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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



### 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

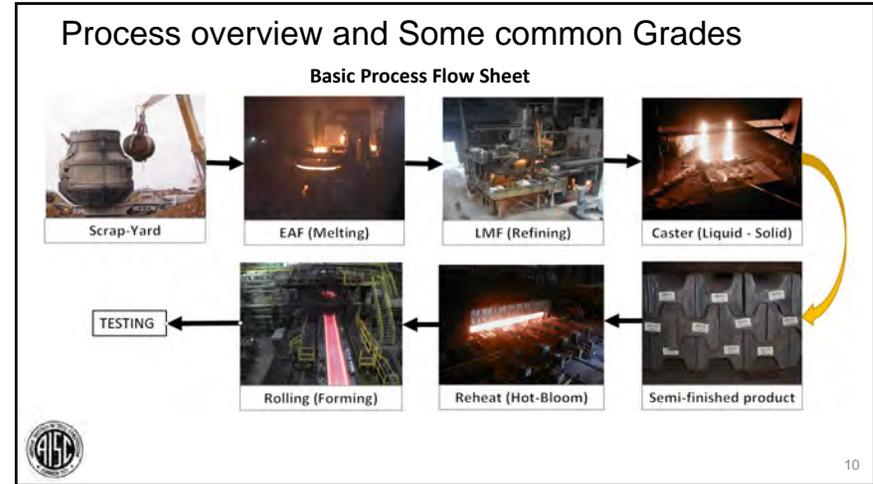


Jim Schoen  
Plant Metallurgist  
Nucor-Yamato Steel



Shane Vernon, P.E.  
Plant Metallurgist  
Nucor-Yamato Steel





**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.



**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.



**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.



**Electric Arc Furnace (EAF) Operations.....**

From cold scrap to 3000°F.....



Electric Arc Furnace (EAF) - Charging Furnace with Scrap



Tapping (Pouring) Heat into Ladle



### Common Scrap Types used for Structural Shapes



#2 Shredded

#1 Heavy Melt

#2 Heavy Melt

P & S



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### SCRAP BUCKET BEING LOADED



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



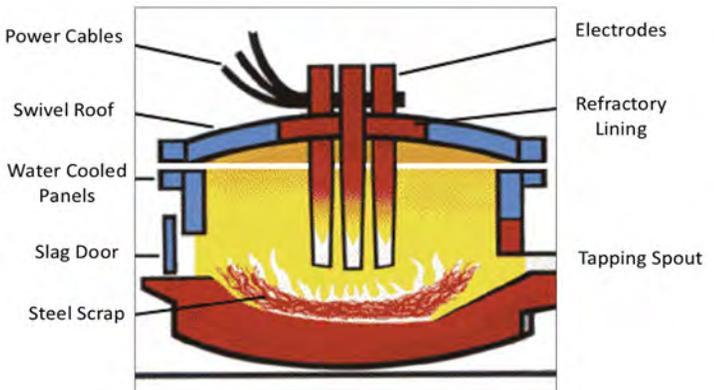
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### SCRAP YARD LOADING VIDEO



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### The Electric Arc Furnace - Melting the scrap



Power Cables

Swivel Roof

Water Cooled Panels

Slag Door

Steel Scrap

Electrodes

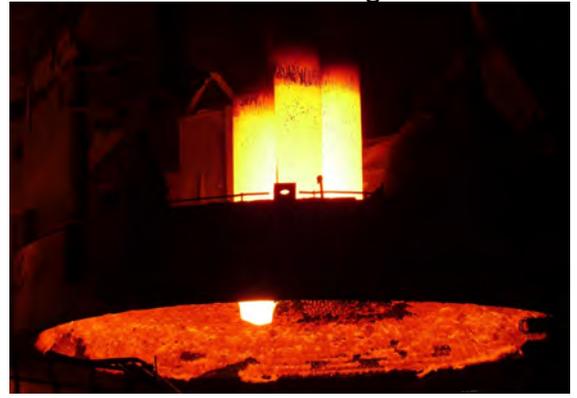
Refractory Lining

Tapping Spout



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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



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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.
Aluminum	2 Al	+	3 O	=	Al <sub>2</sub> O <sub>3</sub>	Alumina	
Magnesium	Mg	+	O	=	MgO	Magnesia	
Titanium	Ti	+	2 O	=	TiO <sub>2</sub>	Titanium Oxides	
Silicon	Si	+	2 O	=	SiO <sub>2</sub>	Silica	
Boron	2 B	+	3 O	=	B <sub>2</sub> O <sub>3</sub>	Boron Oxide	
Columbium	Cb	+	2 O	=	CbO <sub>2</sub>	Columbium Oxide	
Vanadium	2 V	+	5 O	=	VO <sub>2</sub>	Vanadium Oxide	
Manganese	Mn	+	O	=	MnO	Manganese Oxide	Partially Oxidized
Carbon	C	+	O	=	CO	Carbon Monoxide	
Chromium	2 Cr	+	3 O	=	Cr <sub>2</sub> O <sub>3</sub>	Chromium Oxide	
Iron	Fe	+	O	=	FeO	Iron Oxide	
Phosphorous	2 P	+	5 O	=	P <sub>2</sub> O <sub>5</sub>	Phosphorous Oxide	Stays in Steel
Tin	Sn	+	2 O	=	SnO <sub>2</sub>	Tin oxide	
Nickel	Ni	+	O	=	NiO	Nickel Oxide	
Copper	Cu	+	2 O	=	Cu <sub>2</sub> O	Copper Oxide	Lower Potential (Weaker 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.
- $6[P] + 3CaO + 5FeO = 3(CaO \cdot P_2O_5) + 5Fe$



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Furnace Tilted Back and Slagging Off



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## 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 its cleanliness.



