

Heat Treating

Risk Solutions

Heat Treating is a process that involves heating and cooling a solid metal or alloy in a controlled manner in order to change the physical properties of the material being heated or cooled. There are basically three steps in heat treating: heating a metal or alloy part to a controlled temperature; holding (soaking) the temperature for a defined length of time; then cooling the part rapidly or slowly at a controlled rate. This process results in changing the material's microstructure, which changes the material's mechanical properties such as strength, ductility, toughness, and wear resistance.

The question as to why do we need to heat treat a part or parts is somewhat dependent on the manufacturing process and what the part may be used for. Heat treating is used to:

- Removing stresses such as those that typically developed in the initial machining of a part,
- Enhance the properties of metal parts,
- Add wear resistance to the surface of a part by increasing its hardness and, at the same time, increase its resistance to impacts,
- Increase toughness by providing a combination of high tensile strength and good ductility to enhance impact strength,
- Improve the cutting properties of tool steels,
- Enhance electrical properties of materials.

While the heat treating process is rather simple, and the different heat treating processes are basically the same, the difference is related to the required temperature needed for the different metal or alloy being heat treated. The metal or alloy is heated to a temperature range, which is called the "Phase transformation range." It is when the metal or alloy is heated to this phase transformation range, the material's microstructure changes. How long the material is kept at this required temperature and, the specific cooling process used, is based on the properties that need to be achieved for the specific material.



Hartford Steam Boiler

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Several of the more common heat treating processes is:

Annealing - The steady heating of a metal part to a temperature slightly above its transformation range and then allowing it to cool down very slowly.

Normalizing - The steady heating of a metal part to a temperature above its transformation temperature range, followed by a cooling process at a moderate pace. Normalized metals are often cooled in open air at room temperature.

Hardening - The expedient heating of a metal part above the transformation range phase, and hold (soak) at that temperature long enough for uniform heating, then cooling rapidly (quenching).

Stress Relieving - The steady heating of metal to a temperature below the point that any microstructure change occurs. The part is heated uniformly, and then cooled slowly to room temperature.

The heating and soaking process is accomplished by using either an industrial furnaces or oven. Whether a furnace or an oven is used is largely depended on the material being heat treated. In a furnace, the material is heated by direct contact with the flame. In an oven, the material is heated by combustion air using conventional heating. In some case an inert gas is used in the oven to heat the material rather than air. Oven and furnaces are first classified as to whether the material is heated at atmospheric pressure or the material is heated in a vacuum.

In addition to classifying the oven and furnace by the type of environment the material is heated in, oven and furnaces are also classified in two broad categories. This relates to how the units are used in production, which is, batch and continuous operation. Batch ovens or furnaces are used for individual or small series production, whereas continuous-operation ovens or furnaces are used for large series production and mass production.

There is another classification for ovens and furnaces that the National Fire Protection Association (NFPA) uses. In NFPA 86: *Standard for Ovens and Furnaces* oven and furnaces are divided into four classes based on the volatility of the atmosphere within the unit.

- CLASS A ovens and furnaces are heat utilization equipment operating at atmospheric pressure wherein there is a potential explosion or fire hazard that could be occasioned by the presence of flammable volatiles or combustible materials processed or heated in the furnace.
- CLASS B ovens and furnace are heat utilization equipment operating at approximately atmospheric pressure wherein there are no flammable volatiles or combustible materials being heated.
- CLASS C ovens and furnaces are those units in which there is a potential hazard due to a flammable or special atmosphere being used for treatment of material in process.
- CLASS D furnaces operate under vacuum for all or part of the process cycle.

NFPA 86 further divides furnaces into nine types. The categories are based on the furnace's features (inlets and outlets, and doors), and operating temperature. There is a table in NFPA 86 under Class C ovens and furnaces that also provides examples of the various types of furnaces.

In addition to the classifying ovens and furnaces by use and atmosphere, NFPA 86 also defines the safety operating requirements for combustion control of oil and gas fired ovens and furnaces. Because of the details associated with the operations of combustion controls, it is important to review this document to become familiar with the specific requirements associated with oven or furnace combustion controls. Some of the major points to review include the listing of safety equipment or devices, the location of fuel shutoff valve in the event an emergency, the use of the excess temperature devices and interlocks, and purging requirements before the start-up of a furnace or oven.

