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Vacuum Technology in the Field of Metallurgy

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Abstract

The present work gives a bird's eye view of the importance of vacuum with respect to various metallurgical operations. Production of metals in vacuum is carried out to have high purity metals which are required in aero craft industry, nuclear industry etc. Defect free castings are obtained when melting takes place under vacuum. This eliminates gasses and non metallic inclusions to get semi finished and finished products. Manufacturing in vacuum gives high strength, cleaner objects, less residual stresses and less pollution. Applications of vacuum though costly gives better control over the processes and products with tailor made properties.

Keywords:— *Vacuum, Melting, Heat treatment, Strength, Compositional tolerance*

I. Introduction

The use of to vacuum is very ancient. During 1629-1695 it was proved by Christiaan Huygeus that the feather and lead piece have the same velocity of fall in vacuum. Torricellian tube was used for vacuum measurements up to 1875. The pace of developments took place from 1850 onwards, the incandescent lamp by Thomas Alva being one of the noteworthy inventions. As devices were invented in the 20th century like there was a parallel expansion of uses of vacuum, for e.g. radio, TV etc. Metallurgical advantages of using vacuum was also recognized. The following is a schematic figure for applications of vacuum in various Metallurgical fields.

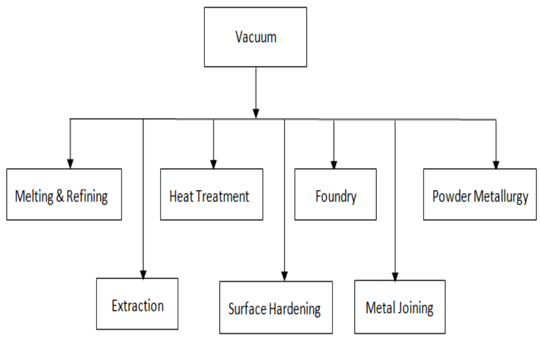

Figure 1 : Various Fields of Applications of Vacuum

2.0 Vacuum Induction Melting has the following advantages [1]:

- 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

2.1 Some Applications of Vacuum Induction Melting are:

- Refining of high purity metal and alloys
- Electrodes for remelting
- Master alloy stick for processes such as investment casting
- Casting of aircraft engine components

III. EXTRACTIVE METALLURGY

Deals with various extraction process used for obtaining a pure metal from its compounds. Both ferrous metals and non ferrous metals have some unique methods of extraction. A schematic figure of extraction processes is given below:

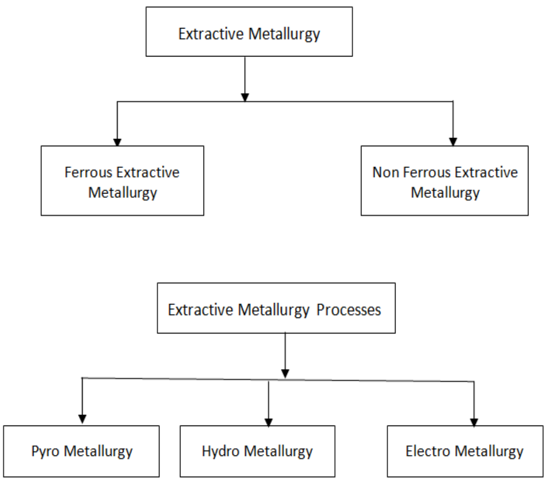

Figure 2 : Schematic of Extraction Processes

In pyro metallurgy usually high temperatures, some flux and reducing agent are used for extraction. The applications of vacuum in extractive metallurgy are Vacuum melting, Vacuum arc re-melting, Degassing of molten steel in vacuum etc . . . are carried out. Reduced pressure can decreases the temperature of operation and the products are much purer.

Reactions possible in vacuum are [2]

(a) Thermal reduction $R(sol) + MA\ (S/L) \leftrightarrow RA(S/L \leftrightarrow) + m(V)$

$R(S/L) + MA(S/L) \leftrightarrow RA(G/V) \leftrightarrow + M(S/L)$

(b) Thermal dissociation

$MA(S/L) \leftrightarrow M(V) + A \leftrightarrow (g/L)$

$MA(S/L) = M(S/L) + A(g)$

(c) Sublimation /Distillation

$M(S/L) - M\ (V)$

where

R-reducing agent

M-metal

A-acid radical

3.1 Vacuum Arc Re-melting:

VAR is a re-melting process which the metal is in the form of an electrode. This electrode is re-melted in vacuum drop by drop and solidified. The improve properties compare to conventional casting are

- More uniform grain structure
- Negligible dendritic structure or small sizes of dendrites
- Free from segregation
- Free from porosity
- Dense and homogeneous structure.

