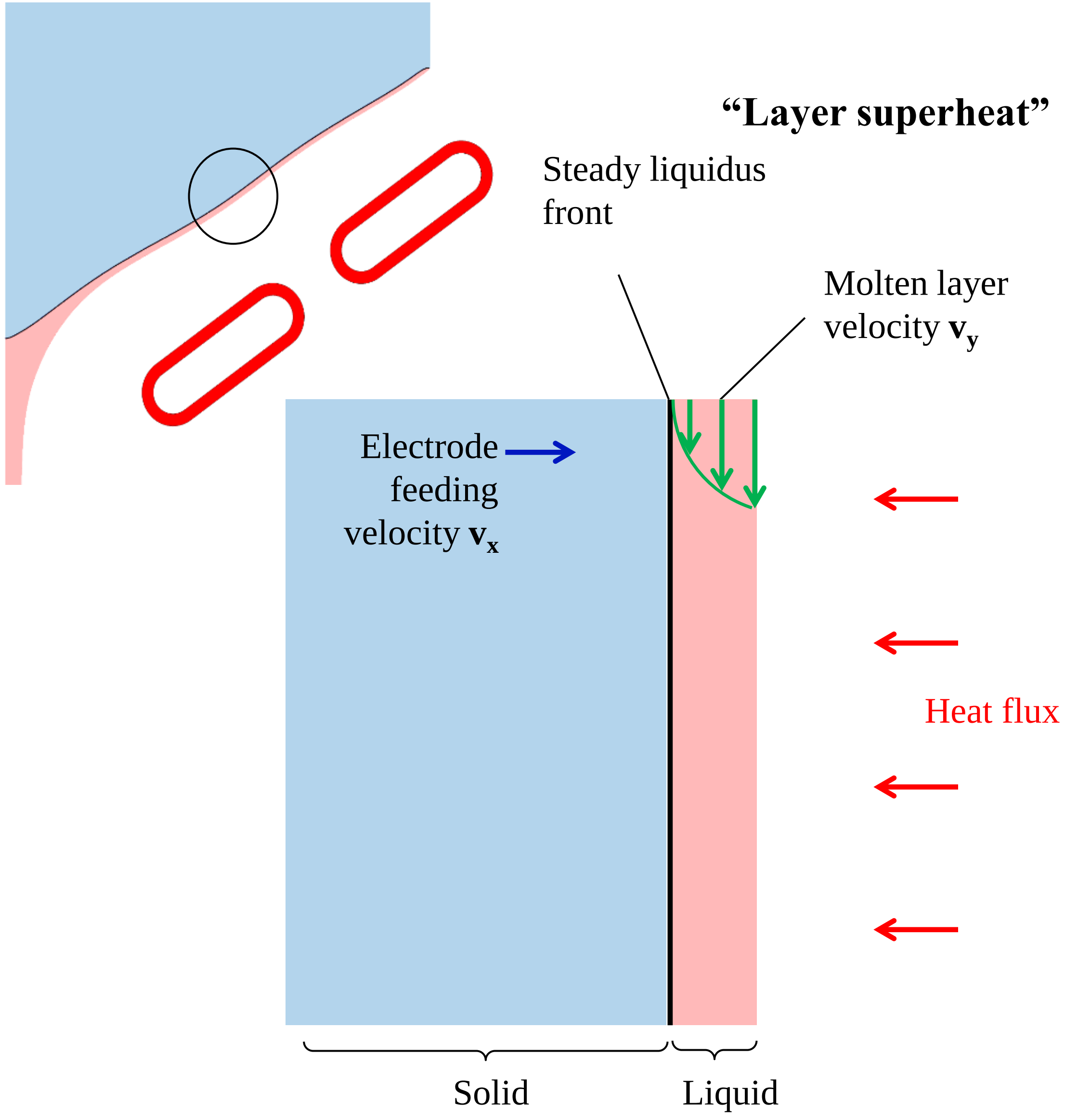

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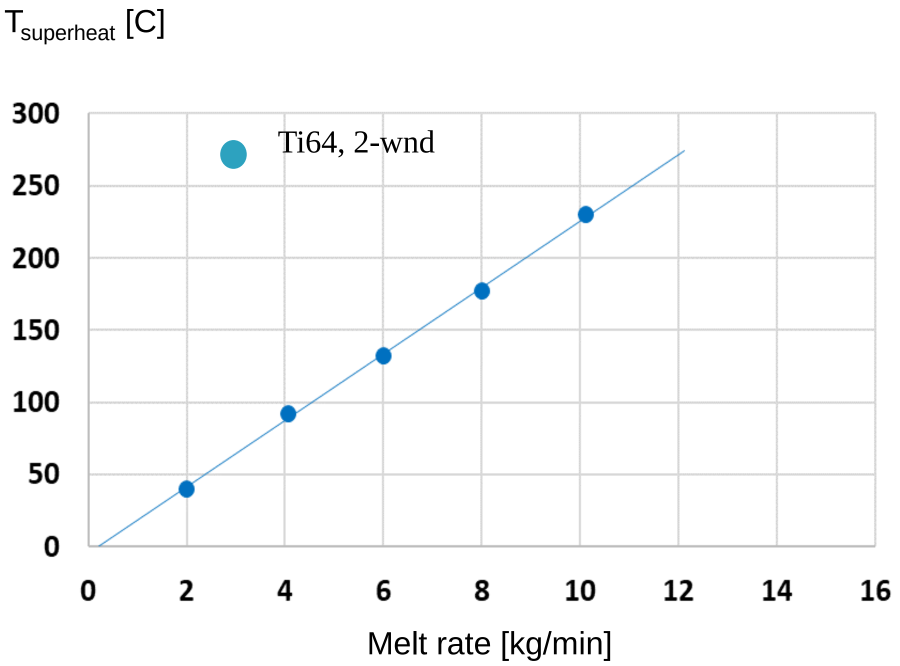

