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TWIP mechanism in processing of high-manganese austenitic steel

L.A. Dobrzański*, W. Borek, J. Mazurkiewicz

Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Konarskiego 18A, 44-100 Gliwice, Poland

* Corresponding e-mail address: leszek.dobrzanski@polsl.pl

ABSTRACT

Purpose: The aim of this paper is to determine the high-manganese austenite propensity to twinning induced by the cold working and its effect on structure and mechanical properties, and especially the strain energy per unit volume of new developed high-manganese Fe-Mn-(Al,Si) high-manganese austenitic TWIP (TWinning Induced Plasticity) steel containing about 25% Mn, 1% Si, 3% Al.

Design/methodology/approach: The essence of the research concerns the analysis of the influence of microstructure evolution during cold plastic deformation. The microstructure of investigated steel was determined in metallographic investigations using light, scanning and high-resolution transmission electron microscopies (HRTEM).

Findings: The activation of intensive mechanical twinning mechanisms in high-manganese austenitic steels, in order to increase strain energy, allows the formation of technological components of complex shape or permits the discharge of energy during cold plastic deformation. According to currently presented views, it is believed that the new austenitic steels with the A1 crystallographic structure containing Mn more than 25 mass.%, Si and Al can provide a significant advance, particularly in automotive applications, because practically there are no more possibilities to improve at the same time the strength and ductility of the steel with A2 crystallographic structure.

Research limitations/implications: Results obtained in static conditions for new developed high-manganese austenitic steel indicate the possibility and purposefulness of their employment for constructional elements of vehicles, especially of the passenger cars to take advantage of the significant growth of their strain energy per unit volume which guarantee reserve of plasticity in the zones of controlled energy absorption during possible collision resulting from activation of twinning induced by cold working, which may lead to significant growth of the passive safety of these vehicles' passengers.

Originality/value: TWIP steels show not only excellent strength, but also have excellent formability due to twinning, thereby leading to an excellent combination of strength, ductility, and formability over conventional dual-phase steels.

Keywords: High manganese steel; TWIP mechanism; Twinning; Twins; Mechanical properties; Structure

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PROPERTIES

1. Introduction

Taking into consideration increased quantity of accessories used in modern cars, decreasing car's weight can be achieved solely by optimization of sections of sheets used for bearing and reinforcing elements as well as for body panelling parts of a car. Application of sheets with lower thickness requires using sheets with higher mechanical properties, however keeping adequate formability [1-4]. The goal of structural elements such as frontal frame side members, bumpers, and the others is to take over the energy of an impact. Therefore, steels that are used for these parts should be characterized by the high value of UTS (ultimate tensile strength) and UEl (uniform elongation), proving the ability of energy absorption. Among the wide variety of recently developed steels, high-manganese austenitic steels with low stacking faulty energy are particularly promising, especially when mechanical twinning occurs [5-11]. Beneficial combination of high strength and ductile properties of these steels depends on structural processes taking place during cold plastic deformation, which are a derivative of SFE of austenite, dependent, in turn on the chemical composition of steel and deformation temperature. High-manganese austenitic steels in the effect of an application of proper heat treatment or thermo-mechanical treatment can be characterized by different structure assuring the advantageous connection of strength and plasticity properties. The Proper determinant of these properties can be plastic deformation energy supply determined by an integral over the surface of cold plastic deformation curve. Obtaining of high strength properties with retaining the high plasticity has a significant influence on the development of high manganese steel groups and their significance for the development of materials engineering [3-17].

2. Materials and methodology

As the material for investigation was chosen a newly developed experimentally high-manganese C-Mn-Si-Al steel of the type X8MnSiAlNbTi25-1-3. Chemical composition of the investigated high-manganese TWIP-type steel was 0.08 mass% C, 24.6 mass% Mn, 0.91 mass% Si, 3.1 mass% Al with micro additions of Nb=0.04 mass% and Ti=0.024 mass%. The high concentration of Mn approx. 25 mass% in the steel with approx. 1 mass% Si and approx. 3 mass% of Al, with the introduction of a controlled concentration of Nb and Ti microadditives with a strong chemical affinity for C and N inhibit the grain growth of the recrystallized austenite, which facilitates the formation of refined structure and thus increasing the strength of steel.

