Engine Expo 2009
Stuttgart

Advanced steels for the internal combustion engines of the future

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Eramet Alliages

DES ALLIAGES,
DES MINERAIS ET DES HOMMES.

ERAMET

Outline

Introduction

Carburizing grade for higher temperatures

PM steels for Diesel injection components

N-alloyed MSS for gasoline injection

Austenitic stainless steels for valves

Conclusions

INTRODUCTION

The Eramet group

Eramet is an integrated mining and metallurgical corporation

- **Nickel**
- **Manganese**
- **Alloys: AUBERT & DUVAL + ERASTEEL**
  - High speed steels
    Cutting tools, cold work, wear parts
  - High performance special steels and super alloys
    Aerospace, power generation, tooling, medical, land&sea transportation
  - Forgings
    Aeronautics, power generation

AUBERT&DUVAL
ERASTEEL

INTRODUCTION

Key aspects in material development for IC engines

Materials innovation drivers in IC engines/
Continuous improvements or technological breakthroughs

Performance improvements

Engine life: Racing, heavy duty engines
Reliability – safety: Light to heavy duty
Weight reduction: Racing
Reduced emissions: Light to heavy duty

Cost reduction

Lower purchasing cost
Materials allowing a global component cost reduction
- Lower component manufacturing cost
- Material allowing to avoid expensive coatings

INTRODUCTION

Key aspects in material development for IC engines

Applications with « large » volumes: Specific grade development

- Valve steels

Applications with « small » volumes: Generic grade development

- High Speed Steels for Diesel Injection parts: Cutting tool, Cold work
- Martensitic Stainless Steels: Bearings, Knives
- Ni-based alloys: Aeronautics

« Large/Small » depends on melting/ development unit size

- Continuous Cast: n x 100 tons
- Air Melted – Ingot Cast/ Remelted ESR: 25-60 t
- Remelted VIM-VAR: 5-10 t
- Powder Metallurgical (PM): 5-10 t

