Technical Bulletin

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Heat treatment and intergranular corrosion

Pickling after incorrect or incompetent heat treatment can seriously damage metal

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Introduction

Everywhere in the world, the successful manufacture of such items as piping, tanks, auxiliary equipment, tools, boiler installations and constructions requires the daily application of heat to iron and steel alloys as well as non-ferrous metals. Heating occurs in many forms and applications. These include welding, cutting, induction bending, induction elements, direct heating with a heat source, electric heaters and indirect heating with gas or hot air.
The construction of iron, steel or non-ferrous systems requires additional heat treatment. Examples are the hardening process of steel, curing, or the stress-free annealing of all common metals when producing structures or machine components. Annealing takes place under a blanket of air or nitrogen (to prevent oxides from forming), under atmospheric conditions in furnaces (with or without electric heating), or in vacuum furnaces. Salt baths are also used for thermal surface treatment. Other applications include a pyrolysis oven or a fluid-bed furnace in which cleaning occurs using a turbulent mixture of gas, sand or corundum at about 400° C.

Steel hardening

Hardening is a term used for the process that increases the hardness and thus the wear-resistance of a metal alloy. This increase in the hardness of an alloy can be useful in a wide range of applications.
In the case of steel, the material is uniformly heated to a cherry red colour (770° C). This colour is an indication of the phase / temperature of the material. Loss of magnetism is also an indication of the correct temperature.
The steel is subsequently cooled in oil or water. The choice of oil or water cooling depends on the composition of the material being cooled. The differences in the heat transfer coefficients of the coolants mean that the material will cool more quickly or slowly. Too slow cooling fails to result in hardening; too rapid cooling can crack or break the material.
After hardening, the steel must be tempered in order to prevent the steel from becoming too brittle. Tempering increases the ductility of the metal. Depending on the alloy and desired hardness, the material is tempered by reheating at a temperature of about 180-650° C and keeping it at that temperature for a set time. Cooling to ambient temperature subsequently occurs in the open air.

Intergranular corrosion in an oven (Photo: Cobra Consultancy)

Induction bending

In producing duplex or stainless steel above-ground and underground gas pipeline networks and alloyed steel pipes for oil transport, use is made of induction-heated thick or thin wall bends with variable radii and legs with diameters ranging from small to as large as 1200 mm, instead of short welded bends.

In addition to alloyed steel bends, all types of applications require use to be made of pipes and bends constructed of very exotic nickel chromium alloys. The bending work is performed on large hydraulically controlled banks where the cross-section of the relevant part of the material is heated to a temperature of 700–1200° C (depending on the type of material), bent and then slowly cooled. This causes mostly black oxides to form on the surface and discolouration to occur.

Stress-free annealing

This procedure involves the removal of the stresses that are built up in the structure after casting, welding, intensive deformation and thermal hardening. For example, the procedure is particularly relevant for the production of pipe branches, manifolds, heat exchangers, and boilers, as well as heaters and economisers, etc.

The temperatures and times used in the process depend on the material, temperatures ranging from 600° C to 1000° C.

The aforementioned heat treatments are specialised, critical work in which a temperature / time range table must be consulted in order to establish the correct temperature for the appropriate time. If done improperly without regard for the correct temperature or the prescribed time, the danger is very great that the metal shall suffer deformation and no longer be in its original condition. Subjecting the surface of this metal to a chemical treatment such as pickling and passivation may cause it to be seriously damaged by the acid. In the case of chrome alloys and stainless steel, there is also a risk of intergranular corrosion.

Intergranular corrosion

Intergranular corrosion is the formation of corrosion along the grain boundaries of an alloy, causing the metal to lose its integrity. Although only a small amount of the alloy corrodes, the damage can be very extensive. In this type of corrosion, the material is specifically affected at the site of the grain boundaries. Intergranular corrosion can only occur after stainless steel has undergone heat treatment (welding, annealing).

In the case of stainless steel, the grain boundaries are susceptible to corrosion if chromium carbides are present (bonds forming between chromium and carbon). These chromium carbides readily form in the heat-affected zone of stainless steel during welding. Excretion of chromium occurs at temperatures ranging from 500 to 800° C. In its normal state, austenitic stainless steel contains carbon, homogeneously dissolved in the austenite crystals. In the described temperature range, this carbon bonds with the available chromium to produce chromium carbide, which is deposited as crystals that accumulate at the boundaries of the austenite crystals. There is subsequent chromium depletion along these boundaries because the chromium in their vicinity is extracted. If stainless steel in such a state is exposed to aggressive environments, an extremely strong type of corrosion occurs at the crystal boundaries, known as intergranular corrosion. This phenomenon may occur even during pickling treatment, rendering the material unusable. Intergranular corrosion can be avoided by choosing stainless steel types with low carbon content (AISI 304L, AISI 316) or stabilized types (AISI 321 or 316 Ti), by using welding techniques that reduce exposure to the stated temperature range, or by solution annealing the stainless steel (at 900 ° C and then rapidly cooling).

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