As part of a the research program following tests of the investigated steel were carried out:

- static tensile strain test with the predetermined deformation and sample rupture.
- metallographic investigations using the methods of light and scanning electron microscopy,
- investigations of thin foils in a high-resolution transmission electron microscope,

Investigations of mechanical properties were performed on a universal testing machine Zwick Z050 with a maximum load range up to 50 kN, and the analysis of the obtained results was performed with the use of the testXpert software II also from Zwick company. The static tensile test was carried out in accordance with the PN-EN ISO 6892-1:2010 standard. In order to analyze the twinning intensity, the samples were stretched to a predetermined elongation of 5, 10, 20 and 30% until sample breaking. Metallographic studies were carried out on specimens made from the tested steel, the samples were mounted in a thermoplastics resin. To reveal the austenite grain boundaries and the deformation bands in the structure of the tested steel, there was used a solution of 10% nitric acid in ethanol as the etching reagent. Structural observations of tested materials were carried out on the Mef4a Leica and Zeiss Axio Observer light microscopy. Metallographic investigations were also performed in a scanning electron microscope Zeiss Supra 35 equipped with Schottky field emission gun electron, detecting secondary electrons (SE) and backscattered electrons (BSE), at an accelerating voltage of 20 kV and a magnification in the range of 500-25000 times. Electron diffraction and structure investigations of thin films were made on a high-resolution transmission electron microscope FEI Titan 80-300 (HRTEM). The value of the acceleration voltage during the tests was 300 kV and the observations itself were conducted in the standard mode with the spatial resolution in the range of 0.1-50 nm.

3. Results and discussion

Structures of the investigated X8MnSiAlNbTi25-1-3 steel after the static tensile test are shown in Figs. 1-3. As even a small deformation of the order of 5 or 10% makes the grains are elongated in the direction of the tensile force. In austenite grains and annealing twins (Fig. 1a, b) are detected bands of intersecting slipping. The increase in elongation of the samples to values of 20-30% in the static tensile test results causes an increase of density of intersecting slipping bands and deformation twins (Fig. 1c,d).

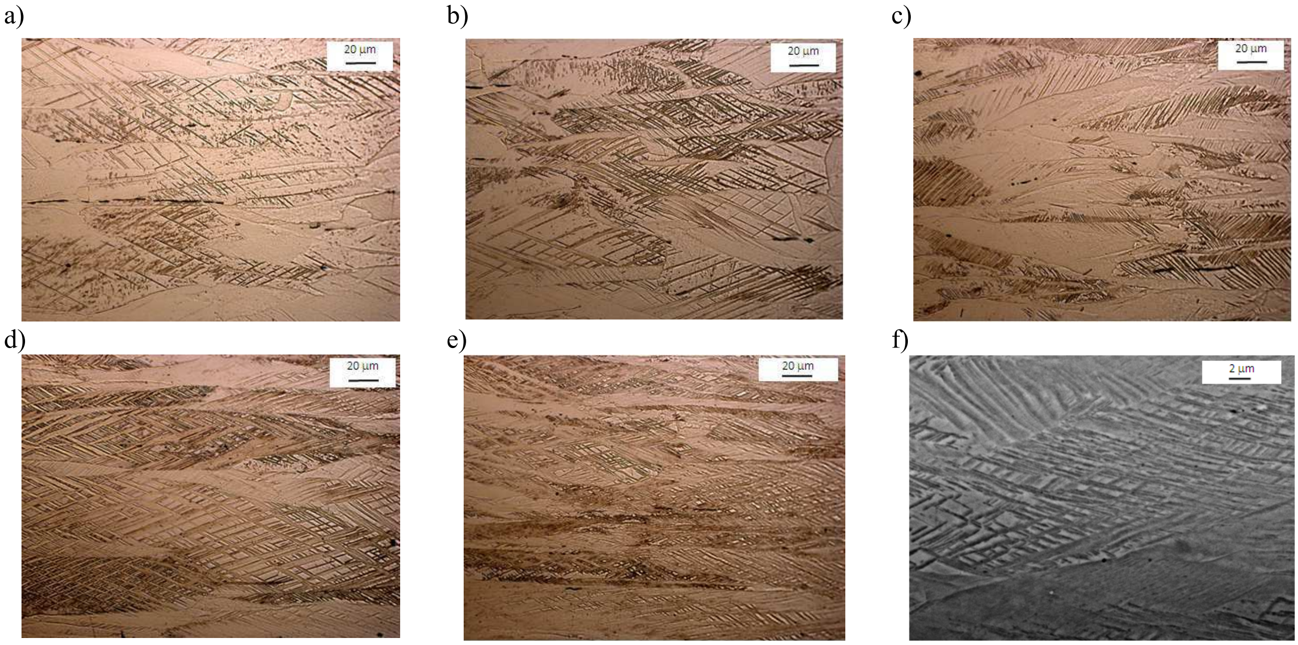

Fig. 1. Structures of the investigated X8MnSiAlNbTi25-1-3 steel after the static tensile test stretched to a predetermined elongation of a) 5%, b) 10%, c) 20%, d) 30%, and e), f) after sample breaking

