Industeel

ArcelorMittal

Mecasteel: the new steel solution for oil and gas mechanical parts applications

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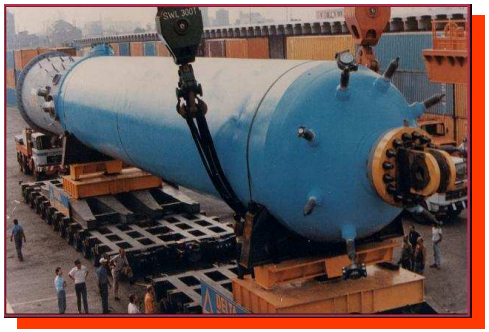
Introduction

INDUSTEEL, which belongs to ArcelorMittal group, is a specialist for both pressure vessel steels for energy markets (oil & gas, refineries, nuclear ….) and pre-hardened thick blocks with improved properties.



Hydro-processing reactor Cr-Mo steel - Plate thickness = 8.3'' (210 mm)

Pre-hardened thick block up to 37.4'' thick (950 mm)

In 2008, Industeel booked 94 KT for the oil & gas industries's big projects (new refineries, existing refinery revamping…)

Main grades: F22, F11, CrMo(V), CMn HIC…

End Users: BP, Shell, Total, Exxon Mobil, Chevron…

Industeel is member of:

- API (American Petroleum Institute)

- MPC (Material Properties Council)

- NACE

Industeel is certified:

- ISO 9001

- ASME Section 3 QSC

What is Mecasteel?

- Mecasteel, developed by Industeel, is a concept of patented **pre-hardened** grades with improved properties compared to standard AISI 4130 / 4140
  - *High homogeneity through the thickness up to 37.4”*
  - *High soundness quality*
  - *Good machinability*
  - *Good weldability*
  - *Delivered with tests certificates*

- These properties are due to the combination of
  - *Adapted chemical analysis*
  - *Unique fabrication process combining forging and rolling*

Why Mecasteel?

Current solution: AISI 4130

- Delivered in softened condition

➔ obligatory thermal treatment to obtain in-service required hardness

- Delivery times for forged material can be long → stock of prefabricated parts

Mecasteel is already delivered prehardened

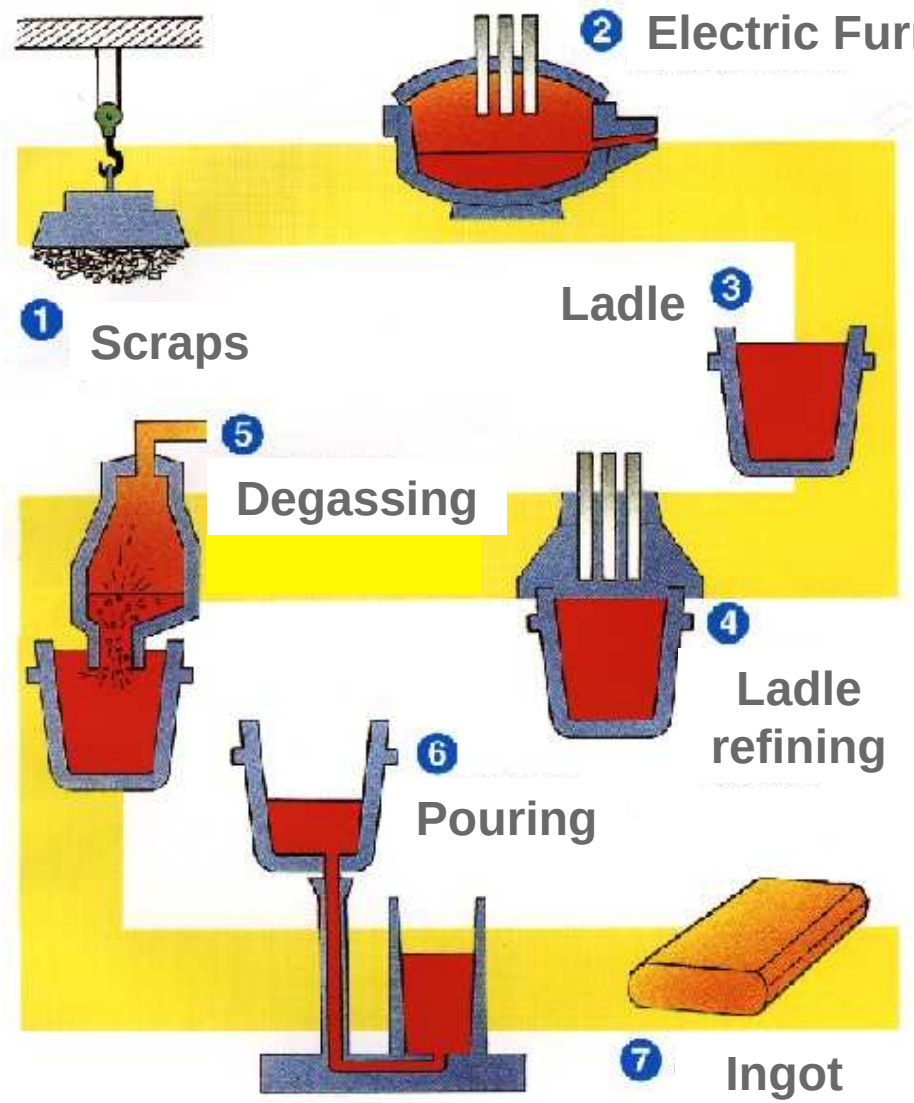
- Machinability is easily feasible
- Hardness is homogeneous through thickness
- No need of further thermal treatment ➔ money and time savings
- Stock of master blocks ready to cut. Short delivery time from Steel Service Centers

Mecasteel range of solutions

- Mecasteel 75:
  - Normalized / Quenched / Tempered
  - 75 KSI minimum Yield Strength guaranteed
  - Charpy V: 15 ft-lbs mini / 20 ft-lbs av. guaranteed down to -75°F (on QTC according to API 16A)
  - In accordance with NACE specifications (MR01-75)
- Mecasteel 90:
  - Quenched / Tempered
  - 90 KSI minimum Yield Strength guaranteed
  - Charpy V: 21 ft-lbs mini / 28 ft-lbs av. guaranteed down to -40°F (on QTC according to API 6A)

A full range of products to answer all requests in term of hardness level

Mecasteel steel making process



Electric furnace

- *Rigorous scraps selection → High Quality → Low Impurities*
- *Removal of Phosphorus (<0,007%)*
- *Ultra low carbon liquid steel*

Heated Ladle Refining

- *Removal of sulfur (<0,002%)*
- *Chemical balance of alloying elements (C,Mo,Cr,Ni…*

Special degassing unit

- *RH type, new investment and*
- *Low Hydrogen content < 1 ppm*

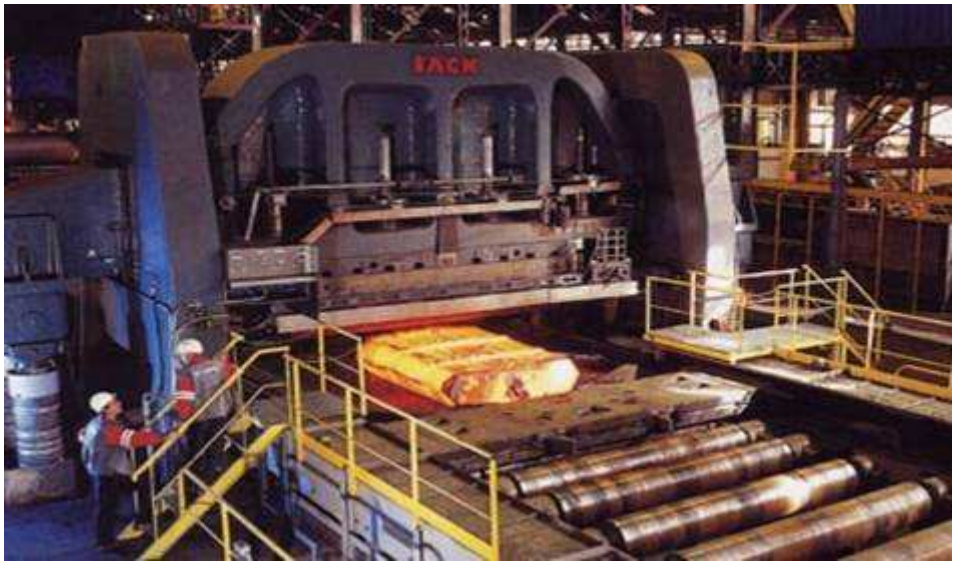
Ingot casting

- *Bottom-poured heavy ingots up to 130T*
- *Inverse mold for improved homogeneity*

Mecasteel block making process

The superposition of both Forging and Rolling allows to give guarantees in :

- ***Soundness / Compactness***
- ***Isotropy***
- ***Regularity of thickness***
- ***Flatness***
- ***Dimension (up to 80” width)***



12600 T press

175’’ wide rolling mill

Industeel experience

Forging + Rolling process is already used for fabrication of thick tube sheets (up to more 24”), with very **stringent specifications**

. Petrochemical Industry

. Nuclear Industry

17.7” thick ¼ tube sheet (>315” diameter) Oil and gas applications

Chemical Analysis

Comparison with AISI 4130

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Typical chemical analyses and hardness

	C	Si	Mn	Cr	Ni	Mo	S	Other	Hardness (HB)
4130 / 30CD4	0.3	0.25	0.8	1.0	<0.5	0.2			
Mecasteel 75	**0.25**	**0.1**	**1.4**	**1.4**	**<0.5**	**0.5**	**<0.007**	**25 ppm B**	**210**
Mecasteel 90	**0.25**	**0.1**	**1.4**	**1.4**	**<0.5**	**0.5**	**<0.020**	**25 ppm B**	**260**

- **Lower C content**
  - → Less detrimental segregations; improved weldability
- **Boron addition with Nitrogen control**
  - → Improved hardenability
  - → Possibility to produce homogeneous thick block up to 37.4”
- **Using of Molybdenum**
  - → Bainitic microstructure through the whole thickness
  - → Improved homogeneity of properties through the thickness (no martensite)
- **Low residual elements**
  - → P < 0.012%

Guaranteed mechanical properties

	Hardness (HB)	Y.S. 0.2 (KSI)	UTS (KSI)	El (%)	Reduction of Area (%)
Mecasteel 75	237 HB max	75 min	95	18	35
Mecasteel 90	235 HB min.	90 min	110	15	30

	Temperature	Longitudinal		Transverse	
		Min. value ft-lb (J)	Av. Value ft-lb (J)	Min. value ft-lb (J)	Av. Value ft-lb (J)
Mecasteel 75	0°F	15 (20)	20 (27)	10 (14)	15 (20)
	-20°F				
	-75°F				
Mecasteel 90	0°F	21 (28)	31 (42)	15 (20)	20 (27)
	-40°F				

Hardenability through thickness

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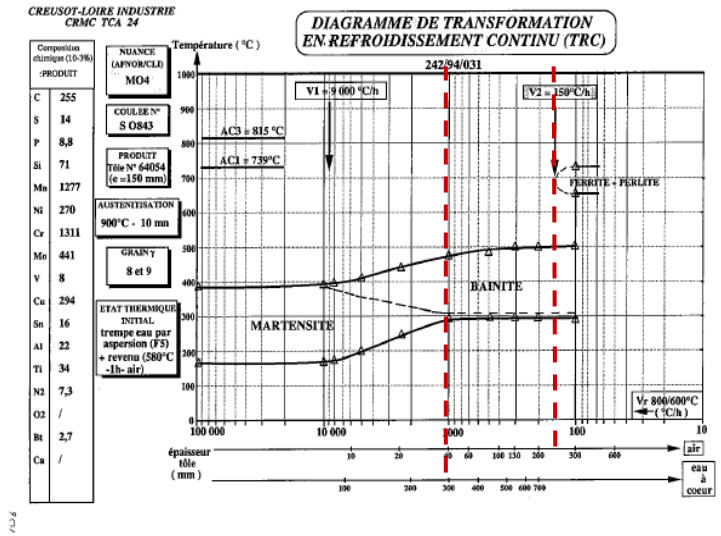
CCT diagram of Mecasteel 90

