FUNDAMENTAL MANUFACTURING PROCESSES

Heat Treating

SCENE 1. CG: FBI warning white text centered on black to blue gradient	WARNING federal law provides severe civil and criminal penalties for the unauthorized reproduction, distribution or exhibition of copyrighted videotapes. © 1999 SME
SCENE 2. CG: disclaimer white text centered on black to blue gradient	Always read the operating manual and safety information provided by the manufacturer before operating any heat treating equipment. Make sure all machine guards are in place, and follow all safety procedures when working with or near heat treating equipment.
SCENE 3. **tape 40, 01:00:00-01:00:12** SME logo, with music CG, SUPER: www.sme.org	
SCENE 4. **tape 25, 01:01:00-01:01:45** fundamental series open, with music	**MUSIC UP AND UNDER** **NARRATION (VO):** THE FUNDAMENTAL MANUFACTURING PROCESSES VIDEO SERIES, EXAMINING THE TOOLS AND TECHNIQUES OF PRECISION MANUFACTURING.
SCENE 5. program title: CG: Heat Treating white text centered on black	**NARRATION (VO):** THIS PROGRAM IS AN INTRODUCTION TO HEAT TREATING.
SCENE 6. **tape 506, 19:07:04-19:07:24** parts pulled from heat, glowing, and transferred to quench for cooling	**NARRATION (VO):** HEAT TREATING PROCESSES ARE USED TO ALTER THE METALLURGICAL STRUCTURE AND MECHANICAL PROPERTIES OF METALS OR ALLOYS THROUGH THE USE OF CONTROLLED

HEATING...,

AND COOLING CYCLES.

SCENE 7.
tape 488, 00:37:00-00:37:20
mill forms being pulled from heat treating furnaces
tape 502, 14:16:01-14:16:05
tooling being heat treated
tape 493, 01:04:40-01:04:54
parts being loaded for heat treating

NARRATION (VO):

HEAT TREATING PROCESSES ARE SOME OF THE MOST WIDELY-USED AND VERSATILE IN MANUFACTURING. THEY ARE UTILIZED TO TREAT MILL FORMS...,

TOOLING..,

AND PARTS.

SCENE 8.
continue previous shot
tape 483, 11:04:09-11:04:30
aircraft taking off
tape 510, 00:02:24-00:02:29
automobile
tape 232, 04:24:36-04:24:41
mill working
tape 485, 11:12:51-11:12:57
power tool
tape 486, 12:10:22-12:10:28
computer working

NARRATION (VO):

THESE HEAT TREATED PARTS ARE VITAL TO THE SATISFACTORY OPERATION OF PRODUCTS, SUCH AS,

AIRCRAFT,

AUTOMOBILES,

MACHINERY,

POWER TOOLS,

AND COMPUTERS.

SCENE 9.
tape 496, 03:04:00-03:04:08
zoom in, non-ferrous metal being quenched
tape 501, 12:24:27-12:24:55
steel coming out glowing red, and conveyed away
CG, SUPER: Carbon Steels
Alloy Steels

NARRATION (VO):

WHILE MOST METALS AND ALLOYS CAN BE HEAT TREATED IN ONE MANNER OR ANOTHER, THIS PROGRAM FOCUSES PRIMARILY ON THE HEAT TREATMENT OF CARBON AND ALLOY STEELS.

SCENE 10.
continue previous shot and cg, super, build onto cg
CG, SUPER: Ferrous Materials
Carbon Steels
Alloy Steels
Tool Steels
Cast Irons
Stainless Steels

NARRATION (VO):

THESE CARBON AND ALLOY STEELS ARE FERROUS MATERIALS, WHICH ARE DEFINED AS ALLOYS CONTAINING MORE THAN 50% IRON. OTHER FERROUS MATERIALS INCLUDE:

TOOL STEELS,

CAST IRONS,

AND STAINLESS STEELS.

SCENE 11.
tape 505, 17:03:27-17:03:59
heat treating operation
CG, SUPER: Mechanical Properties
Tensile Strength
Ductility
Impact Strength/ Toughness
Hardness

NARRATION (VO):

THE PURPOSE OF MOST HEAT TREATING PROCESSES IS TO ALTER THE MECHANICAL PROPERTIES OF METALS. THESE MECHANICAL PROPERTIES INCLUDE:

THE METAL'S TENSILE STRENGTH,

THE DUCTILITY OF THE METAL,

THE IMPACT STRENGTH, OR TOUGHNESS OF THE METAL,

AND THE HARDNESS OF THE METAL.

SCENE 12.
tape 295, 03:17:29-03:17:48
bar being bent
CG, SUPER: Tensile Strength
CG, SUPER: Yield Strength
tape 250, 02:05:30-02:05:40
c.u. part being sheared
CG, SUPER: Ultimate Tensile Strength

NARRATION (VO):

THERE ARE TWO IMPORTANT ASPECTS OF TENSILE STRENGTH. THE FIRST IS YIELD STRENGTH, WHICH IS THE MAXIMUM FORCE A MATERIAL CAN TAKE BEFORE STRETCHING PERMANENTLY. THE SECOND IS ULTIMATE TENSILE STRENGTH WHICH IS THE MAXIMUM FORCE THAT CAN BE APPLIED BEFORE A MATERIAL FRACTURES.

SCENE 13.
CG, SUPER: Ductility
tape 1, 00:04:32-00:04:42
slow-motion turning operation
tape 219, 01:01:30-01:01:40
photomicrography of soft steel turning operation
tape 219, 01:01:45-01:01:55
photomicrography of cast iron turning operation

NARRATION (VO):

DUCTILITY IS THE ABILITY OF A METAL TO BEND OR STRETCH BEFORE IT FRACTURES. HIGHLY DUCTILE METALS, SUCH AS SOFT STEELS OR ALUMINUM, STRETCH A GREAT DEAL BEFORE FRACTURING. LOW DUCTILITY METALS, SUCH AS CAST IRON, DON'T STRETCH MUCH AND FRACTURE EASILY.

SCENE 14.
CG, SUPER: Impact Strength/Toughness
tape 508, 23:06:12-23:06:23
c.u. hammer hitting concrete

NARRATION (VO):

A MATERIAL'S IMPACT STRENGTH, OR TOUGHNESS IS ITS ABILITY TO ABSORB MECHANICAL SHOCKS WITHOUT

FRACTURING.

SCENE 15.
CG, SUPER: Hardness
tape 506, 19:10:43-19:10:55
hardness test being performed
tape 503, 15:22:47-15:23:15
zoom out, c.u. hardness test being performed

NARRATION (VO):

THE HARDNESS OF A MATERIAL IS AN INDICATION OF ITS STRENGTH, BUT ALSO PERTAINS TO WEAR AND SCRATCH RESISTANCE. HARDNESS IS DETERMINED BY PERFORMING A HARDNESS TEST IN WHICH A CALIBRATED FORCE IS USED TO PRESS A SMALL, HARD INDENTER INTO THE SURFACE OF A METAL. THE DEPTH OR SIZE OF THE IMPRESSION IS MEASURED AND CONVERTED INTO A HARDNESS NUMBER. THE LARGER OR DEEPER THE INDENTATION, THE SOFTER THE MATERIAL.

--- TOUCH BLACK ---

SCENE 16.
tape 495, 02:08:24-02:08:32
parts coming out of heat treating
tape 452, 19:18:57-19:19:05
molten metal being poured

NARRATION (VO):

TO UNDERSTAND THE BENEFITS OF HEAT TREATING PROCESSES FIRST REQUIRES AN AWARENESS OF METAL AND ALLOY STRUCTURES.

SCENE 17.
continue previous shot
tape 435, 03:08:13-03:08:25
c.u. metal solidifying

NARRATION (VO):

WHEN A MOLTEN METAL SOLIDIFIES, THE ATOMS ARRANGE THEMSELVES INTO DEFINITE PATTERNS CALLED CRYSTAL STRUCTURES.

SCENE 18.
continue previous shot
tape 514, 00:00:58-00:01:12
GRAPHIC: modeled body-centered cubic
CG, SUPER: Body-Centered Cubic
tape 514, 00:01:18-00:01:32
GRAPHIC: modeled face-centered cubic
CG, SUPER: Face-Centered Cubic

NARRATION (VO):

THE TWO MOST COMMON CRYSTAL STRUCTURES IN METALS ARE:

BODY-CENTERED CUBIC...,

AND FACE-CENTERED CUBIC.

