Materials Behaviour under Impact

High Dynamic Loading of Materials

Part 2

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Presentation Outline

Classic armour steels
(Quenched and tempered steels)

High Nitrogen Steel (HNS)

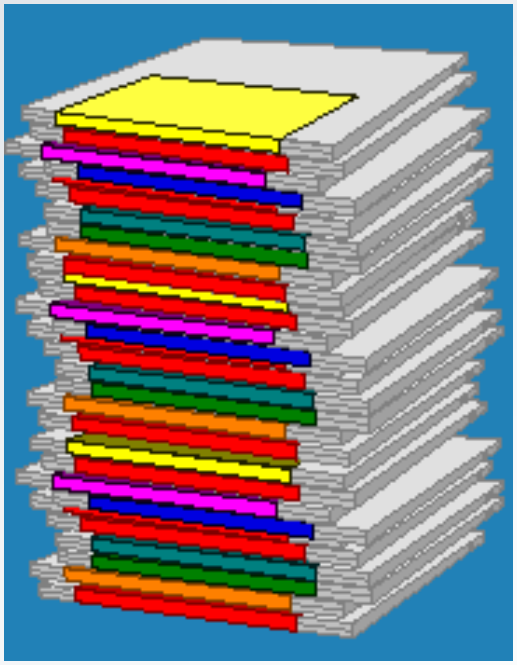
Ausforming steels

Bainitic steel

γ-TiAl

Ti-alloy

MMC



Tailoring of mechanical properties of:

Quenched and tempered steels:

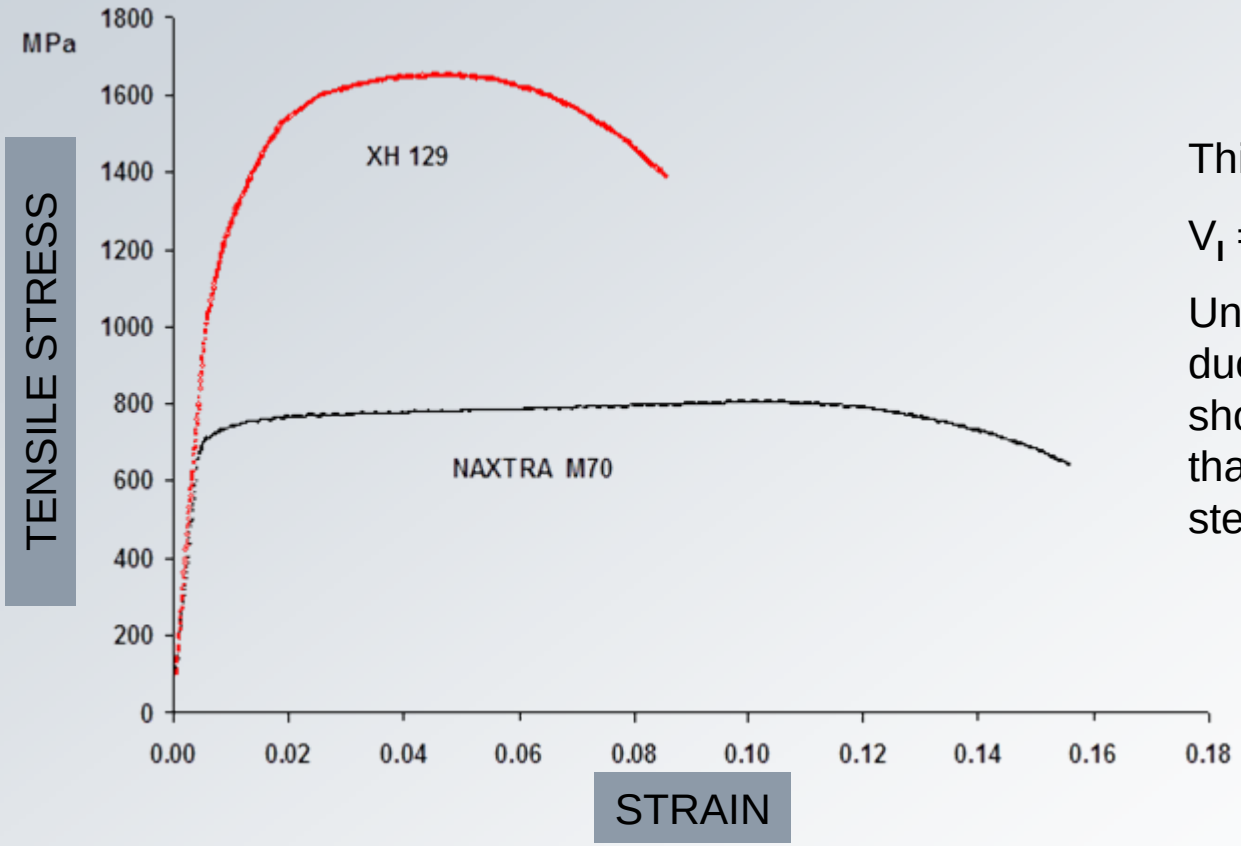
by quenching (hardening) and subsequent tempering

Austenitic steels:

work hardening and annealing

Shielding against low velocity fragments

Hoog K,. Lach E., Maurer R., Rössner H.: Bericht R 134/86



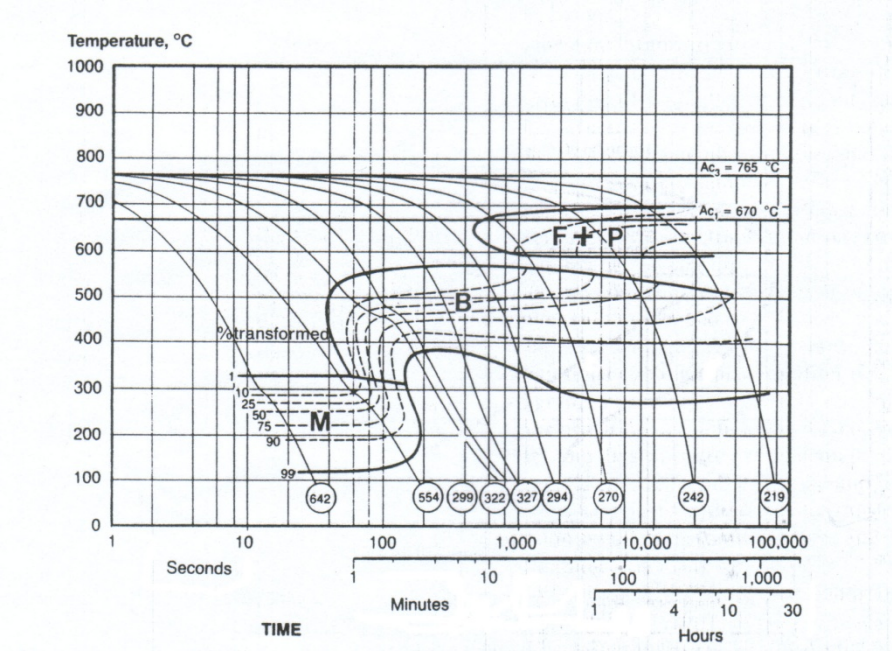
Thickness of the sheet: 3mm

V_I = 300 m/s

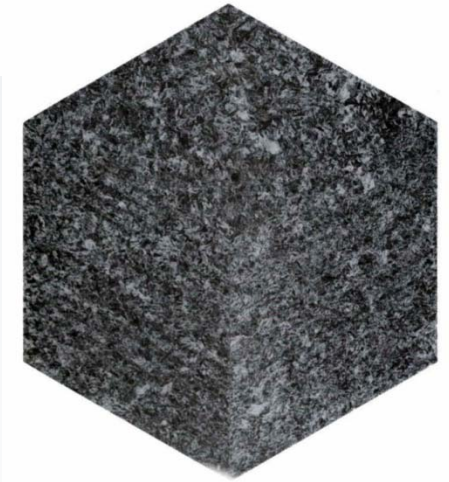
Under this condition the more ductil steel alloy NAXTRA shows a better performance than the high strength armour steel XH 129

