



# Electroslag Remelting (ESR)

Electroslag Remelting Processes  
and Furnaces

# Electroslag Remelting



20 ton ESR furnace capable of melting under protective atmosphere.

## Process Control

Close control of all remelting parameters is required for reproducible production of homogeneous ingots.

To fulfill today's most stringent material quality specifications, ESR furnaces make use of computer controlled process automation. Logic control functions, continuous weighing of the ingot, closed loop control of process parameters, data acquisition and management are handled by dedicated computer systems. These computer systems communicate via field bus or specific interfaces. An operator interface PC (OIP) acting hierarchically as

master of the control system is utilized as the interface between operator and ESR process. The OIP 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 as well as for generation of melt records. Optionally the OIP can be 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.).

ESR has been known since the 1930s, but it took approx. 30 years before it became an acknowledged process for mass production of high-quality ingots. The ESR technology is of interest not only for the production of smaller weight ingots of tool steels and superalloys, but also of heavy forging ingots up to raw ingot weights of 165 tons.

## Process Technology and Process Characteristics

Whereas VAR needs vacuum for refining, in ESR the consumable electrode is dipped into a pool of slag in a water-cooled mold. An electric current (usually AC) passes through the slag, between the electrode and the ingot being formed and superheats the slag so that drops of metal are melted from the electrode. They travel through the slag to the bottom of the water-cooled mold where they solidify. The slag pool is carried upwards as the ingot forms. The new ingot of refined material builds up slowly from the bottom of the mold. It is homogeneous, directionally solidified and free from the central unsoundness that can occur in conventionally cast ingots as they solidify from the outside inwards.

Generally the ESR process offers very high, consistent, and predictable product quality. Finely controlled solidification improves soundness and structural integrity. Ingot surface quality is improved by the formation of a solidified thin slag skin between ingot and mold wall during the remelting operation. This is why ESR is recognized as the preferred production method for high-performance superalloys that are used today in industries such as aerospace and nuclear engineering as well as for heavy forgings. Ingots are obtained with purity levels that were unheard of some years ago. Other branches of engineering are following the examples of the "high-tech" pacesetters and insist on new, high purity levels that can be obtained from ESR with the latest, most sophisticated equipment.



16 ton PESR furnace, max. 16 bar.

## Metallurgy of the Electroslag Remelting Process

Due to the superheated slag that is continuously in touch with the electrode tip, a liquid film of metal forms at the electrode tip. As the developing droplets pass through the slag, the metal is cleaned of non-metallic impurities which are

removed by chemical reaction with the slag or by physical flotation to the top of the molten pool. The remaining inclusions in ESR are very small in size and evenly distributed in the remelted ingot.

Slags for ESR are usually based on calcium fluoride ( $\text{CaF}_2$ ), lime ( $\text{CaO}$ ) and alumina ( $\text{Al}_2\text{O}_3$ ). Magnesia ( $\text{MgO}$ ), titania ( $\text{TiO}_2$ ) and silica ( $\text{SiO}_2$ ) may also be added, depending on the alloy to be remelted. To perform its intended functions, the slag must have some well-defined properties, such as:

