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Steel Construction | From the Mill to Topping Out

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Session Description

18.2 The Manufacturing of Structural Steel Shapes
October 22, 2018

Covered in this session will be a basic overview of modern steelmaking processes involved in the production of W, MC, C, M, L, S, and piling shapes. Topics include:

- Electric arc furnace operations
- Ladle metallurgy furnace operations
- Continuous casting
- Rolling operations
- Testing and metallurgy

AISC Night School Learning Objectives

- List the steps in which steel is manufactured.
- Describe how sustainability is integral in the cradle-to-cradle life cycle of steel.
- Describe how testing of steel, including the charpy v-notch test, ensure quality and toughness of the steel, and ultimately safety in a building.
- Define slag and its roll in the making of structural steel.

Night School 18: Steel Construction

From the Mill to Topping Out
Session 2: The Manufacturing of Structural Steel Shapes
October 22, 2018

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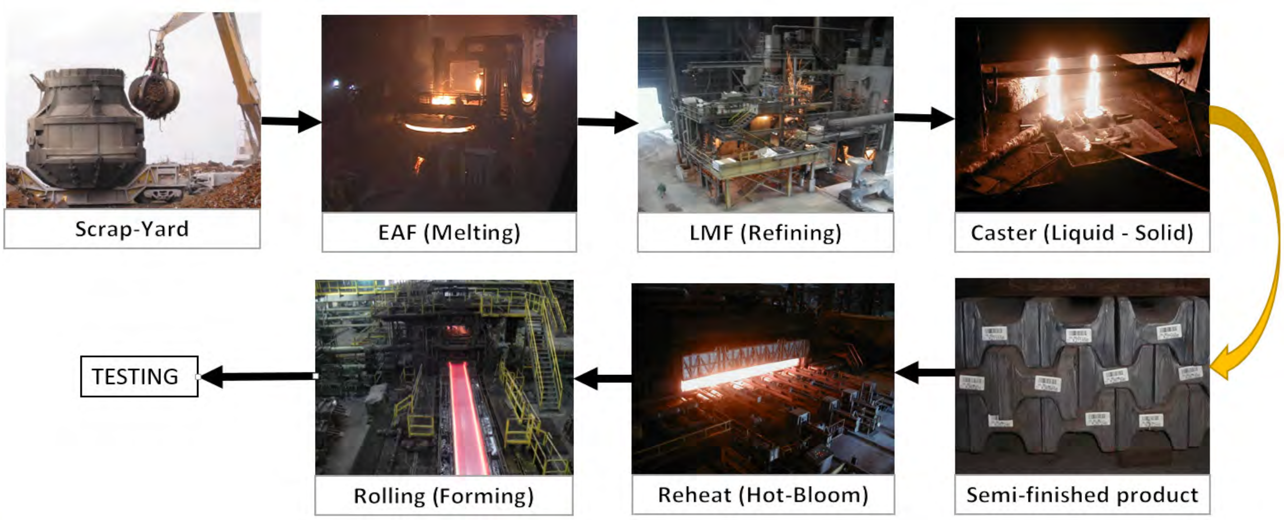
Manufacturing Structural Steel Shapes

Process overview and Some common Grades

Basic Process Flow Sheet



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Structural Steels:

- Aside from bar size shapes, for most structural steel products produced in the US, the carbon is in the 0.05% to 0.10% range. This low carbon content improves toughness and weldability.
- These steels are about 97-98% Iron.
- Other Elements specified include:

Chromium, Copper, Manganese, Molybdenum, Nickel, Niobium (Columbium), Nitrogen, Phosphorus, Silicon, Sulfur, Titanium, and Vanadium, and Tin.

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Overview of Key Elements In Common Structural Steel Shapes

Carbon

- As the amount of carbon present in steel increases, its strength increases.
- Carbon in the steel comes from both the scrap and from additions made at the furnace.
- It is kept low because of its adverse affect on toughness and weldability.

Silicon

- Silicon is added to steel to remove oxygen and is a mild strengthener.

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Manganese

- After carbon, manganese is the most widely used alloying element in the steel industry. Increasing the manganese content in steel increases its strength. Manganese is approximately one-sixth as effective as carbon at strengthening steel.
- Prevents the formation of Iron Sulfides during hot rolling, by forming Manganese Sulfides (thus improving the surface).
- Manganese contributes to the CE adversely affecting weldability.

Chromium

- Chromium improves the corrosion resistance of steel and is also a mild strengthener. A588, in which we make a chromium addition, is a corrosion resistant grade.
- Chromium contributes to the CE adversely affecting weldability.

$$CE = C + Mn/6 + (Cr+Mo+V)/5 + (Ni+Cu)/15$$

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Copper

- Copper is a residual element that is added to A588 for the corrosion index. Sometimes a 0.20% minimum copper is specified to improve corrosion resistance.

Nickel

- Nickel is a mild strengthener and hardener and also improved the toughness of the steel. Nickel in structural steel shapes steel comes from the scrap.

Molybdenum

- Molybdenum increases the hardness, strength, and wear resistance of the steel. In our steel, molybdenum as comes from the scrap (from steel containing molybdenum as an alloy).

**All 3 of these elements contribute to the CE, adversely affecting weldability.

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- Generally speaking, Copper, Chromium, Nickel, and Molybdenum are considered Residuals (there by chance), that come in through the scrap.
- In the residual amounts they are present many structural products, they contribute about 3-4 KSI in strength.

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Vanadium (V)

- Vanadium strengthens the steel, mostly through grain refinement by forming vanadium nitrides during the final stages of rolling. Vanadium contributes to the CE adversely affecting weldability.

Columbium (Cb)/ Niobium (Nb)

- Columbium and Niobium are the same element with the term Columbium being used in the US and Niobium being used in the rest of the world. Columbium, through the formation of Columbium carbides, nitrides and carbonitrides strengthens the steel, mostly through grain refinement during the final stages of rolling.

Nitrogen

- Nitrogen contributes to grain refinement by combining with Vanadium and Columbium.

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Phosphorous

- Phosphorous is an undesirable impurity in non-piling structural steel shapes and enters the steel making process through the scrap.
- It makes the steel brittle and susceptible to cracking. A690, a marine environment piling grade is a case in which phosphorous would be added. It is added for corrosion resistance.

Sulfur

- Like phosphorus, sulfur is an impurity in structural steel which comes from the scrap.
- Sulfur lowers the toughness of the steel and can result in cracking at both the caster and the roll mill.
- Sulfur is removed by adding lime and spar to the heat and stirring at the ladle metallurgy furnace.

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Chemistries and Mechanicals Of Common Structural Shapes Grades

Requirement	A992	A572-50	A588B	A36
Carbon	0.23% max	0.23 max	0.20 max	0.26 max
Manganese	0.50 - 1.60%	0.50 – 1.60	0.75 – 1.35 %	------ (0.85 – 1.35% for > 3” fl. Th.)
Phosphorus	0.035% max	0.04 % max	0.04 % max	0.04 max
Sulfur	0.045% max	0.05 % max	0.05 % max	0.05 max
Silicon	0.40% max	0.15 – 0.40 %	0.15 – 0.50 %	0.40 max (0.15 - 0.40 for > 3” fl. Th.)
Vanadium	0.15%* max	0.01 – 0.15 %*	0.01 – 0.10 %	
Columbium	0.05%* max	0.005-0.05%*	------	
Copper	0.60% max		0.20 – 0.40 %	
Nickel	0.45% max		0.50 % max	
Chromium	0.35% max		0.40 – 0.70 %	
Molybdenum	0.15% max	----	----	
Nitrogen	**	-----	-----	
Max Carbon Equiv.	0.45 (0.47 > 2” fl. Th.)	-----	-----	
Corrosion Index.	------		6.0 min	
Tensile Strength	65 ksi min.	65 ksi min.	70 ksi min.	58 – 80 ksi
Yield Strength	50 - 65 ksi §§	50 ksi min.	50 ksi min.	36 min.
Yield/Tensile Ratio	0.85 max. §	-----	-----	
Elongation (8in.)	18%	18%	18%	20%

The ASTM A588 grade is considered a “weathering” grade because its atmospheric corrosion resistance in most environments is substantially better than that of carbon structural steels with or without copper additions.

- * Cb + V shall not exceed 0.15%
- ** Nitrogen content need not to be determined or reported for any heat that was made
- to a steelmaking practice that produces steel having a nitrogen content not greater than 0.012%.
- §§ 50- 70 ksi for web tested sections.
- § 0.87 max allowed for web tested sections.

All of these steels may be ordered with toughness as a supplementary requirement.

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A913 Grades Becoming More Common

Requirement	A913-15 (Grade 50)	A913-15 (Grade 65)	A913-15 (Grade 70)
Carbon	0.12% max.	0.12% max.	0.12% max.
Manganese	1.60% max.	1.60% max.	1.60% max.
Phosphorus	0.030% max.	0.030% max.	0.030% max.
Sulfur	0.030% max.	0.030% max.	0.030% max.
Silicon	0.40% max.	0.40% max.	0.40% max.
Vanadium	0.06% max.	0.08% max.	0.09% max.
Columbium	0.05% max.	0.05% max.	0.05% max.
Copper	0.45% max.	0.35% max.	0.45% max.
Nickel	0.25% max.	0.25% max.	0.25% max.
Chromium	0.25% max.	0.25% max.	0.25% max.
Molybdenum	0.07% max.	0.07% max.	0.07% max.
Nitrogen			
Max Carbon Equiv.	0.38%	0.43%	0.45%
Tensile Strength	65 ksi min.	80 ksi min.	90 ksi min.
Yield Strength	50 ksi min.	65 ksi min.	70 ksi min.
Yield/Tensile Ratio			
Elongation (8in.)	18% min.	15% min.	14% min.
CVN (Flange Location)	40 ft.lbf. at 70°F	40 ft.lbf. at 70°F	40 ft.lbf. at 70°F

All of these steels may be ordered with additional toughness testing as a supplementary requirement.

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Electric Arc Furnace (EAF) Operations………

From cold scrap to 3000ºF……..

Electric Arc Furnace (EAF) – Charging Furnace with Scrap

Tapping (Pouring) Heat into Ladle

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Common Scrap Types used for Structural Shapes

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SCRAP BUCKET BEING LOADED

A Scrap "Blend" is used based on desired residuals and optimal melting efficiency.

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SCRAP YARD LOADING VIDEO

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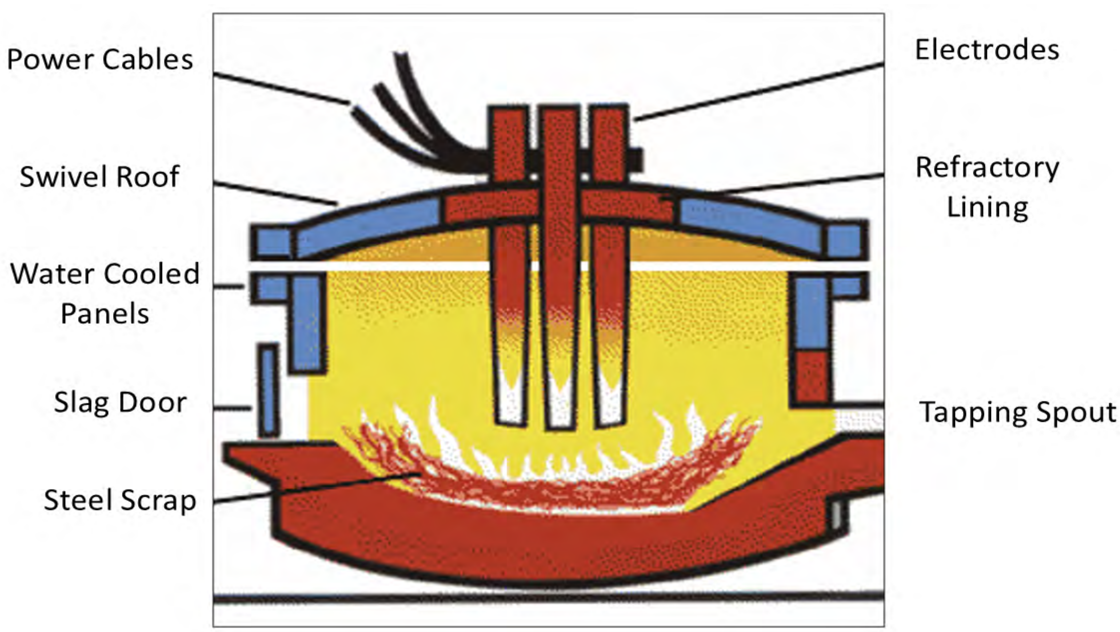
The Electric Arc Furnace - Melting the scrap



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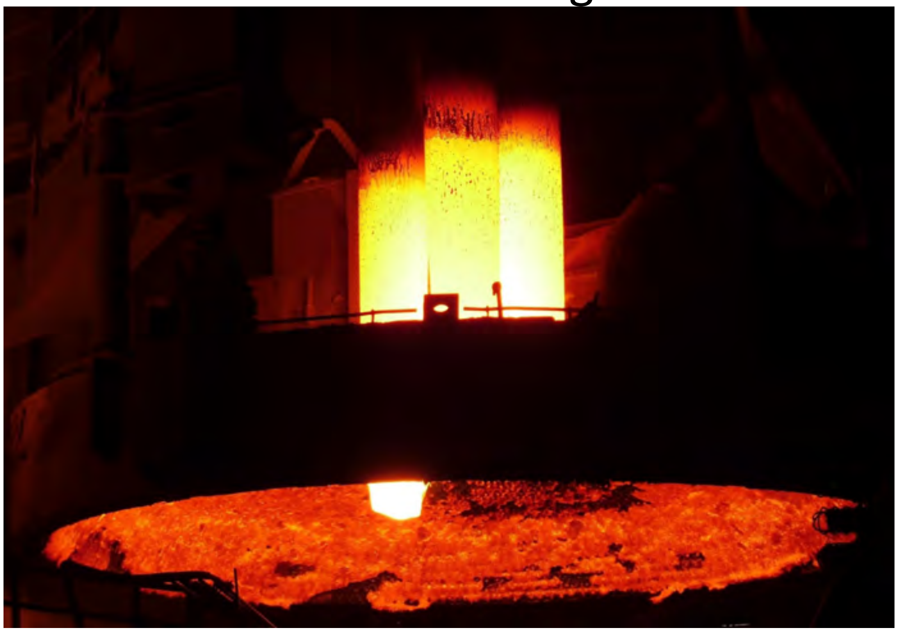
Furnace roof and electrodes raising to swing out for a charge



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Charge bucket being brought in to charge the furnace

26

Charge Being Dropped

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ROOF CLOSE AND BORE–IN VIDEO

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Besides the scrap, lime and carbon are also added during melting.