Classical armour steels

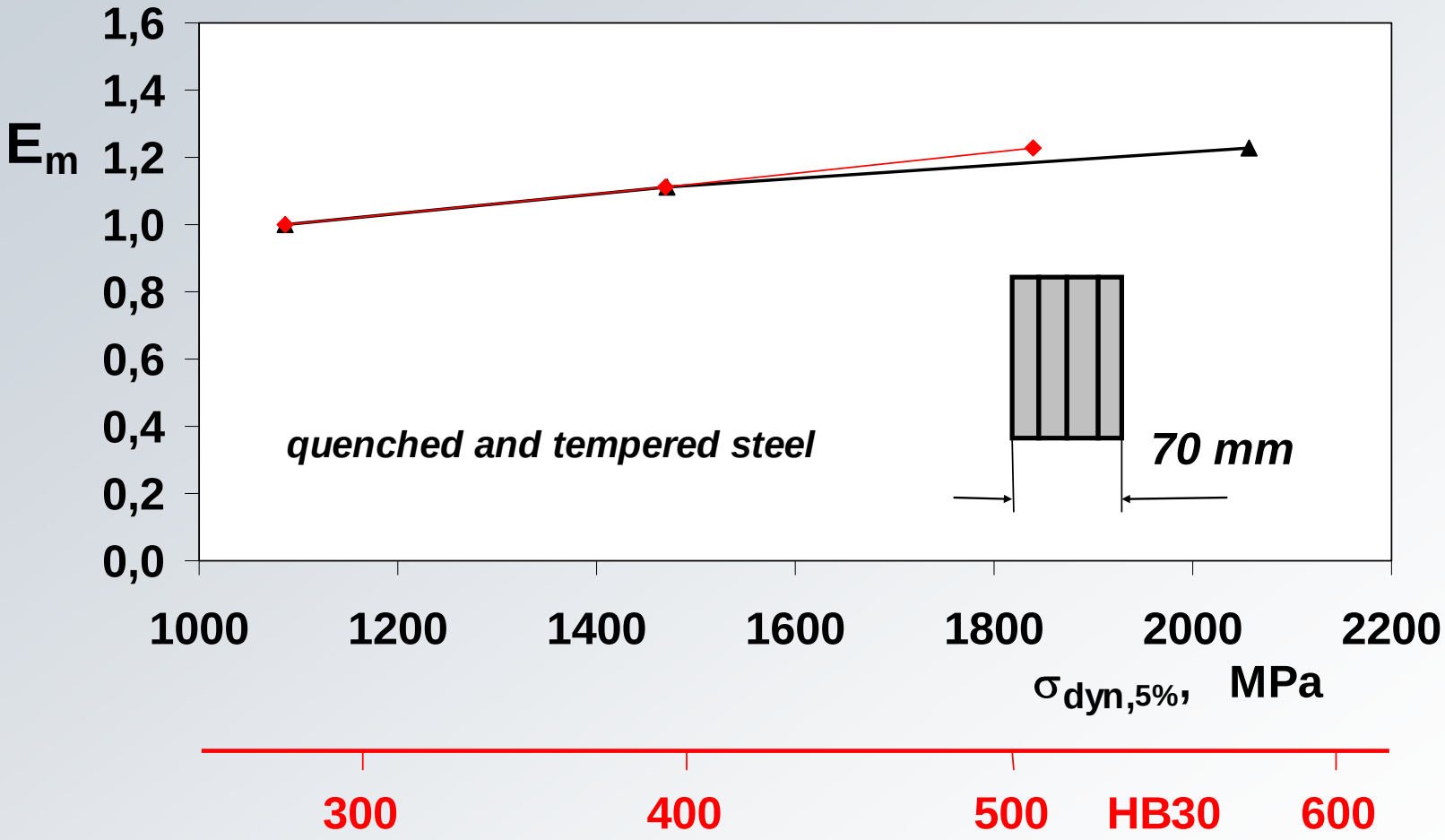
quenched and tempered steels



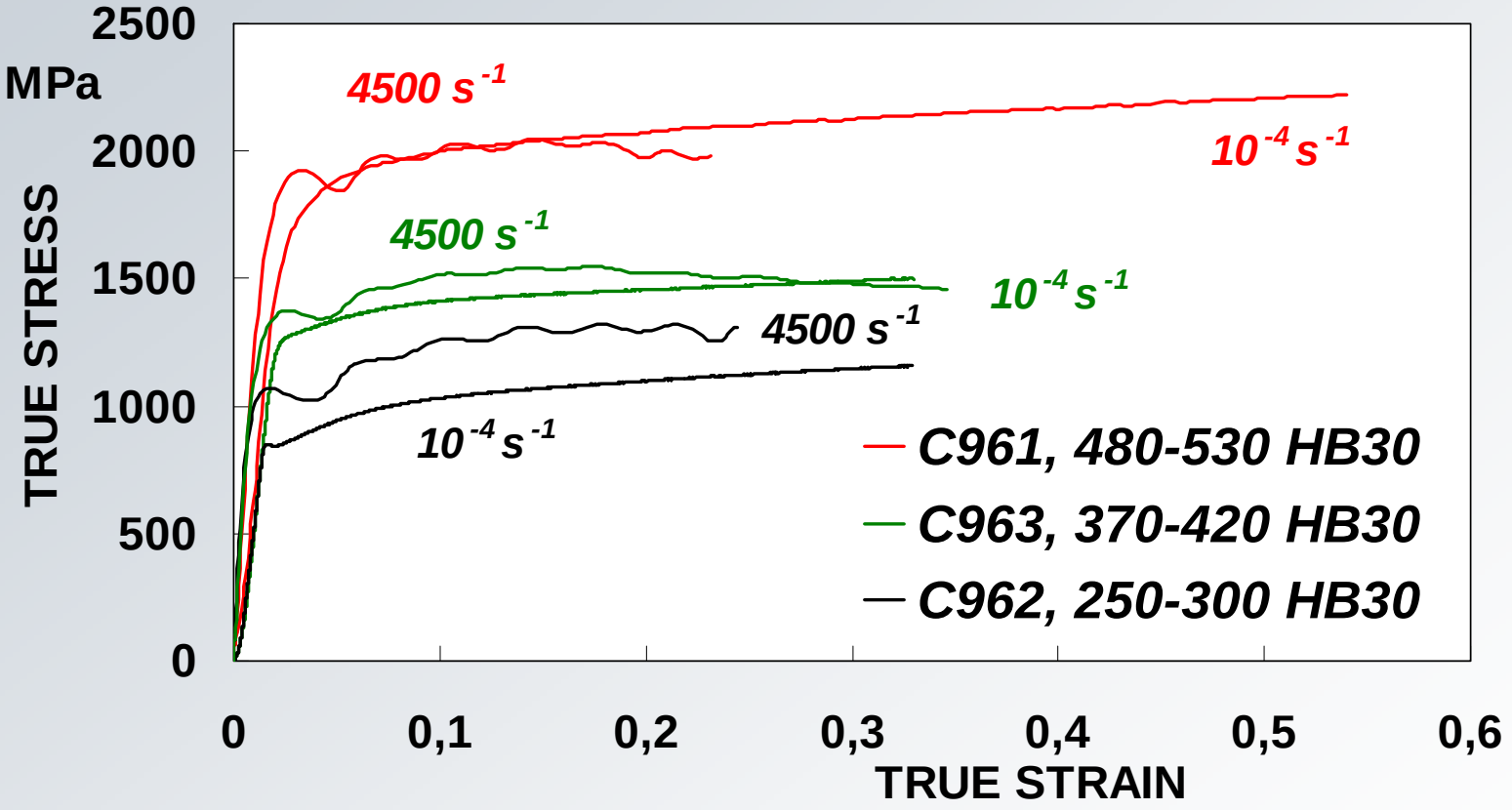
Micro structure
after hot rolling

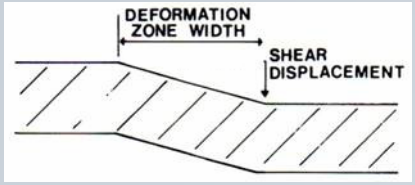


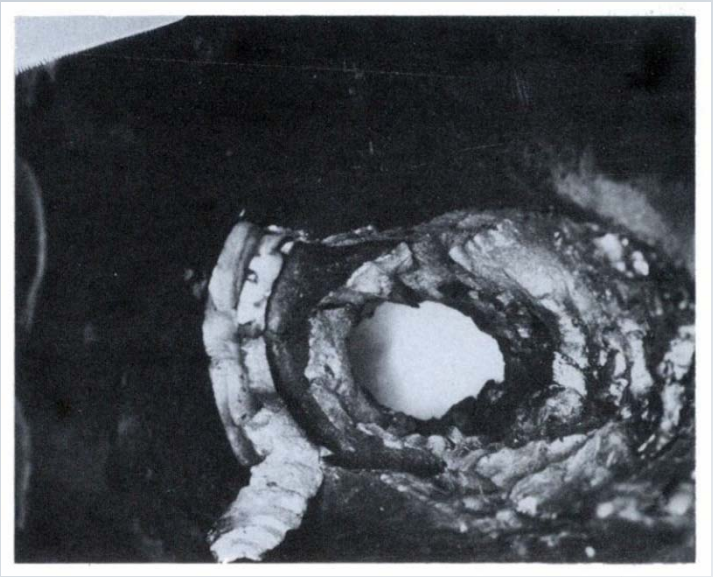
Ballistic Tests on Armour Steel



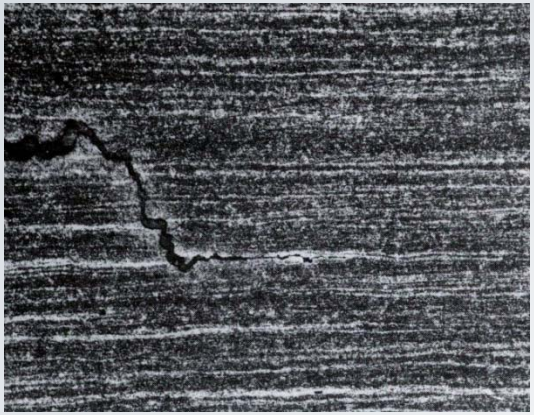
Dyn. Compression Tests on Armour Steels

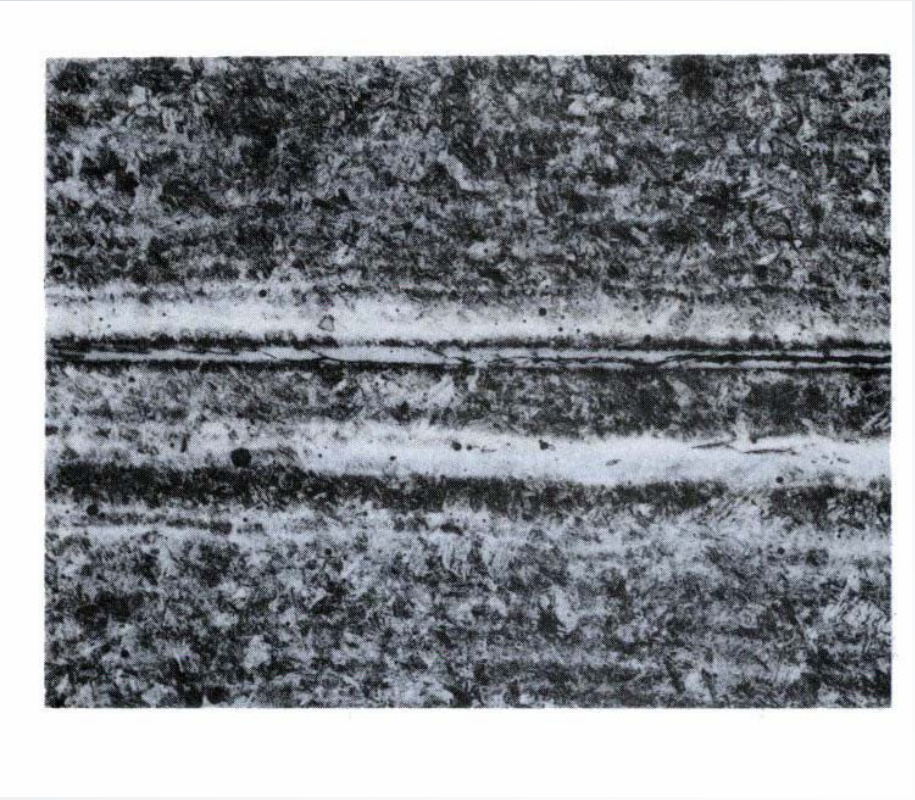




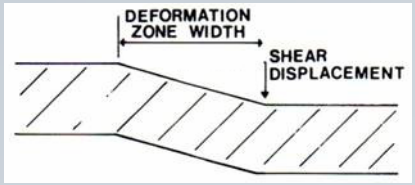


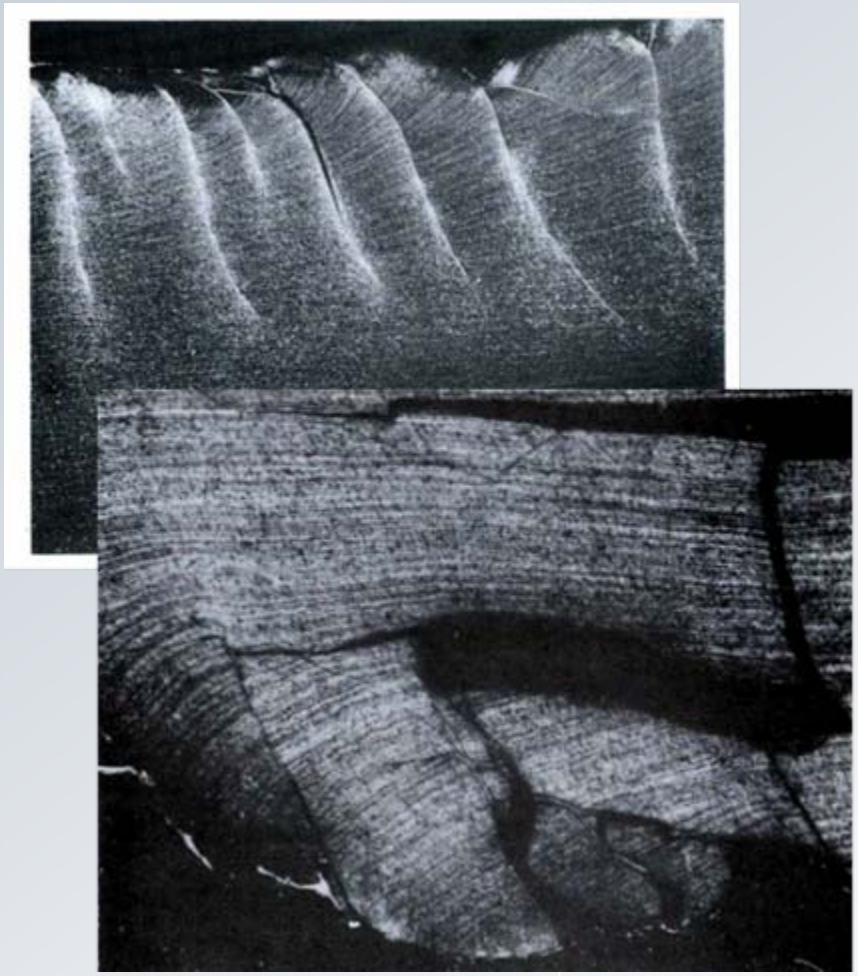
backside
of crater





Micro cracks along the white bands, enrichment of carbid ➔ brittle behaviour





Formation of
ASB

ASB and micro cracks

Austenitic steels: *Hadfield-Steel*

Chem. composition: **13 % Mn und 1.3 % C**

metastable austenitic structure

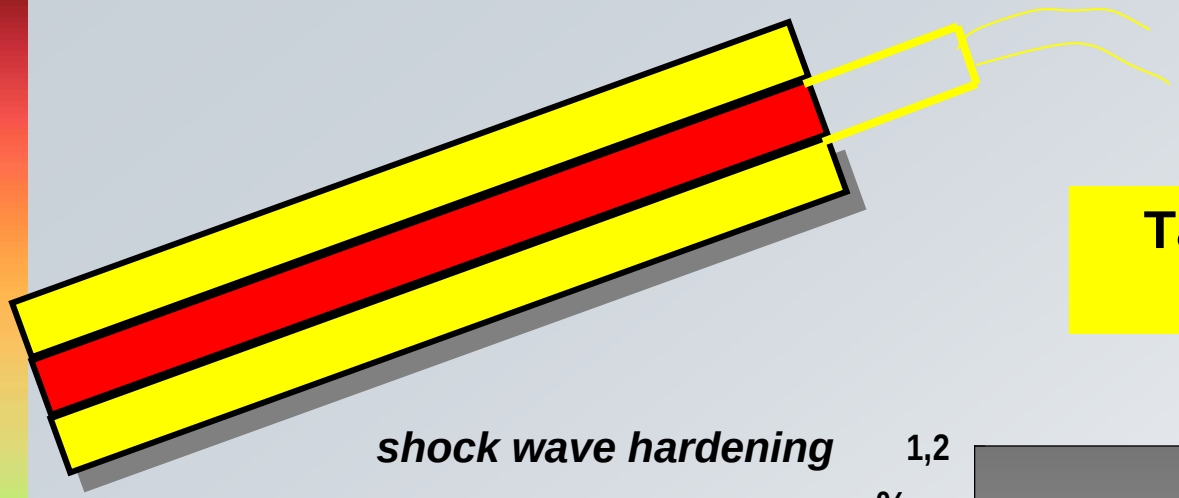
Recommanded for light-weight armour in: MILTECH 5/2007

Initial hardness: 200 HB

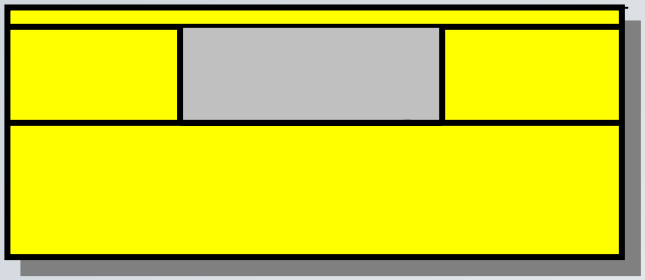
After severe deformation: 500 HB

Strongly strain hardening

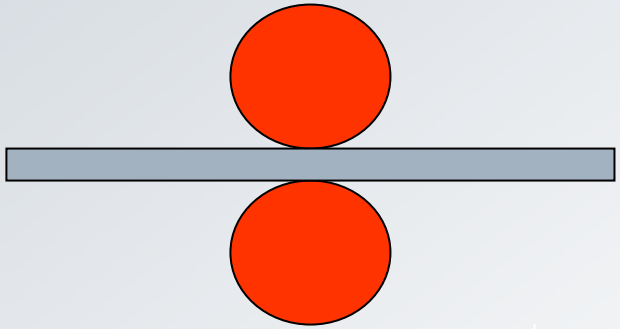
Tailoring of Nitrogen Alloyed Steel



shock wave hardening

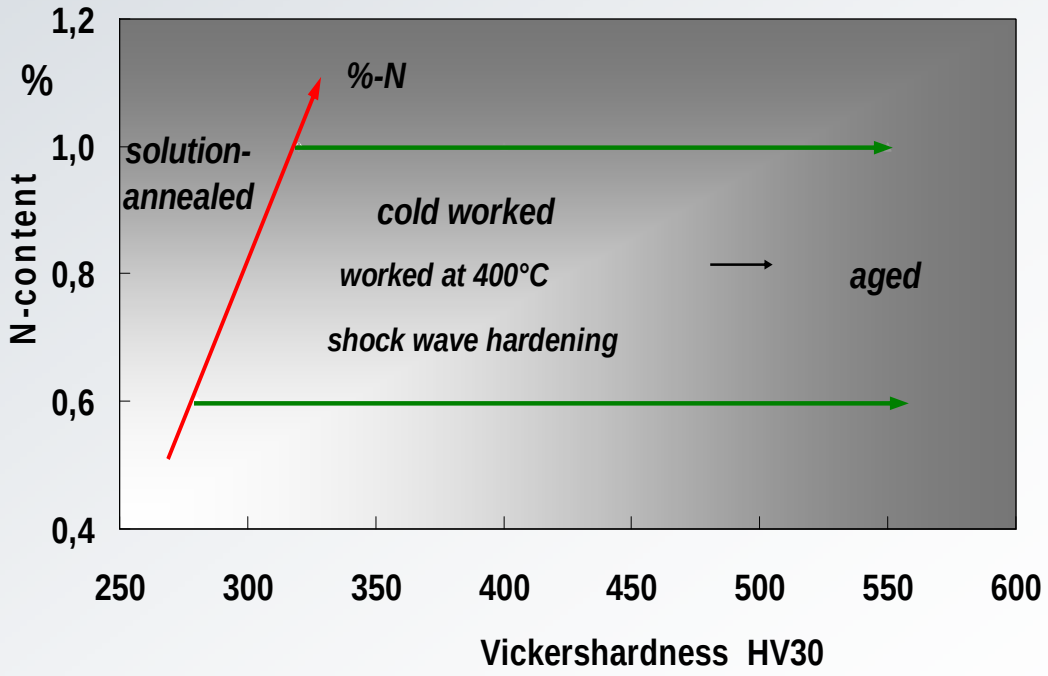


heat treatment

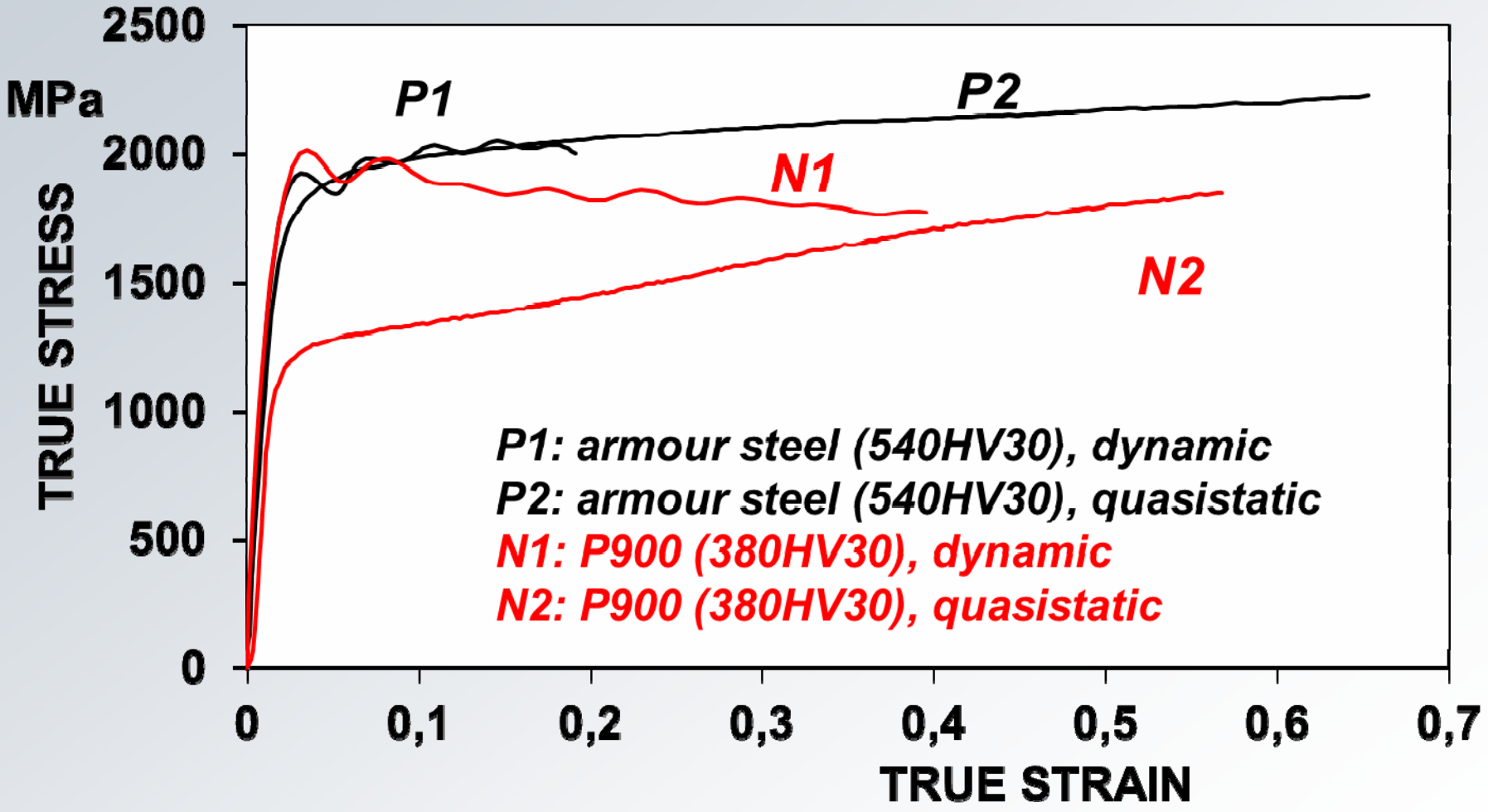


cold working:

rolling, forging

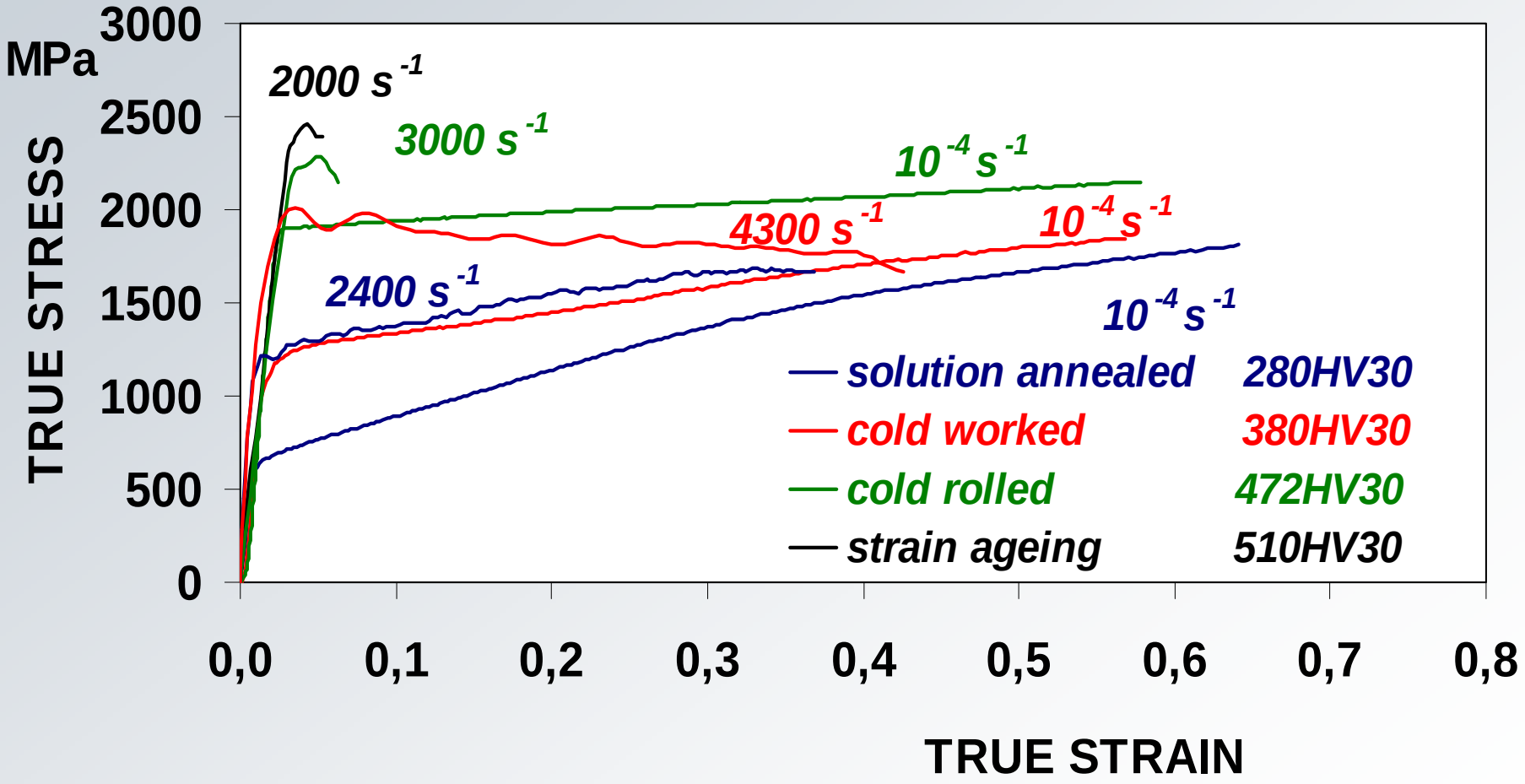


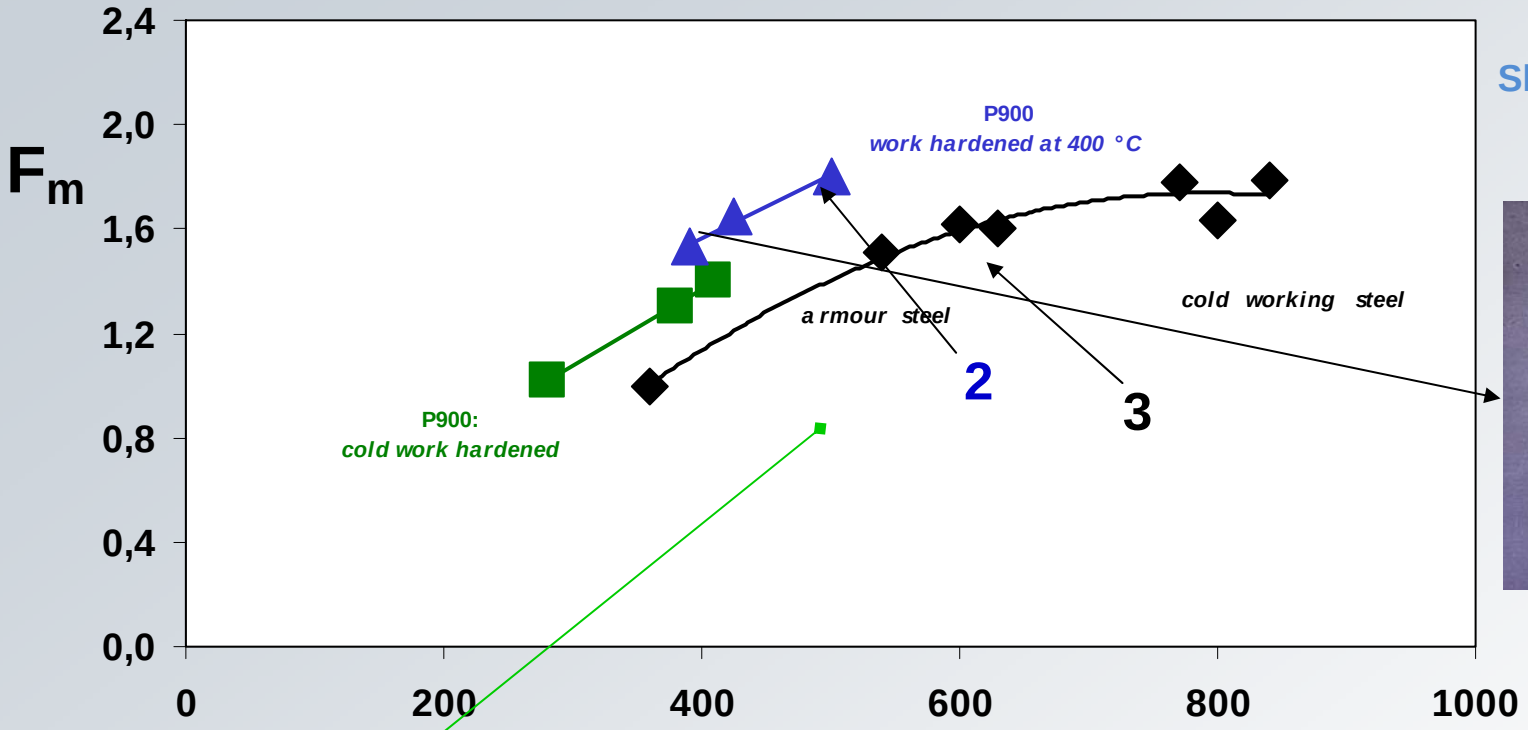
Comparison of HNS and Armour Steel

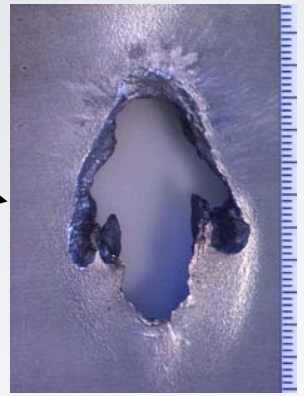


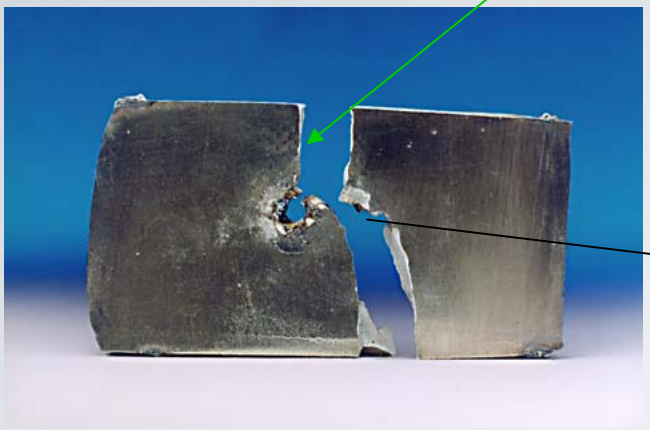
Compression Test on HNS

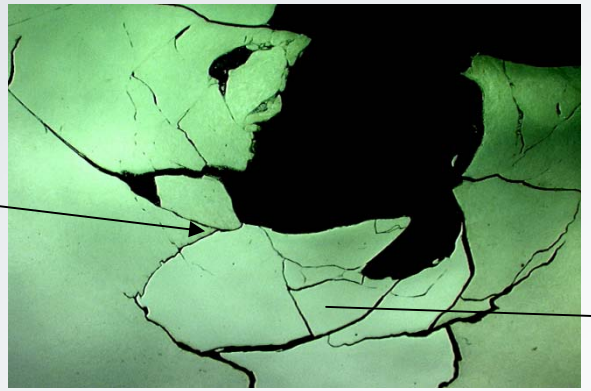
P900 (0.6 % N)

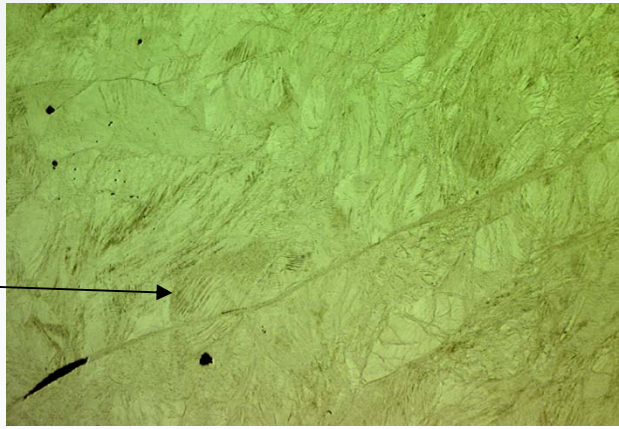








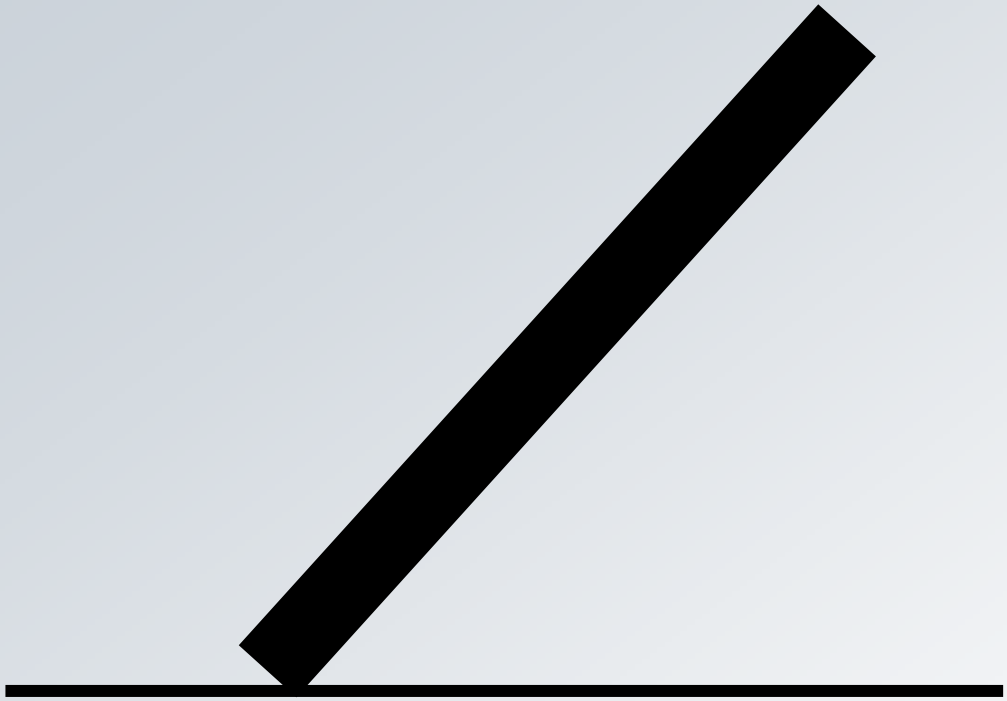




Cold worked and annealed ➔ very brittle under impact condition

Ballistic Test without Cover Plate and Backing

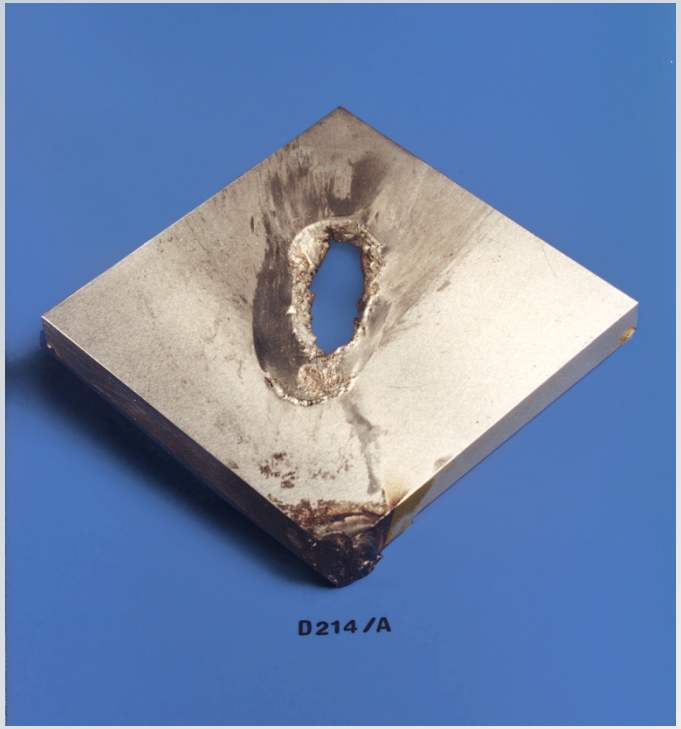
Target NATO 60°



1. Plate: armour steel, treated to 530 HV30
2. Platte: HNS P900, forged at 400 °C to 500 HV30

The ballistic performance of both plates is identical

P900 plate after test without cover plate



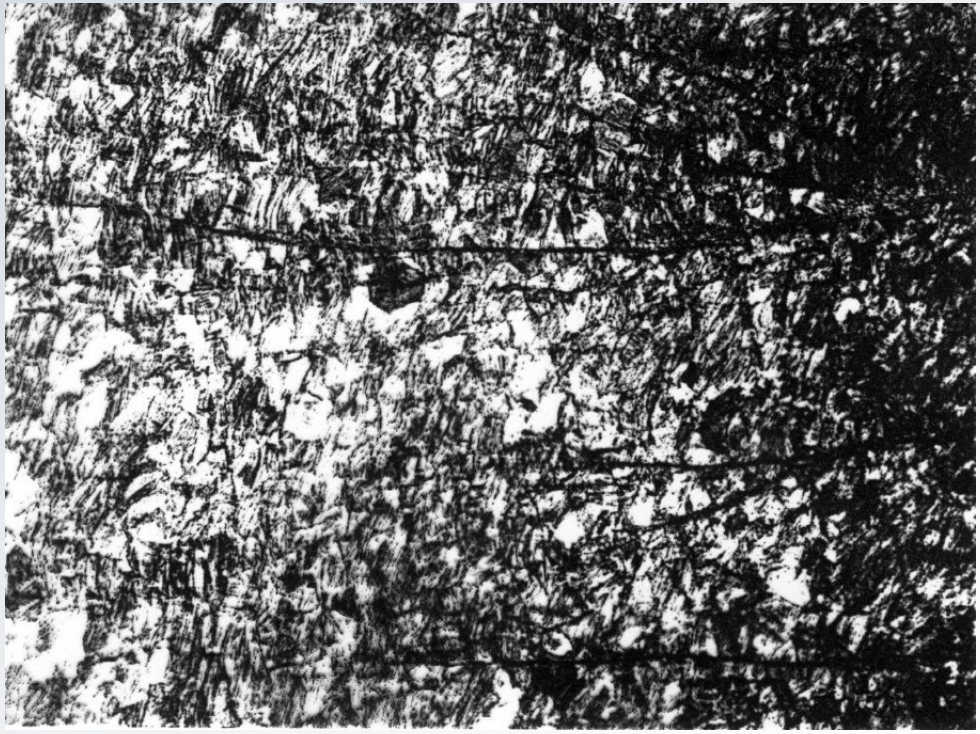
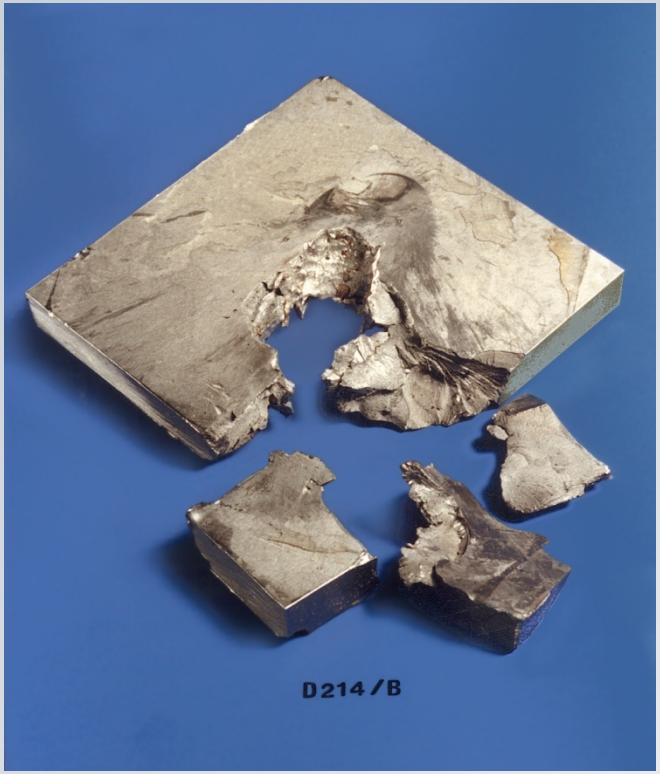
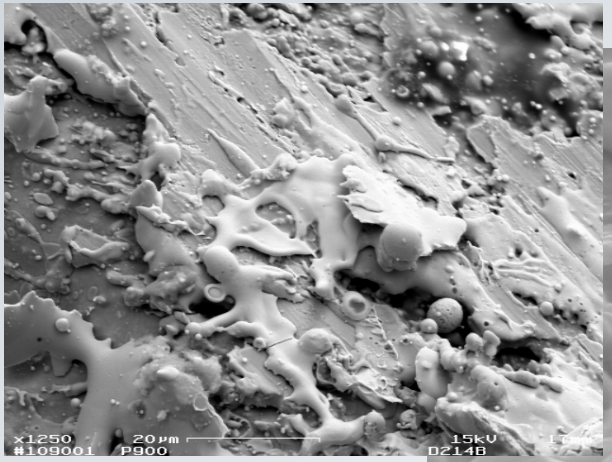


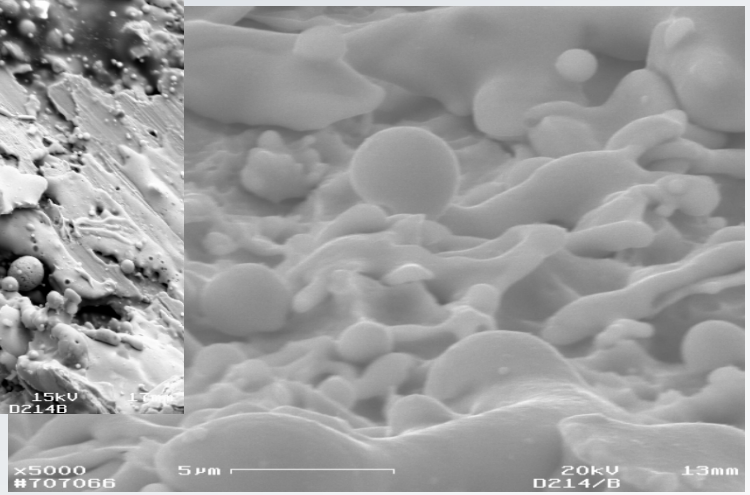
Plate was impacted in the transient and at the onset of steady state region