Steels for Diesel Engines

Meeting emission targets

Higher P: <1000 to ca 3000 bar

Higher T: Up to 450°C

Improved dynamics: α, E/ρ

Lower quality fuels: Corrosion issues

= Key properties

Temperature resistance

Strength/UTS

Fatigue limit

Wear resistance

Carbide pull-out resistance

Specific modulus

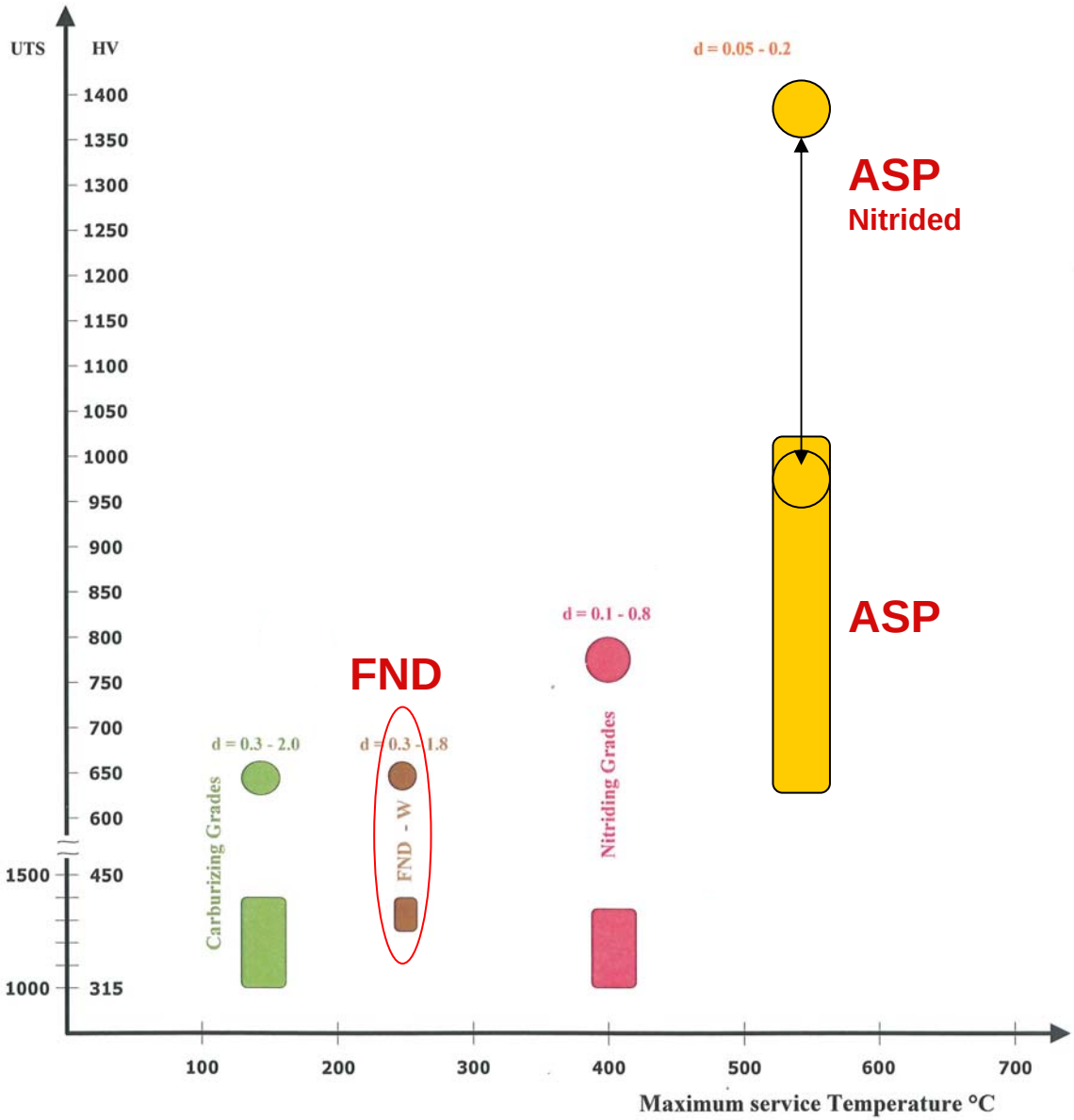
Corrosion resistance

-> High temperature carburizing steels

-> PM Tool Steels/ High-Speed Steels/ Martensitic Stainless Steels

Steels for Diesel Engines

UTS vs Temperature resistance/ Non stainless grades



Steels for Diesel Engines

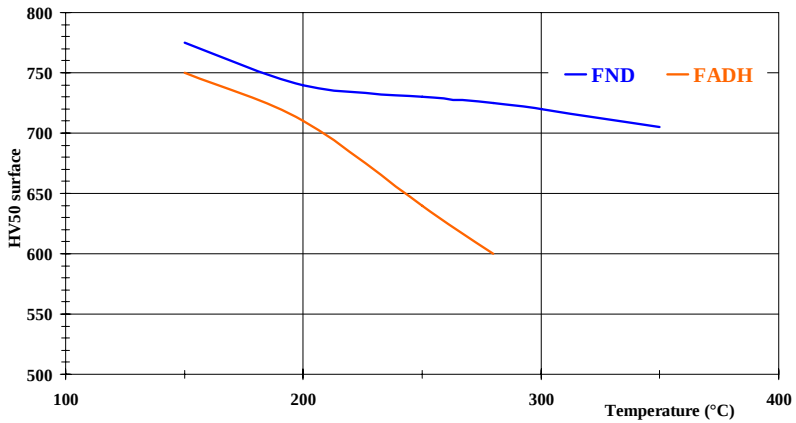
FND/ FND-W A case-hardening grade for higher temperatures

Patented

FND/ FND-W designed to be tempered at 300°C (Si, Mo)

- Can be used up to 250°C+
- Suitable for PVD coating (vs current case-hardening grades)
- Good hardenability/ suitable for gas-quenching = low distortions
- In remelted version (FND-W) + case hardening, L_f /20 M Cycles ~ 1100MPa

Application: Nozzles



Aubert&Duval grade	Designation	Typical chemical composition (%)					
		C	Mn	Si	Ni	Cr	Mo
	20MnCr5	0,20	1,3	0,25	-	1,1	-
MMR1PC	16NiCr6	0,16	0,7	0,25	1,4	1,0	-
BXO	18NiCrMo6	0,18	0,7	0,25	1,4	1,0	0,20
FADH	16NiCrMo13	0,15	0,4	0,25	3,2	1,0	0,25
BXM	17CrNiMo6	0.17	0.7	0.3	1.7	1.7	0.35
FND	15NiMoCr10	0,15	0,4	1,10	2,5	1,0	2,00
FDG	20NiCrMo13	0,20	0,5	0,30	3,0	1,0	0,50
FDHM	25NiCrMo13	0,25	0,6	0,25	3,0	1,3	0,25

Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS for high performance components

ASP is originally an industrial process set up in 1972 and a trade mark of Erasteel

ASP process consists in gas atomization of metallic powders followed by hot isostatic compaction

ASP process brings major microstructural benefits for alloyed steels:
High speed steels : ASP 2023, 2030, 2060, cutting, cold work tools

Improvements in cleanliness have opened components markets

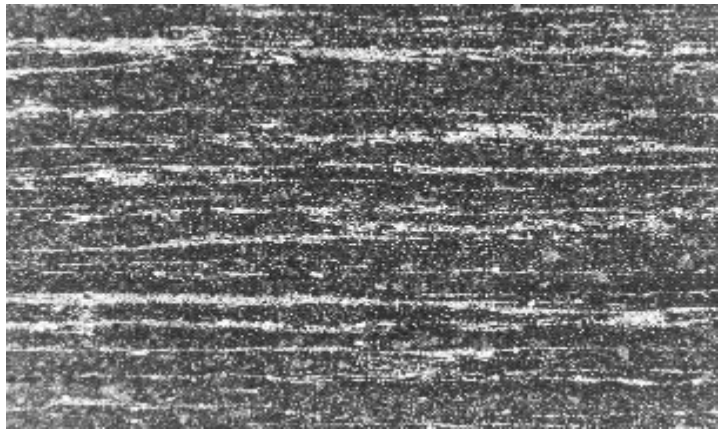
ASP process can be used for other classes of alloys than HSS:
Tool steels, Martensitic Stainless Steels, Superalloys, etc…

Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS for high performance components

A microstructural advantage

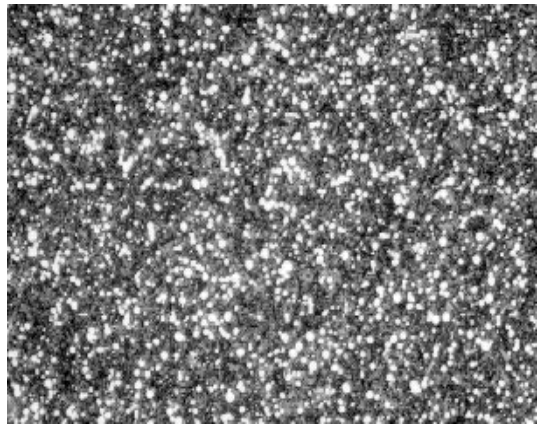
Small, homogeneous, isotropic microstructure



M2

LOM

ASP 2023



Martensitic matrix + carbides (nitrides)

Mo Carbide former (M_6C)

W Carbide former (M_6C)

V, Nb Carbide former (MC)

Partial dissolving
Secondary hardness

Cr Carbide former ($M_{23}C_6/M_7C_3$)

Dissolved in matrix
Secondary hardness

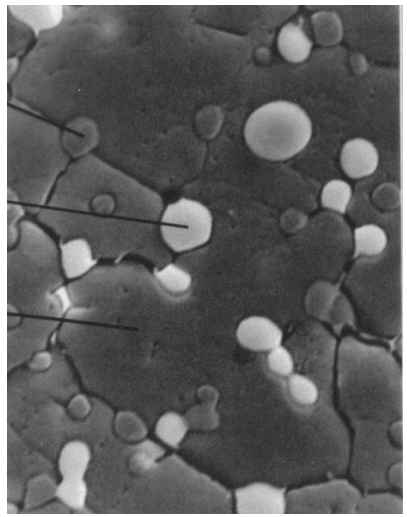
Co Dissolved in matrix

Hardness (“hot hardness”)

MC
(2800 HV)

M_6C
(1600 HV)

MATRIX
(800 HV)