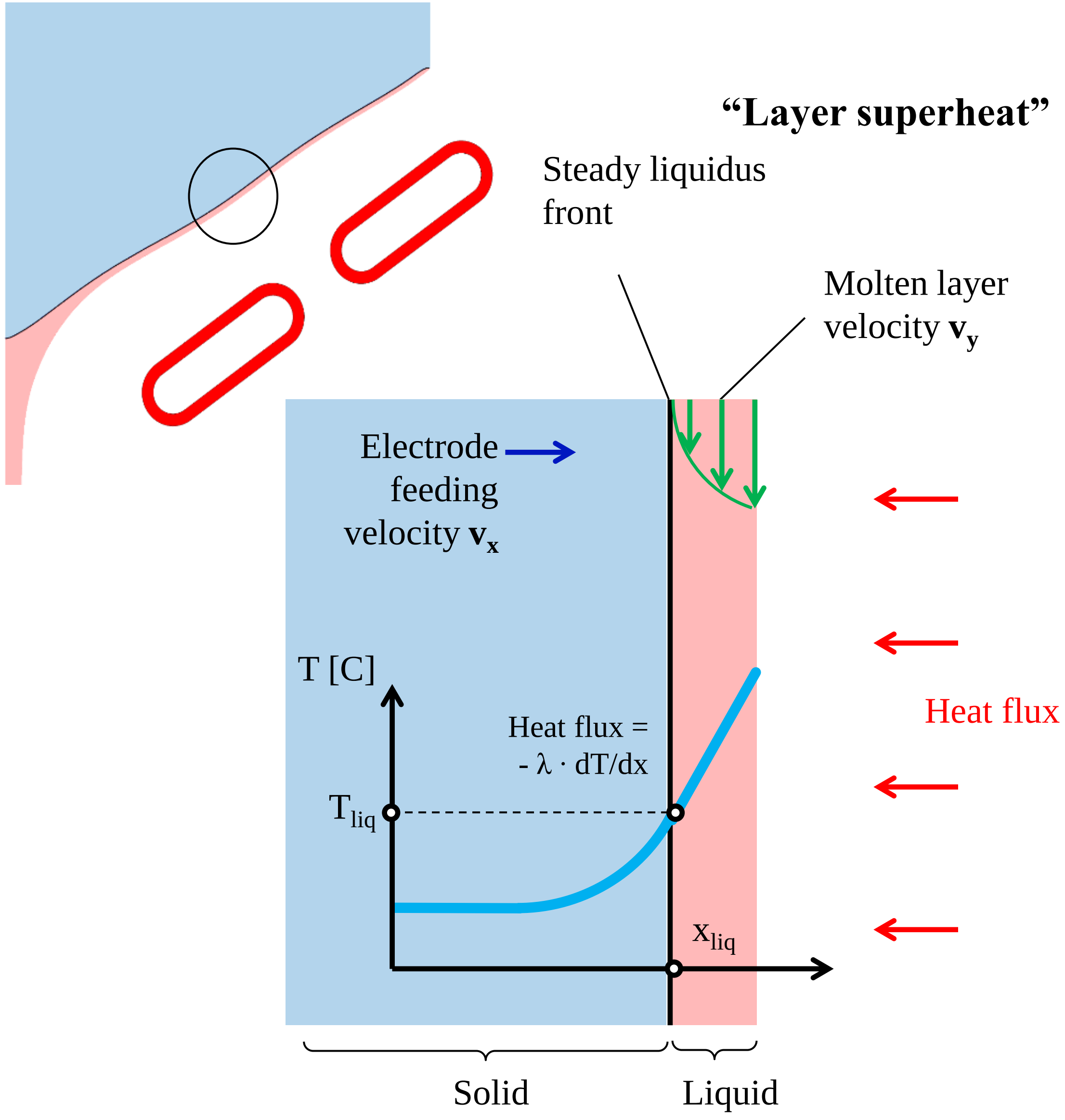

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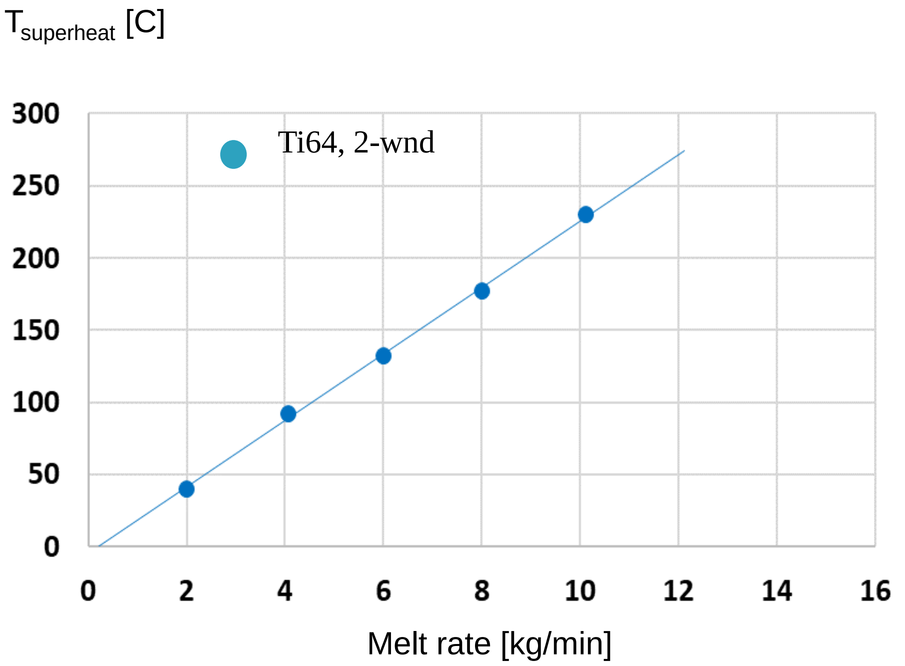

