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PLASMA ANNEALING OF SMALL DIAMETER TUBES

Efficient and High-Speed Alternative to Traditional Radiance Annealing.

Strand annealing furnace has played the dominant role in annealing of stainless steel and nickel alloys tubes for decades. In recent years plasma annealing became increasing deployed amongst stainless steel tube manufacturers especially for the small OD and high-quality applications. Today plasma became a preferred choice for annealing of a wide range of mainstream stainless and nickel alloy and copper tubes up to the ODs of 20mm.

Plasma annealing is been used for medical, nuclear, instrumentation, heat-exchanger and aerospace tubes and in other applications where clean, scratch-free surface is required. Nowadays plasma offers also a small-footprint, high-output, efficient annealing alternative for mainstream stainless steel and copper and alloy applications. Plasma annealers challenge the dominance of the traditional strand annealing furnace in pretty much every aspect of production. Plasma heat treatment offer operational efficiency and finished product quality, whilst offering lower total cost of ownership. Compared to induction heating plasma demonstrates superior surface finish, more homogenous recrystallization and better energy and gas efficiency.

Slow speed of traditional tube furnace means that the annealing of stainless steel tubes generally involves a multi-line set up. Multi-line process is logistically demanding and involves multiple pay-offs and take-ups that can require substantial capital outlay. A multi-line annealing plant takes large workshop area and locks considerable money in working capital related to the material being processed on each of the annealing lines. Furthermore, slow annealing speed means that drawing or rolling processes have to be performed separately, off-line from annealing, which adds to the complexity of process logistics.

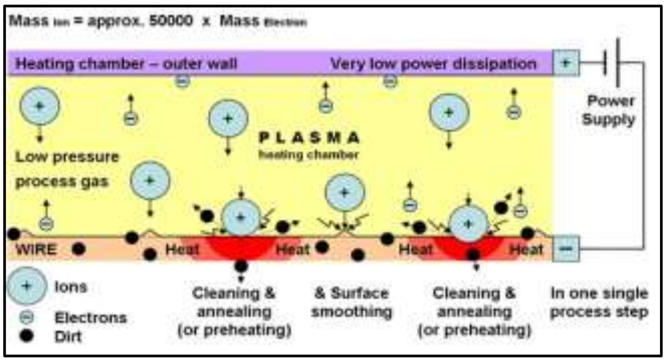

Figure 1. Schematic of plasma treatment

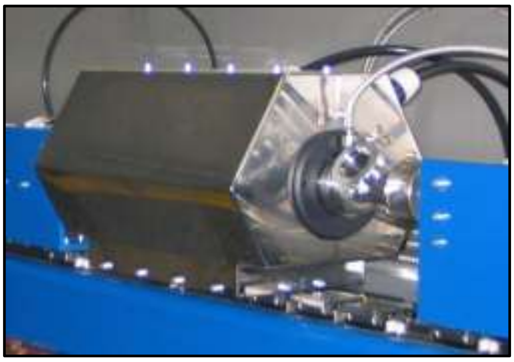

Figure 2. Plasma module

The process speeds of the new plasma annealer are much higher than the process speeds of a traditional tube furnace. This allows a single line plasma annealing plant to substitute multiple lines of a tube annealer, whilst retaining the same output capacity. In some cases it is also possible for plasma annealer to operate in-line with a drawing or a rolling machine.

A schematic of a plasma treatment on a metal surface in the plasma chamber is given in Figure 1. Plasma – an ionized gas - is maintained in the plasma chamber (Figure 2) at low pressure. In the plasma chamber the electric field accelerates ions towards the surface of the processed material and electrons towards the outer wall of the chamber.

Ion bombardment results in heating on the surface of the processed material. On the other hand the electrons have virtually no mass and carry no energy; hence they do not heat the plasma chamber. This makes plasma annealing an efficient technique to heat the material, resulting in only a very small percentage of power being lost as dissipated heat in the plasma chamber. The energy coupling in the plasma process is considerably better than the energy coupling in the typical convection furnace, which is the reason for a compact design of the plasma chamber. Depending on application 70% to 85% of all the power used by plasma annealer is converted into heat in the processed material, which makes the plasma heating much more energy efficient than any conventional tube furnace.

Plasma Heat Treatment

Plasma annealers have so far been designed for tubes up to 20mm OD. The annealing speeds on small diameter tubes up to about 2mm OD can reach up to 20m/s. A 60kW plasma annealer for larger size stainless steel tubes would typically feature output of up to 250kg/h for recrystallization of austenitic stainless steel tube and more for martensitic stainless steels. A 60kW plasma annealer can anneal large size copper and coper alloy tubes at the output of 1200kg/h. Annealing speeds can be high enough to run annealing in-line with standard drawing or welding lines in the smaller dimeter ranges.

Rapid heating and reduced time of recrystallization results in fine grain size. Small grain size with uniform crystal structure in the longitudinal and transversal direction improves material’s susceptibility to cold working and its resistance to surface cracking. For example, grain sizes of 9-10 ASTM are typically achieved in the longitudinal and transversal direction on 316L stainless steels. Copper tubes can be annealed down to Rp0.2% of 50MPa and elongations up to 60%.