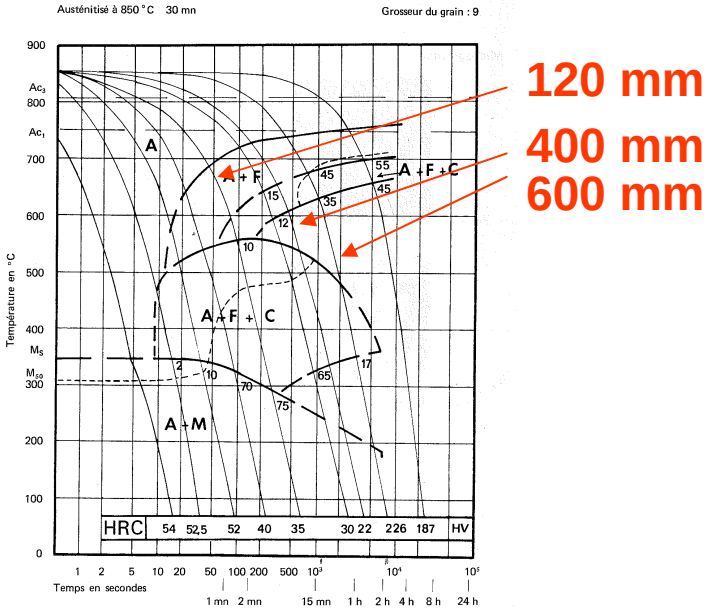


Full bainitic microstructure after air quenching (< 11.8” thick) and after water quenching (11.8”/39.3”)

→ **Microstructure homogeneity through the thickness**

→ **Can be supplied pre-hardened (no further heat treatment after machining)**

CCT diagram of AISI 4130 / 30CrMo4



➢ Impossibility to achieve homogeneous microstructures and properties through thickness of big blocks

➢ Heat treatment has to be done after rough machining

Hardenability through thickness

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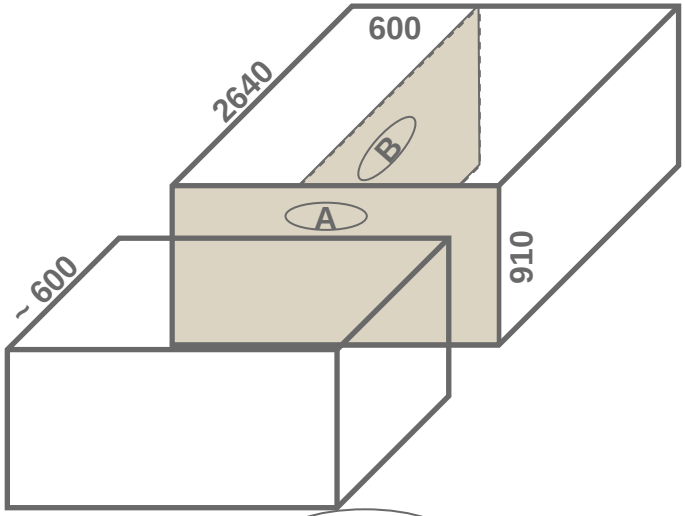
Hardness homogeneity through a 910mm thick block prehardened to 300 HB



A B

	A					B		
50 mm	294	301	305	304	294	303	310	290
¼ t	291	302	301	300	290	300	304	294
½ t	299	301	303	304	300	298	301	309
¼ t	294	300	304	298	294	304	305	300
50 mm	313	313	309	314	306	304	305	296

Hardenability through thickness

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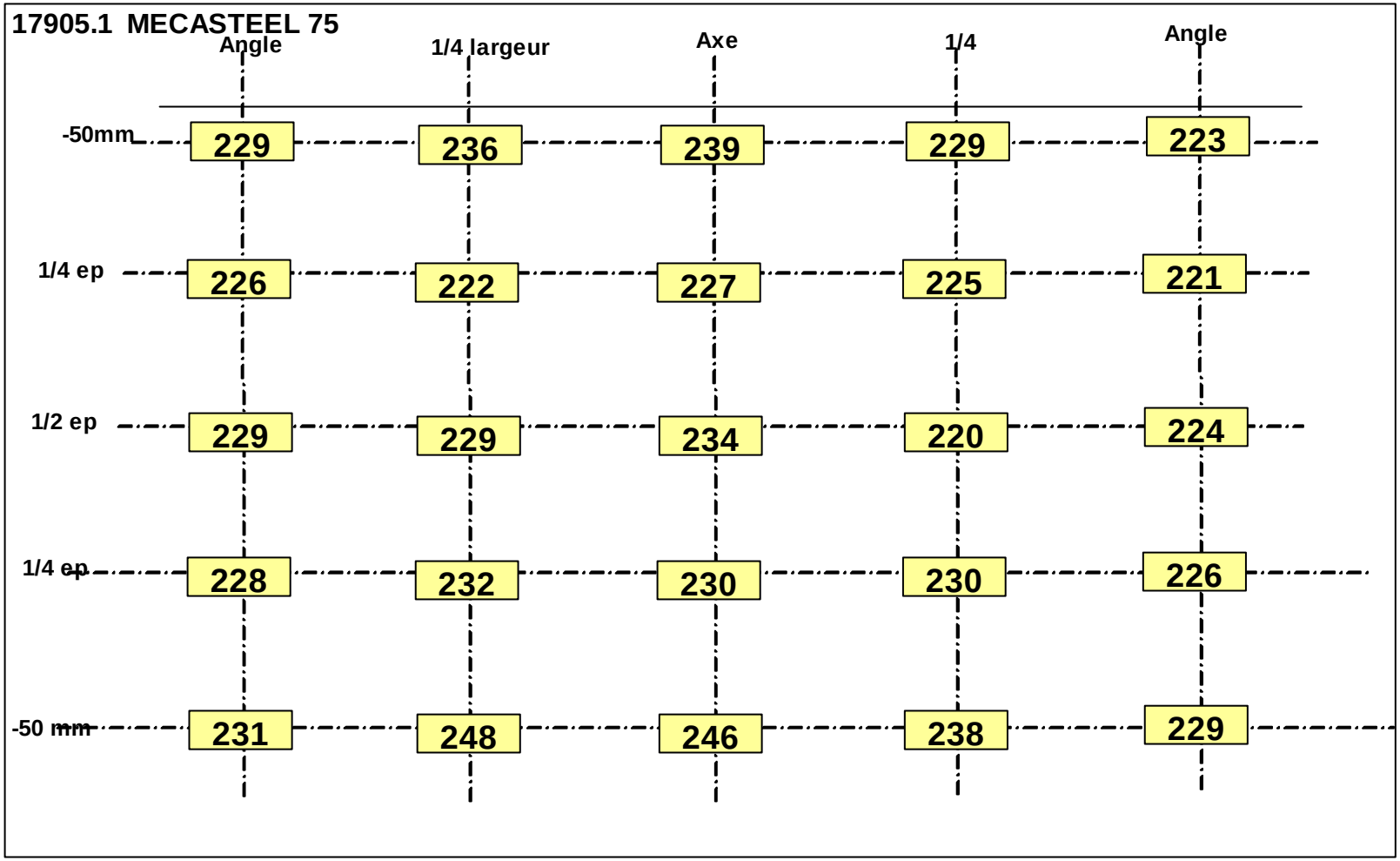
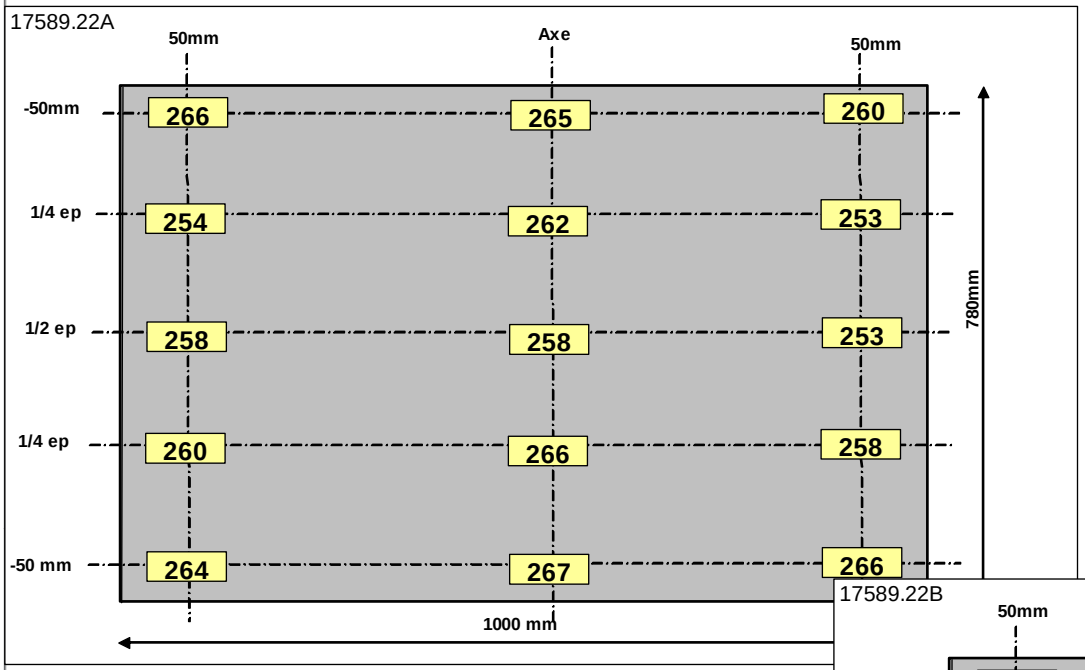
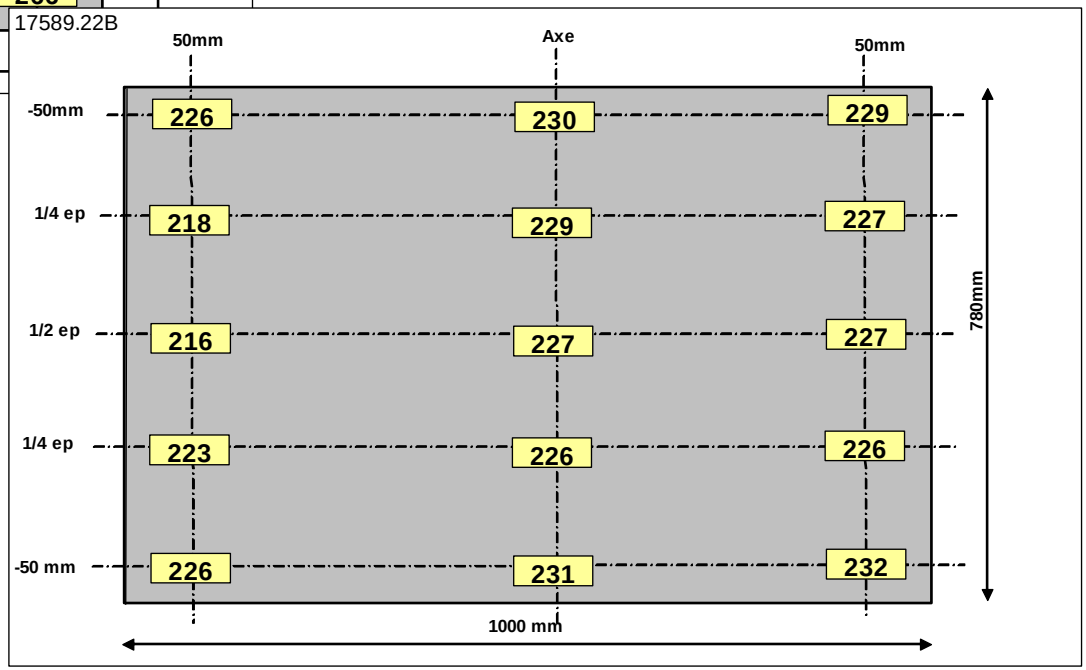
Hardness homogeneity through a 950mm thick block Mecasteel 75 (237 HB max)



Hardenability through thickness



t = 780 mm (30.7")
Mecasteel 90
YS > 90 KSI
235 HB min



t = 780 mm (30.7")
Mecasteel 75
YS > 75 KSI
237 HB max.

