# ALD Vacuum Technologies

High Tech is our Business

# Vacuum Arc Remelting (VAR)

## Vacuum Arc Remelting Processes and Furnaces

# Vacuum Arc Remelting (VAR)

ALD is one of the leading suppliers of vacuum melting furnace technologies for engineered metals

**12 ton VAR furnace from ALD**

**VAR is widely used to improve the cleanliness and refine the structure of standard air-melted or vacuum induction melted ingots (called consumable electrodes). VAR steels and superalloys as well as titanium and zirconium and its alloys are used in a great number of high-integrity applications where cleanliness, homogeneity, improved fatigue and fracture toughness of the final product are essential.**

## Fields of Application

- Aerospace
- Power generation
- Chemical industry
- Medical and nuclear industries

## VAR Applications

- Superalloys for aerospace
- High strength steels
- Ball-bearing steels
- Tool steels (cold and hot work steels) for milling cutters, drill bits, etc.
- Die steels
- Melting of reactive metals (titanium, zirconium and their alloys) for aerospace, chemical industry, off-shore technique and reactor technique

# VAR Advantages & ALD Features

ALD has numerous references in the field offering the highest levels of system automatization

**10 ton VAR furnace from ALD**

### Primary benefits of VAR

- Removal of dissolved gases, such as hydrogen, nitrogen and CO
- Reduction of undesired trace elements with high vapor pressure
- Achievement of directional solidification of the ingot from bottom to top
- Elimination of macro-segregation and reduction of micro-segregation
- Improvement of oxide cleanliness

### Further advantages

- **Removal of Oxides** by chemical and physical processes
- **Removal of Nitrides** by thermally dissociation or reduction by carbon present in the alloy, and final removal via the gas phase
- **Removal of Stable Non-metallic Inclusions**
  Some inclusions (e.g. alumina and titanium-carbonitrides) are removed by flotation during remelting. The remaining inclusions are broken up and evenly distributed in the cross-section of the solidified ingot.

### Features of VAR furnaces from ALD

- Ingot diameters up to 1,500 mm
- Ingot weights up to 50 tons
- Electrode is melted by means of a DC arc under vacuum (electrode negative, melt pool positive)
- Remelting currents up to 50 kA
- Vacuum range: 1 - 0.1 Pa (some applications up to 1,000 Pa)
- Electrode weighing system
- Stable or free-standing gantry design
- Coaxial high current feeding system

# Process Technology and Process Characteristics

## ALD´s process expertise guarantees high process reproducibility and material quality

12 ton VAR furnace from ALD

**VAR is the continuous remelting of a consumable electrode by means of an arc under vacuum.**

The main process stages

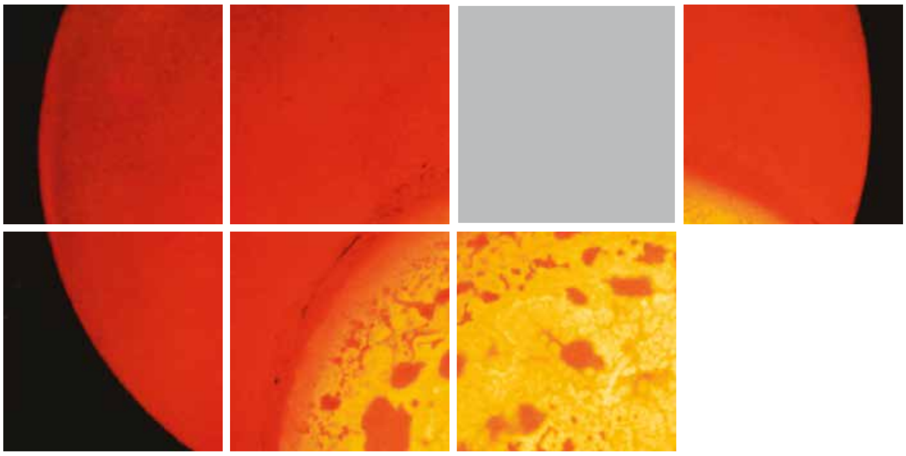
- **A consumable VAR electrode is generated** by VIM, ESR, EB or plasma methods, assembled from titanium sponge, scrap or bulk, or by a prior VAR melt
- **DC power is applied** to strike an arc between the electrode and the baseplate of a copper mold contained in a water jacket
- **The intense heat generated by the electric arc** melts the tip of the electrode and new ingot collects in the mold
- **The melt rate is precisely regulated** by the VAR control system
- **A high vacuum is maintained** throughout the remelting process to remove impurities and prevent oxide formation
- Ingot cooling is controlled for **directional solidification**

