**Practice 5 - Vacuum melting of refractory materials**

**1 академический час**

Commercial vacuum induction melting (VIM) was developed in the early 1950s, having been stimulated by the need to produce superalloys containing reactive elements within an evacuated atmosphere. The process is relatively flexible, featuring the independent control of time, temperature, pressure, and mass transport through melt stirring. As such, VIM offers more control over alloy composition and homogeneity than other vacuum melting processes. Vacuum induction melting can be used to advantage in many applications, particularly in the case of the complex alloys employed in aerospace engineering. The following advantages have a decisive influence on the rapid increase of metal production by VIM:

Flexibility due to small batch sizes Fast change of program for different types of steels and alloys

Easy operation Low losses of alloying elements by oxidation Achievement of very close compositional tolerances

Precise temperature control

Low level of environmental pollution from dust output

Removal of undesired trace elements with high vapor pressures

Removal of dissolved gases, for example, hydrogen and nitrogen

Vacuum induction melting is indispensable in the manufacture of superalloys. Compared to air-melting processes such electric arc furnaces (EAF) with argon oxygen decarburization (AOD) converters, VIM of superalloys provides a considerable reduction in oxygen and nitrogen contents. Accordingly, with fewer oxides and nitrides formed, the microcleanliness of vacuum-melted superalloys is greatly improved compared to air (EAF/AOD)-melted superalloys. Additionally, high-vapor-pressure elements (specifically lead and bismuth) that may enter the scrap circuit during the manufacture of superalloy components are reduced during the melting process. Accordingly, the vacuummelted superalloys (compared to EAF/AODmelted alloys) are improved in fatigue and stress-rupture properties. Control of alloying elements also may be achieved to much tighter levels than in EAF/ AOD products. However, problems can arise in the case of alloying elements with high vapor pressures, such as manganese. Vacuum melting also is more costly than EAF/AOD melting. The EAF/AOD process allows compositional modification (reduction of carbon, titanium, sulfur, silicon, aluminum, etc.). In vacuum melting, the charge remains very close in composition to the nominal chemistry of the initial charge made to the furnace. Minor reductions in carbon content may occur, and most VIM operations now include a deliberate desulfurization step. However, the composition is substantially fixed by choice of the initial charge materials, and these materials are inevitably higher-priced than those that are used in arc-AOD. Process Description A VIM furnace is simply a melting crucible inside a steel shell that is connected to a highspeed vacuum system (Fig. 1). The heart of the furnace is the crucible (Fig. 2) with heating and cooling coils and refractory lining. Heating is done by electric current that passes through a set of induction coils. The coils are made from copper tubing that is cooled by water flowing through the tubing. The passage of current through the coils creates a magnetic field that induces a current in the charge inside the refractory. When the heating of the charge material is sufficient that the charge has become all molten, these magnetic fields cause stirring of the liquid charge. The optimal induction coil frequency for heating the charge varies with the charge shape, size, and melt status (liquid or solid). Older equipment used a single frequency, but newer power supplies are able to be operated at variable frequencies and are adjusted throughout the melt to obtain the most rapid heating/melting conditions.