Annealing power is controlled with a high degree of accuracy via plasma generator. This gives the operator the ability to target mechanical properties with a great degree of accuracy and provides greater flexibility in new product development.

Plasma Surface Treatment

Ion bombardment or ion sputtering on the material surface results in removal of the upper surface layer. Dirty deposits, soaps, lubricants and fine oxides layer break under the ion bombardment in the plasma chamber. The debris and other cracked surface contamination are sucked out of the plasma chamber by the vacuum system and are filtered out through the exhaust installation. The dry surface cleaning and degreasing being performed simultaneously with plasma annealing is of particularly benefit to applications with demanding surface requirements in sectors such as medical (needles, endoscopy ect.), nuclear, oil & gas, chemical and food processing, instrumentation or aerospace to mention a few.

Plasma treatment is nevertheless not designed for removal of excessive amounts of dirt and soaps on the material surface. Excessive surface contamination has to be removed with an appropriate conventional pre-cleaning system that is chosen for specific application.

Plasma treated surface without the oxide layer is activated and highly susceptible to coating and creates a strong bond with polymers or metals. Plasma annealer can be installed in-line with the coating process, such as electroplating, hot dip, taping or extrusion coating, whereby non-oxidizing atmosphere is ensured to the point of coating to avoid the need for wet surface preparation or fluxing. One example of such application is tinning of capillary tubes. Plasma annealed material is brought to the point of coating in protective atmosphere to prevent surface oxide creation before coating is applied. Such in-line configuration avoids the need for chemical surface preparation or other forms of surface activation.

Good surface passivation of plasma annealed materials is achieved by means of cooling in inert atmosphere before the material is exposed to air.

Table 1 lists sample photographs of the plasma annealed tubes of stainless steel, nickel alloy and copper. The difference in surface finish before and after annealing is evident.

Table 1. Material Samples of Plasma Annealed Tubes

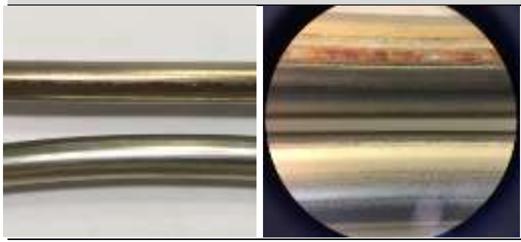

Figure 3. SUS 304L 8.5mm OD x 0.5mm WT

Above: welded tube before annealing with a oxidation along the weld

Below: plasma annealed and weld deoxidized

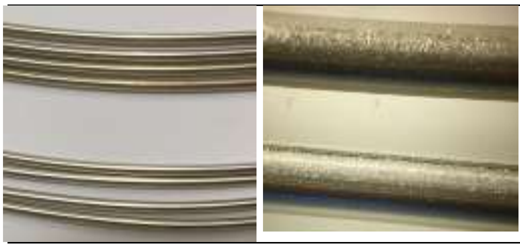

Figure 4. Ni200 2.5mm OD x 0.2mm WT

Above: welded tube, drawn, degreased, before annealing with surface oxidation

Below: plasma annealed with deoxidized surface

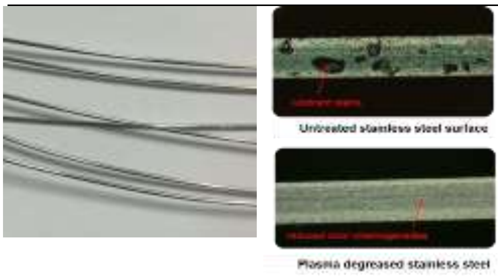

Figure 5. NSUS 316L 0.6mm OD x 0.15mm WT

Above: drawn welded tube, before annealing with surface lubricant deposits

Below: welded tube, drawn and annealed with bright finish for medical applications

Figure 6. Copper Tube 12mm OD

Above: drawn welded tube, before annealing with surface oxidation, lubricant deposits

Below: plasma annealed with bright deoxidized surface

Components of Plasma Annealer

In Figure 7 is a photo of a plasma annealer and its main components. The plasma module and the soak/dwell section sit between two Guides connected to the vacuum system, which maintains protective atmosphere throughout the heating and cooling zones of the machine. The purging gas can include Hydrogen, Nitrogen, Argon, Helium or their mixtures. The gas mixture is chosen to suit the application, in particular material’s specific surface requirements. Usually a rapid hydrogen gas cooling system is applied in stainless steel and nickel alloy applications.

