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Deformation Induced Martensite Formation in TRIP (Transformation Induced Plasticity) Steels

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Abstract
The influence of the quantity and the type of the alloying element in TRIP-steels on the tendency for deformation induced martensite formation during plastic deformation is investigated.

Keywords: austenitic metastable steels, deformation induced martensite, alloying element, TRIP-steels

1. Introduction

The aim of the present work is to investigate the influence of the quantity and the type of the alloying elements in TRIP-steels on the tendency for deformation induced martensite formation during plastic deformation.

2. Materials, methods and experimental results

Five austenite metastable steels with maximum propensity for martensite formation with compositions, corresponding to accepted standard labels according to EN BDS, given in Table 1 were studied. One of the steels is manganese as the others are additionally alloyed with chromium – 5 and 10% (weight) and with molybdenum and vanadium within the limits of 2%.

Table 1. Phase composition, mechanical properties and values of the coefficient K for the investigated alloys

Steel designation-EN BDS		Phase composition after:		R_m	$R_{0,2}$	A_5	K
		quenching	Tensile stress test	*MPa*	*MPa*	%	
1	X30Mn12	A + 20%Ms	A + 20%Ms +32Md	793	221	8,3	3,2
2	X30CrMn5.12	A	A + 56% Md	914	334	18	2,8
3	X30CrMn10.10	A	A + 50% Md	781	211	16,8	2,5
4	X30CrMnMo5.12.2	A	A + 52% Md	998	342	24	2,2
5	X30CrMnV5.12.1	A	A + 50% Md	887	322	15	2,8

Abbreviations: A – austenite, Ms – thermal martensite, Md – deformation martensite

Standard specimens for tensile stress tests of the investigated alloys were quenched in quartz ampoules (inert atmosphere) from 1150ºC (30 min) in water. They were subjected to tensile stress test at ambient temperature till their destruction. With special magneto metric device [1] the concentrations of the deformation induced martensite in function with the plastic deformation degree were registered. The instrumentally derived dependencies are shown in Fig.1 whereas their phase composition, the maximum quantity of the deformation induced martensite and their mechanical properties are given in Table 1.
As it can be seen from Table 1, after quenching, the alloys(with the exception of steel No.1) have austenitic structure whereas the ones subjected to tensile stress test at ambient temperature till their destruction, formed between 50% and 56% deformation induced martensite.
The coefficient K, given in Table 1, is the ratio of the maximum amount of martensite relative to the corresponding degree of maximum deformation at the moment at which the sample brakes. Practically, it reflects the average amount of deformation induced martensite that falls on 1% plastic deformation which can be formulated as the tendency of the alloy toward deformation martensite formation.

3. Discussion of experimental results

On the basis of the experimental results, the following can be said:

- The highest tendency to deformation martensite formation has carbon steels alloyed only with manganese of the type X30Mn12 – steel 1. The studies of other authors [2-6] show that in binary Fe-Mn alloys, the minimal stacking fault energy is observed at 12% concentration of the manganese [2]. It has also been found that TRIP-steels have the greatest propensity to martensite formation at a concentration of carbon of the order of 0.3 weight% [2-6]. For the investigated alloy 1% plastic deformation corresponds to 3.2% deformation induced martensite formed. Despite its high propensity for martensite formation, this steel is hard to find its application. It has two phase structure-austenite and martensite. The martensite is thermal and has no deformational origin. For these steel minor deviations in its chemical composition or production technology lead to unpredictable changes in its phase composition, this is technically unacceptable.
- Presence of 5-10% (weight) chromium/steel – X30CrMn5.12 /leads to stabilizing of the austenite at ambient temperatures and prevents the formation of initial martensite but decreases the ability towards deformation induced martensite formation/coefficient K decreases/. From practical point of view the effect of chromium on the deformation martensite formation in these steels is positive despite the fact that it increases the SFE of the austenite. It was determined that 5% chromium are sufficient to significantly increase the mechanical properties of the steel and its plasticity.
- Increasing of the chromium contend from 5 to 10% (weight) /steel – X30CrMn10.10/ does not affect the alloy's inclination to deformation induced martensite formation. It does not affect the maximum amount of deformation induced martensite formed and does not increase its mechanical properties. Therefore, increasing the amount of chromium in the range above 5% is economically unprofitable.
- The results showed that the additional alloying of chromium-manganese steel with molybdenum steel X30CrMnMo5.12.2, Table 1, in the range of 2-3% (weight) does not lower considerably its tendency to deformation induced martensite formation and does not change the maximum amount of deformation martensite, formed in it. It has a particularly favourable effect on mechanical properties, greatly increasing the plasticity of the steel. Molybdenum is a weak carbide and nitride forming element and, after quenching, is present mainly in the solid solution. Thus, it positively affects its properties over a wider temperature range compared to other more strong carbide and nitride forming elements.