High density of ASB

P900 plate after test with cover plate



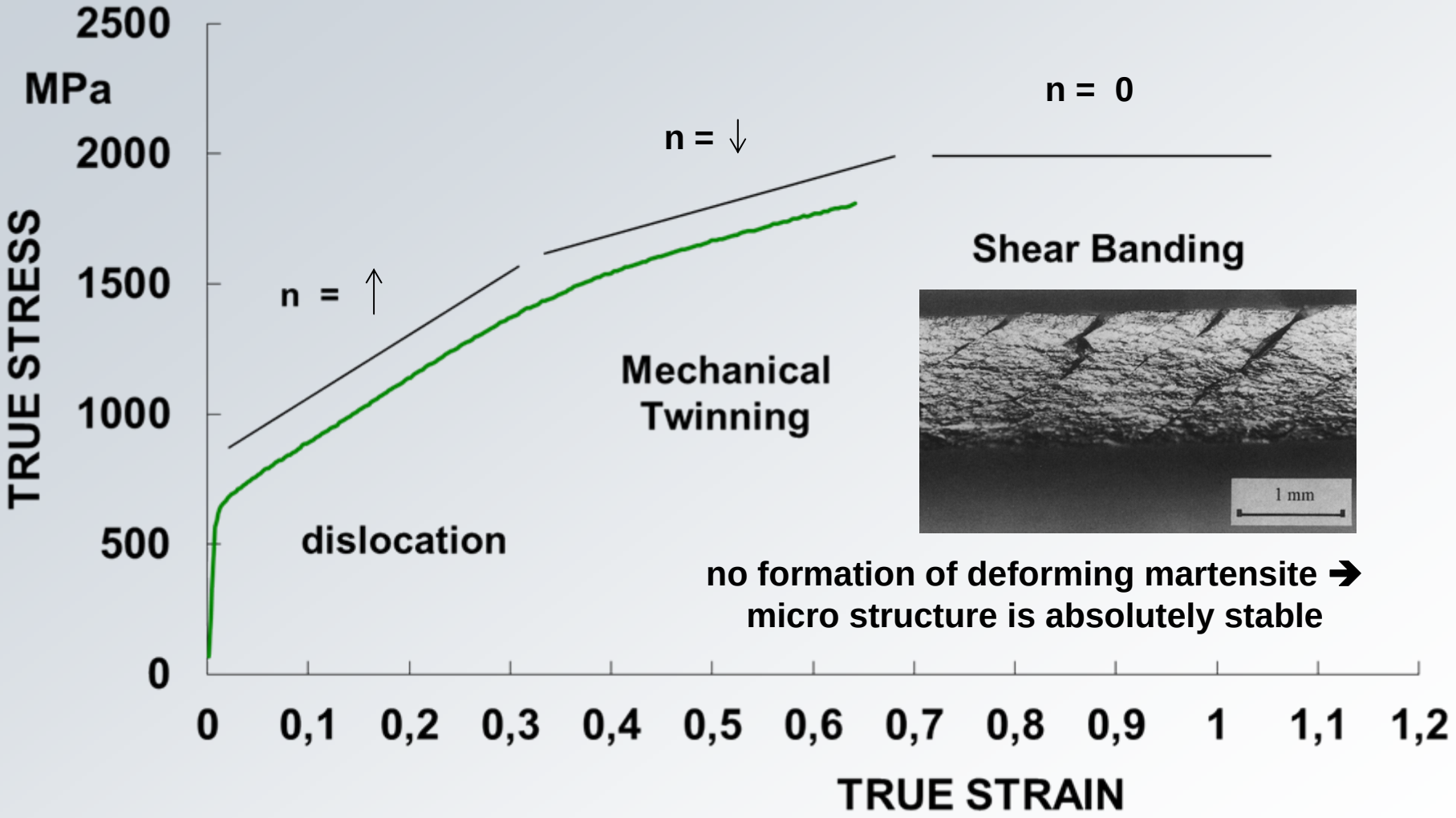




Nr. 2 at 14

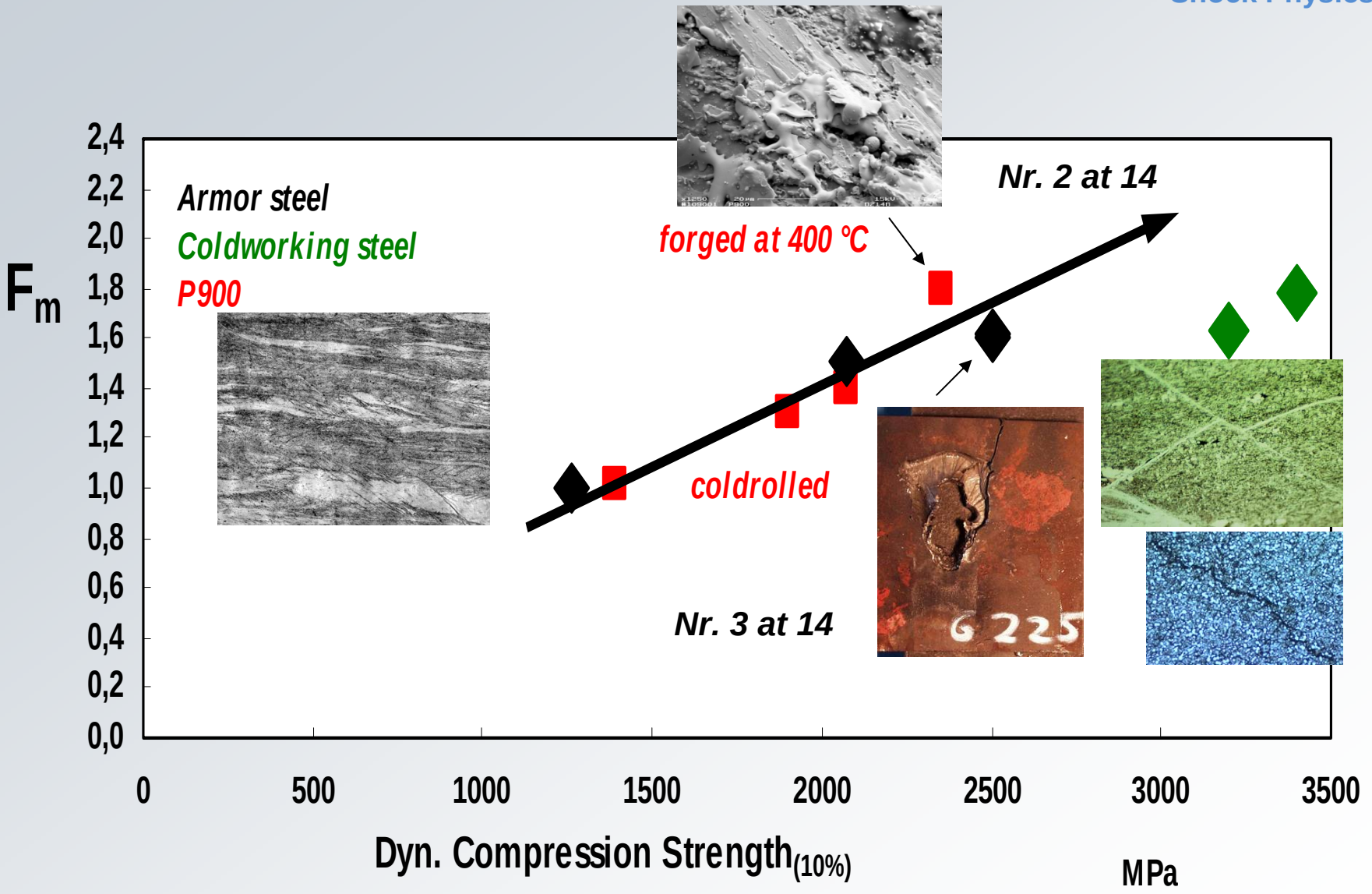
The plate was impacted in the steady state region. Melting of material in ASB‘s.

Micromechanism of HNS

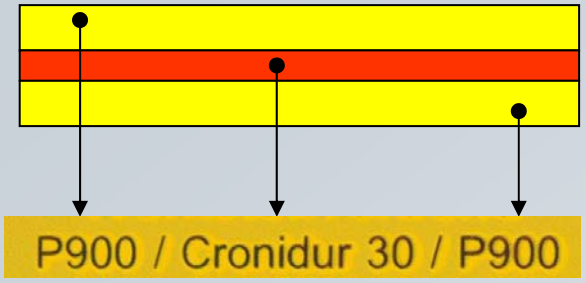


no formation of deforming martensite ➔
micro structure is absolutely stable

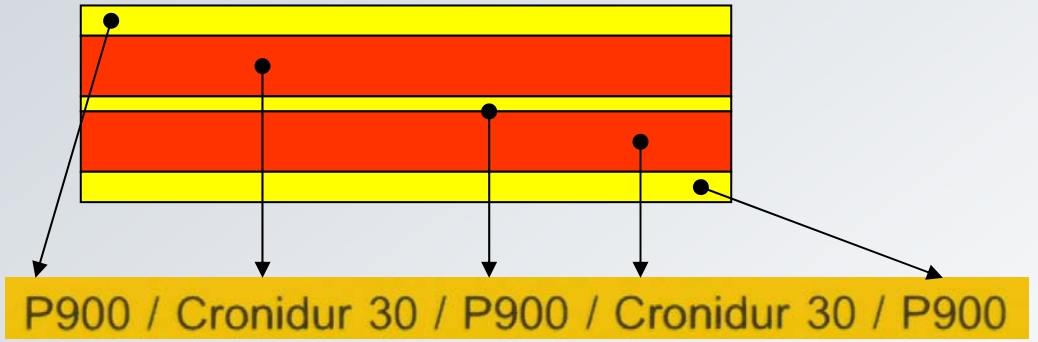
Fm vers. dyn. Compression Strength



Layered Armour
(japanese sword)



4 mm 3 mm 4 mm



2 mm 3 mm 1 mm 3 mm 2 mm

Very High Hardness Steels

melt metallurgy

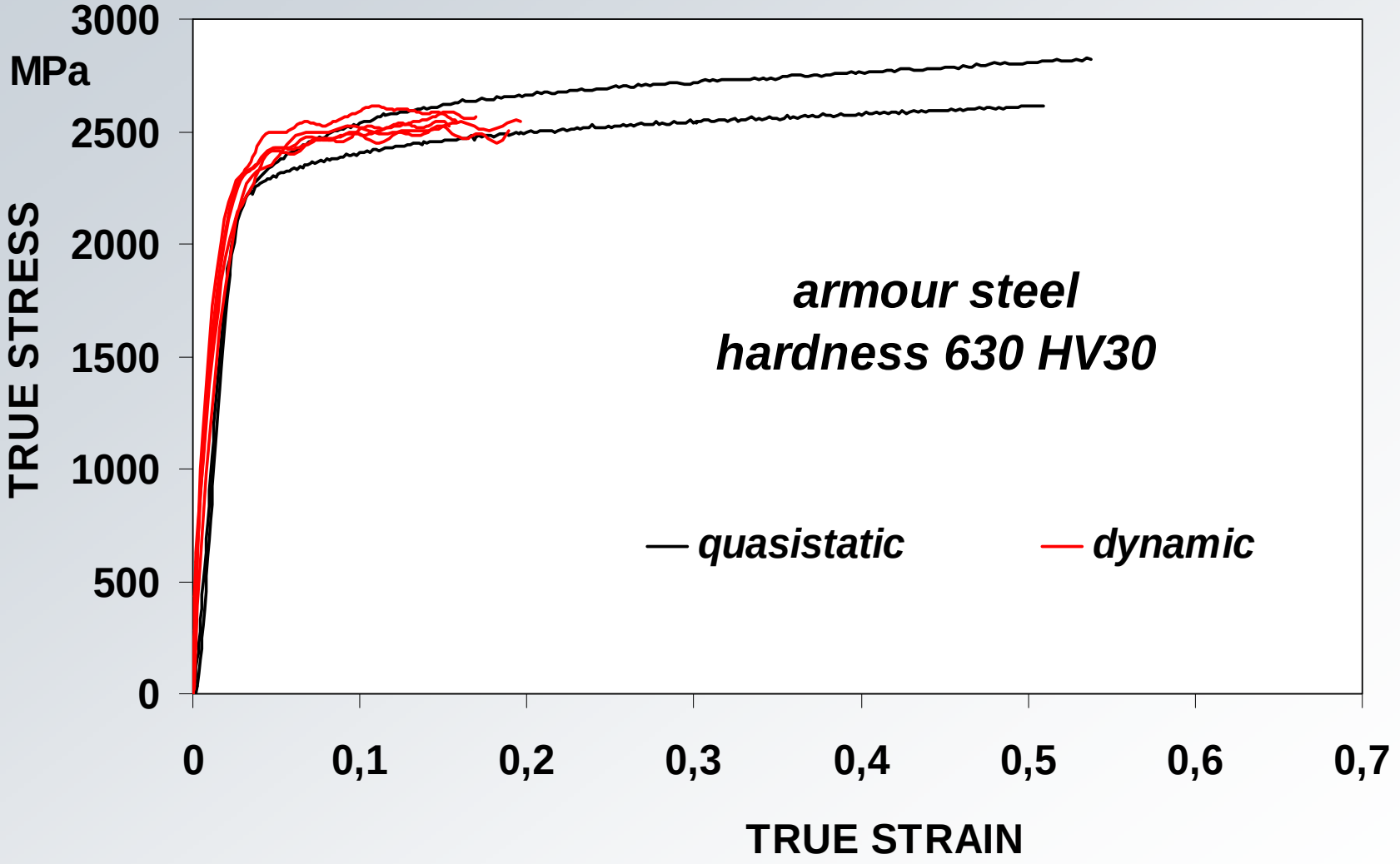
cold working steels

pressureless sintered

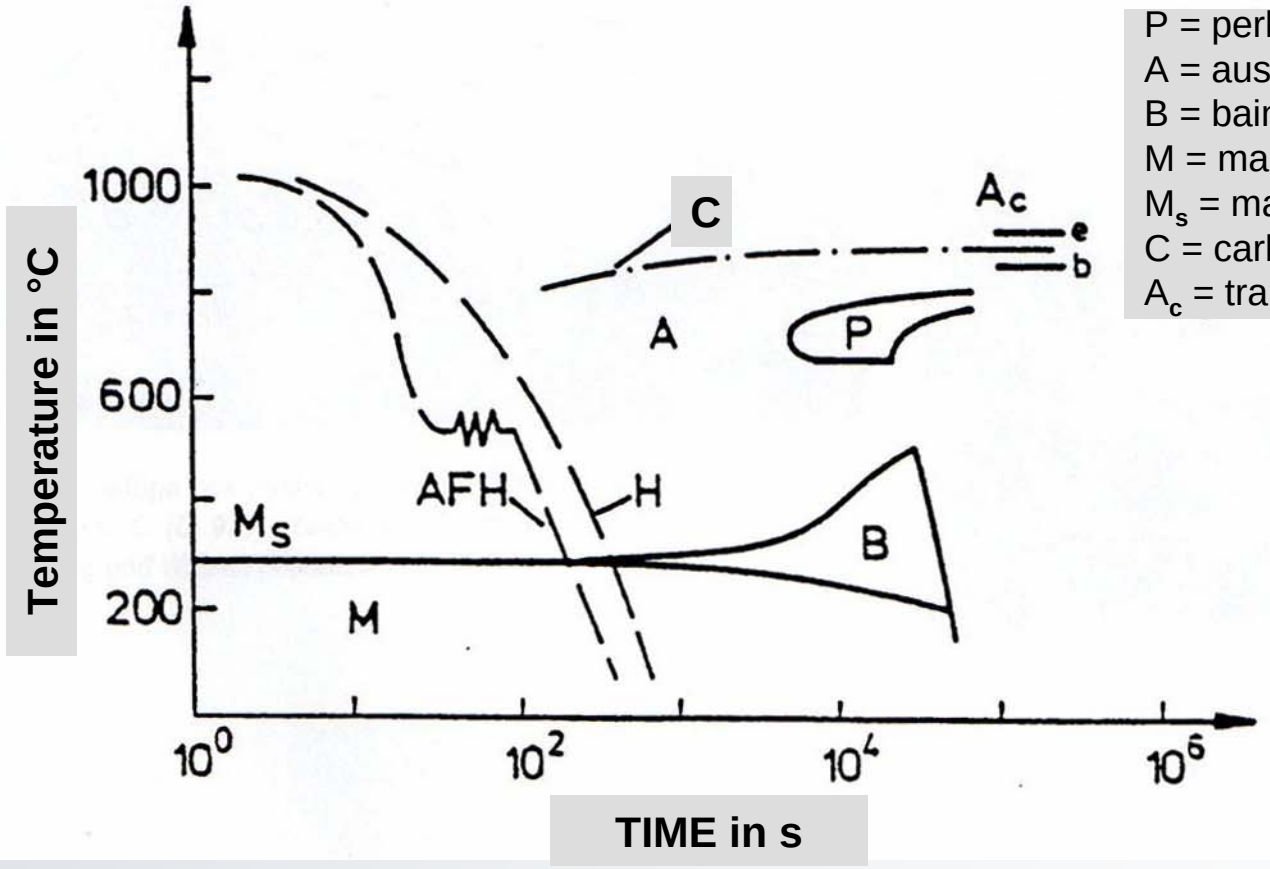
Hot Isostatic Pressed (HIPped)

In general are these steels are too brittle

Compression tests on Mars 300



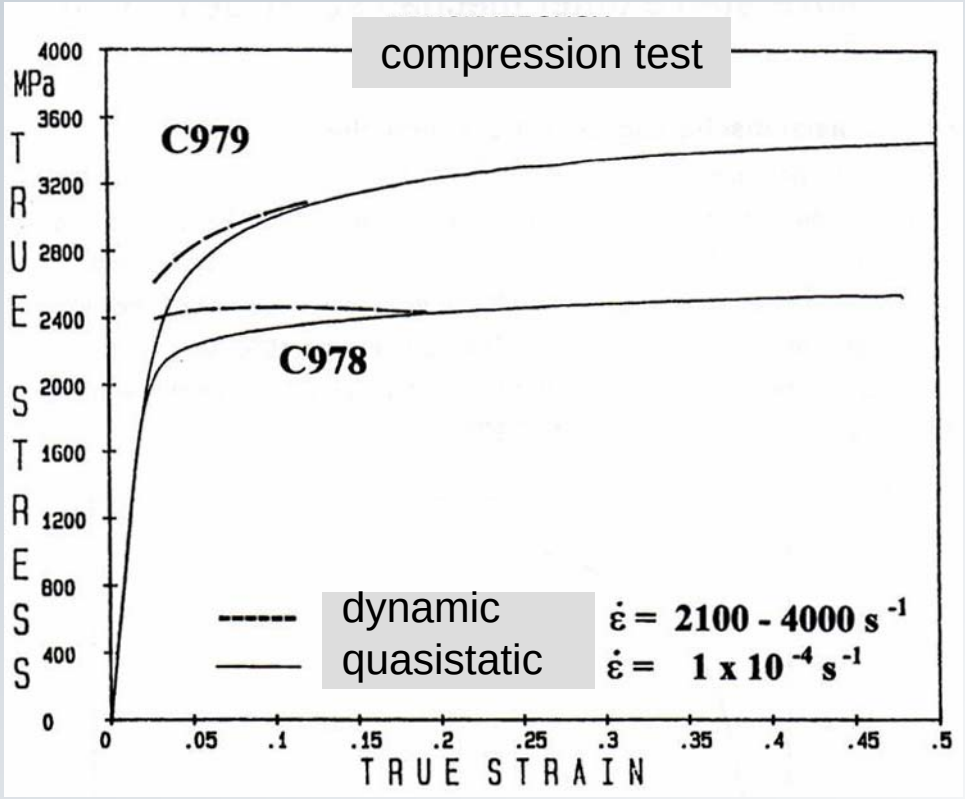
Ausforming Steel



P = perlit nose
A = austenite
B = bainite
M = martensite
M_s = martensite start
C = carbid
A_c = transition temperature

ausforming (AFH) and hardening (H)

Ausforming steels

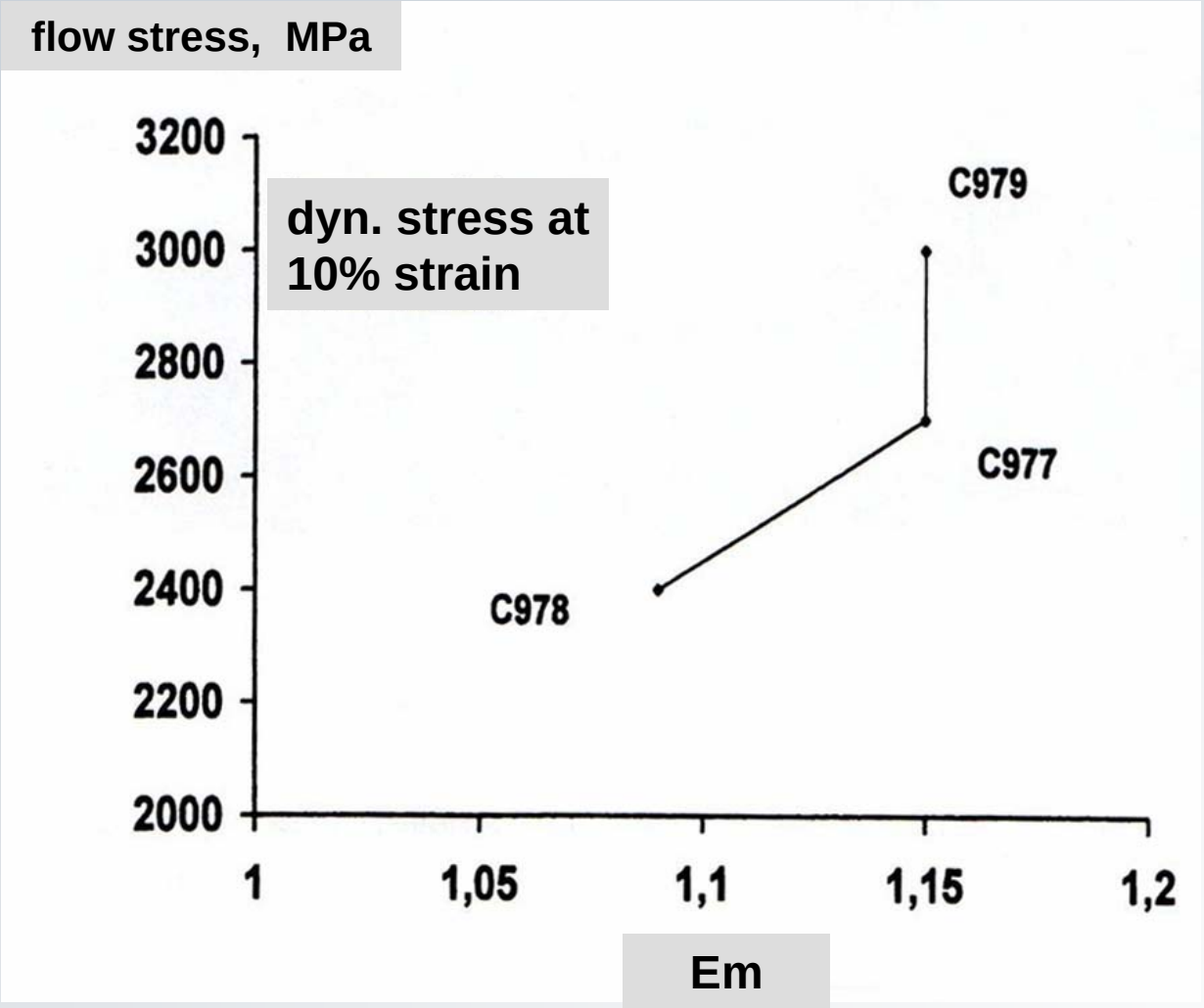


C978: 35NCD16

C979: 45NCD16

(french Norm)