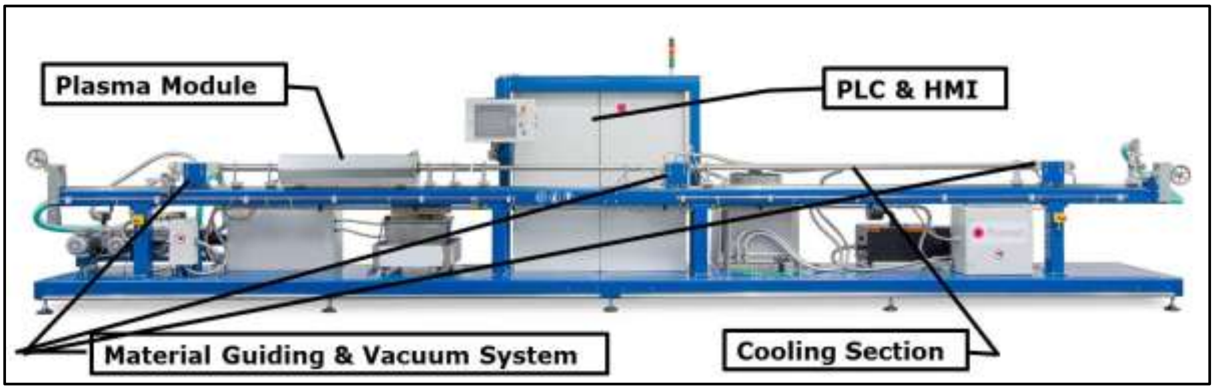

Figure 7. PlasmaANNEALER and its main components

For some applications direct water cooling can be added to the last section of the cooling zone in order to reduce the total length of cooling zone. Direct water cooling is common for copper and its alloy tubes. The process is controlled with PLC and touch-screen HMI.

Figure 8. PlasmaANNEALER for annealing, and degreasing of copper tubes.

Unlike the traditional strand furnace, the plasma annealer can cold start production in few minutes and can be stopped imminently. This avoids the lengthy heating-up and cooling-down times and associated energy costs that are symptomatic for a conventional furnace.

Figure 9. PlasmaANNEALER line for nickel alloy and stainless steel tubes of 0.6mm – 8.5mm OD with inlet and outlet caterpillars, double payoff and takeup (coil + spool).

The gas cooling section in the plasma annealer has a closed loop design to minimize purging gas consumption. Hot material in the plasma zone does not touch any parts of the machine, which is possible to achieve due to the short length of the plasma/heating section. This avoids maintenance costs like tube wear that are common for a conventional strand furnace.

A photograph of the plasma annealer for stainless steel and nickel alloy tubes is given in Figure 9**.** The annealing line on the photograph is 30 meters (100ft) long in total and includes double payoff for spools and coils, inlet caterpillar, plasma annealer with and gas cooling section, caterpillar with dancer and double takeup with coiler and spooler. The plasma heating section on the other hand measures 1 meter. The line can anneal tubes with OD from 0.5mm to 8.5mm.

A qualitative comparison of three alternative heat treatment processes (strand furnace, induction annealer and plasma annealer) is given in the table below. The qualitative comparison would vary considerably depending on application and processed material.

Table 2: Quantitative Process Comparison of plasma, induction and strand annealing furnace

	Strand Furnace	Induction Annealer	Plasma Annealer
Process type	Multi-line / low-speed	Single line / high-speed	Single line / high-speed
Energy cost	High	Low (steel) High (nonfer. & stainless)	Low
Purging gas cost	High	High	Low
Labour cost	High	Low	Low
Maintenance cost	High	Low	Low
Production uptime	Low Cooling down / heating up	High Immediate start and stop	High Immediate start and stop
Production line footprint	Large	Compact	Compact
Capex – furnace	Low	Low/high	High
Capex – payoffs and takeups	High	Low	Low
Working capital locked in material	High	Low	Low
Grain size of finished product	Large	Small	Small
Annealing power control/ temperature control	Limited / Slow	Poor for non-magnetic mat.	Accurate and immediate
Recrystallization uniformity (stainless)	High	Low	High
Surface quality	Poor	Subject to setup	High

In summary, plasma annealer features the following benefits when compared to the traditional tube furnace:

- Bright, scratch-free, pile-free surface finish;
- Small grain size with uniform crystal structure in longitudinal and transversal direction, which results in consistent mechanical properties;
- High production speed allows plasma annealer to run in-line with drawing, welding or subsequent coating processes;
- Simultaneous dry chemical-free surface cleaning (i.e. degreasing and oxide removal) results in superior surface finish;
- Increased uptime through immediate temperature manipulation and no warming up and cooling down times;

- High energy efficiency means considerable energy savings;
- Low purging gas and maintenance costs compared to traditional tube furnace;
- Compact design means short installation and commissioning times;
- About 2/3 smaller shop-floor space than a traditional furnace with equivalent output;
- About 2/3 smaller power connection and traditional furnace with equivalent output;
- Environment and operator friendly production.

Plasma annealer for stainless steel tubes from 6mm – 12.7mm OD is given in Figure 10 The annealer has max annealing output of 250kg/h for stainless steel tubes.

Figure 10. PlasmaANNEALER for annealing or stress relieving tubes with OD range of 6mm to 12.7mm with max output of 250kg/h.

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