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## Slag Foaming

- Carbon is dissolved in steel from scrap, pig iron, and charge carbon.
- Oxygen is injected through lances.
- $C + \frac{1}{2} O_2 = CO$  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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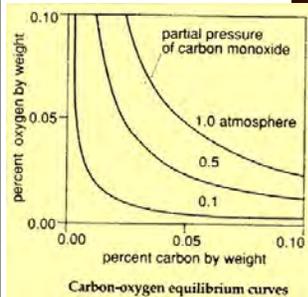
## Slag Foaming

- 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.



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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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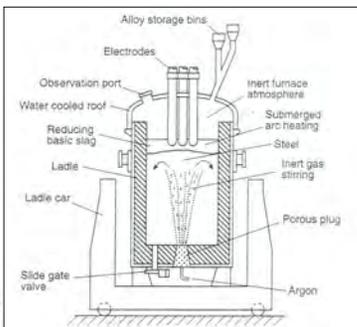
## EAF SUMMARY VIDEO



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## Ladle Metallurgy Furnace (LMF) Operations....

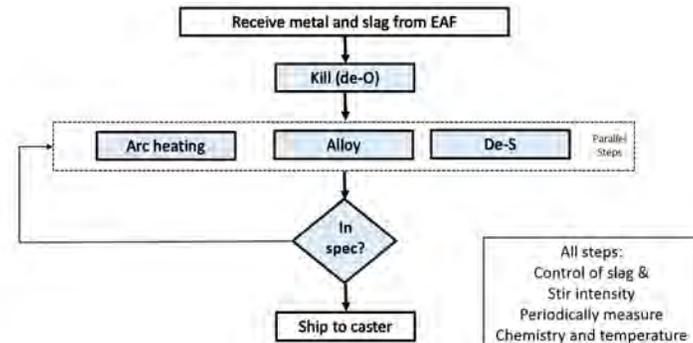
From an "open" heat to the correct temperature, chemistry and on time to the caster....



Ladle of Steel being processed at the LMF



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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<sub>2</sub>)
  - 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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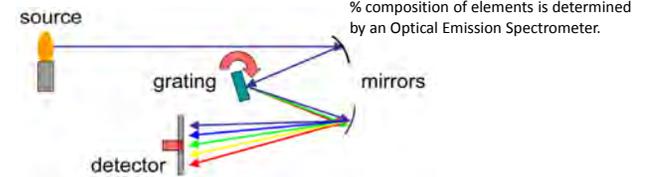
### Typical Chemistry Analysis

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.



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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
  - $\text{Si} + 2[\text{O}] = \text{SiO}_2$  (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

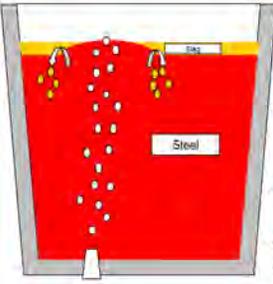
Why S is removed from steel:

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

Desulfurizing slag requirement:

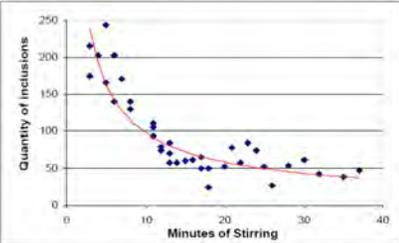
$FeS$	+	$CaO$	$\leftrightarrow$	$FeO$	+	$CaS$
Sulfur in steel as Iron Sulfide		Lime to form slag Calcium oxide		Iron oxide in slag as Iron Oxide		Sulfur in slag as Calcium Sulfide

- 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

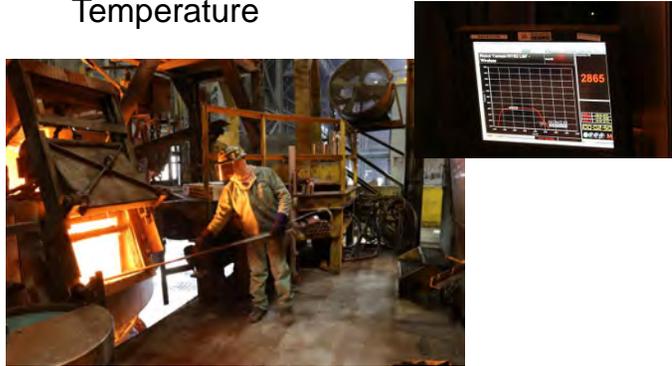


Inclusion evolution in 5 mm<sup>2</sup> surface area measured by EDS  
 Relationship between inclusion content and gas bubbling time in Ternium Siderar (Brandaleze, Martin, Donayo, Pérez & Gomez, 2007).



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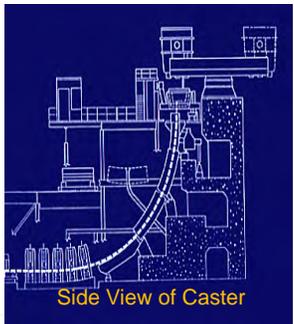
### LMF Operator Measuring the Temperature




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### Continuous Caster Operations.....