SCENE 19.
tape 514, 00:01:38-00:01:52

NARRATION (VO):

GRAPHIC: single, simplified face-centered cubic
tape 514, 00:02:13-00:02:24
GRAPHIC: zoom out, simplified face-centered cubic filling screen
tape 514, 00:04:10-00:04:20
GRAPHIC: developing grains #3
tape 514, 00:04:30-00:04:40
GRAPHIC: developing grains #4
tape 514, 00:04:50-00:05:00
GRAPHIC: developing grains #5
tape 514, 00:05:10-00:05:20
GRAPHIC: developing grains #6
tape 514, 00:05:30-00:05:40
GRAPHIC: developing grains #7
tape 514, 00:05:50-00:06:00
GRAPHIC: developing grains #8
tape 514, 00:06:10-00:06:20
GRAPHIC: developing grains #9
tape 514, 00:06:27-00:06:40
GRAPHIC: grains in boundary

THESE CRYSTAL STRUCTURES GROW UNIFORMLY IN ALL DIRECTIONS WITHIN EACH DEVELOPING CRYSTAL. AS THE METAL COOLS THESE CRYSTALS ARE CONFINED BY THE ADJACENT DEVELOPING CRYSTALS, FORMING GRAINS. THE LINE OF INTERSECTION BETWEEN GRAINS IS CALLED A GRAIN BOUNDARY.

SCENE 20.
tape 514, 00:06:57-00:06:59
confined crystal highlighted #1
tape 514, 00:07:17-00:07:19
confined crystal highlighted #2
tape 514, 00:07:02-00:07:04
confined crystal highlighted #3
tape 514, 00:07:27-00:07:29
confined crystal highlighted #4
tape 514, 00:06:52-00:06:54
confined crystal highlighted #5
tape 514, 00:07:22-00:07:24
confined crystal highlighted #6
tape 514, 00:07:12-00:07:14
confined crystal highlighted #7
tape 514, 00:07:06-00:07:08
confined crystal highlighted #8

NARRATION (VO):

BECAUSE THE GRAINS FORM INDEPENDENTLY, THEIR CRYSTAL STRUCTURES DEVELOP TILTED IN VARIOUS DIRECTIONS.

SCENE 21.
tape 514, 00:08:20-00:08:30
GRAPHIC: flat sheet of atoms, stick connections
tape 514, 00:07:36-00:07:46
ANI: flat sheet of atoms with electromagnetic connections
tape 514, 00:09:11-00:09:27
ANI: arrows appear on opposing sides of atoms top and bottom, pushing towards center, applying load, atoms stretching a lot, load removed, atoms springing back into shape

NARRATION (VO):

ALL ATOMS IN THESE CRYSTALLINE STRUCTURES ARE HELD IN PLACE BY ELECTROMAGNETIC ATTRACTION TO NEIGHBORING ATOMS. IF A FORCE, OR LOAD IS APPLIED TO A METAL, THESE ELECTROMAGNETIC BONDS STRETCH, ALLOWING THE ATOMS TO MOVE SLIGHTLY. WHEN THE LOAD IS REMOVED, THE BONDS PULL THE ATOMS BACK INTO

POSITION.

SCENE 22.
tape 514, 00:10:15-00:10:34
ANI: flat sheet of atoms with electromagnetic connections, arrows appear on opposing sides top and bottom, pushing towards center, applying load to atoms, atoms stretching a lot, then tear apart, continue moving with load being applied

NARRATION (VO):

IF THE APPLIED FORCE EXCEEDS THE METAL'S YIELD STRENGTH, THOSE ELECTROMAGNETIC BONDS WILL BREAK, CAUSING PERMANENT STRETCHING, OR DEFORMATION.

SCENE 23.
continue previous animation
tape 514, 00:11:00-00:11:15
GRAPHIC: flat sheet of atoms, stick connections
tape 514, 00:11:22-00:11:27
GRAPHIC: flat sheet of atoms, alloy atom #1 appears
tape 514, 00:11:32-00:11:37
GRAPHIC: flat sheet of atoms, alloy atom #2 appears
tape 514, 00:11:42-00:11:47
GRAPHIC: flat sheet of atoms, alloy atom #3 appears
tape 514, 00:11:52-00:11:57
GRAPHIC: flat sheet of atoms, alloy atom #4 appears
tape 514, 00:12:02-00:12:07
GRAPHIC: flat sheet of atoms, alloy atom #5 appears
tape 514, 00:12:12-00:12:17
GRAPHIC: flat sheet of atoms, alloy atom #6 appears
tape 514, 00:12:22-00:12:27
GRAPHIC: flat sheet of atoms, alloy atom #7 appears
tape 514, 00:12:32-00:12:37
GRAPHIC: flat sheet of atoms, alloy atom #8 appears
tape 514, 00:12:42-00:12:47
GRAPHIC: flat sheet of atoms, alloy atom #9 appears
tape 514, 00:12:52-00:12:57
GRAPHIC: flat sheet of atoms, alloy atom #10 appears

NARRATION (VO):

TO MAKE METALS STRONGER AND MORE RESISTANT TO DEFORMATION, IT'S NECESSARY TO STRENGTHEN THEIR CRYSTAL STRUCTURES. THIS IS DONE BY ADDING ALLOYING ELEMENTS, WHICH ARE OTHER METALS OR NON-METALLIC ELEMENTS, LIKE CARBON.

SCENE 24.
continue previous sequence

NARRATION (VO):

THE ADDITION OF AN ALLOY INTRODUCES FOREIGN ATOMS WITHIN THE CRYSTAL STRUCTURE OF THE BASE METAL,

DISRUPTING THE STRUCTURAL UNIFORMITY.

THIS DISRUPTION RESULTS IN INCREASED STRENGTH.

SCENE 25.
tape 503, 15:15:47-15:15:55
alloying element added to parts
tape 514, 00:00:50:00
freeze frame, blue background
CG: Alloying Elements
Carbon
Manganese
Chromium
Molybdenum
Silicon
Nickel

NARRATION (VO):

IN ADDITION TO CARBON, OTHER ALLOYING ELEMENTS CAN BE ADDED TO BASE METALS, SUCH AS:

MANGANESE,

CHROMIUM,

MOLYBDENUM,

SILICON,

AND NICKEL.

STEELS CONTAINING SUCH ELEMENTS ARE CALLED ALLOY STEELS.

SCENE 26.
tape 514, 00:11:42-00:11:47
GRAPHIC: flat sheet of atoms, alloy atom #3 appears
tape 514, 00:11:52-00:11:57
GRAPHIC: flat sheet of atoms, alloy atom #4 appears
tape 514, 00:12:02-00:12:07
GRAPHIC: flat sheet of atoms, alloy atom #5 appears
tape 514, 00:12:12-00:12:17
GRAPHIC: flat sheet of atoms, alloy atom #6 appears
tape 514, 00:12:22-00:12:27
GRAPHIC: flat sheet of atoms, alloy atom #7 appears
tape 514, 00:12:32-00:12:37
GRAPHIC: flat sheet of atoms, alloy atom #8 appears
tape 514, 00:12:42-00:12:47
GRAPHIC: flat sheet of atoms, alloy atom #9 appears
tape 514, 00:12:52-00:12:57
GRAPHIC: flat sheet of atoms, alloy atom #10 appears
tape 506, 19:03:21-19:03:36
parts going in for heat treatment

NARRATION (VO):

IN MANY CASES, JUST ADDING AN ALLOYING ELEMENT TO A BASE METAL MAKES IT STRONGER AND HARDER, AND IMPROVES IT’S MECHANICAL PROPERTIES. BUT FOR MOST STEELS, EVEN GREATER PROPERTIES IMPROVEMENT CAN BE ACHIEVED THROUGH HEAT TREATMENT.

