FUNDAMENTAL MANUFACTURING PROCESSES

Heat Treating

SCENE 1.
CG: Through Hardening Processes
white text centered on black

SCENE 2.
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 3.
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 4.
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, 21:11:03-21:11:12
parts going through tempering furnace

NARRATION (VO):

THIS HEAT TREAT PROCESS USUALLY HAS 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 THE MATERIAL.

SCENE 5.
tape 500, 11:09:28-11:09:46

NARRATION (VO):

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

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 6.
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 7.
continue previous graphic
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, 00:14:22-00:14:35
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

NARRATION (VO):

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 8.
tape 514, 00:14:22-00:14:35

NARRATION (VO):

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

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 9.
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 10.
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

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.

as carbon and temperature amount
increase CG, SUPER: 2.0%, 2066°F

SCENE 11.
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 12.
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
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

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

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

SCENE 13.
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
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

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 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 14.
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

NARRATION (VO):

BECAUSE OF ITS CARBON CONTENT, PEARLITE IS STRONGER AND HARDER THAN FERRITE. BY INCREASING

photomicrography of pearlite with 0.10% carbon
CG, SUPER: X 700

THE CARBON OF THE STEEL, A LARGER PROPORTION OF PEARLITE AND, THEREFORE, GREATER STRENGTH IS GAINED.

SCENE 15.
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 16.
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
CG, SUPER: 1333°F
CG, SUPER: Lower Transformation/ A_1 Temperature

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.

SCENE 17.
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

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

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

DEPENDING UPON THE AMOUNT OF CARBON PRESENT.

SCENE 18.
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 19.
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 20.
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 21.
CG, SUPER: Martensite

NARRATION (VO):

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

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 22.
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: <u>Quenching Speed Factors</u>
Quenching Medium
Quench Temperature
Agitation of the Quenching Medium

<u>NARRATION (VO):</u>

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 23.
continue previous shot
CG: <u>Quenching Mediums</u>
Brine
Water
Synthetic Polymers
Oil
Air

<u>NARRATION (VO):</u>

THE VARIOUS QUENCHING MEDIUMS INCLUDE:

BRINE,

WATER,

SYNTHETIC POLYMERS,

OIL,

AND AIR.

SCENE 24.
tape 501, 12:11:07-12:11:15
parts quenched in brine
tape 508, 22:01:22-22:01:30

<u>NARRATION (VO):</u>

BRINE, WHICH IS SALT ADDED TO WATER, QUENCHES

flip image, parts quenched in water	FASTEST,
tape 503, 15:20:04-15:20:10 parts coming out of synthetic polymers	FOLLOWED BY WATER, SYNTHETIC POLYMERS,
tape 507, 21:08:43-21:08:48 parts going into oil quench	AND OIL.
tape 502, 14:12:29-14:12:37 parts being air quenched	AIR QUENCHING IS THE SLOWEST.
SCENE 25. **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 26. **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 27. **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 28. **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 29.
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 30.
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 31.
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 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

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.

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 32.
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 33.
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 34.
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
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

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 SLOWLY.

--- TOUCH BLACK ---

SCENE 35.
tape 493, 01:07:12-01:07:29
austempering operation
tape 514, 00:00:50:00
freeze frame, blue background
CG: Martempering

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 36.
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 37.
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 ---