The charge generally consists of three portions: A virgin portion, which consists of material that has never been vacuum melted A refractory portion, which consists of those virgin elements that are strong oxide formers and have the tendency to increase the solubility of oxides and nitrides in the virgin charge A revert (or scrap) portion, which consists of both internal and external scrap that previously has been vacuum melted Vacuum-melted scrap has already had its gas content reduced to levels consistent with vacuum production. Scrap, however, has the possibility of having become contaminated during the production process, and care (expense) must be taken in the segregation and preparation of scrap materials for vacuum melting. In most VIM furnaces there is a vacuum lock bulk charger located directly over the crucible (Fig. 3). Charge material may be added to the heat through the bulk charger while melting is in process in the crucible. The material to be added is placed in bottom-opening buckets, placed in the bulk charger, and the charger is evacuated. The valve isolating the charger from the melt chamber is opened, and the bucket is lowered to a point close to the crucible top and the bottom opened so as to drop the charge material into the crucible. In constant operation, if a furnace is not to be opened to the atmosphere, all charge material for a heat will be added by this process. Older VIM furnaces may have been designed as single-chamber systems with the mold put inside the furnace before the beginning of the melt. The molten charge is then poured into the mold inside the furnace. Single-chamber furnaces thus must be opened after each heat to extract the molds and put in the new molds. Most furnaces have some system of large vacuum locks for transferring the prepared molds into the melt chamber. In double-chamber furnaces (Fig. 3), there is a separate chamber for the molds. The molten metal is transferred via launders (refractory-lined steel troughs) to a refractory tub (tundish). Some systems are designed to pour directly from the crucible into the tundish. The tundish contains a considerable volume of metal and allows residence time for entrained slag to float to the top of the tundish and be removed from the pour stream. The pour stream exits the bottom of the tundish. The pour time is regulated by pour temperature and the nozzle diameter of the tundish. The typical tundish is designed to provide a low-velocity flow path from the point of entry of the metal to the bottom nozzle. Refractories. Crucibles with a capacity of approximately 4500 to 22,500 kg (10,000 to 50,000 lb) are generally built up from refractory brick. Smaller furnaces, used for production of master melt, may use single-piece crucibles. Refractory brick linings are usually two layers. The backup lining protects the induction coil in the event of a failure of the outer or working lining. The working lining is the primary interface with the metal and is replaced when erosion of the lining becomes excessive. Refractory life is also affected by the expansion of the refractory during the repeated melting cycles. Refractory brick is chosen with regard to resistance to erosion and expansion. Commercially available refractory brick may be incompletely sintered and expands during use, causing loss of crucible integrity. The refractory material used for the crucible lining is based on oxides such as Al2O3, MgO, CaO, or ZrO2 (Table 1). The lining is almost always rammed and sintered; prefabricated brick is used in larger furnaces. Dried silicate, combined with small oxide additions, appears to be very suitable for crucible lining because of its thermal characteristics. Because of an irreversible thermal expansion of 8% above 1000 C (1830 F), a high densification of the lining takes place during sintering. For this reason, this active lining is suitable for foundries. The behavior of the lining refractory with regard to stability at high temperature under vacuum must also be considered. The melting crucible material is not inert and is actually another source of oxygen and other impurities, depending on refractory type and condition. Therefore, both melt refining temperature and refining duration are carefully scrutinized. Proper melt stirring is integral to the deoxidation process and must be optimized through proper furnace power frequency and application procedure to prevent refractory lining erosion, a potential problem particularly during the controlled but more vigorous CO boiling portion of the process.

Production of Nonferrous Materials Apart from melting high-grade steels and superalloys, VIM is being increasingly used for the production of nonferrous metals and alloys. Table 2 shows some examples for possible use in nonferrous metallurgy. Aluminum alloys with additives such as zirconium, titanium, beryllium, cerium, tellurium, and cadmium must be melted under vacuum or under inert gas atmosphere because of their high reactivity with air and, in some cases, their toxicity. Aluminum-lithium alloys are also candidates for VIM processing. Copper Alloys. The production of highpurity copper having less than 2 ppm O can be accomplished only in a vacuum induction furnace. Oxygen content influences the electrical conductivity of copper alloys; the lower the oxygen content, the higher the electrical conductivity (Ref 11). For the production of Fig. 12 Schematic of the vacuum induction degassing and pouring furnace Crucible lining Exchangeable porous plug Basic set Fig. 13 Argon purging system for vacuum induction melting furnaces Vacuum Induction Melting / 7 oxygen-free copper, melting and casting must be carried out under vacuum. Selective Evaporation of Alloying Elements. The use of vacuummetallurgyis primarily linked with degassing and decarburization. A side effect of these treatments is the evaporation of elements with high vapor pressures. In nonferrous metallurgy, this effect is used for the distillation of metals—for example, for the separation of lead and zinc in lead refining, in zinc production, and for the reduction of magnesium and nonalkali metals. Similarly, copper can be refined from copper scrap by using the vacuum to evaporate volatile elements such as lead and zinc (Ref 12).

