SIMULATION OF ARMOX STEELS MECHANICAL PROPERTIES DEGRATATION IN HAZ AFTER SELECTED THERMAL CUTTING PROCESSES

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Abstract

The paper is focused on simulation of conditions which occurs in steels Armox 440, 500 and 600 after their cutting by plasma and laser cutting process. The simulations were carried out with using of TTSteel software which is designed to simulate quenching and tempering processes of steels. The results from simulations were used as a first step in research of changes in HAZ (heat affected zone) after laser and plasma cutting to reduce needed sources in real experiments.

Keywords: Armox 440, 500 and 600, plasma and laser cutting processes, simulation, degradation of mechanical properties, HAZ (heat affected zone), transformation diagrams, CCT, TTT

1 Introduction

Armox 440, 500 and 600 are ultra high strength steels used as a protective material against ballistic threats mainly. Their usage is for example in armament or civil vehicles protections, mobile armament containers protection (as a medical, repair or communication centers), building protection and others. The steels are made by Swedish company SSAB Oxelosund [1].

The main reason of simulations is to determine the level of expected degradation in two characteristic part of HAZ (heat affected zone). The second reason of realized simulation is to acquire transformation diagrams for steels Armox 440, 500 and 600 which are not available in recent publications and any another sources and are that are useful for various experiments with these steels.

These three cases selected according to real processes in HAZ after plasma and laser cutting were simulated:

1. Quenching with extreme rapid cooling according to Armox producer instructions.
2. Simulation of the changes after heating up above A_1 temperature to the area of stabile austenite (1250°C) and cooling on air what corresponds with first (starting) part of HAZ where austenitization occurs.
3. Simulation of the changes after heating below A_1 temperature (500÷600°C) and cooling on air what describing uncontrolled tempering which occurs in the second part of HAZ without austenitization.

2 Method of simulation and input parameters

All simulations were carried out with using of TTSteel 2.1 software which is used by Faculty of Special Technology for simulation and optimization of quenching and tempering processes. The software is designated for determination and calculation of mechanical properties of constructional, micro alloyed and tool steels after their heat treatment. More detailed information about Armox steels and its processing could be found in [1, 2, 3].

The software creates transformation diagram of simulated steels according its chemical composition including temperature limits lines (A_1, A_3, M_s, M_f and others). Then, it calculates cooling curve according the transformation diagram and also input cooling conditions (start temperature, cooling medium parameters and others). Next step is the determination of microstructure phases in simulated sample volume based on stated cooling curve. Finally, the mechanical properties are calculated according to microstructure components in every volume element. More detailed description of TTSteel's work principle and methods used for simulation calculations are mentioned in [4].

The main and most important input parameter of simulation is precise chemical composition of simulated steel which was measured by spectral analyzer Spectrolab Jr CCD owned by Faculty of Special Technology. The principle of atomic spectral analysis and measurement possibilities of Spectrolab Jr CCD is closely described in several literal sources or web pages [5, 6].

Chemical composition acquired by spectral analysis of Armox 440, 500 and 600 samples is shown in tables 1, 2 and 3. Use of very precise measured content of every element instead data from producer datasheets brings more accurate simulation results.

Table 1 *Measured* chemical composition of ARMOX 440T (wt. %)

ARMOX 440T								
C	Si	Mn	P	S	Cr	Mo	Ni	B
0,1883	0,2378	1,115	0,013	0,009	0,882	0,654	2,1410	0,002
Al	Cu	Nb	Ti	V	W	Sn	As	Zr
0,0847	0,0062	0,0203	0,0018	0,0378	0,0078	0,0049	0,0065	0,0053
Zn	La	Fe						
0,0241	0,0027	94,5						

Table 2 *Measured* chemical composition of ARMOX 500 (wt. %)

ARMOX 500T								
C	Si	Mn	P	S	Cr	Mo	Ni	B
0,2738	0,2392	1,102	0,014	0,009	0,811	0,604	1,5830	0,003
Al	Cu	Nb	Ti	V	W	Sn	As	Zr
0,0951	0,0112	0,0023	0,0032	0,0380	0,0129	0,0024	0,0135	0,0042
Zn	La	Fe						
0,0168	0,0013	95,1						

Table 3 *Measured* chemical composition of ARMOX 600T (wt. %)

ARMOX 600T								
C	Si	Mn	P	S	Cr	Mo	Ni	B
0,3417	0,5420	0,934	0,008	0,006	1,253	0,623	2,68	0,004
Al	Cu	Nb	Ti	V	W	Sn	As	Zr
0,0949	0,0121	0,0032	0,0643	0,0124	0,0064	0,0045	0,0029	0,0014
Zn	La	Fe						
0,0721	0,0032	93,3						

3 Simulation of Armox steels cooling after their heat up above A_1 temperature

Two simulations were realized for the cases of Armox steels cooling from the temperature above A_1 what is the area of stabile austenite. The first one corresponds with quenching conditions according to the producer instructions and the second one simulates the conditions of cooling in the air what corresponds with processes in starting part of HAZ. TTSteel software does not allow simulating complete 3D geometry of the Armox semiproduct (thin sheet with specific dimensions) therefore the simulation sample depicted in fig. 1 was chosen from available possibilities as a closest to real shape and dimensions. Its dimensions (axb) are 100x8 mm.

