PROCESSES OF STATIC AND DYNAMIC DEFORMATION OF MANGANESE STEELS AND THEIR INFLUENCE ON CHANGES IN PROPERTIES AND STRUCTURE

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Abstract

High Mn steels is a new type of structural steels, characterised by both high strength and superior formability. The one of this is TWIP steel offers an remarkable opportunity to adjust the mechanical properties modifying the strain hardening. These steel features can therefore lead to a lightweighting of steel components and a reduction of material consumption. These advantages are the key to changing the approach in the design of steel components which emphasise a reduction of fuel consumption as well as the gas emissions. The present paper deals selected aspects of the microstructural effects observed in the high strength TWIP steels which accompany deformation processes with a special emphasis its comparing for two grades steel with different carbon and silicone content.

Keywords: AHSS steels, compression, deformation, microstructure

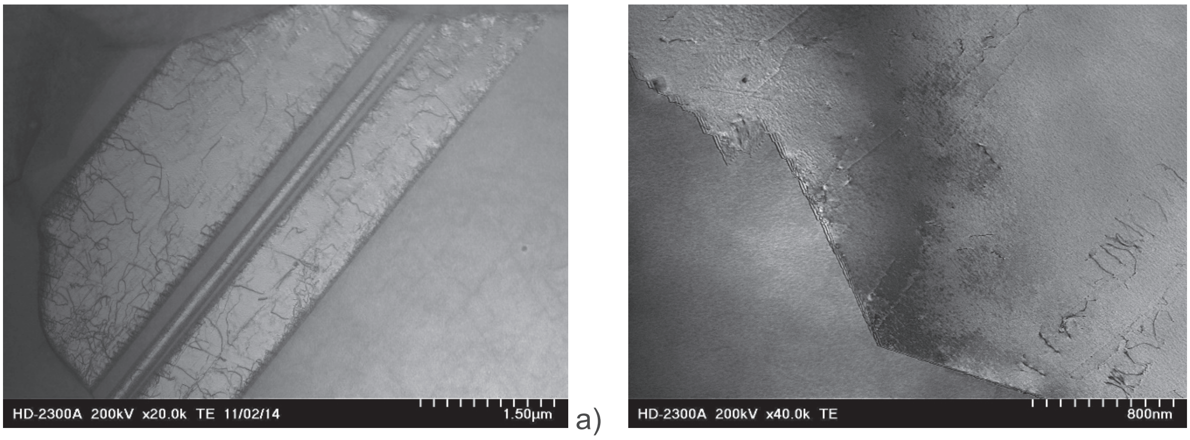
1. INTRODUCTION

Current needs of the most important branches of economy, such as, for instance, automotive and railway industries, are connected with manufacturing of new materials with significantly more favourable set of mechanical and plastic properties, and taking the economic aspects under consideration. Pursuit of reduction in vehicle mass results in application of various material groups such as composites, polymers or light alloy materials, but the most important elements with the highest degree of responsibility for safety are still manufactured from steels [1-4]. However, the approach to designing modern steels with a broad range of strength and plastic properties is changing fundamentally [2-7]. Among these steels, one may include steels from the group work hardened as a result of structural effects induced by plastic deformation [4-9]. Particularly two groups of manganese steels exhibiting opposite effects during deformation, i.e. the ones caused by hardening by mechanical twinning of the austenite, the so-called TWIP effect (twinning induced plasticity), **Figure 1**, and hardening by formation of shear microbands in the austenite, the so-called MBIP effect (microbands induced plasticity), belong to them [5-11]. Both these effects influence uniquely the combination of mechanical and plastic properties, and their occurrence depends on the value of stacking fault energy γSFE which is dependent on the chemical composition. The details of the mechanisms controlling strain-hardening in high manganese steels are still being researched [4-7, 10-16]. The main factor responsible for the capability of manganese steels to deformational hardening is the deformation rate. These materials belong to a group of alloys with significant sensitivity to this parameter of plastic deformation. Deformation rate is one of the basic parameters influencing plastic working process, which may vary in a broad range, while the other parameters are constant or negligibly small. In this context, studies of material may be carried out in a broad range of the deformation rate. Essentially, several characteristic ranges corresponding to various processes of deformation of materials [13-19] were defined. The first range below 10^{-4} s^{-1}, corresponding to material creep, for which the experiments are generally carried out at constant stress, determines the creep curve. The second range at 10^{-4} $s^{-1}\div10^{-2}$ s^{-1} corresponding to the condition of static tests on test machines, allows to determine standard properties of the material. The third range 10^{-2} $s^{-1}\div10^{2}$ s^{-1} is a range of quasi-static tests, carried out using such devices as, among others, universal fast hydraulic machines, pneumatic machines, drop hammers, rotary hammers, Charpy' test, allows to estimate the ability of the material to absorb energy. The fourth range at