Hardenability through thickness

Mecasteel 90 (YS > 90 KSI)

17589-22A t= 780 mm - ¼ width		YS (0.2) MPa (KSI)	UTS MPa (KSI)	Elong. %	Red. of Area %
Length direction	**Skin** **(- 50 mm / 2")**	655 (95.0)	801 (116.2)	23	66
	¼ thickn.	642 (93.1)	793 (115.0)	24	63
	½ thickn.	655 (95.0)	810 (117.5)	18	43
Transv. direction	**Skin** **(- 50 mm / 2")**	680 (98.6)	823 (119.4)	22	64
	¼ thickn.	654 (94.9)	801 (116.2)	18	46
	½ thickn.	655 (95.0)	803 (116.5)	19	50

Mecasteel 75 (YS > 75 KSI)

17589-22B t= 780 mm - ¼ width		YS (0.2) MPa (KSI)	UTS MPa (KSI)	Elong. %	Red. of Area %
Length direction	**Skin** **(- 50 mm / 2")**	552 (80.1)	714 (103.6)	26	68
	¼ thickn.	530 (76.9)	699 (101.4)	24	62
	½ thickn.	535 (77.6)	707 (102.5)	24	65
Transv. direction	**Skin** **(- 50 mm / 2")**	550 (79.8)	709 (102.8)	26	65
	¼ thickn.	533 (77.3)	698 (101.2)	24	58
	½ thickn.	540 (78.3)	710 (103.0)	25	63

Toughness Properties

➢On solid blocks t=780 mm

Mecasteel 90 (YS > 90 KSI)

17589-22A - ¼ width		Average of 3 specimens J (ft.lb)		
		0°C / 32F	**-20°C / -4F**	**-40°C / -40F**
Length direction	**Skin (- 50 mm / 2")**	109 (80)	78 (58)	76 (56)
	¼ thickn.	58 (43)	40 (30)	25 (18)
	½ thickn.	35 (26)	28 (18)	27 (20)
Transv. direction	**Skin (- 50 mm / 2")**	64 (47)	46 (34)	38 (28)
	¼ thickn.	38 (28)	36 (27)	24 (18)
	½ thickn.	40 (29)	26 (19)	27 (20)

Mecasteel 75 (YS > 75 KSI)

17589-22B - ¼ width		Average of 3 specimens J (ft.lb)		
		0°C / 32F	**-20°C / -4F**	**-40°C / -40F**
Length direction	**Skin (- 50 mm / 2")**		74 (55)	45 (33)
	¼ thickn.		42 (31)	25 (18)
	½ thickn.		31 (23)	15 (11)
Transv. direction	**Skin (- 50 mm / 2")**		49 (36)	32 (24)
	¼ thickn.		29 (21)	18 (13)
	½ thickn.		38 (28)	14 (10)

➢On solid blocks t=950 mm

Mecasteel 75 (YS > 75 KSI)

17605 - ½ width		Average of 3 specimens J (ft.lb)		
		0°C / 32F	**-20°C / -4F**	**-40°C / -40F**
Length direction	**Skin**	117 (86)	84 (62)	64 (47)
	¼ thickn.	45 (33)	35 (26)	26 (19)
	½ thickn.	27 (20)	17 (13)	10 (7)

Toughness Properties

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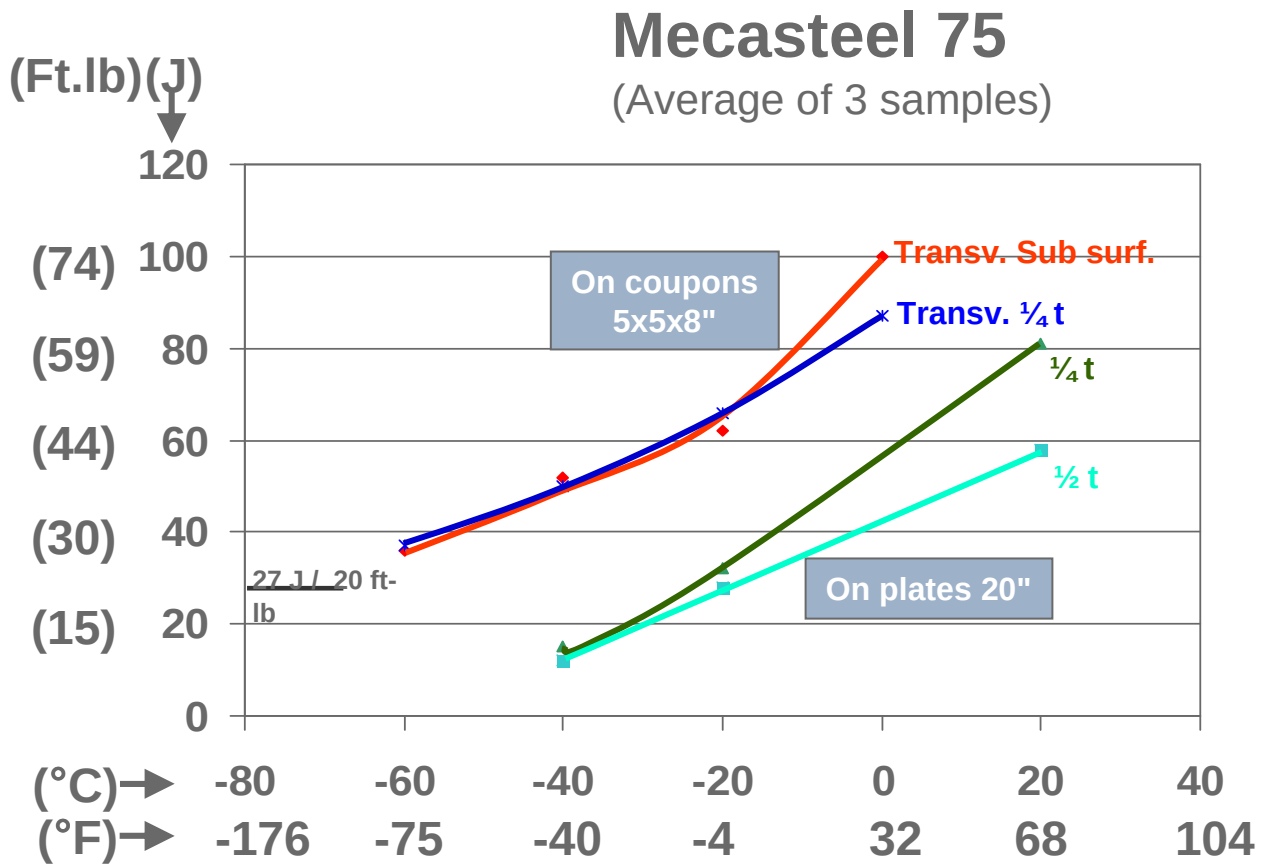
➢On QTC



Typical Mechanical Properties

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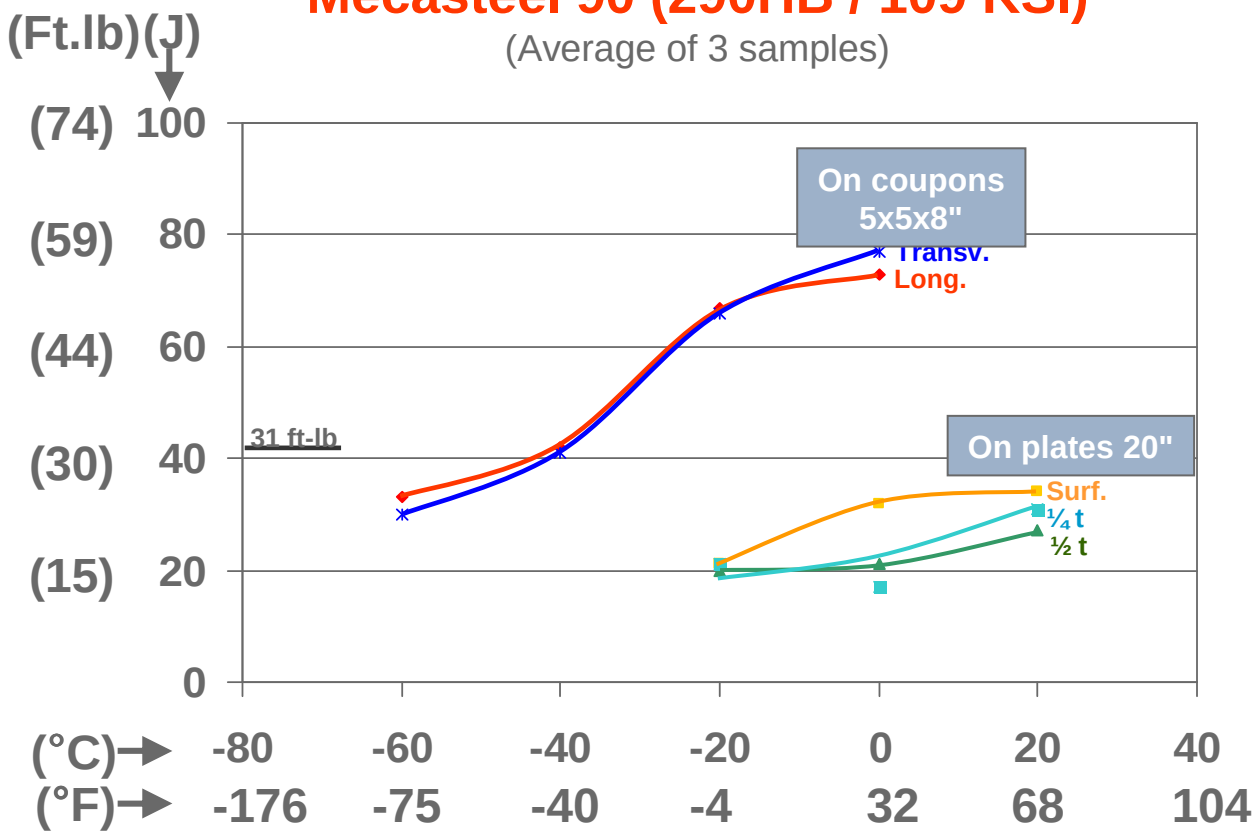
➢ On QTC

Mecasteel 90 (290HB / 109 KSI)