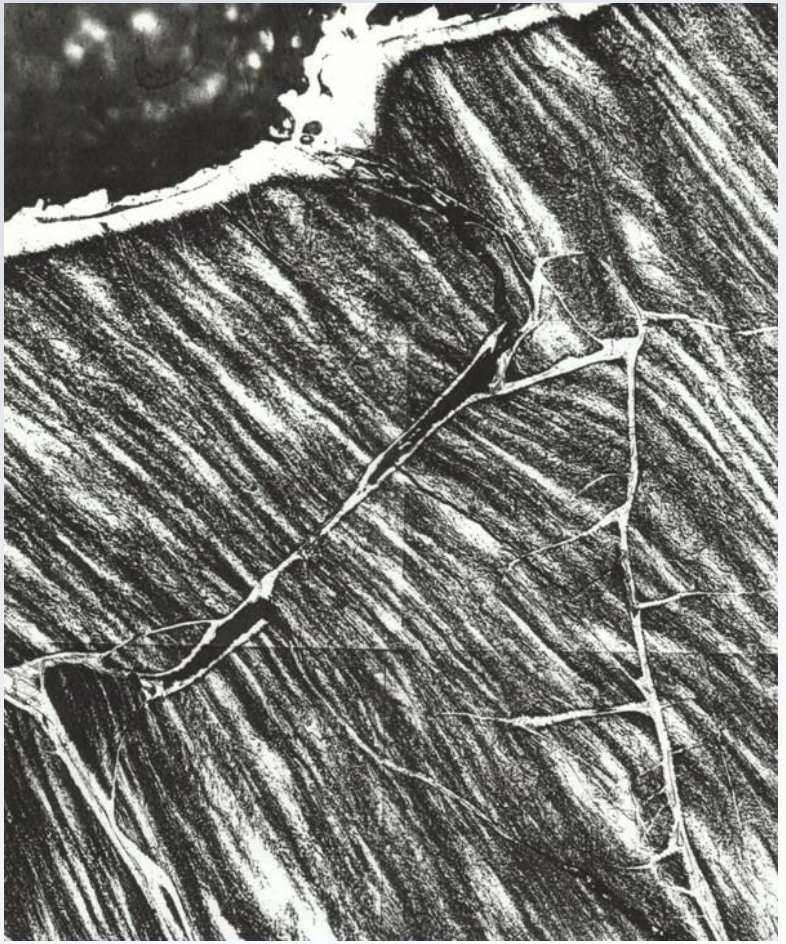
Comparison of high-strength steels



C979: 45NCD16
C977: Mars 300 (0.45 C)
C978: 35NCD16

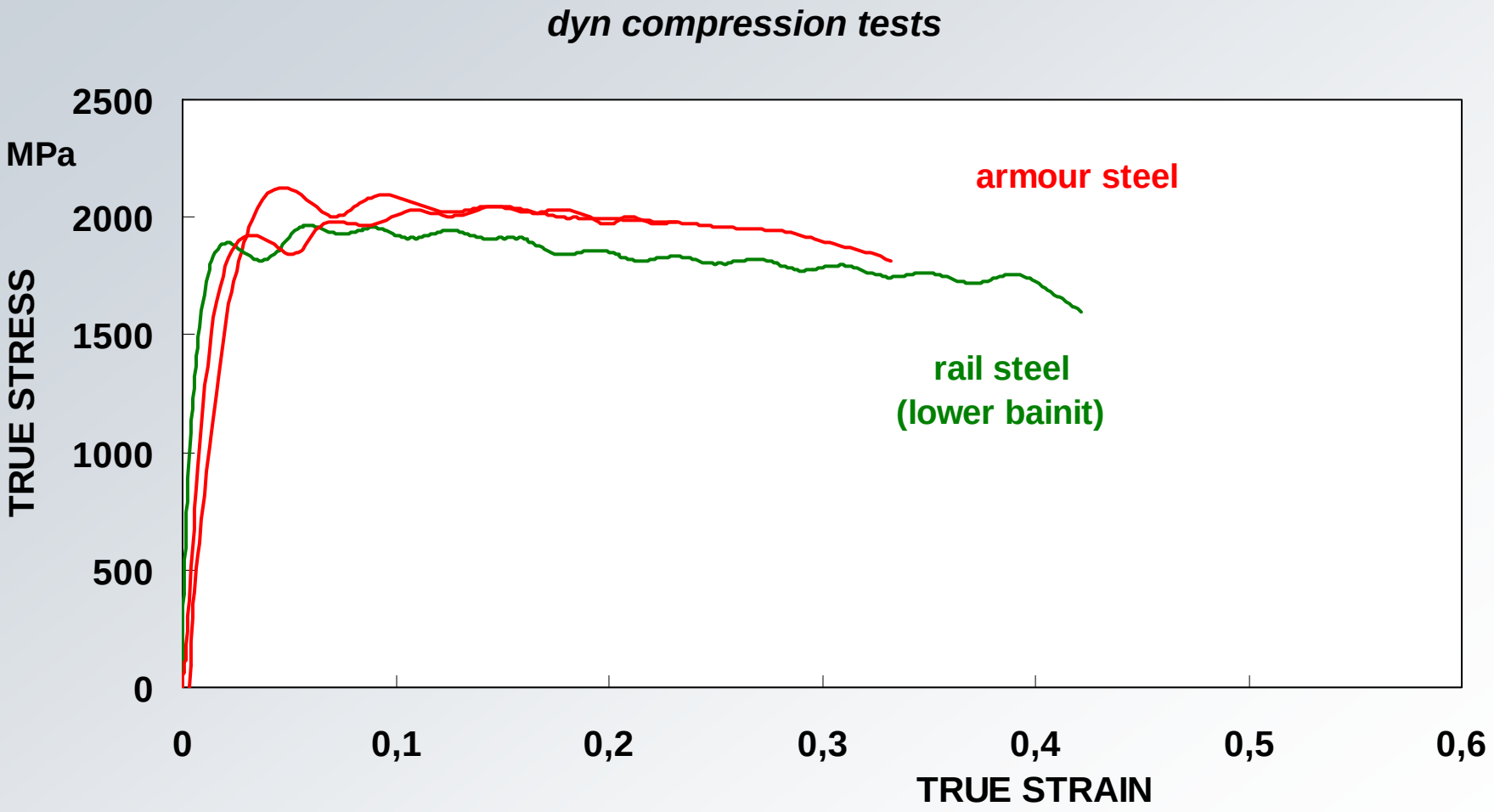
Formation of ASB in high-strength steels

MARS 300

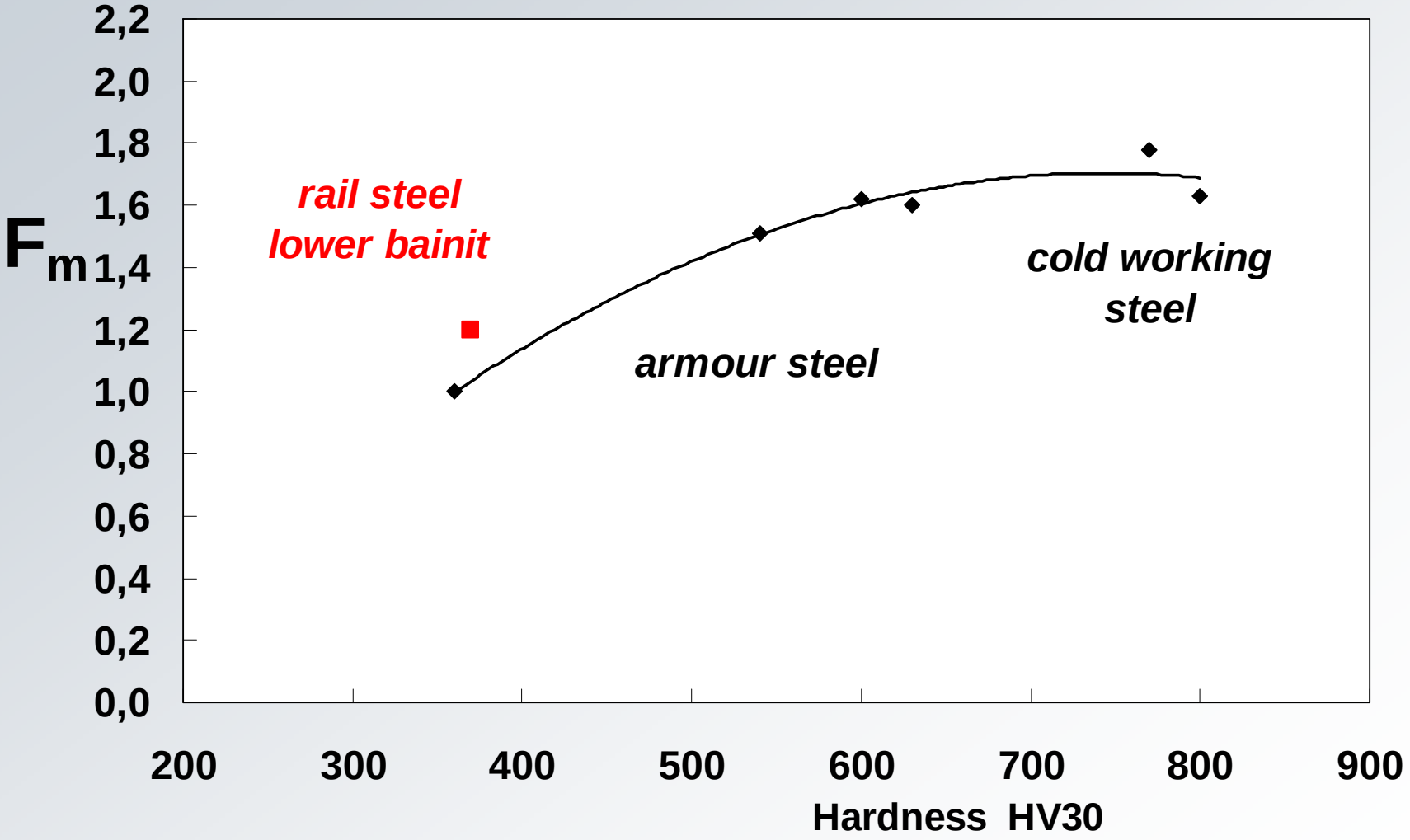


45NCD16

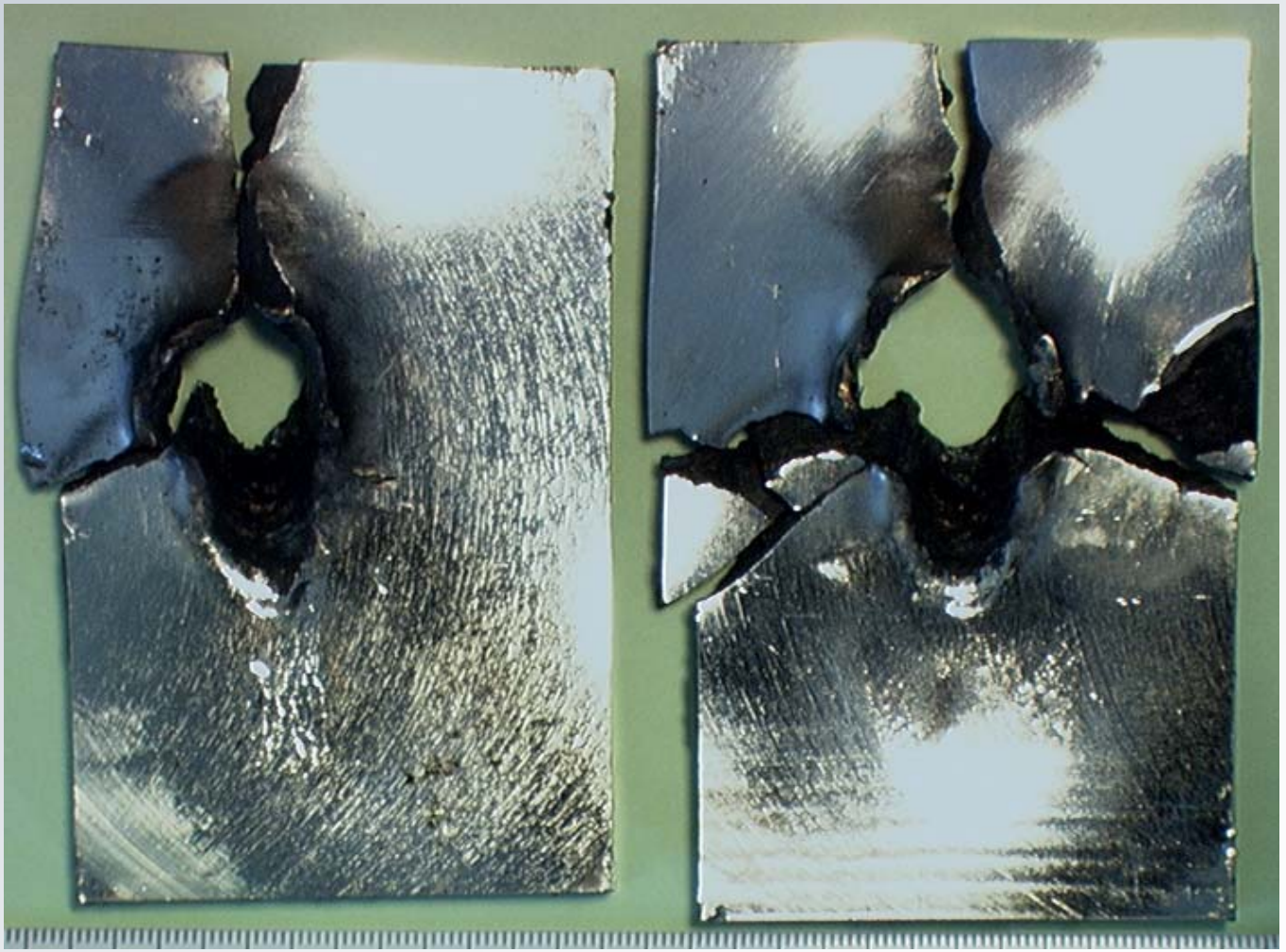
Bainitic steels (lower bainit)