The cooling process that is used is as important as the heating process that is used. However, in some case, the cooling process can be the more hazardous part of the process. The cooling or quenching process can be an integral part of the oven or furnaces or a separate process. The cooling of the material may be as simple as letting the material cool in open air or quench it in a liquid bath or gas. The quenching process is cooling the heated material by immersing it in brine (salt water), water, oil, molten salt, air or gas.

There is a wide range of liquid quenchants used for heat treating applications. Some of the more common liquid quenchants include water, brines, caustics, polymers, oil, and molten salt. Each type of fluid provides different cooling rates, residual effects, and product storage considerations. Of all the quenchants used, oil and molten salt can represent a major potential hazard, if not properly used.

Air

Air quenching is used for cooling alloyed steels. When still air is use, the part should be position so the air can reach all sections of the part. Parts that are cooled with circulated air need to be arranged in the same manner as still air so that there is uniform cooling. Compressed air is used to concentrate the cooling on specific areas of a part. The compressed air must be free of moisture to prevent cracking of the metal.

Gases

The high pressure quenching gases are used in vacuum furnaces. High pressure quenching gas yields far less distortion than liquid (salt, water, polymer, and oil) quenching. The gas quenching medium is a cleaner product, eliminating the need for washing the parts after quenching and disposal of liquid quenching fluids. Gas quenching provides a very uniform heat transfer. Common gas medium include nitrogen, argon, and helium.

Liquids

When quenching material in a liquid bath there are three distinct stages of cooling: the vapor phase; nucleate boiling and convective stage. In the first stage, a vapor blanket is formed around the material. This blanket has an insulating effect and actually slows the cooling process down. As the temperature of the material decreases, the vapor blanket becomes unstable and collapses, initiating the nucleate boiling stage. Heat is removed the fastest in this stage, due to the heat of vaporization. The material continues to cool until the surface temperature drops below the boiling point of the quenchant. Further cooling takes place mostly through convection and some conduction.

There are several proprietary polymers quenchants that are used. The most commonly used formulations are polyalkylene glycols (PAGs), polyvinyl pyrolidines (PVPs), and polysodium acrylates (PSAs). Polymer quenchants can be formulated to provide quenching power ranging from that similar to fast quenching oils to that greater than water. PAGs are used in nearly all heat treating operations, including batch quenching,

integral quenching, continuous quenching, and press quenching. When using polymers for quenching, not all materials need to be washed as done with oil and salt quenching. The thin polymer film left on the parts usually burns off and disappears completely during tempering.

Quench oils that are commonly used will have a flash point between 270°F to 560°F. Because of somewhat low flash point when compared to the temperature of the material being quenched, there are several hazards that represent a fire exposure.

- **Material Transfer** The transfer process needs to minimize any splashing and over flowing of the oil. Partial immersion is a common cause of quench oil fires. The oil at the interface between the hot part and the liquid's surface will start generating oil vapor. If the part, for some reason, is not lowered into oil right away but is held over the oil or held practically in the oil, the oil vapors can be ignited.
- **Oil Temperature control** – the failure of the cooling system can cause the oil to overheat. Quench oil is commonly cooled by water circulating through coils in the tank, in a jacketed tank or by an external heat exchanger. It is important that cooling is maintained during the entire process. The temperature of the water and the oil should be monitored. It is recommended that the operating temperature of the oil in an open temperature quench tank be kept at least 150°F below its flash point.
- **Low oil level** If the oil level is too low and a large part is immersed in the quench oil, the oil can overheat. It is also important that the tank has low level indicators that will be interlocked with alarms.
- **Oil Over flow** – The quench tank should be designed to maintain the oil level with at least 6 inches of freeboard below the top of the tank or opening into the furnace. This requires the tank to have overflow drains and liquid level controls. In addition there should be an emergency drain line and if necessary a pump that would empty the tank in 5 minutes or less.
- Oil can overflow if the size of the material being submerged is greater than the free space, or from the presence of cooling water in the quench tank. Quench oils are cooled directly using water piping or coils or indirectly using heat exchanges. Should a leak develop in the piping, water may enter the tank. Because the oil is lighter the water, the oil will start floating on top of the water raising the level of the oil decreasing the freeboard of the liquids in the tank. This can result in the oil overflowing the tank, splatter and improper quenching. If the quantity of water is great enough, a steam explosion could occur when the hot material is immersed in the quench tank.
- **Exhaust hood** – Hoods, ducts, and vents should be made of noncombustible material for the remove of vapors from the process.
- **Oil Carry-over** - When parts are removed from the quench tank, there needs to be adequate drainage time for the oil to drain from the part. If the part is removed too quickly oil will continue to drain from the part creating an added exposure to the area. The area around the tank should be fire resistive material and the tank should be separated from combustible materials, power equipment and other process equipment. The tank should be located at grade level so if a boiler over would occur it would not develop into a three dimensional fire. If floor drains are provide, the drains should be connected to the waste oil drain sump.