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What happens in the furnaces besides just melting?

Next we will see the oxidation potential of various elements in the scrap.

Some elements oxidize and go out in the slag, others remain.

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Oxidation Potential of Elements in The Scrap

Elements closer to the top of the table are more strongly attracted to oxygen than those at the bottom

Element	Symbol	+	Oxygen	=	Oxide	Common Name	EAF	
Calcium	Ca	+	O	=	CaO	Lime	*All Oxidized to slag in EAF.*	*Greater Potential (Stronger Oxide)*
Aluminum	2 Al	+	3 O	=	Al_2O_3	Alumina		
Magnesium	Mg	+	O	=	MgO	Magnesia		
Titanium	Ti	+	2 O	=	TiO_2	Titanium Oxides		
Silicon	Si	+	2 O	=	SiO_2	Silica		
Boron	2 B	+	3 O	=	B_2O_3	Boron Oxide		
Columbium	Cb	+	2 O	=	CbO_2	Columbium Oxide		
Vanadium	2 V	+	5 O	=	V_2O_5	Vanadium Oxide		
Manganese	Mn	+	O	=	MnO	Manganese Oxide	*Partially Oxidized*	
Carbon	C	+	O	=	CO	Carbon Monoxide		
Chromium	2 Cr	+	3 O	=	Cr_2O_3	Chromium Oxide		
Iron	Fe	+	O	=	FeO	Iron Oxide		
Phosphorous	2 P	+	5 O	=	P_2O_5	Phosphorous Oxide		
Tin	Sn	+	2 O	=	SnO_2	Tin oxide	*Stays In Steel*	*Lower Potential (Weaker Oxide)*
Nickel	Ni	+	O	=	NiO	Nickel Oxide		
Copper	Cu	+	2 O	=	CuO_2	Copper Oxide		

Less Common Elements: antimony (Sb), molybdenum (Mo), arsenic (As), Cobalt (Co) and Tungsten (W) also with weak oxides remain in the steel.

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During melting, a slag is built which floats on the hot metal bath.

What is Slag?

- Slag is made of metal oxides (impurities) in the steel that float to the top because their density is much less than that of steel.
- Slag is made by the addition of lime as well as elements in the steel oxidizing from the oxygen lances, which are also used in the furnace.
- Oxides could also have previously been in the charge scrap that melt in with the steel.

The old Steelmaker's saying…., "The steelmaker takes care of the slag and the slag will take care of the steel."

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Functions of EAF Slag

- Slows temperature loss.
- Protects furnace walls from arc.
- Covers the electrode arc to increase efficiency and slows nitrogen pickup.
- Absorbs Phosphorous.
- Must not chemically erode furnace walls –If the overall pH of the slag is acidic, it will eat away at the furnace so it is very important that proper amounts of MgO and CaO (both basic)are maintained to make the slag pH basic.

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Dephosphorization

- Dephosphorization is possible prior to de-oxidation and while the slag is still oxidizing.
- Needs high FeO and MnO levels to supply oxygen for the reaction.
- $6[P] + 3CaO + 5FeO = 3(CaO \bullet P_2O_5) + 5Fe$

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Furnace Tilted Back and Slagging Off

Importance of Slag Foaming

- A foamy slag will increase the volume (height) of the slag without an increase in mass.
- The slag should be high enough to cover and protect the furnace walls and electrode arc.
- The electrode needs to be in direct contact with the slag and the farther away the electrode can get from the liquid steel, the more power it can put into it which can decrease the time needed to make a heat.
- A foamy slag will help to remove oxides from the steel to increase it's cleanliness.

Slag Foaming

- Carbon is dissolved in steel from scrap, pig iron, and charge carbon.
- Oxygen is injected through lances.
- C + ½ O_2 = CO gas bubbles (oxidation of carbon).
- The bubbles float up through the steel into the slag causing it to foam. This is where proper slag viscosity comes into play.
- All of the O_2 does not find C, some oxidizes iron forming FeO which ends up as part of the slag.

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Slag Foaming

- Fine carbon is injected into slag.
- The C reacts to form pure Fe and CO bubbles that foam the slag. The Fe goes back into the melt.
- Small particles of MgO (magnesium oxide) help to form the CO bubbles and promote good foaming.
- The CO bubbles take time to float through the slag depending on the viscosity.

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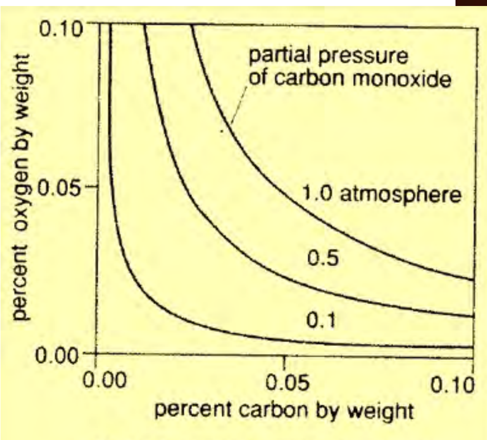
Oxygen and Temperature probe taken at slag door, just prior to tap.



Carbon-oxygen equilibrium curves

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Furnace Tilted forward and Tapping The Heat

Pouring the heat into the ladle.

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Tapping Open

Often Steel is tapped "open" which means the heat is not killed during tap. Deoxidation will happen at the LMF (Ladle Metallurgy Furnace).

- Lower nitrogen pickup

  Nitrogen and oxygen occupy the same sites in the steel. If oxygen is there, it is difficult for nitrogen to be picked up. A producer might average less than 1 ppm nitrogen pickup during tap when tapping open, 12 ppm when killing during tap.

- Lower carbon content

  The solubility of oxygen in steel decreases with decreasing temperature. As the heat cools on the way to the LMF, oxygen is rejected from the steel and combines with carbon to form CO gas. The gas floats out of the steel around the outside of the ladle (the coldest area).

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EAF SUMMARY VIDEO

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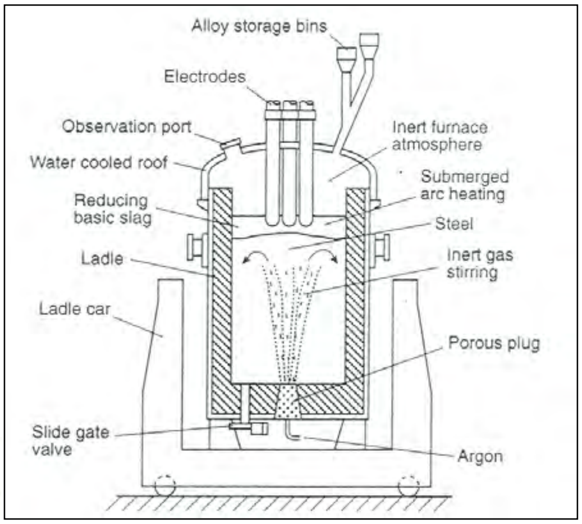
Ladle Metallurgy Furnace (LMF) Operations….

From an “open” heat to the correct temperature, chemistry and on time to the caster….



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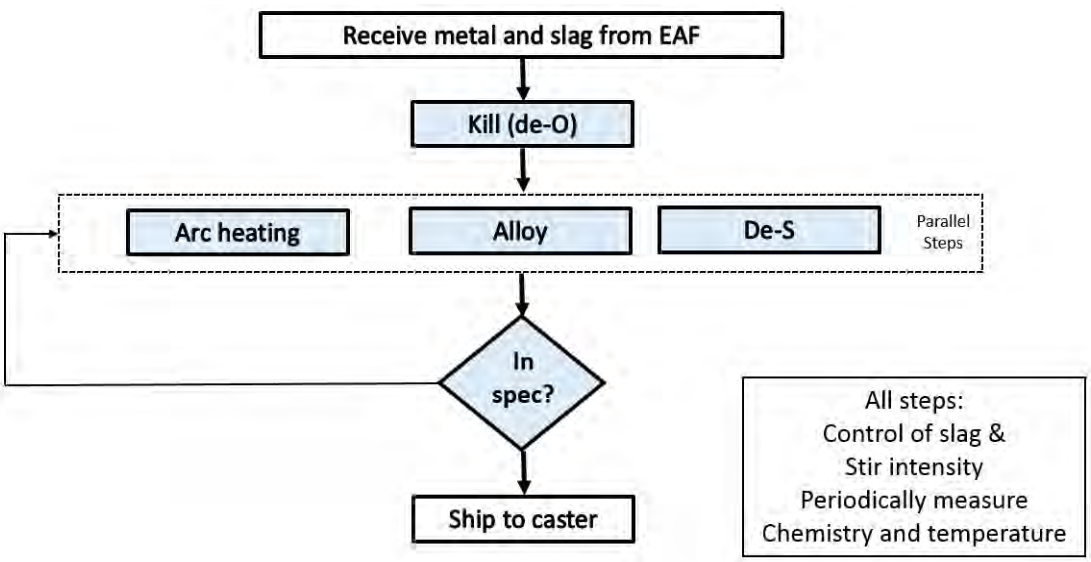

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Ladle Metallurgy Furnace (LMF) Functions

- Recover Fe and Mn from EAF carryover slag
- Deoxidize steel
- Desulfurize steel
- Alloy steel to proper grade specifications
- Rinse/Modify inclusions in steel
- Achieve temperature needed for casting
- Act as buffer between EAF and Caster

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LMF Additions

- Inert Gas (typically Ar)
  - Injected through a top-stir lance, a bottom-stir porous plug, or both
  - Used to gently stir the heat to ensure adequate mixing and to speed up reaction kinetics
- Calcium Carbide
  - Recovers Fe and Mn from carryover EAF slag
  - Reduces alloys needed and processing time required
  - Increases refractory life, slag protection, and slag reaction volume
- Lime (Hi-Cal and/or Dolomitic)
  - Produces a basic slag for similar functions as EAF slag
  - CaO used to desulfurize the steel
- Fluorspar (CaF_2)
  - Aids in fluxing (foaming) the slag
  - Aids in desulfurization

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LMF Additions

- Ferro alloys (FeMn, FeSi, SiMn, FeNb, FeV, FeCr, etc.)
  - Achieve the appropriate chemistry for desired grade
  - Aid in deoxidation (FeSi & SiMn)
  - Shoot for the minimum of the specified range to save $
- Microalloys (Nb, V,)
  - Used for precipitation strengthening and grain refinement
  - Combine with Carbon and/or Nitrogen
- Deoxidants
  - Typically Silicon, rarely Aluminum in the case of structurals
  - Remove the dissolved oxygen from steel; Oxides float out in slag
- Cored Wire
  - Typically Ca-Si wire, which is primarily used for inclusion modification and aiding deoxidation
  - Another method for alloy additions and deoxidants

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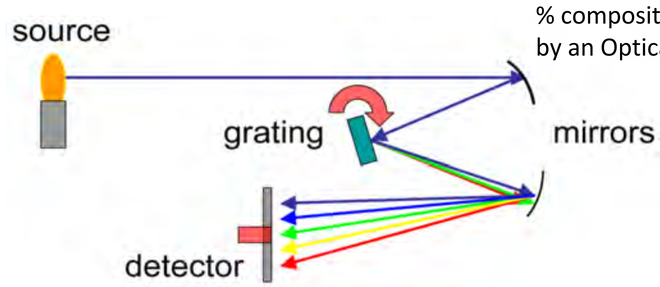
Typical Chemistry Analysis

Heat	EAF#	Sample	LMF#	Date and Time of Sample	Shape	Int. Ch	C	Mn	P	S	SI	Cr	Ni	Cu	Al	Mo	Sn	V	Ti	Nb	N	CE
123456	2	Initial	2	9/29/2018 6:57:46 AM	BB 8	2078	0.044	0.15	0.011	0.034	0.00	0.13	0.1	0.25	0.002	0.076	0.008	0.003	0.001	0.001	0.0075	0.134
123456	2	Stir	2	9/29/2018 7:18:24 AM	BB 8	2078	0.055	1.02	0.015	0.021	0.20	0.14	0.1	0.25	0.002	0.075	0.009	0.006	0.001	0.022	0.0079	0.293
123456	2	Final	2	9/29/2018 7:32:24 AM	BB 8	2078	0.066	1.1	0.015	0.019	0.24	0.14	0.1	0.25	0.002	0.074	0.008	0.005	0.001	0.022	0.0071	0.316

The initial sample is the composition of the open heat when it came to us from the EAF. No alloys have been added. Its what we start with.

