SECONDARY PROCESSING OF UHSLA ARMOX 500 STEEL WITH HEAT BASED TECHNOLOGIES

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Abstract

ARMOX steels are armored steels used for protect devices and facilities against blasts and explosions. Due to this purpose the ARMOX 500 steel has excellent mechanical properties as are high hardness, tensile strength and good toughness. These properties result from specific production process finished with rolling ant then quenching and tempering. The producer of ARMOX steels recommend their secondary processing (cutting, welding, shaping) at temperatures lower than 200°C due to over tempering and degradation of mechanical properties in heat affected areas. The paper describes the mechanism and reason of this degradation including the simulation of cooling process with ARMOX 500 steel.

Keywords: UHSLA steel, ARMOX, secondary processing, mechanical properties, heat treatment

1 Introduction

ARMOX 500 is armored steel used to protect vehicles, building or constructions in armament as well as civil applications. ARMOX steel is used as armor plate in some armored personnel carrier (APC) vehicles as is ALIGATOR vehicle produced in Slovak Republic. Another important armament application of ARMOX steels is production of armored containers used to build mobile army installations as are mobile hospitals, service centre and communication and information centers. (MOKYS system - Mobile Communication System of the Armed Forces of the Slovak Republic) in Slovakia which uses ARMOX steel as armour. Over tempering of ARMOX 500 steel or any other steel with similar production process occurs with using of any secondary production process based on heat transfer (cutting, welding, shaping etc.)

Armox steels production process consists of few important steps to reach their required mechanical properties. First step is continuous casting of slabs with using of ore with high chemical purity. The next step is rolling of the slabs at temperature about 1250°C to refine its microstructure – austenitic grains. Then the slabs are solution annealed at temperature about 850°C. Most important are two final steps – quenching and tempering. The slabs are quenched in continuous furnace from the temperature about 1000°C to harden the steel and finally low tempered at 200°C – 500°C in order to make the hardened steel tougher [1]. The microstructure resulting from this treatment is fine tempered martensite (fig. 1).

The producer of ARMOX steels recommend their secondary processing (cutting, welding, bending and others) at temperatures lower than temperature of tempering (200°C) due to accidental over tempering and degradation of mechanical properties in heat affected areas.

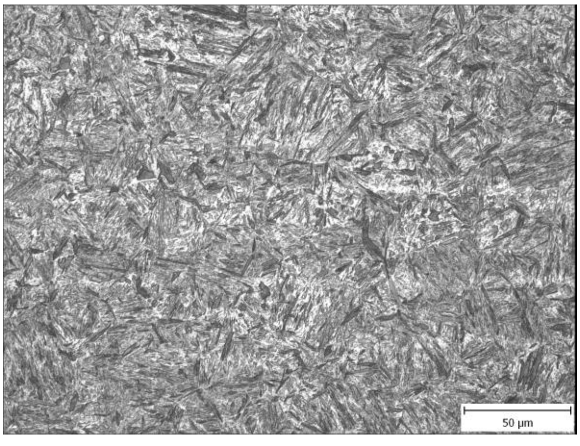

Fig. 1 *Microstructure of Armox 500 – delivered state (mg. 500x)*

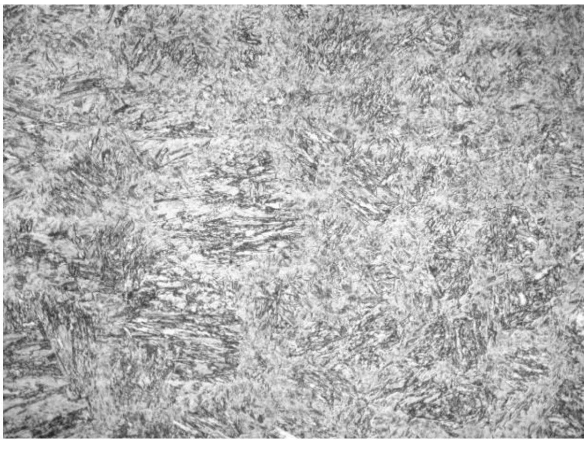

Fig. 2 *Microstructure of Armox 500 affected by over tempering with temperature below A_1 (mg. 500x)*

2 Over tempering of ARMOX steels

Break the recommendation of the producer described before leads to over tempering and therefore to creation of heat affected zones (HAZ) with degraded mechanical properties, hardness mainly.

The reason of degradation lies in microstructure change and could be described with help of tempering theory of steels. The tempering process has four stages according to occurred temperature [2].

