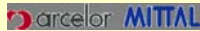
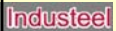


NACE Northern Area Fort McMurray Seminar
**Special Steel Plates for
Oil Sands Applications**

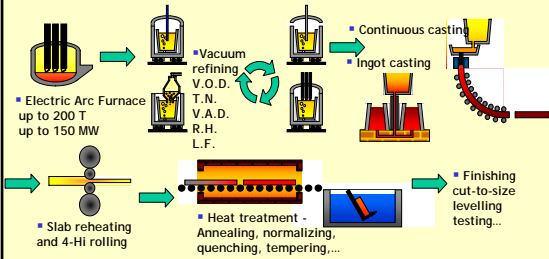
Hichem Ahmed-Chaouch
Montreal, QC

John Grocki
Enfield, CT



How do you make Special Steel plates ?

- Mill facilities include Electric Arc Furnace melting technology as well as Special Ladle Vacuum Refining.
- Larger than standard processing and heat treatment capabilities.
- Project follow-up teams, technical support, dedicated R&D



Some steps in steelmaking



a 200T ladle during casting operations



beginning of hot-rolling operations at 1200°C



metal cutting with oxygen torch

Steels for Special Structural Applications



Racks for offshore industry



Cryogenic tank

4

Stainless Steels

Ship-building



Chemical & Petrochemical Industries



Gas-cleaning



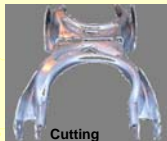
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Specialty Steels

... Wear resistance



Mining,
Public works...



Cutting
Automotive market

... Molds

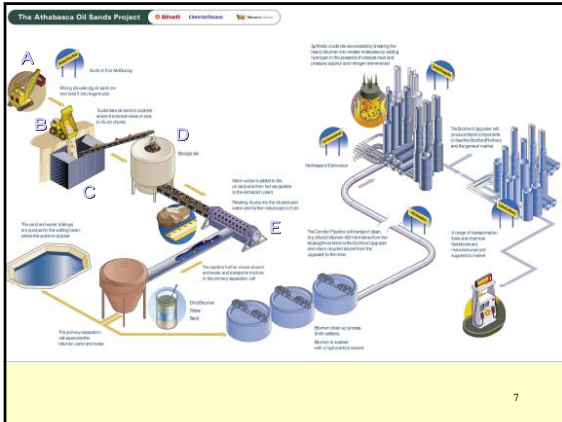


Injec
Auto

... civil and military protection



6



Areas and Devices subjected to severe abrasion and wear

- A Shovels (excavators) ⇒ Buckets
- B Trucks ⇒ Cargo Body
- C Primary Crusher ⇒ Wear parts
- D Storage Silo ⇒ Outlet Hopper, Chutes
- E Rotating Drum ⇒ Drilled Screen

8

**In the Rock and Mineral processing industry
the most common wear resistant products are
Conventional Water Quenched Steels**

400 HB

450 HB

500 HB

Hardness (Water Quenching) ➡ Wear Resistance

9

It is necessary to specify more than just the hardness,

THE WEAR RESISTANCE =

- ✓ **Hardness**
- ✓ **Homogeneous hardness**
- ✓ **Toughness**
- ✓ **Microstructure (fine & homogeneous)**
- ✓ **Heat resistance**
- ✓ **Corrosion resistance**

10

Abrasion Parameters ?

In the Oil Sands processing industry, the main abrasion parameters which have to be considered are :

- IMPACT (High energy)**
- SLIDING (High pressure)**
- Presence of CORROSION**
(sulfur + atmospheric conditions)

11

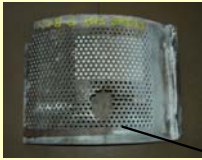
Required for wear resistant steels ?

