



An Introduction to Premium Melting

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AN INTRODUCTION TO PREMIUM MELTING

Many alloys contain elements like aluminum and titanium which, when heated, react with oxygen to form oxides. Oxides are detrimental to premium quality melted alloys.

Premium grade alloys, such as those required by the aerospace, energy, medical and automotive industries, can be protected from the atmosphere and residuals by melting inside a vacuum container. This approach gives the metals producer more control over alloy chemistry.

The result is a cleaner, more uniform product with the superior properties required for critical service applications.

The high-performance specialty alloys manufactured by Carpenter Technology Corporation require the use of sophisticated, controlled melting processes. The company utilizes several types of premium melting furnaces at its main manufacturing plant in Reading, Pennsylvania.



The Premium Melting Process

Three types of premium melting furnaces generally used to produce high-performance specialty alloys in wrought forms are Vacuum Induction Melting (VIM), Electroslag Remelting (ESR) and Vacuum Arc Remelting (VAR) furnaces.

VACUUM INDUCTION MELTING

VIM furnaces are often the starting point in premium melting. They produce alloys that require extra cleanliness and tight compositional control. Alloys melted in the VIM generally contain a sizable amount of oxidizable elements, which, if air melted, would create detrimental inclusions.

Many ferrous alloys that require a high degree of cleanliness – such as bearing steels used in aircraft or power generation applications and medical implant alloys – begin their premium melting journey in the VIM furnace and then move on to one or more additional melting (refining) processes. One example is nickel-base alloys used in aerospace and power generation applications and cobalt-base alloys used in medical applications. In fact, they are always vacuum melted in order to obtain a high-purity microstructure.

Carpenter's 20 metric ton VIM furnaces utilize the latest VIM technology to efficiently deliver high-quality vacuum melted product in large production volumes.

ELECTROSLAG REMELTING

Electroslag Remelting (ESR) is a secondary refining process used to further refine many alloys. As a feedstock it uses consumable electrodes produced either by VIM or conventional air melting.

Conventional ESR improves the microstructure and cleanliness of the VIM, or arc melted alloy, by removing inclusions

as the metal passes through the slag and controlling the solidification rate in the refined metal ingot to minimize chemical segregation. Melting through the slag permits very close compositional control.

A more recent advancement is Pressurized ESR (P-ESR) furnaces, which have the ability to melt alloys under nitrogen pressures of several atmospheres and produce very high nitrogen steel compositions that cannot be achieved via standard air melting techniques. This capability allows the manufacture of new and novel high-nitrogen alloys with unique mechanical properties.

Carpenter's P-ESR furnace is the first production size furnace of its type installed in North America.

ESR is used for many nickel-base and iron-base alloys, including valve steels in automotive applications, steels that have been used for drill collars in oil and gas exploration, many stainless steels in medical applications, and other alloys whose end-use applications require high microstructural cleanliness. Fastener grades can also be Electroslag Remelted.

ESR is sometimes used as a middle step in producing alloys for critical aerospace applications.

VACUUM ARC REMELTING

Vacuum Arc Remelting (VAR) is another secondary refining process that enhances the quality of metal that had undergone primary air melting and/or was melted, or remelted, in arc, VIM or ESR furnaces. The VAR feedstock is consumable electrodes produced by VIM or conventional air melting. VAR, like ESR, depends on controlled cooling and solidification of the remelted

ingot to minimize chemical segregation. VAR is also the final melting step for many aerospace alloys, especially high-temperature alloys used for rotating parts because the VAR process effectively removes dissolved gas and oxide inclusions.

LEADING THE WAY IN PREMIUM MELTING

Both ESR and VAR employ state-of-the-art automated control equipment, including the latest computer hardware and software to manage every phase of the melting process. With external variables, such as human intervention, all but eliminated after the melt program (recipe) is downloaded into the computerized controller, the end product is consistently reproducible.

Double vacuum melting – the combination of the VIM and VAR processes – yields a high-purity product. Some materials that are double vacuum melted include certain aerospace alloys, high-strength steels, bearing steels and medical alloys.

Triple melting (VIM-ESR-VAR) achieves the highest quality premium melted products to date. By taking advantage of the refining characteristics of all three melting processes, it results in a high-quality product with a cleaner, more homogenous microstructure. VIM-ESR-VAR melting is mostly used for rotating-part aerospace and power generation alloys.