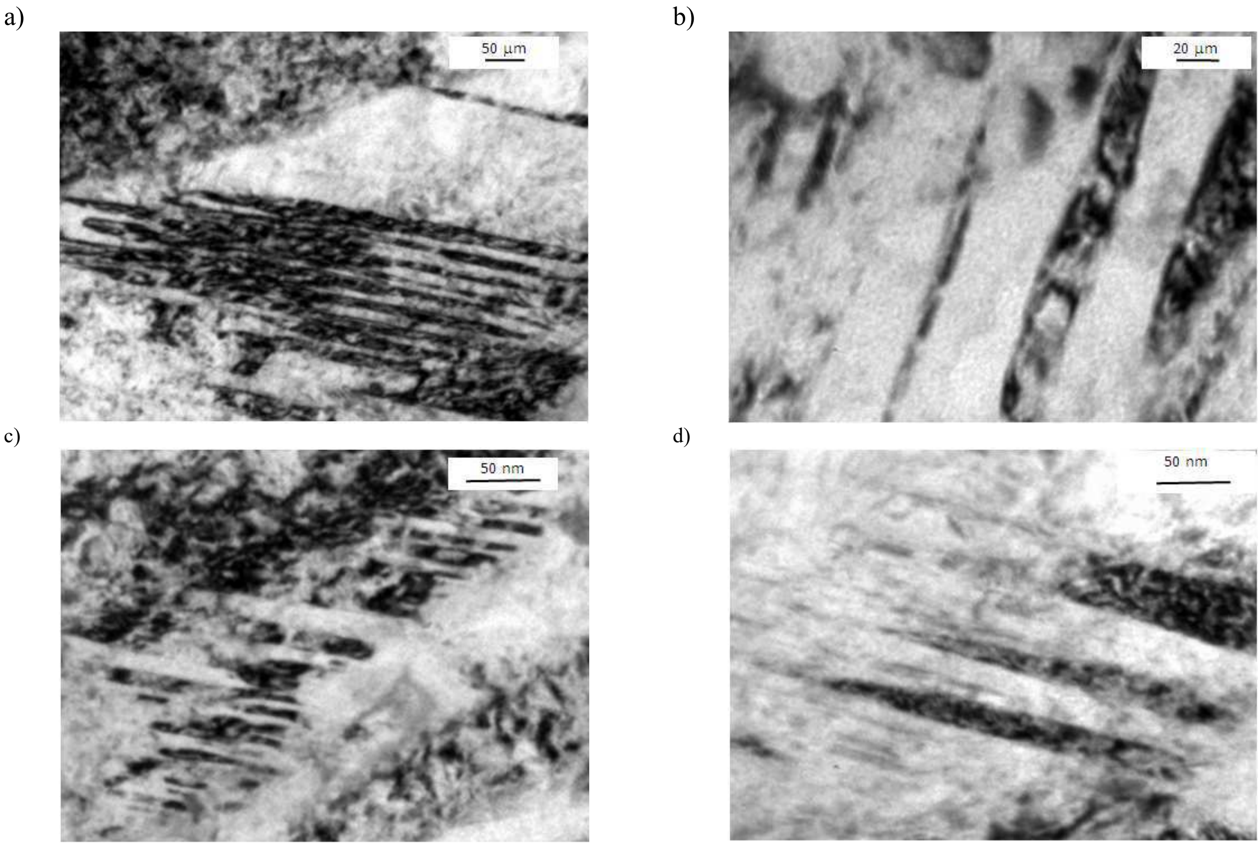

Fig. 2. Twinned austenite area in the structure of thin films in X8MnSiAlNbTi25-1-3 steel after the static tensile test stretched to a predetermined elongation of a-d) 20%