ALD has improved the basic design of VAR furnace in computer control and regulation continuously over the years to achieve:

- Fully-Automatic remelting processes
- Improved Reproducibility of the metallurgical properties

# Directional Solidification of the Vacuum Arc Remelting Process

## Precise control of the local solidification rate of the temperature gradient at the liquid/solid interface



**Achieving the optimum VAR ingot solidification structure requires precise control of the local solidification rate and the temperature gradient at the liquid/solid interface.**

### High Temperature Gradient

at the solidification front must be maintained during the entire remelting process to achieve a directed dendritic primary structure.

### Dendrite Growth Direction

conforms to the direction of the temperature gradient, i.e., the direction of the heat flow at the moment of solidification, at the solidification front. The direction of the heat flow is always perpendicular to the solidification front or, in case of a curved interface, perpendicular to the respective tangent. The growth direction of the dendrites is thus a function of the melt pool profile during solidification.

### Melt Pool Profile

As pool depth increases with the remelting rate, the growth angle of the dendrites, with respect to the ingot axis, also increases. Without proper VAR melt controls, the ingot core can solidify non-directionally, e.g. in equiaxed grains, leading to segregation and micro-shrinkage. Even in the case of directional solidification, micro-segregation increases with dendrite arm spacing. A solidification structure with dendrites parallel to the ingot axis yields optimal results.

### Optimal Melt Rates

A good ingot surface requires a certain level of energy input. Optimal melt rates and energy inputs depend on ingot diameter and material grade, which means that the necessary low remelting rates for large diameter ingots cannot always be maintained to achieve axis-parallel crystallization.

# Understanding and Preventing Solidification Defects

**Metallurgists agree that in spite of directional solidification, defects such as "tree ring patterns", "freckles" and "white spots" can occur in remelted ingots. These defects can lead to rejection of the ingot, particularly in the case of special alloys.**

## Tree ring patterns

- Can be identified in a macro-etched transverse section as light-etching rings
- Usually represent a negative crystal segregation
- Seem to have little effect on material properties

## Freckles

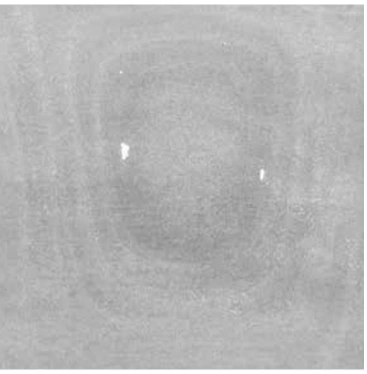
Freckles and white spots have a much greater effect on material properties as compared to tree ring patterns and can represent a significant cause for premature failure of turbine disks in aircraft engines.

## White Spots

- White spots are typical defects in VAR ingots. They are recognizable as light etching spots on a macro-etched surface
- They are lower in alloying elements, e.g. titanium and niobium in Inconel 718

**ALD mitigates these problems in the VAR with precise and stable melt rate and arc gap control, and robust power supplies designed specifically for this purpose.**

Tree Ring Patterns



Freckles

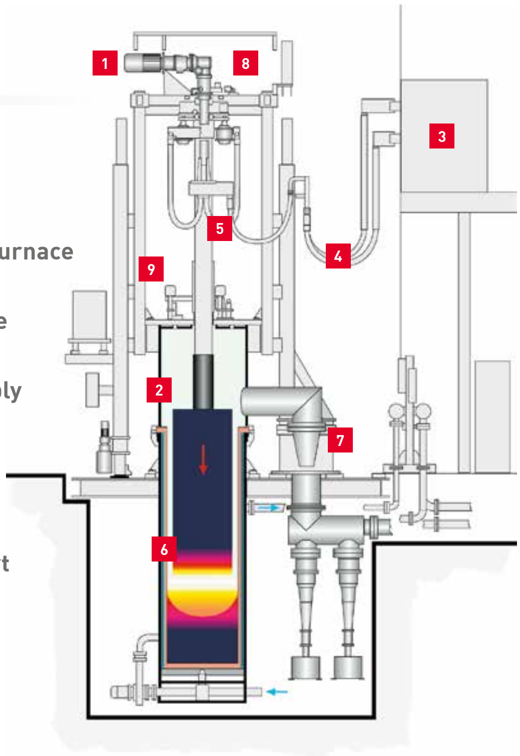
White Spots

Intended

# ALD VAR Furnaces Design Features

Schematic of the VAR furnace

1 Electrode feed drive
2 Furnace chamber
3 Melting power supply
4 Busbars/cables
5 Electrode ram
6 Water jacket with crucible
7 Vacuum suction port
8 X-Y adjustment
9 Load cell system