The stir sample is the composition of the heat once it has been de-oxidized and most of the alloys added.

The final sample is the composition of the heat when it is sent to the caster. This is the chemistry on the test report.



% composition of elements is determined by an Optical Emission Spectrometer.

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Typical Changes in % composition during A992 Processing

- Si will increase since it is the de-oxidant.
- Mn, V, and or Nb will also increase since they are alloying elements.
- S will decrease.

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Functions of LMF Slag

- Absorb inclusions formed from deoxidation.
- Desulfurize the steel.
- Thermally insulate the steel.
- Prevent reoxidation.
- Prevent nitrogen pickup from electrode arc.
- Must not chemically attack ladle walls.
- Protect ladle walls from arc.

Again…The old Steelmaker's saying…., "The steelmaker takes care of the slag and the slag will take care of the steel."

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"Killing" the Heat

- "Killing" simply means removing the dissolved oxygen from the steel
- Solubility of oxygen in steel at room temperature is **ZERO.**
- It is necessary to remove almost all of the oxygen from the steel before casting.
- Steel is typically killed with additions of silicon alloys (but occasionally Aluminum.

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Si-Killed Heats

- Silicon Reaction
  - Si + 2[O] = SiO_2 (silica)
  - Silica is solid at steelmaking temperatures, and will either float out in the slag, or combine with Mn to form molten Manganese Silicates.
  - These inclusions are generally larger and appear in higher concentrations in the steel than alumina or aluminate inclusions, but do not cause the same choking problems.

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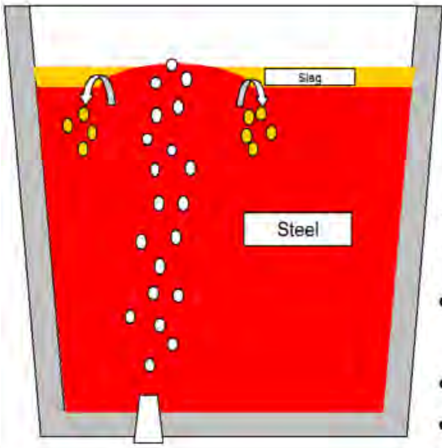
Desulfurization



Why S is removed from steel:

- Improve metallurgical properties – toughness
- Improve castability, minimizes cracking

Desulfurizing slag requirement:

$$FeS + CaO \leftrightarrow FeO + CaS$$

FeS	CaO	FeO	CaS
Sulfur in steel as Iron Sulfide	Lime to form slag Calcium oxide	Iron oxide in slag as Iron Oxide	Sulfur in slag as Calcium Sulfide

- Sufficient volume to cover the arc and not get sulfur saturated (< 1.5% S)
- Liquid
- Basic but not lime oversaturated
- Deoxidized – light or white in color (%FeO + %MnO < 1%)

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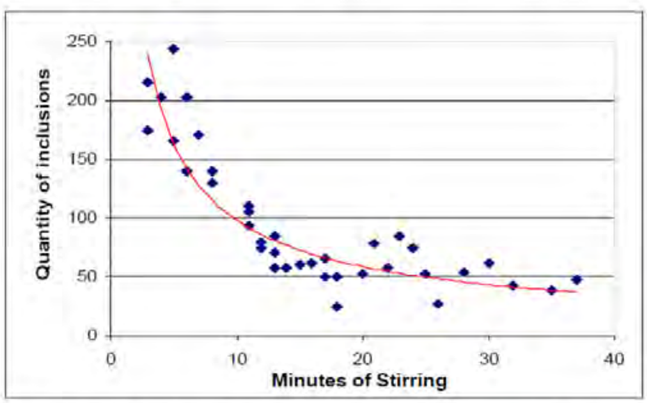
Impact of Stir Time on Inclusion Content



Inclusion evolution in 5 mm^2 surface area measured by EDS
Relationship between inclusion content and gas bubbling time in Ternium Siderar (Brandaleze, Martin, Donayo, Pérez & Gomez, 2007).

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LMF Operator Measuring the Temperature

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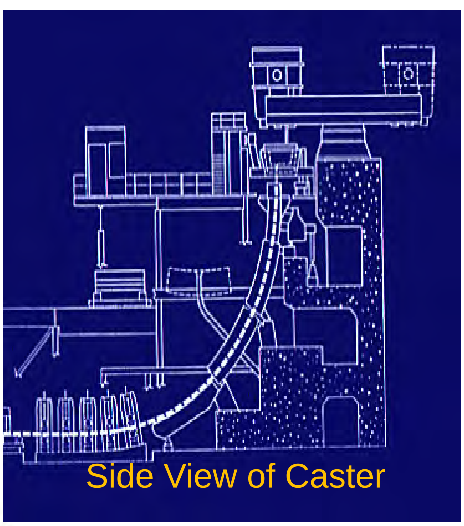
Continuous Caster Operations………

From liquid to a solid beam blank or bloom……..


Side View of Caster


Strands in Straighteners


Tagged Beam Blanks ready to roll

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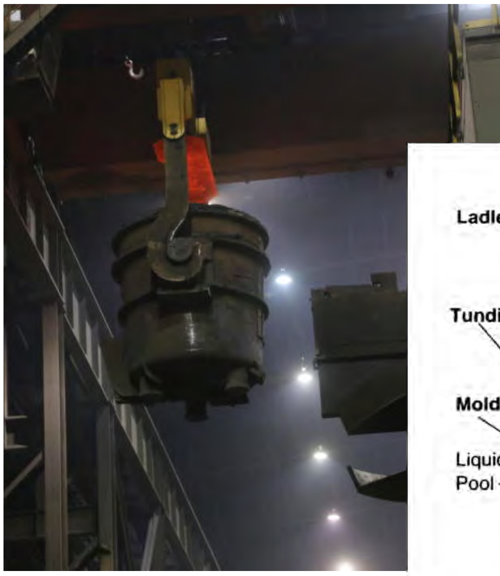
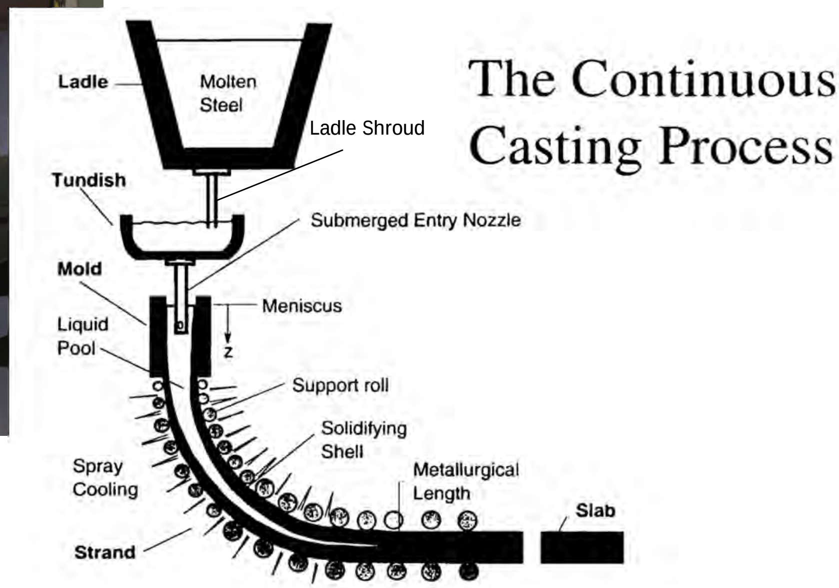
Casting





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Casting

- Steel from the ladle is fed through a ceramic tube (ladle shroud) into a tundish.
- It is important to not let the level in the ladle get too low because it can vortex, pulling slag down with the steel into the tundish.
- A slide gate regulates the flow out of the ladle to the tundish.
- The tundish distributes the steel to each strand of the caster. The steel can either be allowed to flow openly from the tundish to the mold, or be surrounded by another ceramic tube (Submerged Entry Nozzle or Funnel Shroud)
- Each strand of the caster then flows into a water cooled copper mold of the desired semi-finished shape.

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Ladle Shrouds

- Protects steel stream from reoxidation
- Must be properly aligned for effective use and maximum life
- Gaskets can also help to achieve proper seal

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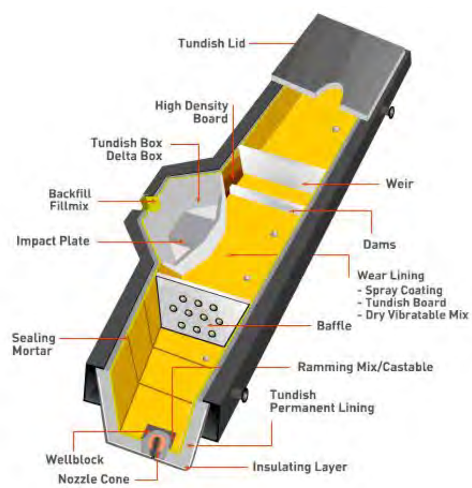
Tundish Functions

- Serves as a buffer so that when a ladle runs out of steel, the caster can still be fed while the ladles are changed

- Allows the steel flow time to stabilize before entering the mold by using impact pads, dams, weirs, and/or baffles to reduce turbulence



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Tundish Functions

Completely Stripped out Tundish

Tundish in Service

Completely Finished Tundish

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Tundish Flow Control

- Tundish designs can vary greatly from mill to mill based upon products produced and quality required.
- A flux is often put on top to protect the steel from re-oxidation, thermally insulate the steel, and to absorb any inclusions that float to the top.
- Si-killed shops will generally use metering nozzles to control the flow from the tundish to the mold, as choking is not a major concern.
- Al-killed shops will generally use stopper rods and/or slide gates for their tundish flow control, to combat choking due to inclusion buildup on the SEN's.

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Flow Into the Molds

- Open Stream
  - Used in Si-killed mills where surface quality is not overly stringent
  - Either mold powders or oils can be used.

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Casting Molds

- Typical Mold Features
  - Water-cooled Copper Mold Face (usually plated)
    - Allows for rapid heat removal from the molten steel to quickly form the solidified shell
    - The shell must be thick enough to contain the liquid core before it exits the mold
  - Mold Oscillation
    - Keeps the solidifying shell from sticking to the mold
    - Compressive stresses help heal up surface fissures and/or porosity
  - Mold Taper
    - Accommodates the shrinkage characteristics of the steel grade being produced
    - Significantly different grades require different tapers

64

Casting Molds

65

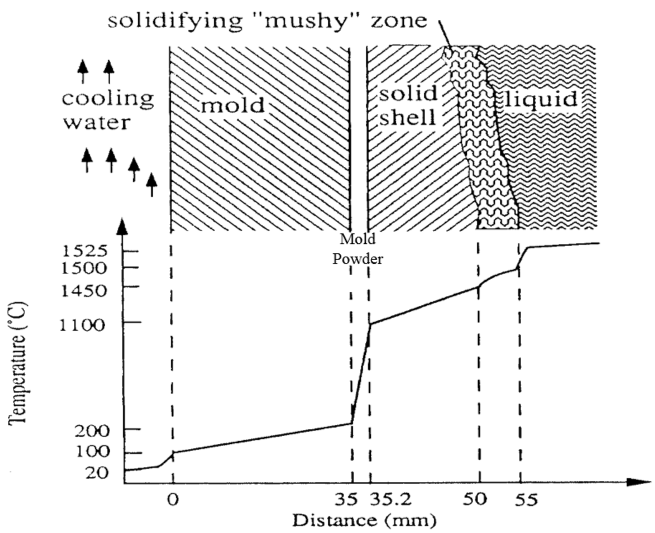
Functions of Mold Oils and Powders

- Lubrication
  - Both oils and powders provide sufficient lubrication to aid in keeping the steel shell from sticking to the mold
- Absorption of Non-Metallic Inclusions
  - Both oils and powders
- Thermal Insulation and Re-oxidation Protection
  - Powders also provide these benefits at the steel meniscus (top of steel level in the mold).
- Heat Transfer
  - Powders are more effective at controlling the heat transfer between the steel shell – mold interface