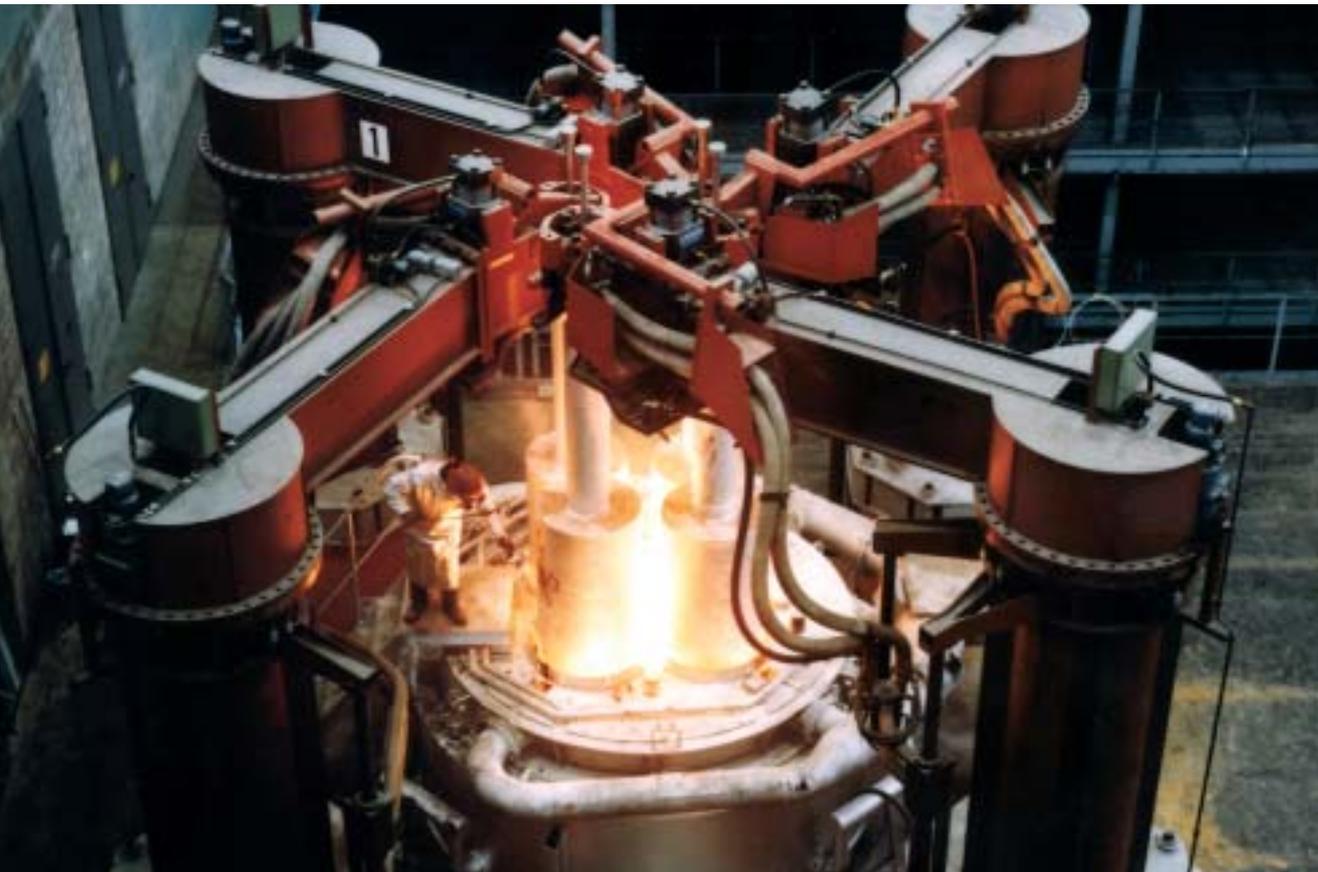
- Its melting point must be lower than that of the metal to be remelted;
- It must be electrically efficient;
- Its composition should be selected to ensure the desired chemical reactions;
- It must have suitable viscosity at remelting temperature.

In spite of directional dendritic solidification various defects, such as the formation of tree ring patterns and freckles, can occur in remelted ingots. Reasons for the occurrence of these defects are the same as in VAR. It is important to note that white spots normally do not occur in an ESR ingot. The dendrite skeletons or small broken pieces from the electrode must pass the superheated slag and have enough time to become molten before they reach the solidification front. This prevents white spots.

The ingot surface covered by a thin slag skin needs no conditioning prior to forging. Electrodes for remelting can be used in the as-cast condition.

## Electroslag Remelting Furnaces

Significant advances have been made over the years in plant design, coaxial current feeding and particularly in computer control and regulation with the objective of achieving a fully-automatic remelting process. This in turn has resulted in improved metallurgical properties of the products.



165 ton ESR furnace.

