Influence of strain rate on mechanical properties and structure of high-Mn steels

Wojciech Borek

ABSTRACT

The purpose of this paper is to determine the influence of high strain rate deformation on structure and mechanical properties of high-Mn austenitic TWIP steels tested under static and dynamic tensile conditions. Low and high strain deformation rates in range from 0.001 s^{-1} to 1000 s^{-1}, have a significant effect on forming the structure and mechanical properties of high-manganese austenitic steels. Also the strain energy per unit volume of advanced high-Mn TWIP steels containing Mn, Al, SI and some of that steels with Nb and Ti microadditions, with various structures after their heat- and thermo-mechanical treatments increases considerably in dynamic conditions. That group of steels not only show excellent strength, but also have excellent formability due to twinning, thereby leading to excellent combination of strength, ductility, and formability over conventional dual phase steels or TRansformation Induced Plasticity TRIP steels. The microstructure of investigated steels was determined in metallographic investigations using light, scanning and high-resolution transmission electron microscopies (HRTEM). Results obtained in static and dynamic conditions for new-developed high-manganese austenitic steels 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 result in significant growth of the passive safety of these vehicles' passengers.

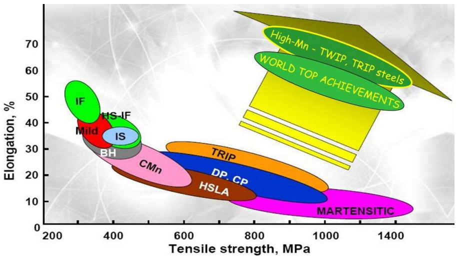

Figure 1. Comparison of conventional mechanical properties of steel and steel with advantageous mixture of strength and plasticity properties, type TWIP and TRIP (the arrow illustrates the trend of currently commenced and executed scientific and research works)

MATERIALS

Table 1. Chemical composition of investigated high-manganese TRIP and TWIP type steels, mass fraction

Steel designation	Chemical composition, mass fraction										
	C	Mn	Si	Al	Nb	Ti	P_{max}	S_{max}	Ce	La	Nd
X11MnSiAlNbTi18-1-3 TRIP type steel	0.11	18.25	1.20	3.29	0.027	0.025	0.002	0.003	0.019	0.005	0.007
X8MnSiAlNbTi25-1-3 TWIP type steel	0.08	24.60	0.91	3.10	0.040	0.024	0.002	0.003	0.005	0.001	0.002

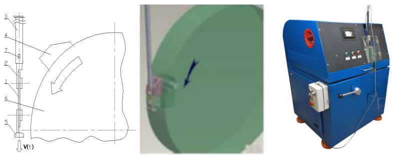

Figure 2. View of the laboratory dynamic tensile test machine – rotary hammer RSO

High-manganese TRIP - X11MnSiAlNbTi18-1-3 and TWIP - X8MnSiAlNbTi25-1-3 steels under investigation containing 18-25% Mn, 0.9-1.20% Si, 3% Al, and microadditions Nb and Ti. The chemical compositions of investigated steels were shown in Table 1. Nb and Ti microadditions were added in order to refine the structure in the initial state and achieve precipitation hardening of investigated high-manganese steels. Steels are characterized by high metallurgical purity, associated with low concentrations of S and P contaminants and gases. Melts were modified with rare earth elements.

RESULTS

Static and dynamic tensile tests were performed in order to investigate mechanical properties, especially strain energy per unit volume of high-manganese austenitic steels. This group of steels will be applied on constructional elements which can transfer loads during front or side impact collisions. On figures 7 - 9 are presented austenitic structures of high manganese steels with mechanical and micro twins and slip bands obtained after static and dynamic tensile tests. Mechanism of twinning and martensitic transformation induced by the cold working of the high-manganese austenitic steels results in growth of the strain energy per unit volume after the successive cold deformation. On Figure 3 is presented representative tensile curve of the TRIP and TWIP type steels with designated strain energy per unit volume after the cold deformation equal respectively 227.50 and 263.33 MJ/m³. Energy increase can be achieved by increasing the strain rate cold plastic deformation (Figure 4), for instance for TWIP type steel acceleration of deformation to 500 s^{-1} causes that energy per unit volume increases by approximately 200 MJ/m³ in comparison with energy determined in static condition (Figure 3). In case of TRIP type steel increasing strain rate to 250 s^{-1} causes increasing doubles energy per unit volume from 227,5 MJ/m³ (Figure 3) to 529,49 MJ/m³ (Figure 4). The high-manganese austenitic steels with the properly formed structure and properties and especially with the big strain energy per unit volume yield the possibility to be used for the constructional elements of cards affecting advantageously the passive safety of the vehicles' passengers.

Apart from chemical composition, the strain rate has an important effect on the creation of deformation twins and martensite ε and α` in the structure of high manganese austenitic steels. Changes in the rate of plastic deformation cause large changes in R_m and $R_{p0.2}$ for steel where a martensitic transformation is induced during cold plastic deformation (Figure 5). A higher rate of plastic deformation at a constant test temperature though reduces elongation by about 10-15% in comparison with maximum value obtained for strain rate about 250-500 s^{-1}. This stems from the adiabatic heating of a specimen during tension with high plastic deformation rates thus increasing stacking-fault energy. The mechanical properties of high manganese austenitic steels, with their plasticity induced by twinning, in the function of a plastic deformation rate, are shown in Figure 6. An increase in the rate of plastic deformation at a constant test temperature is increasing a yield point from 480 to 850MPa. An increase in the rate of plastic deformation above 1s^{-1} is increasing tensile strength from 550 to 900MPa. The values of total elongation are growing as the rate of plastic deformation rises to 250 s^{-1}. After exceeding the minimum value, growth in the rate of plastic deformation causes slight falling in total elongation. Maximum elongation though reaches the value of 60% with tensile strength of 700MPa. A high value of elongation is caused by an intensive curve of mechanical twinning (Figure 6).