10^2 s^{-1}÷10^4 s^{-1} is a range of tests applying high deformation rates. Under such conditions, experimental tests for compression or torsion are carried out, but with limited starting lengths of sample grips. Considering the fast-changing deformation processes, devices based on elastic wave propagation theory are used. The fifth range > 10^4 s^{-1} is called a range of very high deformation rates, obtained by generation of plane waves in uniaxial deformation state [7,10,13]. The study of properties of high manganese steels under static conditions is a popular practice however, the results of these studies are still insufficient. In the paper several properties as well as the detailed microstructure analysis after static and dynamic deformation was performed of manganese TWIP steel.

2. EXPERIMENTAL PROCEDURE

A manganese steels A - Fe - 30 wt.% Mn - 5 wt.% Al - 5 wt.% Si - 3 wt.% C and B - Fe - 26 wt.% Mn - 5 wt.% Al - 5 wt.% Si - 0.6 wt.% C, was the materials for studies. The steels was prepared according to the procedure descripted in […]. After the forging, the bars were supersaturated from a temperature of 1150°C - 1170°C. Both studied steels had a monophase austenitic structure (**Figure 1**), with a hardness 160 - 185 HV2. Research in the field of static loads was carried out using the Instron servohydraulic testing machine with a strain rate 0.01 s^{-1}. The Hopkinson modified rod method was used for research in the field of high strain rates. Cylindrical samples of dimensions h = 5 mm, d_0 = 5 mm were used. The compression test was carried out at a speed of 2600 s^{-1}. The test sample was placed between two rods 1 m long and 400 mm in diameter made of high-strength steel (Maraging steel) and fixed in Teflon bearings. The deformation of the samples was limited by means of limiting rings, which in turn results in a real (logarithmic) deformation value of 0.1; 0.22 The structural studies were carried out by optical light microscopy and in the submicroscopic scale, using transmission scanning electron microscopy. The hardness measurement was carried out by Vickers method under a load of 2 kg.



a) b)

Figure 1 Microstructure of steels after supersaturation a) A, b) B, STEM, visible grain boundary of austenite annealing twins and dislocations

3. RESULTS AND ITS DISCUSSION

The results of the static and dynamic deformation of both steels are shown in **Table 1**. The YS value during the static as well as the dynamic conditions are very similar. Increasing the deformation value up to 0.1 and 0.22 it shows the changes in properties of both steels. It can be seen that steel B is stronger than steel A. This is undoubtedly due to the different chemical composition of both steels. As we also note, the C content probably plays a major role. The increase in Si content in steel A does not compensate for the strengthening resulting from the higher C content in steel B.

Table 1 Results obtained in static tensile test of steel

Strain rate, s^{-1}	Steel	YS, MPa	Steel	σ, MPa (ε = 0.1)	Steel	σ, MPa (ε = 0.22)
0.01	Steel A	412	Steel A	555	Steel A	765
	Steel B	395	Steel B	600	Steel B	820
~2500	Steel A	720	Steel A	845	Steel A	1053
	Steel B	715	Steel B	850	Steel B	1080

Microstructure analysis of Steel A and B after static compression tests are visible in **Figure 2** and **Figure 3.**

We found the several dislocations as well as the stacking faults in the structure of steel A. A local areas with high accumulation of dislocations occur. The slip takes place in two slip systems. The initiation of the mechanical twins creation are observed. In steel B we also can see the several dislocations which move in two slip systems. The several stacking faults are visible and the mechanical twins they form in the structure. High dislocation density they often occur in a very large area.