A fully coaxial furnace design is required for remelting of segregation-sensitive alloys in order to prevent melt stirring by stray magnetic fields.

Shielding of the melt space with protective atmosphere has been the latest trend in recent years. Remelting under increased pressure to increase the nitrogen content in the ingot is another variation of ESR. ESR furnaces can be designed for remelting of round, square and rectangular (slab) ingots.

Finally, computer controlled process automation has been developed to perform similarly to ALD's automatic melt control system (AMC) described under VAR. Important to mention here is that ALD's electrode immersion depth control into the slag is based on slag resistance or slag resistance swing. Using the resistance parameter automatically decouples the

immersion depth and remelting rate control loops which are otherwise cross-influencing each other.

Also for ESR it can be stated that ALD's automatic melt control system (AMC) is unsurpassed in the world for its inherent features, ease of operation and last but not least its accuracy and repeatability of control, producing ingots with excellent properties, including:

- Homogeneous, sound and directionally solidified structure;
- High degree of cleanliness;
- Free of internal flaws (e.g. hydrogen flakes);
- Free of macro-segregation;
- Smooth ingot surface resulting in a high ingot yield.

## Electroslag Remelting of Heavy Forging Ingots

At the end of the 1960s, the concept of using ESR plants to manufacture large forging ingots gained acceptance. Increasing demand for larger electrical power generating units required forging ingots weighing 100 tons or more for manufacturing of generator and turbine shafts. ALD's largest ESR furnace, commissioned in the early 1970s, allows to manufacture ingots of 2,300 mm diameter and 5,000 mm length weighing up to 165 tons. The furnace operates with ingot withdrawal employing four consumable electrodes remelted simultaneously in the large diameter mold and replacing the consumed electrodes with subsequent ones and as many as necessary to produce the desired ingot weight.

Directional solidification must be ensured over the entire ingot cross-section and length to avoid interior defects, such as macrosegregation, shrinkage cavities and nonuniform distribution of inclusions. By maintaining the correct remelting rate and slag temperature, directional solidification can be achieved for ingot diameters as large as 2,300 mm. Accordingly, the ESR ingot is free from macro-segregation in spite of the large diameter. The cleanliness and homogeneity of ESR ingots result in excellent mechanical properties as compared to conventionally cast steel ingots.



165 ton ESR ingot, 2,300 mm diameter x 5,000 mm long.

## Process Variations

Three ESR process variations have been developed by ALD:

- Remelting under increased pressure (PESR);
- Remelting under inert gas atmosphere (IESR);
- Remelting under reduced pressure (VAC-ESR).

## Pressure Electroslag Remelting (PESR)

Over the past 30 years, nitrogen has become increasingly attractive as an inexpensive alloying element for enhancing the properties of steel. In austenitic steel, nitrogen, particularly in dissolved form, increases yield strength by forming a super-saturated solid solution. With ferritic steel grades, the aim is to achieve a fine dispersion of nitrides comparable to the microstructure obtained by quenching and tempering iron-carbon alloys. For the production of these new materials, it is essential that a sufficiently high amount of nitrogen above the solubility limit under normal pressure is introduced into the molten steel and that nitrogen loss is prevented during solidification. As the solubility of nitrogen is proportional to the square root of its partial pressure, it is possible to introduce large amounts of nitrogen into the melt and allow it to solidify under higher pressure. This has been verified by the electroslag remelting process at an operating pressure of 42 bar.

Due to the extremely short dwell time of the metal droplets in the liquid phase during remelting, the nitrogen pick-up via the gas phase is insufficient. The nitrogen must, therefore, be supplied continuously during remelting in the form of solid nitrogen-bearing additives. The high pressure in the system serves exclusively to retain the nitrogen introduced into the molten steel. The pressure level depends on the composition of the alloy and on the desired nitrogen content of the remelted ingot.

