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ISSN 0543-5846
METABK 52(4) 441-444 (2013)
UDC – UDK 669.15-194.3: 621.039.333:001.891.53 = 111

INFLUENCE OF THERMAL TREATMENT ON STRUCTURE AND CORROSION PROPERTIES OF HIGH MANGANESE TRIPLEX STEELS

Received – Prispjelo: 2012-09-12
Accepted – Prihvaćeno: 2013-03-05
Original Scientific Paper – Izvorni znanstveni rad

In this paper corrosion properties of X70MnAl28-9 TRIPLEX steel were tested after hot rolling and subsequent aging at 500 °C for 6, 30 and 60 min. and at 600 °C for the same times. For comparison related steels(X100MnAl28-12, X70Mn22, C20) were also used. The microstructure wascharacterized by light microscopy, SEM, energy disperse X-ray microanalysis. The corrosion behaviour of steels wasexamined by light and scanning electron microscopy, electrochemical techniques (potenciodynamic polarization method, linear polarization, using NaCl and H_2SO_4 water solutions), salt spray test and gravimetric method. Aging has relatively small influence on corrosion resistance of X70MnAl28-9 steel. The localized corrosion in relation to structure and phases is discussed and compared in terms of dissolution, pitting and changes inchemical composition.

Key words: triplex steels, structure, corrosion, polarization tests

INTRODUCTION

The increasing requirements of automotive (transport) industry have resulted in development of steels with a higher strength properties and high plastic deformability. Several types of steels have been developed and recommended for different part of cars with high energy absorption capability in case of accident [1,2]. From Hadfield and TWIP (twinning–induced plasticity) steels have been developed high manganese TRIPLEX steels.

The advanced TRIPLEX steels contain 25-30 % Mn, 6 – 12 % Al and 0,6-1,2 % C (wt. %). The structure of triplex is characterized by stable austenitic phase with higher stacking fault energy (100-120 mJ/m^2) and very fine coherent k–carbides $(FeMn)_3AlC$ with fcc $L1_2$ type structure, dispersed in matrix [3]. Small volume fraction (5 – 10 %) of δ-ferrite can be also formed in structure after rolling. High manganese steels show higher strength values (R_m=1100 MPa) and simultaneously high plasticity (A=60 %). The advantage of stated steels is higher absorption energy (E_s=0,4-0,5 J/mm^3) and lower density (6,5-7,5 Mg/m^3) as compared with commercial carbon steel.

The mechanical properties and corrosion resistance of X50Mn22 (TWIP) steel after heat treatment and forging has been studied in work [4]. After exposition in 3,5 % NaCl water solution the corrosion was revealed primarily in deformation twins interfaces. The fine grain size and the boundaries of deformation twins, acting as numerous trapping sites, are favourable for a lower local corrosion penetration and better corrosion resistance.

The corrosion resistance tests were carried out on two similar high-manganese steels X7MnSiAlNbTi26-3-3 and X5MnSiAlNbTi24-3-2with a different structure in aqueous sulphur acid solution [5]. The steel of higher aluminium concentration has a single-phase austenitic structure with many annealing twins and the second contains some fraction of martensitic phases of lamellar morphology. Higher mass decrement of first steel is probably a result of the lower aluminium content compared to second steel. The decisive influence on corrosion resistance of examined steels has their chemical composition, which determines high rate of Mn and Fe dissolution in acidic media, i.e. general corrosion and formation of pitting [5].

The electroless coating Ni-P were used to enhance the corrosion resistance of TWIP (Fe-25Mn, Fe-25Mn-3Al) steels. The potentiodyna-mic polarization tests in 3,5 % NaCl and 0,1 M H_2SO_4 showed that Ni-P coating significantly improved the corrosion resistance in both media [6].Thelocal galvanic corrosion is possible between base material and more noble coating. There is possibility of application of new coatings (Ni-Cr, Cr_3C_2) resistant to corrosion and wear of parts [7].

The aim of the work is comparison of structure and corrosion resistance of TRIPLEX steel X70MnAl28-9 after aging.

STEELS AND EXPERIMENTAL METHODS

For corrosion tests TRIPLEX steel of composition (wt. %): 0,70 % C, 28 % Mn, 8,6 % Al (at.%: 2,9 % C,

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25,4 % Mn, 15,9 % Al) was used. The samples of steel plate were prepared in the state after hot rolling (1 100 °C –920 °C) and after aging at temperature 500 °C for 6 min., 30 min and 60 min, as well as at 600 °C for the same holding times (i.e. 5, 30 and 60 min.) with subsequent water cooling each sample. The scaled and rough surfaces of samples were wet ground by SiC paper (up to No. 1000 grain size), then cleaned and drayed. The nominal dimensions of samples were 43 × 28 × 1,8 mm. For comparison purposes related steels (0,7 % C, 22 % Mn; 1,0 % C, 28 % Mn) and commercial carbon steels (C20, CSN 11 375, 11 523) were chosen. Surfaces of samples were prepared in a similar manner as in case of the first steel.