1 µm

Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Typical compositions

	Grades	Normalized des.	C	N	Si	Cr	W	Mo	V	Co	Nb	HRC
HSS.TS	**M50**	1.3551	0,84			4	0	4,2	1,1			64
	ABC III	1.3333	0,99			4	2,8	2,7	2,4			64
	M2	1.3343	0,9			4	6,3	4,9	1,85			65
	T1	1.3355	0,75			4	18	0	1			65
	ASP 2012	1.3397	0,6			4	2,1	2	1,5			58
	ASP 2017	1.3288	0,8			4	3	3	1	8	1	65
	ASP 2005	1.3377	1,5			4	2,5	2,5	4			64
	ASP 2004	1.3361	1,4			4	5,8	5	4,1			66
	ASP 2023	1.3395	1,23			4	6,4	5	3,1			66
	Bimax 42	1.3247	1,1		0,6	4	2	10	1	8		69
	ASP 2060	1.3292	2,3			4	6	7	6	10		69
MSS	**APZ10**	X120CrMoVN19-2	1,15			19		2,1	0,6			62
	PM 618	AISI 618	1,05		0,5	14		4	0,2			63

Eutectic solidification with primary carbides: Coarse isolated carbides + stringers

High temperature tempering 450 - 560°C

Combination of hardness, impact and wear resistance

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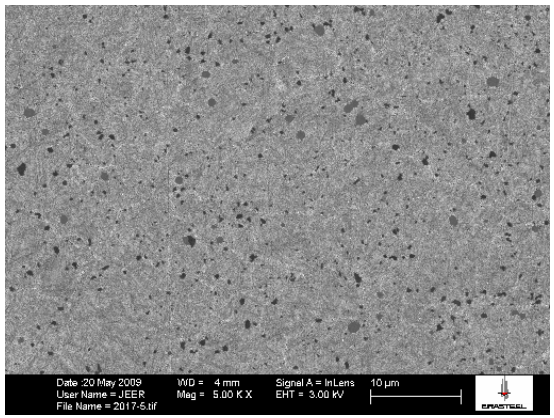
Steels for Diesel Engines

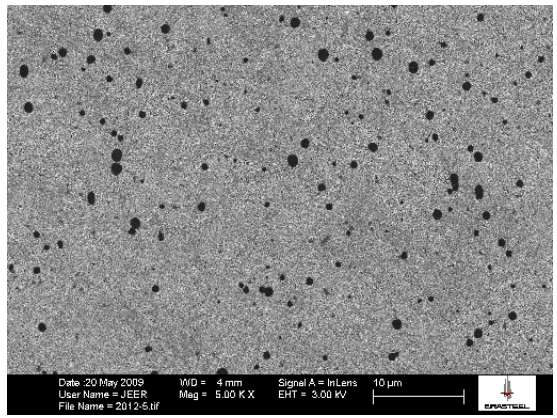
PM High-speed steels/ tool steels/ MSS for high performance components

A wide range of microstructures

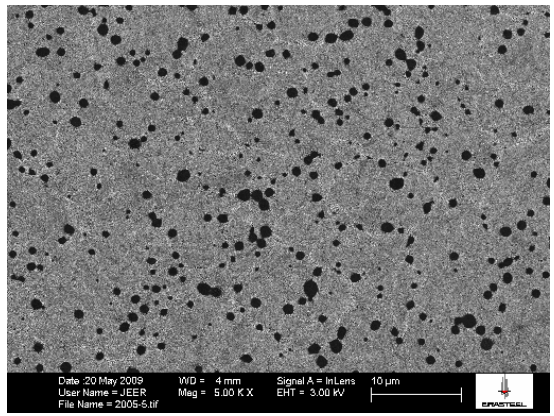
ASP 2017



ASP 2012



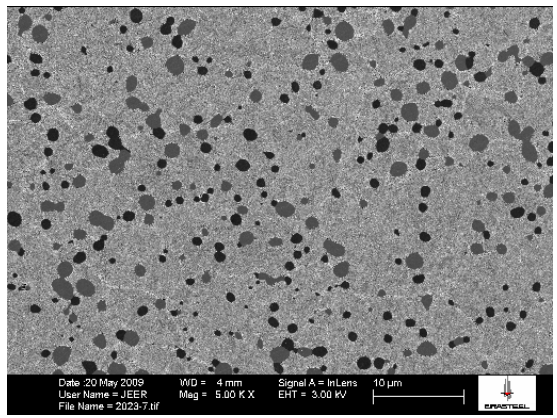
ASP 2005



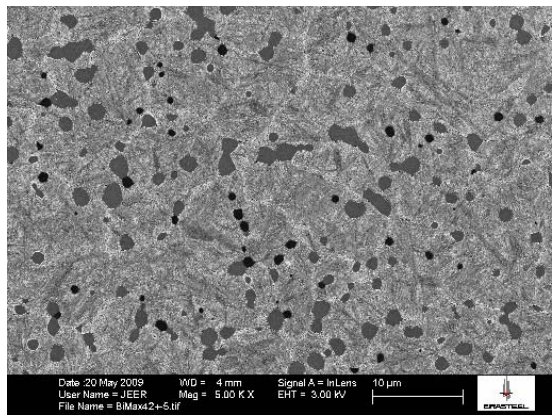
MC
(2800 HV)

M_6C
(1600 HV)