SCENE 27.
continue previous shot

NARRATION (VO):

tape 514, 00:00:50:00 freeze frame, blue background CG: Through Hardening Processes Increase the strength & hardness throughout an alloy's cross-section Surface Hardening Processes Create different properties at the surface than at the center of a metal structure Softening Processes Decrease the hardness of metals and alloys	HEAT TREATING PROCESSES CAN BE CLASSIFIED INTO THREE GROUPINGS: THROUGH-HARDENING PROCESSES THAT INCREASE THE STRENGTH AND HARDNESS THROUGHOUT AN ALLOY'S CROSS-SECTION, SURFACE HARDENING PROCESSES THAT CREATE DIFFERENT PROPERTIES AT THE SURFACE THAN AT THE CENTER OF A METAL STRUCTURE, AND SOFTENING PROCESSES THAT DECREASE THE HARDNESS OF METALS AND ALLOYS. --- FADE TO BLACK ---
SCENE 28. CG: Through Hardening Processes white text centered on black	
SCENE 29. **tape 501, 12:10:03-12:10:20** parts going in for heat treating	**NARRATION (VO):** HARDENING PROCESSES ARE THE MOST COMMON TYPE OF HEAT TREATMENT. SUCH PROCESSES ARE USED TO INCREASE THE HARDNESS, STRENGTH AND WEAR RESISTANCE OF METALS AND ALLOYS.
SCENE 30. **tape 501, 12:07:44-12:08:01** heat treating operation CG, SUPER: Harden & Temper Quench & Temper Harden & Draw Austenitize, Quench & Temper	**NARRATION (VO):** THE MOST COMMON HARDENING PROCESS HAS SEVERAL NAMES: HARDEN AND TEMPER, QUENCH AND TEMPER, HARDEN AND DRAW, AND AUSTENITIZE, QUENCH AND TEMPER.
SCENE 31. CG, SUPER: Heating Stage **tape 507, 21:07:27-21:07:40** parts going into furnace	**NARRATION (VO):** THIS HEAT TREAT PROCESS USUALLY HAS THREE STAGES:

CG, SUPER: Quench/Cooling Stage
tape 507, 21:09:45-21:09:58
parts being quenched
CG, SUPER: Reheat/Tempering Stage
tape 507, 21:11:03-21:11:12
parts going through tempering furnace

A HEATING STAGE TO TRANSFORM THE METALLURGICAL STRUCTURE OF AN ALLOY...,

A QUENCH, OR COOLING STAGE TO PRODUCE A HARDER METALLURGICAL STRUCTURE...,

AND A REHEAT, OR TEMPERING STAGE TO ACHIEVE THE DESIRED HARDNESS AND STRENGTH LEVEL IN THE MATERIAL.

SCENE 32.
tape 500, 11:09:28-11:09:46
zoom in, parts going into furnace
tape 508, 23:05:04-23:05:25
c.u. looking at phase diagram
CG, SUPER: Temperature
Alloy Composition
Various Metallurgical Changes That Occur In A Particular Alloy During Heating & Cooling

NARRATION (VO):

TO BETTER UNDERSTAND HOW HEAT TREATING MODIFIES THE METALLURGICAL STRUCTURES OF CARBON AND ALLOY STEELS, LET'S USE A PHASE DIAGRAM. PHASE DIAGRAMS ARE VALUABLE TO HEAT TREATERS BECAUSE THEY SHOW THE RELATIONSHIPS AMONG TEMPERATURE, ALLOY COMPOSITION, AND THE VARIOUS METALLURGICAL CHANGES THAT OCCUR WITHIN PARTICULAR ALLOYS DURING HEATING AND COOLING.

SCENE 33.
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, including text, Temperature, Carbon (% by weight), nothing highlighted
CG, SUPER: Iron-Carbon Phase Diagram
tape 514, 00:13:25-00:13:32
GRAPHIC: Iron-Carbon Phase Diagram with text, Temperature range and text highlighted
tape 514, 00:13:45-00:13:58
GRAPHIC: Iron-Carbon Phase Diagram with text, Carbon range and text highlighted
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, nothing highlighted

NARRATION (VO):

THIS DIAGRAM IS THE IRON-CARBON PHASE DIAGRAM.

LET'S EXAMINE HOW TEMPERATURE...,

AND CARBON CONTENT COMBINE TO PROVIDE A VARIETY OF METALLURGICAL STRUCTURES.

SCENE 34.
continue previous graphic
tape 514, 00:14:02-00:14:18

NARRATION (VO):

GRAPHIC: iron-carbon phase diagram, wipe from bottom up, left hand side line completely highlighted
CG, SUPER: Ferrite
tape 514, 00:14:22-00:14:35
GRAPHIC: iron-carbon phase diagram, nothing highlighted, dot indicating room temperature appears
tape 514, 00:00:58-00:01:12
GRAPHIC: ferrite's body-centered cubic crystal structure

THE LEFT HAND SIDE OF THIS DIAGRAM IS FERRITE. FERRITE IS IRON CONTAINING AN EXTREMELY MINUTE AMOUNT OF CARBON. AT ROOM TEMPERATURE, FERRITE IS MAGNETIC, RELATIVELY SOFT AND HAS A BODY-CENTERED CUBIC CRYSTAL STRUCTURE.

SCENE 35.
tape 514, 00:14:22-00:14:35
GRAPHIC: iron-carbon phase diagram, nothing highlighted, dot indicating room temperature appears
CG, SUPER: The amount of carbon that can be dissolved in ferrite is practically zero
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, nothing highlighted
tape 514, 00:15:11-00:15:23
GRAPHIC: iron-carbon phase diagram, line trailing up to indicate maximum amount of carbon dissolvable in ferrite, 0.025% at 1333°f, dot appears at that point
CG, SUPER: arrow, 0.025%, 1333°F

NARRATION (VO):

AT ROOM TEMPERATURE, THE SOLID SOLUBILITY, OR THE AMOUNT OF CARBON THAT CAN BE DISSOLVED IN FERRITE, IS PRACTICALLY ZERO. THE AMOUNT OF CARBON DISSOLVABLE IN FERRITE INCREASES TO ONLY A MAXIMUM OF 0.025% AT 1333°F.

SCENE 36.
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, nothing highlighted
tape 514, 00:15:56-00:16:05
GRAPHIC: iron-carbon phase diagram, left hand side, line scrolling from bottom up to 1670°f, dot appears at that temperature
CG, SUPER: 1670°f
tape 514, 00:16:42-00:16:50
GRAPHIC: ferrite's body-centered cubic crystal structure
CG, SUPER: Ferrite
tape 514, 00:17:02-00:17:19
GRAPHIC: austenite's face-centered cubic crystal structure
CG, SUPER: Austenite

NARRATION (VO):

WHEN HEATED TO 1670°F, FERRITE'S BODY-CENTERED CUBIC CRYSTAL STRUCTURE REARRANGES ITSELF INTO A FACE-CENTERED CUBIC STRUCTURE KNOWN AS AUSTENITE.

SCENE 37.
continue previous graphic
tape 514, 00:17:22-00:17:38
GRAPHIC: austenite's face-centered cubic crystal structure, carbon particles appear
tape 514, 00:17:48-00:18:10
GRAPHIC: iron-carbon phase diagram, nothing highlighted, dot appearing at 0.80% of carbon at 1333°f
CG, SUPER: 0.80%, 1333°F
tape 514, 00:18:17-00:18:38
GRAPHIC: iron-carbon phase diagram, dot at 0.80% carbon, 1333°f, wipe line off screen as carbon and temperature amount increase CG, SUPER: 2.0%, 2066°F

NARRATION (VO):

THIS TRANSFORMATION TO AUSTENITE IS AN IMPORTANT PHASE IN THE HEAT TREATMENT OF STEELS. AUSTENITE'S CRYSTAL STRUCTURE ALLOWS IT TO ABSORB UP TO 0.80% OF CARBON AT 1333°F, INCREASING TO A MAXIMUM OF 2.0% AT 2066°F.

SCENE 38.
REPLACE NARRATION IN SCENE WITH
tape 515, 01:00:16-01:00:29
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, nothing highlighted
tape 514, 00:18:42-00:18:52
GRAPHIC: iron-carbon phase diagram, scrolling from bottom up, right hand side line completely highlighted
CG, SUPER: Cementite

NARRATION (VO):

THE RIGHT HAND SIDE OF THIS IRON-CARBON PHASE DIAGRAM REPRESENTS CEMENTITE, ALSO KNOWN AS IRON CARBIDE. CEMENTITE CONTAINS 6.67% CARBON.