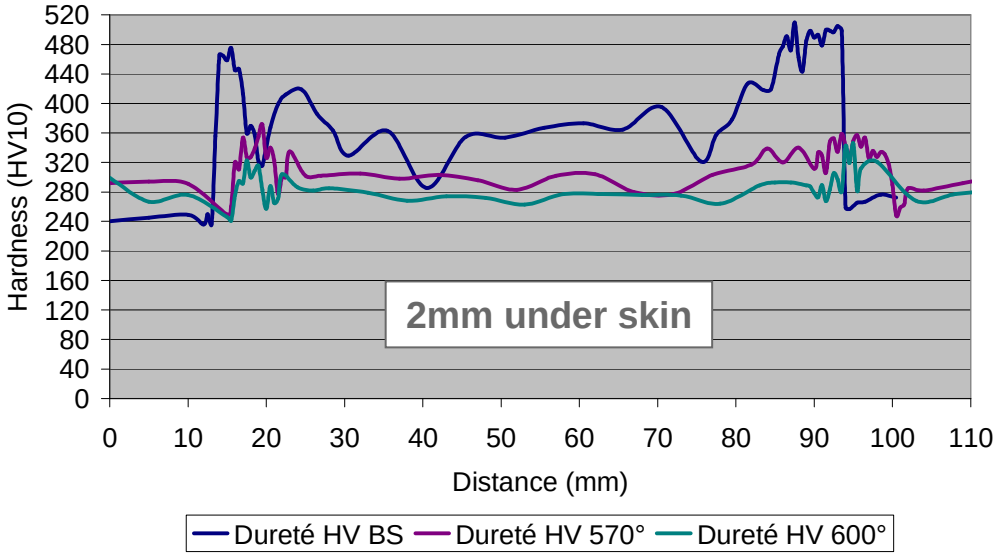
(Average of 3 samples)

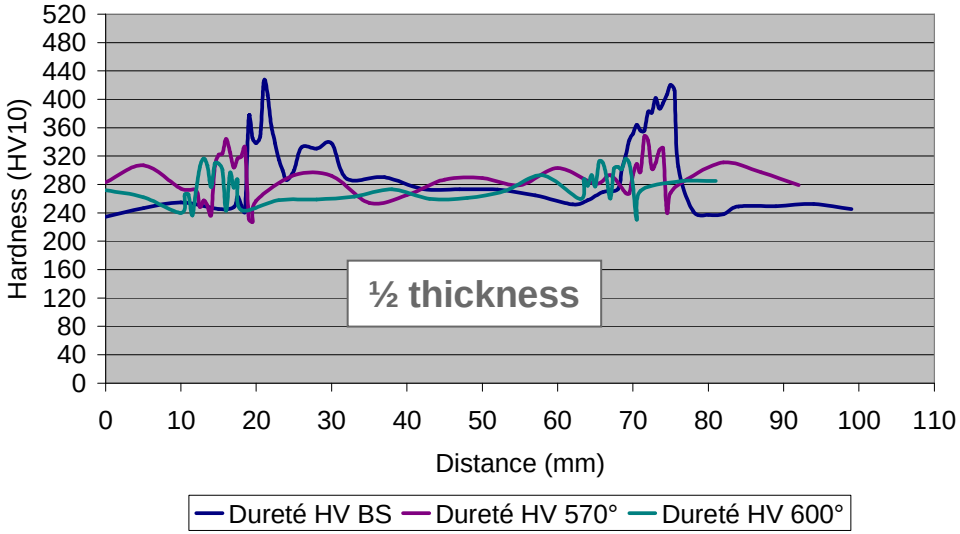


Weldability Mecasteel 90

80 mm (3.25’’) thick welded joint
Welding process: GMAW
Welding consummable: 25CrMo4 (4120)
Heat input: 1.5-2kJ/mm
Preheating: 140℃ (284℉)

Weldability Mecasteel 90





Hardness profiles
As welded and after PWHT
570℃ or 600℃ 2h

Weldability Mecasteel 90

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Tensile test results on MECASTEEL 90 Weld

PWHT	Sampling	YS MPa	YS ksi	UTS MPa	UTS ksi	El%	Rupture
570℃ - 2h	Base Material	780	113.2	895	129.9	18	
	Weld Metal	740	107.4	865	125.5	13	
	Transverse			835	121.2	8	**Weld metal**
600℃ - 2h	Base Material	720	104.5	847	122.9	19	
	Weld Metal	657	95.4	786	114.1	13	
	Transverse			770	111.8	9	**Weld metal**

Charpy V test results on MECASTEEL 90 Welded joint

PWHT	Sampling	-20℃ Indiv(J)			Indiv (ft.lb)		
570℃ -2h	Weld Metal	41	42	45	30	31	33
	Fusion Line	53	54	60	39	40	44
	Fusion Line + 1mm	44	65	66	33	48	49
	Fusion Line + 3mm	42	60	71	31	44	53
	Base Material	48	54	56	36	40	41
600℃-2h	Weld Metal	39	42	50	29	31	37
	Fusion Line	45	51	57	33	38	42
	Fusion Line + 1mm	63	69	83	47	51	61
	Fusion Line + 3mm	53	62	69	39	46	51
	Base Material	63	69	72	47	51	53

Example of Mecasteel 90 application
New gear for rolling machine

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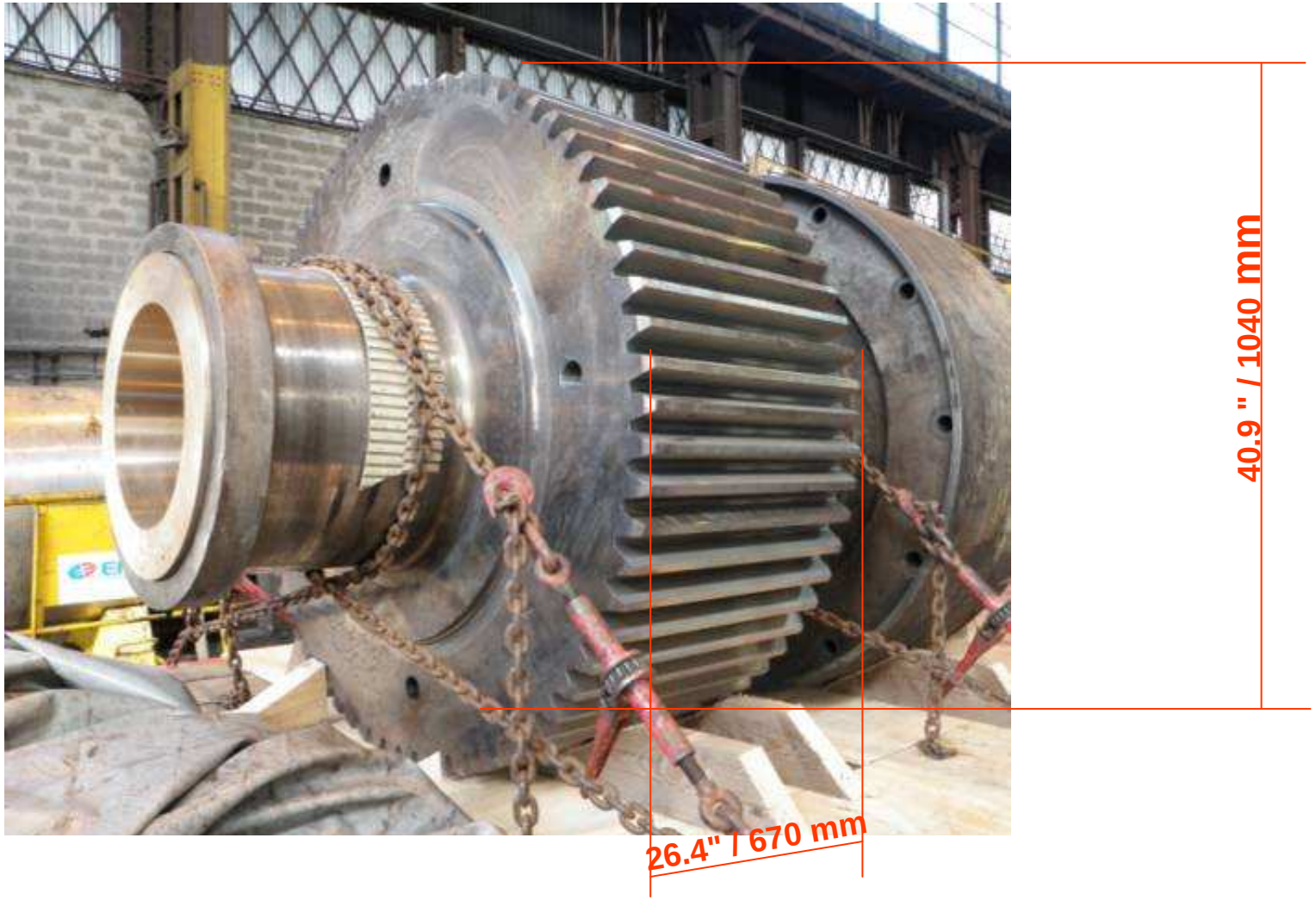

Example of Mecasteel 90 application
New gear for rolling machine

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Tensile test

	YS 0.2		UTS		EL	RA
	MPa	*ksi*	*MPa*	*ksi*	*%*	*%*
Spec.	**>510**	**> 74**	**735 / 883**	**107/128**	**> 16**	
50mm (2") under the skin	703	102	847	123	18	56
¼ thickness	723	105	857	125	23	65

Charpy V / long. direction

At 0°C (-4°F)	**Kv 1** *J (ft – lb)*	**Kv 2** *J (ft – lb)*	**Kv 3** *J (ft – lb)*	**Average** *J (ft – lb)*
50 mm (2") under the skin	73 (54)	72 (53)	58 (43)	68 (50)
¼ épaisseur	46 (34)	46 (34)	39 (29)	44 (32)

Example of Mecasteel 75 using: Repair of big press cylinder

Cylindrical part of the jack (AISI 4142)

New head made from a 28.3” thick Mecasteel 75 block

Example of Mecasteel 75 using: Repair of big press cylinder

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Material specification

YS > 550MPa (80ksi)
UTS : 750/900MPa (109/131 ksi)
Charpy V : 0℃ 20J indiv / 27J average (15/20 ft/ lb)

Results obtained after adapted tempering treatment

		Tensile			Charpy V (0℃)			
Prélèvement	Orientation	YS (MPa)	UTS (MPa)	El%	Indiv (J)			moy (J)
Spécification		>=550	750/900	>=15	>=20			>=27
1/4 Thickness	Transverse	649	789	16	44	40	36	40,0
	Through thickness	644	785	15	31	32	30	31,0
1/2 thickness	Transverse	643	778	15	36	38	36	36,7
	Through thickness	640	777	13	29	28	25	27,3

Very good homogeneity and isotropy of properties

Characterization of 22” thick Mecasteel 75 block

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Typical oil and gas specification for AISI 4130 forged pieces

Material Specification

Hardness: 200 – 235 BHN
Ultimate Tensile Strength UTS > 95ksi (655 MPa)
Yield strength YS > 75ksi (515 MPa)
Reduction of area Z > 35 %
Elongation A > 17 %
Charpy V impact tests

UT specification

Example: No indication equal or larger than the one done from a 1/8’’ flat bottom hole