66

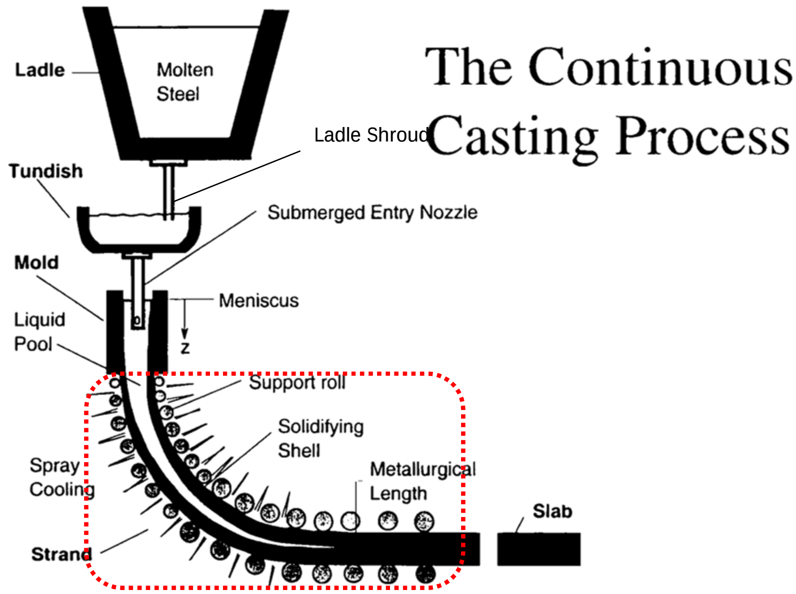
Heat Transfer

Schematic of Heat Flow in Continuous Casting



67

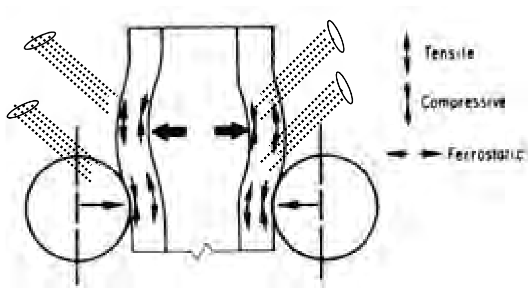
Secondary Cooling and Containment



68

Secondary Cooling and Containment

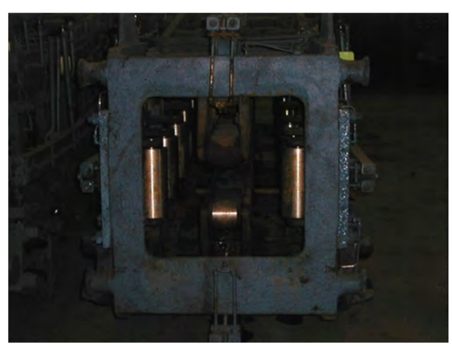
- Extends from the bottom of the mold, through complete solidification, to the cutoff operation
- As the strand leaves the mold, it passes through a series of water spray zones
- In each zone, the strand is supported by containment rolls



69

Secondary Cooling and Containment (Segments below the mold)

Containment Chamber



Containment Rolls

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Strands in Spray Chambers

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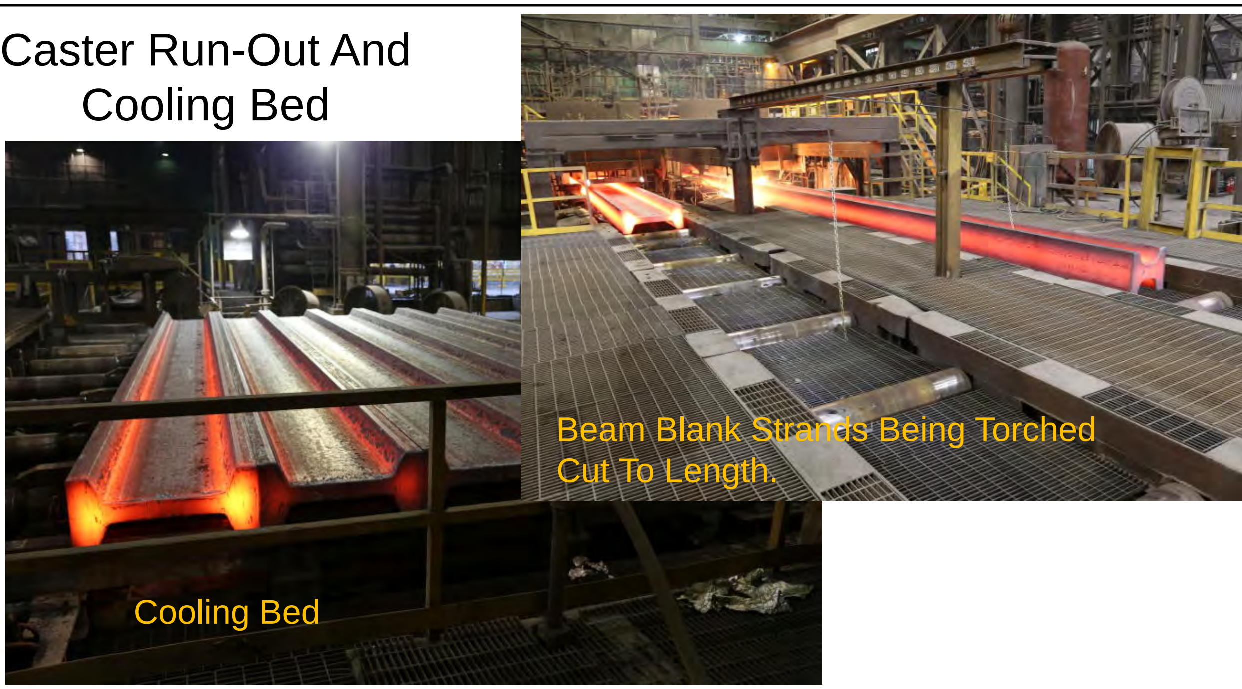
Caster Run-Out And Cooling Bed



72

Semi-Finished Cast Shapes

- Blooms – rectangular; typically W $\leq$ 2T. and cross-sectional area $\geq$ 36-in^2.
- Billet – rectangular; typically W $\leq$ 2T and cross-sectional area $\leq$ 36-in^2.
- Slab – rectangular
- Beam Blank – "Dogbone" shaped.

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Rolling Mill Operations

From beam blank or bloom to finished product

74

2 Main types of Rolling Mills

Reversing Mill

Continuous Mill

75

Types of Rolls and Mill Stands

Breakdown Mill Rolls – Getting the beam blank into the product Family

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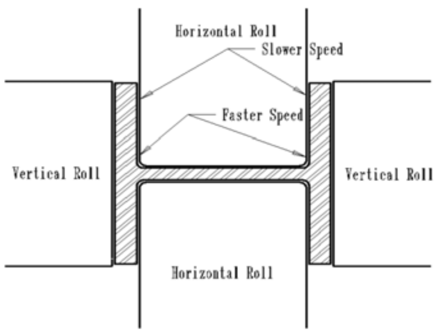
Types of Rolls and Mill Stands (Cont.)

Universal Rougher / Edger Mill (UR/E) – Getting the Product Dimensions

Universal Rougher



Edger Mill

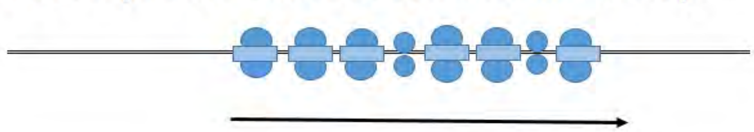
Universal Rougher – Works the web and flanges (inside and out).
Edger Rolls – Squares up the flange tips.

77

Common Types of Shapes Rolling Mills

Continuous Mills – Generally used for smaller sections and where a limited number of Beam Blank sizes are used. Arrow denotes bar movement.

Example of a continuous Mill Set-up



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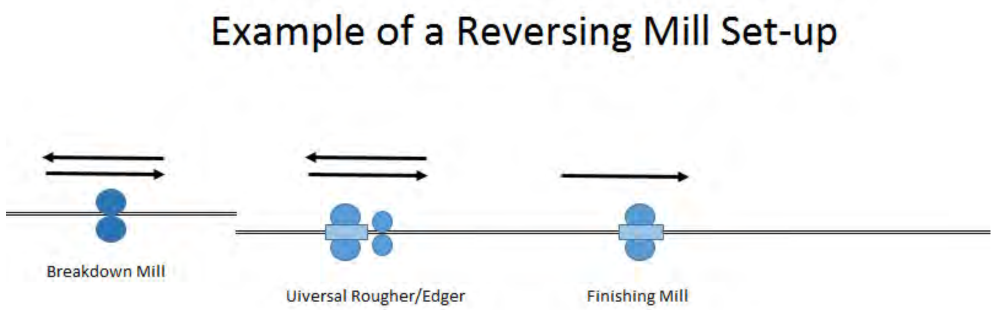
Common Types of Shapes Rolling Mills (Cont.)

Reversing Mills – Generally used when there is a wide range of section depths and foot weights. Arrows denote bar Movement.



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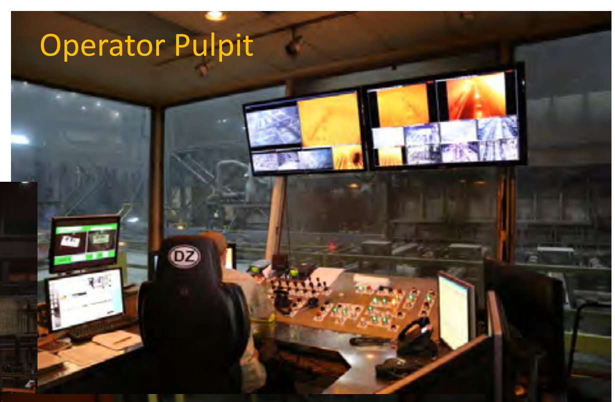
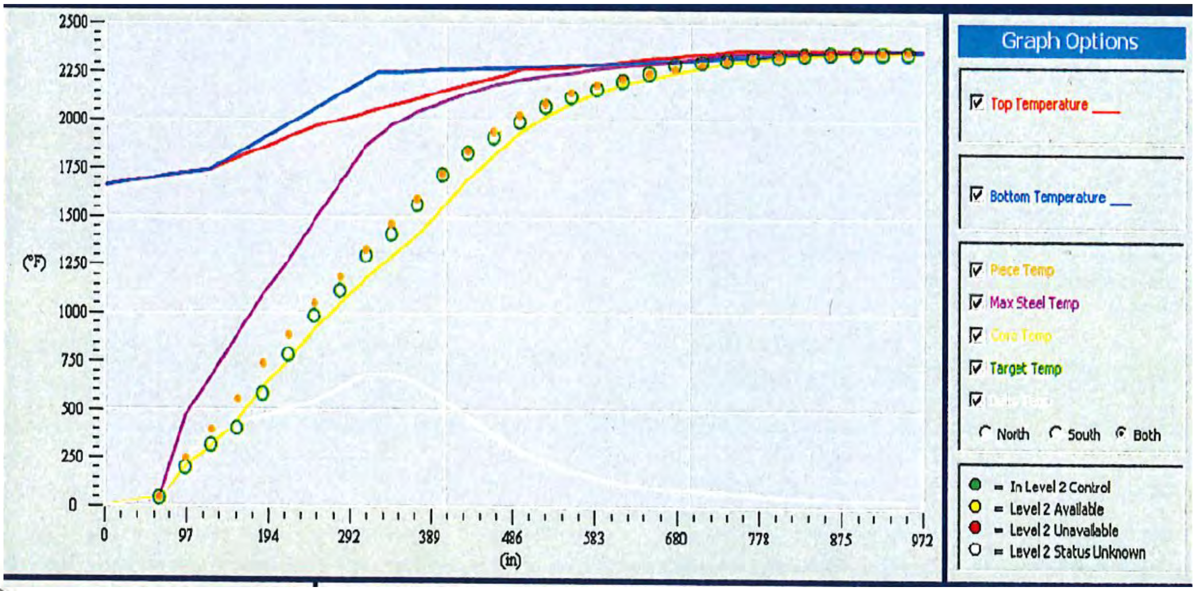
Reheat furnace Operations



80

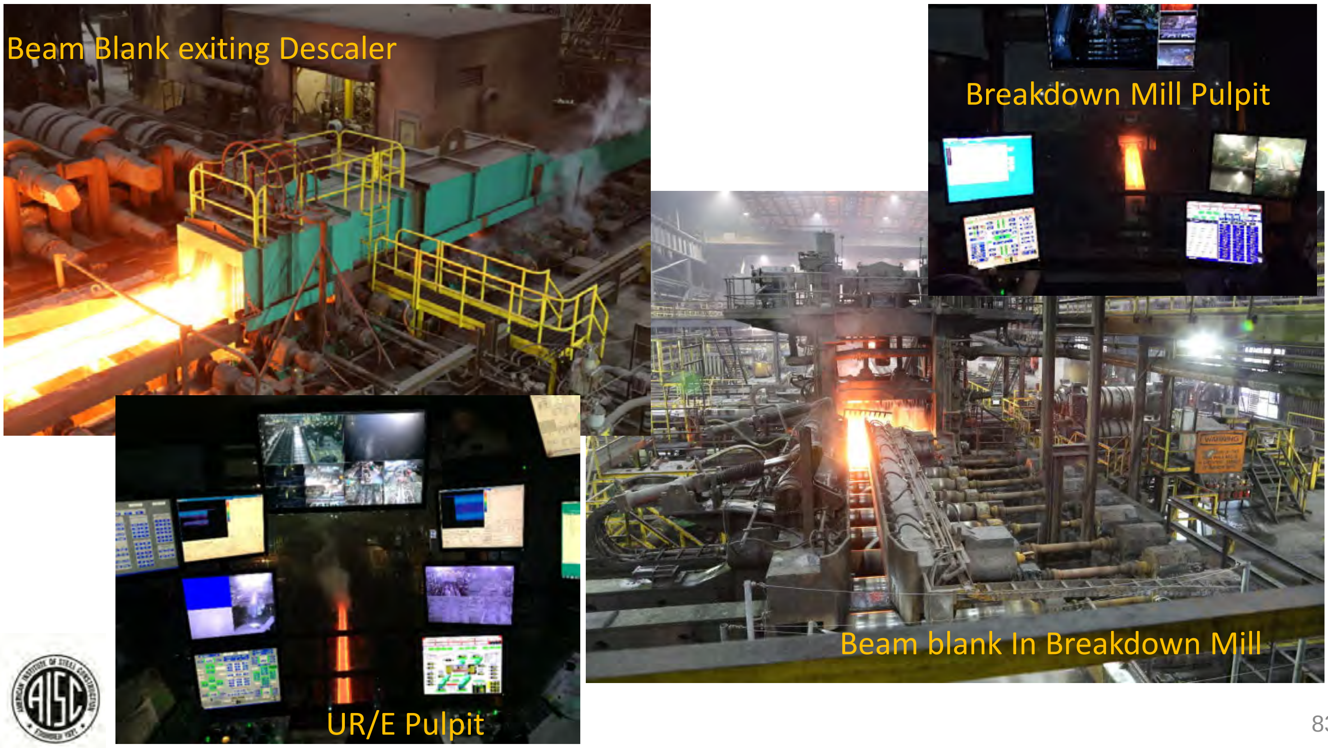
Example of Reheat Furnace Temperature Model (81' Furnace)