SCENE 39.
REPLACE NARRATION IN SCENE WITH
tape 515, 01:00:29-01:01:15
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, nothing highlighted
tape 514, 00:14:02-00:14:18
GRAPHIC: iron-carbon phase diagram, wipe from bottom up, left hand side line completely highlighted
CG, SUPER: Ferrite
tape 514, 00:18:42-00:18:52
GRAPHIC: iron-carbon phase diagram, scrolling from bottom up, right hand side line completely highlighted
CG, SUPER: Cementite
tape 514, 00:19:03-00:19:18
GRAPHIC: iron-carbon phase diagram, 0% to 2.0% range completely highlighted

NARRATION (VO):

THOUGH THIS PHASE DIAGRAM RANGES FROM FERRITE, WITH VERY LOW CARBON CONTENT, TO CEMENTITE, WITH 6.67% CARBON, MOST STEELS CONTAIN LESS THAN 2.0% CARBON. THE CARBON CONTENT IS THE MAJOR FACTOR IN DETERMINING THE PROPERTIES THAT CAN BE DEVELOPED IN STEEL. THE USE OF VERY LOW CARBON CONTENTS OR VERY HIGH CARBON CONTENTS PROVIDES MANY DIFFERENT STEEL COMPOSITIONS WITH VERY DIFFERENT PROPERTIES. FOR THIS REASON, STEEL IS SUITED TO A WIDE RANGE OF ENGINEERING APPLICATIONS. LET'S TAKE A CLOSER

tape 514, 00:13:45-00:13:58
GRAPHIC: Iron-Carbon Phase Diagram with text, Carbon range and text highlighted
tape 514, 00:19:43-00:19:53
GRAPHIC: iron-carbon phase diagram, everything grayed back
tape 514, 00:19:22-00:19:38
GRAPHIC: iron-carbon phase diagram, wipe, entire diagram from left to right
tape 480, 12:09:20-12:09:29
forging operation
tape 232, 04:14:26-04:14:33
milling
tape 513, 03:02:28-03:02:33
scissors lift and building struts
tape 509, 12:10:50-12:10:58
tractor being built
tape 512, 01:10:21-01:10:23
train
tape 483, 11:02:35-11:02:40
jet on runway
tape 514, 00:13:03-00:13:18
GRAPHIC: iron-carbon phase diagram, nothing highlighted
tape 514, 00:20:02-00:20:18
GRAPHIC: detail zoom up from iron-carbon phase diagram showing up to 1% carbon content range only, nothing highlighted

LOOK AT SOME EXAMPLES OF HOW CARBON AFFECTS THE HARDNESS OF STEELS.

SCENE 40.
REPLACE NARRATION IN SCENE WITH
tape 515, 01:02:28-01:03:33
continue previous graphic
tape 514, 00:20:22-00:20:38
GRAPHIC: detail of iron-carbon phase diagram, line appears at 0.030% carbon, moving up to 1700°F
tape 514, 00:20:42-00:20:58
GRAPHIC: detail of iron-carbon phase diagram showing, at 1700°F wipe, showing window of austenitic grains
tape 514, 00:20:22-00:20:38
GRAPHIC: detail of iron-carbon phase diagram showing line at 0.030% carbon, 1700°F
tape 514, 00:21:02-00:21:18
GRAPHIC: detail of iron-carbon phase diagram showing, wipe line down to temperature of 1650°F, continues moving down to 1333°F
tape 514, 00:21:22-00:21:38

NARRATION (VO):

IF STEEL CONTAINING 0.030% CARBON IS HEATED TO ABOUT 1700°F, THE STRUCTURE WILL CONSIST ENTIRELY OF AUSTENITE. IF IT IS THEN COOLED SLOWLY, AT ABOUT 1650°F, THE AUSTENITE BEGINS TO TRANSFORM TO FERRITE. AS COOLING CONTINUES, MORE AND MORE FERRITE IS FORMED, UNTIL AT 1333°F, THE REMAINING AUSTENITE TRANSFORMS COMPLETELY. FERRITE CAN RETAIN ONLY 0.025% CARBON AT THIS TEMPERATURE, SO TO ACCOMMODATE THE CARBON IN EXCESS OF THIS AMOUNT, THE REMAINING AUSTENITE TRANSFORMS TO A

GRAPHIC: detail of iron-carbon phase diagram showing, at 1333°F line scrolls showing window of pearlite metallurgical structure CG, SUPER: arrow, Cementite CG, SUPER: arrow, Ferrite CG, SUPER: Pearlite **tape 508, 23:14:35-23:14:55** photomicrography of pearlite CG, SUPER: X 700	MIXTURE OF FERRITE AND CEMENTITE IN ALTERNATING THIN, PLATE-LIKE LAYERS. THIS STRUCTURE IS REFERRED TO AS PEARLITE. AT ROOM TEMPERATE, THE STEEL IS MOSTLY FERRITE WITH PATCHES OF PEARLITE.
SCENE 41. continue previous image **tape 508, 23:16:10-23:16:20** photomicrography of ferrite CG, SUPER: X 100 **tape 508, 23:14:10-23:14:20** photomicrography of pearlite with 0.10% carbon CG, SUPER: X 700	**NARRATION (VO):** BECAUSE OF ITS CARBON CONTENT, PEARLITE IS STRONGER AND HARDER THAN FERRITE. BY INCREASING THE CARBON OF THE STEEL, A LARGER PROPORTION OF PEARLITE AND, THEREFORE, GREATER STRENGTH IS GAINED.
SCENE 42. **REPLACE NARRATION IN SCENE WITH** **tape 515, 01:04:09-01:04:24** **tape 514, 00:20:02-00:20:18** GRAPHIC: detail zoom up from iron-carbon phase diagram showing up to 1% carbon content range only, nothing highlighted **tape 514, 00:21:48-00:22:00** GRAPHIC: detail of iron-carbon phase diagram showing, dot appears at 0.20% carbon and room temperature **tape 508, 23:15:10-23:15:20** photomicrography of pearlite with 0.20% carbon CG, SUPER: X 400	**NARRATION (VO):** FOR EXAMPLE, A STEEL CONTAINING 0.20% OF CARBON AT ROOM TEMPERATURE ALSO HAS A FERRITE AND PEARLITE STRUCTURE, BUT WITH MORE CEMENTITE IN THE FORM OF PEARLITE TO ACCOMMODATE THE HIGHER AMOUNT OF CARBON.
SCENE 43. **REPLACE NARRATION IN SCENE WITH** **tape 515, 01:04:25-01:04:42** **tape 514, 00:21:53-00:22:06** GRAPHIC: detail of iron-carbon phase diagram showing, dot at 0.20% carbon and room temperature **tape 514, 00:22:33-00:22:53** GRAPHIC: detail of iron-carbon phase diagram showing, dot at 0.20% carbon and room temperature, wipe line up until it reaches 1333°f, dot appears	**NARRATION (VO):** IF THIS STEEL IS HEATED UP, AT 1333°F THE CEMENTITE DISSOLVES AND THE FERRITE BEGINS TO TRANSFORM TO AUSTENITE. THIS TEMPERATURE IS KNOWN AS THE LOWER TRANSFORMATION OR A-1 TEMPERATURE.

CG, SUPER: 1333°F
CG, SUPER: Lower Transformation/
A_1 Temperature

SCENE 44.
continue previous graphic
tape 514, 00:23:25-00:23:47
GRAPHIC: detail of iron-carbon phase diagram showing, dot at 0.20% carbon and 1333°f, dot begins to raise until it reaches 1560°
CG, SUPER: 1560°F
CG, SUPER: Upper Transformation/
A_3 Temperature
tape 514, 00:20:02-00:20:18
GRAPHIC: detail zoom up from iron-carbon phase diagram showing up to 1% carbon content range only, nothing highlighted
tape 514, 00:23:52-00:24:08
GRAPHIC: detail of iron-carbon phase diagram showing, dot following along entire visible upper transformation temperature range

NARRATION (VO):

AS THE TEMPERATURE INCREASES, MORE FERRITE CHANGES TO AUSTENITE, UNTIL, AT ABOUT 1560°F, THE STEEL IS ENTIRELY AUSTENITE. THIS TEMPERATURE IS CALLED THE UPPER TRANSFORMATION OR A-3 TEMPERATURE. THIS UPPER TRANSFORMATION TEMPERATURE RANGE WILL VARY DEPENDING UPON THE AMOUNT OF CARBON PRESENT.

SCENE 45.
REPLACE NARRATION IN SCENE WITH
tape 515, 01:05:34-01:06:06
tape 505, 17:24:33-17:24:55
zoom out, parts going into furnace
tape 506, 18:05:22-18:05:40
hot parts in window
tape 506, 18:09:23-18:09:42
parts coming out of quench tank

NARRATION (VO):

HARDENING PROCESSES BEGIN BY BREAKING DOWN AN ALLOY'S FERRITE AND CEMENTITE BY HEATING THEM TO WITHIN THE AUSTENITIC RANGE. WITHIN THIS RANGE, AN ALLOY CAN DISSOLVE MUCH MORE CARBON. THE KEY TO HARDENING IS THEN PREVENTING THE FERRITE AND CEMENTITE FROM RE-FORMING WHEN THE ALLOY IS COOLED BACK TO ROOM TEMPERATURE. THIS IS ACHIEVED THROUGH QUENCHING, OR COOLING THE ALLOY TOO QUICKLY FOR THE FERRITE AND CEMENTITE TO FORM INTO PEARLITE.

SCENE 46.
tape 508, 23:13:10-23:13:20
photomicrography of microstructure
tape 514, 00:00:50:00
freeze frame, blue background
CG: Bainite
Martensite

NARRATION (VO):

TWO COMMON MICROSTRUCTURES WHICH CAN BE PRODUCED BY AUSTENITIZING AND QUENCHING ARE:

BAINITE,

AND MARTENSITE.