Carpenter's assortment of premium melting furnaces, as well as its own arc melting/argon-oxygen-decarburization (AOD) shop, allows the tailoring of alloy quality to customer requirements. Carpenter's capacity to produce VIM, ESR, and VAR product is among the largest in the world with the ability to deliver small and large quantity orders of high-quality alloys.



VIM

In Vacuum Induction Melting (VIM) – a melting process that results in reduced gas content and good alloy chemistry control – an electrode or ingot is created, generally by melting vacuum-grade revert, virgin alloys or pre-refined material produced by conventional air melting techniques.

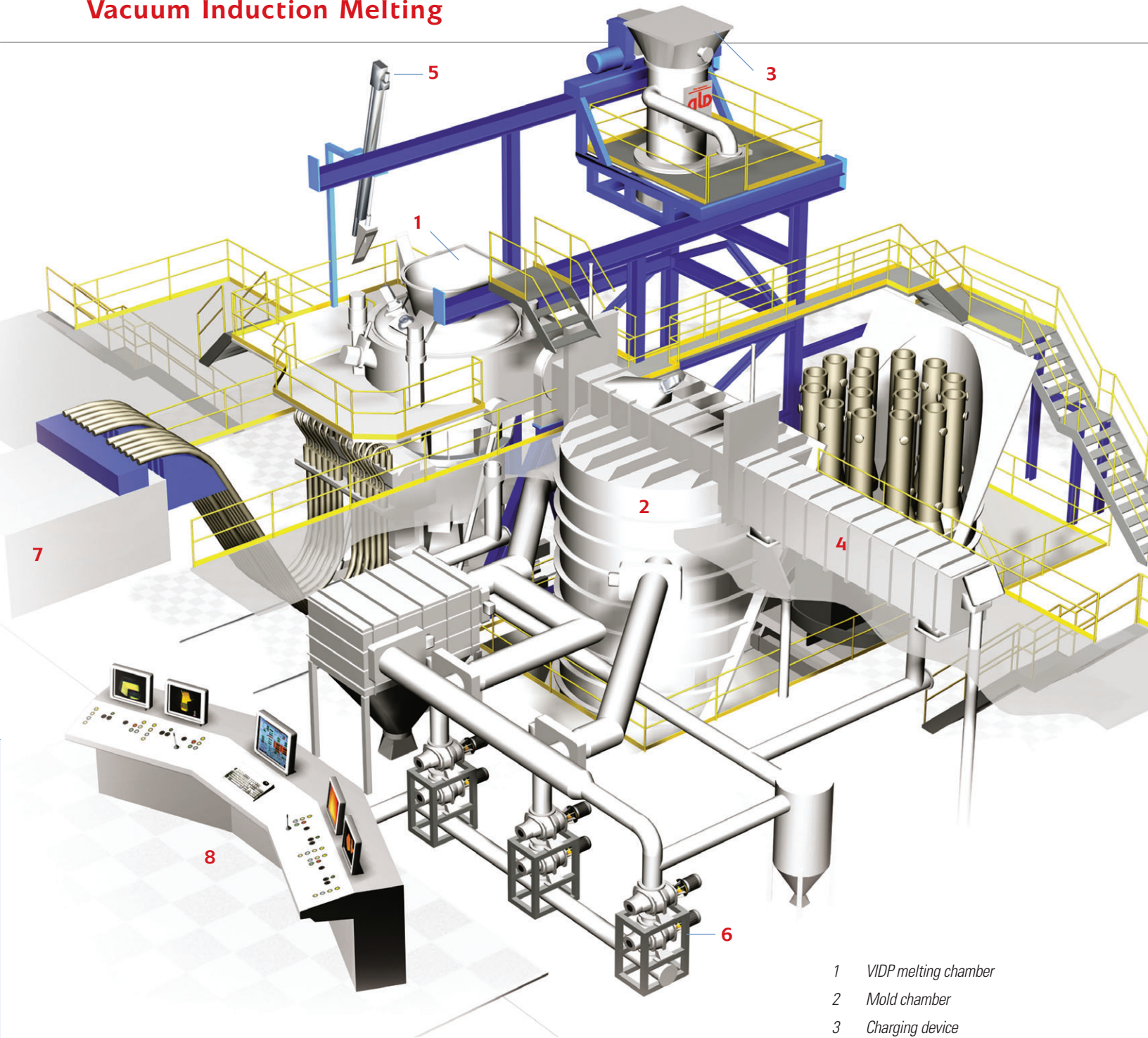
The vacuum induction process uses a completely enclosed, airtight vessel under vacuum. A mechanical vacuum pump system is the most common method of evacuating the air from the chamber.

