



## Thermal and Deformation Martensite in TRIP (Transformation Induced Plasticity) Steels

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### Abstract

The purpose of the present thesis is to investigate the special features of the austenite after quenching and of the martensite after cooling and deformation in manganese metastable steels.

**Keywords:** Microstructure parameters, austenite, martensite, deformation, TRIP-steels.

## 1. Introduction

The austenite metastable steels known as TRIP /Transformation Induced Plasticity/- steels have balanced chemical composition which guarantees austenite phase composition after quenching. During cooling below ambient temperatures large part of it turns into martensite which can be designated as “thermal martensite” whereas during deformation at ambient temperatures the austenite turns into the so called “deformation induced martensite” [1-6].

The aim of the present work is to determine some particularities of the microstructure of the three types martensite phases obtained on cooling and plastic deformation from the initial metastable austenite.

## 2. Material, method and experimental data

Three carbon austenitic-metastable manganese steels known in the literature as TRIP- steels were studied. Two of them are manganese with 12% and 16% respectively and the third one is additionally alloyed with chromium. The chemical composition is shown in Table 1.

**Table 1. Chemical composition of the investigated alloys**

Alloy		Chemical composition (mass. %)			
N	Designation	C	Cr	Mn	Si
1	X30Mn12	0.330	-	11.07	1.30
2	X30Mn16	0.275	-	16.18	1.75
3	X30CrMn5.12	0.380	4.80	11.20	1.02

Standard specimens for tensile strength tests and XRD analysis /15x15x3 mm/ placed in quartz ampoule (inert atmosphere) were quenched from 1150 °C in water. Some of the specimens were cooled in liquid nitrogen as others were subjected to tensile strength deformation up to their rupture.

During the tensile strength tests a special magneto metric device [7] recorded the quantity of martensite in the samples during the plastic deformation process. Continuous recording of the

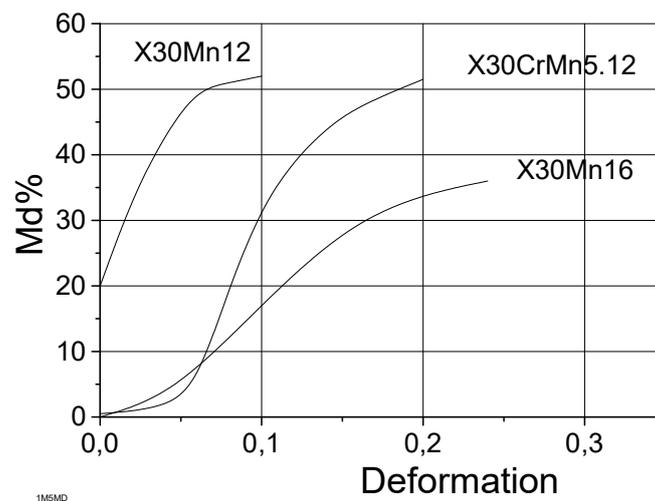
process is also performed as shown in Fig.1. Some of the samples for XRD analysis were subjected to 40% deformation at ambient temperatures in a rolling mill. This guarantees maximum quantity of deformation induced martensite achievable for these steels according to the tensile tests. Other part of the samples were subjected to XRD analysis after 24- hour stay in liquid nitrogen which ensures that the maximum amount of martensite is obtained by thermal route- Fig.1, Table 2.

The XRD analysis was carried out with standard apparatus “Philips” using Co- $K_{\alpha}$  radiation. The entire spectrum from  $40^{\circ}$   $2\theta$  to  $140^{\circ}$   $2\theta$  were taken for the investigated alloys. The diffraction lines-  $(111)_{\gamma}$  of austenite and  $(110)_{\alpha}$ ,  $(211)_{\alpha}$ ,  $(220)_{\alpha}$  of the martensite were taken with lower speed of  $0,02^{\circ}/\text{min}$  and step of  $20 \text{ sec}/\text{step}$ . As standard a specimen of “Armco” iron after process of annealing was used.

The ball of the hereditary austenite grain of the alloys is maintained in the limits of 7-8.

The maximal quantities of deformation induced and thermal martensite in the investigated alloys are shown in Table 2.

The micro structural parameters of austenite and martensite were investigated with XRD analysis by using respectively two and three diffraction lines via methods described in details in [8,9]. The results for the domain size –  $D$ , micro strains of the lattice –  $\epsilon$  for martensite and austenite and the concentration of the stacking faults in austenite –  $\alpha$  are given in Table 3.