- ✓ **Hardness**
- ✓ **Homogeneous hardness**
- ✓ **Toughness (crack resistance)**
- ✓ **Moderate corrosion resistance**

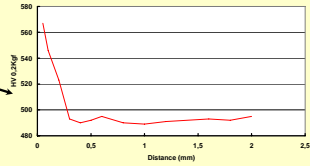
12

Reactive surface

Optimal combination of Composition & Heat Treatment
 (Surface hardening on a TRIP steel 500 HB sample exposed to an abrasive service)

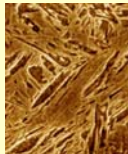


- ✓ Superficial workhardening : +78HV
- ✓ Affected thickness : 300µm



Microstructure

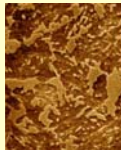
WATER QUENCHED



X 3000

- ✓ Martensite
- ✓ lamellar structure (brittle)
- ✓ No Micro Carbides

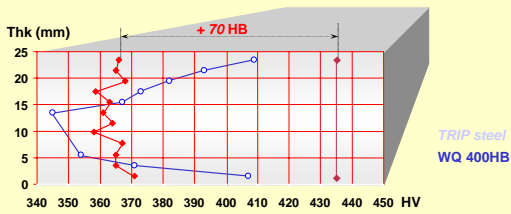
TRIP steel



X 3000

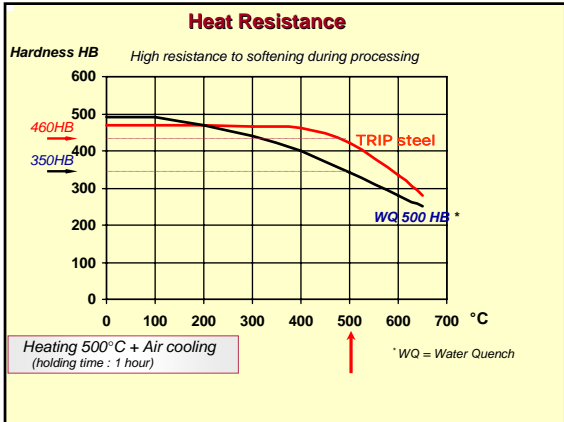
- ✓ (Martensite - Bainite) + retained Austenite
- ✓ fine structure
- ✓ Micro Carbides (Cr, Mo, Ti)

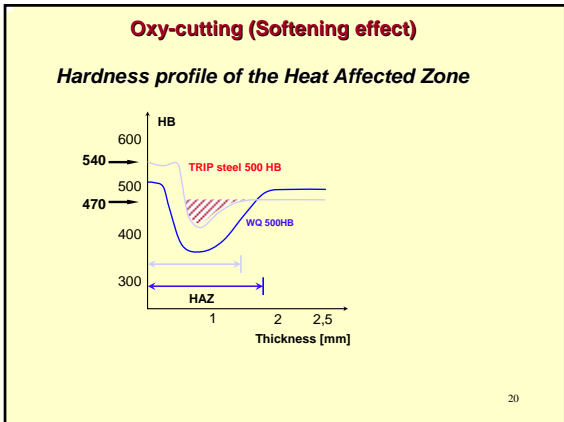
Consistent Hardness

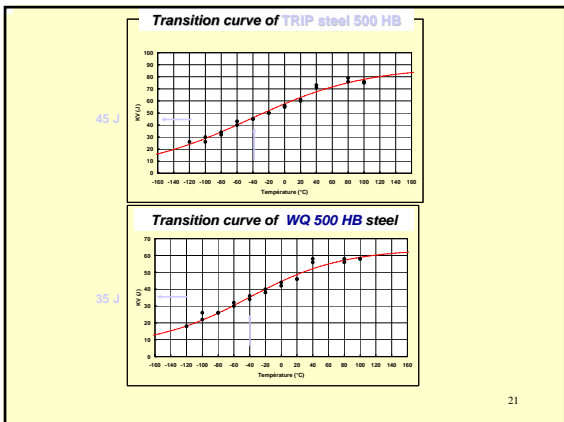


Homogeneous Hardness

- ↓
- Homogenous performance
- ✓ Wear rate
 - ✓ Machinability







Lab Tests with wet COAL

Test description : 'stirring machine' which creates conditions of sliding abrasion mixed with impact (close to field conditions)



Test description : a specimen of the steel is rotated (600 rpm) in the abrasive grit. The abrasive wear is quantified by the weight loss of the sample after a given number of rotation sequences.

Abrasive grit : can be adapted to an application, by selecting the particle size, 4-9mm for typical coal provided by a coal mine.

