Institut Jean Lamour

PENSER LES MATÉRIAUX DE DEMAIN

The roles of carbon and nitrogen on metallurgical response of low alloy steels to carbonitriding

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Introduction

The need of materials combining core toughness and both fatigue and wear resistances has led to the development of several surface treatment techniques.

Although carbonitriding has been known for most of the last century, the role of nitrogen on mechanical properties of treated parts remains still unclear.

The present work seeks for better understanding on the role of this element as well the one of carbon in the metallurgical responses of alloys 16NiCrMo13 and 23MnCrMo5.

Source: Safran Group.

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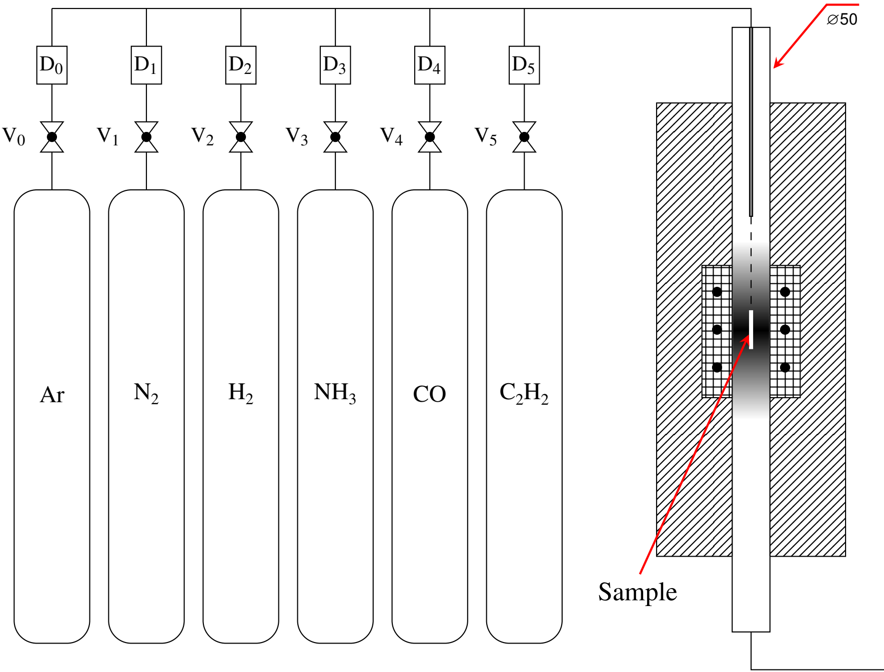
Experimental description



D0
D1
D2
D3
D4
D5
V0
V1
V2
V3
V4
V5
Ar
N2
H2
NH3
CO
C2H2
∅50
Sample

Treatment conditions

Thermochemical treatments:

Treatment	Enrichment (hours) at 1173 K		
	Carbon	Diffusion	Nitrogen
Carburizing	2 h	4 h (16NiCrMo13) 3 h (23MnCrMo5)	-
Nitriding	-	-	3 h
Carbonitriding	2 h	1 h (16NiCrMo13) 0 h (23MnCrMo5)	3 h

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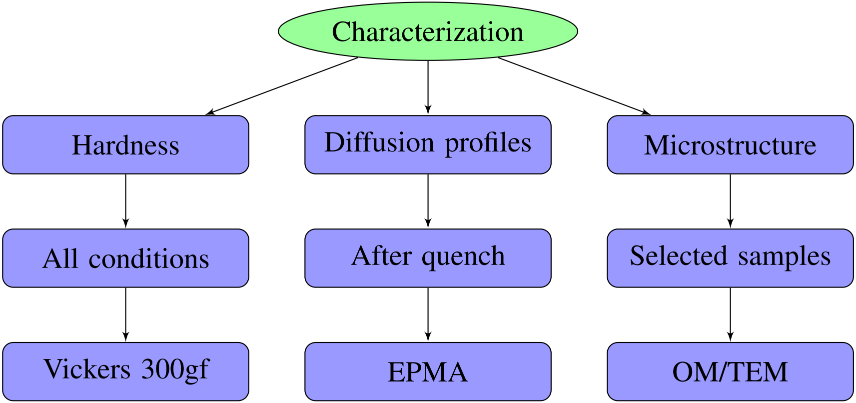
Post-treatments:

Condition	Step 1	Step 2	Step 3
0	Oil quench (298 K)	Cryogenic treatment (77 K)	-
1			Tempering at 453 K during 70 h
2			Tempering at 573 K during 18 h

Materials characterization



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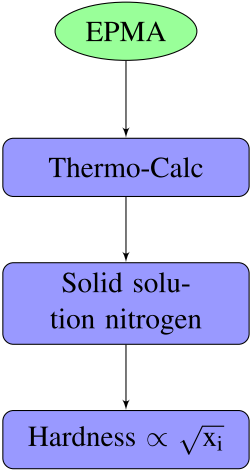
Results and discussion

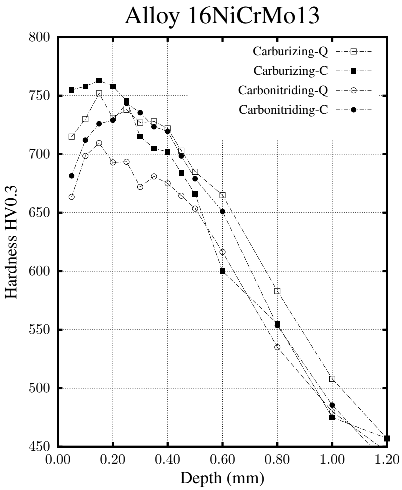
Response to quenching: effect of interstitials

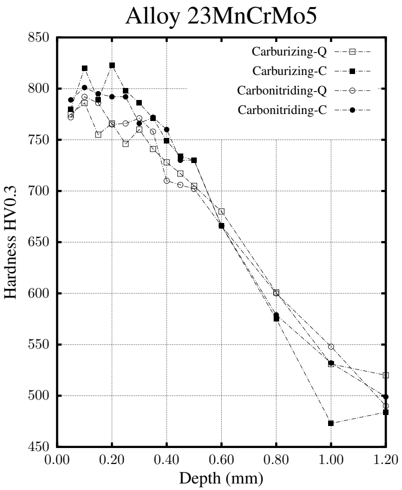


- Thermo-Calc™ was used in order to make an estimation of the solid solution nitrogen in austenite before quenching.
- Linear dependence of hardness after quenching with the square root of the mole fraction of interstitial elements in solid solution.

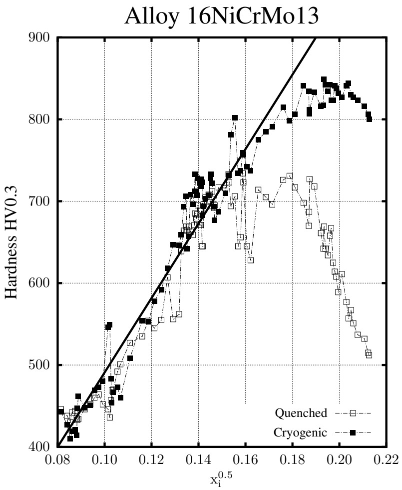
$$\sigma_y = \sum_m \sigma_m + \sum_n k_n d_n^{-0.5} + \alpha G b(\rho_0 + f(x_i))^{0.5}$$

Response to quenching: cryogenic treatment





Response to quenching: role of interstitials



- Hardening limit at around $x_i^{0.5} \approxeq 0.16 \rightarrow w_i \approxeq 0.55\%$wt. in solution for oil quench.
- Retained austenite reduction due to cryogenic treatment allows mechanical improvement up to $x_i^{0.5} \approxeq 0.20 \rightarrow w_i \approxeq 0.90\%$wt. of total carbon and nitrogen in solution.
- Hardness plateau possibly linked to non-transformed austenite.