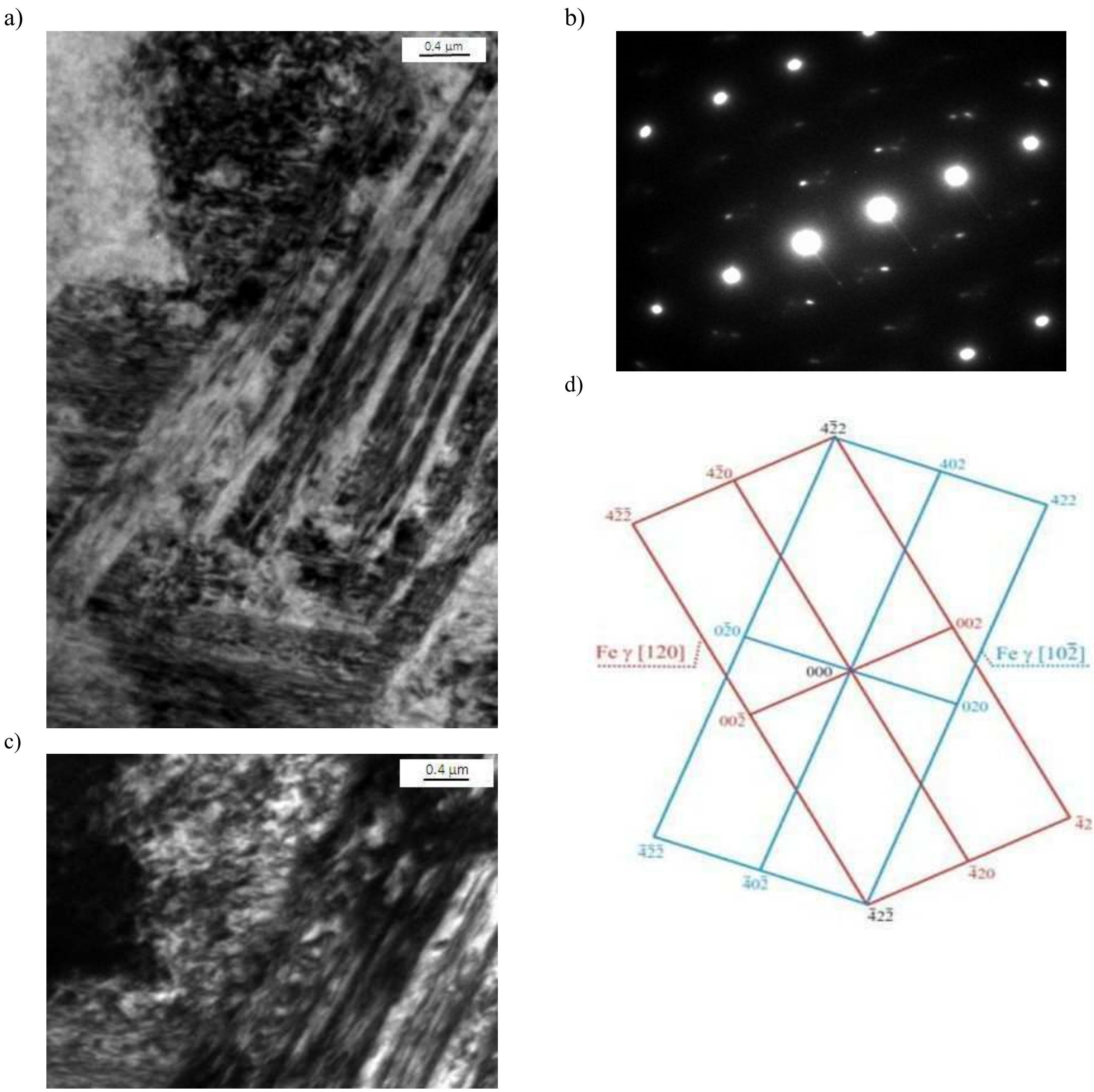

Fig. 3. Deformation twins intersecting in two different systems in the thin foil structure of the X73MnSiAlNbTi25-1-3 steel, steel structure observed in transmission electron microscope after static tensile test until break; a) bright field, b) diffraction pattern from the area in Fig. a), c), the dark field from the spot(002) Fe_{γ} from the area presented in Fig. a); d) solution of the diffraction pattern

The structures of the samples deformed until rupture is characterized by highly elongated and deformed austenite grains in the stretch direction as well as with high-density slip bands and deformation twins (Fig. 1e, f). Thin foils investigations by transmission electron microscopy have revealed that the structure of the newly developed high-manganese austenitic steel X8MnSiAlNbTi25-1-3 after the static tensile test consists mainly of grain with a high dislocation density with numerous twins (Fig. 2, 3), localized mainly in largely deformed grains with various intersecting slip systems. With the use of high resolution transmission electron microscopy was confirmed the primary mechanism of TWIP (Twinning Induced Plasticity) is closely related to the cold plastic deformation through the activation of twinning in mutually intersecting system (Fig. 3)