Results are expressed in **wear index** :

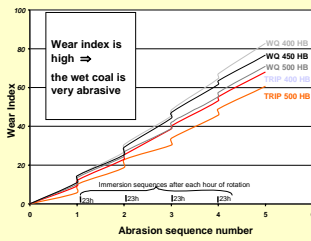
$$\frac{\Delta Pt}{P_0} \times 10^4$$

ΔPt : weight loss at time t
 P_0 : initial sample weight

A higher wear index corresponds to a higher wear rate

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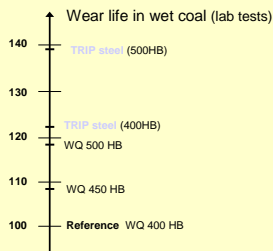
Behavior in wet coal (coal +20wt% water)



TRIP steels show a good wear resistance in the wet coal media used for lab testing

23

Behavior in wet coal (coal +20 wgt % water)



24

WQ Concept

Traditional route

- ✓ Basic Composition (C,Mn,B)
- ✓ Water Quench

↓

- Martensitic structure (hardness only)

↓

- ✓ Wear resistance
- ✓ Workability (gives good results for common applications)

TRIP Concept

Alternative Concept

- ✓ Specific Composition
- ✓ Controlled Cooling

↓

- Micro carbides (Cr,Mo,Ti)
- Trip effect


↓

Perfect Balance


- ✓ High wear life
- ✓ Improved workability (answer for specific applications)

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Mining - typical applications of TRIP steels




buckets




TRIP (field test on separator)




crushers



shovels



standard



wear plates

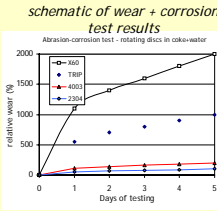
26

Slurry pipes / hydrotransport - materials for abrasion and corrosion combined

- The wear mechanism is much more linked to corrosion than abrasion : it is the "rust" particles that are eroded away.
- Strong, easily processable : stainless steels have a good behaviour

steel type	typical abrasion corrosion life span	typical minimum temperature	behaviour vs low pH, sulfur compounds, salts...
"X60"	1	depends on steel	will rust
TRIP	2-3 not formable as pipe	0°C	will rust
dual-phase 41003/4003	5-15	-20°C	fair
duplex 2304	15-25	-40°C	better

schematic of wear + corrosion test results



Abrasion-corrosion test - rotating discs in oxic-water

under field testing

suggested next step 27

What are Duplex Stainless Steels ?

- A family of stainless steels whose:
- structures are approximately 50/50 austenite and ferrite
- physical properties are a combination of the ferritic and the austenitic grades

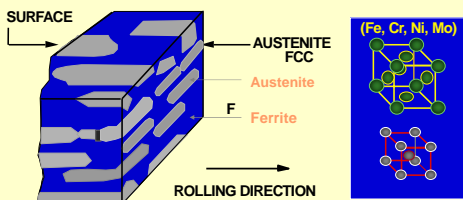
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Chemistry of Duplex SS

Name	UNS No.	C	Cr	Ni	Mo	N	Cu
2304	S32304	.03	23	4	0.5	.12	
2205	S31803	.03	21.8	5	2.8	.12	
2205	S32205	.03	22.5	5	3.2	.16	
2507	S32750	.03	25	7	4.0	.28	.5
255	S32550	.03	25.5	5.5	3.4	.20	2.0

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DUPLEX STAINLESS STEEL MICROSTRUCTURE



PHASE	COMPOSITION					
	C	N	Cr	Ni	Mo	% VOLUME
FERRITE	0,015	0,03	24,5	4,5	3,8	50 %
AUSTENITE	0,025	0,30	20,5	7,5	2,6	50 %
COMPOSITION 31803/UR 45 N	0,02	0,17	22,5	6	3,2	

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General Corrosion

- Similar to relative austenitic alloys.
(2304 is similar to 304 & 316)
- General corrosion resistance can vary greatly with changes in concentration, pH, temperature and impurities. It is important to discuss these variables for any application!

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Duplex vs. Austenitic

- | Duplex Grades | Austenitic Grades |
|---------------|-------------------|
| • | 304L |
| • 2304 | 316L |
| • | 317L |
| • | 317LMN |
| • 2205 | |
| • | 904L |
| • 255 / 2507 | |
| • | 6Mo Grades |
- (increased resistance)

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Localized Corrosion

- Pitting / Crevice
- { PREN = Cr + 3.3Mo + 16N }

Grade	PREN
304L	19
316L	24
2304	25
317L	30
317LMN	33
2205(S32205)	35
904L	35
255	42
2507	43
6Mo Grades	45

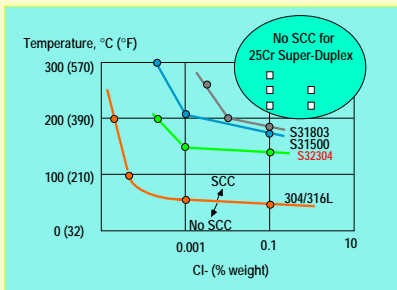
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Chloride Stress Corrosion Cracking

- The greatest advantage for duplex stainless steels is their **improved resistance to CSCC** when compared to the austenitic grades.
- Only the 25% Nickel grades have similar CSCC resistance.

