



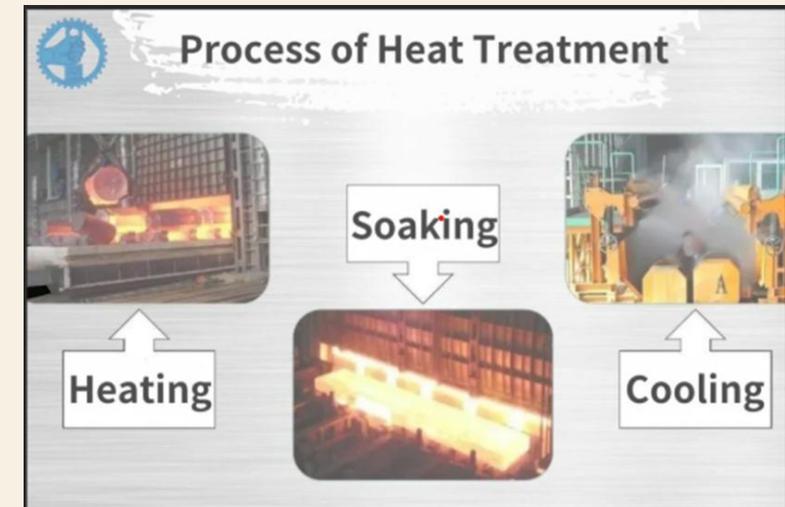
METALLURGY FOR THE NON METALLURGIST

PRACTICAL HEAT TREATMENT OF STEEL

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INTRODUCTION

- The generally accepted definition of heat-treating metals and metal alloys is heating, soaking, and cooling a solid structure of metal and/or metal alloy in a way as to obtain certain conditions and/or properties. Heat treating alters the properties of metals in several ways to make them stronger, tougher, harder, or to prepare them to serve a certain application, i.e. Corrosion Resistance, Wear Resistance, Fatigue, ..etc.
- All steels respond to one or more type of heat treatment processes. These processes allow for the various mechanical properties desired in a steel component. This is accomplished through variations in the type, amount and size of grains, and microstructural constituents.
- Some of the reasons for heat treating metal and metal alloy components include the following:
 - **Remove Stresses**
 - **Refine Grain Structure**
 - **Alter Properties**
 - **Add Wear and Corrosion Resistance to the Surface**
 - **Increase Toughness**
 - **Change or Modify Magnetic Properties**
 - **Modify or Upgrade Electrical Properties**
 - **Improve Machinability**



GLOSSARY

- **Alloy Steel:** Steel that contains specific amounts of alloying elements other than carbon and commonly accepted elements such as Cu, Mn, Si, S, and P.
- **Carbon Steel:** Steel which contains no specific amounts of elements other than Cu, Si, and Mn and contains only an incidental amounts of any elements other than C, Mn, Si, P, Cu, and S.
- **Cast Iron:** Large family of cast ferrous alloys in which the carbon content exceeds the solubility of carbon in austenite at the eutectic temperature. In various instances, the word cast will be left of. The terms Gray Iron, White Iron, Malleable Iron and Ductile Iron can be used.
- **Decarburization:** Loss of carbon from the surface layer of a carbon-containing alloy due to a chemical reaction.
- **Hardness:** Resistance of the metal to plastic deformation usually by indentation.
- **Martensite:** Metastable phase, the hardest, in steel which forms by the transformation of austenite to below the MS temperature.
- **Microhardness:** Hardness of material as determined by forcing an indenter into the surface of the material under light loads (500 or 1000 g).
- **Pusher Furnace:** Continuous furnace in which parts are pushed from one end to the other where they can be removed.
- **Quench Cracking:** Fracture of the metal during quenching from elevated temperature. Observed mainly in high hardness and low toughness material (Hardened carbon steel, alloy or tool steel).
- **Selective Quenching:** Quenching only certain portions of a part.
- **Slack Quenching:** Incomplete hardening of steel due to slower quenching rate than the critical one.
- **Transformation Temperature:** The temperature at which a change in the phase occurs.