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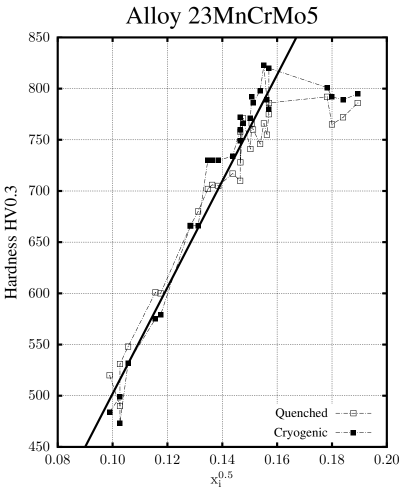

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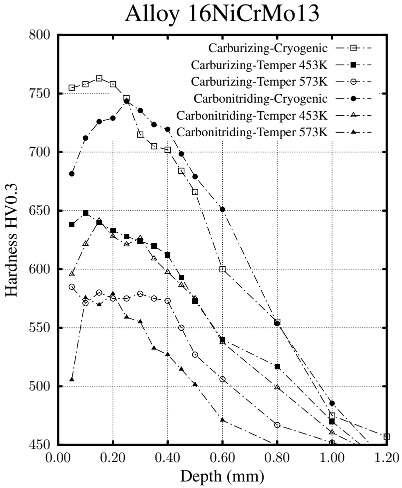
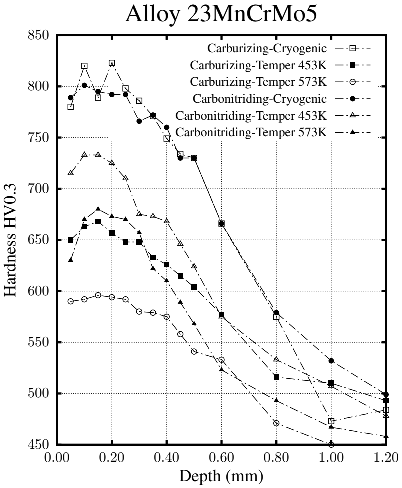
Tempering effects: role of carbon and microstructure

As-quenched hardness
↓
Temper hardness
↓
ΔHV vs. Depth

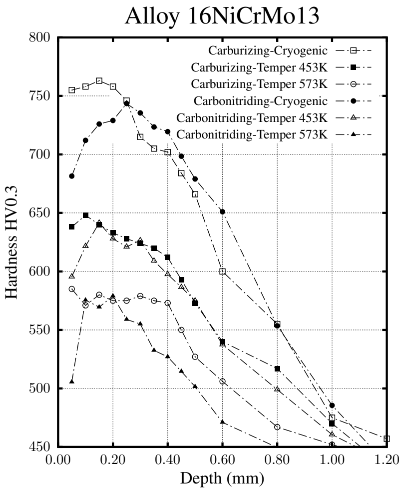
- Alloy 16NiCrMo13: retained austenite decomposes into ferrite + carbides leading to maximum hardness loss below surface.
- Contributions of both microstructure and composition are taken into account, and plots cannot obtained in terms of composition.
- Microstructural analysis reveals possible precipitation influence in hardness control.

Tempering effects





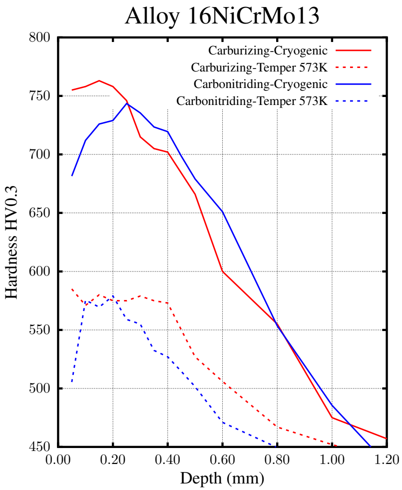
Tempering effects

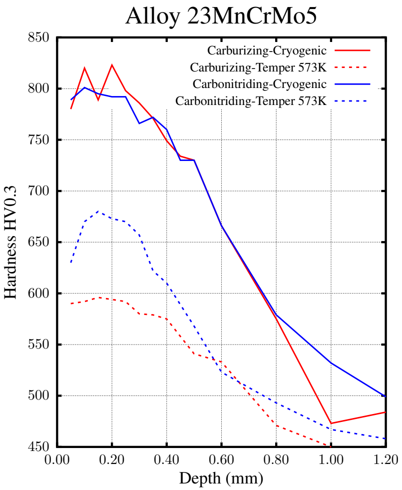


Hardness measurement provides quantitative information for practical applications but nothing about the mechanics of softening is given.