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STRESS CORROSION CRACKING RESISTANCE vs TEMPERATURE and Cl-



35

Mechanical Properties

- Duplex Stainless Steels have roughly **twice the yield strength** of their counterpart austenitic grades.
- This allows equipment designers to use thinner gauge material for vessel construction!

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Room Temperature Strength

Grade	Min Tensile(KSI)	Min Yield(KSI)	%Elong.
2304	87	58	25
2205	95	65	25
2507	116	80	15
255	110	80	15
304	70	25	40
316L	70	25	40
317LMN	80	35	40
6Mo	94	43	35

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ASME (allowable stress in KSI)

Grade	@100F	200F	300F	400F	500F	600F
2304	24.9	24.0	22.5	21.7	21.3	21.0
2205	25.7	25.7	24.8	23.9	23.3	23.1
2507	33.1	33.0	31.2	30.1	29.6	29.4
255	31.4	31.3	29.5	28.6	28.2	--
316/316L	20.0	17.3	15.6	14.3	13.3	12.6
316L	16.7	14.2	12.7	11.7	10.9	10.4
317LMN	20.5	18.9	16.7	15.6	15.1	--
6Mo	24.9	23.2	21.3	19.8	18.3	17.3

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Hardness

- High hardness provides better wear resistance in abrasive environments.

Grade	Max. Hardness (BHN)
304L	215
316L	217
317L	217
317LMN	223
904L	220
6Mo	240
2304	290
2205	293
255	302
2507	310

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Thermal Expansion ($^{\circ}\text{F}\times 10$)

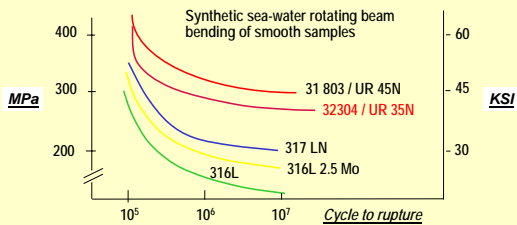
Grade	@212F	392F	572F	754F	932F
C- Steel	6.70	7.22	--	7.78	--
2304	7.22	7.50	7.78	8.06	8.33
2205	7.22	7.50	7.78	8.06	8.33
2507	7.22	7.50	7.78	8.06	8.33
255	6.72	7.00	7.22	7.39	7.56
304L	9.10	9.40	9.60	9.80	10.00 ₄₃

Heat Transfer

- Provides a **5% advantage** compared to austenitic grades.
- This advantage is increased when design strength is used to decrease wall thickness!

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FATIGUE - CORROSION RESISTANCE



Fatigue and fatigue corrosion resistance of stainless steels are enhanced by the use of duplex grades (higher mechanical properties, chromium content and duplex microstructure)

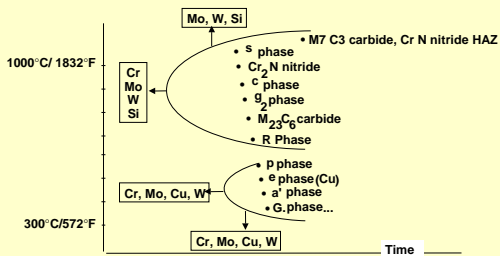
45

Fracture Toughness

- Due to the high ferrite content the Duplex SS have a ductile – brittle transition temperature of -50°F.
- This restricts the **minimum operating temperature to -50°F.**
- In certain circumstances the Duplex SS may be used down to -100°F.

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TYPICAL PRECIPITATIONS



Possible precipitations in super duplex stainless steels
2304 ~8 hours for significant sigma vs. 2205 ~1 hour

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Fabrication

Fabrication with the 2304 will be different but no more difficult than with the austenitic grades.