PROCESSES

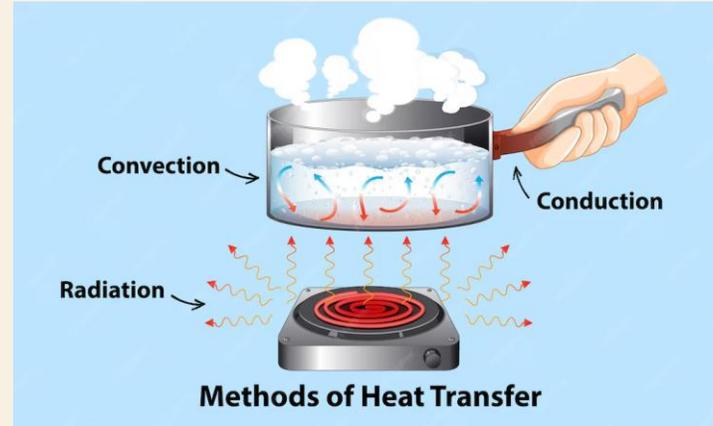
- **Normalizing:** Heating steel above its upper transformation temperature followed by cooling to well below transformation temperature range.
- **Annealing:** Heating to and holding at a suitable temperature followed by cooling at a suitable rate.
- **Neutral Hardening:** Process of forming Austenite by heating well into the transformation range.
- **Induction Hardening:** Rapid heating using a magnetic field of conductive material above transformation temperature followed by rapid quenching
- **Quenching:** Rapid cooling of metal from Austenitizing temperature by immersing the metal in a liquid or gaseous medium.
- **Tempering:** Reheating the hardened steel to a temperature below the transformation temperature (Generally below 1300°F).
- **Stress Relieving:** Like tempering stress relieving is done by Heating to below the lower transformation temperature for steels.
- **Carburizing:** Diffusion of carbon into the surface of ferrous alloys (low-medium carbon steels) by heating to a temperature above the upper transformation temperature.
- **Carbonitriding:** Diffusion of carbon and nitrogen into the surface of ferrous alloys (low carbon steels) by heating to temperatures above the transformation temperature.
- **Nitriding:** Diffusion of nitrogen into the surface layers of certain ferrous alloys by holding at a temperature below the lower transformation temperature with nitrogen atmosphere.
- **Nitrocarburizing:** Nitrogen and carbon are diffused into the surface of the steel at the Nitriding temperature by either molten salt or gas.

HEAT TREAT EQUIPMENT

Heat treating equipment are those devices used during heat treat processes. This includes heating devices (Furnaces and Ovens), fixtures, holding devices, quenching systems, atmospheres and temperature control systems.

❑ Heat Treat Devices

- Normally classified as Ovens or Furnaces based on their operating temperatures.
- Devices that operate up to 1000 F are Ovens and devices that operate over 1000 F are Furnaces.



❑ Heating Modes

- **Conduction:** Heat Transfer from one location of a work piece to another due to increased atom vibration under the influence of elevated temperature gradient.
- **Convection:** Best described as transferring heat by mixing one volume of fluid (liquid or gas) with another. Homes that are hot air heated are good example.
- **Radiation:** Heat transfer by emission. When a body is heated it emits radiant energy. When this energy strike another body, some of it will be absorbed, raising the matter atomic activity level and thus producing heat.
- **Most furnaces that operate above 1100 F are heated by radiation.**

HEAT TREAT EQUIPMENT

Batch Type Furnaces

- Most convenient, can be adapted to any heat treat operation, and do not occupy large areas.
- Batch-type furnace refers to one that is loaded with charge and then closed for pre-established heating cycle. The workload may then be cooled in the furnace.
- The work area is surrounded by gas-heated radiant tubes and is convectionally assisted by bottom or top fans.

Pit Furnaces

- Heated by convection and are popular in the aerospace industry.
- Minimal maintenance, easy to facilitate and does not occupy large spaces.
- Good for large mass type of parts.

Continuous Furnaces

- Basically an “in-one-end” and “out-the-other-end” type units.
- Mainly used for continuous high production of similar parts.