The furnace consists of a refractory vessel or “crucible” surrounded by a water-cooled copper induction coil. The metal to be melted is placed inside the refractory crucible where alternating electrical

current is passed through the induction coil. The electrical current creates a magnetic field that inductively heats and consequently melts the metal inside the furnace.

The composition of the alloys being melted is very important and adjusted to tight limits before pouring into molds for further processing. When the metal is fully refined and the correct composition achieved, the furnace is tilted for pouring into refractory tundishes or launders that transfer the metal to prepared cast iron molds.

Vacuum Induction Melting



- 1 VIDP melting chamber
- 2 Mold chamber
- 3 Charging device
- 4 Tundish lock
- 5 Temperature measurement probe
- 6 Vacuum system
- 7 Power supply
- 8 System control desk

Electroslag Remelting

ESR

The Electroslag Remelting (ESR) process follows the primary melting of many alloys. ESR combines fully controlled metal melting conditions with fully controlled solidification conditions. AC electrical power is applied to the electrode that has been produced either by VIM or conventional air melting. The transfer of the electrical current through the refractory slag creates resistive or “Joule” heating of the slag that elevates its temperature to the molten state. This molten slag then becomes the medium through which the electrode is melted in the ESR process.

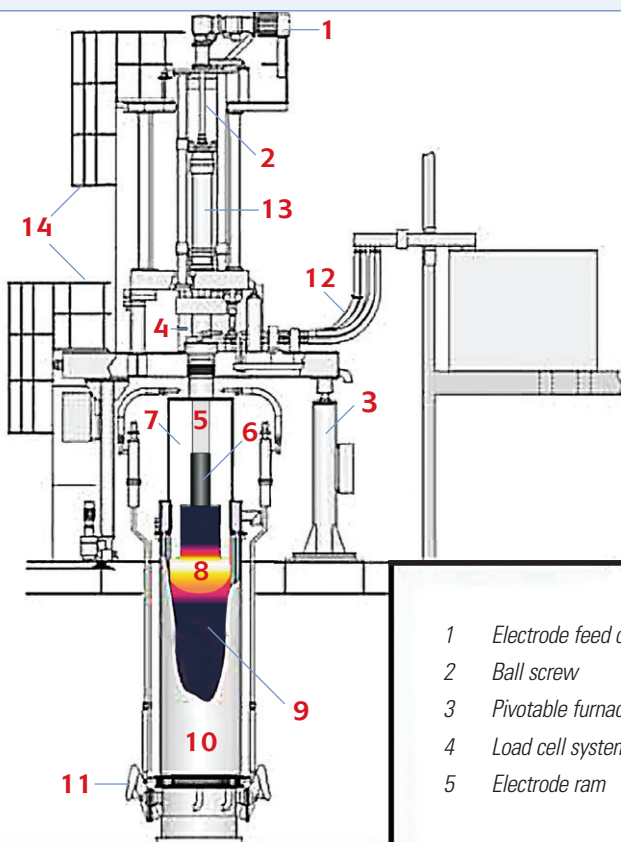
The alloy electrode is inserted just under the top surface of the molten slag. This slag is of lighter density than the molten metal and always rests on top of the ingot's molten metal pool. Droplets of molten metal form on the bottom of the electrode and fall through the slag to form a metal pool below the molten slag. The surface tensions between the molten slag and molten metal are also quite high and discourage mixing of the two liquids during ESR. The metal pool is then solidified in a water-cooled mold in a highly controlled fashion to form an ESR ingot with minimal chemical segregation that is fully dense with no internal pipe cavity that is common to arc or VIM cast electrodes.

The $\text{CaF}_2/\text{CaO}/\text{Al}_2\text{O}_3$ slag is the heating component of the system. It also acts as a solvent for non-metallic oxides, removes free oxygen and sulfur, protects the molten metal from contamination, and acts as a lubricant and lining medium within the copper mold.

The water-cooled mold extracts the heat that was created during the melting process and generates a shallow molten pool that favors relatively quick solidification. This increases chemical homogeneity and improves inclusion distribution.