**Fig.1. Dependence of the deformation induced martensite concentrations during the tensile test with the plastic deformation degree.**

**Table 2. Martensite quantity**

N	Alloys	After quenching Mt	After plastic deformation Md	After cooling in liquid nitrogen Mt
1	X30Mn12	20	32	32
2	X30CrMn16	-	36.9	31
3	X30CrMn5.12	-	56	22

Note: Md-deformation induced martensite, Mt-thermal martensite

**Table 3. Micro structural parameters of the austenite, of the deformation induced martensite and of the thermal one-after cooling in liquid nitrogen**

N	Alloy	Austenite			Deformational martensite Md		Thermal martensite Mt	
		$\epsilon \cdot 10^3$	$\alpha \cdot 10^4$	D. $10^8$ [cm]	$\epsilon \cdot 10^3$	D. $10^8$ [cm]	$\epsilon \cdot 10^3$	D. $10^8$ [cm]
1	X30Mn12	1.42	46.5	375	6.78	143	5.02	198
2	X30CrMn16	2.93	55.0	210	7.22	143	5.17	187
3	X30CrMn5.12	2.22	66.5	175	7.20	130	5.94	159

Note: Md-deformation induced martensite, Mt-thermal martensite

### 3. Discussion of the experimental results

The deformation induced martensite in contrast to the thermal martensite can be formed only in austenite with low stacking fault energy. Such an austenite is characterized with broadly cut partial dislocations, surrounding stacking fault areas which according to the crystallography represent hexagonal or the so called epsilon-martensite. The interception of two stacking faults represents crystallographically a ready martensite nucleus [10-14].

Hence the stacking fault energy is the main factor which determines the tendency of given austenite for martensite formation.

The results shown in Table 2 and 3 show:

- For all the investigated alloys the quantity of the thermal martensite is smaller than that of the deformation induced one.
- The deformation induced martensite is characterized with smaller domain sizes-D and larger values of the micro strains- $\epsilon$  leading to more tense structure compared to the thermal one.

In contrast to the other alloys, alloy 1 after quenching revealed the presence of initial martensite at room temperature. This shows that the alloy has martensite start point above ambient temperature. It is characterized with increased value of the domain size-D and increased concentration of the stacking faults of the solid solution- $\alpha$  – Table 3, which is reciprocal to their stacking fault energy.

The deformation martensite formed in this alloy means moving of the martensite start point of formation during plastic deformation towards subzero temperatures, meaning stabilization of the austenite. This is a feature that makes the relationship between deformation and thermal martensite in practice. The energy incentive to form a martensite phase of "thermal" origin is replaced with „mechanical" meaning that the deformation martensite kinetics is a sequel of the thermal martensite one.

The increasing of the quantity of manganese above 12% /alloy 2/ leads to decreasing of stacking fault concentration in austenite. It could be assumed that the concentration of the manganese around 12% is optimal meaning the stacking fault energy is minimal. This concentration of manganese has also been established by research by other authors [1], shown in Fig.2. For the nickel alloys this concentration is considerably much higher- around 35% [1] which speaks of the greater technological advantage of manganese austenitic-metastable steels compared to that of nickel ones.

The additional alloying of alloy 1 with 5% chromium (alloy 3) stabilizes austenite and moves martensite starting point above ambient temperature. The results show increase of the values of micro strains and decrease of the domain size – D values and stacking faults concentration i.e. increasing of the stacking fault energy of the austenite – Table 2. Despite that, an increase of deformation martensite concentration is observed which is contrary to the model of Olson G. and Cohen M. which can be explained with the presence of autocatalytic mechanism of

formation of austenite and/or with the reducing of the nucleus formation activation energy which imposes additional studies.

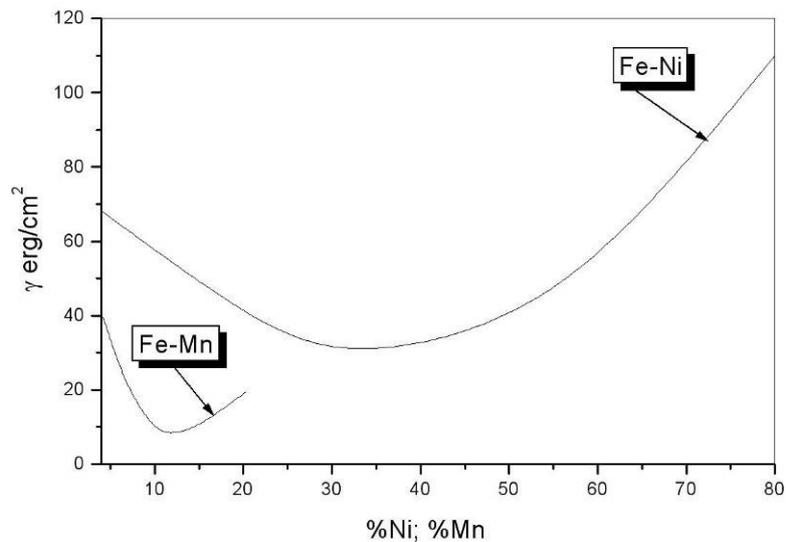


Fig.2. Stacking fault energy dependence of concentration of manganese and nickel [1]

## 4. Conclusions

For all the investigated alloys the quantity of the thermal martensite is smaller than that of the deformation induced one.

The deformation induced martensite is characterized with more tense structure compared to the thermal one.

The kinetics of the deformation induced martensite formation can be considered as a continuation of the thermal martensite formation kinetics.

The energy stimulus for the thermal martensite phase formation could be substituted with that of the deformation induced one.

The additional alloying of alloy 1 with 4% manganese (alloy 2) stabilizes austenite and moves martensite starting point above ambient temperature.

The additional alloying of alloy 1 with 5% chromium (alloy 3) stabilizes austenite and moves martensite starting point above ambient temperature similarly as the manganese alloying with 12% or more percent but increases deformation induced martensite concentration.

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