Vacuum Furnaces

- Prevent reactions at the surface of the part such as oxidation or decarburization.
- Remove surface contaminants resulting from fabrications or machining



HEAT TREAT ATMOSPHERE

- Controlled in heat treating processes to obtain certain product characteristics.
 - Protect surface – subsurface against Oxidation (Scale & IGO)
 - Prevent decarburization (loss of Surface Carbon)
 - Unchanged surface chemistry
 - Controlled condition of surface change; Case Hardening
- Types of Furnace atmospheres
 - Exothermic Gas
 - Endothermic Gas
 - Nitrogen Gas
 - Vacuum Atmospheres
 - Dissociated Ammonia



QUENCHING MEDIUMS, STEEL TYPES, QUALITY

Definition

- Rapid cooling of a metal from a suitable elevated temperature to develop an acceptable as quenched microstructure and hardness
- Conventional Quenchants include **Oil, Polymer, Water, Forced air, Forced Nitrogen Gas**
- Selection of quenching medium depends on Hardenability of metal and mass. Oil is the most used quenchant in steel HT
 - **Quenching rate vs. hardness.**
 - **Oil temperature vs. Distortion.**

Steel Numbering System

- United Numbering System (UNS) by **ASTM E 527** and **SAE J 1086** established by AISI or SAE for carbon and alloy steel.

	Carbon Steel
➤ 10XX	<u>Nonresulfurized, 1.00% Mn Maximum</u>
➤ 11XX	<u>Resulfurized</u>
➤ 12XX	<u>Rephosphorized and Resulfurized</u>
➤ 15XX	<u>Nonresulfurized and over 1.00% Mn</u>

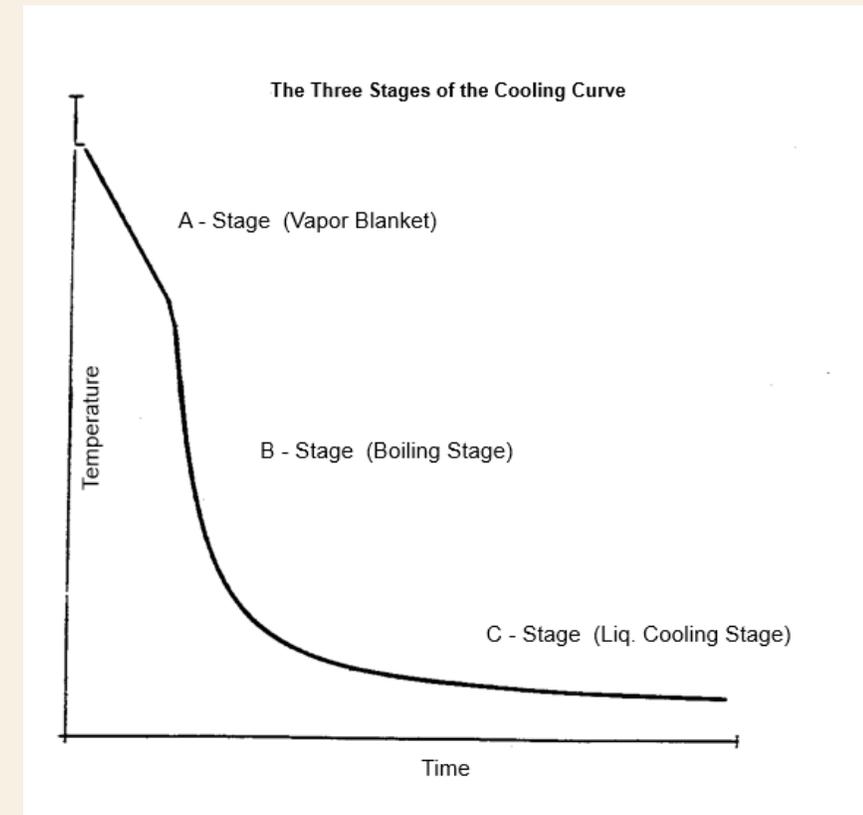
(XX = Mean of Carbon Content in the Steel)

	Alloy Steel
13XX	Manganese
40XX	Molybdenum
41XX	Chromium – Molybdenum
43XX	Nickel - Chromium – Molybdenum
50XX	Chromium
61XX	Chromium – Vanadium
86XX	Nickel - Chromium – Molybdenum
92XX	Silicon

- Stainless Steel – 4 different grades
 - Austenitic – High %Ni
 - Ferritic Grades – High %Cr
 - Martensitic Grades – High %C
 - Precipitation Hardening Grades – Combination Cr, Ni, Cu and other alloying elements (Mo, Al, Ti).