10 µm



ASP 2023



Bimax 42

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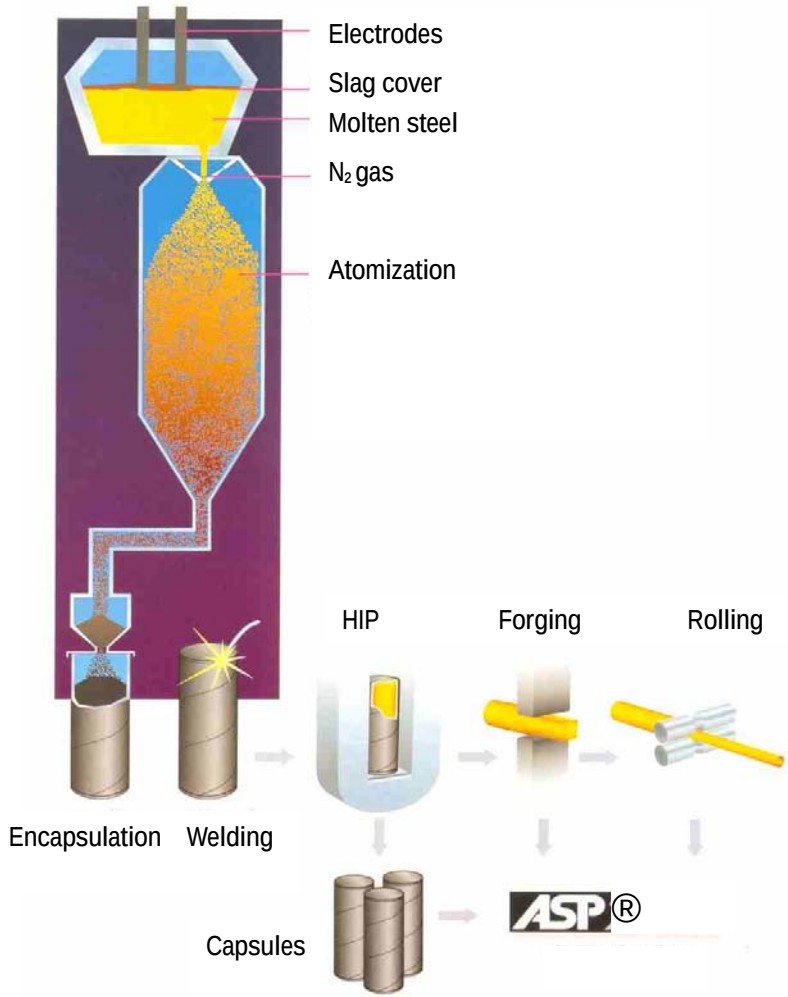
Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

The ASP process

- ESH Process
- Gas atomisation (N_2)
- Spherical powders
- HIP 1000bar at ca 1100°C
- Fully dense
- Forged&Rolled



® Registered trade mark

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Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS for high performance components

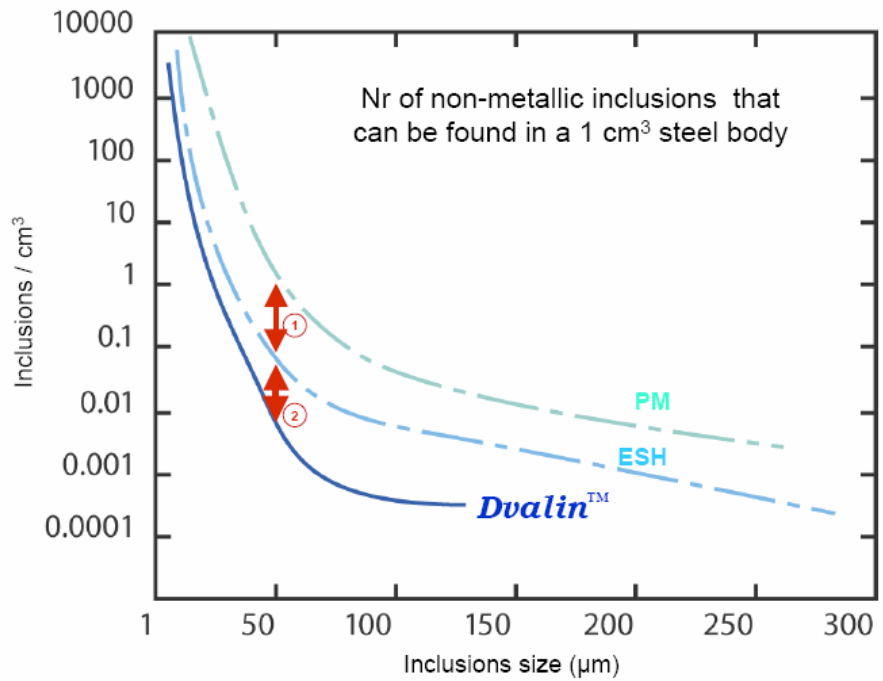
Very high cleanliness

Typical ASTM E45 ratings:
A 0 B 0 C 0 D 0,5

Inclusion content can no longer be defined by a norm such as ASTM

Cleanliness = Process control

Process development based on:
- LOM and SEM NMI assessments
- Ultra-Sonic Destructive analysis
- Fatigue testing



Evolving process: Step and continuous improvements

Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties of ASP grades

Temper resistance

Wear resistance

Hardness vs Impact toughness

Strength

Fatigue resistance

Specific modulus

Suitable for nitriding

Corrosion resistance

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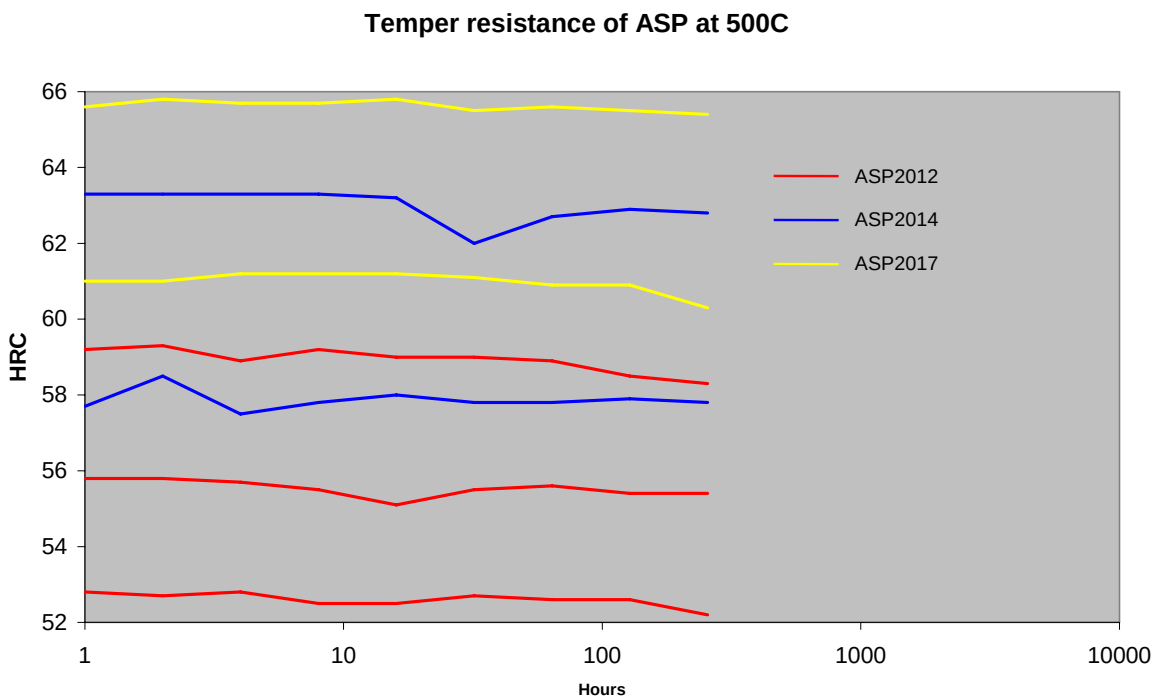
Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties: Temper resistance