48

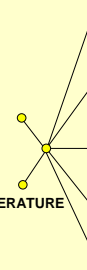
Welding

- Welding procedures must be developed to achieve acceptable corrosion resistance and mechanical properties/toughness in the weld zone.
- Welding of Duplex SS is not difficult. It is just *different!*
- *2304 is welder friendly!*

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WHAT ABOUT WELDED STRUCTURES ?

WE NEED

- CORROSION RESISTANCE
 - TOUGHNESS AT LOW TEMPERATURE
- 
- CONTROL OF FERRITE
Not required for 2304 when using fully austenitic 309L filler metal
 - CONTROL OF OXYGEN CONTENT
SAW with appropriate flux basicity
 - CONTROL OF HYDROGEN CONTENT
Degassing of welding consummables...
No hydrogen in shielding gas
 - CONTROL OF NITROGEN LEVEL
Not required for 2304 when using 309L filler metal
 - CONTROL OF THERMAL CYCLE
Thermal stability minimizes potential for sigma phase from slow cooling

50

Weld Procedure Pre-qualification

- A data base program to pre-evaluate weld procedures for Duplex SS is available.
- The program can be used to predict structural, corrosion resistance and mechanical characteristics of the weld zone (HAZ and weld deposit).

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Standard Specifications

Grade	ASTM	ASME	(Sect VIII Div I)
2304(S32304)	A240	SA240	yes
2205(S31803)	A240	SA240	yes
2205(S32205)	A240	--	no
255 (S32550)	A240	SA240	yes
2507(S32750)	A240	SA789/790	tube/pipe only

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Cost Comparison

Cost ratio based on 304L=1.0 (pattern mill plate)

Duplex	Austenitic
• 2304=1.05	304L=1.00
• 2205=1.45	316L=1.45
• 255=2.15	317L=1.90
• 2507=2.20	317LMN=2.40
• 904L=3.20	
• 6Mo=3.40-4.30	
• C-family=10.80-11.60	

USS - US Market Mill Direct Prices

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2205 - 2304 DUPLEX COST SAVINGS

If you save weight (wall thickness reductions) :

- You reduce the amount of material needed for the project
- You reduce the labor costs (weldings of thinner plates)
- You reduce transportation costs
- You reduce erection costs
- You reduce structural costs (concrete...)



THINK ABOUT TOTAL COSTS



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What 2304 Means!

- An *excellent* engineering material!
- A *very* cost effective material!
- Comparable to 304/316 in corrosion resistance – with improved CSCC.
- Twice the yield strength of 304/316.
- Advantageous physical properties.
- Covered by standard specifications.
- Advantages with both material cost and engineered fabrication cost.

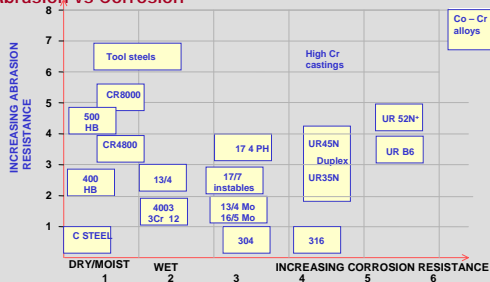
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The use of 2304 to replace 304L and 316L in many designs can offer cost savings and provide improved performance.

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GENERAL BEHAVIOUR OF MATERIALS

Abrasion vs Corrosion



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Other equipment / materials to help minimize maintenance costs

- special C-Mn steels, specifically melted and mill-guaranteed, for HIC resistance in H₂S-containing environments
 - *minimizing Hydrogen Induced Cracking phenomena*
- special Cr-Mo materials for resistance to disbonding of clad overlays in hydrogen-containing atmospheres
 - *Vanadium alloyed 2.25Cr-1Mo steels with enhanced resistance*
- special 5Cr-0.5Mo steel plate material for sulfur containing process fluids
 - *parts of upgraders / refineries - also heaters, boilers (API RP 571)*
- special creep resistant 9%Cr steels for ultra-hot steam piping (up to 600°C)
 - *e.g. for power plants, but also boilers etc... with sulfur content*
- special 2205 duplex stainless steel grades for low temperature conditions
 - *high strength, inherent corrosion resistance, and advanced metallurgy for base material and weld toughness guarantees down to -60°C*

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Other equipment / materials to help minimize maintenance costs

**What are your problems ?
What kind of a steel material would you like to have ?**

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