For low tempering are important first two mainly. First stage (about 200°C) is characterized with coherent carbon precipitation from martensite in a form of ε phase (Fe2C, Fe2,4C). Decrease of over saturation of martensite with carbon leads to hardness decrease. This change is noticeable at steel with relative higher carbon content.

Also diffusion process of some alloying elements start at that temperature and these may start precipitating from martensite and then make the steel less hard.

There is shown a microstructure of Armox 550 affected by over tempering with temperature below A1 (app. 500°C) on fig. 2. The microstructure is prepared from the sample of welding joint and shown the area in the middle of HAZ (heat affected zone).

Scientific sources indicate a decrease of hardness from 47.6 HRC to 28.6 HRC (40%) by exposure the ARMOX 440 armored steel with temperature about 650°C for 5 minutes. Tensile strength decreases from 1476 MPa to 451 MPa (70%) at the same conditions [3]. Characteristics of ARMOX 500T armored steel

Chemical composition and mechanical properties of ARMOX 500T steel guaranteed by producer in the datasheet is shown in Table 1.

Table 1 *Chemical composition and mechanical properties of ARMOX 500 [5]*

Armox 500 T	Chemical composition [wt. %]								
	C	Si	Mn	P	S	Cr	Ni	Mo	B
	0.32	0.1-0.4	1.2	0.015	0.010	1.0	1.8	0.7	0.005

Armox 500 T	Mechanical properties				
	Tensile strength Rm [MPa]	Yield strength $R_{p0.2}$ [MPa]	Toughness KV [J]	Hardness HBW	Elongation A5 [%]
	1750	1250	25	540	8

3 Simulation of ARMOX 500 free cooling

The simulation was made in TTSteel 2.1 software for simulating of quenching and tempering of low alloyed steels. Input chemical composition of ARMOX 500 steel for simulation was obtained from producer's datasheets and is in the Table 1.

Simulation was realized two times with two different starting conditions. First one with starting temperature 1000°C and second one with starting temperature 500°C. In both two cases was simulated free cooling in the air with temperature of 20°C.

First step of steel heat treatment simulation in TTSteel software is calculation of CCT diagram of the steel based on chemical composition including critical temperatures (Ac1, Ac3). Calculated CCT diagram for ARMOX 500T steel is show in Fig. 3.

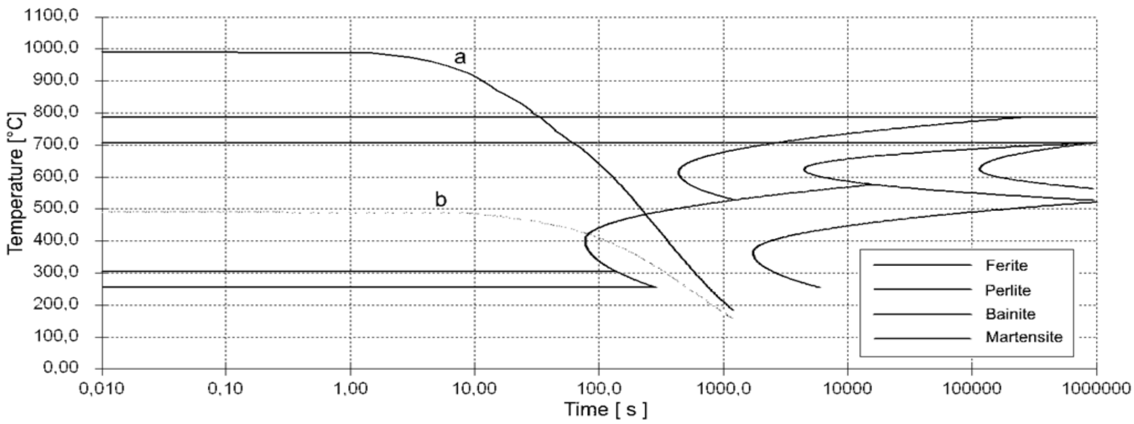

Fig. 3 *CCT diagram of ARMOX 500T cooling,*

a – starting temperure 1000°C, b – starting temperature 500°C

Second step of the simulation is the calculation of cooling curve from which results the ratio of structural components in percentage (bainite, martensite) present in the microstructure after cooling.

The last, third steep is calculation of final mechanical properties after heat treatment based on ratio of structural components.

The results of simulation compared with values of mechanical properties in delivered state are in the Table 2.