Objective: prove that Mecasteel 75 fulfills this specification

Characterization of 22” thick Mecasteel 75 block

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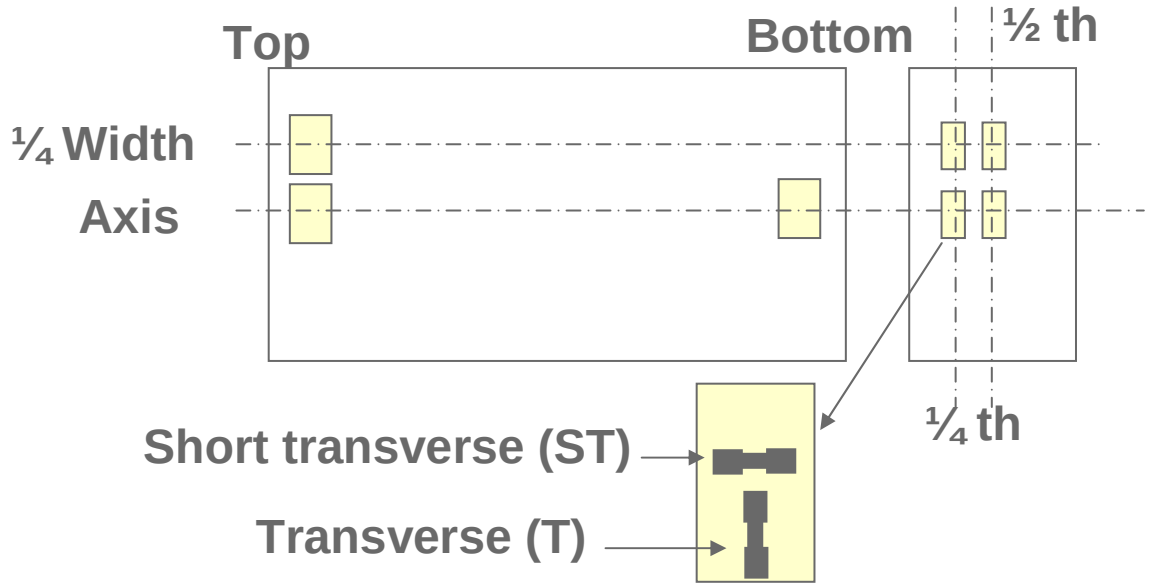
Mecasteel 75 – Specific thermal treatments

- Normalization (1670°F)
- Quenching (1634°F)
- Tempering (1220°F)

Obtained hardness **215/225 BHN**

Mechanical characteristics determined for different sampling locations



Characterization of 22” thick Mecasteel 75 block

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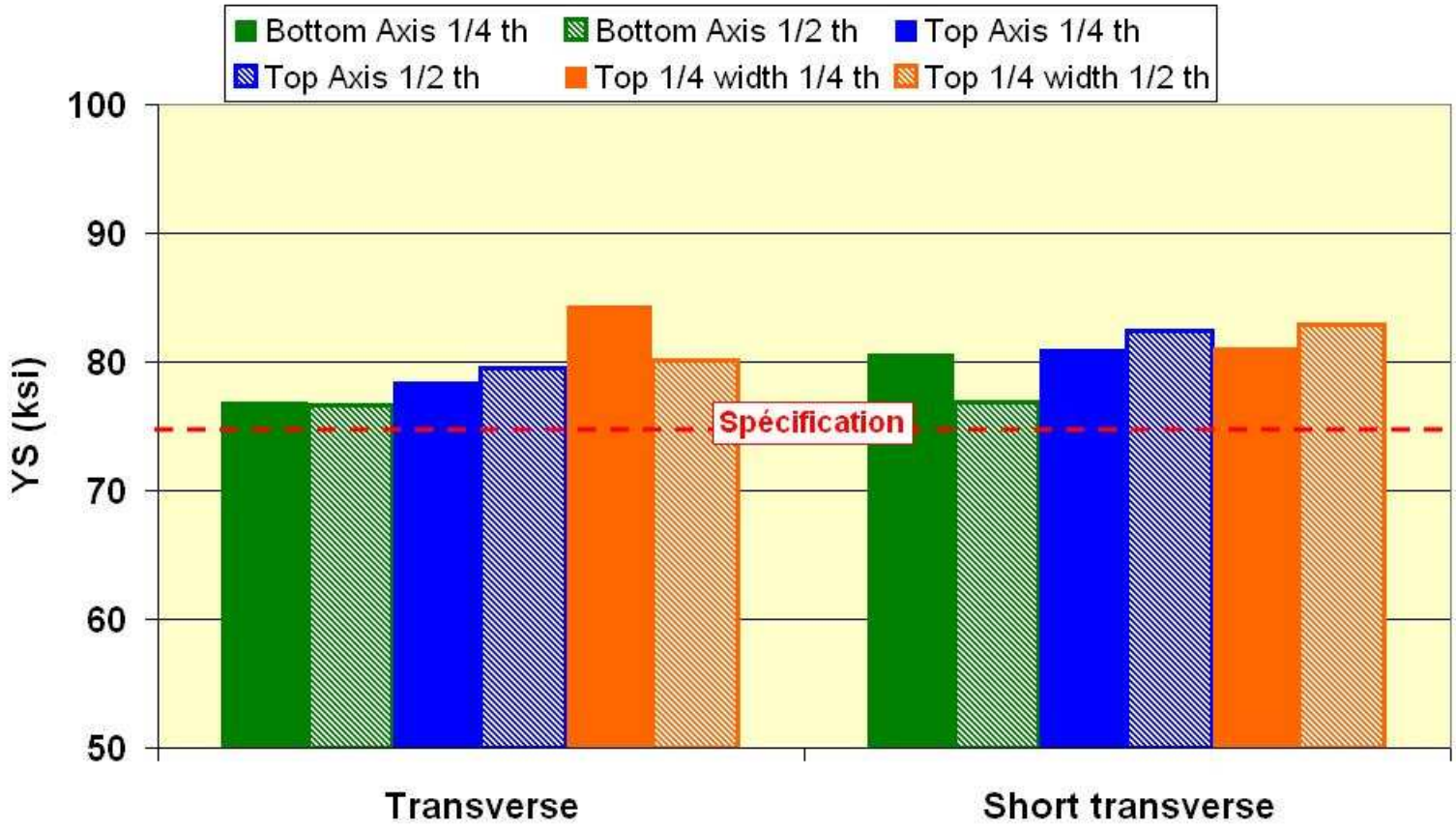
Tensile test results : Yield Strength



Characterization of 22” thick Mecasteel 75 block

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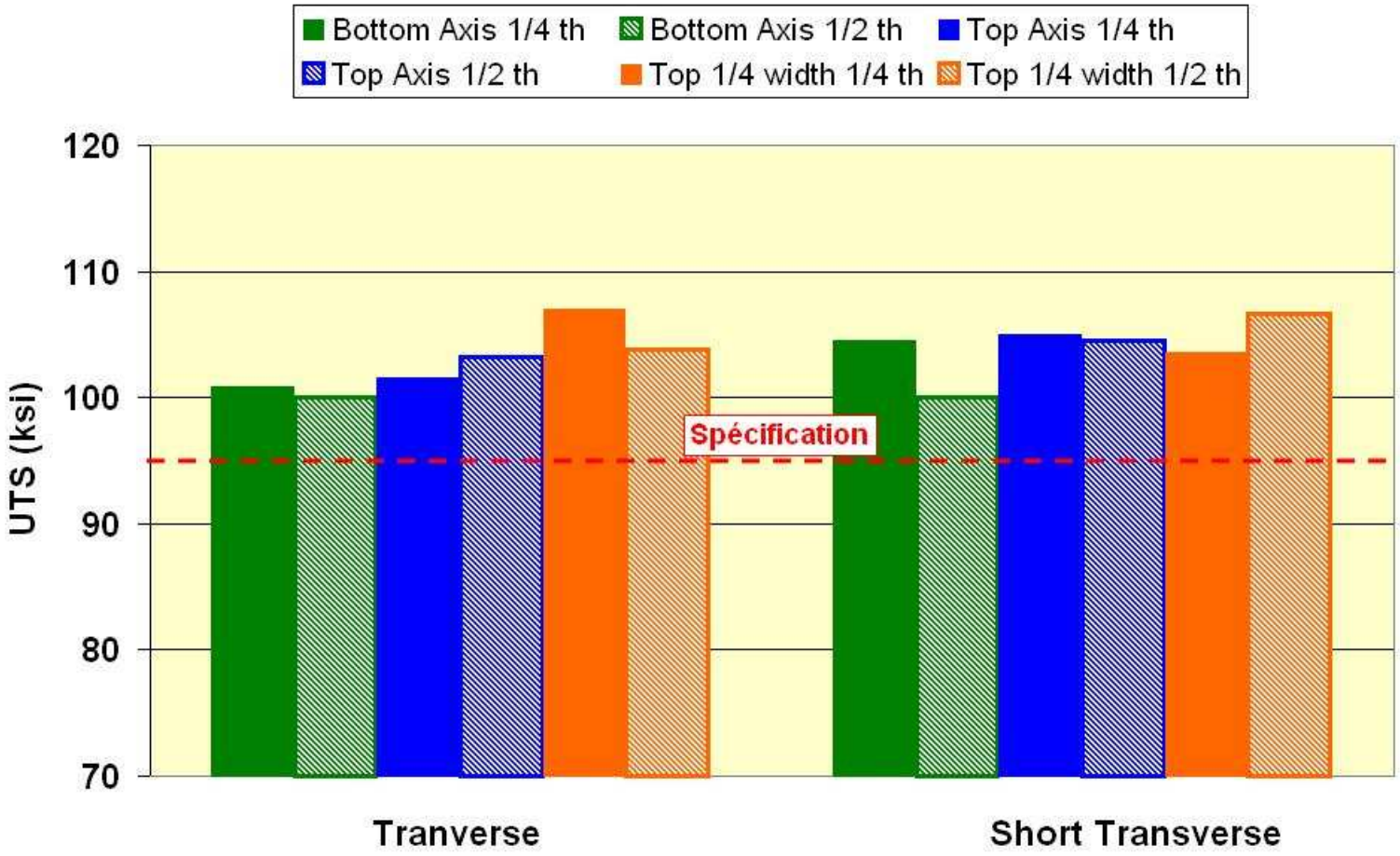
Tensile test results : Ultimate Tensile Strength



Characterization of 22” thick Mecasteel 75 block

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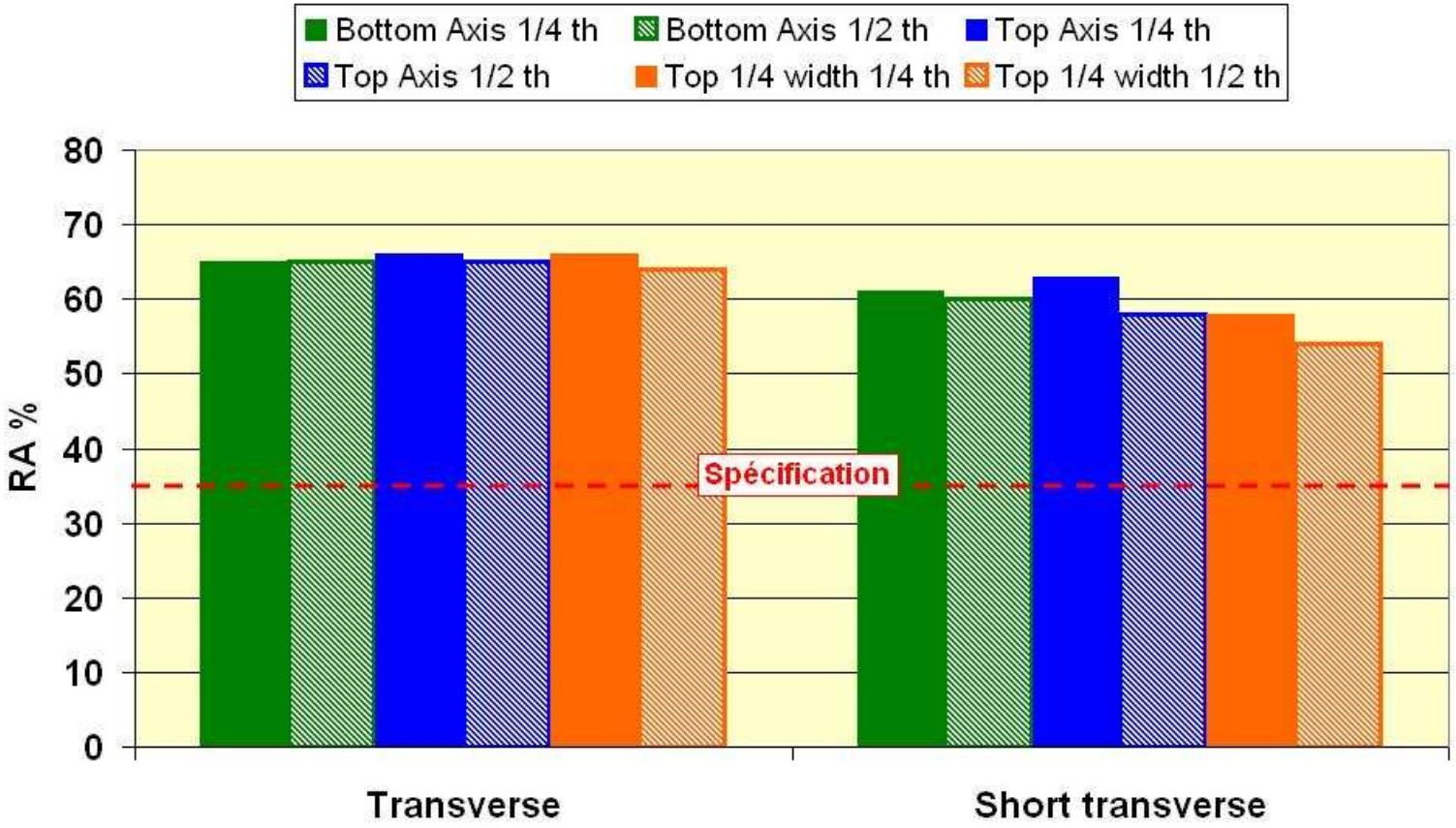
Tensile test results : Reduction of Area