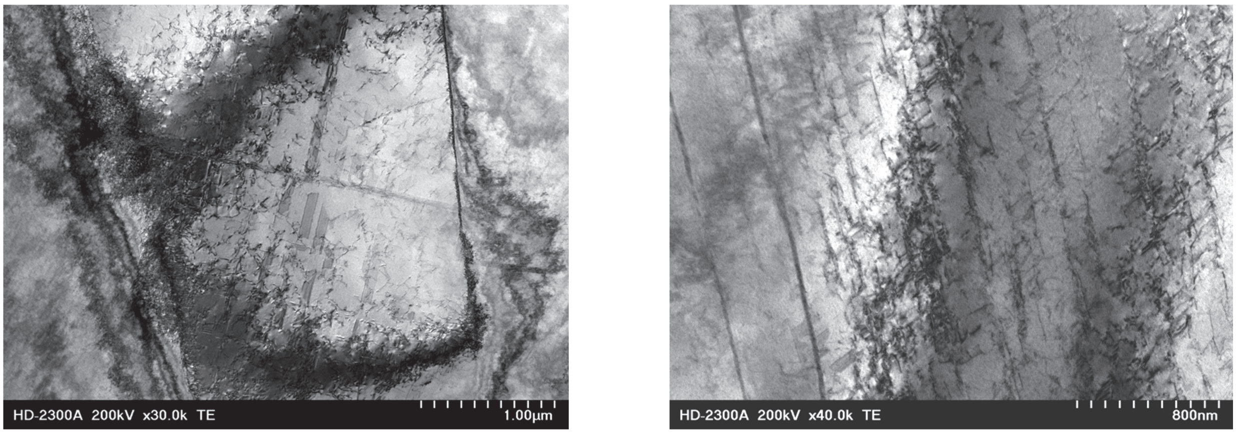


Figure 2 Microstructure of steel A after static deformation a) ε = 0.1, b) ε = 0.22, STEM, visible dislocation structure, stacking faults, slip in two systems, creation of first mechanical.

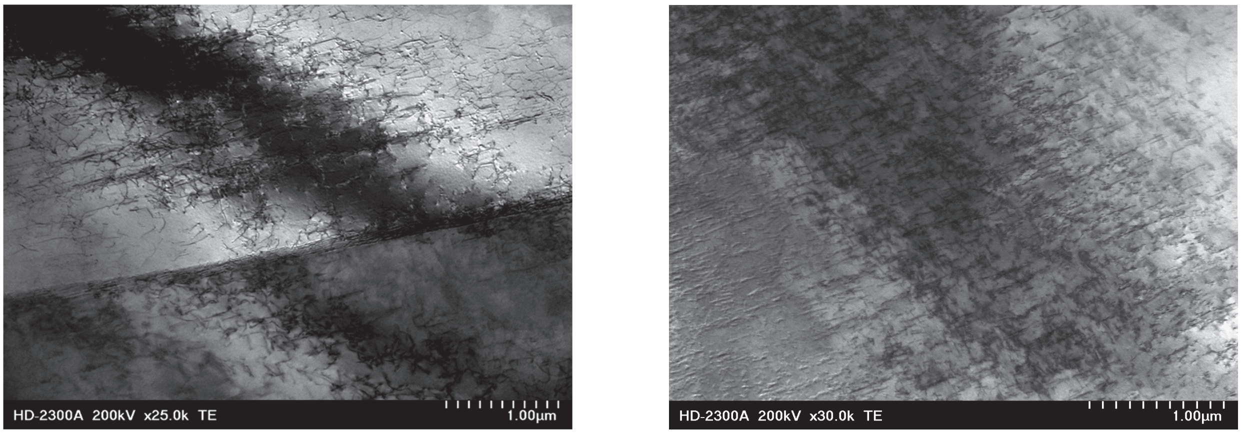


Figure 3 Microstructure of steel B after static deformation a) ε = 0.1, b) ε = 0.22, STEM, visible dislocation structure, few stacking faults, slip in two systems.

Dynamic deformation leads to structure evolution in steel A as well as in steel B. In steel A the mechanical twins they begin to prevail in structure. In dislocation matrix the formation of dislocation cells was started. In areas with high dislocation density the dislocation walls are formed. We also observed the areas where the microband formed, for example, at the boundary of three grains.