SCENE 47.
CG, SUPER: Bainite
tape 493, 01:24:25-01:24:40
photomicrography of bainite
CG, SUPER: X 200
tape 493, 01:24:00-01:24:15
photomicrography of bainite
CG, SUPER: X 200

NARRATION (VO):

BAINITE IS SIMILAR TO PEARLITE, BUT IT HAS A FEATHERY APPEARANCE AND IS STRONGER AND HARDER. BAINITE IS PRODUCED BY QUENCHING SOME HIGH ALLOY STEELS FASTER THAN FOR WHAT IS NEEDED TO PRODUCE PEARLITE.

SCENE 48.
CG, SUPER: Martensite
tape 508, 23:16:40-23:16:50
photomicrography of martensite
CG, SUPER: X 200
tape 508, 23:17:40-23:17:50
photomicrography of martensite
CG, SUPER: X 250

NARRATION (VO):

MARTENSITE IS PRODUCED THROUGH MORE RAPID QUENCHING, FORMING A STRUCTURE OF HIGH CARBON, NEEDLE-LIKE CRYSTALS. MARTENSITE IS EXTREMELY HARD AND BRITTLE. IT LACKS TOUGHNESS AND USUALLY REQUIRES TEMPERING BEFORE USE.

--- TOUCH BLACK ---

SCENE 49.
tape 508, 22:01:13-22:01:32
parts being quenched
CG, SUPER: The Metallurgical Structure Required
The Steel's Thickness
The Steel's Hardenability
tape 488, 00:41:30-00:42:06
zoom in, wrought parts being quenched
CG, SUPER: "Don't Quench a Steel Any Faster Than Necessary"
CG, SUPER: Quenching Speed Factors
Quenching Medium
Quench Temperature
Agitation of the Quenching Medium

NARRATION (VO):

THE CHOICE OF QUENCHING METHOD, AND THE SPEED OF THE QUENCH IS DEPENDENT UPON THE METALLURGICAL STRUCTURE REQUIRED IN THE STEEL, THE STEEL'S THICKNESS, AND ITS HARDENABILITY, WHICH IS HOW EASILY OR DEEPLY A STEEL CAN HARDEN. THE RULE IS: DON'T QUENCH A STEEL ANY FASTER THAN NECESSARY. THIS QUENCHING SPEED IS AFFECTED BY SEVERAL FACTORS, INCLUDING:

THE QUENCHING MEDIUM,

QUENCH TEMPERATURE,

AND AGITATION OF THE QUENCHING MEDIUM.

SCENE 50.
continue previous shot

NARRATION (VO):

CG: Quenching Mediums
Brine
Water
Synthetic Polymers
Oil
Air

THE VARIOUS QUENCHING MEDIUMS INCLUDE:

BRINE,

WATER,

SYNTHETIC POLYMERS,

OIL,

AND AIR.

SCENE 51.
tape 501, 12:11:07-12:11:15
parts quenched in brine
tape 508, 22:01:22-22:01:30
flip image, parts quenched in water
tape 503, 15:20:04-15:20:10
parts coming out of synthetic polymers
tape 507, 21:08:43-21:08:48
parts going into oil quench
tape 502, 14:12:29-14:12:37
parts being air quenched

NARRATION (VO):

BRINE, WHICH IS SALT ADDED TO WATER, QUENCHES FASTEST,

FOLLOWED BY WATER,

SYNTHETIC POLYMERS,

AND OIL.

AIR QUENCHING IS THE SLOWEST.

SCENE 52.
tape 506, 18:07:17-18:07:36
parts coming out of quench, pan to heat exchanger

NARRATION (VO):

QUENCH TEMPERATURE MUST BE CONTROLLED TO GET CONSISTENT METALLURGICAL PROPERTIES FROM SEVERAL DIFFERENT BATCHES OF LIKE PARTS. MOST MODERN QUENCH TANKS USE HEAT EXCHANGERS TO MAINTAIN THE PROPER FLUID TEMPERATURE.

SCENE 53.
tape 493, 01:18:04-01:18:14
pull back, propellers circulating quench tanks
tape 488, 00:42:21-00:42:34
zoom in, parts going into quench

NARRATION (VO):

QUENCH TANKS ARE ALSO EQUIPPED WITH CIRCULATING PROPELLERS, OR PUMPS AND NOZZLES TO PERMIT FASTER QUENCHING. THEY ALSO BREAK UP STAGNANT POCKETS OF FLUID THAT COULD CAUSE DIFFERENTIAL QUENCHING AND HARDNESS VARIATIONS IN WORKPIECES.

--- TOUCH BLACK ---

SCENE 54.
tape 505, 17:08:33-17:08:46

NARRATION (VO):

parts coming out of quench	ONCE PARTS ARE HEATED AND QUENCHED THEY ARE STRONGER, HARDER, AND, UNFORTUNATELY, MORE BRITTLE.
SCENE 55. **tape 505, 17:18:02-17:18:38** pull back, parts going through tempering furnace	**NARRATION (VO):** THIS BRITTLENESS IS REMOVED THROUGH THE TEMPERING, OR DRAWING PROCESS. HERE, THE HARDENED STEEL IS REHEATED TO A TEMPERATURE BELOW ITS LOWER TRANSFORMATION TEMPERATURE AND THEN AIR COOLED.
SCENE 56. continue previous shot CG, SUPER: Relieves Quench Induced Stresses Reducing Brittleness Reducing Strength/ Hardness Provides Degree Of Toughness Provides Ductility	**NARRATION (VO):** TEMPERING RELIEVES QUENCH INDUCED STRESSES, REDUCING THE BRITTLENESS, AS WELL AS THE STRENGTH AND HARDNESS OF A MATERIAL. THIS PROVIDES A DEGREE OF TOUGHNESS AND DUCTILITY TO THE HARDENED MATERIAL. --- TOUCH BLACK ---
SCENE 57. **tape 501, 12:22:25-12:22:52** c.u. pan of parts in hardening process **tape 514, 00:00:50:00** freeze frame, blue background CG: The Austenite Grain Size The Size Of The Workpiece	**NARRATION (VO):** IN THE PROCESS OF HARDENING, THERE ARE SOME SIGNIFICANT FACTORS THAT AFFECT THE PROPERTIES OF THE QUENCHED STEEL. THESE FACTORS INCLUDE: THE AUSTENITE GRAIN SIZE, AND THE SIZE OF THE WORKPIECE.
SCENE 58. **tape 500, 11:16:41-11:16:47** heated parts in furnace window GRAPHIC: detail of iron-carbon phase diagram showing, nothing highlighted **tape 514, 00:24:15-00:24:27** GRAPHIC: detail of iron-carbon phase diagram showing, line at 0.5% carbon, raising past 1360°f **tape 514, 00:24:33-00:24:45** GRAPHIC: detail of iron-carbon	**NARRATION (VO):** WHEN A STEEL IS HEATED ABOVE ITS UPPER TRANSFORMATION TEMPERATURE, AUSTENITE GRAINS BEGIN TO FORM OUT OF THE FERRITE. THE LONGER THE STEEL IS HELD AT AUSTENITIZING TEMPERATURE OR THE HIGHER THAT TEMPERATURE, THE LARGER THOSE GRAINS GROW.

phase diagram showing, line raising past 1360°f, wipe on inset window #1
tape 514, 00:24:53-00:25:05
GRAPHIC: detail of iron-carbon phase diagram showing, line raising past 1360°f, wipe on inset window #2
tape 514, 00:25:13-00:25:25
GRAPHIC: detail of iron-carbon phase diagram showing, line raising past 1360°f, wipe on inset window #3
tape 514, 00:25:33-00:25:45
GRAPHIC: detail of iron-carbon phase diagram showing, line raising past 1360°f, wipe on inset window #4
tape 514, 00:25:53-00:23:05
GRAPHIC: detail of iron-carbon phase diagram showing, line raising past 1360°f, wipe on inset window #5

SCENE 59.
continue previous graphic

NARRATION (VO):

AS THE GRAINS GROW, THEY RAISE THE STEEL'S HARDENABILITY, MAKING IT HARDER, MORE BRITTLE AND MORE PRONE TO CRACKING DURING QUENCHING, OR LATER, DUE TO INTERNAL STRESSES.

SCENE 60.
tape 500, 11:18:53-11:19:10
pan, heated parts inside furnace

NARRATION (VO):

HEAT TREATERS MUST CAREFULLY MONITOR AUSTENITIZING TEMPERATURES AND TIMES. GRAIN SIZE MAY BE THE DIFFERENCE BETWEEN SUCCESS OR FAILURE.