Characterization of 22” thick Mecasteel 75 block

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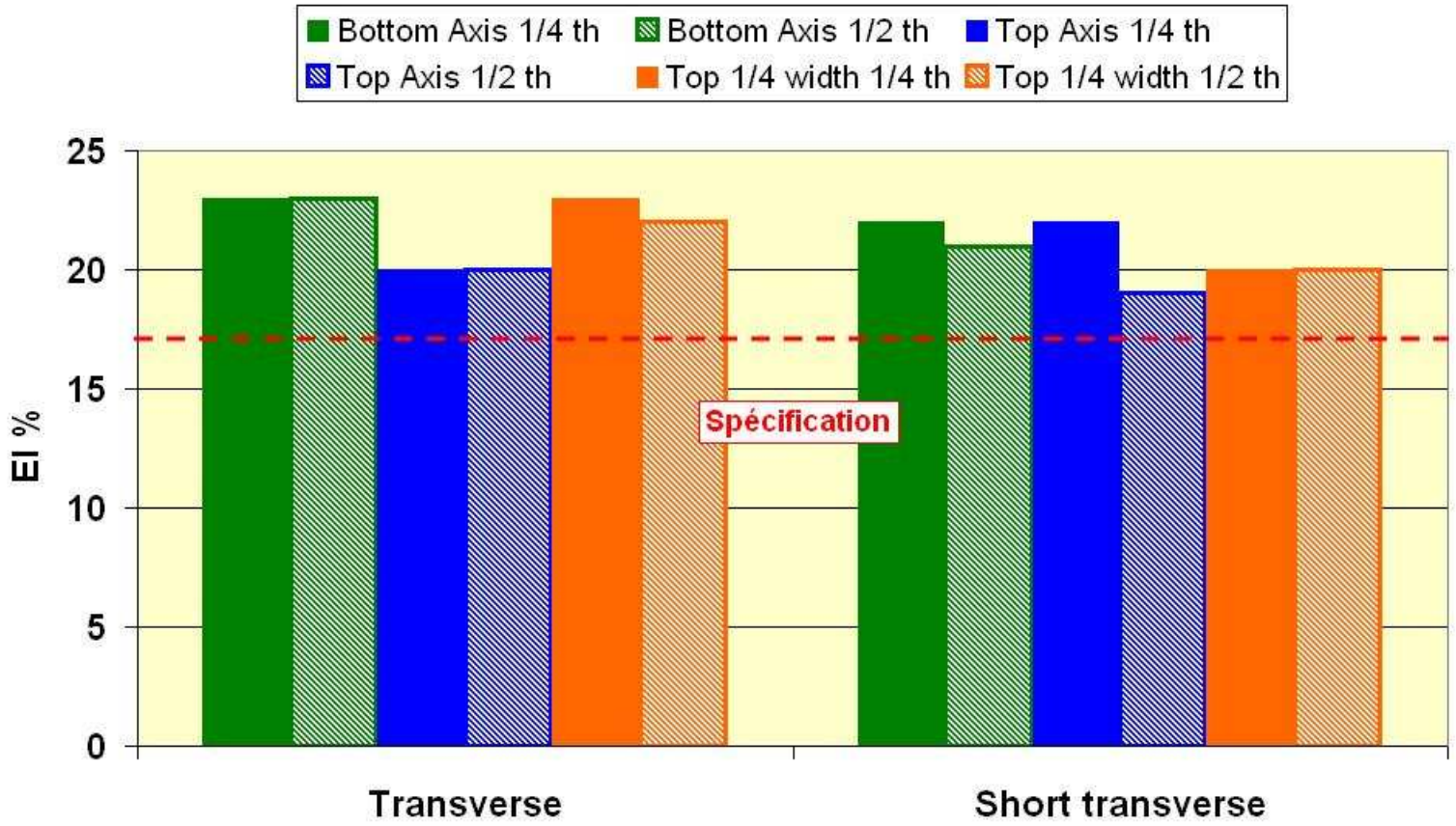
Tensile test results : Elongation



Characterization of 22” thick Mecasteel 75 block

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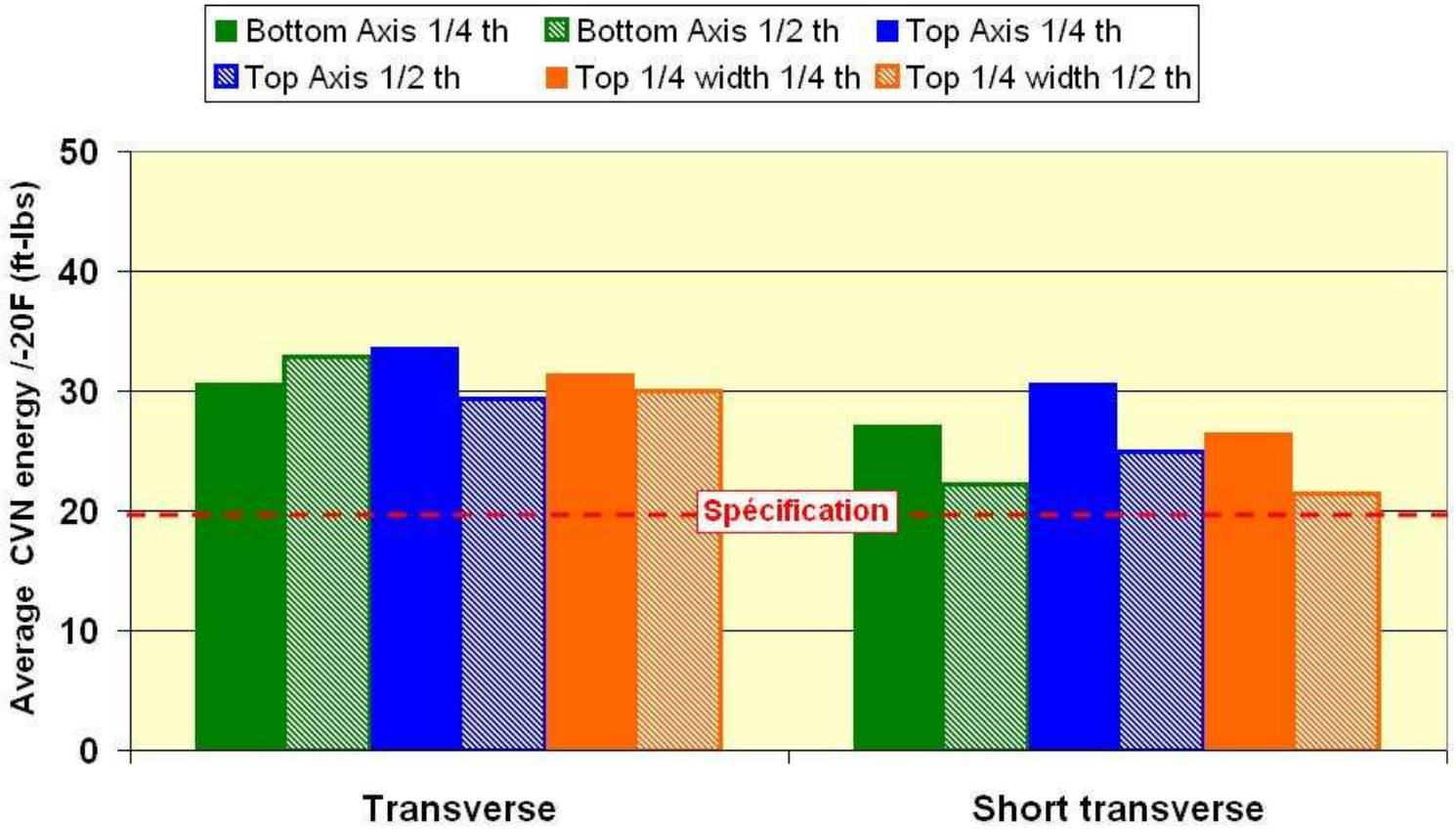
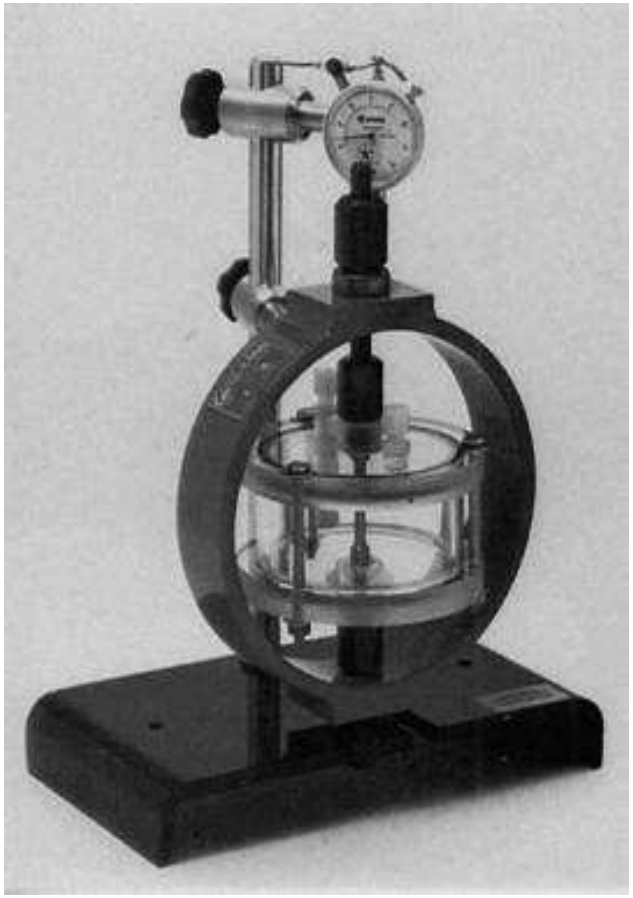
Charpy V – tests results



Characterization of 22” thick Mecasteel 75 block

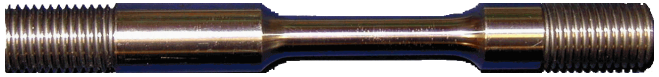
NACE tests:
Tests performed: SSC tests according to NACE TM01-77



Environment: NACl50g/l +CH3CCOH
PH 2.7
Continuous H2S bubbling

Test duration : Up to 720h (1month)