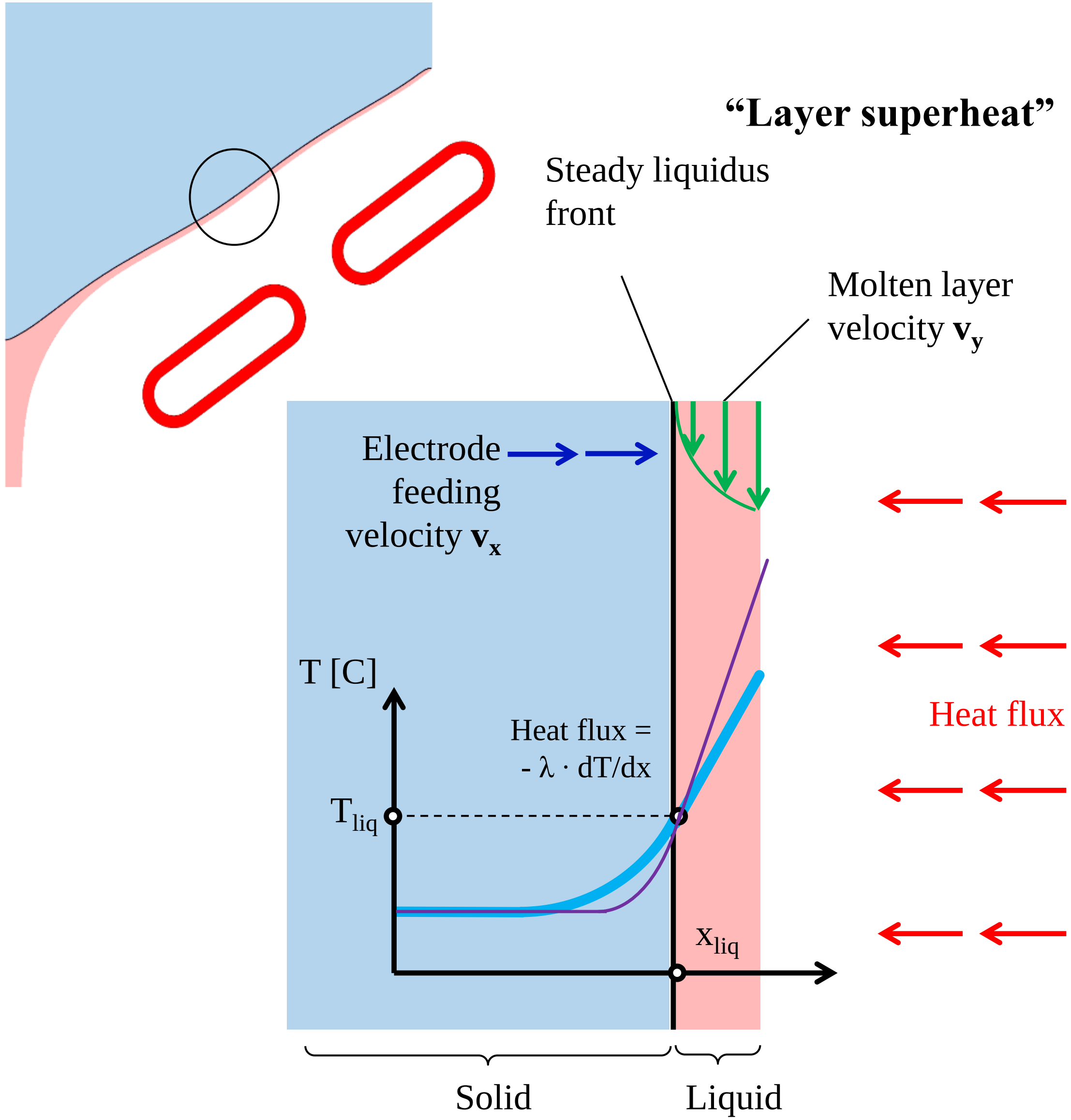

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