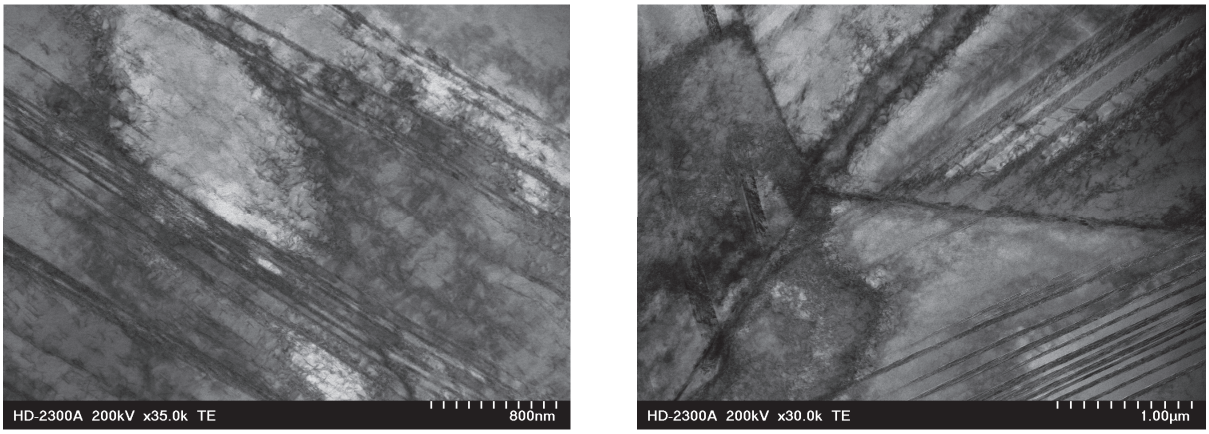


Figure 4 Microstructure of steel A after dynamic deformation a) ε = 0.1, b) ε = 0.22, STEM, visible dislocation cells, several mechanical twins , microbands , shear bands creation

In the steel B the microstructure consist from areas with large accumulation of mechanical twins next to the areas where the dislocation structure rebuilding process occurs. We observed the double dislocations walls. The characteristic microbands and shear bands as the effects of the structure remodelling as a result of the location of the deformation are noticed. The formation of twin bundles takes place.

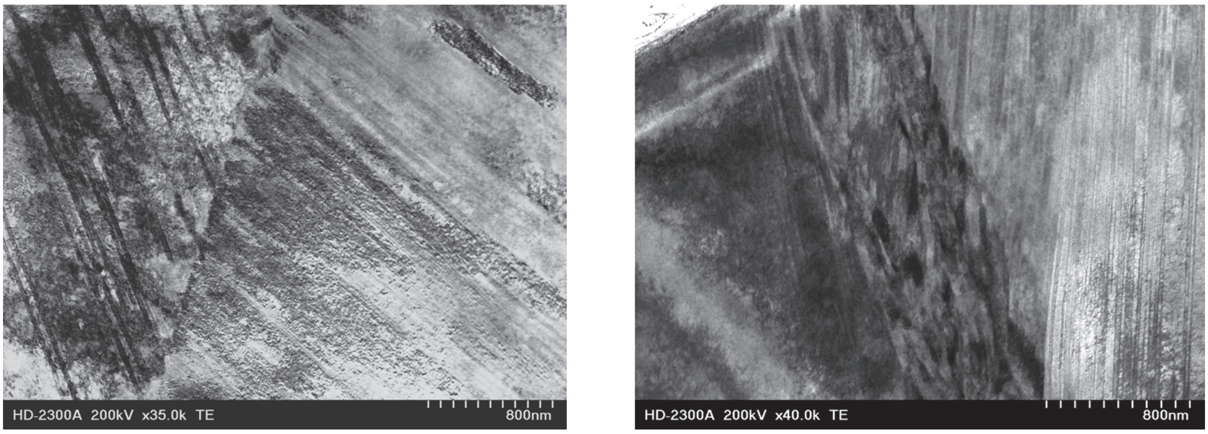


Figure 5 Microstructure of steel B after dynamic deformation a) ε = 0.1, b) ε = 0.22, STEM, visible high dislocation density, several mechanical twins, microbands , shear bands creation

4. CONCLUSIONS

In the literature more and more attention is devoted to the structural analysis of the plastic deformation mechanisms of AHSS. The purpose is to answer the question how to predict the behavior of a structure element in vehicles where a new generation of steel is used. To understand this issue it is necessary to perform a series of tests of properties under different conditions and above all, making a thorough analysis of structural changes that accompany the processes of deformation of AHSS steel. While the chemical composition was different, the YS obtained in the static compression tests were similar. The difference was obtained at a higher deformation value. Steel A showed a lower strain value of about 50 MPa than steel A. This could be due to a higher carbon content in steel B. This is also confirmed by the microstructural analysis. In steel B a much higher density of dislocations was observed in in static deformation conditions than in the steel A. The differences in the mechanical properties obtained in the dynamic conditions are smaller. Both the value of YS and stress value for strain 0.1 and 0.22 in steel A and steel B are similar. this can be explained by a much more intense remodeling of the structure that is observed in steel B. The compensating the stress value by double dislocations walls, microbands and shear bands creating as the effects of the structure rebuilding by localization of deformation are noticed. The plastic deformation was promoted by the formation twins as well as the twin bundles.

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