Table of Contents

• Consarc & Inductotherm Group
• Consarc Technology Team
• Melting Process:
  – Process Goals
  – Main Steps
  – Main Key Elements
• Final conclusions
What We Do

- Melting, Holding and Pouring
- Billet and Bar Forging
- Heating and Heat Treating
- Brazing and Soldering
- Strip Heating and Coating
- Pipe and Tube Production
- Pipe Coating
- Wire Production
- Vacuum Melting
- Vacuum Heating
Consarc have designed, manufactured and delivered vacuum furnaces for industry for over 50 years.
Products and Applications

MELTING APPLICATIONS

- Vacuum Induction Melting (VIM)
- Vacuum Arc Remelting (VAR)
- Electroslag Remelting (ESR)
- **Vacuum Precision Investment Casting (VPIC)**
- Vacuum Inert Gas Atomizing (VIM-IGA)
- Vacuum Cap Furnaces (VCAP)
- Induction Skull Melting (ISM)
- Induction Vacuum Ladle
- Custom/Proprietary Processes

HEATING APPLICATIONS

- High Temperature Heat Treat (to 3000°C)
- Vacuum Heat Treatment/Brazing
- Chemical Vapor Disposition/Infiltration
- Diffusion Bonding
- Vacuum De-Oiling/Custom/Proprietary Processes
Table of Contents

• Consarc & Inductotherm Group
• Consarc Technology Team
• Melting Process:
  – Process Goals
  – Main Steps
  – Main Key Elements
• Final conclusions
Consarc Technology Team

• Consarc has recently created a New Technology Team.
• Team supports:
  – Sales during offer stage
  – Engineering during product development
  – Service during commissioning and testing at customer site
  – Customers during production
• The team contains 8 people:
  – 3 full time members based in Europe.
  – 4 full time members based in USA.
  – 1 full time member based in Japan.
• Network of consultants (field specific).
• Team has far researching backgrounds and production of various materials, processes and processing equipment with a focus on VIM, ESR, VAR, VPIC, VIM-IGA and ISM technologies.
Table of Contents

• Consarc & Inductotherm Group
• Consarc Technology Team
• Melting Process:
  – Process Goals
  – Main Steps
  – Main Key Elements
• Final conclusions

Consarc Vertical 45Kg Induction Skull Melting Furnace (ISM).
Melting Process Goals

• **Quality** — *good chemistry and clean melt*—
  – **Metallurgy**: melting process should not impact negatively the chemistry of the alloy.
  – **Liner/crucible integrity**: melting process should happen producing no damage or breakage of the liner/crucible.

• **Consistency** — *always the same process*—
  – **Human factor**: avoid them or keeping to the minimum.
  – **Material**: prevent any material change factors.
  – **Machine**: avoid any deleterious machine effect due to its wrong behaviour.

• **Productivity** — *melt fast*—
  – **To enable producing as many casts as possible**, then reducing the cost (especially applicable to equiax casting process).
# Table of Contents

- Consarc & Inductotherm Group
- Consarc Technology Team
- Melting Process:
  - Process Goals
  - Main Steps
  - Main Key Elements
- Final conclusions

*Consarc combined DSSX and Equiax VPIC Furnace.*

50kg DSSX, 100kg Equiax
Melting Process Main Steps

Basic VPIC process flowchart (EQUIAX)

PROCESS AWAY FROM THE VPIC FURNACE

Process

Shell mold
Mold wrapping
Mold preheating

PROCESS IN THE VPIC FURNACE

Ingot/Liner

Ingot melting

Mold transfer in
Mold pour
Mold transfer out

Casted mold

(Ref. [1], [2], [3], [4])
# Basic VPIC process flowchart (DSSX)

## Material
- Shell mold
- Mold wrapping
- Mold preheating

## Process
- Mold transfer in
- Mold heating
- Mold pour
- Mold withdrawal
- Mold transfer out

## Process Away from the VPIC Furnace
- Ingot/Liner

## Process in the VPIC Furnace
- Ingot melting

(Ref. [1], [2], [3], [4])
Basic Melting Process Flowchart

- Ingot/Liner
- Liner and Ingot Loading
- Ingot melting
- Melt temp measure
- Melt dross evaluation
- Melt pour temp regulation
- Melt ready to pour

Inductotherm Induction Coil Unit
Table of Contents

- Consarc & Inductotherm Group
- Consarc Technology Team
- Melting Process:
  - Process Goals
  - Main Steps
  - Main Key Elements
- Final conclusions
Melting Process Key Elements