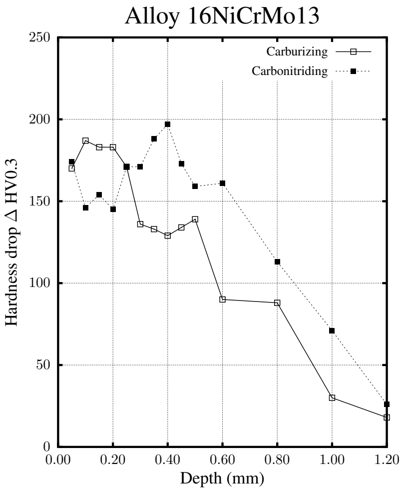
In order to obtain such data, comparison between the initial state and a tempered specimen is performed.

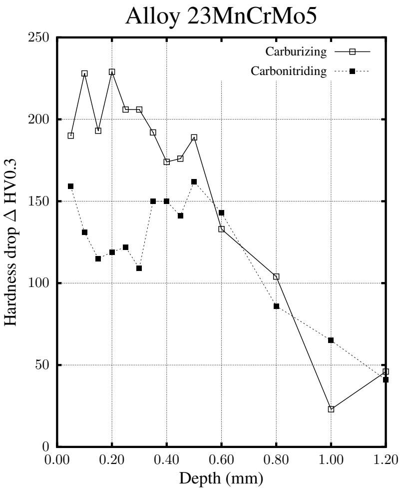
Tempering effects at 573 K





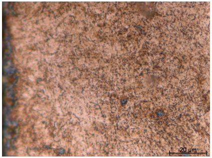
Tempering effects at 573 K

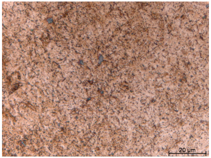


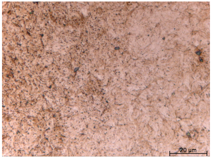


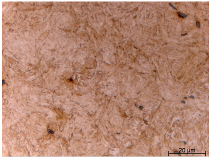
Carbonitriding: behavior of alloy 23MnCrMo5

Formation of high temperature nitrides.





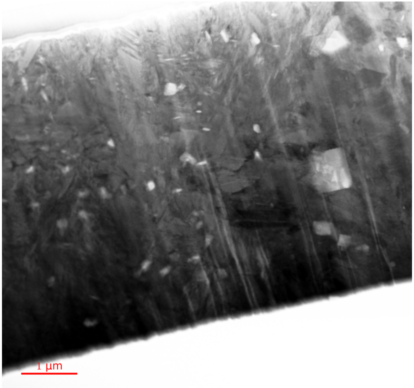




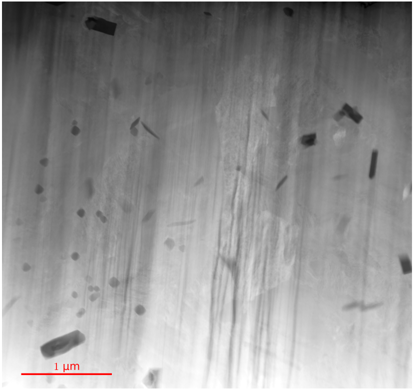
0.05 mm	0.90 % wt N
0.15 mm	0.75 % wt N
0.25 mm	0.37 % wt N
0.45 mm	0.05 % wt N

Precipitate identification

As-quenched

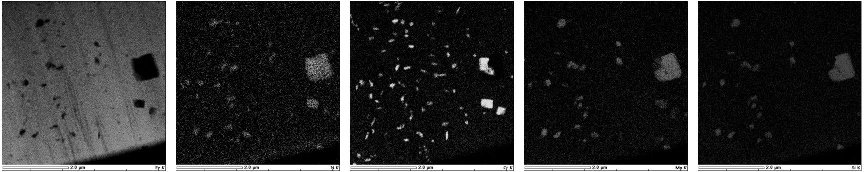


Tempered at 573 K

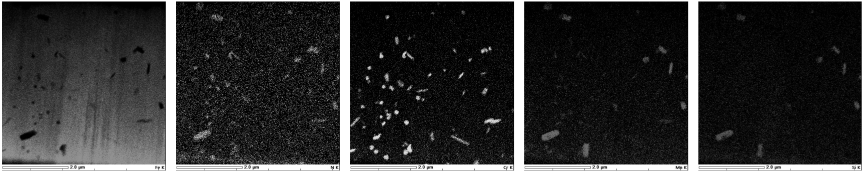


Carbonitriding: behavior of alloy 23MnCrMo5

As-quenched.