Bainitic steel

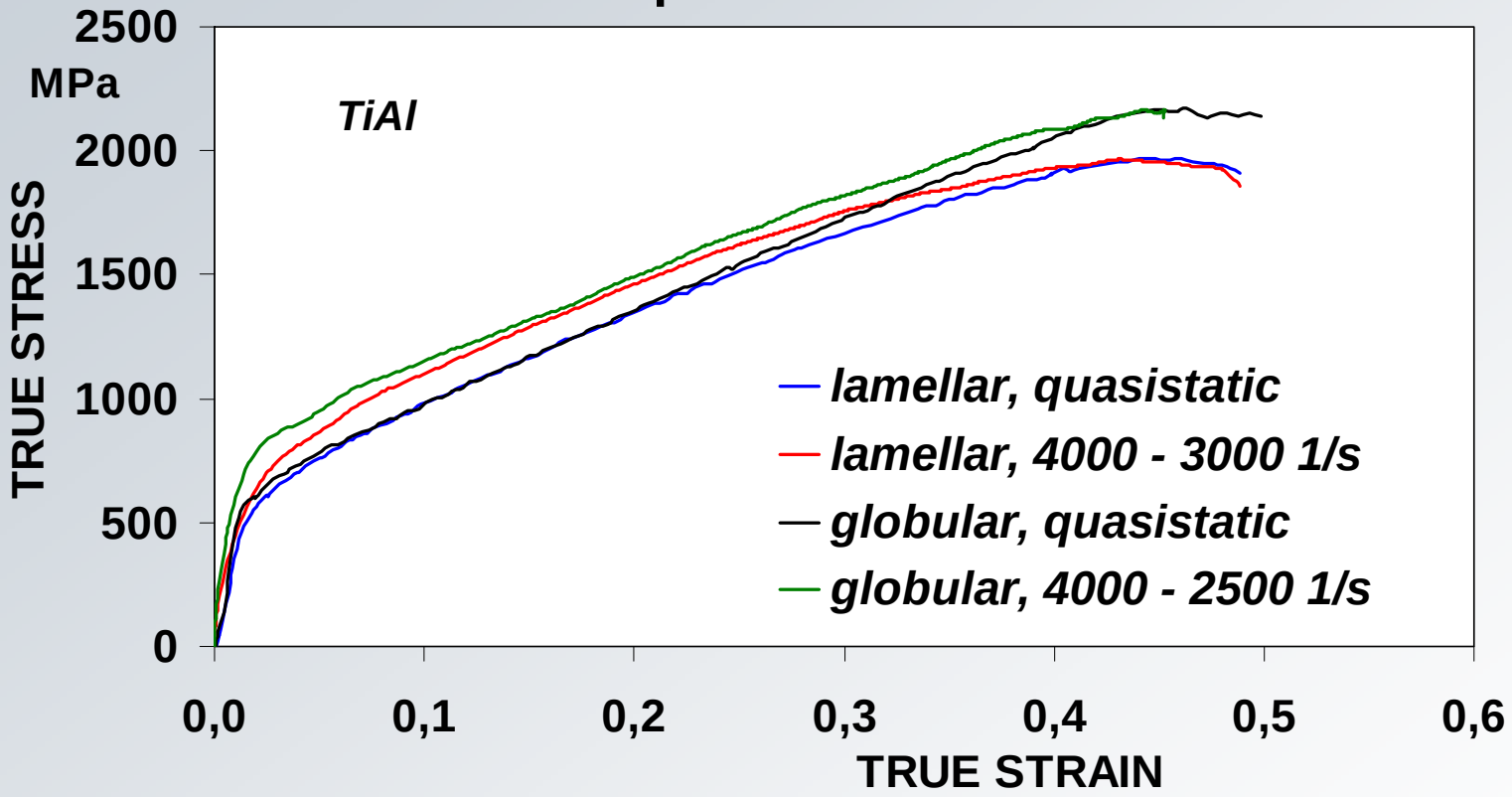


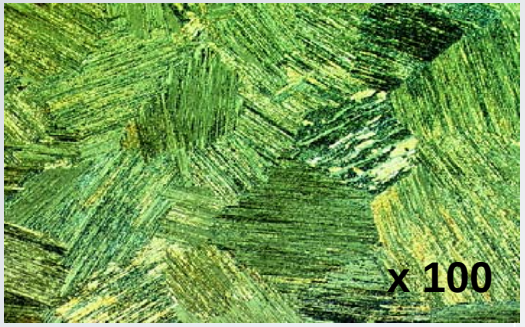
Lower bainit is brittle



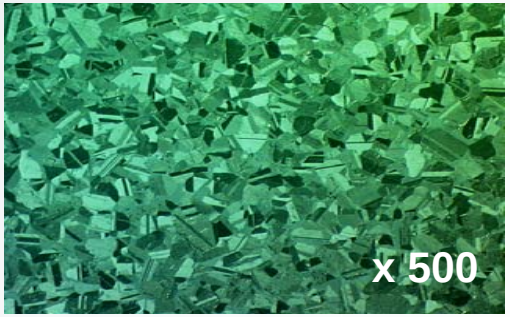
γ-TiAl

Compression test

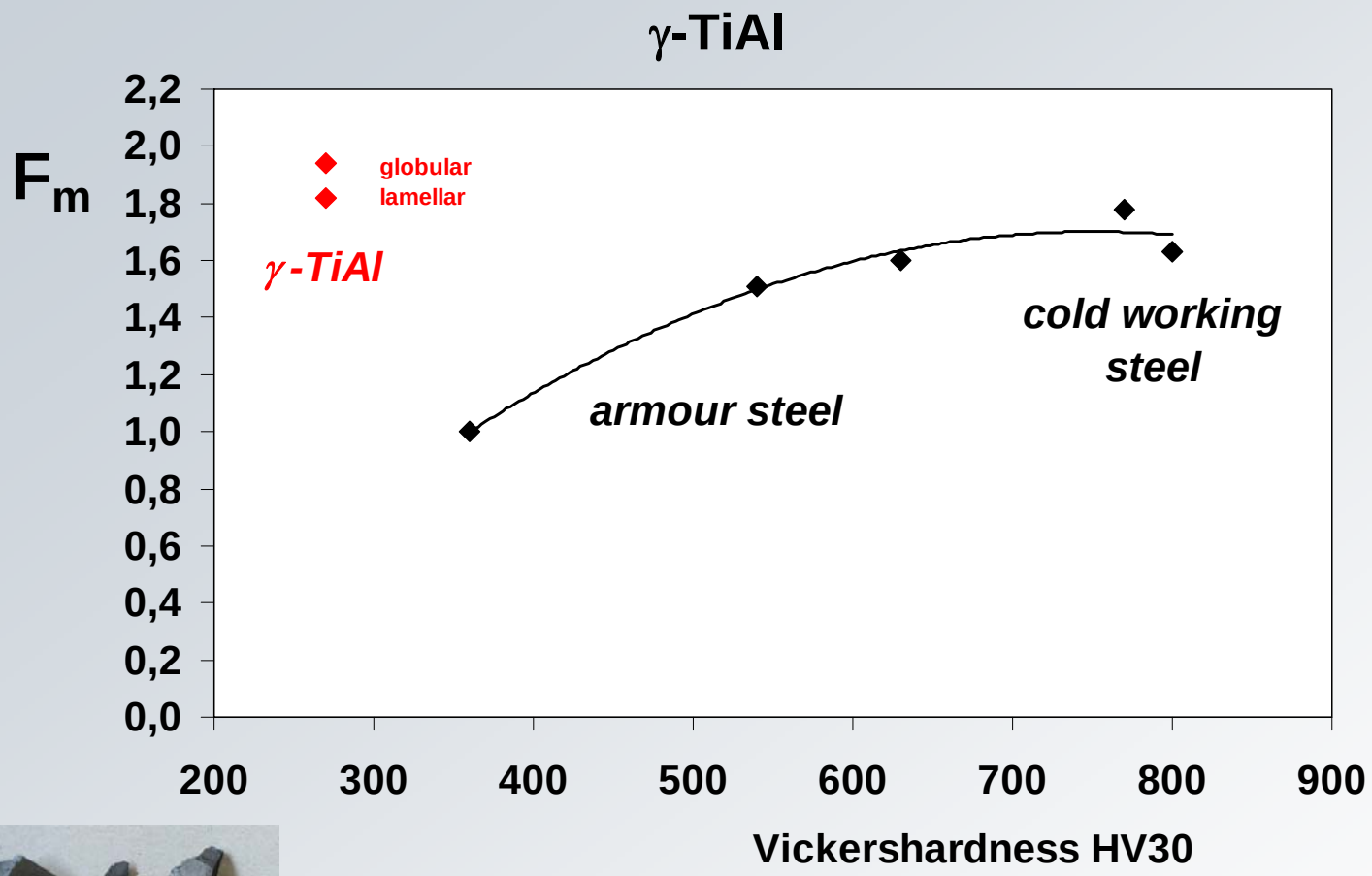




lamellar
micro
structure

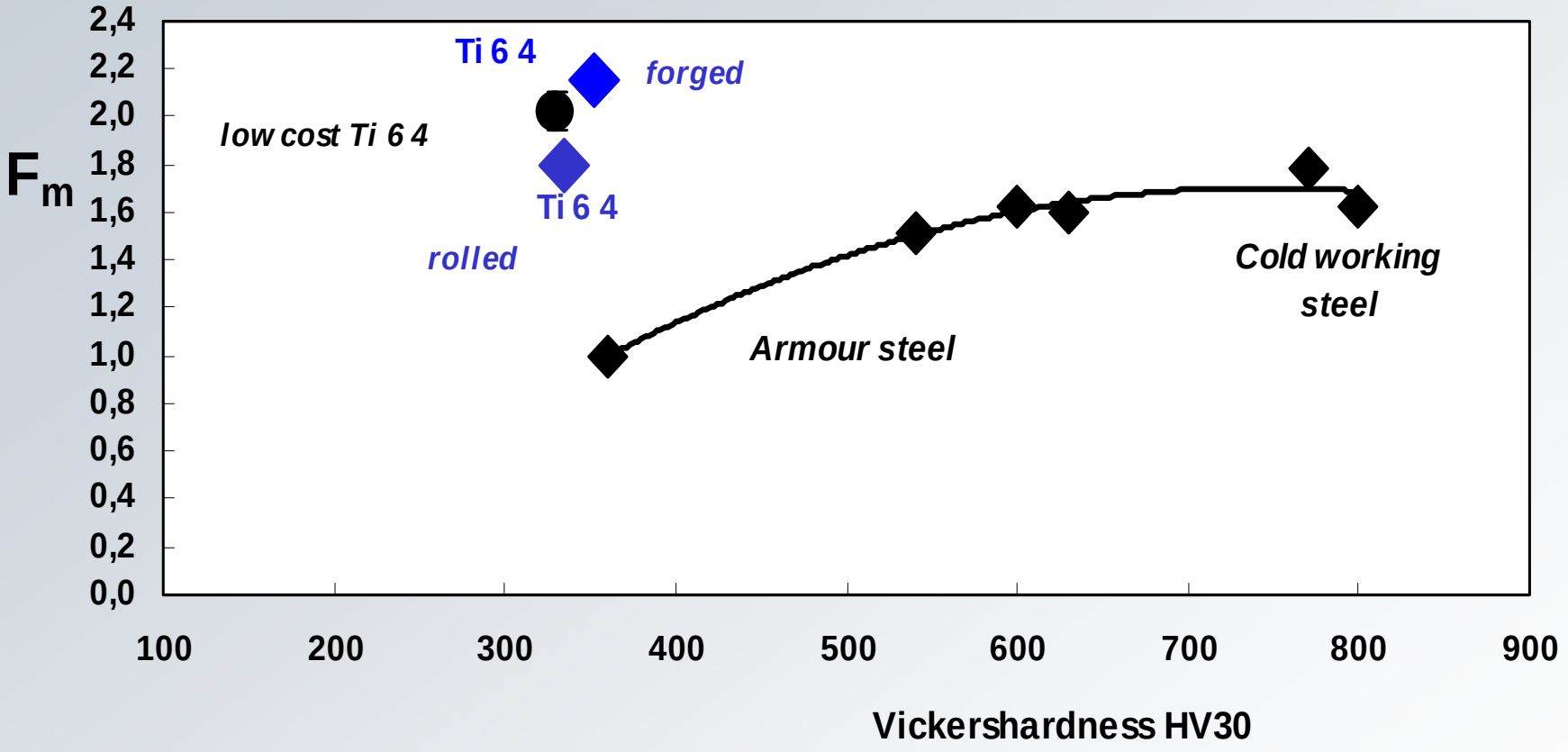


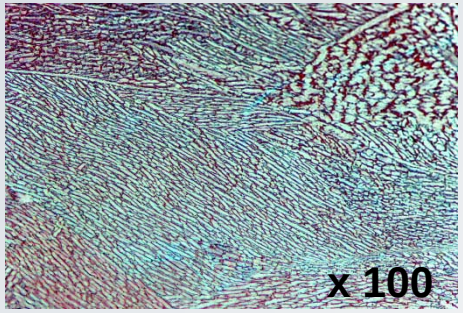
globular
micro
structure



After the ballistic test

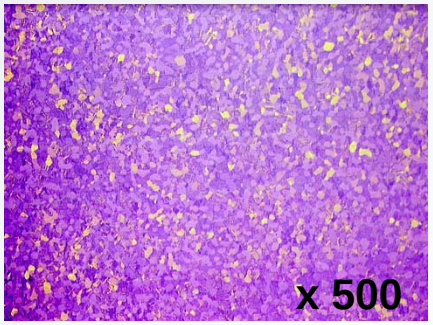
Ti alloy Ti 6 4





rolled, lamellar micro structure

slow cooling rate



forged, globular micro structure

recrystallisation

Ti 17 alloy *(thermomechanical treatment)*

specimen 26: $\varphi = 0.7$ **solution annealing T = 820 °C 4 h**
tempern T = 680 °C 8 h, hardness: 391 HV30

specimen 27: $\varphi = 0.7$ **solution annealing T = 820 °C 4 h**
tempern T = 580 °C 8 h, hardness: 463 HV30

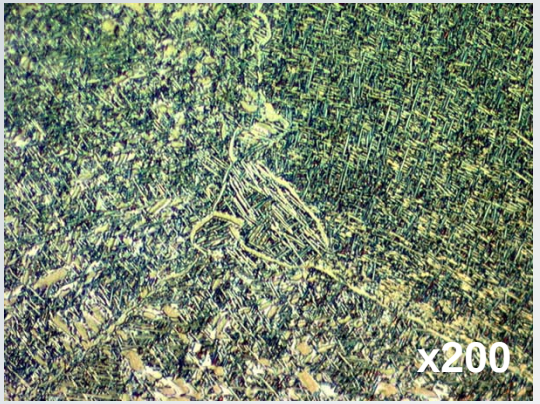
specimen 28: $\varphi = 0.9$ **solution annealing T = 910 °C 1 h**
tempern T = 560 °C 8 h, hardness: 507 HV30

specimen 29: $\varphi = 0.9$ **solution annealing T = 910 °C 1 h**
tempern T = 680 °C 8 h, hardness: 387 HV30

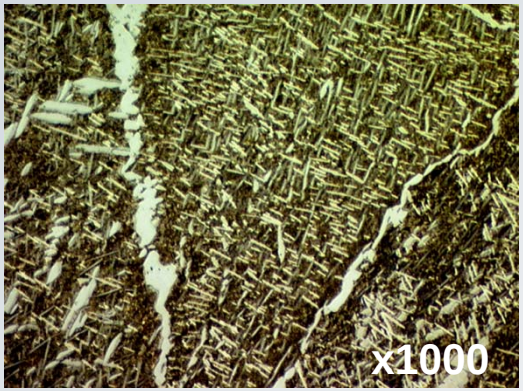
Al	Sn	Zr	Cr	Mo	O	N	C	H
4.9	2	2.04	4	3.94	0.47	0.004	0.016	0.006