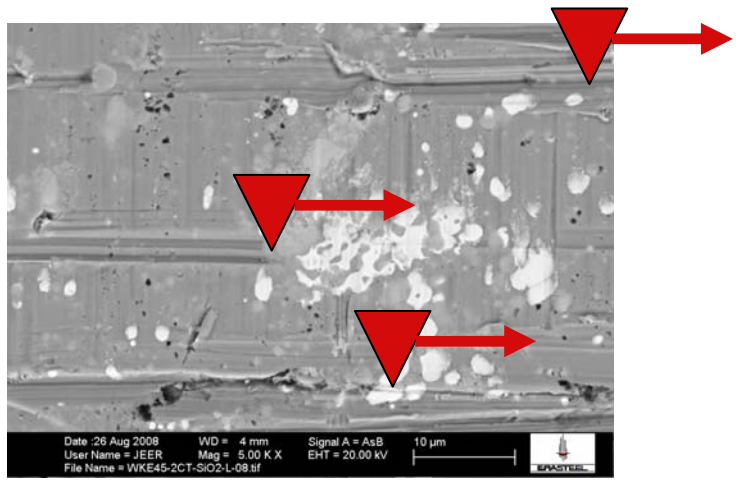
Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties: Wear resistance

Adhesive wear:	Smooth surfaces + nitriding
Abrasive wear:	Hardness, carbides (types, fv, sizes)
Cavitation/erosion wear:	Hardness, carbides fv, fatigue resistance

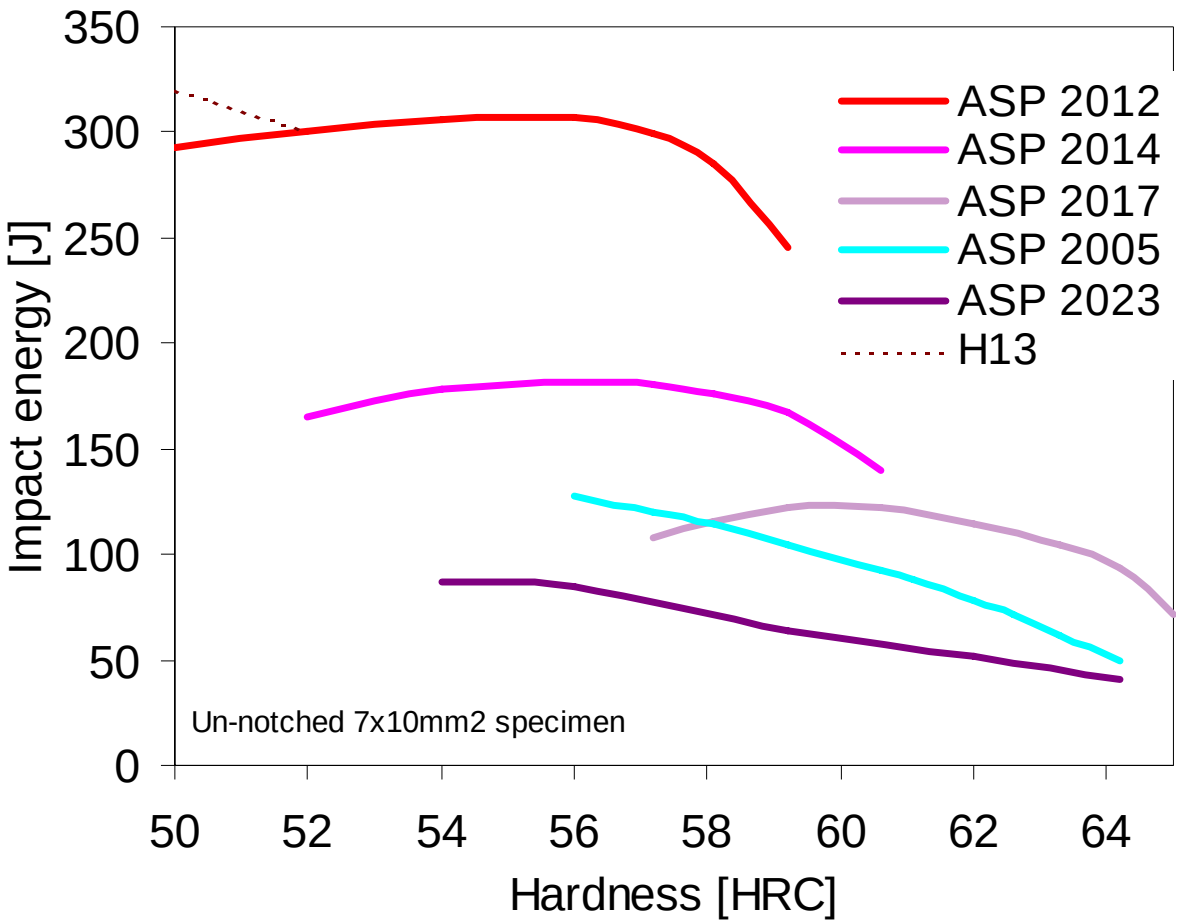
- Hard matrix
- Hard carbides
- Many carbides



Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

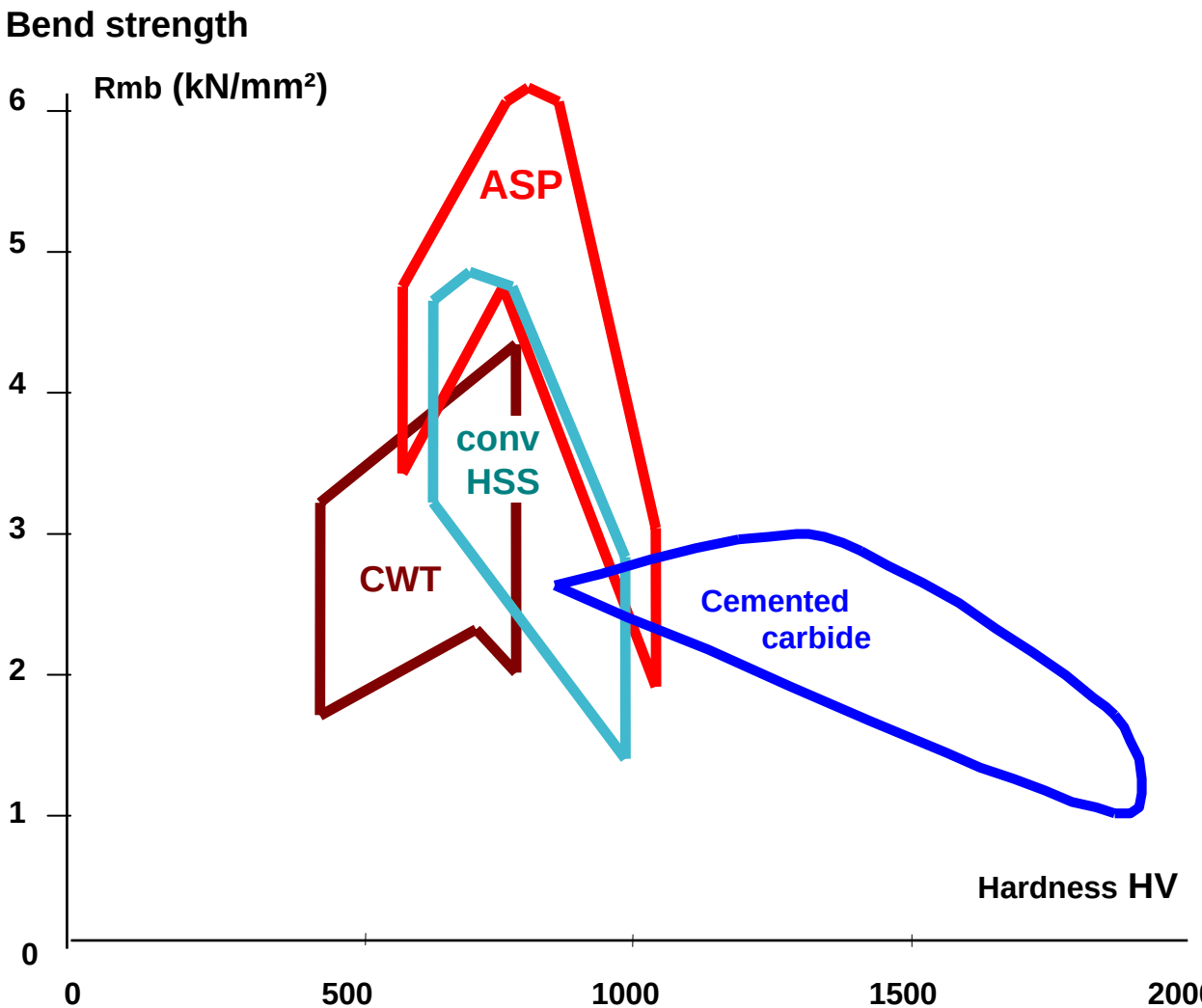
Key properties: Impact Toughness vs Hardness



Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties: Strength

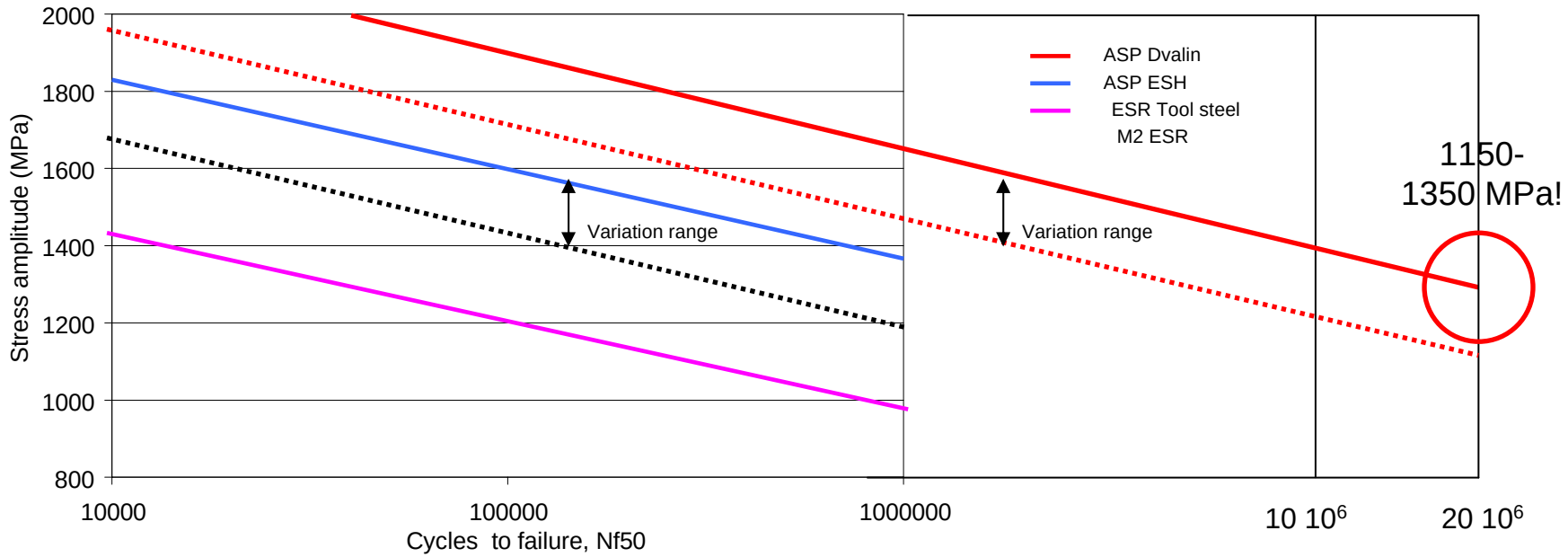


Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties: Fatigue resistance

Inclusions, carbide clusters and heat treatement



Rotating bending fatigue

Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties: Specific modulus E/ρ

Grades	C	W	Mo	V	Co	Nb	Hardness range (HRC)	Wear resistance index	Density	E(GPa)	Specific modulus	Charpy (Nm) at max HRC	Max hardness (HRC)	Charpy (Nm) at 62 HRC
ASP 2012	0,6	2,1	2	1,5			up to 58	+	7,8	220	28,2	280	58,0	NA
ASP 2017	0,8	3	3	1	8	1	up to 65	+	8	235	29,4	70	65,0	115
ASP 2005	1,5	2,5	2,5	4			up to 64	+++	7,8	220	28,2	50	64,0	90
ASP 2004	1,4	5,8	5	4,1			up to 66	++++	8	240	30,0	35	66,0	65
ASP 2023	1,23	6,4	5	3,1			up to 66	+++	8	230	28,8	35	66,0	50
Bimax 42	1,1	2	10	1	8		67 - 69	++	8	225	28,1	15	69,0	NA
ASP 2053	2,45	4	3	8			up to 65	+++++	7,7	250	32,5	40	65,0	50
ASP 2060	2,3	6	7	6	10		up to 69	+++++	7,9	250	31,6	14	69,0	21

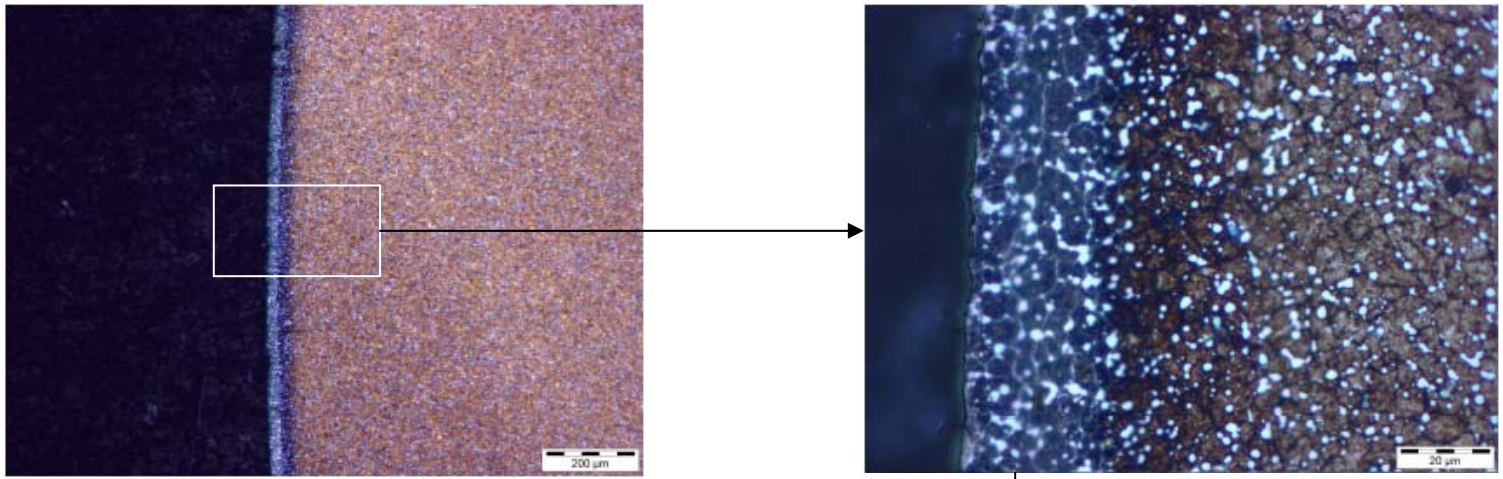
+ 25% vs construction steels!

Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

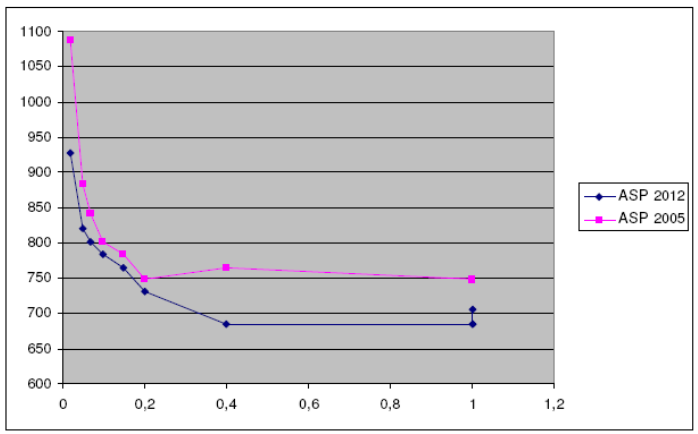
Key properties: Suitable for nitriding

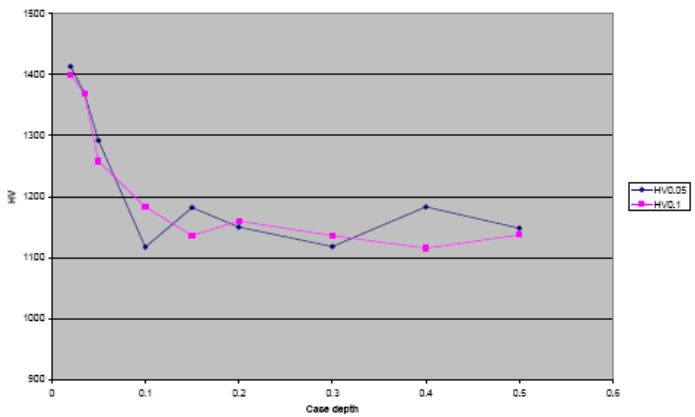
Vs Fatigue, Wear, Friction: Cost efficient alternative to Cermets/ Ceramics



Gx 50 : nitrided layer with a visual case depth about 80 microns

Microhardness profil :





Conventional case depth (core hardness + 100HV): 0.05-0.07mm

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Steels for Diesel Engines

PM High-speed steels/ tool steels/ MSS
for high performance components

Key properties: Corrosion resistance

PM Martensitic stainless steels

APZ10
PM AISI 618

PM knife/ tooling grades offering
- Temper resistance
- Abrasion resistance
- Fatigue resistance
- Impact resistance