81

BAR DISCHARGING, THEN DESCALING VIDEO

82



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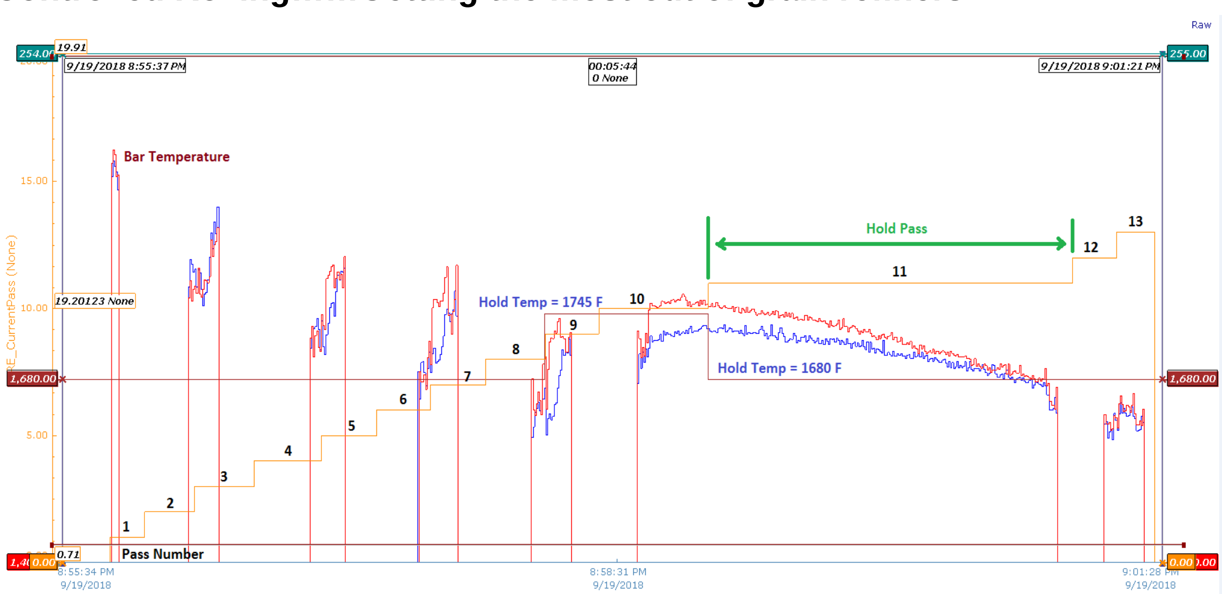
Controlled Rolling……Getting the most out of grain refiners



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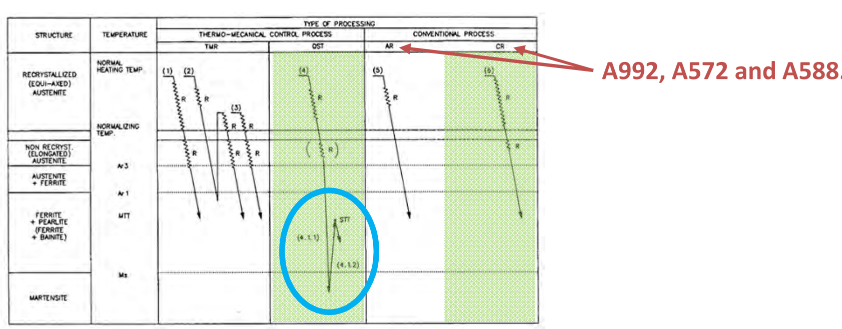
BAR GOING THROUGH URE MILL VIDEO

85

ASTM Grade A913

ASTM A913 – Specification for High-Strength Low-Alloy Steel Shapes of Structural Quality, Produced by Quenching and Self-Tempering Process (QST)

- Intense water cooling is applied to the whole surface of the beam
- Cooling is interrupted before the core is affected by the quench
- Outer layers are tempered by the remaining heat from the core of the beam. Self-tempering temperature between 1100°F – 1300°F



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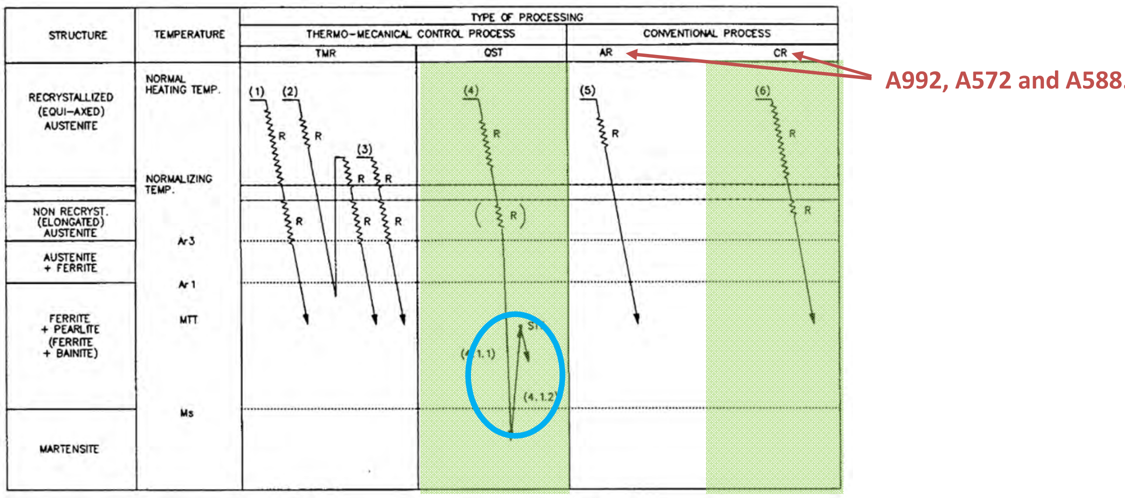
A closer look At Grade A913

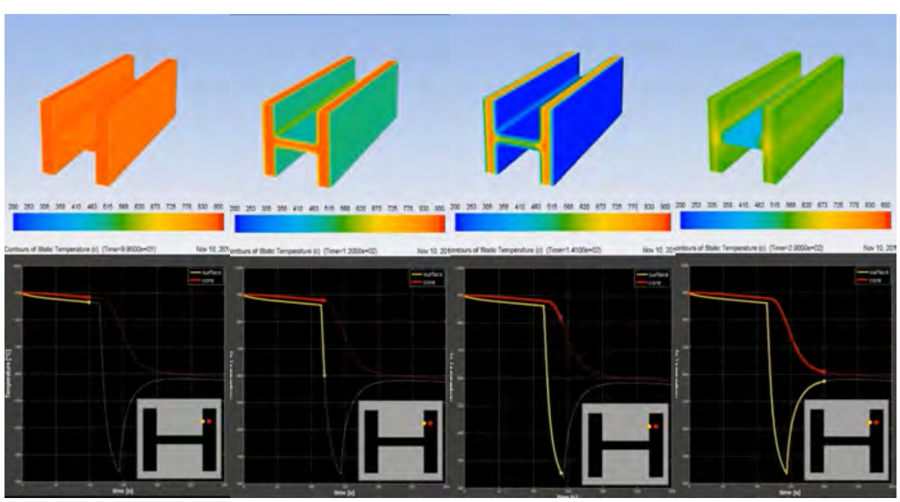
Self-tempering temperature between 1100°F – 1300°F.



87

QST Product Surface vs. Core Temperature

General Temperature Description of Process



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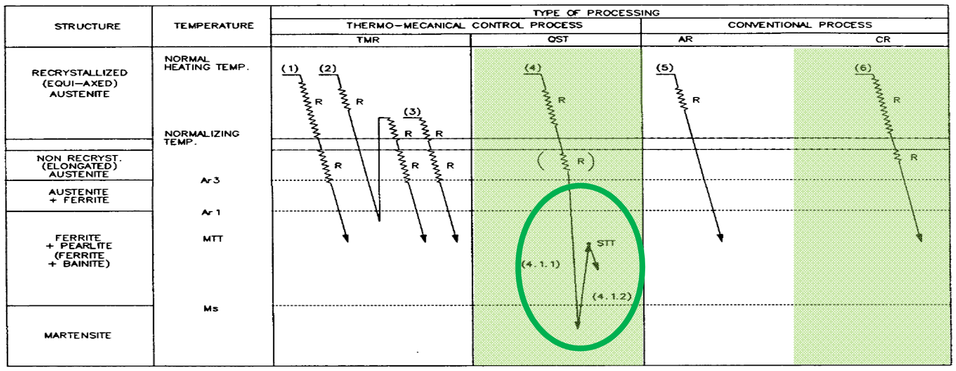
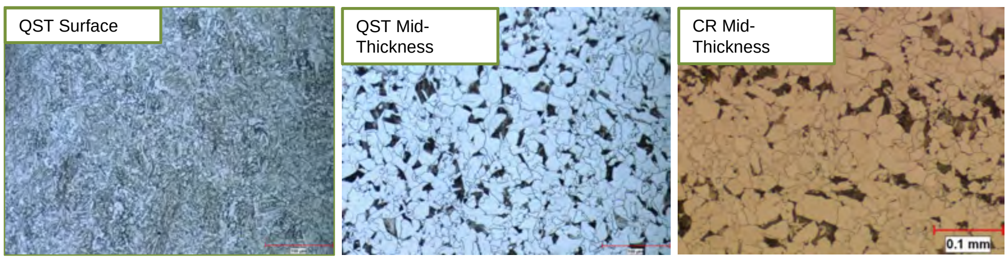
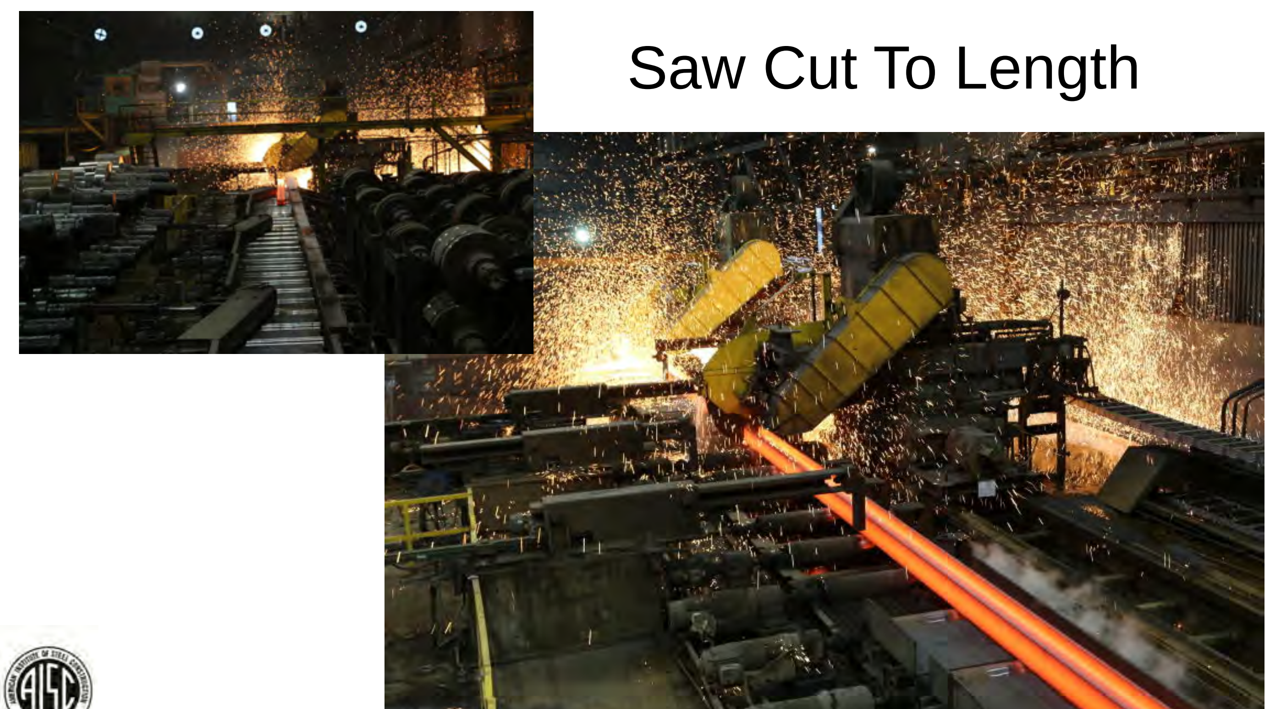
Quenching and Self-Tempering: The Process





Saw Cut To Length



Dimensional Checks

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Straightening

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Straightening (Cont.)