Objective:
Determination of maximum stress level which not give failure within one month



Test specimen

Characterization of 22” thick Mecasteel 75 block

NACE tests:
Tests performed: SSC tests according to NACE TM01-77

Sampling : *A: Top end ¼ width – ¼ th Transverse direc tion*
B: Bottom end ½ width – ¼ th Transverse direction

Stress (ksi)	%SMYS	Sampling	
		A	B
37.5	50	NF	NF
52.5	70	NF	NF
60	80	NF	NF
NF: No failure in 720h			

- **Threshold stress for failure > 80%SMYS**
- **Equivalent to results found for pressure vessel steels**

Conclusion

- Chemical composition and fabrication process of Mecasteel grades result in homogeneous and isotropic properties up to 37.4’’ thick
- Mecasteel grades are supplied in pre-hardened condition (no need for additional quality treatments)
- Mecasteel grades offer different levels of hardness to fulfill a maximum of requests
- Mecasteel grades’ tempering heat treatment can be adapted to fulfill specifications
- Mecasteel 75 is adapted for sour service
- Quick delivery time from American partner- BICO Steel Service Centers
- In addition to Mecasteel grades, Industeel can provide standard grades like F22 in short delivery times

Appendix 1

Data about ArcelorMittal - Industeel

ArcelorMittal
a leading position in the most attractive markets

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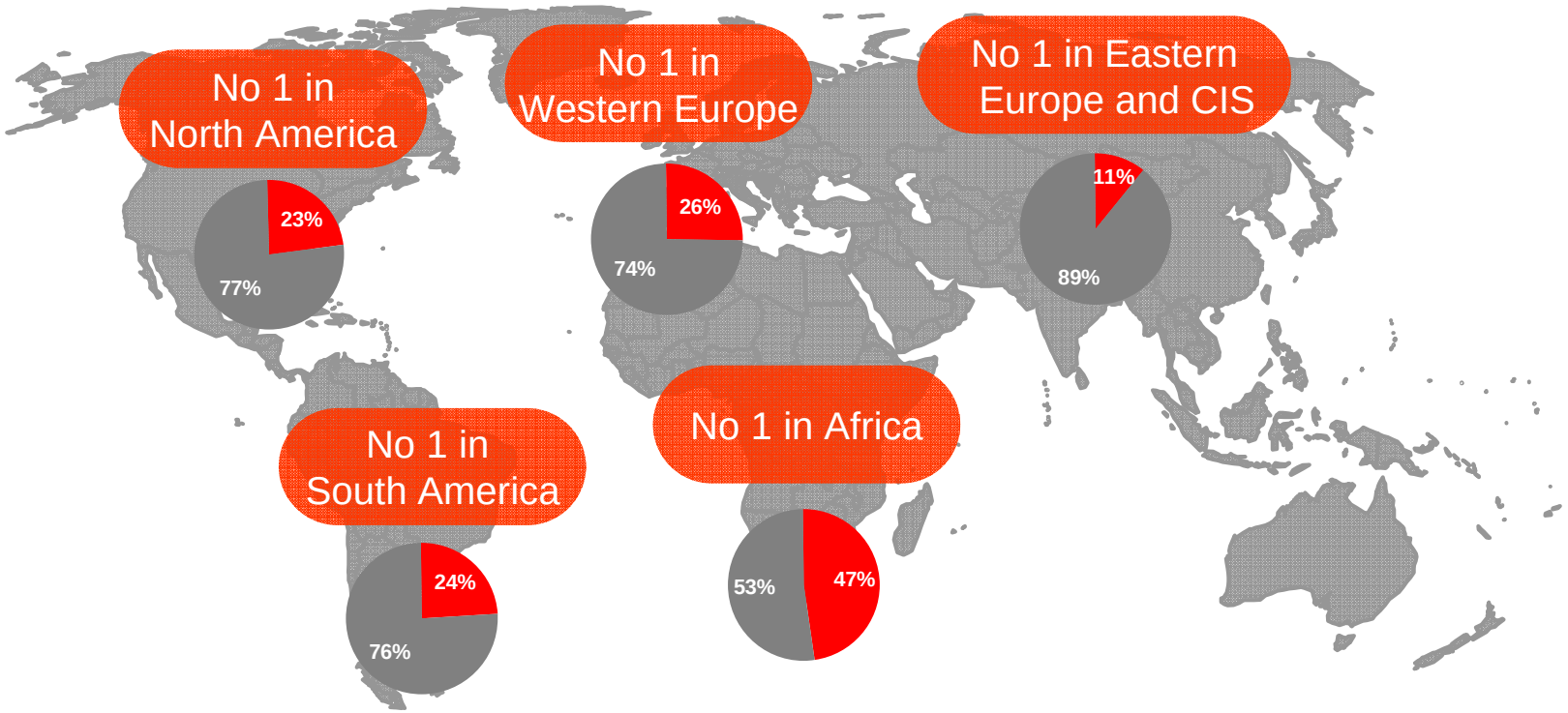
Market position and market share estimates by region*



Number 1 in 5 regions and 4 continents

*Source ArcelorMittal estimates based on IISI crude steel production

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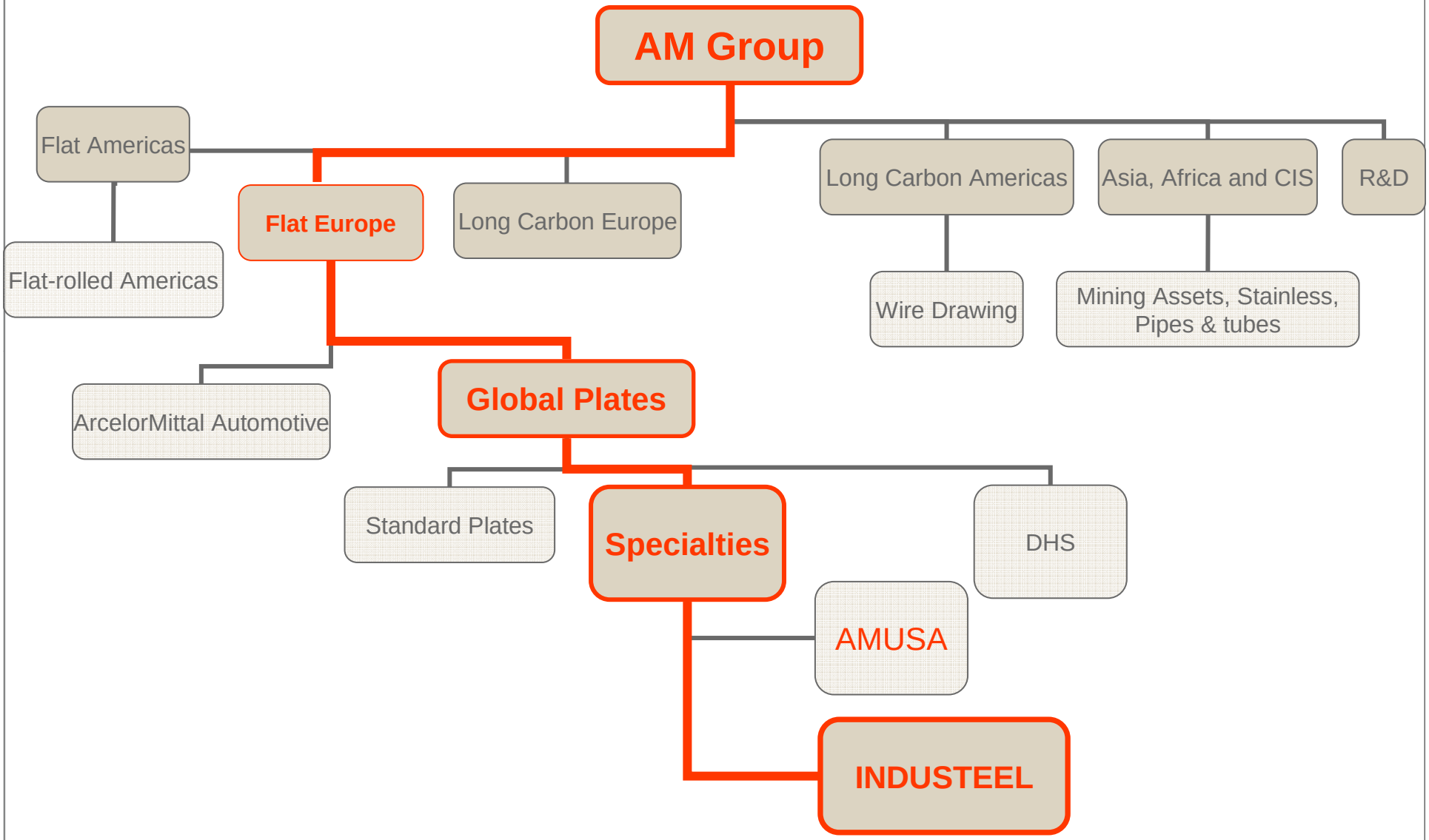
Others

ArcelorMittal Business Segments



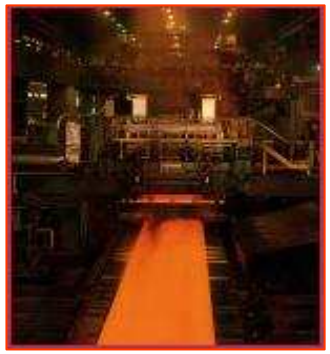
Industeel Production Sites

ArcelorMittal

3 STEEL SHOPS

3 Electric Arc Furnaces 80 to 200 t
Heated ladle refining under vacuum, VOD, VAD, RH
1 continuous caster
2 bottom poured ingot casters

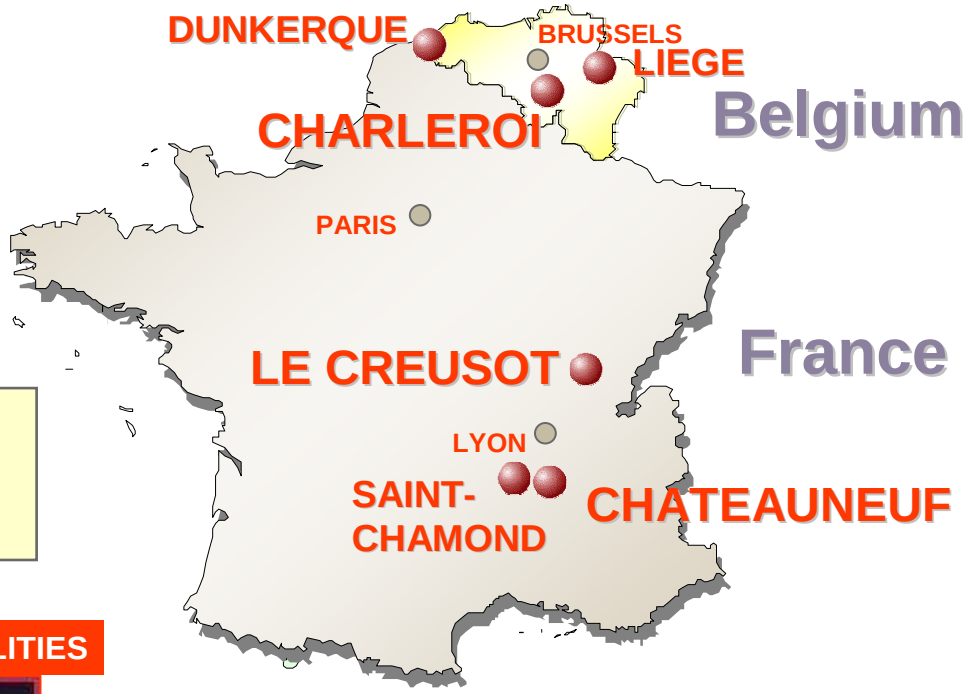
3 QUARTO MILLS



Width Quarto : 3.5 to 4.6 m
Roll opening : 570 to 1300 mm

3 FINISHING FACILITIES

Heat treatments
Water and oil quenching
Leveling
Cutting
Forming
Surface-Grinding
…