Potentiodynamic cyclic polarization test for pitting was performed according to standard [8] using 0,1 mol/l NaCl water solution at room temperature. Polarization measurements were performed using a potentiostat-galvanostat PGP201 and special corrosion cell with three-electrode connection. The corrosion potential values (E_{cor} or open circuit potential OCP) were measured before potentiodynamic test. Linear polarization test of uniform corrosion was conducted in 0,1 mol/l H_2SO_4 under similar conditions as for NaCl solution.

Sodium chloride containing water solutions are prescribed for corrosion testing of materials and surface layers for automotive parts. Neutral salt spray test was performed according to standard [9] in corrosion testing system LIEBISH S400 M-TR, where the samples were exposed for 6 and 12 hours. Gravimetric method was applied for comparison of corrosionrate.The surfaces and crosssections of specimens were observed after corrosion tests using light microscopy, scanning electron microscopy (SEM) and energy dispersed X-ray micro-analysis.

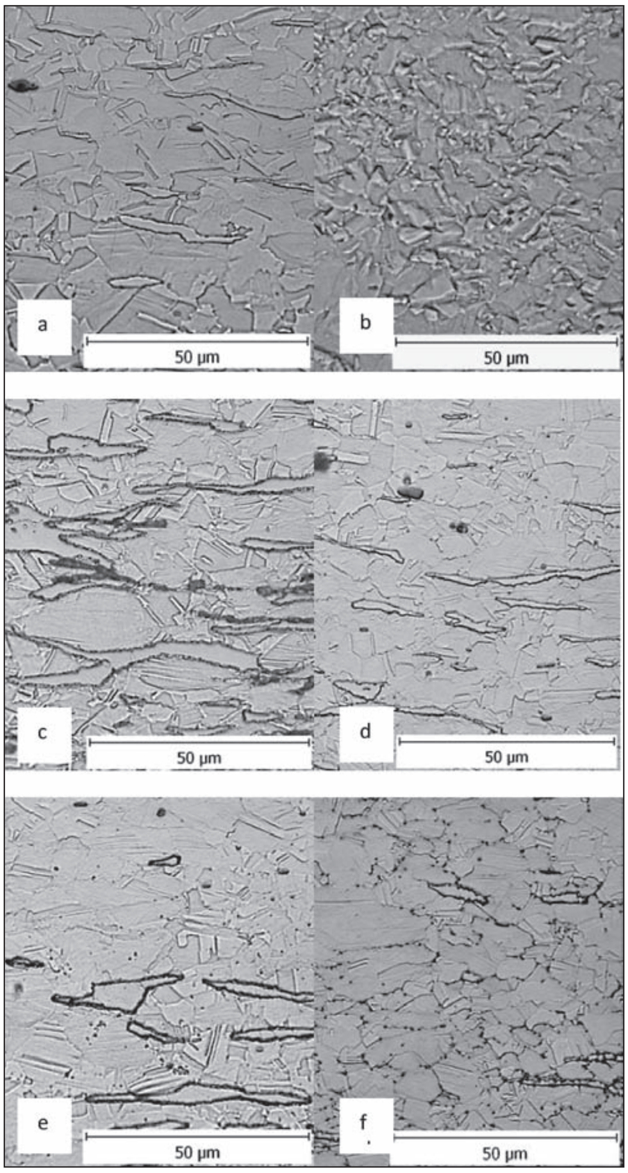

Figure 1 Structure X70MnAl28-9 steel: a, b) after rolling, c) aging 500°C/6´, d) aging 600°C/6´, e) 500°C/60´, f) 600°C/60´

RESULTS AND DISCUSSION

The structures of tested TRIPLEX steel are documented in Figure 1 (a-f), where after aging small particles (k-carbides) are preferentially found along the boundaries of ferrite and austenite. At higher aging temperature and/or for longer holding time, δ-ferrite local content was lower and k-carbides had larger size (coarsening).

At very high magnification the carbides of dimension 10-100 nm dispersed in matrix were observed using electron microscope (Figure 2), probably along the border or edges of stacking faults and slip bands [10].