Gag Press

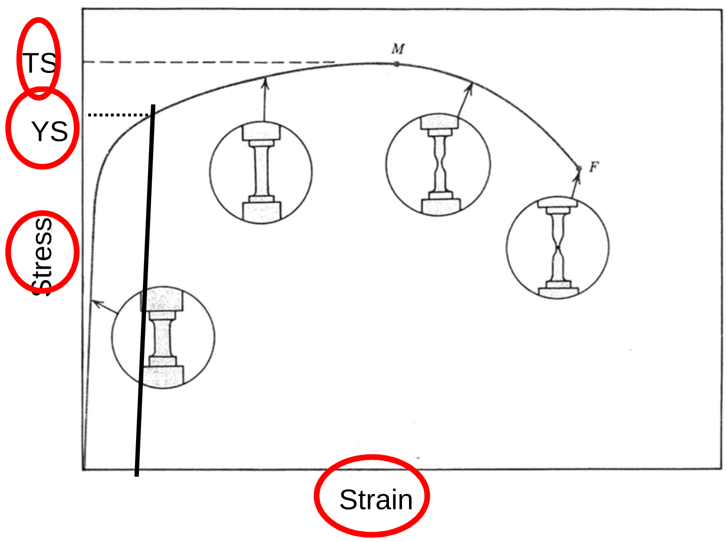
93

Final Product Inspection and Tagging

94

Metallurgy and Testing

How do we make the steel properties……..



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Tensile Testing

- Tensile testing - is the measurement of yield strength (In KSI or Mpa), tensile strength(also in KSI or Mpa), elongation (In %) and the yield to tensile ratio (unitless)
- In this test, 2 specimens per heat per size are tested.
- Always longitudinal to the rolling direction and taken 1/3 the distance from the flange tip to the web center.

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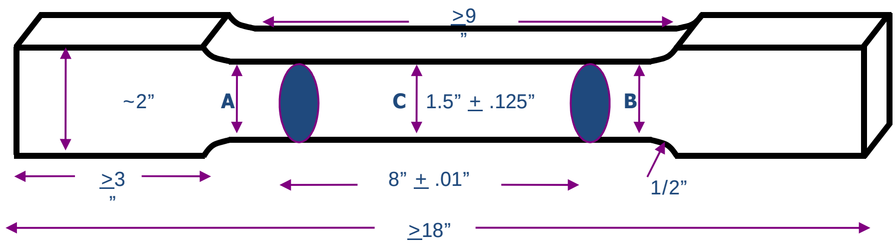
Sample Preparation: ASTM A370 Requirements Fig 3. Plate Type Specimen



- Maximum variation from end to end of the reduced section is 0.004” (A – B ≤ 0.004”)
- Maximum variation from either end to the center of the reduced section is 0.015” (A – C and B – C ≤ 0.015”)

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Harvesting Samples

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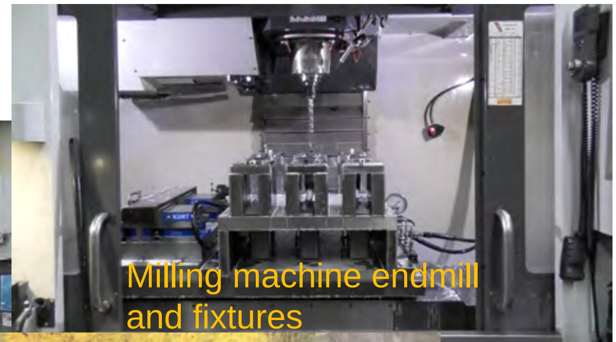
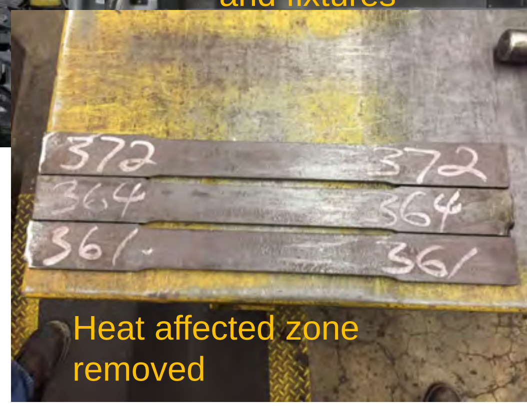
Milling of Samples





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TENSILE TESTING VIDEO

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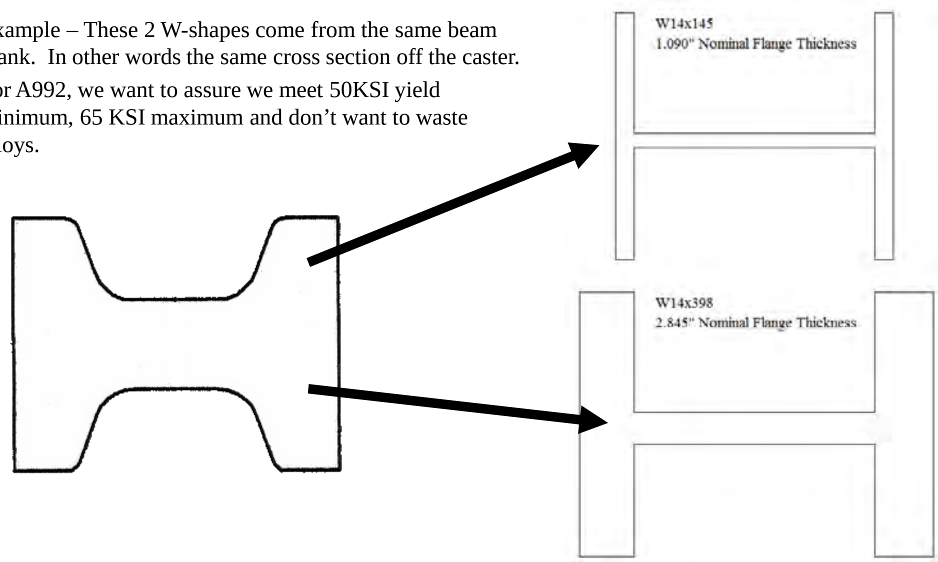
How are chemistries arrived at to meet Tensile requirements?

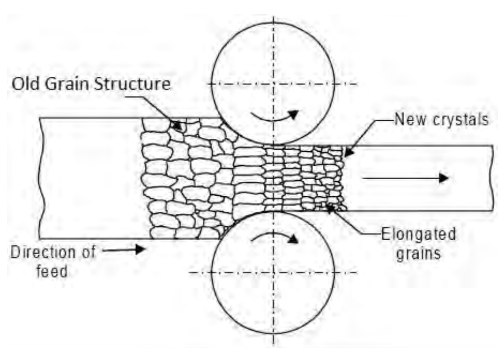
Example – These 2 W-shapes come from the same beam blank. In other words the same cross section off the caster.

For A992, we want to assure we meet 50KSI yield minimum, 65 KSI maximum and don't want to waste alloys.



101

Grain Formation / Refinement During Rolling has to take place.



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Example of How many Beam Blank or Bloom sizes May be Used By a Shape Producer

Beam Blank or Bloom		*Product Family (Example: W14x16)*		*Final ASTM Product (example: W14x211)*
18 Different Cast Shapes of various sizes	→	69 Different Product Groups	→	354 Different Final Products

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ASTM A992 – 11 (2015) Chemistry and Mechanical Requirements

A992/A992M – 11 (2015)

TABLE 1 Chemical Requirements (Heat Analysis)

Element	Composition, %
Carbon, max	0.23
Manganese,	0.50 to 1.60[A]
Silicon, max	0.40
Vanadium, max	0.15[B]
Columbium, max	0.05[B]
Phosphorus, max	0.035
Sulfur, max	0.045
Copper, max	0.60
Nickel, max	0.45
Chromium, max	0.35
Molybdenum, max	0.15

[A] Provided that the ratio of manganese to sulfur is not less than 20 to 1, the minimum limit for manganese for shapes with flange or leg thickness not exceeding 1 in. [25 mm] shall be 0.30 %.
[B] The sum of columbium and vanadium shall not exceed 0.15 %.

$$CE = C + (Mn)/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$$

We use our own ranges within the A992 Table 1 Chemical Requirements Table in order to meet the Table 2 Tensile Requirements.

TABLE 2 Tensile Requirements

Tensile strength, min ksi [MPa]	65 [450]
Yield point, ksi [MPa]	50 to 65 [345 to 450][A]
Yield to tensile ratio, max	0.85[B]
Elongation in 8 in. [200 mm], min, %[C]	18
Elongation in 2 in. [50 mm], min, %[C]	21

[A] A maximum yield strength of 70 ksi [480 MPa] is permitted for structural shapes that are required to be tested from the web location.
[B] A maximum ratio of 0.87 is permitted for structural shapes that are tested from the web location.
[C] See elongation requirement adjustments under the Tension Tests section of Specification A6/A6M.