Main Key Elements

1. *Induction Power Supply (VIP®)*: it creates the power needed to melt the alloy.
2. *Induction Melting coil*: it contains the liner/crucible.
3. *Ingot*: the alloy to be melted.
4. *Liner/crucible*: to hold the alloy.
5. *Ingot/Liner loading stage*: to load and unload liners, and load alloy.
7. *Cameras and viewports*: to record/witness the melting process.
8. *Vacuum system*: to prevent any oxidation, as well as trace elements and harmful impurities removal from the alloy, during melting.
9. *Melting Procedure*: specific procedure used for heating and melting the alloy (key factor).
Melting Process Key Elements

VIP UNIT

INGOT/LINER LOADING SYSTEM

INGOT

LINER/Crucible

VIEWPORT

DIP TC

CAMERA/OPTICAL PYROMETER

MELTING COIL
VIP® Unit

- Inductotherm VIP® unit converts multi-phase line voltage into a **single-phase variable frequency current** injected into the induction coil.
- Power and frequency selection matching the load:
  - The **power** directly heats metal inside the induction coil, and it is sized depending on the melting rate and total charge to be processed.
  - The **frequency** is calculated to get the best coupling and stirring effect. Consarc offers multifrequency VIP® based on the customer charge demands.
- The best VIP® unit design gives the **quickest**, and **most reliable-efficient-accurate** melting process.
Induction Melting Coil

- The melting process happens in the coil because the magnetic induction fields created inside it couple to the ingot and then melt it.
- Coils are connected to the VIP® through the power leads.
- The size of the coil and the number of turns is calculated by the maximum and minimum alloy to be melted.
- If melting range is big, the best solution is to have different size coils and exchange them when required.
- Consarc enables easy and safe coil changes due to coil-lead connections out of the vacuum.
Melting Process Key Elements

3 Ingot (Alloy)

- The **ingot size** should try to maximize the liner/crucible internal diameter for an optimum coupling, and then, fastest melting.
- **One ingot loading** is preferable to multiple loads. If multiple is done, the small piece ingot should be loaded into the bottom of the liner.
- **Chamfered bottom** is recommended for a safe contact with liner/crucible, preventing any scratching.
- **Soft loading** needed also to prevent scratching.
- Both incoming ingot and final casting **chemistry** shall be controlled, to guarantee a good melting practice.
Liner/Crucible

- **One Shot Liners** always preferable due to their quality advantage against single rammed crucibles.
- **Material** selection is a key factor to prevent or minimize reaction between the alloy and the refractory:
  - Fused silica as the most standard one.
  - Alumina and Zirconia for reactive alloys.
- **Drying** of liner before its use is very recommendable due to yield improvements.
- **Liner Size** shall meet the charge requirements guaranteeing a % of filling.
- **Backup crucible** shall have minimum 13mm gap inside the coil to make the ramming properly.
Melting Process Key Elements

Refactory/Melt interactions

1. Deposits of metal splashes from melt into the liner wall.
2. Spalling of splashes back into the melt.
3. Metal vapour transfer from melt to the liner wall.
4. Atmosphere interactions with melt surface.
5. Liner vapor expanding into the atmosphere.
6. Liner vapor transfer to liner wall and alloy.
7. Skull-dross layer formation into the liner wall.
8. Metal vapour of diffusion into liner.
10. Metal vapour expansion into atmosphere.
12. Agglomeration of slag/dross on crucible wall.

(Ref. [10])
Melting Process Key Elements

5 Ingot/Liner Loading

- **Soft loading** is always required to avoid scratching (horizontal loaders preferable).
- **Vertical loading** systems for big charge situations approx. >100Kg.
- **Horizontal loaders** for smaller charges approx. <=100Kg.
- Consarc offers **liner disposal** systems for quick liner removal, saving process cycle time.
Temperature Measuring Devices

- **Optical pyrometers** for continuous melt temperature measuring:
  - External sight glass with isolation valve protection.
  - Argon bleed with mass flow control.
  - Alloy emissivity/slope correction factor (also in the recipe).
  - Automatic correlation/compensation to DIP TC reading if required.
  - Dual pyrometer systems for a consistent process.
  - Laser sighting/Integrated camera option/Air curtain system option.