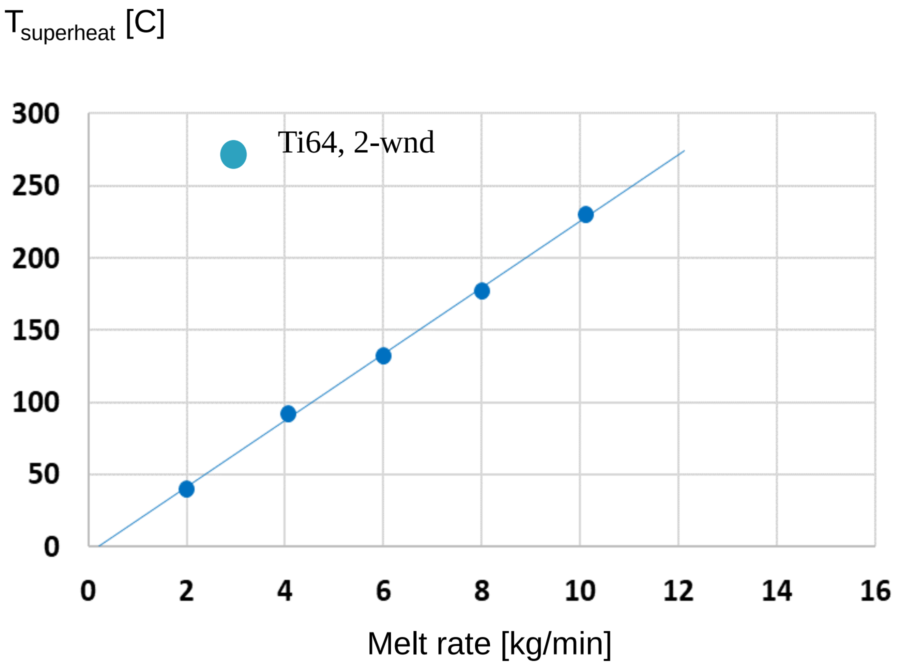
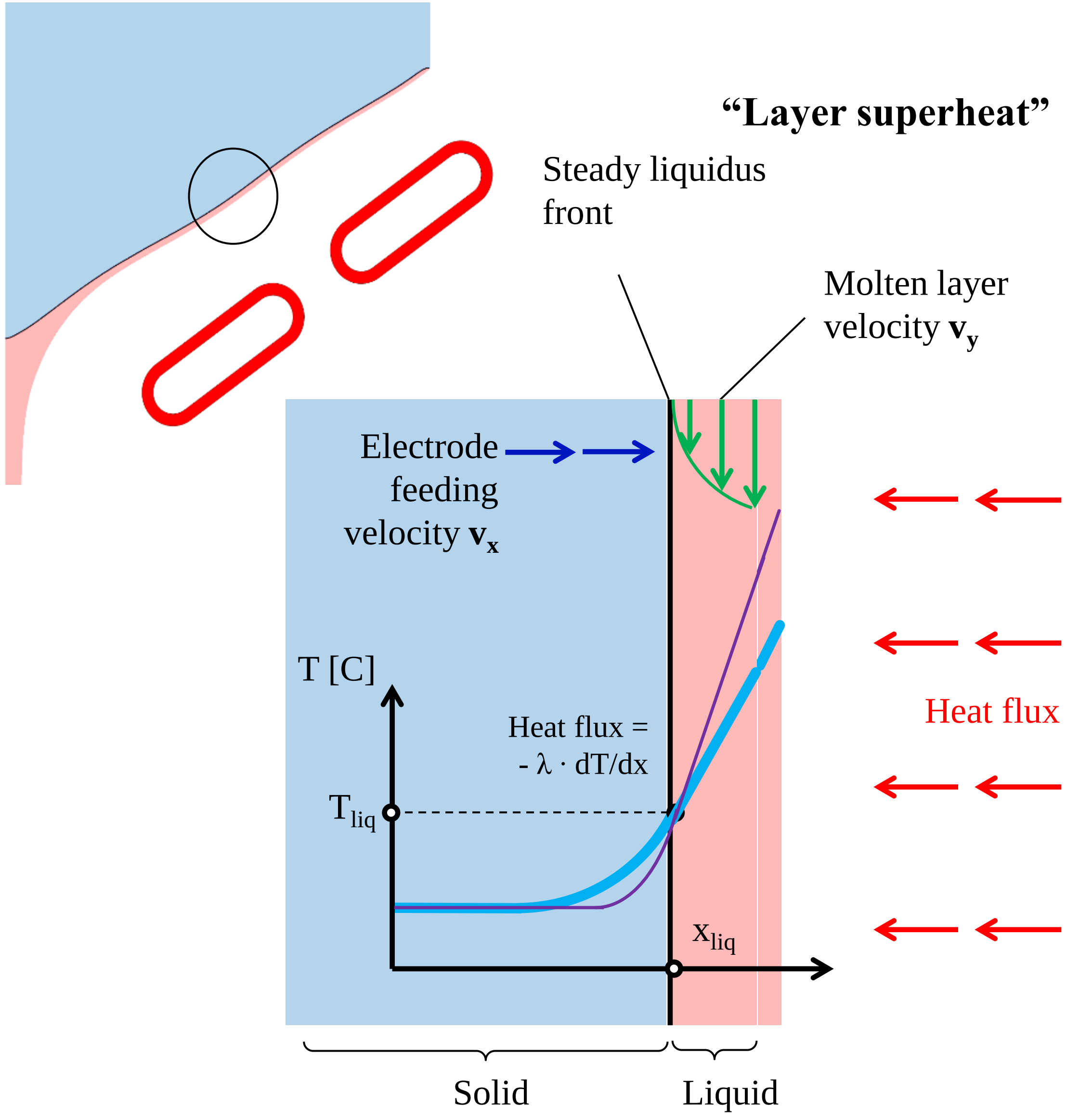