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



Side View of Caster



Strands in Straighteners

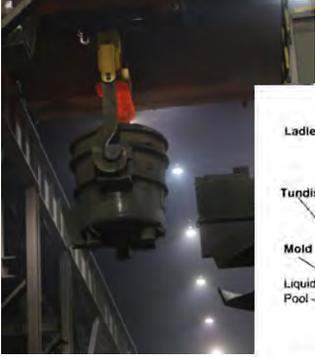


Tagged Beam Blanks ready to roll

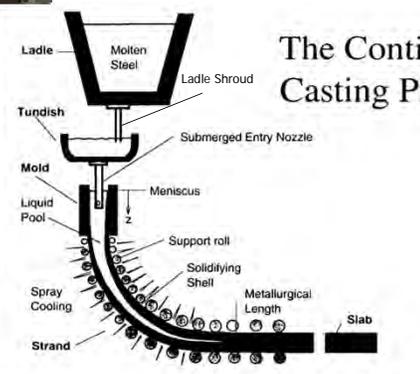


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## Casting



### The Continuous Casting Process



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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

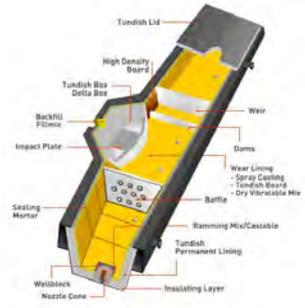
- Protects steel stream from reoxidation
- Must be properly aligned for effective use and maximum life
- Gaskets can also help to achieve proper seal



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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

Completely Finished Tundish

Tundish in Service



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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



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## Casting Molds



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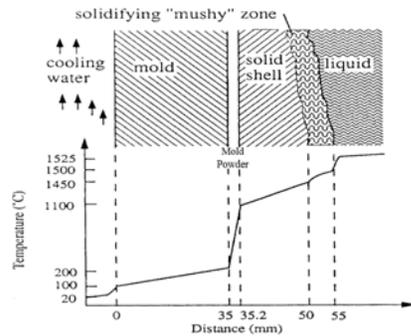
## Functions of Mold Oils and Powders

- 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

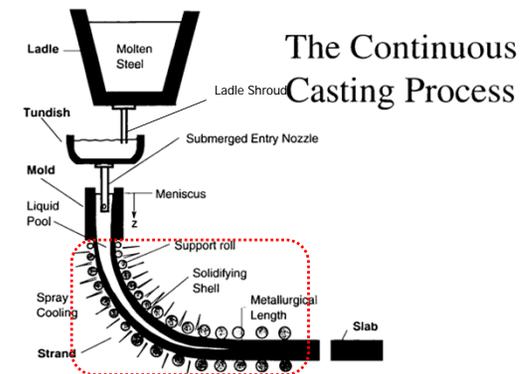
## Heat Transfer

Schematic of Heat Flow in Continuous Casting



67

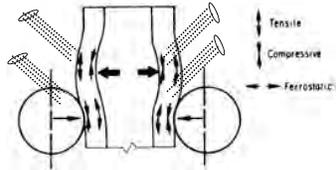
## Secondary Cooling and Containment



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



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### Secondary Cooling and Containment (Segments below the mold)



Containment Chamber



Containment Rolls



70

### Strands in Spray Chambers



71

### Caster Run-Out And Cooling Bed



Cooling Bed



Beam Blank Strands Being Torched Cut To Length.



72



### Semi-Finished Cast Shapes

- Blooms – rectangular; typically  $W \leq 2T$ , and cross-sectional area  $\geq 36\text{-in}^2$ .
- Billet – rectangular; typically  $W \leq 2T$  and cross-sectional area  $\leq 36\text{-in}^2$ .
- Slab – rectangular
- Beam Blank – “Dogbone” shaped.



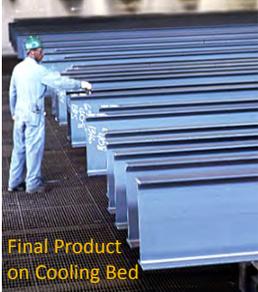
73

### Rolling Mill Operations

From beam blank or bloom to finished product



Beam Blank Being Discharged From Reheat



Final Product on Cooling Bed



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



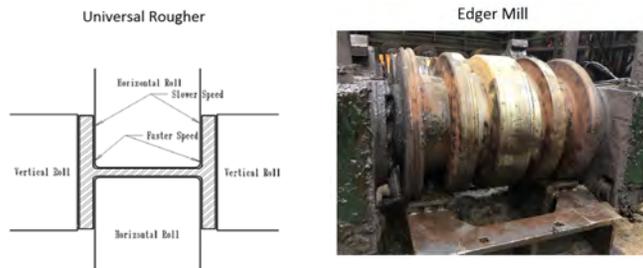
Gets the rough section depth and flange height



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### Types of Rolls and Mill Stands (Cont.)

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



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

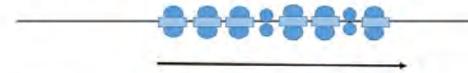


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### Common Types of Shapes Rolling Mills

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

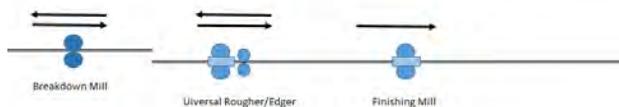


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### Common Types of Shapes Rolling Mills (Cont.)