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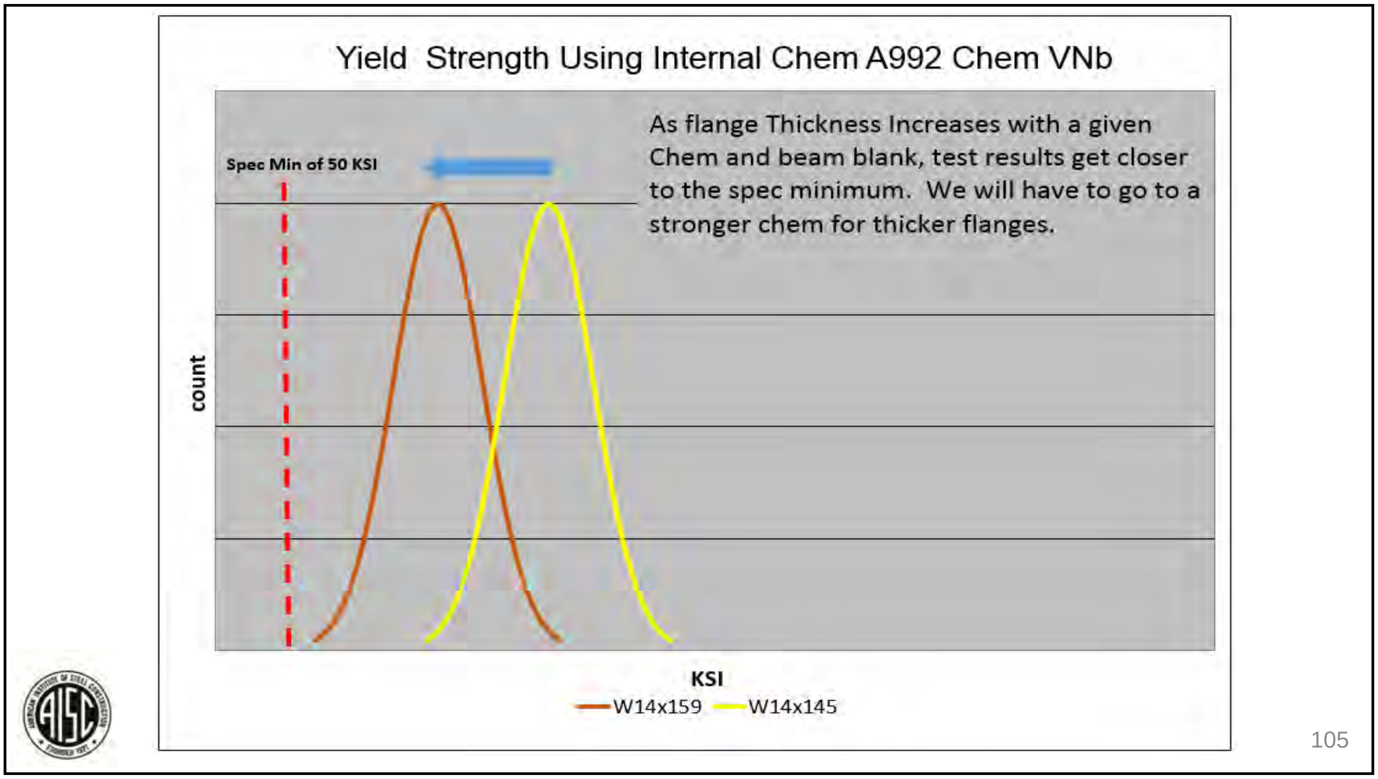
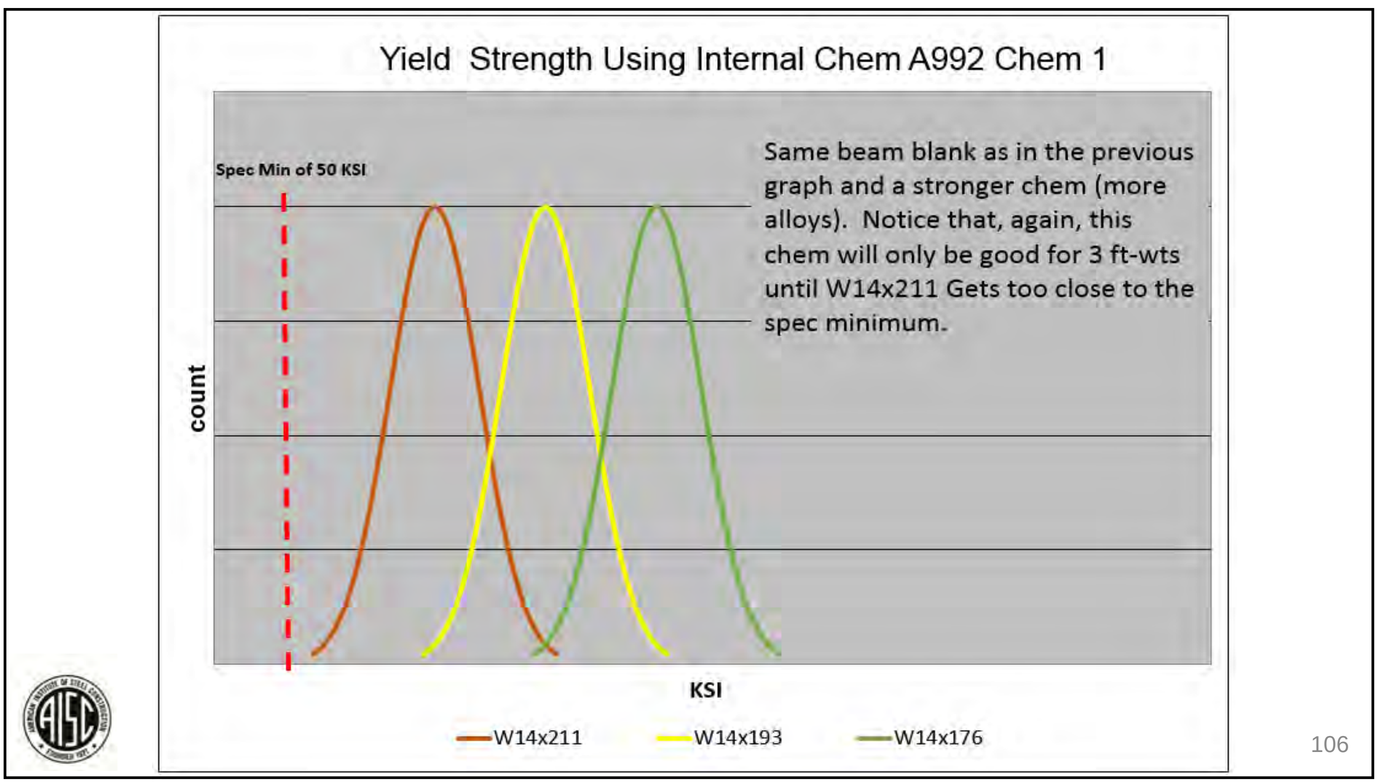
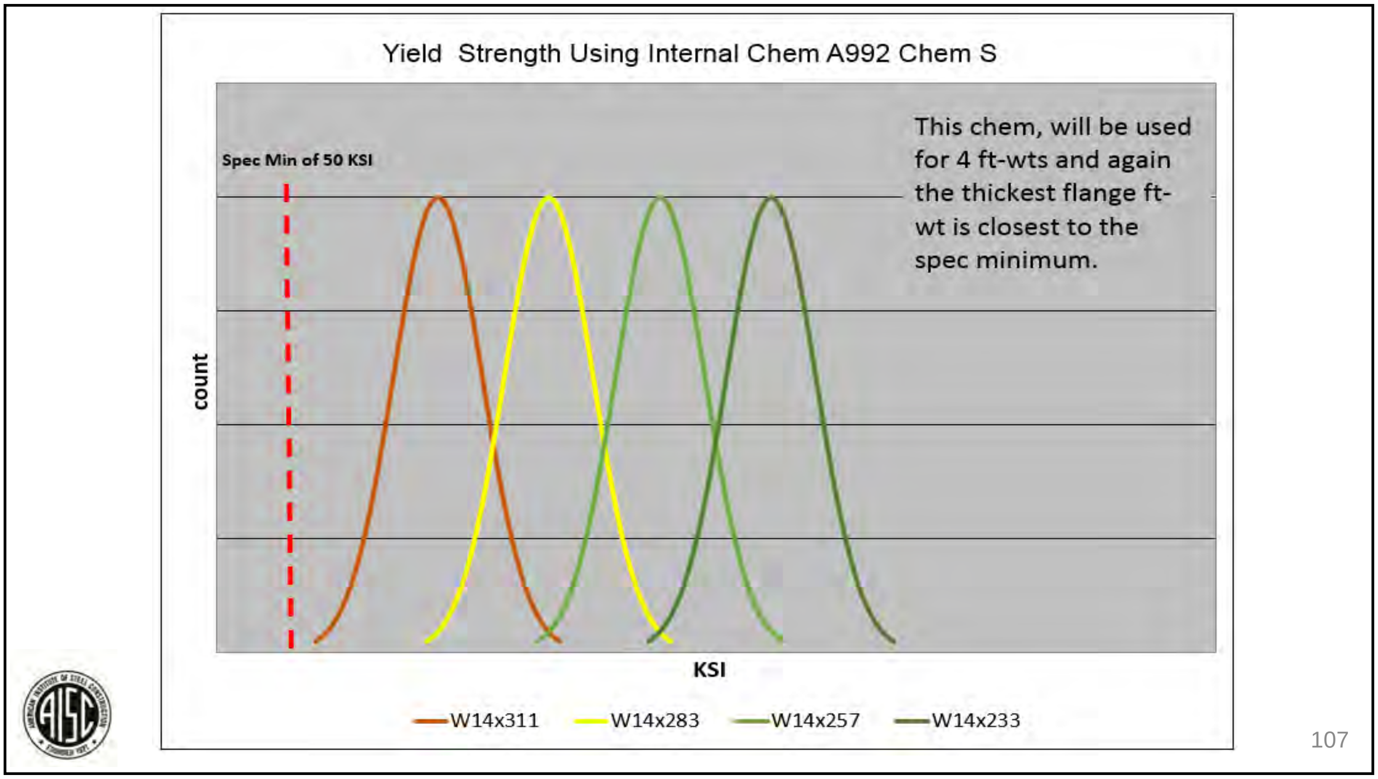
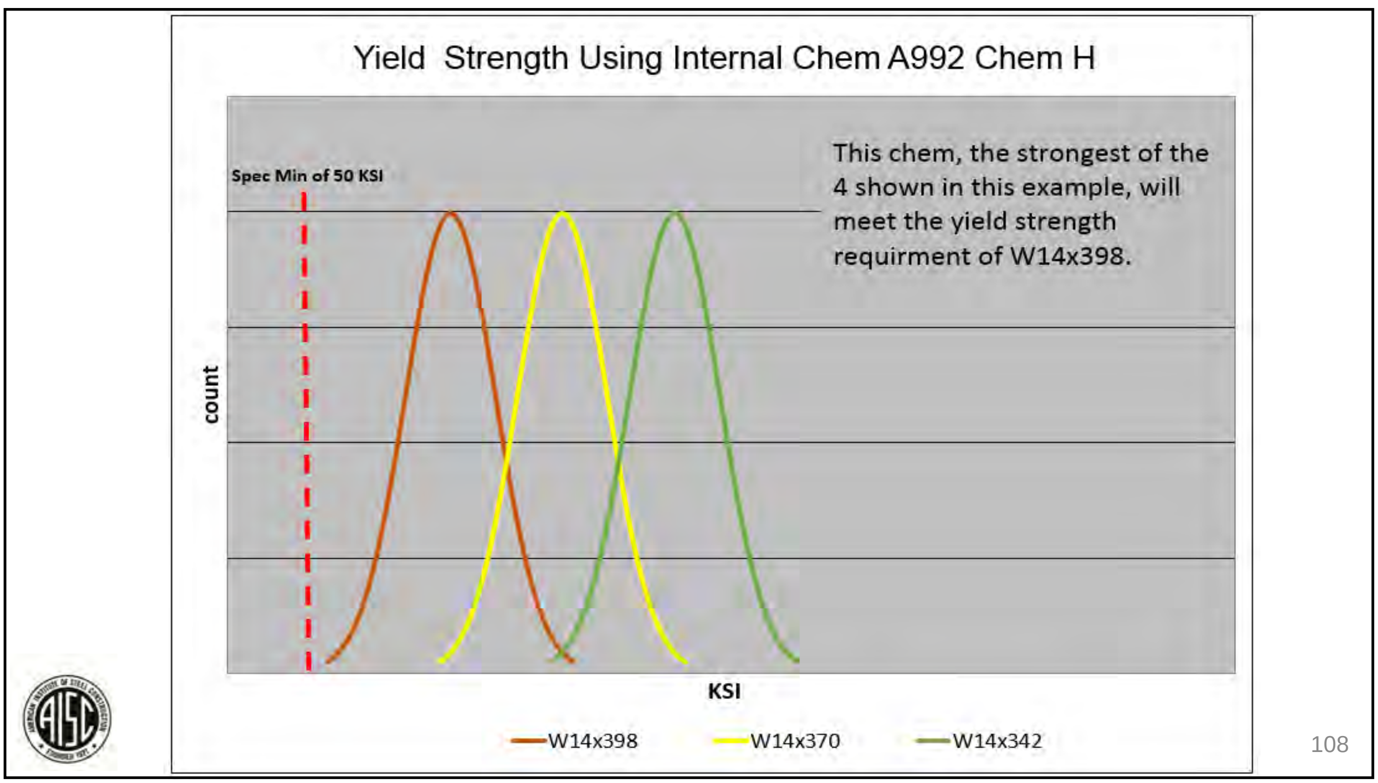

Yield Strength Using Internal Chem A992 Chem VNb
As flange Thickness Increases with a given Chem and beam blank, test results get closer to the spec minimum. We will have to go to a stronger chem for thicker flanges.
Spec Min of 50 KSI
count
KSI
W14x159
W14x145
105


Yield Strength Using Internal Chem A992 Chem 1
Same beam blank as in the previous graph and a stronger chem (more alloys). Notice that, again, this chem will only be good for 3 ft-wts until W14x211 Gets too close to the spec minimum.
Spec Min of 50 KSI
count
KSI
W14x211
W14x193
W14x176
106


Yield Strength Using Internal Chem A992 Chem S
This chem, will be used for 4 ft-wts and again the thickest flange ft-wt is closest to the spec minimum.
Spec Min of 50 KSI
count
KSI
W14x311
W14x283
W14x257
W14x233
107


Yield Strength Using Internal Chem A992 Chem H
This chem, the strongest of the 4 shown in this example, will meet the yield strength requirment of W14x398.
Spec Min of 50 KSI
count
KSI
W14x398
W14x370
W14x342
108

Charpy Testing

- Charpy (CVN) testing - is used to measure the steel's toughness. Put another way, it is a way to quantify the steel's resistance to crack propagation. The test measures the amount of energy absorbed (reported in either ft-bs or Joules) during the fracture of a specimen. The specimen is notched. The notch allows for a predetermined crack initiation location.
- In this test, the specimens (always 3 per test) are tested at a specified temperature.

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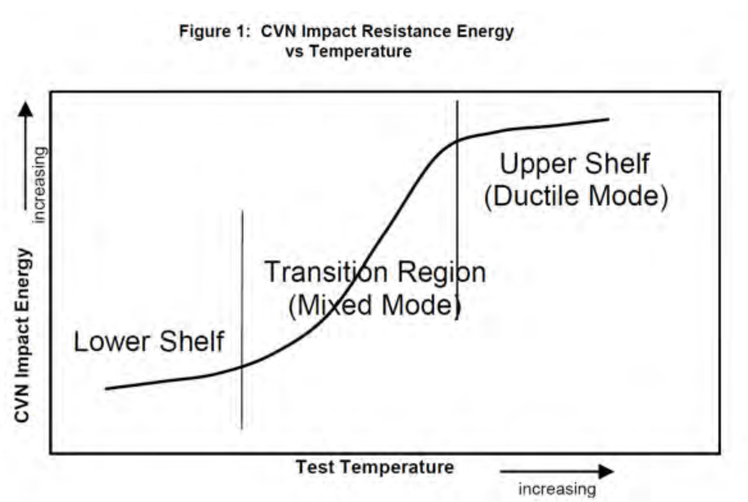
CVN Transition Curve



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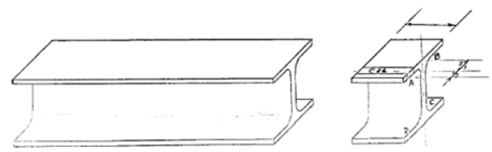
CVN Test Locations

CVN Flange location



NOTE 1—CIL = Charpy impact longitudinal.
NOTE 2—Test coupon for impact specimens may be taken from locations A, B, C, or D as shown laid out at location A.