+

Acceptable corrosion resistance with 500°C tempering

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ERASTEEL

N-Alloyed MSS for gasoline injection

X15TN

Patented

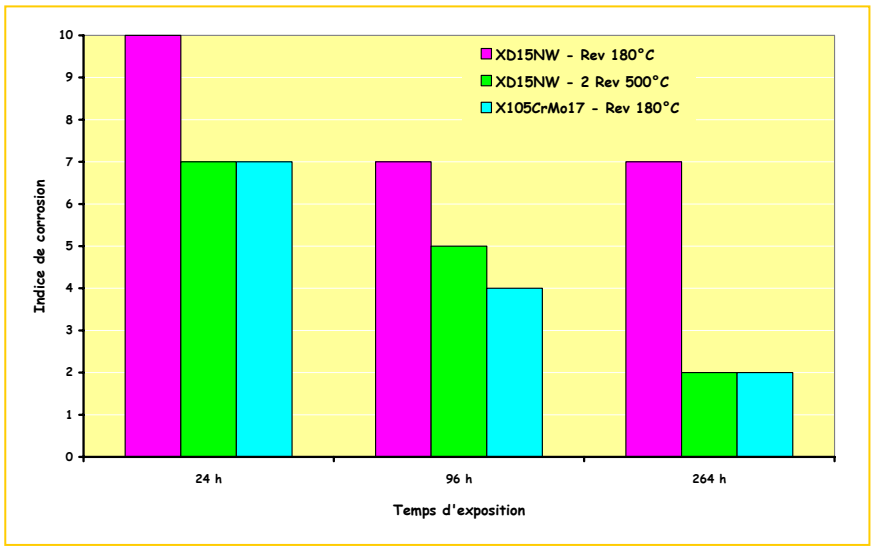
High N Content -> Good PREN

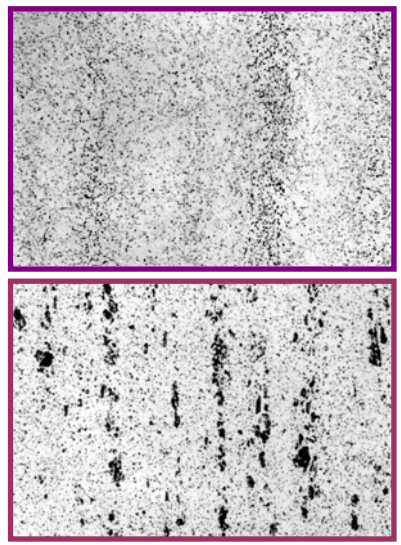
Carbide/Nitrided size decrease vs C alloyed MSS (such as 440C)

X15TN originally a flying bearing grade -> AMS

- Produced by ESR process, specific know-how -> Fatigue limit 20MC ca 1000MPa
- Hardness: 58-60 HRC (high T temper, cryogenic treatment)
- Good to excellent corrosion resistance
- Good weldability

<u>A validated solution for demanding gasoline injection applications</u>





X15TN

XDBDW
(440C)

N-Alloyed MSS for gasoline injection and inlet valves

XD16N

Patented

High N Content -> Good PREN

Carbide/Nitrided size decrease vs C-alloyed MSS (such as 440C)

XD16N originally an inlet valve steel

- Air melted
- Hardness: 57-58 HRC (high T temper, cryogenic treatment)
- Quench cracking resistance
- Induction hardenable
- Good temperature resistance (High Si)
- Good corrosion resistance (High N)

Cost-efficient alternative to XD15N, still superior to 440C

Grades	Normalized des.	C	N	Si	Mn	Cr	Mo	V	Max HRC	PR EN
XD15N-W	1.4123	0,42	0,25			16	1,8	0,2	60	*17*
XD16N	-	0,5	0,15	2	1	16	0,3	0,3	58	*6*
AISI 440C/ XDBD	1.3544	1,1				18	0,75		62	*-13*

AUBERT&DUVAL

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Valve steels/ Exhaust valve

Austenitic valve steel with improved properties X26RC

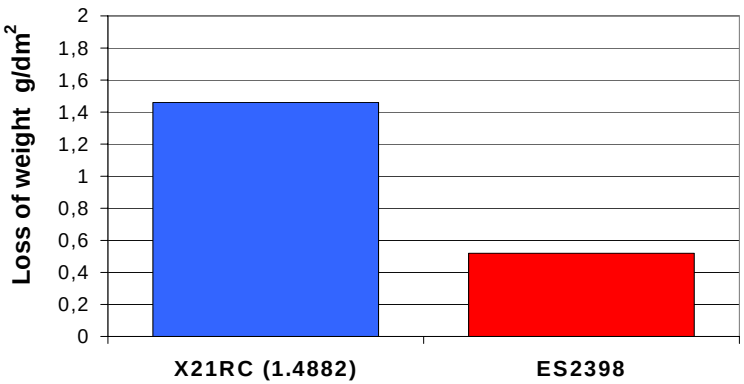
Patented

X26RC closes the gap between austenitic valve steels and Ni-based superalloys with low Ni content

Aubert&Duval grade	Designation	Typical chemical composition (%)							
		C	Mn	Cr	Ni	N	Nb	Fe	other
X21RC	X50CrMnNiNbN21-9 1.4885	0,50	9	21	3,7	0,45	1,9	Base	W
X26RC	X30CrNiMnNb25-12 -	0,30	5	25,5	12	0,55	2	Base	
EA1	NiCr20TiAl 2.4952	0,06	<1	19	75	-	-	< 3	Ti,Al

A&D Grades	UTS (MPa)	0.2% YS (MPa)	UTS (MPa)
	20°C		700°C
X21RC	950	550	480
X26RC	960	560	585
EA1	1050	620	675

Comparative mechanical properties
(Solutioned + aged)



Oxidation resistance 850°C 100h + pickling

CONCLUSIONS

Case hardening and stainless steels with increased Si/Mo contents resist softening during high temperature use

PM steels offer evolutive and exciting property combinations for critical components in high performance IC engines

N-Alloyed martensitic stainless steels are very interesting materials to fight biofuel corrosion in gasoline injection

Advanced steels with appropriate surface treatment can be more competitive than cheaper steels + expensive coatings or cermets/ ceramics

Alloy content reduction and air-melting for good enough performance allow achieving cost reduction for large volume applications

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ERASTEEL