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

Example of a Reversing Mill Set-up

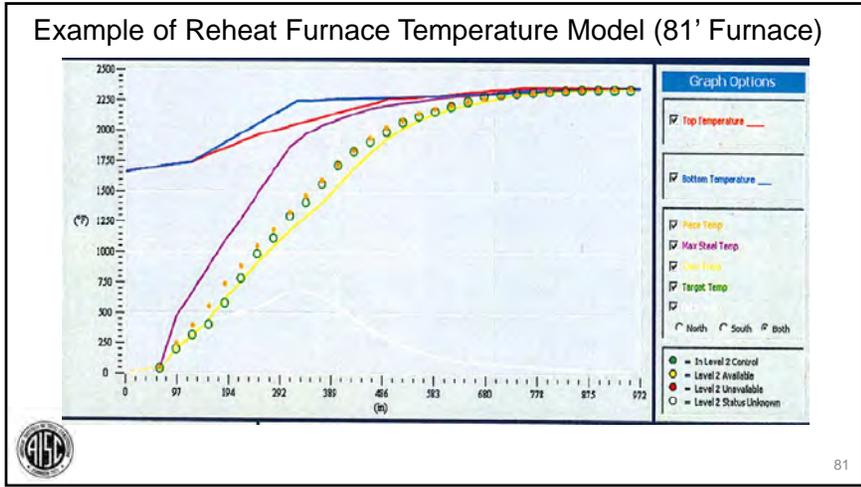


79

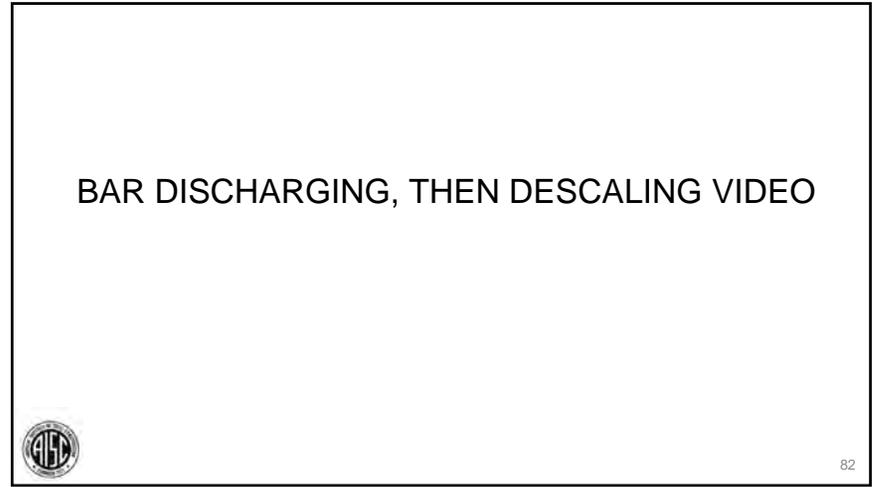
### Reheat furnace Operations



80



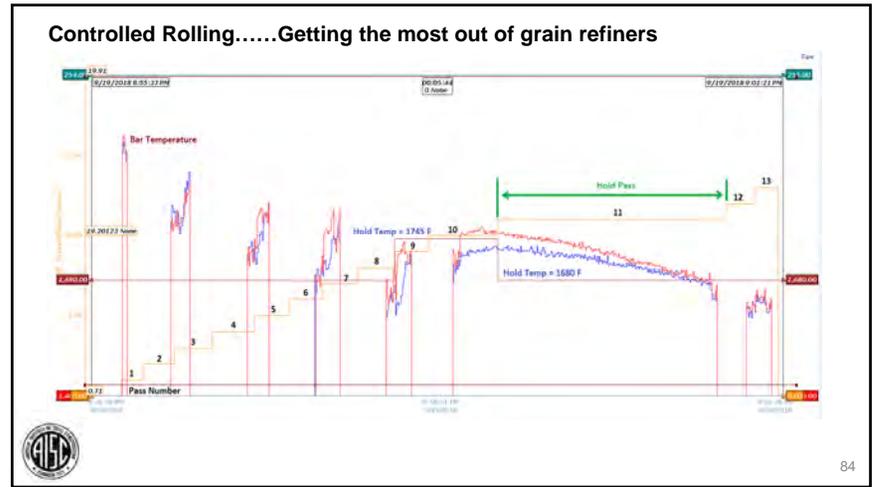
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82

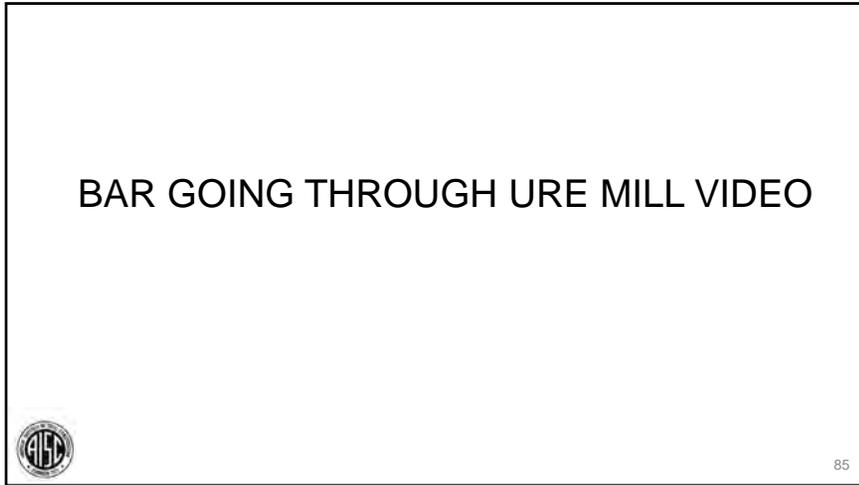


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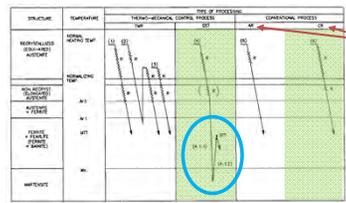