Molten salt quenchant that are used have a wide operating temperature range of 300°F to 2,400°F. It is a unique medium, in which the vapor phase (the first stage) of quenching does not exist. Its high thermal conductivity with good agitation and the addition of water provides for fast quenching rates. Most of the heat extraction is by convection. As a result, distortion is minimized and the hardness achieved is more uniform and consistent.

Because molten salt has a low surface tension, in open salt baths, the molten salt can pop or splatter during the operation. In other operations, the molten salt can spill when parts are removed from the bath or furnace. If there are combustible materials, including the floor, the combustible material can be easily ignited. The hazards associated with molten salt can be divided into three areas.

- Fire caused by contact with the molten salt with other combustibles,
- Explosion of the salt mixture due to physical or chemical reaction, and
- Personnel

A larger concern would be a liquid such as water or oil from an outside source that is either sprayed or carried on material in to the salt bath. If a liquid is carried into the salt bath from a part that was cleaned, but not completely dried or not cleaned properly this can result in a violent reaction. If the quantity of the liquid is significant enough, an explosion can occur. Because the salts that are used for molten salt baths are specific temperature and application, the improper mixing or combining different salts such as nitrates and cyanide can result in a chemical reaction. Second, different salts can have chemical reaction with different materials. If aluminum parts are immersed in a nitrate salt bath at or near its melting point, it may result in a fire or explosion. Magnesium alloys should never be immersed in a nitrate salt.

Extra care needs to be taken with the use of nitrates. Nitrates are particularly hazardous because this material is capable of starting and supporting combustion. Heated nitrate salt will react with carbonaceous materials, such as oil, soot, tar, graphite, and cyanides. The accidental mixing of cyanides with molten nitrates can cause an explosion.

Safe Guards and Controls

It is important that the equipment being used for heating treating have the proper safety features installed per the equipment manufacturer, NFPA 86 requirements and any local code or standards. There should be a written inspection and maintenance program. The program should include procedures for testing all controls and their interlocks at least every six months.

While not all inclusive,

Ovens and furnaces require:

- properly designed combustion controls
- excess temperature controls,
- high temperature monitoring and interlocks
- Alarms.

Quench tanks require:

- Liquid level monitoring and interlocks
- excess temperature controls,
- high temperature monitoring and interlocks
- Alarms.

For both oil quenching and molten salt quenching, the medium used must be considered a potential fire hazard. This requires added controls and protection features when using quench oils or quench salts.

Oil

Protection:

Because quench oil is a combustible, automatic sprinkler protection should be provided over the area of open quench tanks. If the tank is an integral part of the furnace, depending on the equipment design, sprinkler protection should be installed outside the equipment, and a gaseous extinguishing agent may be used in the enclosure. For open tanks, an automatic dry chemical system may also be installed. In addition, hand held extinguisher should be available in the area.

Storage:

Quenching oil need to be handled and stored in the same way as any combustible liquid. The storage of these oils must be in accordance with NFPA 30 Flammable and Combustible liquid Code.

Quench Salts

Protection:

Because of the reaction molten salt would have with water, sprinkler protection should not be used above this equipment. A CO₂ or a Dry chemical extinguishing system should be used. It is important that the extinguishing system be designed specifically for the hazard and the equipment. In addition hand held extinguisher (non water based) should be available in the area.

Storage:

All chemical salts should be stored in tightly sealed container to prevent liquids or moisture from entering. Nitrate salts should be stored in a fire resistance room away from heater, and other reactive salts such as cyanide salt. It is important that storage is in accordance with manufacture's recommendation. A MSDS for the chemical being used should be available for review.