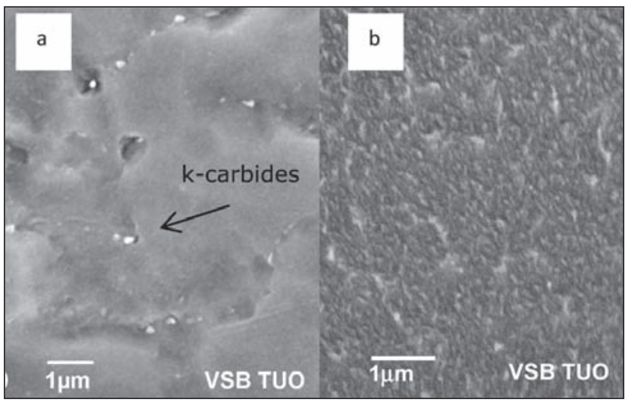

Figure 2 Structure after aging: a) 500°C/30´, b) 500°C/60´, k-carbides are white, light

Based on measured polarization measure-ments and recorded curves (Figure 3) values of electrochemical corrosion parameters were determined: E_{cor} – corrosion potential, R_p – polarization resistance, which is inversely proportional to corrosion rate (r_c=B/R_p, B – constant), E_d – depassivation potential (for current density J_d=100 μA/cm^2), E_r – repassivation potential (J_r=10 μA/cm^2). In general, the higher values of pitting potentials (E_d, E_r) were found, the greater resistance to pitting corrosion was revealed. It is also necessary to consider the differences between pitting potentials and corrosion ones that are E_d-$E_{cor}$and E_r-E_{cor}.

The differences in values of corrosion potential and polarization resistance are relatively small for tested samples with respect to dispersion, Table 1.

Table 1 **Aging temperatureand timesof samples. Values of selected parameters**

Sam. / No.	State Aging	E_{cor}/ mV	R_p/ kΩcm²	E_{cor} / mV	R_p / Ωcm²
7	Rolled	-355	10,3	-611	31,0
11	500°C/6´	-447	16,7	-617	32,0
12	500°C/30´	-393	13,4	-616	29,8
13	500°C/60´	-362	4,55	-617	29,5
14	600°C/6´	-442	2,61	-611	29,6
15	600°C/30´	-472	4,99	-610	26,6
16	600°C/60´	-469	3,63	-624	22,1
	Solution	0,1 M NaCl		0,1 M H_2SO_4	

At aging conditions 600 °C/30-60 min, lowered R_p values were found out (at passive state in NaCl solution or active state in H_2SO_4 one). Similar decreasing trend was registered in values of pitting potentials E_d, E_r, see Figure 4, i.e. lowered resistance to pitting. Weight loss may characterize total extent of pitting corrosion.

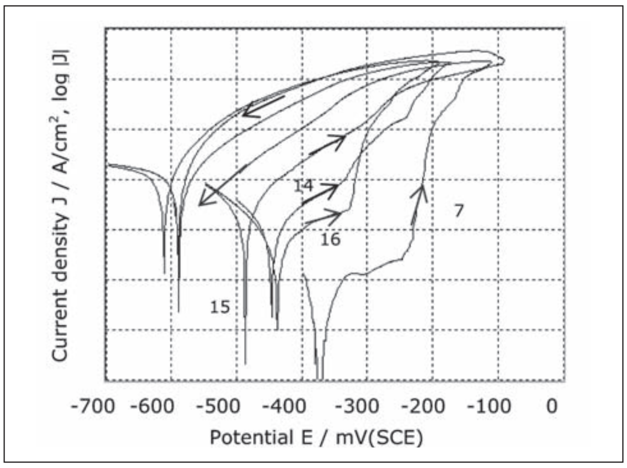

Figure 3 Typical potentiodynamic polarization curves of samples 7, 14-16, see Table 1

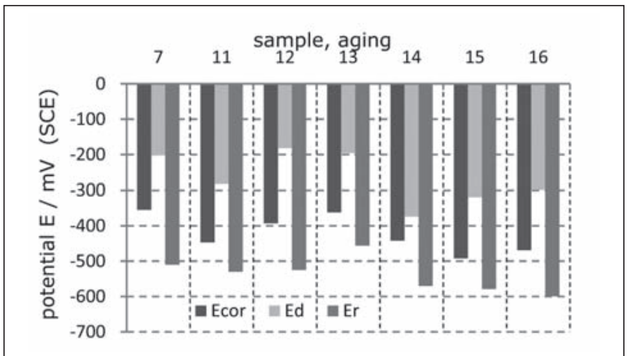

Figure 4 Comparison of pitting corrosion resistance

After 6 and 12 hours exposition in saline mist, the mass changes of TRIPLEX steel is 2-3 times lower as compared to carbon steels (Figure 5), which is explained by protective effect of aluminium.