### ASTM Grade A913

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

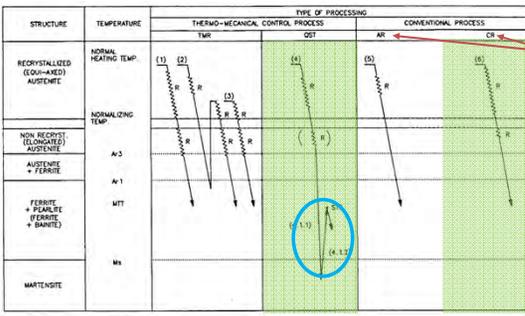
- Intense water cooling is applied to the whole surface of the beam
- Cooling is interrupted before the core is affected by the quench
- Outer layers are tempered by the remaining heat from the core of the beam. Self-tempering temperature between 1100°F – 1300°F



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### A closer look At Grade A913

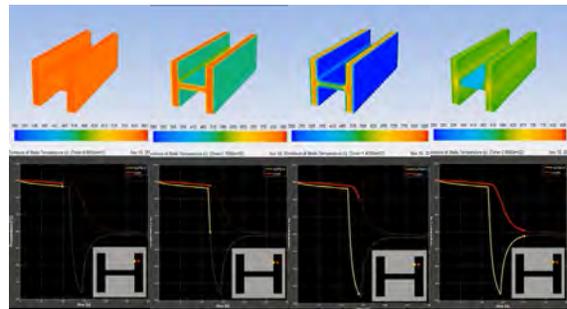
Self-tempering temperature between 1100°F – 1300°F.



87

### QST Product Surface vs. Core Temperature

General Temperature Description of Process



88

### Quenching and Self-Tempering: The Process

STRUCTURE	TEMPERATURE	RATE OF PROCESSING		
		THERMO-MECHANICAL CONTROL PROCESS	QST	CONVENTIONAL PROCESS
RECRYSTALLIZED (LOW-ALLOY) AUSTENITE	NORMAL HEATING TEMP.			
HIGH-ALLOY (ELONGATED) AUSTENITE	NORMAL HEATING TEMP.			
	AV-3			
FERRITE + FERRITE OF FERRITE + BAINITE	AV-1			
	MFT			
MARTENSITE	MU			

QST Surface

QST Mid-Thickness

CR Mid-Thickness

0.1 mm

### Saw Cut To Length

### Dimensional Checks

Ft-wt

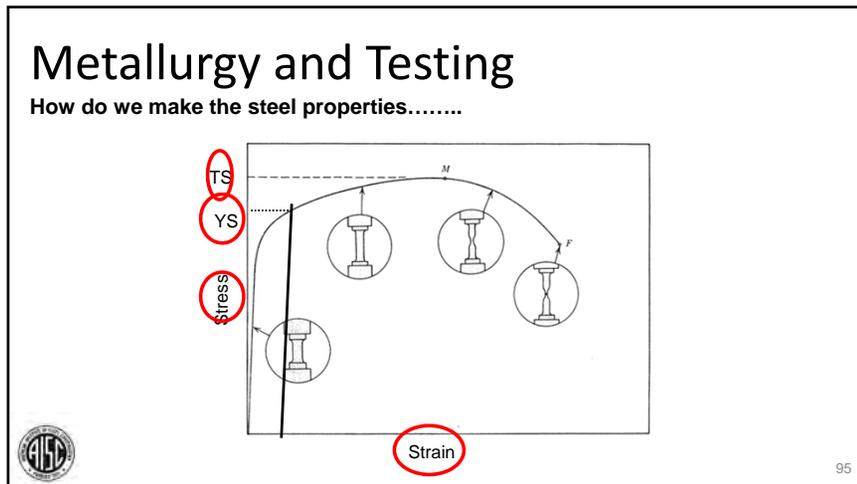
Web Off Center & Surface Quality

Section Depth

### Straightening

Rotary Straightener

Load and Temperature Measurements



- ### 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.
- 96

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

- Maximum variation from end to end of the reduced section is 0.004" ( $A - B \leq 0.004"$ )
- Maximum variation from either end to the center of the reduced section is 0.015" ( $A - C$  and  $B - C \leq 0.015"$ )

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**Harvesting Samples**

Test piece harvested at mill      Test specimen being torched from flange

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**Milling of Samples**

Milling machine endmill and fixtures

Milling Machine to remove Heat affected zone from torch

Heat affected zone removed

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**TENSILE TESTING VIDEO**

100

### 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.

W14x115  
1.090" Nominal Flange Thickness

W14x98  
2.845" Nominal Flange Thickness

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### 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

<u>Beam Blank or Bloom</u>	<u>Product Family</u> <i>(Example: W14x16)</i>	<u>Final ASTM Product</u> <i>(example: W14x211)</i>
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)**

Element	Composition, %
Carbon, max	0.23
Manganese, max	0.50 to 1.60 <sup>a</sup>
Silicon, max	0.40
Vanadium, max	0.15 <sup>b</sup>
Chromium, max	0.05 <sup>b</sup>
Phosphorus, max	0.025
Sulfur, max	0.045
Copper, max	0.60
Nickel, max	0.45
Chromium, max	0.35
Molybdenum, max	0.15

<sup>a</sup> Provided that the ratio of manganese to sulfur is not less than 20 to 1, the maximum limit for manganese for shapes with flange or leg thickness not exceeding 1 in. (25 mm) shall be 0.30 %.