Pressure ESR (P-ESR) is an even more advanced process than standard ESR. With pressure ESR the metal is melted under elevated nitrogen pressure, permitting the production of alloys with high levels of nitrogen.

For P-ESR, the standard ESR crucible is enclosed and becomes a pressure vessel melt chamber. With this design, the pressure above the slag can be increased to levels that are significantly above normal atmospheric pressure levels, enabling much higher levels of nitrogen to be achieved.



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

Vacuum Arc Remelting

The P-ESR furnace can also melt at atmospheric pressure, in an air atmosphere or with an inert gas cover of argon over the slag. Having an inert gas cover over the slag enables enhanced compositional control of reactive elements, such as aluminum and titanium, during melting.

The high-nitrogen compositions from the P-ESR process cannot be achieved through either conventional ESR or VAR melting techniques.

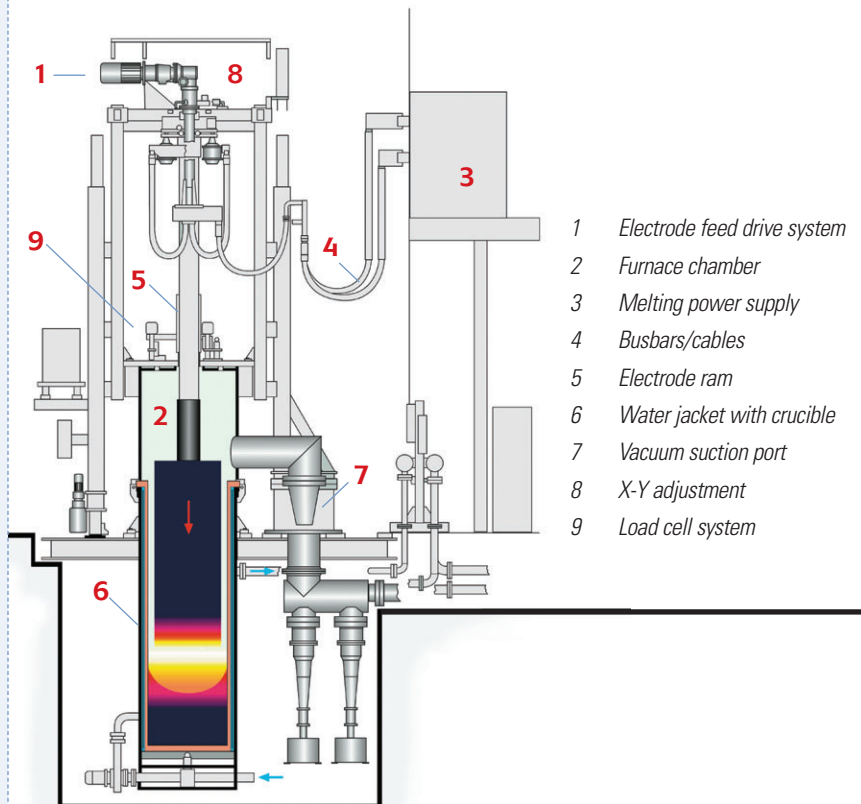
VAR

In the Vacuum Arc Remelting (VAR) furnace, the DC electric current is passed through the electrode. The electric arc that is created is similar to a welding arc and produces the heat necessary for remelting of the electrode. Metal droplets form on the bottom of the electrode in an analogous fashion to ESR, thereby melting the electrode inside the vacuum chamber. The subsequent resolidification of the ingot inside a water-cooled copper mold helps to give the remelted material its superior properties.

The highly controlled solidification during the VAR process is designed to eliminate ingot macrosegregation and significantly reduces microsegregation. Chemical segregation of the elements of an alloy is undesirable and, therefore, must be eliminated if alloys are to achieve peak mechanical properties. VAR is the final melting step in this process. Heat treating and hot working of the ingot eliminate the remaining chemical segregation of the microstructure. The concentration of non-metallic inclusions is also reduced in VAR, thereby enhancing the cleanliness of the material.

VAR facilitates the removal of gases and volatile elements. Since VAR melting is performed in water-cooled copper crucibles, this process eliminates undesirable metal/refractory reactions.

Many chemical reactions are favored at the low pressures and high temperatures obtained during VAR, including dissociation of less stable oxides and undesirable tramp elements, melting of carbides, deoxidation and degasification. The VAR process results in a clean, homogenous microstructure.





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