Microstructure and Phase Composition of Deformation Martenzite Formation in Nitrogen TRIP-steel

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Abstract:
The methods of magnetometric- and X-ray diffraction analysis were used to study the phase composition and deformation dependences of martensite formation in the temperature range 20–100ºC for four carbon and nitrogen alloy manganese and chromium-manganese austenitic unstable steels. The influence of nitrogen and chromium on the microstructural parameters of austenite of thermal and deformation martensite under different thermo-deformation conditions of phase transformations has been established.

Keywords: Deformation martensite, thermal martensite, magnetometric analysis, X-ray diffraction analysis, phase composition, microstructural parameters, TRIP-(Transformation Induced Plasticity) steels, stacking fault energy – SFE

1. Introduction

Austenitic-unstable steels have a chemical composition that provides after hardening austenitic structure, in plastic deformation in a certain temperature range to form deformation martensite [1-4] and in negative temperatures form, s.c. thermal martensite. It is known that the replacement of carbon with an equivalent amount of nitrogen in austenitic-unstable steels reduces the stacking fault energy – (SFE) of the solid solution of austenite and this gives new opportunities for the formation of martensite at different temperature-deformation conditions. The aim of the present work is to study the influence of nitrogen on the microstructure, phase composition and deformation kinetics of martensite formation in TRIP (Transformation Induced Plasticity) steels.

2. Material, methodology and experimental results

The aim of study are four austenitic-unstable steels with chemical composition shown in Table 1. Two of them are alloyed with nitrogen and the other two – additionally with chromium. This allows to obtain comparative data on the role of nitrogen and chromium on the deformation martensite formation in manganese steels. The samples were performed on standard microprobe bodies for tension and those for X-ray diffraction analysis with dimensions 15x5x3 mm.
The samples are pre-quenched by 1000° C in water. The studies were conducted in three modes of impact preparation:
- After hardening from austenitic state without additional effects;
- After hardened and retained 24 hours in liquid nitrogen;
- After hardening and subsequent plastic deformation /rolling/ 40% for X-ray samples.
The magneto metric phase analysis of all tested samples before the tests shows that they are austenitic and the amount of magnetic phase in them does not exceed 3%. With the help of a magneto metric device mounted on a standard tensile testing apparatus, the quantity and the process of the formed martensite are registered with a continuous record as a function of the applied deformation to the destruction of the samples at different temperatures – fig. 1 a)-d).

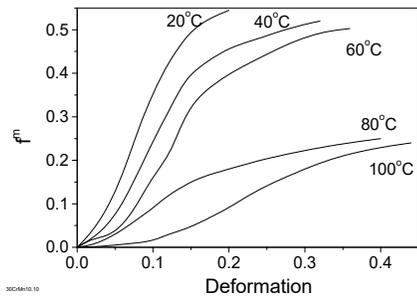**Table 1. Chemical composition of the austenitic-unstable steels**

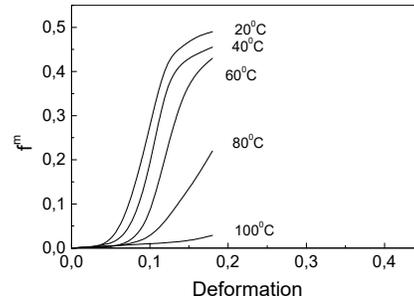| N	designation	C	N	Cr	Mn
1.	X30Mn16	0,275	0,038	-	16,18
2.	X0A30Mn16	0,036	0,246	-	16,76
3.	X30CrMn.10.10	0,260	-	9,90	9,13
4.	X10A20CrMn10.10	0,100	0,203	10,85	10,44
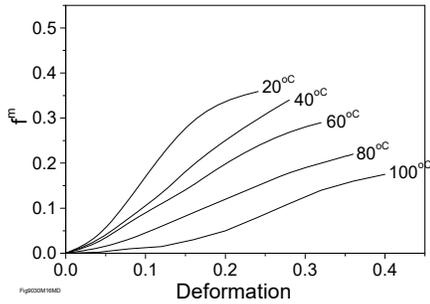
a) X30Mn16
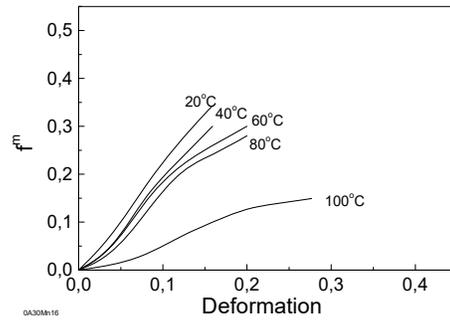
b) X0A30Mn16

c) X30CrMn10.10

d) X10A20CrMn10.10

Fig. 1. Values of martensite formed as a function of the applied deformation at different temperatures

The microstructural parameters of austenite were examined X-ray structurally with standard equipment: micro-deformation – ε, size of the crystal domains D, concentration of the defects in the arrangement – α, along the width of three lines of reflection for austenite.