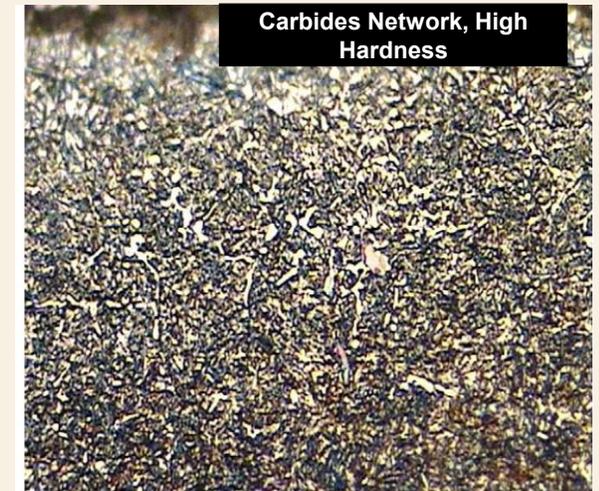
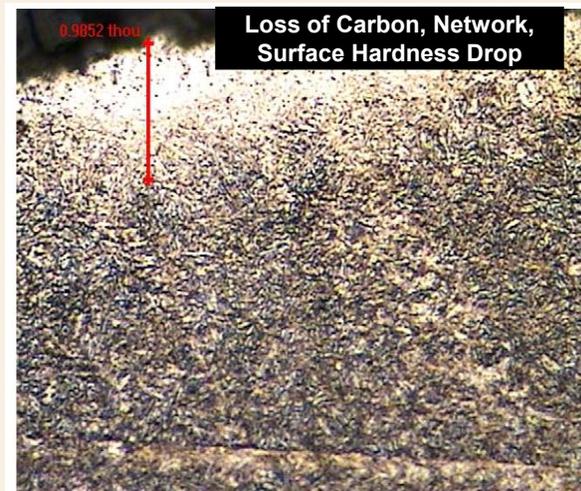
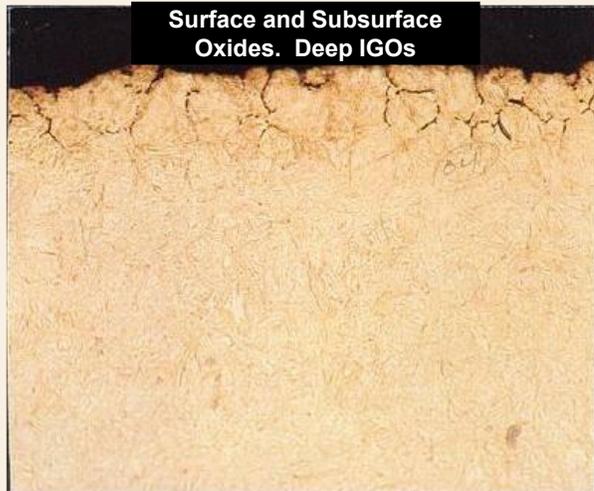
Quality Systems in HT

- CQI – 9; Automotive Requirements, Annual Self Assessment
- NADCAP; Aerospace, Registrar Certification