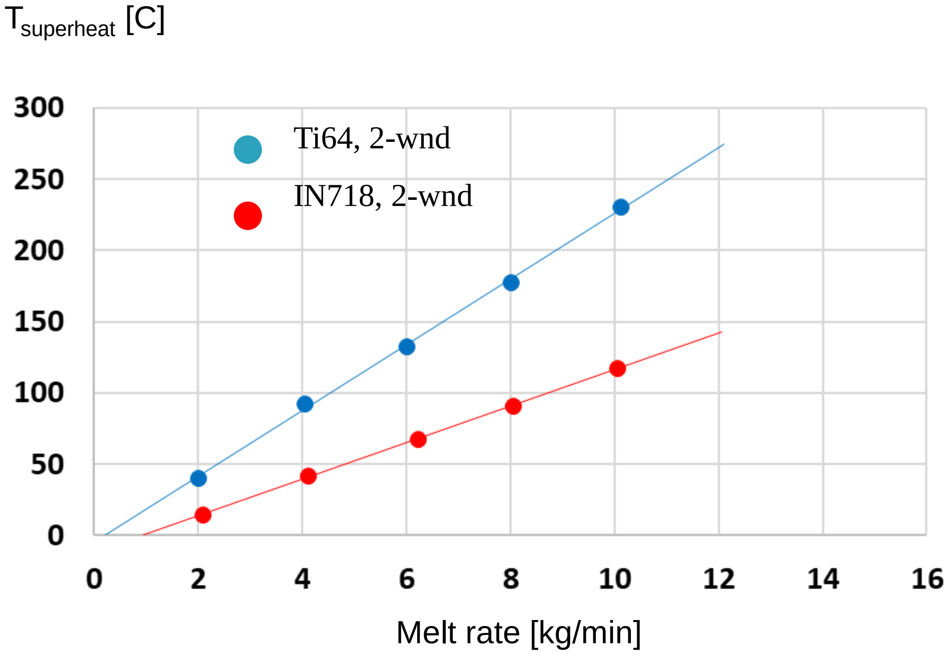


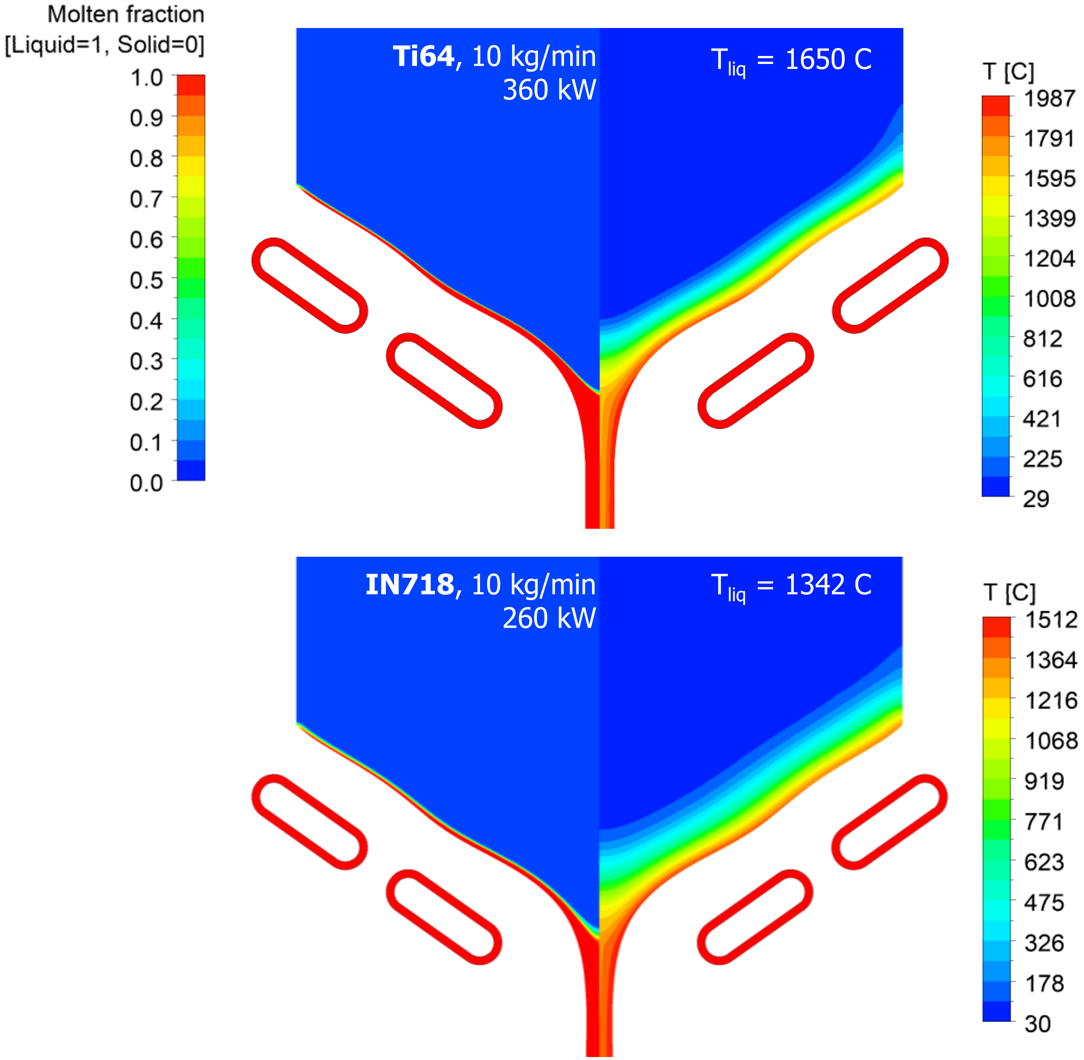
Parameter study – electrode material

The superheat depends on material properties

$\rho\uparrow, \lambda\uparrow, T_{liq}\downarrow, C_{p,solid}\downarrow, C_{p,liquid}\uparrow, L\downarrow$ …