- **Dip TC** devices for pyrometer discrete checking/calibration:
  - Accurate and automatic immersion.
  - Quick change type B thermocouple probe.
  - Multi-dip sheath design, single use TC or interchangeable designs.
  - Not affected by the alloy type.
  - Trend towards less use of this system (potential contamination)
Cameras/Viewports

- **Cameras** very recommendable to witness the process and assure a consistent melting cycles. Also to evaluate the dross level of the melt before pouring.

- **Viewports** for the operators located in appropriate positions to watch the process properly.
Vacuum System

- **Vacuum** to make sure a stable level of pressure during the melting stage, preventing any **oxidation** of the melt:

- Vacuum systems are based on 2 systems:
  1. **High vacuum systems:**
     - *Diffusion pumps* high vacuum (~10e-4 mbar) during melting.
     - *Oil Vapour Boosters* lower vacuum (~10e-3 mbar), but more stable vacuum.
  2. **Roughing vacuum systems:** based on mechanical and roots type pumps, achieve ~10e-2 mbar vacuum ranges.

(Ref. [11], [12], [13])
Melting Process Key Elements

- **Avoid too deep vacuum**: alloy composition could be affected by vaporization of elements during melting. The longer time at temperature and at the vacuum level, the greater the loss of the metallic elements by evaporation.

![Element Vaporization Temperature as a function of the Pressure](image)

- **Avoid leaks**: leak up rate test is the key factor rather than vacuum level. Always better dynamic tests instead of static.

(Ref. [14])
Melting Procedure

- **Automatic** melting recipe for a consistent melting stage:
  - Prevents human factor as the melting cycle runs automatically.
  - Contains regulation of power during the solid and liquid stages of melting.
  - Avoids metal splashes by the programmed reduction of power when necessary.
  - Targets repeatable total melting time/energy.
  - Assures the same minimum metal-refractory interaction time avoiding undesirable inclusions.
  - Assures the same thermal cycle.
Melting Process Key Elements

• **Additional process controls:**
  
  – *KPV data logging*: the ability to record and subsequently analyse all Key Process Variable data.
  
  – *Tracking Variables*: the ability, in an automated manner, to create alarms for defined parameters that are out of tolerance through a cycle. The following figure includes an example of a tracking variables graph monitoring the melting kW with the time, defining a high and low level tolerance limits.

![Example of Consarc Typical Tracking variables system for melting kW](image-url)

---

Non Confidential © 2020 Consarc Engineering Ltd
Melting Process Key Elements

Basic Theoretical Melting Graph

- Ingot loads
- Heating starts
- Heating continues
- Melt starts
- Melt continues
- Melt finishes
- Ingot floats
- PID control regulates temperature

- Ingot starts getting red
- Ingot gets more red
- Ingot gets more red
- Melt splashes require reducing the power
- There is enough melt, splashes disappear and power can be raised again
- Ingot starts floating
- Ingot floats
Table of Contents

• Consarc & Inductotherm Group
• Consarc Technology Team
• Melting Process:
  – Process Goals
  – Main Steps
  – Main Key Elements
• Final conclusions
Final Conclusions

➢ Melting stage is one of the most critical activities in the Investment Casting Process.

➢ It is a key point for a successful and defect free casting process.

➢ It involves several important stages/activities to be controlled and improved:

1. **VIP® power unit and coil designs**, to match and accommodate all the melting requirements (*productivity and consistency)*.

2. **Ingot preparation and sizing**, to prevent scratching, and to have the best induction coupling during melting stage (*quality and consistency)*.

3. **Liner/Crucible material and shape selection**, to have the minimum and most controlled melt-refractory reaction (*quality and consistency)*.
4. *Ingot and Liner/Crucible loading*, to have the fast and reliable charge (*consistency and productivity*).

5. *Melting witnessing/controlling* with viewports/cameras and pyro dip-TC systems, to have process control (*quality and consistency*).

6. *Vacuum system*, to protect the alloy from oxidation and accurate chemical control (*quality and consistency*).

7. *Appropriate melting procedure/automation/logging/control* for an accurate, fast and consistent melting process (*quality, consistency and productivity*).
Thanks

References:
[1] milwakerec.com
[2] dalme.com
[3] foundrymag.com
[4] aerometals.com
[6] ihi.co.jp
[7] TW metals
[8] fireline Inc
[9] zircoa.com
[10] production of inclusion free inclusion castings... Thomas J. Thornton
[12] edwards.com
[13] Leybold.com