

Influence of nitrogen on low temperature stress-induced martensitic transformation in 316L stainless steel and its consequences on the mechanical behavior.

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Introduction

Martensitic transformation can occur in austenitic stainless steel whether the temperature is lower than  $M_s$  or higher if strained. Such metastable steels have been studied as well from a point of view of the martensite formation (e.g. 1) as from a point of view of the mechanical response due to the transformed phase (e.g. 2). By the way, no single tendency was observed so that the presence of martensite can sometimes be seen as advantageous or as deleterious (3).

By another way austenitic stainless steel has usually poor mechanical properties and alloying appears to be suitable to strengthen these steels particularly with interstitial nitrogen. A planar slip was reported (4) in the high nitrogen steel (HNS) for which peculiar mechanical properties may be observed.

The aim of this work is therefore to precise the role nitrogen plays on the mechanical properties especially through the ability (or not) to transform austenite into martensite.

Materials and Experimental Methods

AISI 316L austenitic stainless steels were used for this study and the chemical composition is given in table I.

Steel identification	C	N	Cr	Ni	Mn
200	0.024	0.033	17.40	13.58	1.601
201	0.018	0.077	17.14	13.56	1.647
202	0.016	0.135	17.32	13.69	1.652
203	0.029	0.235	17.22	13.69	1.518

Table I : Chemical composition of studied steels.

All steels were homogenized at 1125°C then water quenched; this results in a grain size ranging from 55  $\mu\text{m}$  to 80  $\mu\text{m}$ . No magnetic phase was detected after the heat treatment.

Non-standardized (but identical for every test) round specimens were machined and tested at 77 K and 300 K using stroke displacement mode of a MTS machine.

After deformation, X ray measurements (Co anticathod) were performed at room temperature on a polished surface cut off as near as possible from the fractured surface.

T.E.M. investigations were also done on a 200 CX JEOL and S.E.M. observations on a Cambridge 250.

## Results

Fig. 1 shows stress-strain diagram for two test temperatures and for different steels. The curves were deduced from the load-displacement diagrams which did not present serrated yielding in that temperature range.

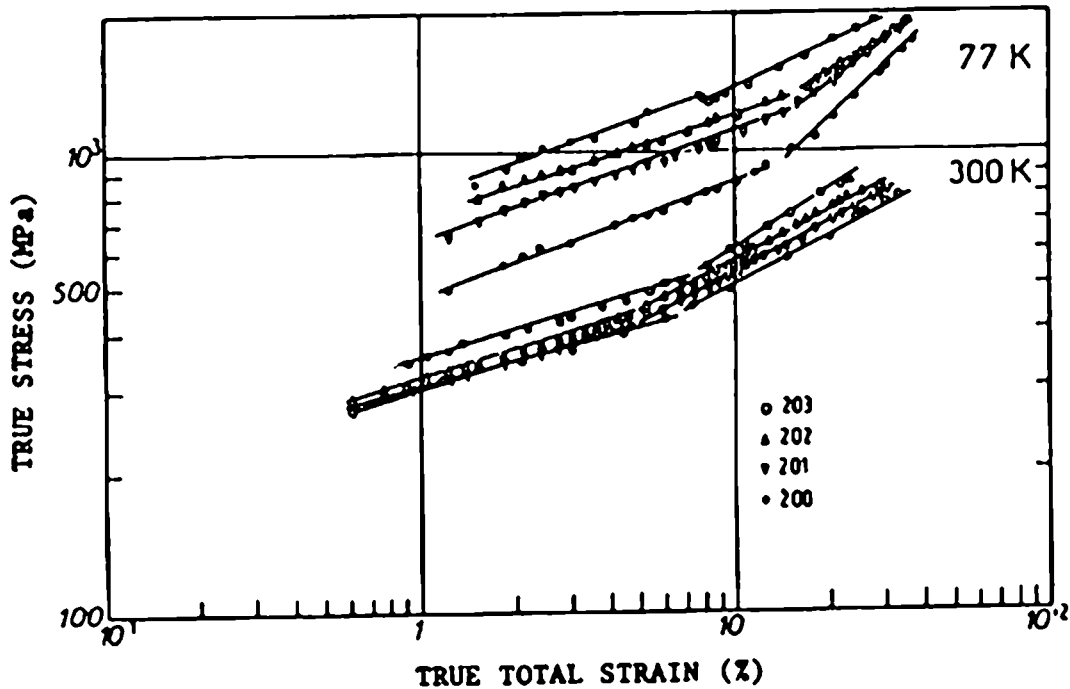


Fig. 1: plastic behavior of the stainless steels at 77 K and 300 K

As can be seen for each case, the flow curves consist in two stages leading in two sets of strength factor  $K$  and strain hardening exponent  $n$  of the empirical equation  $\sigma = K\epsilon^n$ . It is observed that the lines intersect at coordinates almost independent of nitrogen content but more strongly dependent of temperature.