3.2 De-Gasification In Vacuum:

The main aim of vacuum treatment of steel is to remove the gases before solidification to eliminate blow holes. A schematic figure of vacuum treatment of steel is given below. Deoxidization of steels in vacuum requires some minimum carbon. The basis for deoxidization in vacuum is C + O = CO. The forward reaction is favored in vacuum as partial pressure of CO decreases in vacuum. Vacuum treatment of steels is based on the Sievert's law when states that

$$p_g = \sqrt{Kp_g}$$

By exposing the molten steel to vacuum the following advantages are seen

- Less hydrogen
- Less nitrogen
- Less oxygen
- Removal of non-metallic inclusions

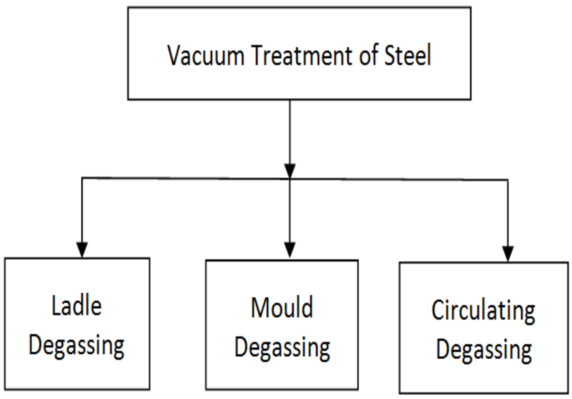

Figure 3 : Schematic Figure of Vacuum Treatment of Steel

IV. HEAT TREATMENT PROCESSES

Heat Treatment processes The carried out in vacuum are

- Annealing and solution annealing to alter the strength and hardness.
- Stress-relief which prevents distortion of the sample
- Tempering
- Age hardening a stronger alloy
- Cryogenic treatment to remove stresses and improve wear resistance

4.1 The Materials commonly heat treated in vacuum are

- Ferrous alloys
- Some stainless steel alloys
- nickel based super alloys
- Tool steels
- Ti alloys
- Non ferrous alloys

V. SURFACE HARDENING

Surface hardening is to obtain a stronger surface for have better wear resistance of parts with the interior possessing soft & toughness properties. This type of treatment helps resistance to failure by impact also. Surface hardening treatments include Carburizing, Nitriding, Carbo-nitriding is an expensive process applied to LCS & MCS generally [3]. In vacuum the air and reactive elements are diminished which results in the following benefits:—

- No scaling or distortion of the test sample
- The is ready for further processing
- Cleaning is not required
- No Contamination due to absence of heat transfer by connection area
- Uniform temperature range in vacuum furnace
- Temperature controlled over a small
- Quick cooling (Quenching)
- Process can be computer controlled

5.1 Vacuum Carburizing

Vacuum Carburizing is non-equilibrium, boost-diffusion-type carburizing process in which the steel being processed is austenitized in a rough vacuum, carburized in a partial pressure of hydrocarbon gas, diffused in a rough vacuum, and then quenched in either oil or gas. Compared to conventional atmosphere carburizing, vacuum carburizing offers excellent uniformity and repeatability because of the high degree of process control possible with vacuum furnaces, improved mechanical properties due to the lack of inter-granular oxidation, and potentially reduced cycle times particularly when the higher process temperatures possible with vacuum furnaces are used [4].

5.2 Process Overview

- Vacuum carburizing steel is typically a four-step process:
- Heat and soak step at carburizing temperature to ensure temperature uniformity throughout steel
- Boost step to increase carbon content of austenite
- Diffusion step to provide gradual case/core transition
- Oil-quenching step. In addition, a reheat step prior to quenching may also be necessary for grain
- Refinement.

Vacuum carburizing offers advantages not only in manufacturing planning/process control and engineering, but also in manufacturing. Cycle - times can be reduced, particularly if even slightly higher carburizing temperatures are used. Preheating and post-carburizing heat treatment can also be performed in a vacuum, resulting in very clean parts that do not require the post cleaning associated with conventional atmosphere carburizing. The equipment can be started and shut down quickly using utilities only when the furnace is actually processing work, resulting in significant utilities savings. Heat and exhaust from vacuum-carburizing furnaces are much less than those emitted with conventional atmosphere carburizing methods. Therefore, the furnace can be located adjacent to other machine tools in a comfortable working environment. Other high temperature processes, such as brazing, can be performed in the same furnace (depending on furnace construction) and possibly can be combined to reduce cycle time along with the need to heat, cool, and handle the work twice.

5.3 Furnace Design

Vacuum carburizing is usually performed in a furnace specifically designed for this application, with or without oil and/or gas-quenching capability and modified with the controls and plumbing required for vacuum carburizing. The furnace can be of either graphite construction (graphite insulation and heating elements) or ceramic construction (refractory board insulation and silicon carbide heating elements). Graphite construction permits higher operating temperatures useful for a multipurpose furnace, whereas ceramic construction is well suited for vacuum carburizing because it can be safely operated in air at process temperatures for die quenching or for facilitating soot removal [3].