<sup>b</sup> The sum of columbium and vanadium shall not exceed 0.15 %.

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

**TABLE 2 Tensile Requirements**

Tensile strength, min ksi (MPa)	65 (450)
Yield point, ksi (MPa)	50 to 65 [345 to 450] <sup>a</sup>
Yield to tensile ratio, max	0.95 <sup>b</sup>
Elongation in 8 in. (200 mm), min, % <sup>c</sup>	18
Elongation in 2 in. (50 mm), min, % <sup>c</sup>	21

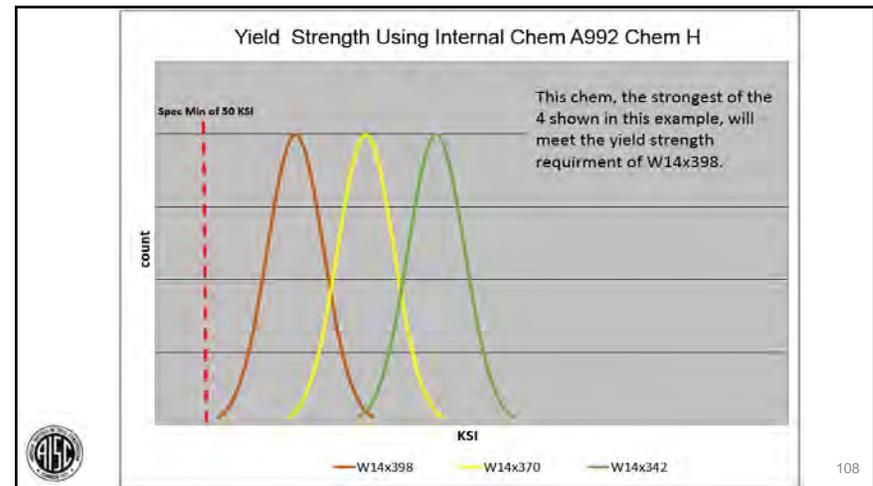
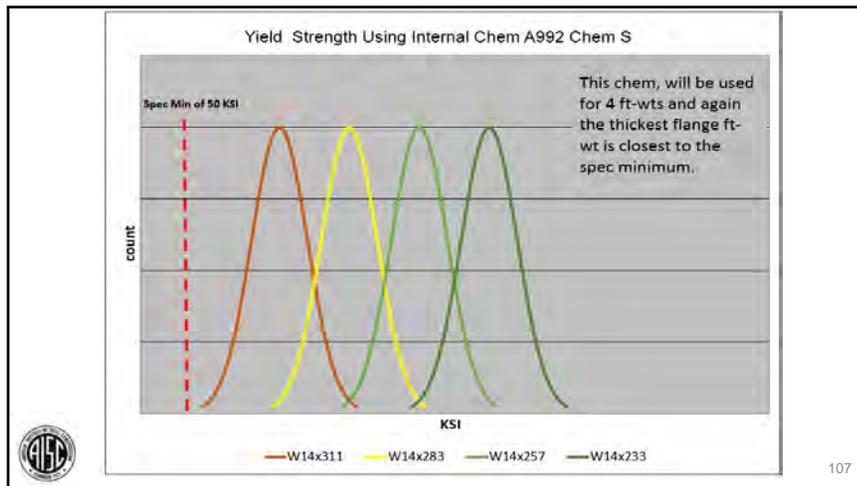
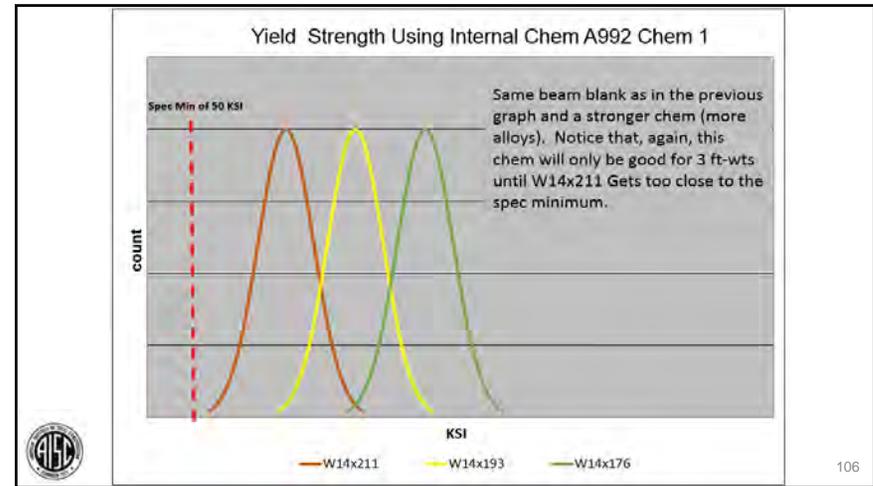
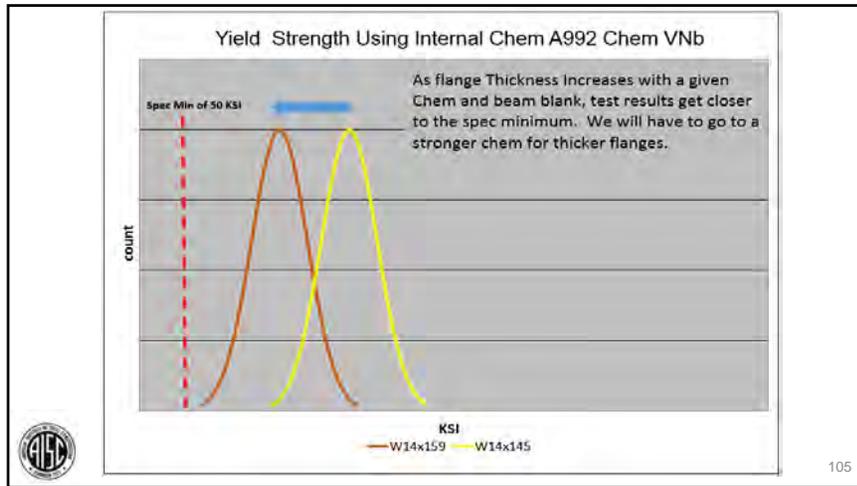
<sup>a</sup> A maximum yield strength of 70 ksi (480 MPa) is permitted for structural shapes that are required to be tested from the web location.