The evolution of the macroscopic yield stress  $\sigma_E$  and yield strength  $\sigma_m$  as a function of nitrogen content is reported in Fig. 2a while Fig. 2b displays the variation of elongation  $A$  and reduction of area  $\epsilon$  with nitrogen content. While  $\sigma_E$  do not vary much with N content at 300 K, it strongly increases with N content at 77 K.  $\sigma_m$  slightly increases with N at both test temperatures and strongly increases for a given nitrogen content when test temperature decreases.

$\epsilon$  and  $A$  do not strongly depend on the temperature and N content. However, it should be noticed that elongation is very similar or slightly higher at 77 K than 300 K. The latter peculiar behavior has already been pointed out by Sanderson and Llewellyn (5) for high nickel stainless steel.

X-Ray investigations with diffractometer show that phase transformation occurs especially at 77 K. The  $\alpha'$  martensite diffraction peak corresponding to  $\{110\}$  planes type decreases with N content as it can be seen in the table II in which the areas

under the (111) peaks of austenite, (002)  $\epsilon$  martensite and (110)  $\alpha'$  martensite peaks are collected too.

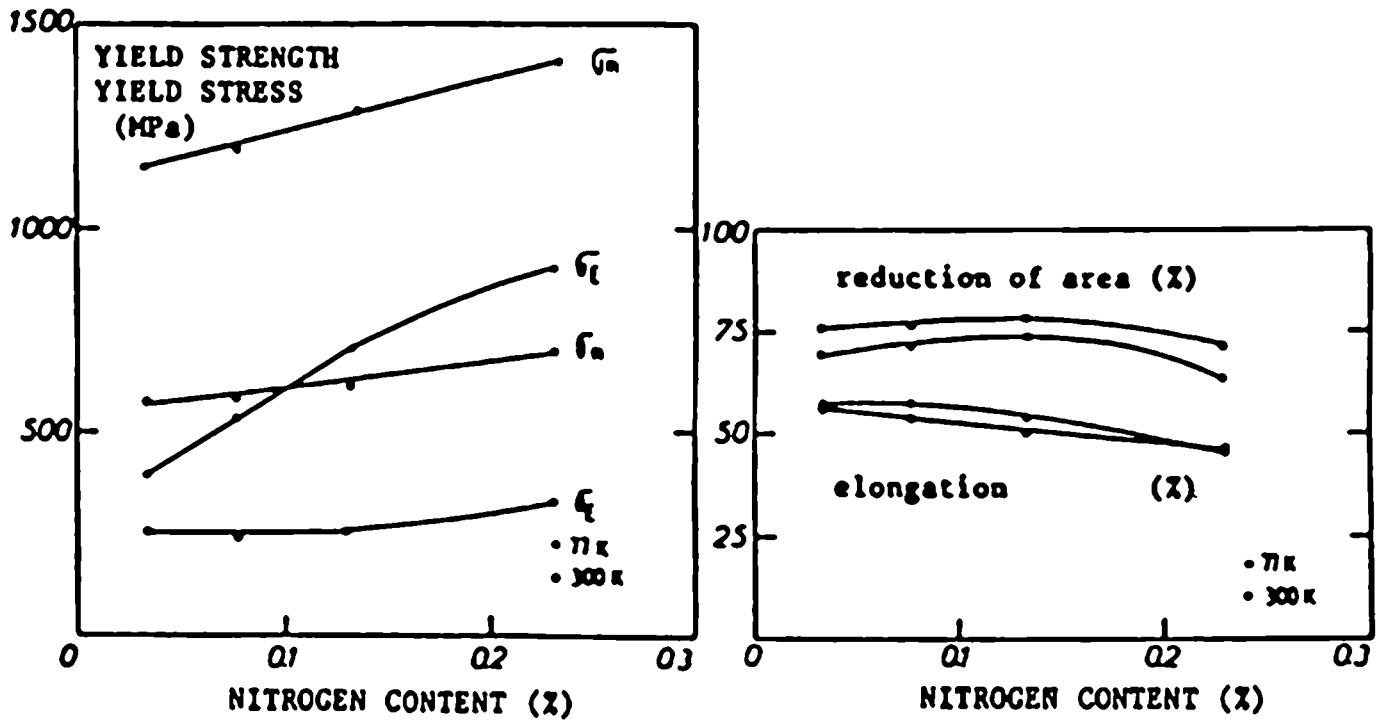


Fig. 2: tensile properties as a function of nitrogen content

	0.03 % N steel	0.08 % N steel	0.135 % N steel	0.235 % N steel
$\alpha'$ 110	2261	1561	737	400
$\epsilon$ 002	130	35	479	2500
$\gamma$ 111	162	200	109	
$\frac{\alpha'}{\alpha' + \epsilon + \gamma}$	0.886	0.869	0.556	0.138
$\frac{\epsilon}{\alpha' + \epsilon + \gamma}$	0.0051	0.019	0.361	0.862
$\frac{\gamma}{\alpha' + \epsilon + \gamma}$	0.0063	0.111	0.083	

Table I: area (in arbitrary units) under  $\alpha'$  110,  $\epsilon$  002 and  $\gamma$  111 peaks and their relative area with respect to cumulated area. Texture correction is not taken into account.