Positive effect of Al and rather negative influence of Mn on corrosion is confirmed by comparative test with reference steels, Table 2. In this table compared steels are marked:

A -X70MnAl28-9, B - X100MnAl28-12, C - C20,D - X70Mn22.

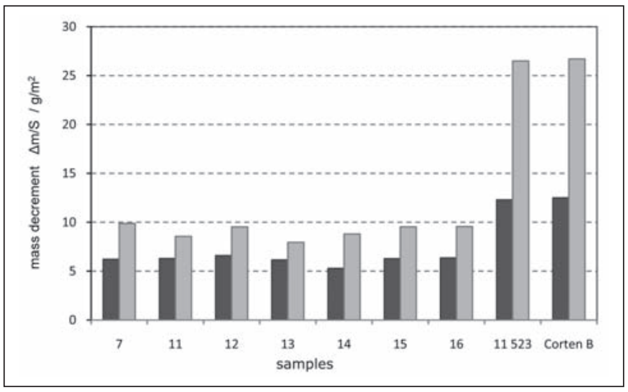

Figure 5 Comparison of general corrosion of tested steelsby gravimetric method

The high manganese content and heterogeneous structure may reduce corrosion resistance in many environments. Aluminium can contribute to passivation of tested steel, but less than chromium. From testing is confirmed thatprimary are changes in chemical composition, secondary are changes in structure for corrosion behaviour, depending on redistribution of Mn, Al and C.

Table 2 **Comparison of corrosion parameters of steels in solutions**

steel	Δm/S / g/m²	- E_{cor} / mV	- E_d / mV	- E_r / mV	- E_{cor} / mV	R_p Ω*cm²
A	9,1	423	265	538	613	31,2
B	7,8	424	258	454	614	38,3
C	15,3	493	431	528	515	-
D	16,1	710	674	705	557	23,7
	salt mist and NaCl solution				H_2SO_4solution	

Oval dimples were typically formed in all samples tested in salt mist, Figure 6. They mainly contain Al (20 – 30 %) and O (50-70 %), lower Fe and Mn amount (≤10 %). The lighter upper layers contain Fe (30 – 50 %), O (30 – 40 %) and lower Mn, Al portion.In corrosion products were also detected Cl, Si, S, Ca, Na (≤ 5% wt.). Similar chemical composition was confirmedby surface microanalysis of corrosion products.

The relation between aging parameters and maximum depth of pitting was difficult to find out on the

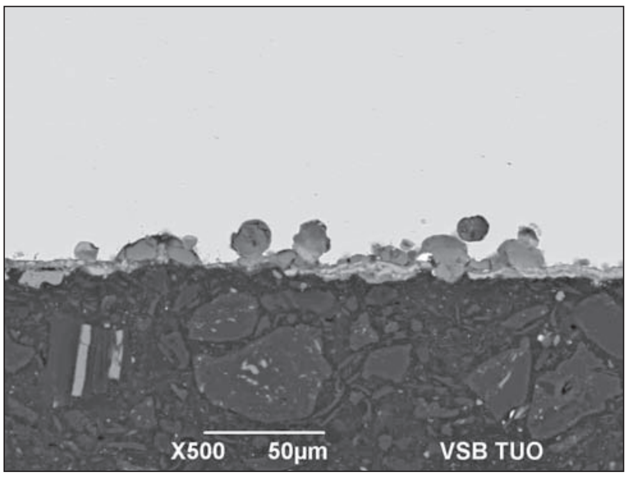

Figure 6 Corrosion of steel X70MnAl28-9,500°C/6min, after salt spray test (SEM, signal BEC)

base of metallography sections. Local maximal pit depths were measured in the range of 20-120 μm after salt spray test.

CONCLUSION

Advanced TRIPLEX steels have higher strength and plastic properties and are perspective material for some automotive parts. Metallographic study and standard corrosion tests were performed on X70MnAl28-9TRIPLEX steel after aging (500 – 600 °C/6-60 min).The differences in structure after aging have small influence on corrosion resistance changes in tested solutions(0,1 M NaCl, salt mist, and 0,1 M H_2SO_4). Manganese shows detrimental influence on corrosion, aluminium increases corrosion resistance. The carbides or Al-depleted phases or areas are local places for initiationof pitting corrosion.TRIPLEX steel has higher corrosion resistance than compared TWIP (X70Mn22) or commercial steel (C20).

Acknowledgements

This paper was created in the project No. CZ.1.05/2.1.00/01.0040 "Regional Materials Science and Technology Centre" within the frame of the operation programme "Research and Development for Innovations" financed by the Structural Funds and from the state budget of the Czech Republic.

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Note: The translator for English language is Zdeněk Friedrych, Ostrava, Czech Republic