$\rightarrow$ grad T$\downarrow$ $\rightarrow$ layer superheat$\downarrow$

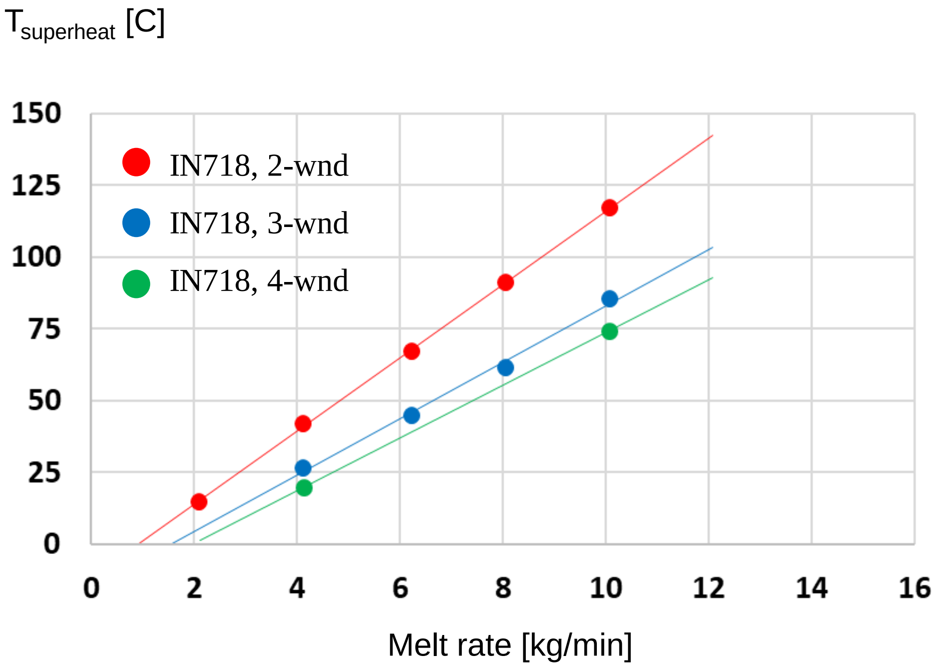




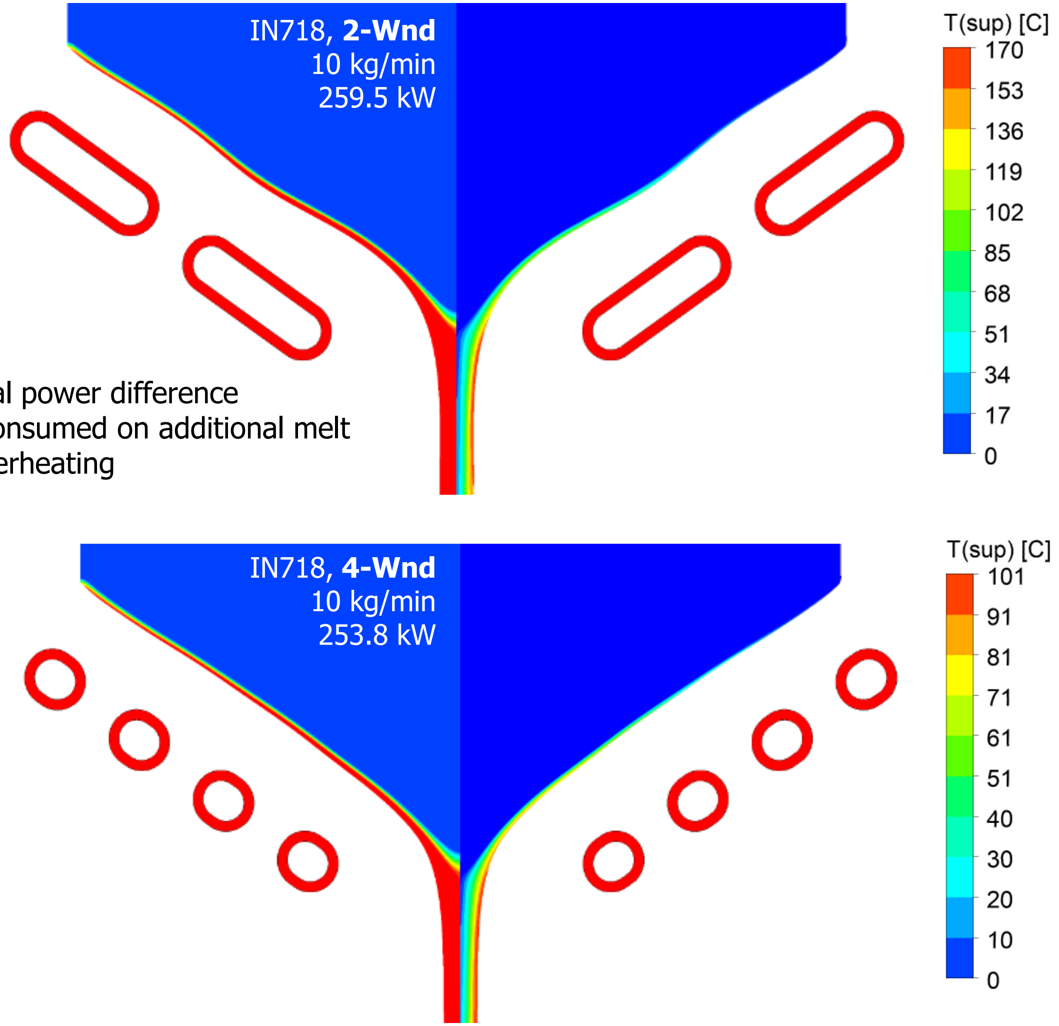
Parameter study – number of inductor windings