Table 2 *ARMOX 500T properties calculated by cooling simulation*

ARMOX 500T properties calculated by simulaton		Starting Temperature		Delivered conditions
		500 °C	1000 °C	
Critical temperatures [°C]	A_{c3}	786		-
	A_{c1}	707		-
Structural components [%]	Bainite	81	84,5	-
	Martensite	19	15,5	-
Mechanical properties	Rm [MPa]	1335	1312	1750
	Rp0,2 [MPa]	1070	1049	1250
	HV / HB	441 / 418	435/413	610 / 540

The simulation confirms that the over tempering on temperatures about Ac1 and uncontrolled cooling leads to microstructure change. Origin tempered martensite microstructure is changed to bainitic one.

4 Experiment realization

There was realized experimental measurement to describe the affection of origin Armox 550 with temperature over tempering temperature specified by producer. For experiment was used Vicker's Hardness Test according to EN ISO 6507-1. Parameters of test were chosen as follows: Load F=4,903 N, Time of indentation t = 4 s.

Microhardness HV0,5 was measured on the cross section of the welded joint through HAZ (heat affect area), weld metal and back to HAZ on the opposite side of the sample. The hardness of base material was measured outside the HAZ in the area unaffected by temperature. Measured values are shown in Table 3 and graphically presented in Fig. 4.

Table 3 *Values of HV0,5 in cross section of Armox 550 weld joint and base material*

Measurement no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sample 1	430	410	386	377	367	346	301	486	520
Sample 2	429	427	400	386	351	342	329	415	482
Sample 3	389	366	351	321	306	400	476	588	506
Measurement no.	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Sample 1	501	206	187	506	438	387	324	345	367
Sample 2	594	249	239	484	518	316	397	400	331
Sample 3	387	201	489	524	303	336	327	353	398
Measurement no.	**19**	**20**	**21**	**22**	**23**	**24**	**25**	Base material	
Sample 1	397	400	425	446	451	457	454	458	
Sample 2	358	381	404	426	436	460	457	465	
Sample 3	394	413	425	441	453	462	468	472	

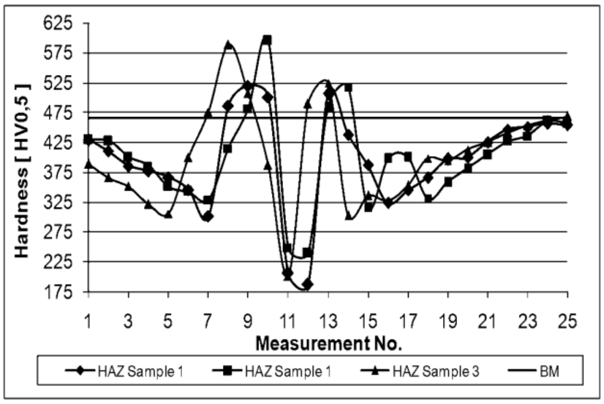

Fig. 4 *Graph of micro hardness HV0.5 through HAZ in comparison with the hardness of BM*

Imprints from 1 to 7 (and 15 to 25) were made in area of HAZ affected by temperatures below A1 (without recrystallization). Hardness decreases slowly in proportion to affecting temperature.

Imprints from 8 to 10 (and 13 to 14) were made in area of HAZ by temperature over A1. The recrystallization occurs in this area, therefore the microstructure became very coarse martensitic structure. Hardness increases very noticeably, but the area of material became brittle by this change in microstructure.

Imprints 11 and 12 were made in area of welded metal; therefore the hardness is very low with values about level of hardness of used consumable material.

Values in the brackets show numbers of imprints in corresponding areas on the other side of welded joint.

5 Conclusion

The cooling simulation, study of microstructure and also Vicker's micro hardness test provides results confirming noticeable degradation of mechanical properties (hardness, tensile strength) in areas of material affected by over tempering. Parameters of tempering (temperature and time) are chosen very carefully by the producer of ARMOX 550 to achieve specific required high mechanical properties. Additional exposure of the material to temperatures over tempering temperature causes the accidental continue of tempering process and therefore the degradation of mechanical properties of the material. The intensity of degradation rises proportionally with increase of temperature level and time of exposure.

This effect certainly occurs in others armored steels of ARMOX kind or steels produced by similar way like ARMOX steels are (e.g. SECURE steels). These steels are used in military and civil areas to provide more security to protect human life and valuable vehicles, devices or buildings. Therefore there is important need for further research in this area to find the way how to minimize described negative effect.

The authors' achievements and originality of research, and the authors' input in the undertaken subject matter and the value of study should be emphasised. Practical applications and possible directions of further research can be pointed out.

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