FIG. 2 Shape Test Location

CVN Core location

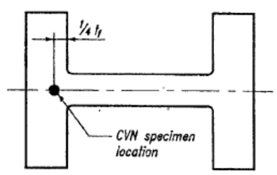
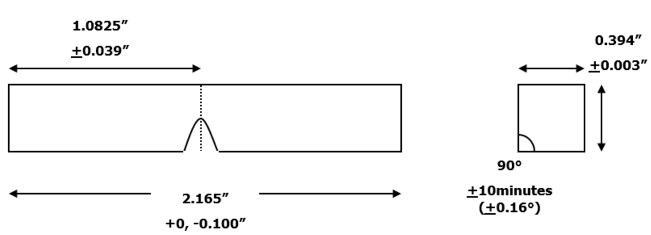
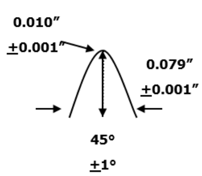


FIG. 3 Alternate Core Location for CVN Specimens

Charpy Sample Tolerances

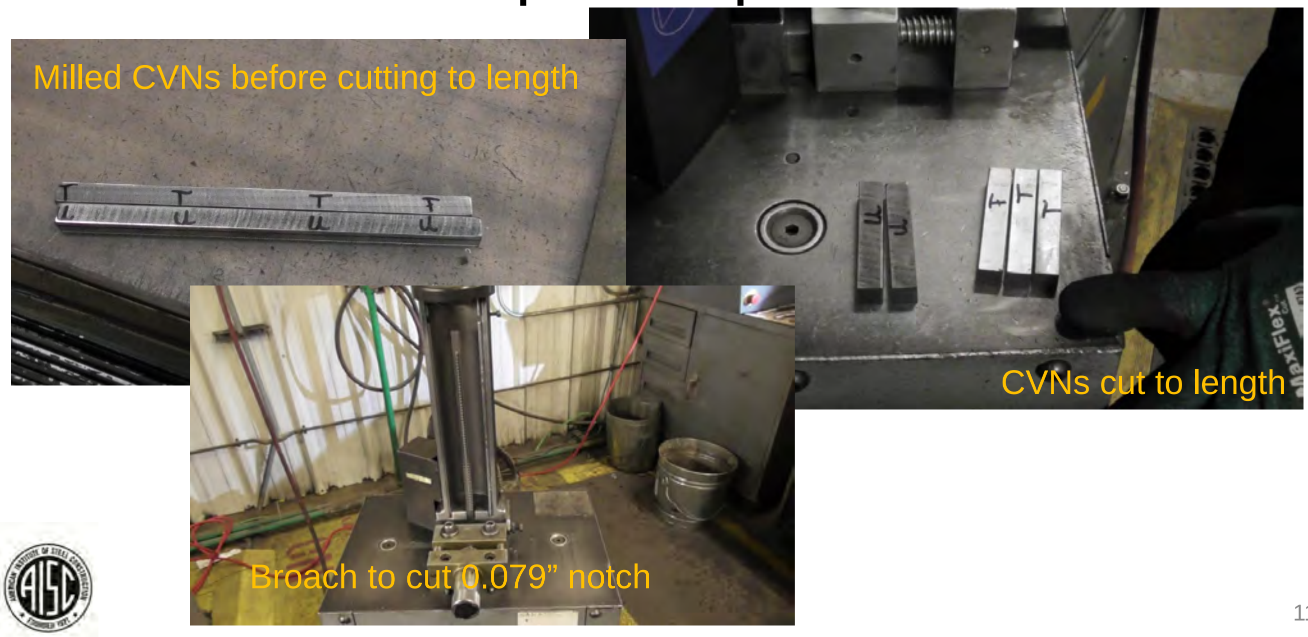




Finish Requirements

Notched Surface and Opposite	Other two surfaces
2 microns	4 microns

CVN Sample Preparation



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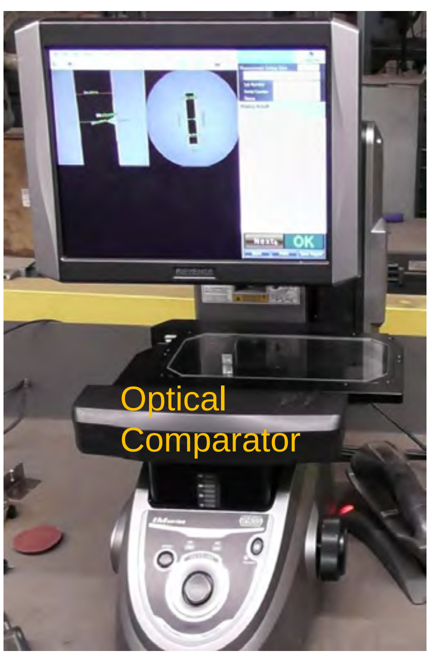
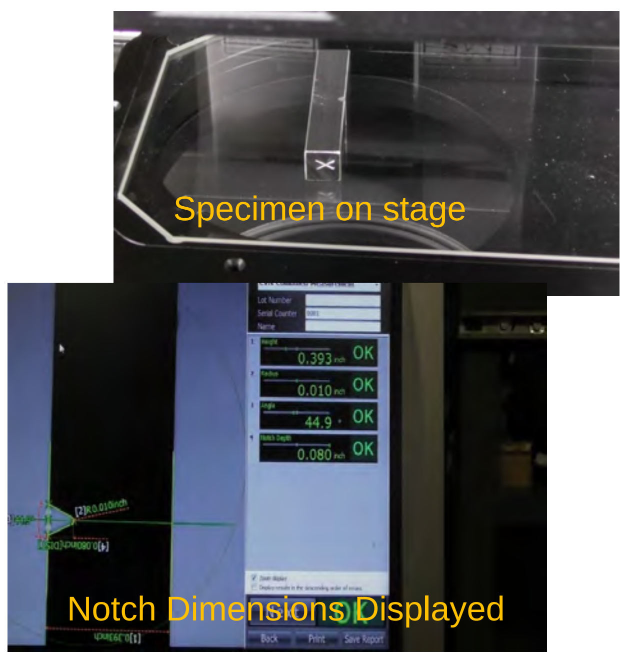
Verification of Notch Geometry





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Cooling

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Testing

116

Testing (Cont)

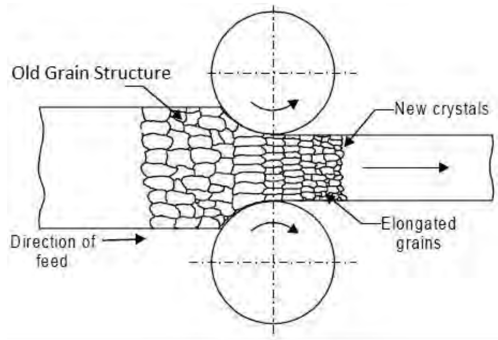
117

How do we meet CVN Properties?

- Carbon is kept under 0.10%.
- Sulfur contents are kept under 0.030%.
- Rolling temperatures are carefully controlled at specific passes for each particular product.

118

Grain Formation / Refinement During Rolling has to take place.



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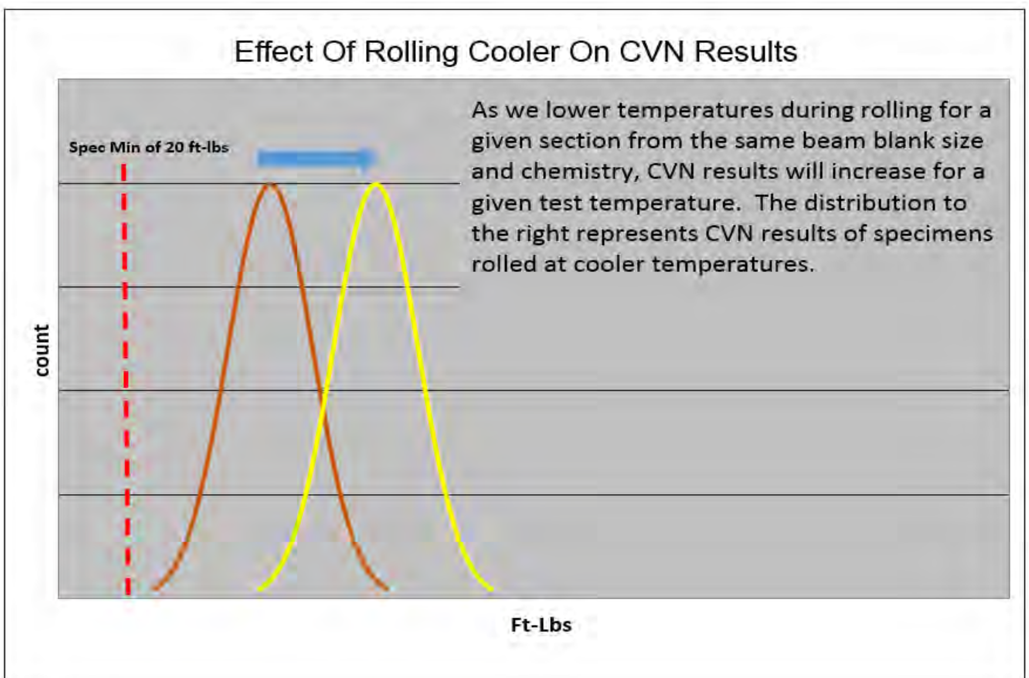
How Lowering Temperature During Rolling Affects CVN Results



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CVN TESTING VIDEO

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In Summary, the manufacturing of structural steel shapes, for the most part is a controlled and predictable process. One might say that the steel producer knows what the test results are going to be, when the scrap is purchased……

AISC | Questions?

Smarter.
Stronger.
Steel.

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Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

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Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- New reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

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8-Session Registrants

CEU/PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.

125

8-Session Registrants

Access to the quiz: Information for accessing the quiz will be emailed to you by Wednesday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG

Quiz and Attendance records: Posted Tuesday mornings. www.aisc.org/nightschool - click on Current Course Details.

Reasons for quiz:

- EEU – must take all quizzes and final to receive EEU
- CEUs/PDHS – If you watch a recorded session you must take quiz for CEUs/PDHs.
- REINFORCEMENT – Reinforce what you learned tonight. Get more out of the course.

NOTE: If you attend the live presentation, you do not have to take the quizzes to receive CEUs/PDHs.

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8-Session Registrants

Access to the recording: Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available for three weeks. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

CEUs/PDHS – If you watch a recorded session you must take AND PASS the quiz for CEUs/PDHs.

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Night School Resources for 8-session package Registrants

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

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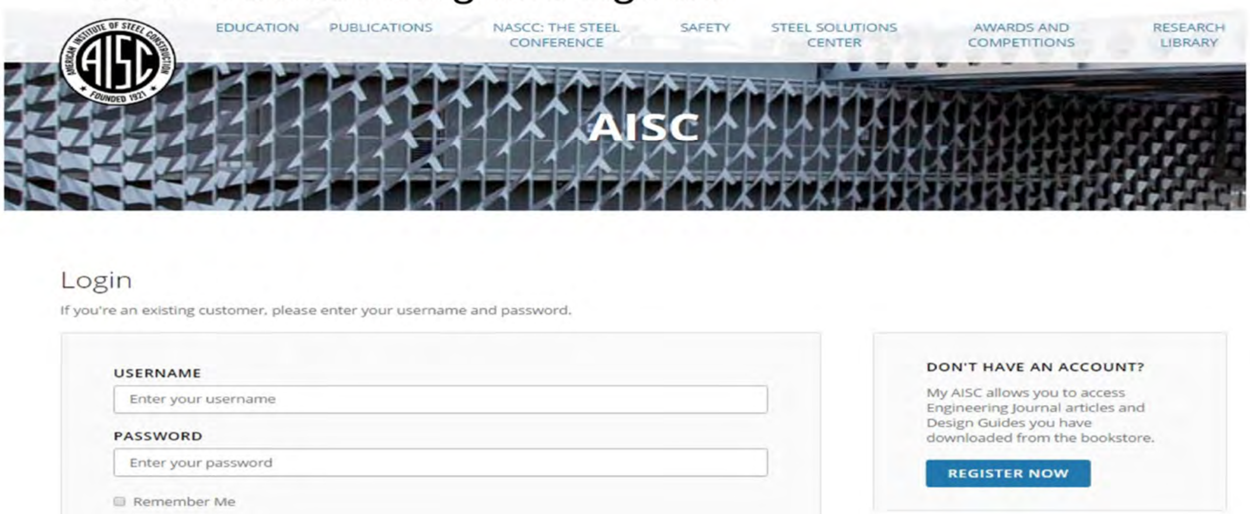
Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.



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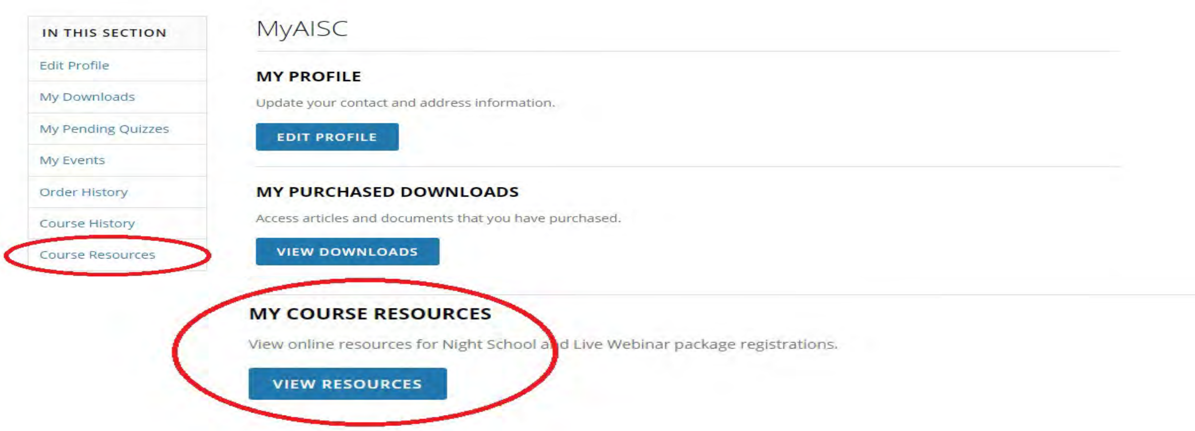
Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.



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Night School Resources for 8-session package Registrants

- Weekly "quiz and recording" email.
- Weekly updates of the master Quiz and Attendance record found at www.aisc.org/nightschool. Scroll down to Quiz and Attendance records.
  - Updated on Tuesday mornings.

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Night School Resources for 8-session package Registrants

- Webinar connection information:
  - Found in your registration confirmation/receipt.
  - Reminder email sent out Monday mornings.
- Link to handouts also found here.

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AISC | Thank you

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Stronger.
Steel.

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