- Alloying of the TRIP-steels with vanadium steel X30CrMnV5.12.1, increases its ability towards martensite formation /K-2,8/ but decreases its mechanical properties and plasticity. Another characteristic result is that vanadium modifies the character of the dependence deformation martensite – deformation degree – Fig.1 as significantly increases its “incubation” period in terms of the deformation degree, probably due to the presence of insoluble vanadium Carbides along the grain boundaries.

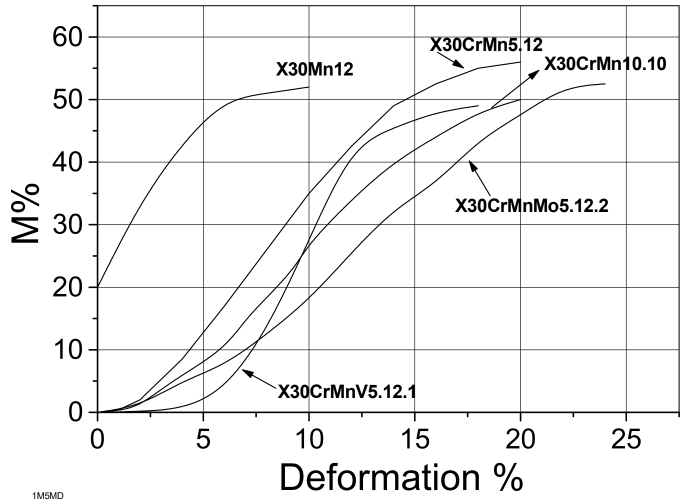

Fig.1. Dependence of deformation induced martensite quantities in function of the plastic deformation degree

The type of relationships shown above for the amount of deformation martensite by the degree of deformation – Fig. 1, is distinguished from that of the anisothemal dependence on the formation of "thermal" martensite/ formed as consequence of the temperature change/ derived from our other researches. The thermal martensite is characterized with the absence of incubation period since the formation of thermal martensite has a heterogeneous and / or autocatalytic nature.
The deformation induced martensite shows an incubation period with respect to the applied deformation. This confirms the model and the theory of Olson G. and Cohen M. [7, 8], according to which the presence of an "incubation" period is associated with the formation of ε-martensite and α-nucleus of a size capable of growing spontaneously.

4. Conclusions

The results obtained led to the following main conclusions:
- The highest tendency to deformation induced martensite formation has carbon steels alloyed with manganese only.
- The presence of 5% (weight) chromium /alloys 1 and 2 /leads to stabilization of the austenite at room temperature, prevents the appearance of initial martensite and does not reduce its tendency to deformation martensite formation.
- Increasing of the chromium content up to 10% (weight) does not positively affect the maximum amount of deformation martensite formed and does not increase the mechanical properties of the alloys.

- The additional alloying of chromium-manganese alloys with molybdenum does not significantly reduce the inclination of the steel to deformation martensite formation and does not change the maximum amount of deformation martensite in them. It has a beneficial effect on the mechanical properties, greatly increasing the plasticity of the steel.
- Alloying of the TRIP-steels with vanadium increases their tendency to martensite formation, but it aggravates the mechanical properties and plasticity. Vanadium modifies the nature of the dependence: deformation induced martensite-deformation degree, significantly increasing the "incubation" period in terms of deformation.

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