<sup>b</sup> A maximum ratio of 0.87 is permitted for structural shapes that are tested from the web location.

<sup>c</sup> See elongation requirement adjustments under the Tension Tests section of Specification A6/A6M.

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

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## Charpy Testing

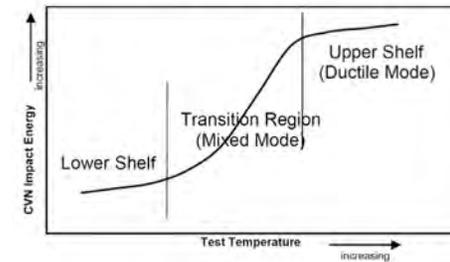
- Charpy (CVN) testing - is used to measure the steel's toughness. Put another way, it is a way to quantify the steel's resistance to crack propagation. The test measures the amount of energy absorbed (reported in either ft-bs or Joules) during the fracture of a specimen. The specimen is notched. The 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

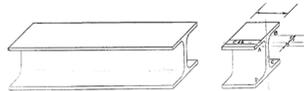
Figure 1: CVN Impact Resistance Energy vs Temperature



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## CVN Test Locations

CVN Flange location



Note 1 - CE - 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

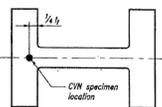
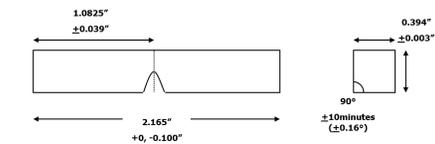


FIG. 3 Alternate Core Location for CVN Specimens



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## Charpy Sample Tolerances



### Finish Requirements

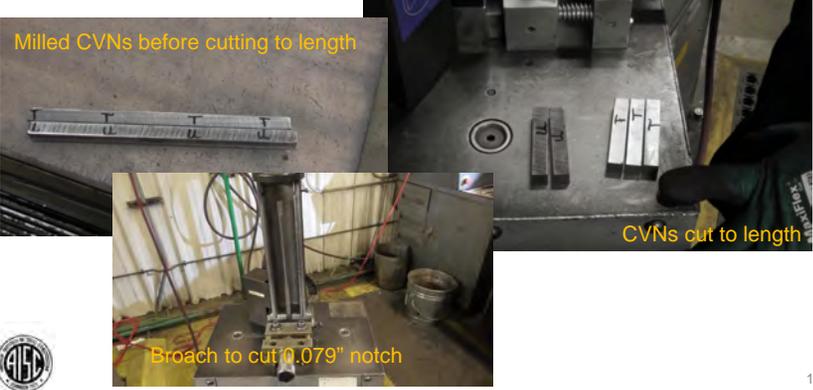
Notched Surface and Opposite  
 2 microns

Other two surfaces  
 4 microns



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### CVN Sample Preparation



Milled CVNs before cutting to length

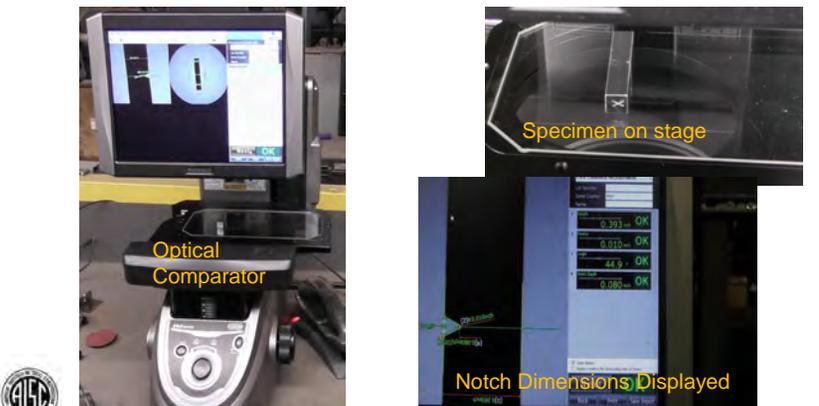
CVNs cut to length

Broach to cut 0.079" notch



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### Verification of Notch Geometry