For HNS  $\alpha'$ 110 peak is weak and diffraction from  $\gamma$ 111 and  $\epsilon$ 002 do not lead to two resolved peak as for the other steels.

Though phase transformation differently occurs from steel to steel and from 77K to 300K, the fracture analyses only differ from a macroscopic aspect for the low and high nitrogen steel. The former exhibits "smooth" cup and cone fracture while an irregular surface is found for the latter. However, S.E.M. observations do not show fundamental difference in the fracture mode. Only ductile type rupture is present on the fracture surface as well in the area failed by axial tension as that failed by shear (Fig.3).

T.E.M. investigation has also been performed especially on the HNS. The microstructure found in the broken specimen is very complex because of the important amount of deformation. As it is consistent with the X ray measurement, the structure observed after fracture was found to consist in martensite and faulted austenite at 77 K. At 300 K, similar feature is also locally seen but areas displaying dislocations arrangements of "diffuse" cells were found (Fig. 4).

### Discussion

For each steel,  $M_s$  is never reached and well below 77 K proved by the absence of magnetic phase after cooling to 77 K. X ray measurements clearly show that nitrogen favors the  $\epsilon$  martensite phase which is clearly related with faulted austenite in the presence of stress.

It is shown that nitrogen already well known to stabilize austenite on cooling preserves also  $\alpha'$  martensite during straining. At 300 K, solid solution strengthening is responsible for the increase of yield stress and yield strength.

Decreasing test temperature increases these values because dislocation glide become more difficult on the one hand and because of the effect of interstitial on the other hand. If it is assumed that lowering temperature tends to promote planar slip, one could easily explain that  $\alpha'$  martensite forms because the deformation is confined on at least 2 sets of slip bands which intersect and leads to high stress concentration sites. This is typically observed in real metastable austenite - for example Fe-18Cr-8Ni - for which  $M_d$  is above the test temperature. Though no micrographic evidence of formation of  $\alpha'$  at band cross is available for the more unstable austenite which is studied here mainly because of the high complexity of microstructure, this cannot be excluded. Since both nitrogen and low temperature promote planar slip, a very planar configuration is expected at 77 K for HNS. However we feel that this similar effect proceeds from two different sources : in LNS (low nitrogen steel) at low temperature planar glide results from inhibition of cross slip. In HNS planar glide is related with the increasing stability of hexagonal  $\epsilon$  phase and therefore with the lowering of the stacking fault energy. While in LNS  $\alpha'$  martensite appears as a mechanical consequence of strain and stress concentrations, in HNS  $\alpha'$  martensite occurrence is delayed by the  $\epsilon$  transient stage. This demonstrates that temperature lowering and nitrogen have not a similar role and explains the different amount of  $\alpha'$  martensite in the LNS and HNS.