Different treated Ti 17

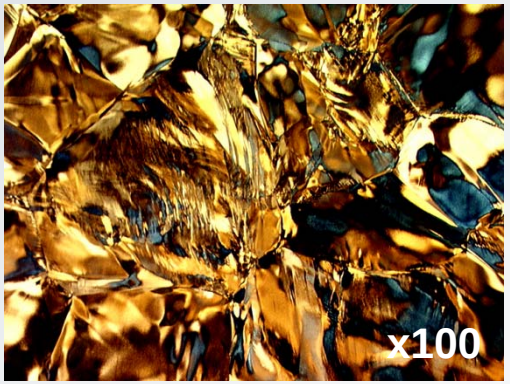
initial micro structure



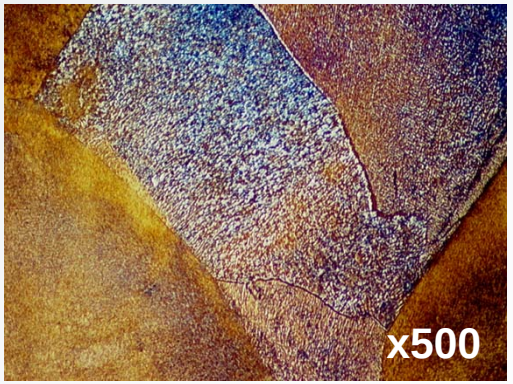
specimen 26



specimen 27

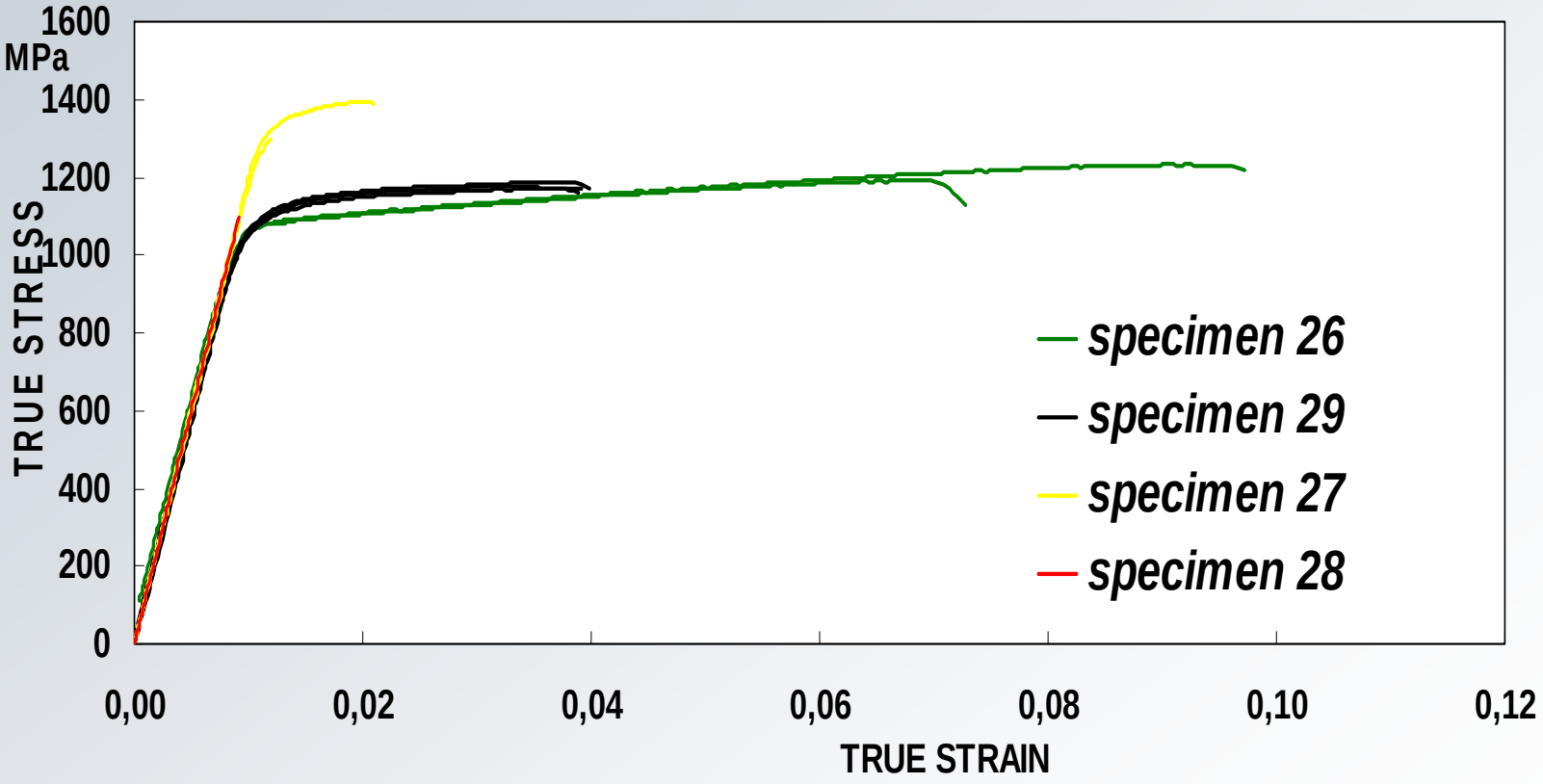


specimen 28

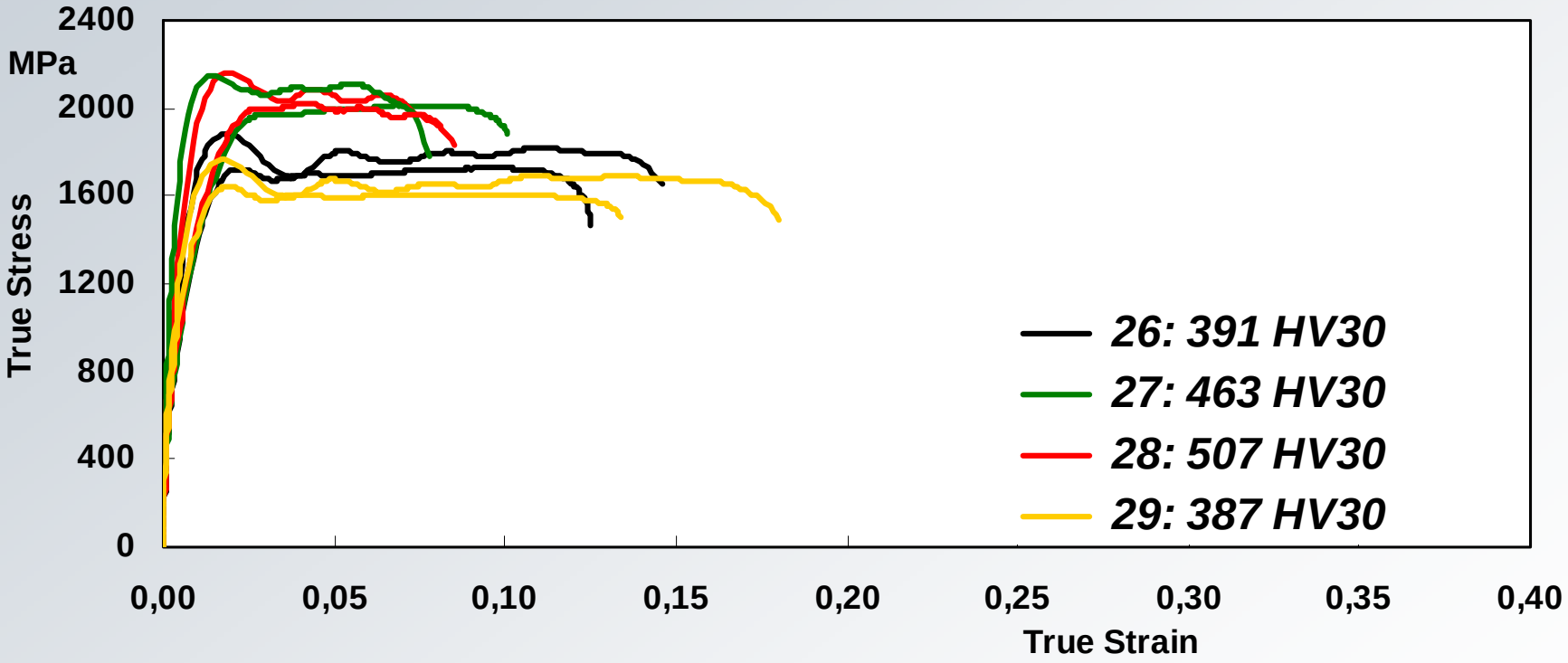


specimen 29

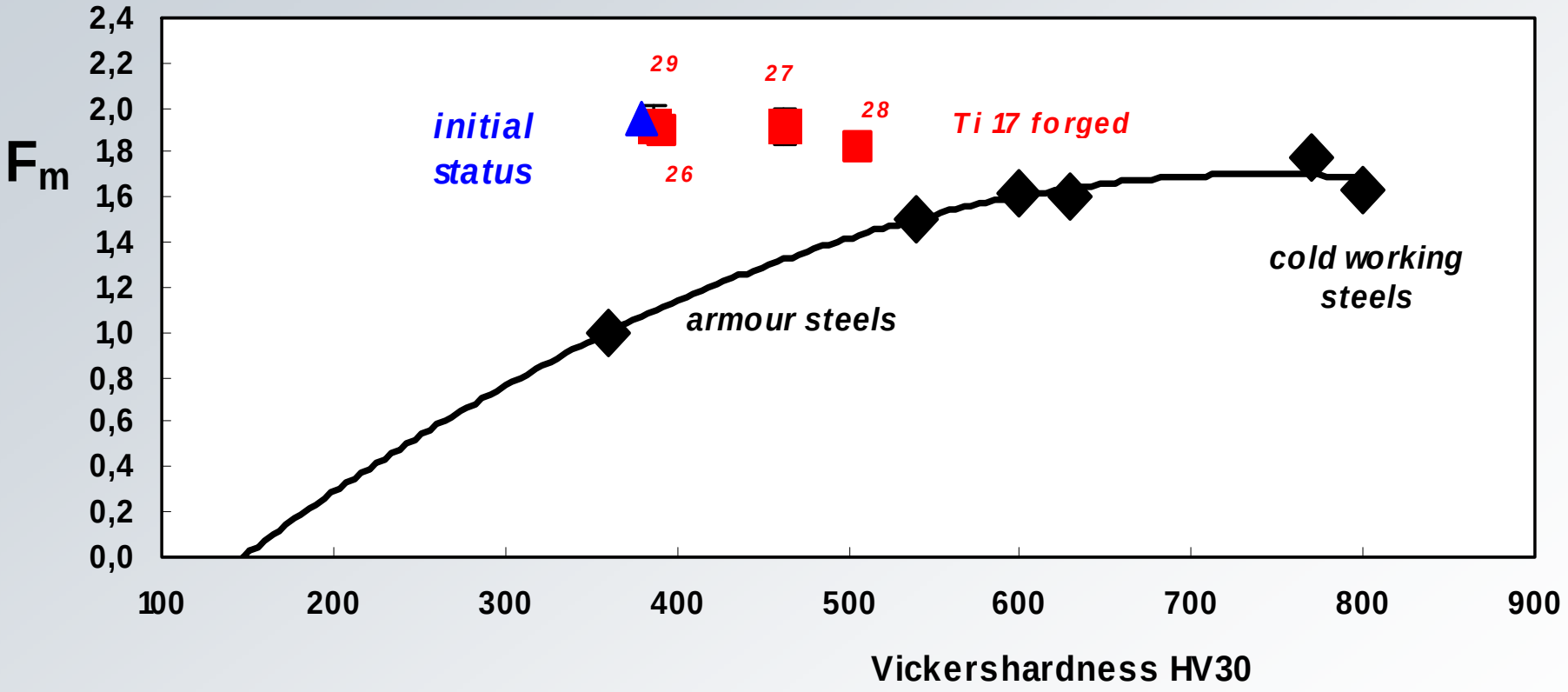
Quasistatic tensile test



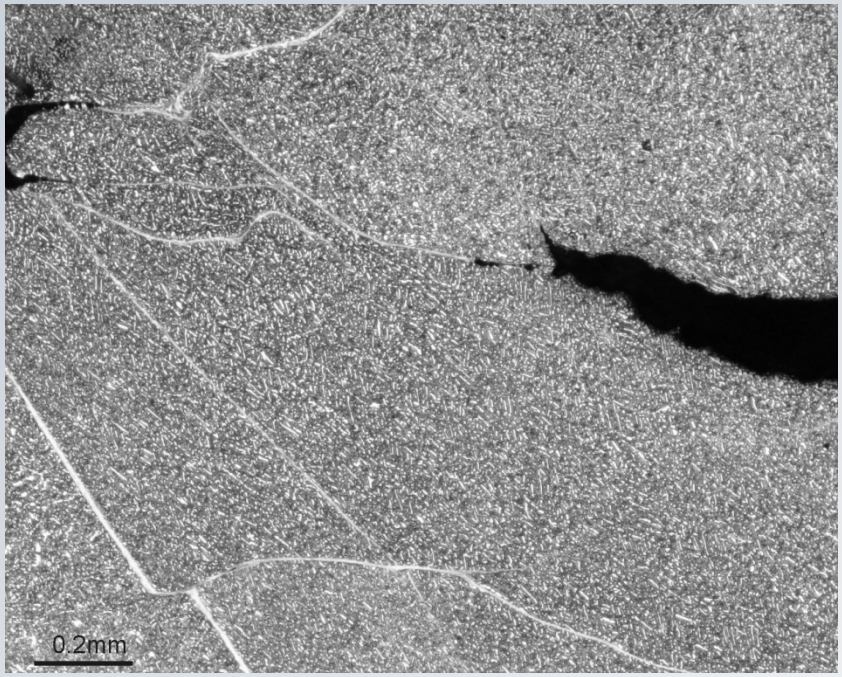
Dyn. Compression Test

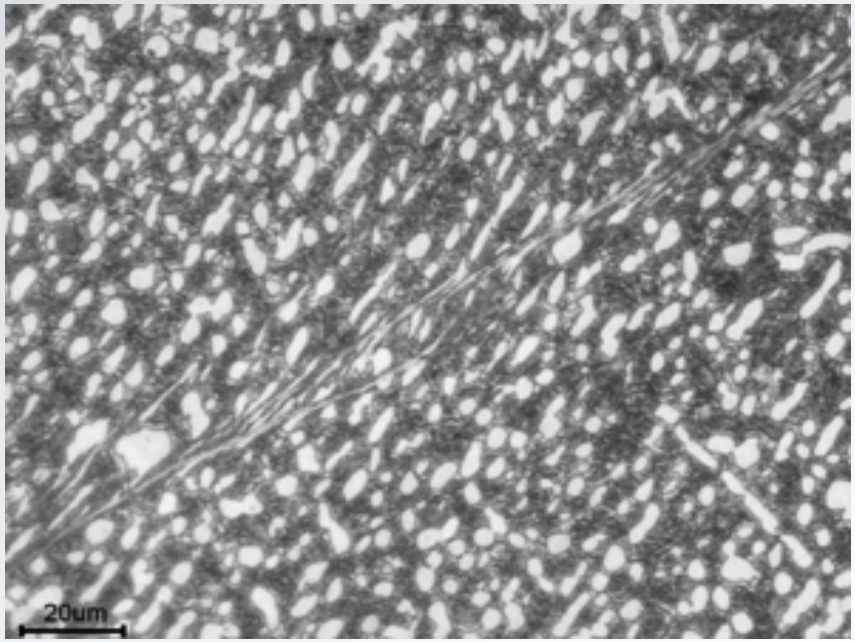


Ballistic Tests



Ti alloy Ti17





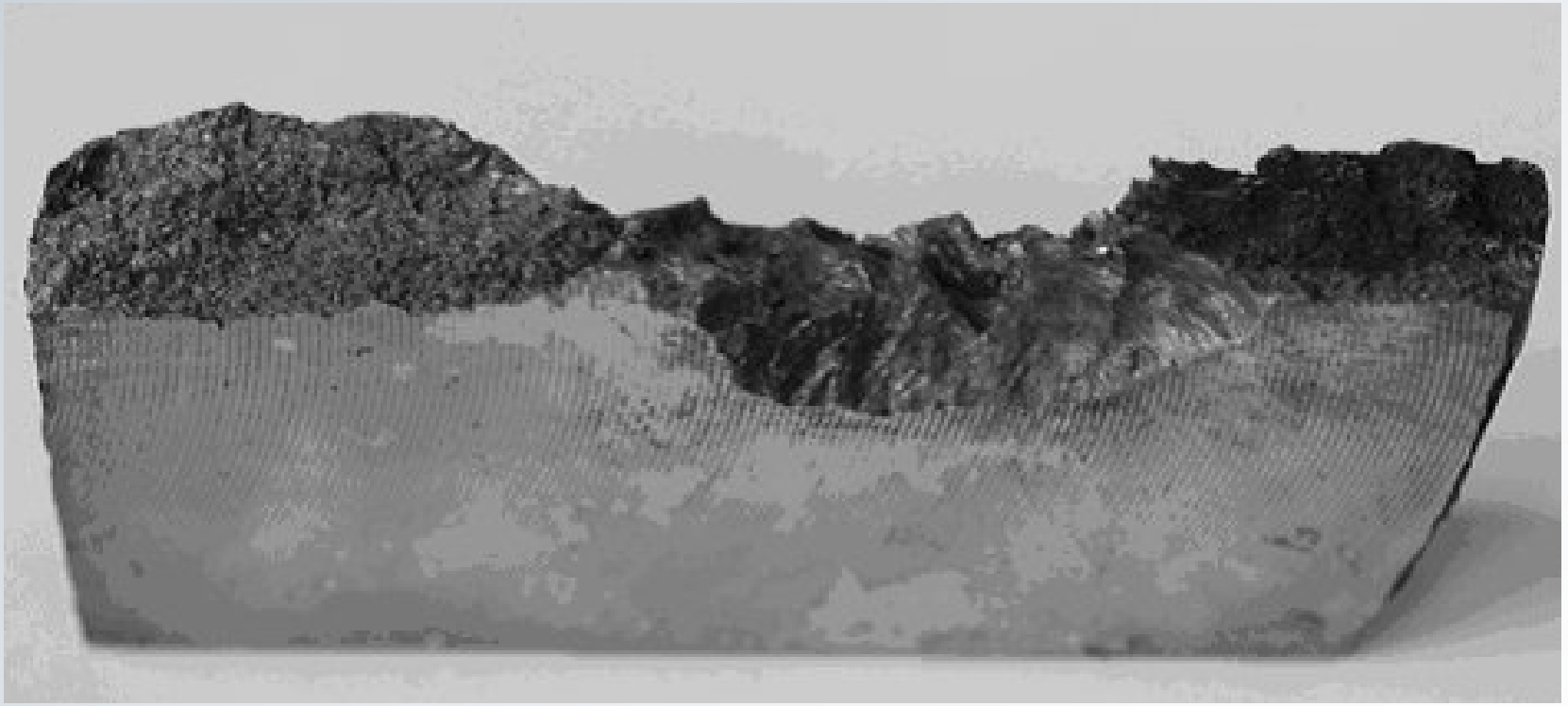
Initial status

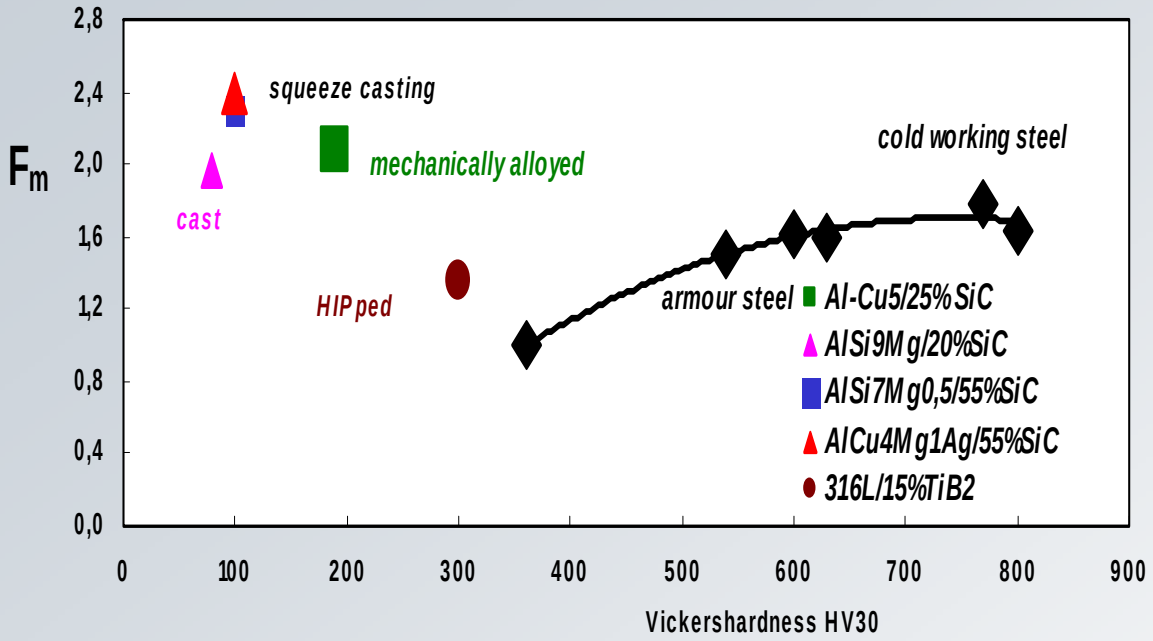
ASB: width = 30 μm

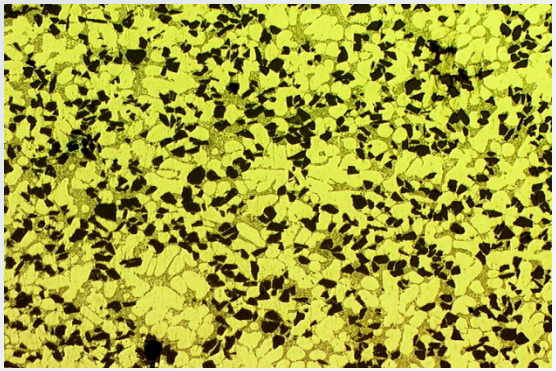
Specimen 28

ASB: width = 4 μm

Ti 17 specimen 28

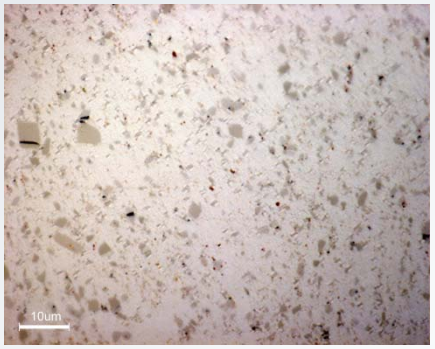


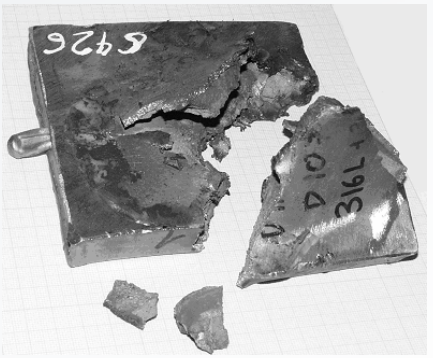




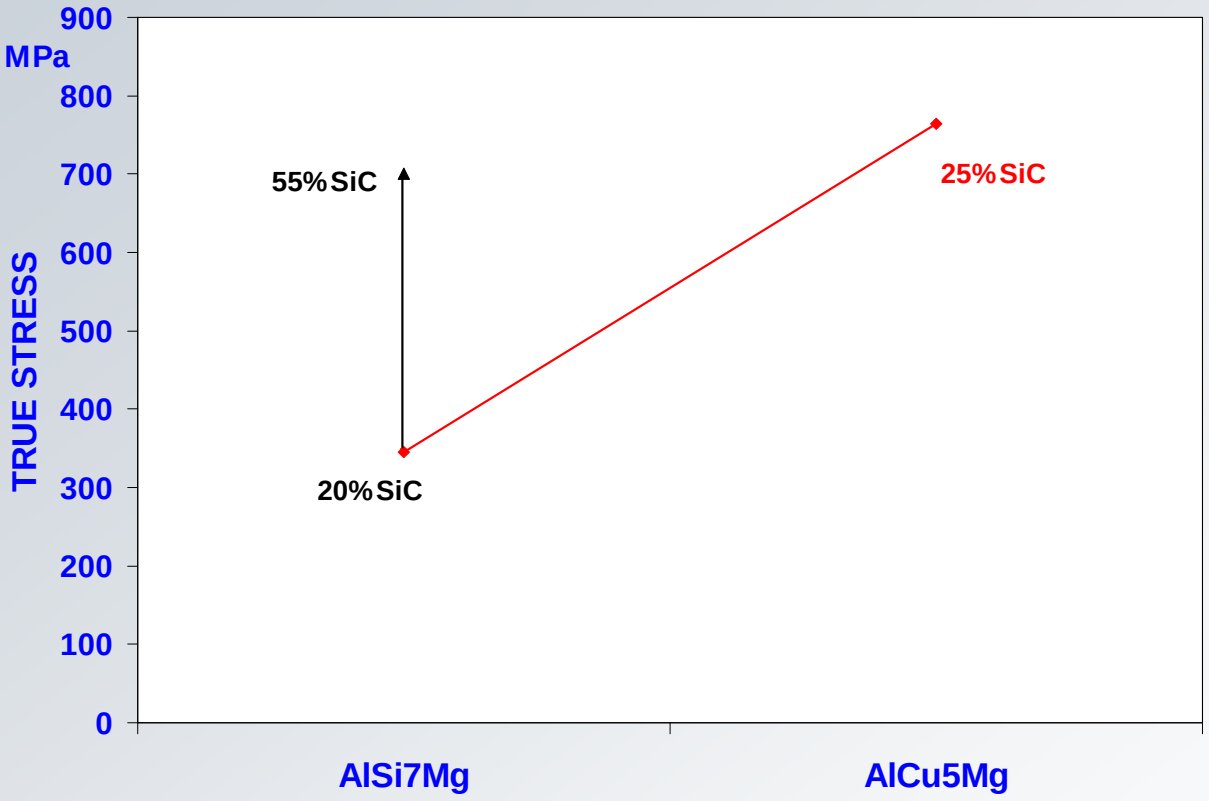
cast AlSi9Mg/20%SiC

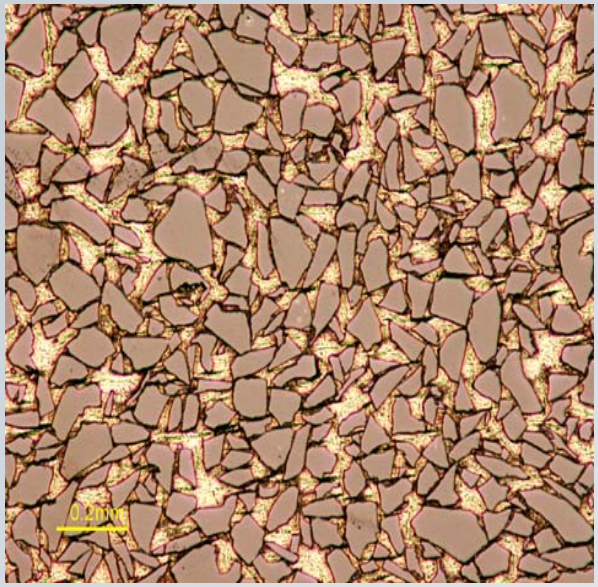
Al-Cu5/25% SiC

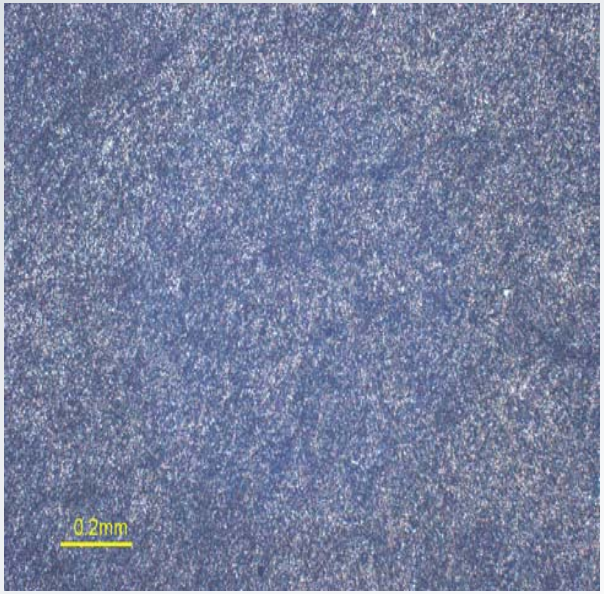




316L/15%TiB_2


900
MPa
800
700
600
500
400
300
200
100
0
TRUE STRESS
55% SiC
25% SiC
20% SiC
AlSi7Mg
AlCu5Mg

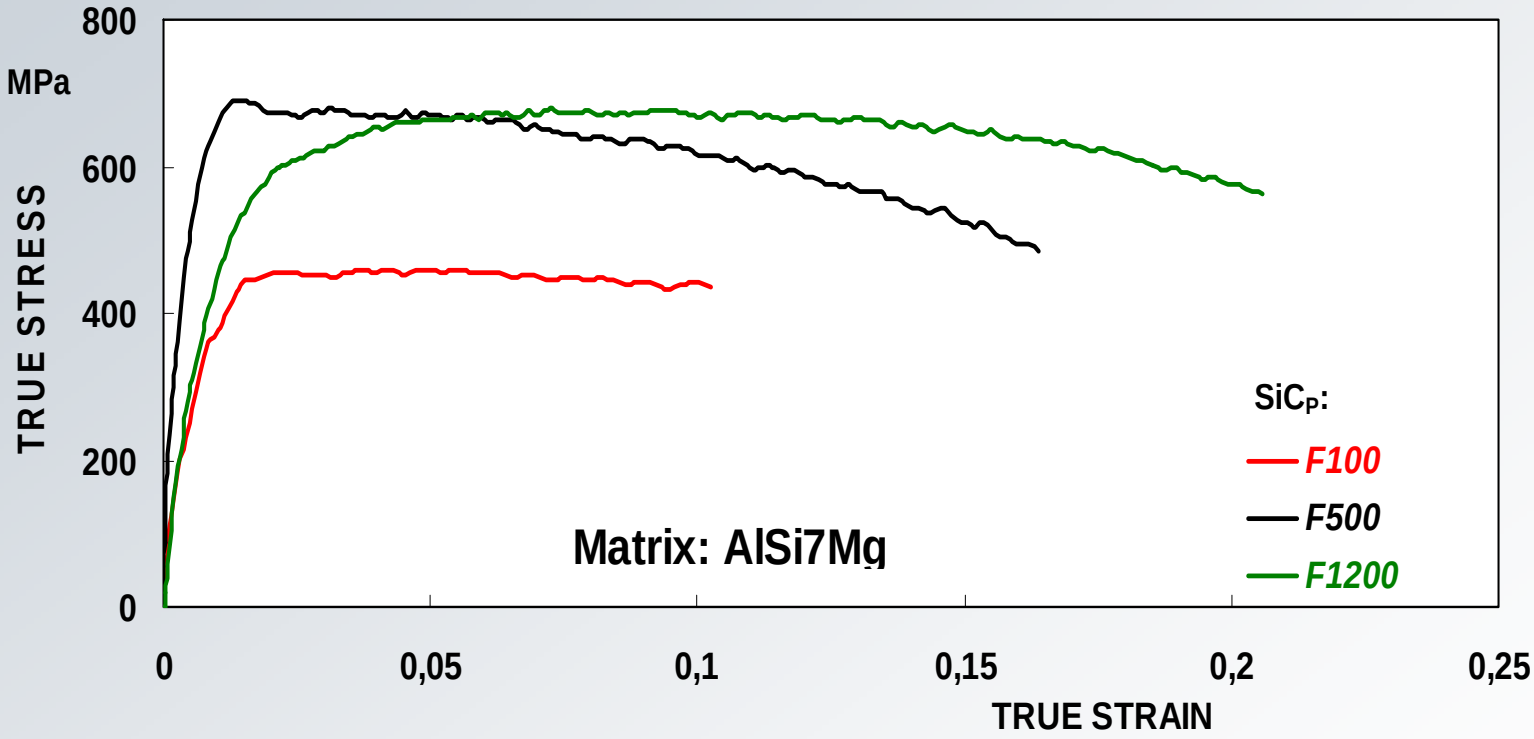