All sites ISO 9001:2000 certified

Industeel Products Overview

Stainless & Clad steels

Austenitic, ferritic, H. Resist.
Uranus® duplex, superduplex
Carbon + stainless clad

Cryogenic steels

Cryelso® 9% Ni, 5% Ni,
Cryelso® 36% Ni

Pres. Vessel & Structural steels

Cromelso ®
Cr Mo, CrMoV
CMn HIC, 3,5%Ni

Jack up rigs

Superelso ® 500
Superelso ® 690CR

Mold & Tool steels

Superplast ® 300 - 400
Tenasteel ®

Wear resistant steels

Fora 360 - 400 – 450
Creusabro ® 4800 - 8000

High Strength steels

Carelso ® 690 – 960 Q -

Protection steels

Mars ® 190 – 240 - 300

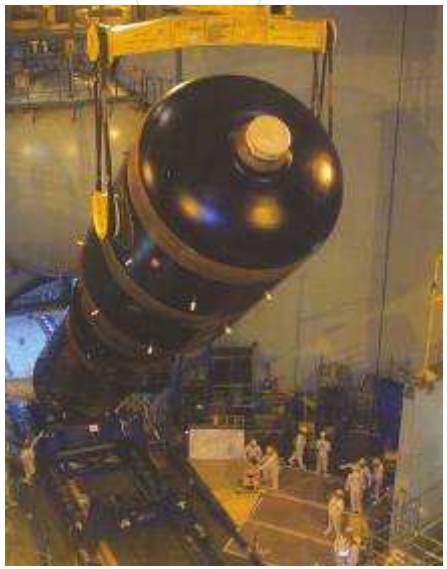
Industeel : Pressure vessels steels

- Refining
- Petrochemical
- Gas (cryogenic)
- Offshore
- Energy (nuclear, thermal)
- …

… For LNG storage tanks

… For oil & gas

… For nuclear power plant



Trademarks

SUPERELSO®
CARELSO®
CRYELSO®
CROMELSO®

Industeel : Stainless and Clad steels

- Pollution Control
- Desalination
- Chemical / Petrochemical
- Gas
- Offshore
- Nuclear Energy
- Refining
- Pulp and paper
- …

… For refining

… For chemical tankers..

… For chemical/petrochemical industry...

Trademark
URANUS®

Certifications

QUALITY SYSTEM CERTIFICATE

ClassNK NIPPON KAIJI KYOKAI
4-7, KIOI-CHO, CHIYODA-KU, TOKYO102, JAPAN.
TELEX : J22975 CLASSNK 2324280 CLASNKJ
CABLE : CLASSNK TOKYO

CREUSOT LOIRE INDUSTRIE,
Le Creusot Plant Plate Mill

Our Ref. : 97EW307ROL
Date : 26 June 1997

Usine du Creusot BP56F-71202
LE CREUSOT CEDEX, FRANCE

Dear Sir,

Approval of the Manufacturing Process on Stainless Steel Plates

We have the pleasure of informing you that, in view of the satisfactory results of the test report, we approve your manufacturing process of Stainless steel plates under the following conditions ;

1. Works : CREUSOT LOIRE INDUSTRIE.

KSUS304L, KSUS304LN	Cr-Ni Austenitic Stainless Steel
KSUS316L, KSUS316LN, KSUS317L, KSUS317LN, 316L(ASTM A240, USN S31603)	Cr-Ni-Mo Austenitic Stainless Steel
URANUS45N(ASTM A240, UNS S31803)	Cr-Ni-Mo Austenitic-Ferristic Stainless Steel

Note) The Table includes the Grades approved in 95EW172ROL.

(to be cont.)

DNV

DET NORSKE VERITAS
MANUFACTURING SURVEY ARRANGEMENT

MSA No. R-1565
The MSA consists of 5 pages

Between
Creusot Loire Industrie (C.L.I.), le Creusot Plant
Le Creusot Cedex, France

and
Det Norske Veritas
DNV Lyon Office

Extent

This Manufacturing Survey Arrangement (MSA) is applicable to ROLLED STEEL PLATES OF APPROVED NV GRADES

DET NORSKE VERITAS AS · VERITASVEIEN 1, 1322 HØVIK, NORWAY · TEL: (+47) 67 57 99 00 · FAX: (+47) 67 57 99 11
Form No.: 20.90a Issue: January 98 Page 1 of 5

INDUSTEEL plants are attested

ISO 9001 VERSION 2000

Appendix 2

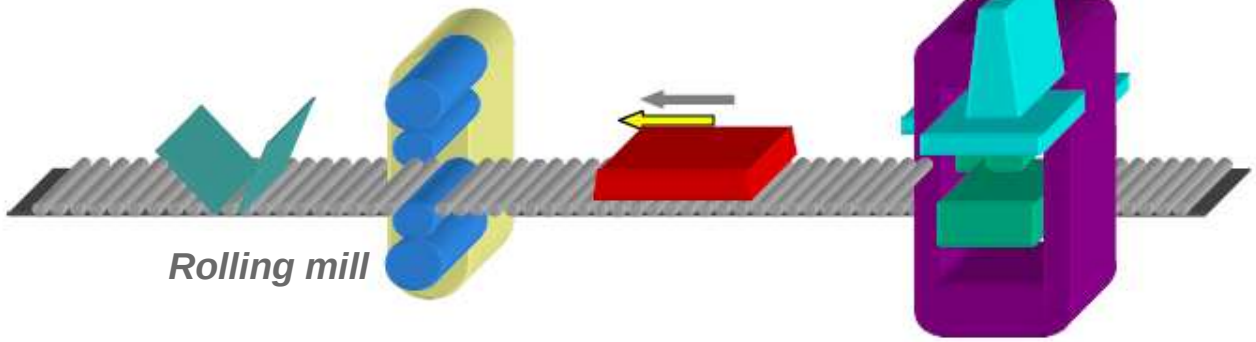
Forged Rolled process of Industeel

Industeel rolling / forging process

ArcelorMittal

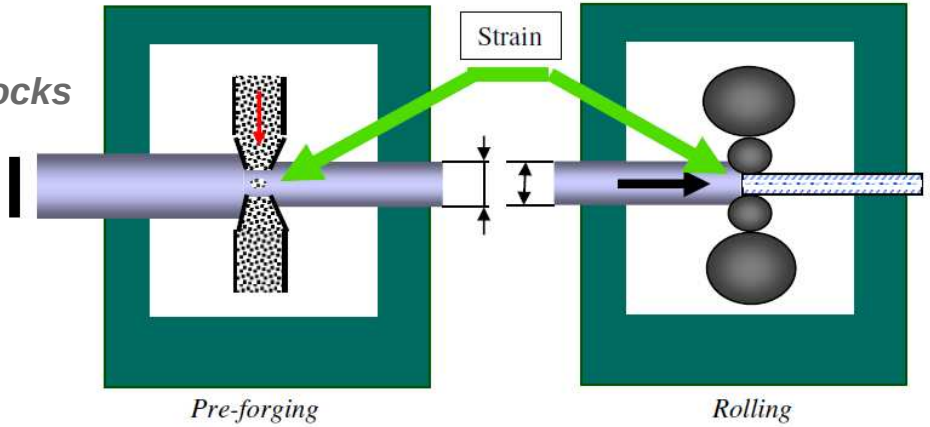
Combined process in same heat

Forging press 12600 T



Rolling mill

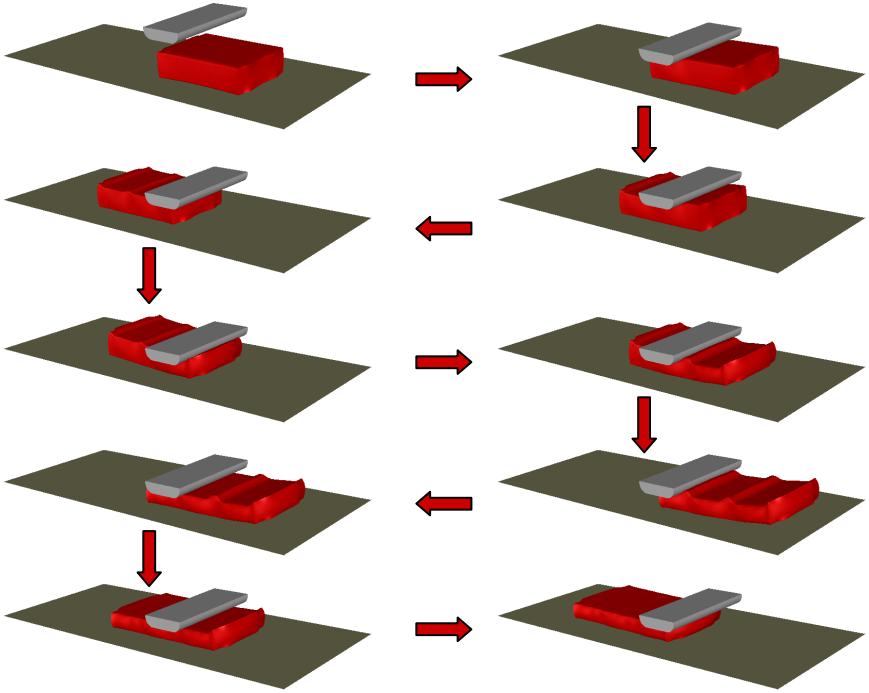
Different deformations applied to blocks



Efficiency of forging process

ArcelorMittal

Forging in several passes with overlaping



Strong deformation applied on the center of the block

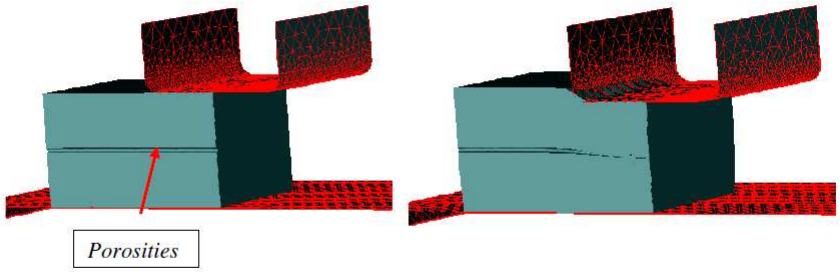


Figure 3: Effect of pre-forging on porosities (CRMC Data obtained with Forge 3®).

Forging ratio

- Industeel forging ratio is between 1.8 / 4
- Forging ratio 3/1 is used to make differentiation between forging and castings
- ASTM doesn't require any minimum reduction ratio

ASTM A788-06 "Standard Specification for Steel Forgings

3.2 *steel forging*—the product of a substantially compressive plastic working operation that consolidates the material and produces the desired shape. The plastic working may be performed by a hammer, press, forging machine, or ring rolling machine, and must deform the material to produce an essentially wrought structure. Hot rolling operations may be used to produce blooms or billets for reforging. Forgings may be subdivided into the following three classes on the basis of their forging temperatures:

Quality of forged products

- Quality depends on whole forging process

Initial quality of the ingot	Solidification structure / soundness
Temperature of the product at time of deformation	Efficiency of forging – local deformation
Power of the press	
Tool shape	
Number of intermediate reheatings	Grain coarsening

- Forging ratio gives no indication of the quality of forgings
- Quality is shown by
  - Product compactness (UT) → Industeel guarantee ASTM A388 - 1/8" FBH
  - Mechanical properties (Isotropy)
- Industeel is certified by ASME for plates and forged components (ASME code section III)