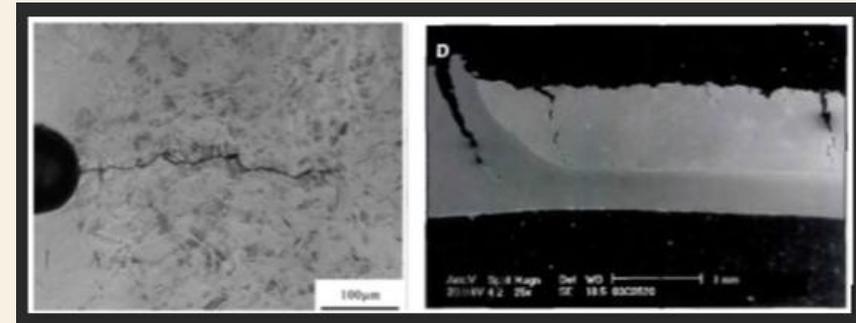
COMMON ISSUES OF HEAT TREATMENT ON PLATING PROCESSES

- Heat treatment of steel significantly alters the part surface and subsurface state chemically and physically.
 - Heat treat scale and oxides
 - Surface oxides, dark iron oxides layer increases with temperature of HT process
 - Subsurface intergranular – grain boundary – oxides depth (especially common in atmospheric conventional HT)
 - Heat tint and discoloration – heat affected zone – localized heating (induction hardening, welding)
 - Carbonized residues
 - Oily film, thickness-condition, will increase based on quench oil type and temperature (oil temp can be 300 – 500 F)
 - Marquenching in molten salt (up to 575 F bath)
 - Post hardening washing and tempering processes (possible creation of wax film)
 - Polymer ingress into forging-casting unmachined surfaces during induction hardening (extremely difficult to remove)
 - Surface texture-roughness
 - High temperature HT will impact part's surfaces – pitting, scratches, dimples – plating will expose such conditions
 - Variation in surface hardness with microstructure alteration such as decarburized layer, carbide formation, and porosity-inclusions
 - Quenching can create micro-macro level cracks (high tensile stresses and high thermal gradient)
 - Distortion rates post conventional quenching (warpage, shrinking-growth (IDs smaller, OD bigger)), plating thickness can cause out of tolerance condition



HYDROGEN EMBRITTLEMENT

- Occurs when metal surface is exposed to ionized H₂. Atoms diffuse into the hardened metal faster than combining with other molecules on the surface.
- Most prone alloys are those with hardness greater than 30 on the HRC scale.
- High strength steels, especially Martensitic SS, PH grades SS, and high strength-low alloy steels such as 4340 are most vulnerable.
- Not only the conventional pickling and electroplating causes embrittlement, welding and exposure to H₂S corrosive environments are also factors.
- **Best practices in minimizing embrittlement include:**
 - Steel choice – Engineering
 - Use of Alkaline base chemistry for cleaning
 - Using low Hydrogen producing plating chemistry
 - Bake relieve within 1-2 hours after plating
- **Detection methods which can be implemented**
 - NDT for potential cracking such as Liquid Penetrants, Magnetic Particle Inspection, Eddie Current, Ultrasonic
 - ❖ **Recommended when processing aerospace embrittlement susceptible material.**
 - **ASTM B850-98 and AMS 2759/9 Industry and Aerospace Bake Requirements**
 - **ASTM F519 – Test Method for Evaluating Potential Embrittlement**



ASTM B850-98

Partialist of hydrogen embrittlement relief treatment bake times/temperatures for some common high-strength steels.

Tensile Strength (MPa)	Tensile Strength (000 psi)	Rockwell Hardness HRC	Post-Plate Bake Time at 190°-220°C or 374°-428°F
1701-1800	247-261	49-51	Minimum 22 Hours
1601-1700	232-247	47-49	Minimum 20 Hours
1501-1600	218-232	45-47	Minimum 18 Hours
1401-1500	203-218	43-45	Minimum 16 Hours
1301-1400	189-203	39-43	Minimum 14 Hours
1201-1300	174-189	36-39	Minimum 12 Hours
1101-1200	160-174	33-36	Minimum 10 Hours
1001-1100	145-160	31-33	Minimum 8 Hours

About the presenter

- **Al Odeh, Global Supplier Quality Manager at GKN Automotive**, Heat Treating and Surface Finishing, with over **26 years of experience** in heat treating, finishing, and metallurgical practices.
- Championed the design and startup of **multiple heat-treating plants, electro-electroless plating lines, organic (dry and liquid) coating sites, fully operational metallurgical and chemical laboratories**, and successfully led organizations through **NADCAP, ISO 9001, and A2LA accreditations**, with a strong emphasis on process control, failure prevention, and **hydrogen embrittlement risk mitigation**.
- A dedicated technical educator, he has delivered practical heat treating and surface finishing courses at **technical colleges and Fortune 500 companies** using his self-authored training materials.
- Al holds a **Bachelor of Science in Metallurgical Engineering** from the **University of Illinois** and is a **Six Sigma Black Belt**.

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