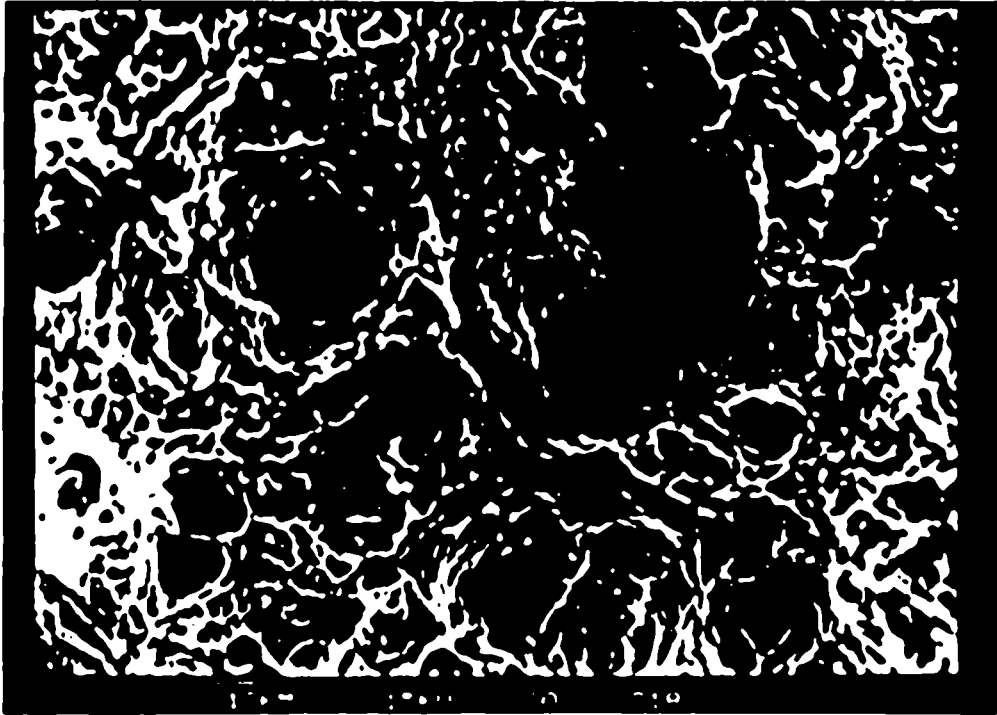


Fig. 3: HNS (0.235 N) fracture surface obtained at 300K (S.E.M. micrograph)

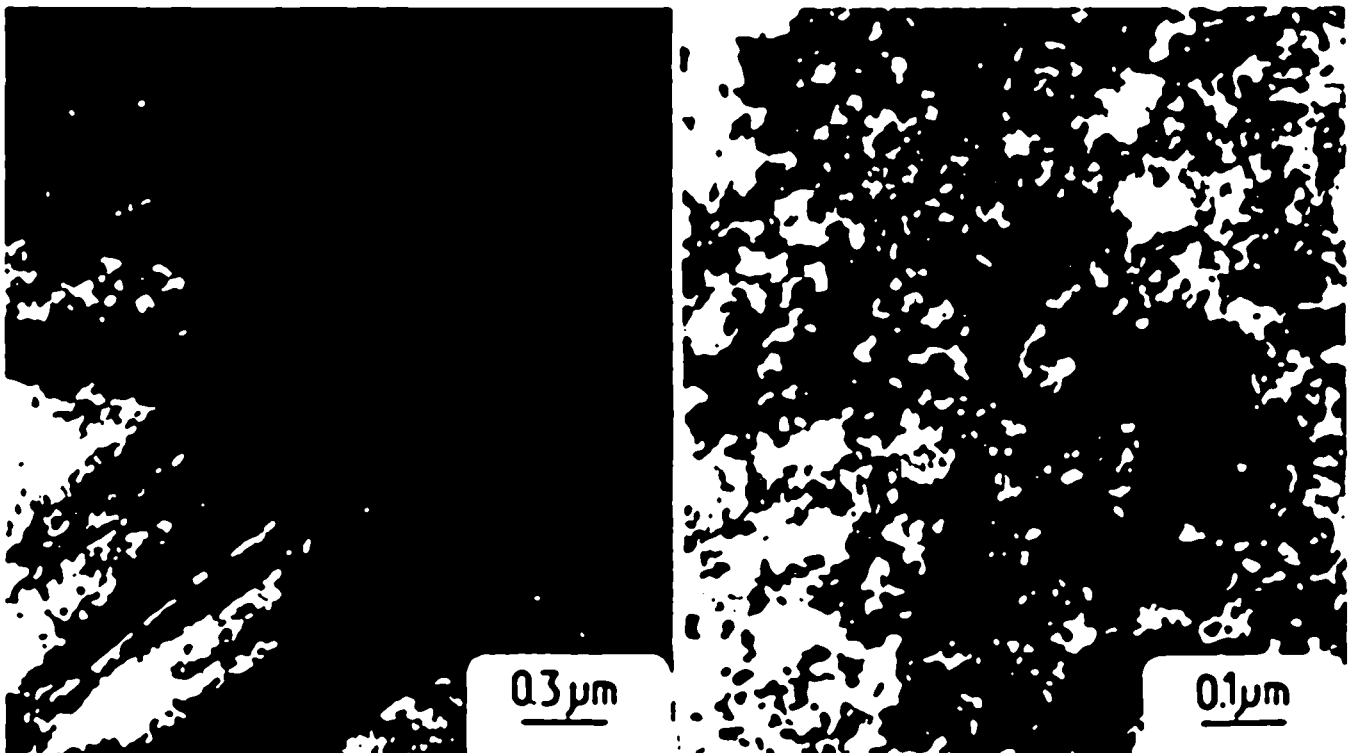


Fig. 4: TEM micrograph of area containing transformed phases (left) and cellular type arrangement (0.235N) 300K (right)

### Conclusion

From this study, it can be concluded that nitrogen acts according to 2 processes :

- interstitial effect
- lowering stacking fault energy.

The mechanical behavior is then affected by solid solution strengthening due to nitrogen interstitial at 300 K. At 77 K, a competitive effect occurs between nitrogen interstitial (effect on SFE) and martensitic transformation (mechanical effect).

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