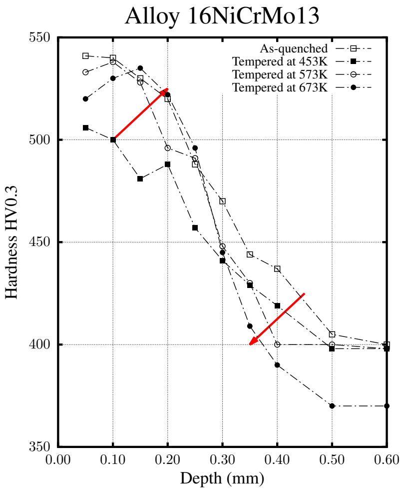


Tempered at 573 K.



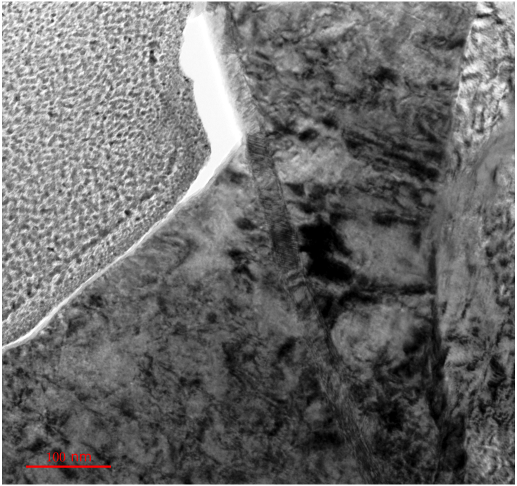
Fe N Cr Mn Si

Secondary precipitation: nitriding of alloy 16NiCrMo13



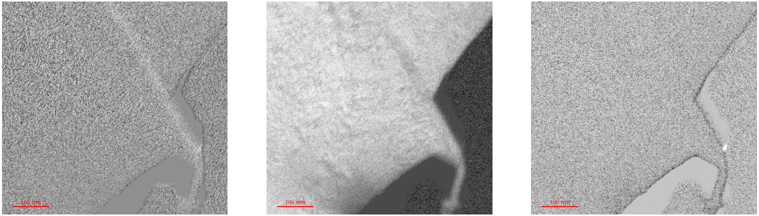
- Hardness drops when tempering is conducted at 453 K for long duration (70 h) but at 573 K, as-quenched hardness is almost preserved in surface after 18 h of tempering, although decreases steeper to the core.
- Even at 673 K (18 h) surface hardness is kept, although important core hardness decrease is measured.

Precipitate identification at 573 K



Precipitate identification at 573 K - EELS

Nitrogen | Iron | Chromium



A slip zone containing nitrogen but no chromium with enhanced iron content has been observed between adjacent martensite laths.

Such formation are not present in as-quenched samples and were identified as being the unexpected Fe_4N.

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Summary and perspectives

Summary and perspectives

Hardening responses as a function of total interstitial content led to the critical amount of these elements implying non-transformed austenite in alloy 16NiCrMo13 even after cryogenic treatment. Working below these levels is suggested as a mean to possibly achieve better fatigue performance.

Manganese-silicon nitrides are formed at treatment temperature for alloy 23MnCrMo5. Their structure remain unidentified.

Alloy 23MnCrMo5 shows higher remaining hardening after temper when highly enriched in nitrogen, what is possibly linked to the precipitation of mixed chromium-manganese nitrides.

The presence of unexpected Fe_4N is possibly the key to explain temper-hardening observed in austenitic nitrided samples.

Ongoing studies by transmission electron microscopy will in close future provide better understanding of nitrogen effects on the remaining hardness after temper of thermo-chemically treated low-alloy steels.

Thank you!