The obtained results of the mechanical properties of the static tensile strength test are as follows: ultimate tensile strength UTS - 559MPa; yield strength $YS_{0.2}$ - 475 MPa; uniform elongation UE_l - 45 %. The mean value of the strain energy per unit volume is equal E -239 MJ/m^3, whereas the ratio $YS_{0.2}$/UTS is 0,85 and is much higher compared to conventional steels used for structural cars components. The most important mechanical property from the point of view steels application in road vehicles - characteristic for the high-manganese steels - is the strain energy per unit volume, which is the energy for the accumulation possible during dynamic loading, e.g. during a vehicle collision. The average value of the strain energy per unit volume for the tested steels was determined by calculating the area under the curve of the true stress - true strain diagram. Figure 4 shows a representative curve of the true stress - true strain ratio with the determined strain energy per unit volume, as the integral of the stress - strain curve.

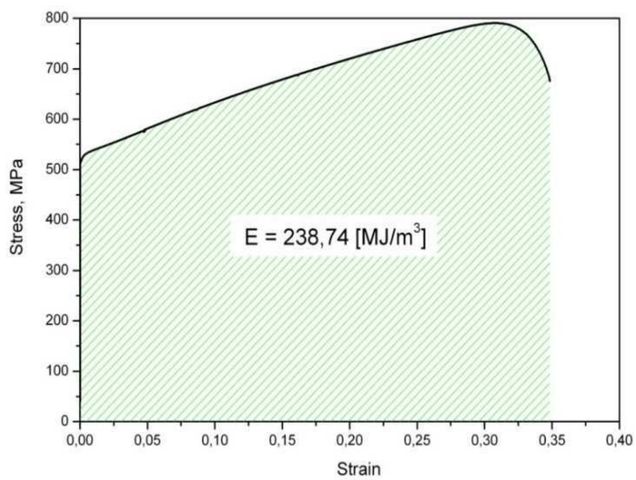

Fig. 4. Representative tensile curve for a steel X8MnSiAlNbTi25-1-3 with designated strain energy per unit volume after the cold plastic deformation

In order to increase the value of strain energy per unit volume for the steel X8MnSiAlNbTi25-1-3 even of 80% there should be either reduced the deformation temperature of up to -70 °C, or increased the rate of plastic deformation to a value of 1000 s^{-1}. In case of the investigated austenitic high - manganese steels used for structural components of cars it can be seen, that increase of the mechanical properties in terms of dynamic plastic deformation, while maintaining very good plastic properties improve the suitability of these steels in service conditions. It is also possible to change shape, thickness, size and primarily obtain weight reduction of structural elements whose main function is to absorb energy during a vehicle crash, made of austenitic high-manganese steels while maintaining the same or even better mechanical and plastic properties. Detailed results of mechanical properties obtained under dynamic conditions of the austenitic high - manganese X8MnSiAlNbTi25-1-3 steels and other steels of different chemical composition will be published in the following scientific publications.

4. Conclusions

On the basis of the carried out investigations it was found that the primary reason for the increase of the strain energy per unit volume during cold plastic deformation under static conditions is activating mechanical twinning in mutual intersecting system, even at low elongation of 5 or 10%, and the presence of mutually intersecting bands of slipping and deformation twins austenite grains and annealing twins, thickening with increasing elongation to 20-30% until break, confirming the basic mechanism of TWIP (Twinning Induced Plasticity).

The activation of intensive mechanical twinning mechanisms in high-manganese austenitic steels, in order to increase strain energy, allows the formation of technological components of complex shape or permits the discharge of energy during cold plastic deformation. Today's requirements for quality cars and other transport possibilities, are related mainly to the implementation of programs to improve the passive safety of traffic users, vehicle weight decrease as low as possible and the consequent reduced fuel consumption with associated exhaust emissions into the atmosphere, as well as are related to comfort, aesthetics and many other aspects. According to currently presented views, it is believed that the new austenitic steels with the A1 crystallographic structure containing Mn more than 25 mass.%, Si and Al can provide a significant advance, particularly in automotive applications, because practically there are no more possibilities to improve at the same time the strength and ductility of the steel with A2 crystallographic structure.

Acknowledgements

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