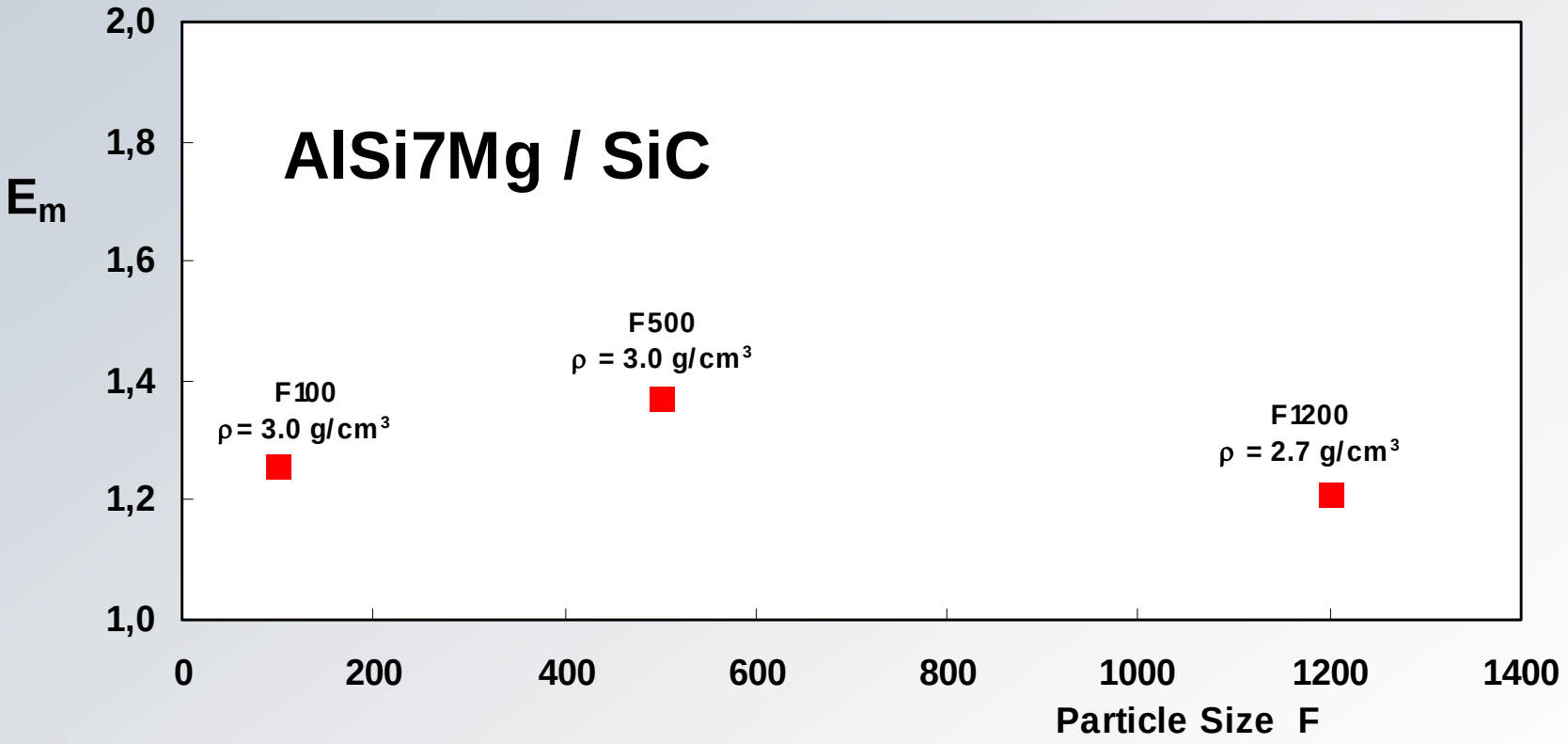
AlSi7Mg reinforced by 55 - 60 % SiC of size:

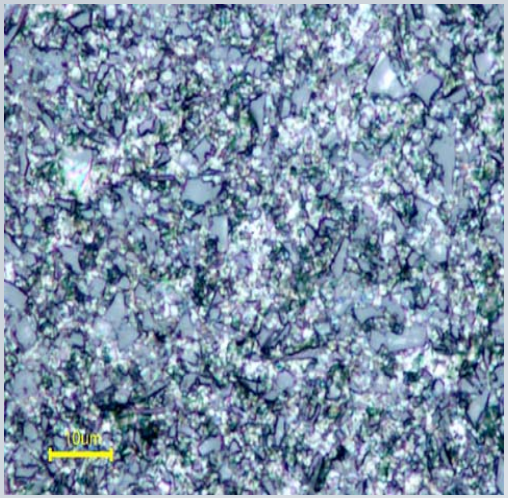
F100	F500	F1200
106 – 150 µm	5 – 25 µm	1 – 5 µm

Dynamic Compression Tests

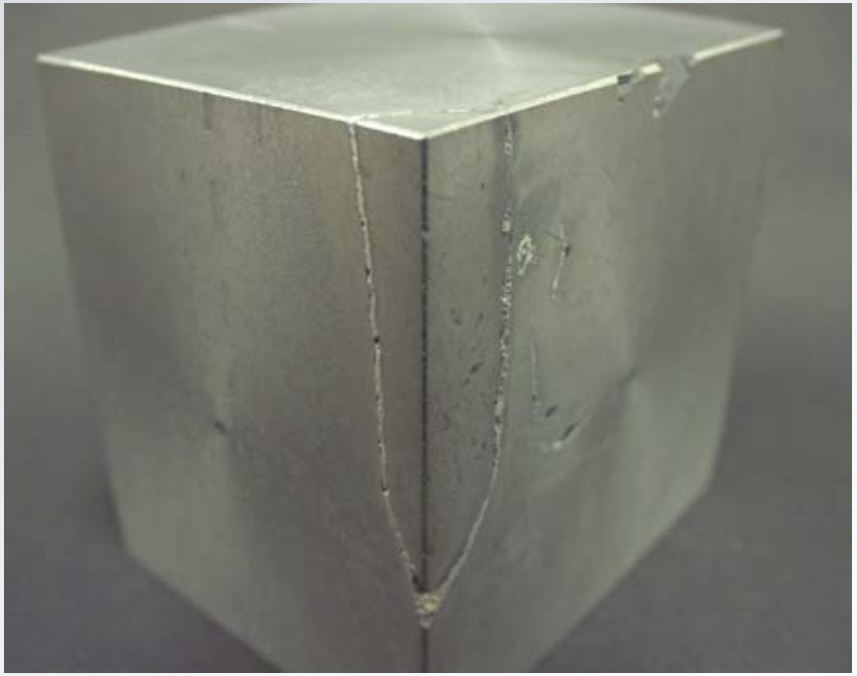


Ballistic Tests





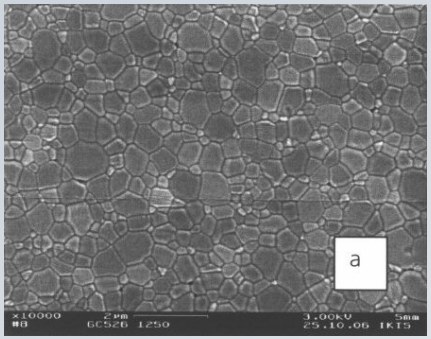
AlSi7Mg reinforced by SiC-particles of size F1200



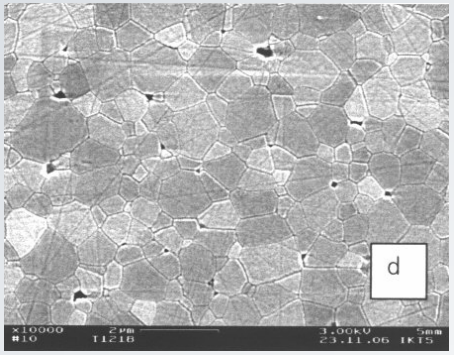
Gaspressure infiltration

Submicro Ceramic

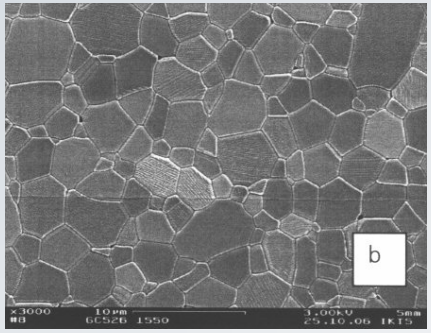
Al_2O_3, *grain size: 0.6 µm - 9.82 µm*



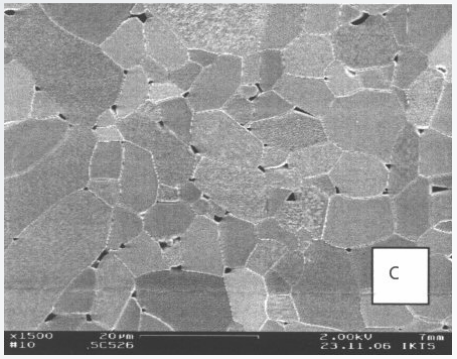
grain-Ø: 0.6 µm



grain-Ø: 0.91 µm

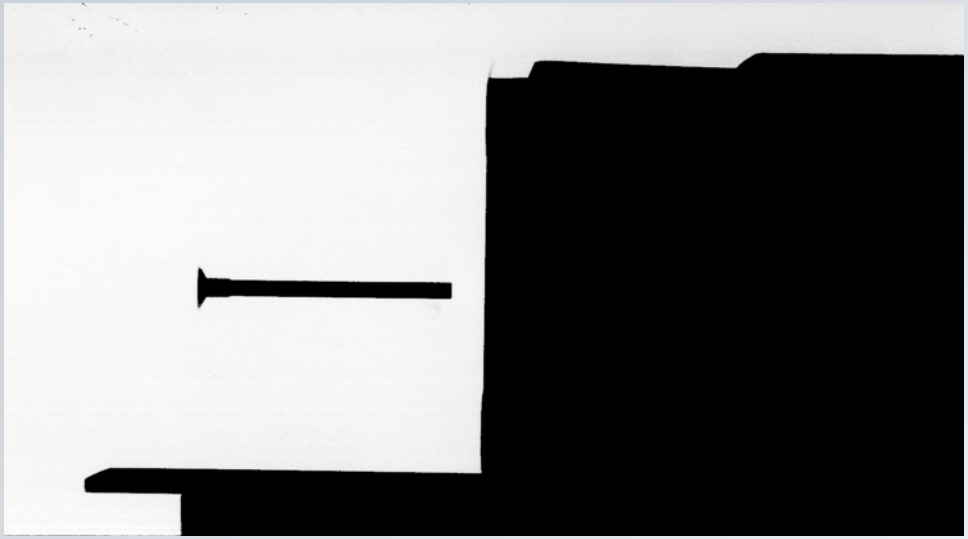


grain-Ø: 3.76 µm



grain-Ø: 9.82 µm

Ballistic Test and Materials Properties

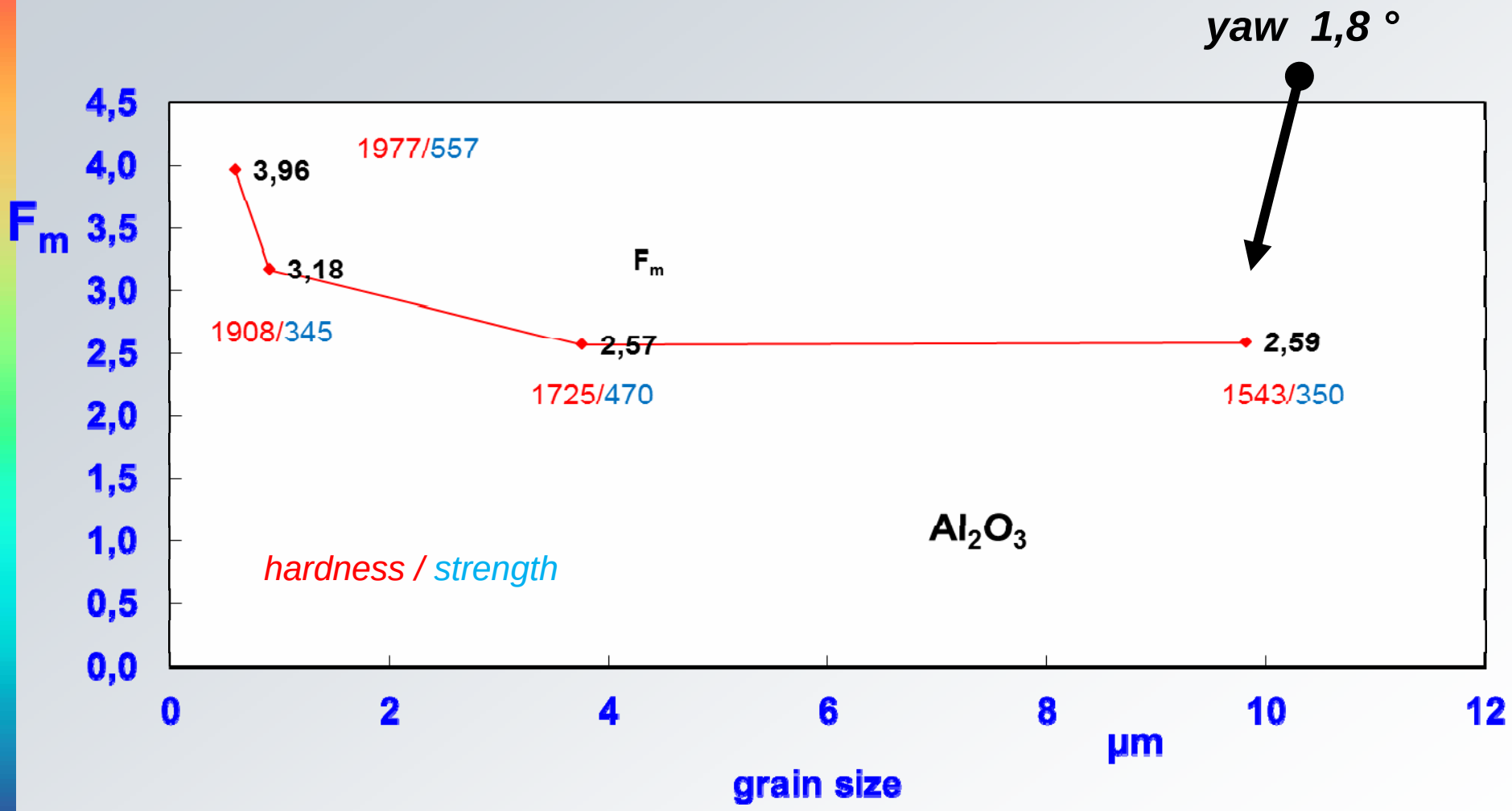


Al_2O_3

	grain-Ø	yaw
a	0,6	0°
b	3,76	0°
c	9,82	1,8°
d	0,91	0,2°

	grain-Ø	hardness	strength 4-point bending test
	µm	HV10	MPa
a	0,6	**1977 ± 32**	**557 ± 35**
b	3,76	**1725 ± 22**	**470 ± 31**
c	9,82	**1543 ± 46**	**350 ± 16**
d	0,91	**1908 ± 15**	**345 ± 30**

Ballistic Tests



Ballistic Tests