SCENE 61.
tape 495, 02:11:49-02:12:10
wrought workpieces going into heat treating furnace
tape 514, 00:26:13-00:26:23
GRAPHIC: thin workpiece next to thick workpiece, both heated up
tape 514, 00:26:31-00:26:49
GRAPHIC: thin workpiece next to thick workpiece, cooled down, thick part still glowing in center
tape 514, 00:26:53-00:27:05

NARRATION (VO):

THE WORKPIECE SIZE ALSO AFFECTS HOW EASILY A STEEL CAN BE HARDENED. THE HEAVIER THE CROSS-SECTION OF THE PIECE, THE SLOWER ITS CENTER WILL COOL IN THE QUENCH. AS A RESULT, ITS SURFACE MAY BE HARD, BUT ITS CENTER WILL BE SOFTER SINCE IT COOLED MORE

GRAPHIC: thin workpiece next to thick workpiece, cooled down, thick part still glowing in center #2
tape 514, 00:27:13-00:27:20
GRAPHIC: thin workpiece next to thick workpiece, both cooled down completely

SLOWLY.

--- TOUCH BLACK ---

SCENE 62.
tape 493, 01:07:12-01:07:29
austempering operation
tape 514, 00:00:50:00
freeze frame, blue background
CG: Martempering
Austempering

NARRATION (VO):

THERE ARE A FEW MODIFIED HARDENING PROCESSES THAT PRODUCE GOOD STRENGTH AND HARDNESS WITHOUT CREATING HIGH INTERNAL STRESSES AND CRACKING. THESE PROCESSES INCLUDE:

MARTEMPERING...,

AND AUSTEMPERING.

SCENE 63.
CG, SUPER: Martempering
tape 501, 12:09:18-12:09:36
heated parts dipped in salt bath in martempering operation
tape 500, 11:05:18-11:05:30
parts pulled from salt bath

NARRATION (VO):

IN MARTEMPERING, THE HEATED STEEL IS QUENCHED IN A SALT BATH AT A TEMPERATURE JUST ABOVE WHERE MARTENSITE BEGINS TO FORM. IT'S LEFT THERE UNTIL ITS TEMPERATURE EQUALIZES THROUGHOUT, THEN IT'S TAKEN FROM THE SALT AND COOLED TO ROOM TEMPERATURE. PARTS ARE THEN TEMPERED TO THE DESIRED STRENGTH.

SCENE 64.
CG, SUPER: Austempering
tape 493, 01:13:25-01:13:40
parts in furnace window
tape 493, 01:19:48-01:20:07
pan from furnace to quenched parts coming up conveyor

NARRATION (VO):

IN AUSTEMPERING, THE HEATED STEEL IS QUENCHED FROM ITS AUSTENITIZING TEMPERATURE RAPIDLY IN A SALT BATH, AND HELD THERE UNTIL ITS STRUCTURE TRANSFORMS FROM AUSTENITE TO BAINITE. THE STEEL IS THEN AIR COOLED TO ROOM TEMPERATURE. SUBSEQUENT TEMPERING IS OPTIONAL, DEPENDING ON THE PROPERTIES REQUIRED.

--- FADE TO BLACK ---

SCENE 65.
CG: Surface Hardening Processes
white text centered on black

SCENE 66.
tape 503, 15:09:41-15:09:46
pan c.u. of crankshaft
tape 502, 14:15:09-14:15:13
gears
tape 485, 11:22:30-11:22:44
zoom in to bearing loading into furnace

NARRATION (VO):

PARTS SUCH AS CRANKSHAFTS...,

GEARS...,

AND BEARINGS NEED TO BE HARDENED TO WITHSTAND THOUSANDS OF HOURS OF USE WHILE BEING TOUGH ENOUGH TO RESIST THE SUDDEN SHOCKS OF SPEED AND POWER CHANGES.

SCENE 67.
tape 499, 08:04:01-08:04:13
pan from unprocessed part to case hardened part

NARRATION (VO):

THESE REQUIREMENTS ARE MET USING CASE HARDENING PROCESSES WHICH PROVIDE A HARD, WEAR-RESISTANT SURFACE, OR CASE, OVER A TOUGH, SHOCK-RESISTANT INTERIOR.

SCENE 68.
tape 507, 21:14:10-21:14:29
flame hardening operation
CG, SUPER: Case Hardening Methods
Differential Heat Treating
Differential Metal Structure

NARRATION (VO):

THERE ARE TWO METHODS OF CASE HARDENING:

DIFFERENTIAL HEAT TREATING,

AND DIFFERENTIAL METAL STRUCTURE.

SCENE 69.
continue previous shot
CG, SUPER: Differential Heat Treating
tape 504, 16:05:13-16:05:31
induction heating operation

NARRATION (VO):

DIFFERENTIAL HEAT TREATING BRINGS ONLY THE SURFACE OF A STEEL PART RAPIDLY UP TO ITS AUSTENITIZING TEMPERATURE WHILE KEEPING THE INTERIOR WELL BELOW THAT POINT. AS SOON AS THE SURFACE REACHES TEMPERATURE, OFTEN WITHIN A FEW SECONDS, THE PART

IS QUENCHED.

SCENE 70.
continue previous shot
tape 514, 00:00:50:00
freeze frame, blue background
CG: Differential Heat Treating Processes
Flame Hardening
Induction Hardening

NARRATION (VO):

THE TWO PRIMARY TYPES OF DIFFERENTIAL HEAT TREATING ARE:

FLAME HARDENING,

AND INDUCTION HARDENING.

SCENE 71.
CG, SUPER: Flame Hardening
tape 507, 21:18:17-21:18:36
zoom out, flame hardening operation

NARRATION (VO):

FLAME HARDENING USES AN OXYGEN-GAS TORCH OR TORCHES TO BRING THE PART SURFACE QUICKLY TO THE AUSTENITIZING TEMPERATURE. ONCE THAT TEMPERATURE IS REACHED, THE PART IS QUENCHED.

SCENE 72.
CG, SUPER: Induction Hardening
tape 498, 07:18:28-07:19:00
induction heating operation

NARRATION (VO):

INDUCTION HARDENING PRODUCES THE SAME RESULTS ELECTRICALLY USING INDUCTION COILS. THESE COILS DEVELOP A STRONG MAGNETIC FIELD AROUND THE PART, CAUSING ELECTRIC CURRENT TO FLOW THROUGH IT. BECAUSE OF THE ELECTRICAL RESISTANCE OF STEEL, THE INDUCED CURRENT FLOW HEATS THE PART. ONCE UP TO TEMPERATURE THE PART IS QUENCHED.

--- TOUCH BLACK ---

SCENE 73.
CG, SUPER: Differential Metal Structure
tape 514, 00:27:54-00:27:57
ANI: part in furnace
tape 514, 00:28:01-00:28:11
ANI: cutaway of part in furnace
tape 514, 00:28:16-00:28:27
ANI: surface of cutaway highlights in furnace
tape 514, 00:28:30-00:28:40
GRAPHIC: cutaway cooled down, surface altered

NARRATION (VO):

DIFFERENTIAL METAL STRUCTURE SURFACE HARDENING PROCESSES ALTER THE CHEMICAL COMPOSITION OF THE WORKPIECE SURFACE, BUT NOT ITS INTERIOR. THE ENTIRE WORKPIECE CAN THEN BE SUBJECTED TO THE SAME HEAT TREATING CYCLE. THE SURFACE RESPONDS MORE TO HEAT TREATING, BECOMING HARDER THAN THE INTERIOR.

SCENE 74.
tape 485, 11:24:18-11:24:26
bearings falling out other side of furnace
tape 514, 00:00:50:00
freeze frame, blue background
CG: Differential Metal Structure Processes
Carburizing
Nitriding
Carbonitriding

NARRATION (VO):

DIFFERENTIAL METAL STRUCTURE PROCESSES INCLUDE:

CARBURIZING,

NITRIDING,

AND CARBONITRIDING.

SCENE 75.
CG, SUPER: Carburizing
tape 499, 09:06:30-09:06:52
carburizing operation, parts loaded in
tape 499, 09:07:18-09:07:27
door closing

NARRATION (VO):

IN CARBURIZING, THE WORKPIECE IS PLACED IN A CARBON-RICH GAS, LIQUID OR SOLID AND THEN HEATED TO A TEMPERATURE AT LEAST 100°F HIGHER THAN ITS UPPER TRANSFORMATION TEMPERATURE. CARBON IS ABSORBED FROM THE CARBON-RICH SOURCE INTO THE STEEL AND SLOWLY DIFFUSES INTO THE SURFACE LAYERS.