The microstructural parameters of martensite; micro-deformation – ε, size of the crystal domains D and tetragonality – T, along the width of two lines of reflection [5-10]. The methodologies are based on the principle that each microstructural parameter of the solid solution expands in a certain way each of the lines of reflection. The analysis was performed on the basis of lines $(111)_\gamma$, $(200)_\gamma$, $(220)_\gamma$ of austenite and $(110)_\alpha$ and $(220)_\alpha$ of martensite. It is known that the higher values of the lengths of the crystal domains D and that of the concentration of the – SFE lower values of the stacking fault energy [1]. The values of martensite in the test specimens after immersion in liquid nitrogen or plastic deformation of 40% was determined by the ratio of the heights of the lines $(110)_\alpha$ and $(111)_\gamma$ [12]. The values of the microstructural parameters of austenite and martensite after different thermo-deformation effects are shown in table 2 and 3.

Table 2. Microstructural parameters of austenite

N	designation	preliminary processing	$\varepsilon \cdot 10^3$	$\alpha \cdot 10^4$	$D \cdot 10^8$ cm
1	X30Mn16	hardened	0.78	50.5	344
		hardened+liquid nitrogen	1.05	32	318
		hardened+def.30-40%	2.9	35	210
2	X0A30Mn16	hardened	0.41	55,5	379
		hardened+liquid nitrogen	0.92	39	327
		hardened+def.30-40%	1.88	42	240
3	X30CrMn10.10	hardened	1.32	62	262
		hardened+liquid nitrogen	1.73	48	245
		hardened+def.30-40%	2.38	57	204
4	X10A20CrMn10.10	hardened	1.06	64.5	348
		hardened+liquid nitrogen	1.50	39	303
		hardened+def.30-40%	1.97	51.5	228

Table 3. Microstructural parameters of martensite

N	designation	preliminary processing	$\varepsilon \cdot 10^3$	$D \cdot 10^8$ cm	$T \cdot 10^3$	Martensite %
1	X30Mn16	hardened+liquid nitrogen	5.17	187	2.67	31
		hardened+def.30-40%	7.22	143	3.82	36
2	X0A30Mn16	hardened+liquid nitrogen	5.74	165	2.54	28
		hardened+def.30-40%	7.45	125	3.60	32
3	X30CrMn10.10	hardened+liquid nitrogen	5.88	145	2.51	32
		hardened+def.30-40%	7.33	125	3.72	54,5
4	X10A20CrMn10.10	hardened+liquid nitrogen	6.12	138	2.08	30
		hardened+def.30-40%	8.19	120	2.78	49

Our results – Fig.1 a) – d) show that the deformation dependences of martensite formation in austenitic unstable steels are characterized by an initial, weak dependence, which can be called "incubation period" in terms of deformation. Such a period is absent in all non-diffusion, non-deformation martensitic transformations. This shows that there are no ready- made martensitic nucleus available in TRIP steel austenite. They are formed in the initial stages of plastic deformation up to about 5% after which the process of growth of martensite nucleus and the course of autocatalytic processes probably become decisive.

Table 4. Value of the intensity coefficient Ki at different deformation temperatures

N	designation	Ki				
		20°C	40°C	60°C	80°C	100°C
1	X30Mn16	1.50	1.20	0.90	0.60	0.44
2	X0A30Mn16	2.06	1.88	1.50	1.40	0.54
3	X30CrMn.10.10	2.72	1.62	1.39	0.63	0.53
4	X10A20CrMn10.10	2.65	2.36	2.06	1.30	0.20

3. Discussion of experimental results

Comparing the values of the microstructural parameters of austenite in the hardened state – table. 2, it can be concluded:
- − Nitrogen austenite is characterized by a lower value of the micro deformations in the lattice and larger sizes of the crystal domains D associated with the lower SFE. This result is in agreement with the electron microscopic studies published in the literature

by other authors [11-13] who observed wider areas of stacking fault and widely split partial dislocations in nitrogen austenite compared to carbon.

- – Chromium increases the microstructural deformations and stresses in the austenite lattice, preserving the overall effect of nitrogen on the reduction of the size of the domains in both types of martensite formation.

Comparing the microstructural parameters of austenite after the formation of thermal martensite upon cooling in liquid nitrogen and of deformation martensite after plastic deformation, with those after hardening – Table. 2 and 3, it is found that in both martensitic transformations, the remaining unconverted austenite has lower values of the lengths of the crystal domains and of the concentrations of the stacking fault in at increased values of the micro-deformations.

The tendency of austenitic-unstable steels to deformation martensite formation can be conditionally determined from the maximum amount of formed deformation martensite – M_{max} and from the ratio of this maximum amount of martensite formed for one percent of deformation/intensity coefficient – K_i – fig. 2 and table 4.