## Remelting under Inert Gas Atmosphere (IESR)

As a consequence of ALD's development work in PESR processing, ALD nowadays recommends to conduct the ESR process under a fully enclosed inert gas atmosphere at atmospheric pressure. This is a great step forward in freeing the ESR process from hydrogen pick-up problem and the influence of seasonal atmospheric changes. In addition it allows remelting under oxygen-free inert gas.

The following results have been obtained:

- Oxidation of electrode and slag is completely avoided;
- Oxidizing loss of elements such as Ti, Zr, Al, Si, etc. is almost completely avoided.

This is especially important when remelting high Al and Ti-containing alloys, like superalloys with very narrow analytical ranges;

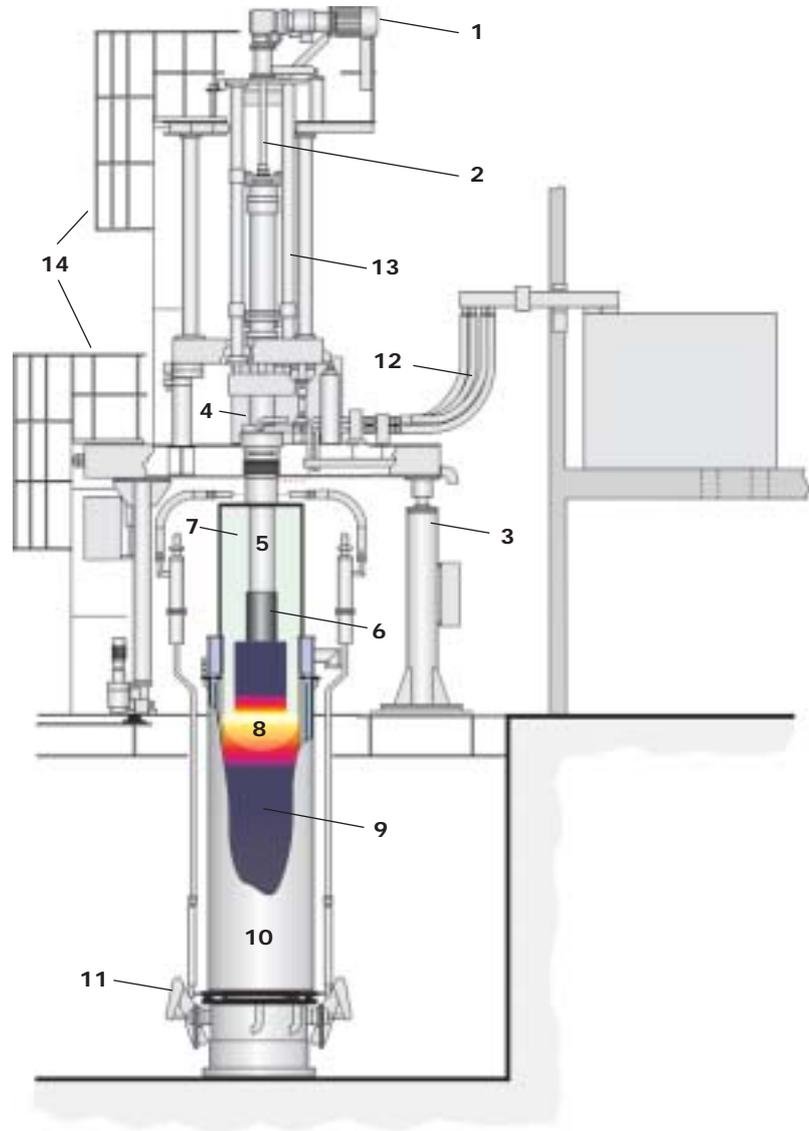
- Better cleanliness in the ingot is achieved;
- When using argon as the inert gas, pick-up of nitrogen and hydrogen is avoided; (When using nitrogen as the inert gas, some pick-up of nitrogen is possible.)

Due to the absence of oxygen in the furnace atmosphere, desulfurization via the gas phase is no longer optimal. However, sulfur is today taken care of by ladle metallurgy in the making of steel electrodes.