If the total power level is kept the same:

Less number of inductor windings increases melt superheat



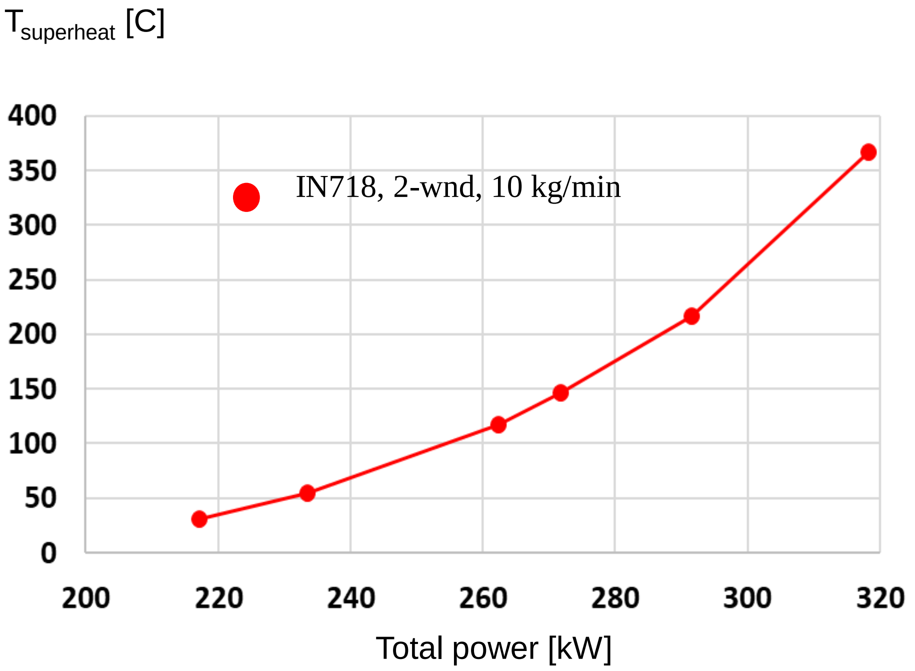
Total power difference
is consumed on additional melt
superheating