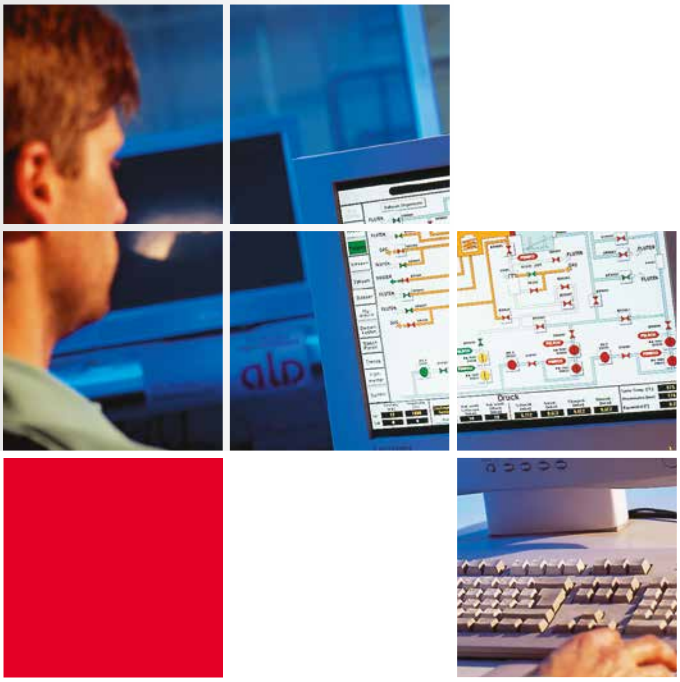



## Design Features of all ALD VAR Furnaces

- Gantry design of furnace head super-structure features simple platform installation with no flexure of the super-structure under load. Consistent centering of the electrode.
- Proven electro-mechanical dual electrode drive system for very precise control of small melt speeds during the remelting process and fast speeds for charging procedures.
- Remotely controlled, pneumatically operated electrode/ stub clamp with maximum melting current transfer to the electrode.
- The furnace is of fully coaxial design avoiding stirring action of the melt bath due to unsymmetrical magnetic stray fields.
- Power supply with space saving design, thyristor or saturable reactor control designed specifically for fast response and tight current control.
- Sophisticated weight management system including highly accurate, fully temperature compensated load cell system and statistical based melt rate algorithm.
- Completely automatic operation of the furnace by the use of password-protected preset melt recipes, stored locally or downloaded from any host system.
- Statistical Process Analysis (SPA) is possible with the data acquisition system of the Operator Interface PC in combination with the optional Supervisory Sytem PC.

# VAR Process Control

ALD's automatic melt control system (AMC) is unsurpassed in the world for its accuracy, reproducible metallurgical quality and ease of operation



**ALD provides precise control of all VAR remelting parameters for reproducible production of homogeneous ingots, which are free of macro-segregation and show controlled solidification structure and superior cleanliness.**

## Computer controlled process automation used by VAR furnaces fulfills today's most stringent material quality specifications.

ALD's VAR control systems handle:

- Logic control functions
- Continuous weighing of the consumable electrode
- Closed loop control of process parameters (e.g. remelting rate, arc gap based on arc voltage or drop short pulse rate)
- Data acquisition
- Data management

## Communication via field bus or specific interfaces

## Operator interface PC (OIP)

- Acts hierarchically as master of the automatic melt control system (AMC)
- Utilized as interface between operator and VAR process
- Serves for process visualization, featuring parameter indications, graphic displays and soft keys for operator commands, editing and handling of remelting recipes, data acquisition and storage and for generation of melt records
- Can be optionally equipped with an Ethernet network interface which may be utilized for data transfer to other computers connected to the local area network (e.g. supervisory PC, customer's main frame, etc.)

## Melt Recipes

- ALD furnaces work with established remelting parameters, stored as remelting recipes on hard disk, for repeatable VAR production of specific ingot sizes and material grade combinations, to assure full metallurgical ingot quality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MetaCom / VAR / 09.13