Two furnace concepts are available, one with a protective hood system of relative tightness, the other with a fully vacuum-tight protective hood system that allows the complete exchange of air against an inert gas atmosphere prior to starting the remelting process.

## Electroslag Remelting under Vacuum (VAC-ESR)

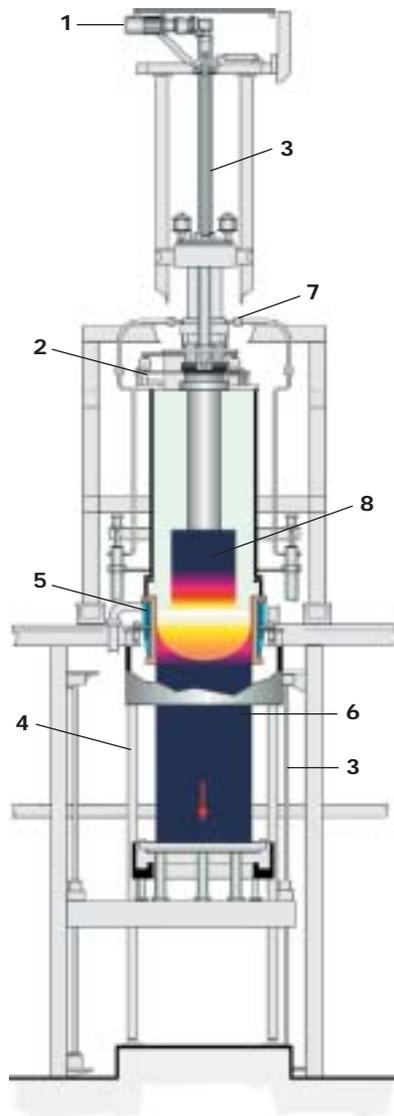
Electroslag remelting under vacuum is another newly developed process. Remelting is carried out under vacuum as in VAR, however, using a slag. Problems of oxidation of the melt do not arise. In addition, dissolved gases such as hydrogen and nitrogen, can be removed and



**Schematic of IESR furnace**

- |                                    |                                  |
|------------------------------------|----------------------------------|
| 1 Electrode feed drive system      | 8 Slag pool                      |
| 2 Ball screw                       | 9 Ingot                          |
| 3 Pivotable furnace support gantry | 10 Mold assembly                 |
| 4 Load cell system                 | 11 High current contact assembly |
| 5 Electrode ram                    | 12 Power cables                  |
| 6 Electrode stub                   | 13 Ram guiding system            |
| 7 Protective gas chamber           | 14 Maintenance platforms         |

the danger of white spots, as encountered during VAR, is reduced to a minimum. Thus, the advantages of both ESR and VAR are combined in one process. That is of interest for superalloys or titanium remelting.



#### ESR furnace with retractable base plate for ingot withdrawal

- |                          |                    |
|--------------------------|--------------------|
| 1 Electrode drive system | 6 Ingot            |
| 2 Load cell system       | 7 Sliding contacts |
| 3 Ball screws            | 8 Electrode        |
| 4 Bus tubes              | 9 X-Y adjustment   |
| 5 Mold assembly          |                    |

## Furnace Types

ALD has developed five basic ESR furnace concepts:

### Pilot Systems

for stationary and moving mold applications. These are particularly well-suited for experimental and pilot production, and for the performance of high-versatility ESR operation at low investment cost.

### Stationary Mold Systems

with two fixed remelting stations and one pivoting furnace head. These are particularly suited for efficient production at high production rates.

### Ingot Withdrawal Systems

with central ingot withdrawal station and electrode exchange capability, and two outer stations for remelting in stationary molds. The central station is particularly suited for remelting of large diameter ingots. Smaller diameter ingots may be remelted simultaneously in the outer stations.

### Atmospheric Protection Systems

for stationary mold application with closed furnace hood system to remelt under inert gas atmosphere. These systems are particularly recommended when remelting Ti, Al and rare-earth containing alloys or alloys with low Al content (< 0.005).