SCENE 76.
continue previous shot

NARRATION (VO):

CARBURIZING BUILDS HIGH CARBON CONCENTRATIONS CLOSE TO THE SURFACE OF LOW CARBON STEELS.

SCENE 77.
tape 499, 09:03:43-09:03:58
carburized load is quenched within unit
tape 508, 23:03:36-23:03:46
zoom in, cutaway, casing and tough interior of bearing

NARRATION (VO):

BECAUSE THE STEEL IS AUSTENITIZED WHILE IT'S BEING CARBURIZED, IT'S USUALLY QUENCHED DIRECTLY OUT OF THE CARBURIZING FURNACE IN A TANK CONTAINED IN THE HEAT TREATING UNIT. ONCE TEMPERED, WORKPIECES EXHIBIT A HARD, STRONG, HIGH CARBON STEEL CASE OVER A TOUGHER, MORE DUCTILE, LOWER CARBON INTERIOR.

SCENE 78.
CG, SUPER: Nitriding
tape 507, 20:02:16-20:02:35
nitriding operation

NARRATION (VO):

NITRIDING DIFFUSES NITROGEN INSTEAD OF CARBON INTO THE SURFACE OF STEEL. THIS FORMS EXTREMELY HARD

ALLOYS CALLED NITRIDES.

SCENE 79.
tape 508, 23:18:10-23:18:20
GRAPHIC: cutaway of nitrided part
tape 508, 23:18:40-23:18:50
GRAPHIC: cutaway of nitrided part, arrow appears showing case depth
tape 507, 20:06:20-20:06:29
nitriding operation

NARRATION (VO):

ALTHOUGH ITS CASE DEPTH IS MUCH SHALLOWER, NITRIDING CAN BE DONE AT LOWER TEMPERATURES THAN CARBURIZING. THIS REDUCES DIMENSIONAL GROWTH AND DISTORTION.

SCENE 80.
tape 507, 20:05:25-20:05:41
zoom out parts in nitriding operation

NARRATION (VO):

THE STEEL SURFACE REMAINS BRIGHT AND SCALE-FREE, MAKING NITRIDING IDEAL FOR SURFACE HARDENING OF TOOLS, DIES, CYLINDER LININGS AND OTHER FINISH-MACHINED OR GROUND PARTS.

SCENE 81.
CG, SUPER: Carbonitriding
tape 495, 02:06:21-02:06:45
parts going into carbonitriding operation
tape 495, 02:22:52-02:23:15
coming out of carbonitriding operation

NARRATION (VO):

CARBONITRIDING IS A COMBINATION OF CARBURIZING AND NITRIDING. THE PROCESS IS SIMILAR TO CARBURIZING, BUT NITROGEN IS ADDED TO THE CARBURIZING GAS, PRODUCING A CASE HARDER THAN CARBURIZING ALONE. CARBONITRIDING CAN IMPROVE PRODUCTIVITY BY PRODUCING A CASE OF A GIVEN HARDNESS WITH A SHORTER FURNACE CYCLE.

--- FADE TO BLACK ---

SCENE 82.
CG: Softening Processes
white text centered on black

SCENE 83.
tape 497, 05:22:01-05:22:26
parts being stress relieved
CG, SUPER: Annealing
Normalizing
Stress Relieving

NARRATION (VO):

ALTHOUGH MOST HEAT TREATMENT IS DONE FOR HARDENING AND STRENGTHENING PURPOSES, THERE ARE SEVERAL PROCESSES USED TO SOFTEN METALS, INCLUDING:

ANNEALING,

NORMALIZING,

AND STRESS RELIEVING.

SCENE 84.
CG, SUPER: Annealing
tape 498, 06:05:50-06:06:00
annealing operation
tape 489, 12:00:43-12:00:57
cold working operation
tape 514, 00:29:13-00:29:23
GRAPHIC: cold worked part
tape 514, 00:29:28-00:29:38
GRAPHIC: cold worked part, inset wipes on showing detail

NARRATION (VO):

ANNEALING IS USED TO SOFTEN WORK HARDENED MATERIALS. WORK HARDENING USUALLY OCCURS WHEN METALS ARE DEFORMED WITHOUT HEATING THEM FIRST, THIS IS CALLED COLD WORKING. BECAUSE COLD WORKING DEFORMS THE METAL GRAINS, THE WORKPIECE BECOMES HARD, BRITTLE AND HIGHLY STRESSED.

SCENE 85.
tape 514, 00:29:41-00:29:54
GRAPHIC: cold worked part, inset wipes on showing detail, part heated up
tape 514, 00:29:57-00:30:09
GRAPHIC: cold worked part, inset wipes on showing detail, part heated up, grains recrystallize
tape 514, 00:30:12-00:30:27
GRAPHIC: cold worked part, inset wipes on showing detail, part cooled down with recrystallized grains

NARRATION (VO):

ANNEALING IS USED TO REMOVE THE WORK HARDENING BY HEATING THE WORKPIECE TO A POINT WHERE THE DEFORMED GRAIN STRUCTURE RECRYSTALLIZES AND SOFTENS. THIS REMOVES THE HARDNESS, BRITTLENESS AND STRESSES.

--- TOUCH BLACK ---

SCENE 86.
CG, SUPER: Normalizing
tape 495, 02:18:47-02:19:06
normalizing operation

NARRATION (VO):

IN NORMALIZING, THE STEEL IS HEATED ABOVE ITS UPPER TRANSFORMATION TEMPERATURE AND AIR COOLED TO ROOM TEMPERATURE. THIS REFINES THE GRAIN STRUCTURE.

--- TOUCH BLACK ---

SCENE 87.
CG, SUPER: Stress Relieving
tape 497, 05:18:22-05:18:32
stress relieving operation
tape 195, 02:12:27-02:12:36
ending, cold working screw operation

NARRATION (VO):

STRESS RELIEVING OR STRESS-RELIEF ANNEALING IS A METHOD OF REDUCING THE STRESSES INTRODUCED INTO

tape 228, 03:04:51-03:05:13 machining operation **tape 509, 12:17:01-12:17:15** welding operation	PARTS BY COLD WORKING..., MACHINING..., WELDING AND OTHER OPERATIONS.
SCENE 88. **tape 497, 05:16:54-05:17:12** stress relieving operation, parts going in **tape 497, 05:23:30-05:23:40** stress relieving operation, parts coming out	**NARRATION (VO):** IT INVOLVES HEATING WORKPIECES TO A LOW-TO-MODERATE TEMPERATURE, AND HOLDING THEM AT THAT TEMPERATURE LONG ENOUGH TO RELAX THE STRESSES, BUT NOT RECRYSTALLIZE THE MATERIAL. THE WORKPIECES ARE THEN AIR COOLED TO ROOM TEMPERATURE, WHICH PREVENTS THE REINTRODUCTION OF STRESSES. --- FADE TO BLACK ---
SCENE 89. CG: Review white text on black **tape 63, 12:00:15-12:03:49** review music	**MUSIC UP AND UNDER** **NARRATION (VO):** LET'S REVIEW THE MATERIAL CONTAINED IN THIS VIDEOTAPE.
SCENE 90. **tape 506, 19:07:04-19:07:24** parts pulled from heat, glowing, and transferred to quench for cooling	**NARRATION (VO):** HEAT TREATING PROCESSES ARE USED TO ALTER THE METALLURGICAL STRUCTURE AND MECHANICAL PROPERTIES OF METALS OR ALLOYS THROUGH THE USE OF CONTROLLED HEATING..., AND COOLING CYCLES.
SCENE 91. **tape 505, 17:03:27-17:03:59** heat treating operation CG: Mechanical Properties Tensile Strength Ductility Impact Strength/Toughness Hardness	**NARRATION (VO):** THE PURPOSE OF MOST HEAT TREATING PROCESSES IS TO ALTER THE MECHANICAL PROPERTIES OF METALS. THESE MECHANICAL PROPERTIES INCLUDE: THE METAL'S TENSILE STRENGTH, THE DUCTILITY OF THE METAL,

THE IMPACT STRENGTH, OR TOUGHNESS OF THE METAL, AND THE HARDNESS OF THE METAL.

SCENE 92.
continue previous shot
tape 514, 00:00:50:00
freeze frame, blue background
CG: Through Hardening Processes
Increase the strength & hardness throughout an alloy's cross-section
Surface Hardening Processes
Create different properties at the surface than at the center of a metal structure
Softening Processes
Decrease the hardness of metals and alloys

NARRATION (VO):

HEAT TREATING PROCESSES CAN BE CLASSIFIED INTO THREE GROUPINGS:

THROUGH-HARDENING PROCESSES THAT INCREASE THE STRENGTH AND HARDNESS THROUGHOUT AN ALLOY'S CROSS-SECTION,

SURFACE HARDENING PROCESSES THAT CREATE DIFFERENT PROPERTIES AT THE SURFACE THAN AT THE CENTER OF A METAL STRUCTURE,

AND SOFTENING PROCESSES THAT DECREASE THE HARDNESS OF METALS AND ALLOYS.