The results showed that chromium significantly increases the maximum amount of formed deformation martensite Fig.2, which means that it strongly affects both the processes of embryogenesis and the later stages of growth and autocatalysis of martensite.
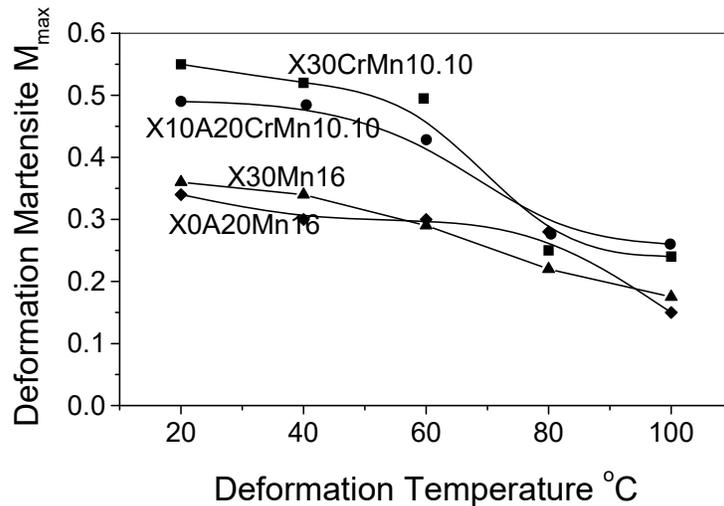
Fig. 2. Dependence of the maximum amount of formed deformation martensite – M_{max} of the deformation temperature

Experimental results show that nitrogen, in both manganese and chromium-manganese alloys, has little effect on the maximum amount of deformation martensite formed, but definitely increases the coefficient K_i.

Studies of the microstructural parameters of martensite obtained by thermal and deformation path showed that:

- – The presence of chromium in the studied alloys increases the amount of martensite by about 20-25%, regardless of the amount of nitrogen in them – table. 3;
- – Deformation martensite is characterized by higher internal micro-deformations of the lattice and smaller in size of the crystal domains, compared to the thermal one;
- – The deformation martensite has a higher degree of tetragonality than the thermal one. This shows that the processes of phase transformation during deformation take place in areas richer in carbon, with a higher initial martensitic point, compared to the

thermal one. Therefore, the cold plastic deformation contributes to the destabilization of austenite and is an additional energy stimulus for the formation and growth of martensite needles.

Approximating the results of fig. 2 to higher temperatures, it can be assumed that all the austenitic-unstable temperature limit of martensite formation during deformation considered by us is in the range of 120-150°C.

Unlike thermal, deformation martensite can be formed only in austenite with low SFE which in crystallographic terms represent hexagonal or s.c. epsilon-martensite and the intersection of two defects in the arrangement – ready martensite nucleus (11-13). It is clear that the temperature dependence of the tendency to martensite formation of austenitic-unstable steels, determined by M_{max} and K_i, is directly related to the temperature dependence of the SFE.

4. Conclusions

- The deformation dependences of austenitic unstable steels are characterized by the presence of an "incubation period" which shows that martensite nuclei are formed in the initial stages of plastic deformation up to about 5%.
- Nitrogen-doped austenite is characterized by a lower value of the micro-deformations in the lattice and larger sizes of the crystal domains D, associated with the SFE.
- The process of transformation of austenite into martensite proceeds with gradual depletion of the places in austenite with the longest length of the domains in austenite, places with minimal SFE in austenite.
- Nitrogen, in both manganese and chromium-manganese alloys, has little effect on the maximum amount of deformation martensite formed, but increases the rate of the amount of deformation martensite per unit of deformation.
- The main reason for the increased tendency of TRIP-steels to deformation martensitic formation of nitrogenous austenite is the SFE.
- Chromium significantly increases the maximum amount of formed deformation martensite Fig.2, which means that it strongly influences both the processes of nucleation and the later stages of growth and autocatalysis of martensite needles.
- It was found that chromium increases the microstructural deformations and stresses in the austenite lattice, preserving the overall effect of nitrogen on the reduction of the lengths of the domains in both types of martensite formation.
- The presence of chromium in the studied alloys increases the amount of martensite by about 20-25%, regardless of the amount of nitrogen in them.
- In all studied alloys the formed amount of thermal martensite is less than the maximum amount of deformation.
- Deformation martensite is characterized by higher internal micro-deformations of the lattice, smaller size of the crystal domains and a higher degree of tetragonality compared to thermal.
- Nitrogen martensite (thermal and deformation) are characterized by lower tetragonality than carbon, and this effect is enhanced by the presence of chromium in the solid solution.
- Deformation martensite is characterized by higher internal micro-deformation of the lattice and smaller in size of the crystal domains, compared to the thermal one.
- The deformation martensite has a higher degree of tetragonality than the thermal one. This says that cold plastic deformation helps to destabilize austenite and is an additional energy stimulus for the formation and growth of martensite needles.

– The temperature limit of formation of deformation martensite in the considered austenit-unstable at deformation is up to 120-150ºC and weakly depends on the nitrogen content in them.

Acknowledgements

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