Optical Comparator

Specimen on stage

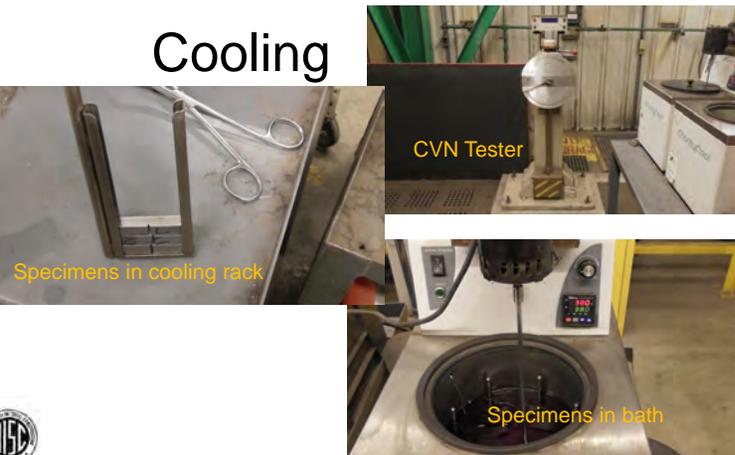
Notch Dimensions Displayed

0.383	OK
0.570	OK
44.9	OK
0.085	OK



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### Cooling



Specimens in cooling rack

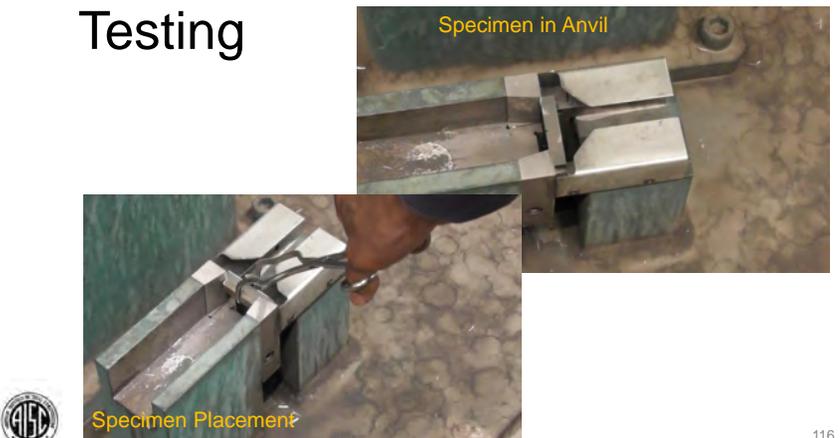
CVN Tester

Specimens in bath



115

### Testing



Specimen in Anvil

Specimen Placement



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## Testing (Cont)



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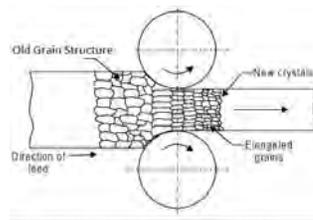
## How do we meet CVN Properties?

- 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.



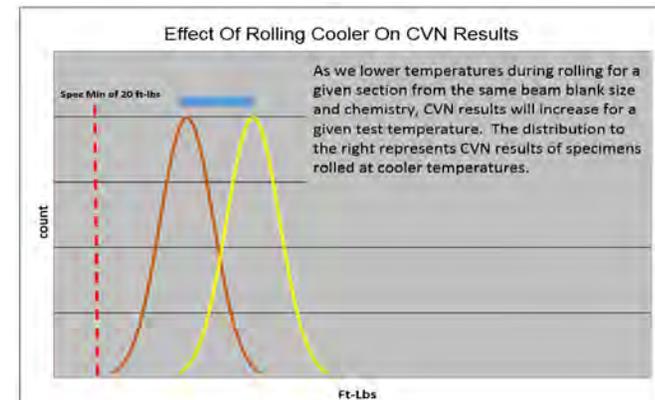
118

## 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?



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Within 2 business days...

- You will receive an email on how to report attendance from: [registration@aisc.org](mailto: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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- Password: Same as AISC website password.



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



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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](http://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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Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

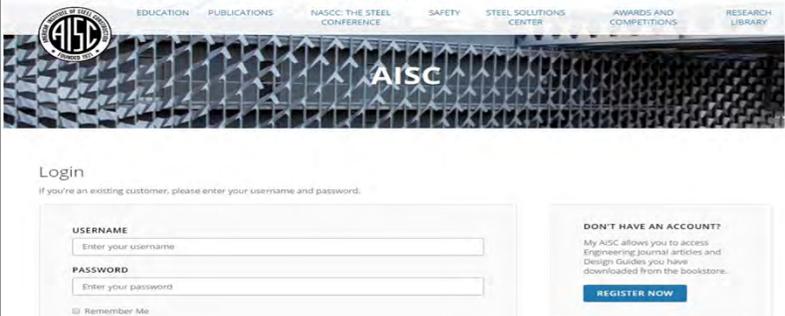


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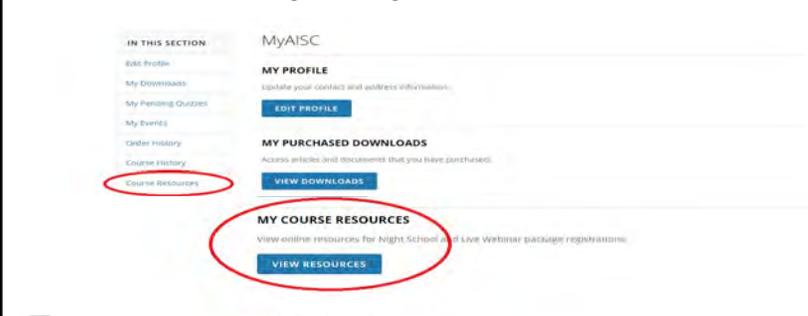
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- Weekly “quiz and recording” email.
- Weekly updates of the master Quiz and Attendance record found at [www.aisc.org/nightschool](http://www.aisc.org/nightschool). Scroll down to Quiz and Attendance records.
  - Updated on Tuesday mornings.



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



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