5.4 Vacuum Carburizing Process Salient Features are :

- No intercrystalline oxidizing.
- Reduces distortion and overall size change
- Superior Part cleanliness
- Reduced heat treatment time
- Perfectly controlled and reproducible Carburizing depths and narrow tolerances
- Ability to provide a choice of the surface carbon content.
- Improved fatigue resistance.
- Gas or oil quenching (high pressure gas quench up to 20 bar in specialized cold cell).
- Processing temperatures range up to 2208°F (1250°C).

The heat treatment cycle can be computer simulated and can guarantee the exact requested carbon profile.

VI. VACUUM CASTING

Vacuum Casting Vacuum mold casting, also known in manufacturing industry as the V process, employs a sand mold that contains no moisture or binders. The internal cavity of the mold holds the shape of the casting due to forces exerted by the pressure of a vacuum.

6.1 Manufacturing by Vacuum Mold Casting Offers the Following Advantages [5] :

- In vacuum mold casting manufacture there is no need for special molding sands or binders.
- Sand recovery and reconditioning a common problem in metal casting industry, is very easy due to the lack of binders and other agents in the sand.
- When manufacturing parts by vacuum mold casting the sand mold contains no water, so moisture related metal casting defects are eliminated.
- The size of risers can be significantly reduced for this metal casting process, making it more efficient in the use of material.
- Casting manufacture by vacuum molding is a relatively slow process.
- Vacuum mold casting is not well suited to automation.

VII. METAL JOINING PROCESSES

Metal Joining Processes are classified as follows:

1. Welding
2. Brazing
3. Soldering

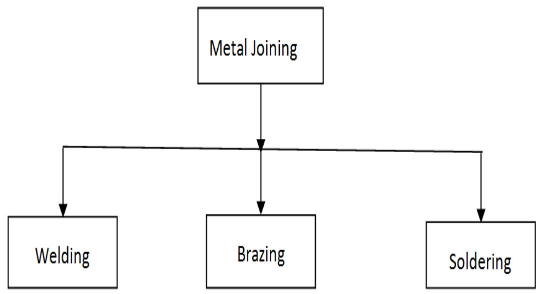

Figure 4 : Schematic Figure of Metal Joining Processes

7.1 Laser Welding Under Vacuum:

The coupling-in window for coupling the laser beam into a vacuum is the key part of vacuum system for laser welding. The ambient pressure has a significant influence on the phenomena of laser welding. Besides, the vacuum environment is a benefit to further understanding the physical process of laser keyhole welding

Advantages of Laser Welding Under Vacuum:

- Increased welding depth
- Contamination due to spatter & vaporization is reduced
- Absence of pores/elimination
- No need of inert gas
- Process stability, simple device.

7.2 Electron Beam Welding

In this welding accelerated, focused electrons provide the energy required in the *weld* zone. In order to prevent the scattering and absorption of the electrons, the process is carried out in a high *vacuum*. This also makes it possible to *weld* highly reactive materials.

Advantages of Electro-Beam Welding:

- High weld depth to width ratio is increased
- Elimination of multiple pass welds
- Narrower HAZ

- No gas contamination
- Excellent for rejoing materials
- Automation

7.3 Brazing

Brazing as a group of joining processes that produce coalescence of materials by heating them to the brazing temperature and by using a filler metal (solder) having a liquidus above 840°F (450°C) and below the solidus of the base metals.

Advantages of Brazing:

- Extremely clean
- Flux free braze joints
- Improved temperature uniformity
- Low residual stress

7.4 Soldering:

The purpose of flux material is to remove remaining oxides and to reduce the surface tension in order to promote wetting of the dissimilar materials' surfaces. However, if exposed to vacuum or a high temperature environment, the effects of the flux on the electronic component are harmful.

Advantages of Soldering:

- Void red
- Flux free soldering with formic acid
- Soldering temperature up to 400°C
- Ref. PINK GmbH thermo systems
- Double sided PCB possible
- Process can be switched off & on

VIII. Powder Metallurgy

Powder Metallurgy is one of the important manufacturing processes especially for the production of composite materials. The brief steps in manufacturing are powder production, followed by compaction into suitable size and shape subsequently sintering to get the required strength and hardness. Powder production plays an important role as it influences te size and shape of the powder ad bulk powders which in turn influences powder characteristics like apparent density, flow rate, compressibility etc. Production of powders in vacuum by atomization techniques reduces the surface oxidation of powders and improves their purity. Sintering of powder compact in vacuum enhances its strength and hardness as the atmosphere is controlled and surface impunities will be lessened.

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