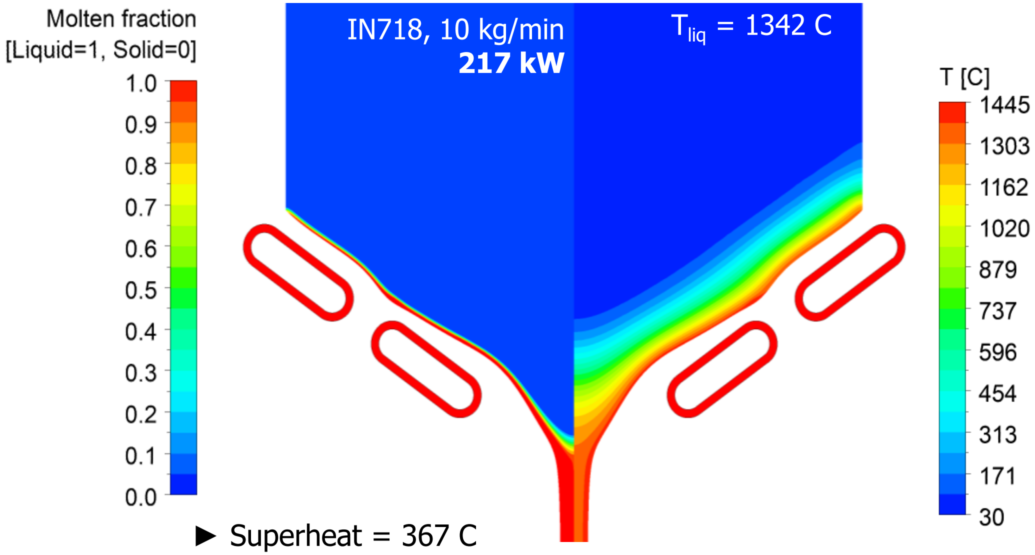
Parameter study – total power

**If the melt rate kept constant,
the superheat can be independently tuned by
the total power**

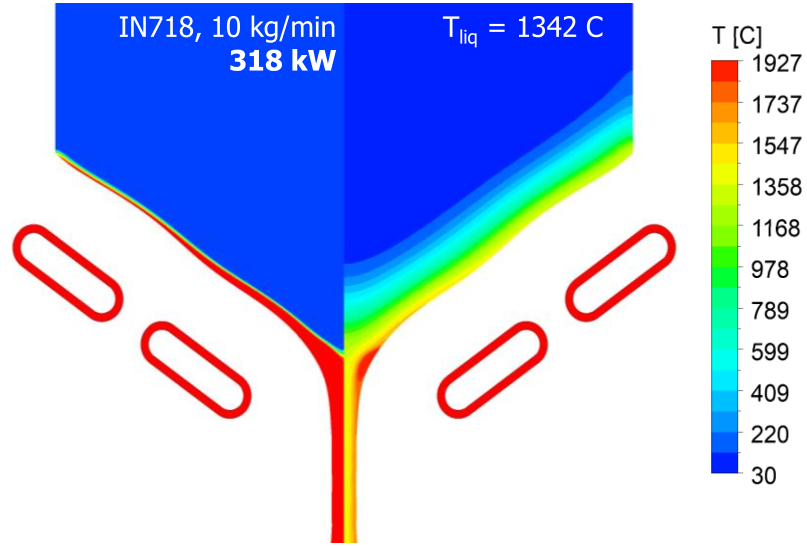
Wide-range, contact-free adjustment of the superheat is especially beneficial during **large castings**



► Superheat = 31 C



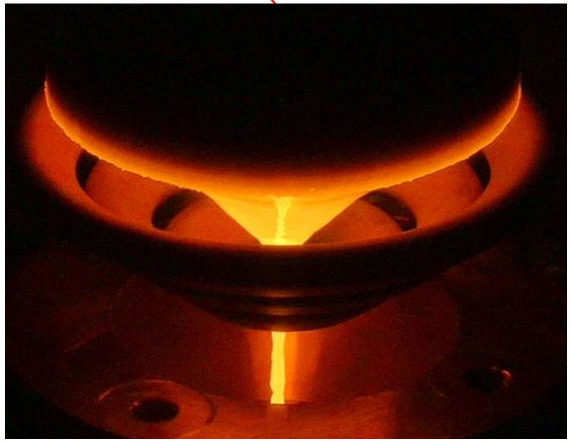
► Superheat = 367 C

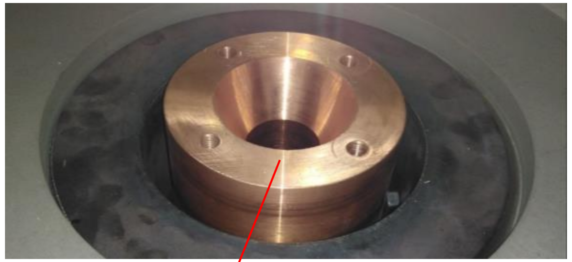


Parameter study – indirect verification

- ► EIGA-melting of the electrode and resolidification in the copper mould
- ► Resolidified ingot surface quality as a qualitative indicator of the melt superheat
- ► Tests done using real EIGA-furnace with 100 kW power limit

Ti64 electrode, Ø55 mm





Massive non-cooled copper mould

0.5 kg/min (Ti64)
40 kW

0.5 kg/min (Ti64)
54 kW

1.0 kg/min (Ti64)
92 kW

Conclusions

EIGA electrode melting for Investment Casting

- Crucible-free (no wear/no consumables), contact-less melting
- Ultimate casting purity
- Easy to operate, reproducible, reliable
- Electrode → higher productivity & flexibility
- Melt rates up 10 kg/min proved in simulation; Higher melt rates possible

  Power: 360 kW (Ti64), 260 kW (IN718)
- High superheat (up to 400 C) can be achieved and

  can be adjusted independently
- High efficiency of melting process compared to VIM, EB or VAR

	Unit		
		VIM-IC	Electrode Melting
Power	kW	175	260
Casting Weight	kg	25	25
Melt + Cast Rate	kg/min	3	10
Time (Process Step)	min	8.3	2.5
Power Consumption	kWh	24.3	10.8

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Conclusions

ALD is looking for interested partners to:

- Intensify discussion on the new melting process for DS/SC investment castings
- If all requirements can be meet, next step is designing a pilot system
- Experiments on the pilot system
- Analysis of data and development of the process