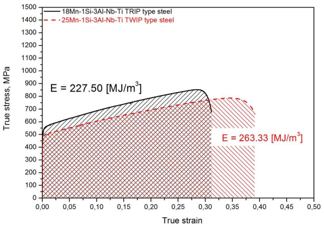

Figure 3. Representative tensile curve of selected TRIP and TWIP type steels with designated strain energy per unit volume after the cold deformation in static conditions

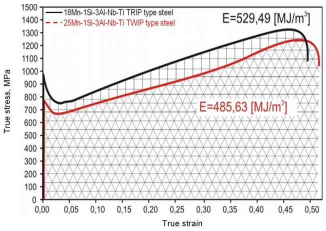

Figure 4. Representative tensile curve of selected TRIP and TWIP type steels with designated strain energy per unit volume after dynamic tensile tests in ambient temperature of deformation with strain rate respectively ($250s^{-1}$) and ($500s^{-1}$)

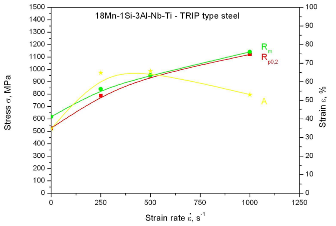

Figure 5. Influence of strain rate on mechanical properties of high manganese 18Mn-1Si-3Al-Nb-Ti TRIP type steel: Yield stress $R_{p0.2}$, tensile strength R_m and total elongation A

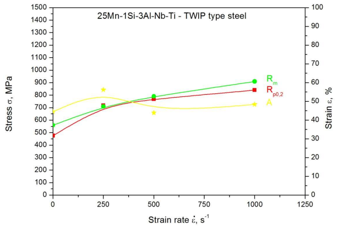

Figure 6. Influence of strain rate on mechanical properties of high manganese 25Mn-1Si-3Al-Nb-Ti TWIP type steel: Yield stress $R_{p0.2}$, tensile strength R_m and total elongation A

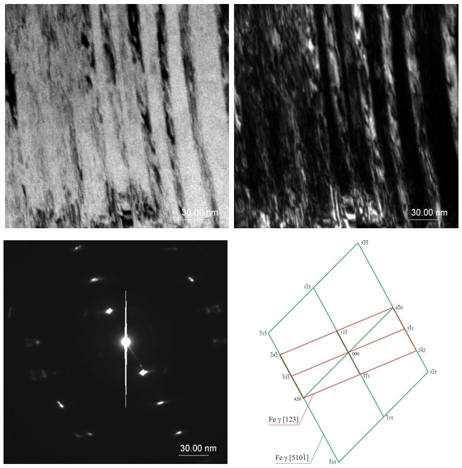

Figure. 7. Deformation twins in the 25Mn-1Si-3Al-Nb-Ti TWIP steel: bright field; dark field from the plain Feγ; diffraction pattern; solution of the diffraction pattern. Feγ [123] is the zone axis of the matrix as well the corresponding zone axis of the twins Feγ [5 10 1̄]

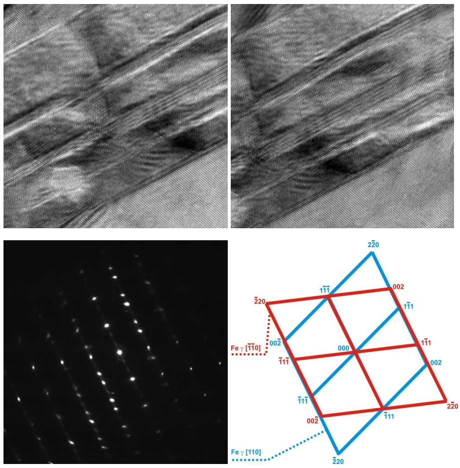

Figure. 8. Twinned austenite area in the 25Mn-1Si-3Al-Nb-Ti TWIP type steel; bright field; dark field from the (11̄1) plain Feγ; diffraction pattern; solution of the diffraction pattern

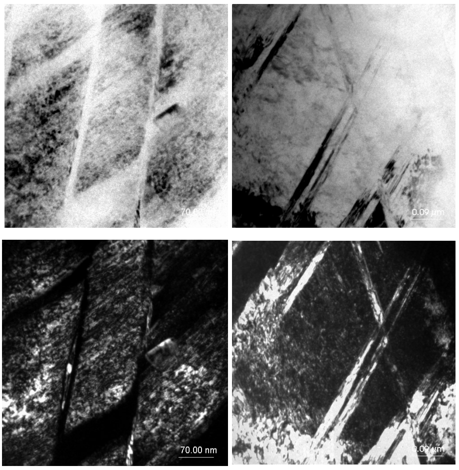

Figure. 9. Austenitic structures of high manganese TRIP steels with intersected ε martensite plates obtained after dynamic tensile test; bright field; dark field

Department of Engineering Materials and Biomaterials,
Silesian University of Technology
Wojciech.borek@polsl.pl

APMME 2021