## Pressurized / Vacuum Systems

Completely sealed systems for ESR operations under vacuum, inert gas, or increased pressure. These systems are particularly suited for producing ESR ingots with high contents of nitrogen or reactive elements.

### ESR Features:

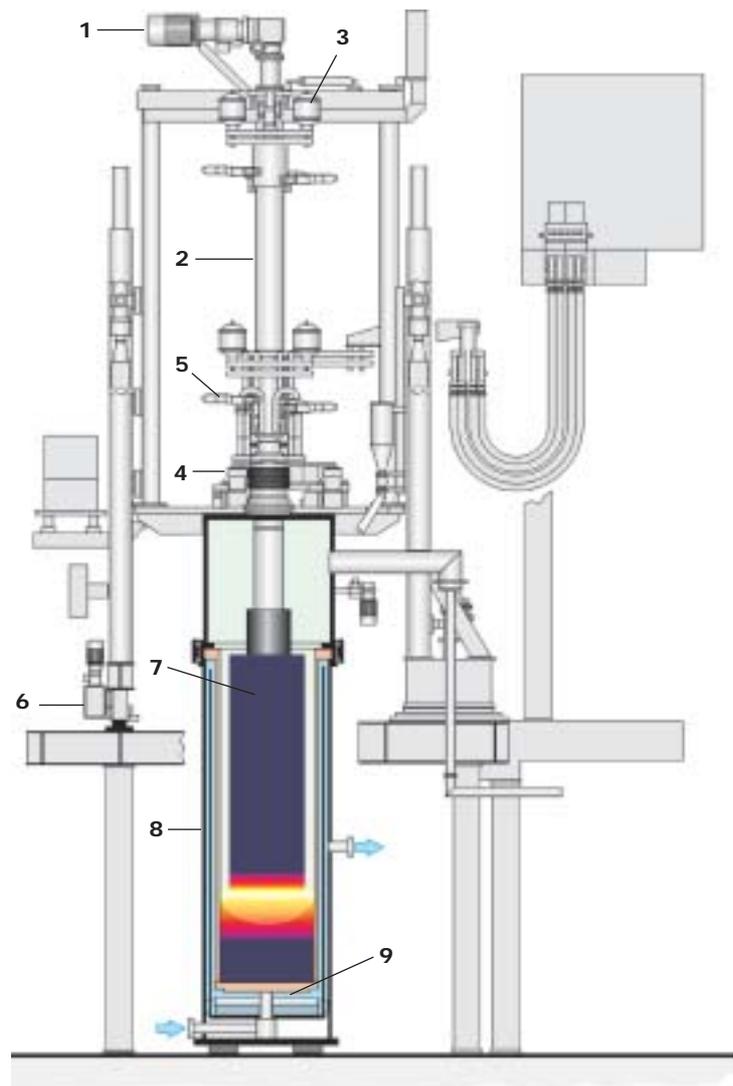
- Ingot weights from 100 kg to 165 metric tons;
- Alternating current as remelting energy with melting currents from 3 kA to 92 kA;
- Ingot diameters from 170 mm to 2,300 mm, depending on material being remelted;
- Circular, square and rectangular ingot shapes are possible;
- ALD offers systems for special processes such as remelting under pressure, protective gas or vacuum. A growing market share is anticipated for these processes, especially the IESR process under inert gas atmosphere.

### ESR Applications:

- Tool steels for milling cutters, mining, etc.;
- Die steels for the glass, plastics and automotive industries;
- Ball-bearing steels;
- Steels for turbine and generator shafts;
- Superalloys for aerospace and power turbines;
- Nickel-base alloys for the chemical industry;
- Cold rolls.

## Schematic of PESR furnace with stationary mold

- |                     |                    |
|---------------------|--------------------|
| 1 Ram drive system, | 5 Sliding contact, |
| 2 Electrode ram,    | 6 Pivoting drive,  |
| 3 X-Y adjustment,   | 7 Electrode,       |
| 4 Load cell system, | 8 Water jacket,    |
|                     | 9 Base plate       |



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