SCENE 93.
CG, SUPER: Heating Stage
tape 507, 21:07:27-21:07:40
parts going into furnace
CG, SUPER: Quench/Cooling Stage
tape 507, 21:09:45-21:09:58
parts being quenched
CG, SUPER: Reheat/Tempering Stage
tape 507, 21:10:50-21:11:00
parts going through tempering furnace

NARRATION (VO):

HEAT TREAT HARDENING PROCESSES USUALLY HAVE THREE STAGES:

A HEATING STAGE TO TRANSFORM THE METALLURGICAL STRUCTURE OF AN ALLOY...,

A QUENCH, OR COOLING STAGE TO PRODUCE A HARDER METALLURGICAL STRUCTURE...,

AND A REHEAT, OR TEMPERING STAGE TO ACHIEVE THE DESIRED HARDNESS AND STRENGTH LEVEL IN A METALLURGICAL STRUCTURE.

SCENE 94.
REPLACE NARRATION IN SCENE WITH
tape 515, 01:06:17-01:06:37
tape 506, 18:05:22-18:05:40
hot parts in window
tape 514, 00:17:02-00:17:19
GRAPHIC: austenite's face-centered cubic crystal structure
tape 514, 00:17:22-00:17:38

NARRATION (VO):

HARDENING PROCESSES BREAK DOWN AN ALLOY'S FERRITE AND CEMENTITE BY HEATING THEM TO WITHIN THE AUSTENITIC RANGE. WITHIN THIS RANGE, AN ALLOY CAN

GRAPHIC: austenite's face-centered cubic crystal structure, carbon particles appear
tape 505, 17:24:33-17:24:55
zoom out, parts going into furnace

DISSOLVE MUCH MORE CARBON. THE CARBON CONTENT IS THE MAJOR FACTOR IN DETERMINING THE PROPERTIES THAT CAN BE DEVELOPED IN STEEL.

SCENE 95.
REPLACE NARRATION IN SCENE WITH
tape 515, 01:07:05-01:07:23
tape 506, 18:09:23-18:09:42
parts coming out of quench tank
tape 508, 22:01:13-22:01:32
parts being quenched

NARRATION (VO):

THE KEY TO HARDENING IS THEN PREVENTING THE FERRITE AND CEMENTITE FROM RE-FORMING WHEN THE ALLOY IS COOLED BACK TO ROOM TEMPERATURE. THIS IS ACHIEVED THROUGH QUENCHING, OR COOLING THE ALLOY TOO QUICKLY FOR THE FERRITE AND CEMENTITE TO FORM INTO PEARLITE.

SCENE 96.
tape 501, 12:11:07-12:11:15
parts quenched in brine
tape 508, 22:01:22-22:01:30
parts quenched in water
tape 503, 15:20:04-15:20:10
parts coming up out of synthetic polymer
tape 507, 21:08:43-21:08:48
parts coming up out of oil quench
tape 502, 14:12:29-14:12:37
parts using air quench

NARRATION (VO):

THE VARIOUS QUENCHING MEDIUMS INCLUDE:

BRINE, WHICH QUENCHES FASTEST...,

WATER...,

SYNTHETIC POLYMERS...,

OIL...,

AND AIR, WHICH QUENCHES SLOWEST.

SCENE 97.
tape 505, 17:08:33-17:08:46
parts coming out of quench

NARRATION (VO):

ONCE PARTS ARE HEATED AND QUENCHED THEY ARE STRONGER, HARDER, AND, UNFORTUNATELY, MORE BRITTLE.

SCENE 98.
tape 505, 17:18:02-17:18:38
pull back, parts going through tempering furnace

NARRATION (VO):

THIS BRITTLENESS IS REMOVED THROUGH THE TEMPERING, OR DRAWING PROCESS. HERE, THE HARDENED STEEL IS REHEATED TO A TEMPERATURE BELOW ITS LOWER TRANSFORMATION TEMPERATURE AND THEN AIR COOLED.

SCENE 99.
tape 507, 21:14:10-21:14:29
flame hardening operation
CG, SUPER: Case Hardening Methods
Differential Heat Treating
Differential Metal Structure

NARRATION (VO):

THERE ARE TWO METHODS OF CASE HARDENING:

DIFFERENTIAL HEAT TREATING,

AND DIFFERENTIAL METAL STRUCTURE.

SCENE 100.
tape 498, 07:18:28-07:19:00
induction heating operation
CG, SUPER: Differential Heat Treating

NARRATION (VO):

DIFFERENTIAL HEAT TREATING BRINGS ONLY THE SURFACE OF A STEEL PART RAPIDLY UP TO ITS AUSTENITIZING TEMPERATURE WHILE KEEPING THE INTERIOR WELL BELOW THAT POINT.

SCENE 101.
CG, SUPER: Flame Hardening
tape 507, 21:18:17-21:18:36
flame hardening operation
CG, SUPER: Induction Hardening
tape 504, 16:05:13-16:05:31
induction hardening operation

NARRATION (VO):

THE TWO PRIMARY TYPES OF DIFFERENTIAL HEAT TREATING ARE:

FLAME HARDENING...,

AND INDUCTION HARDENING.

SCENE 102.
CG, SUPER: Differential Metal Structure
tape 514, 00:27:54-00:27:57
ANI: part in furnace
tape 514, 00:28:01-00:28:11
ANI: cutaway of part in furnace
tape 514, 00:28:16-00:28:27
ANI: surface of cutaway highlights in furnace
tape 514, 00:28:30-00:28:40
GRAPHIC: cutaway cooled down, surface altered

NARRATION (VO):

DIFFERENTIAL METAL STRUCTURE PROCESSES ALTER THE CHEMICAL COMPOSITION OF THE WORKPIECE SURFACE, BUT NOT ITS INTERIOR. THE ENTIRE WORKPIECE CAN THEN BE SUBJECTED TO THE SAME HEAT TREATING CYCLE. THE SURFACE RESPONDS MORE TO HEAT TREATING, BECOMING HARDER THAN THE INTERIOR.

SCENE 103.
tape 499, 09:06:30-09:06:52
carburizing operation
CG, SUPER: Carburizing
Nitriding
Carbonitriding

NARRATION (VO):

DIFFERENTIAL METAL STRUCTURE CASE HARDENING PROCESSES INCLUDE:

CARBURIZING...,

NITRIDING...,

AND CARBONITRIDING.

SCENE 104.
tape 497, 05:22:01-05:22:26
parts being stress relieved
CG, SUPER: Annealing
Normalizing
Stress Relieving

NARRATION (VO):

ALTHOUGH MOST HEAT TREATMENT IS DONE FOR HARDENING AND STRENGTHENING PURPOSES, THERE ARE SEVERAL PROCESSES USED TO SOFTEN METALS, INCLUDING:

ANNEALING...,

NORMALIZING...,

AND STRESS RELIEVING.

--- FADE TO BLACK ---

SCENE 105.
CG, ROLL: credits
white text on black, fade up
mid-screen

Produced By:
The Society Of Manufacturing Engineers

Executive Producer:
Steven Bollinger

Producer/Director/Cameraman:
Jerome T. Cook

Written By:
Richard L. Bennett

Graphics By:
Jerome T. Cook
Dennis Summers

Equipment Access Provided By:
Alpha Steel Treating Company
Applied Process Inc.
Atmosphere Annealing, Inc.
Austemper, Inc.
Bodycote Michigan Induction

Dynamic Metal Treating, Inc.
Hansen-Balk Steel Treating Company
Progressive Heat Treating Company
Specialty Heat Treating, Inc.
State Heat Treat, Inc.
Sun Steel Treating, Inc.

Visual Materials Provided By:
Briem Engineering
Donald G. Jarvis
Masco Tech
Scot Forge
Sun Steel Treating, Inc.

Technical & Editorial Consulting:
Donald G. Jarvis, Jarvis Consulting

Production Assistance Provided By:
Steve Bollinger
Julie Moyer
Lance Rosol

Video Editing:
Communicore Visual Communications

SCENE 106.
CG: disclaimer
white text centered on black

Some machinery in this program had safety equipment removed to allow better recording of certain processes.
Always read the safety information provided in the manufacturers' manual before machine operation.

SCENE 107.
tape 40, 01:00:00-01:00:12
SME logo
CG, SUPER: www.sme.org