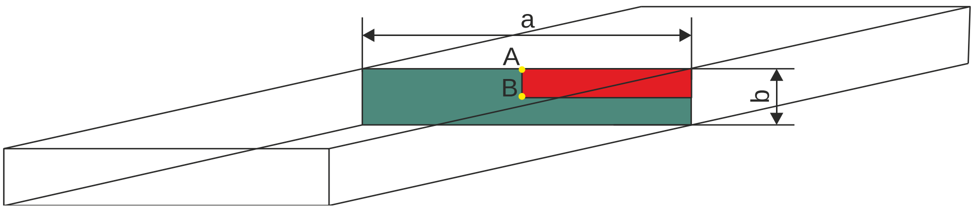

Fig.1 *Sample used for simulations*

(a=100 mm, b=8 mm)

The water was chosen as a cooling medium and starting temperature 1250°C for quenching simulation according to information from Armox producer. The simulation proves 100% martensitic phase under those cooling conditions for every of simulated steels. With small variations, simulation results correspond with datasheet for Armox steels by their producer.

Second simulation was realized in conditions of slow cooling on air with temperature 20°C where the starting temperature was also 1250°C. The high ratio of bainite (about 80%) was determined under these cooling conditions for every of simulated steels.

As an example, austenite transformation diagram for Armox 440 determined by simulation is shown in fig. 2. Cooling curve no. 1 corresponds to quenching conditions and curve no. 2 corresponds to slow cooling on air. Similar transformation diagrams were obtained for Armox 500 and 600 too. The basic limit temperatures determined by simulation for all simulated steels are stated in table 4.

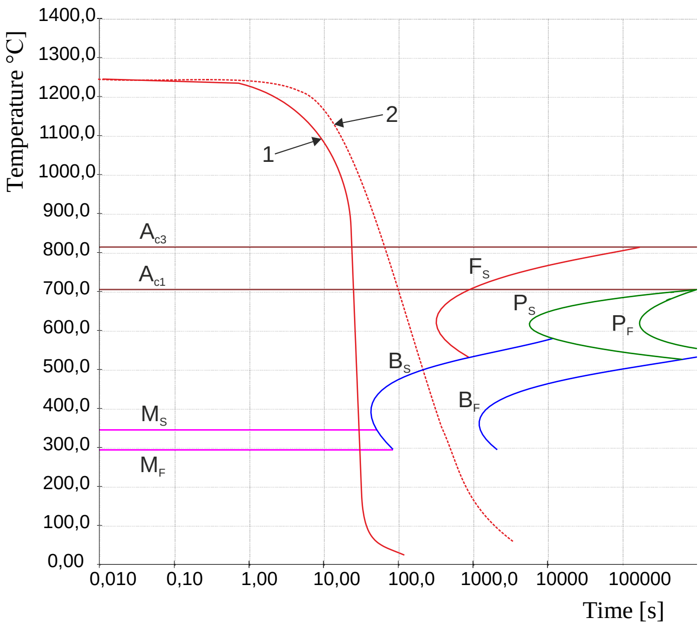

Fig.2 *Austenite transformation diagram of Armox 440*
1-Quenching, 2-cooling on air

Table 4 *Limit temperatures of Armox steels 440, 500 and 600 for austenite transformation diagram*

Oceľ	Základné hraničné teploty [°C]			
	A_{c3}	A_{c1}	M_S	M_F
Armox 440T	815	705	344	294
Armox 500T	806	712	328	278
Armox 600T	782	707	287	237

The results from simulations are show in tables 5, 6 and 7 for each of simulated steels. Mechanical properties values correspond to microstructures determined from simulation.

Table 5 Simulation results for Armox 440 steel

Conditions	Armox 440T – mechanical properties			
	R_m [MPa]	$R_{p0,2}$ [MPa]	Hardness [HV]	Microstructure
After quenching	1603	1328	490	100% martenzit
After cooling on air	1288	1033	398	77% bainit, 23% martenzit
Difference [%]	-20 %	-22 %	-19 %	

The Parameters acquired by quenching simulation is considered as base values in comparison with the values from the simulation of cooling on air. The degradation of mechanical properties was noticed as expected and appropriate differences are show in the last row of tables 5, 6 and 7.

The decrease of the properties is in range of 20-30% besides the original values determined by quenching simulation. The degradation of tensile strength, yield point and hardness is almost uniform for every of simulated steels. Most significant decrease was noticed at Armox 500 steel.

Table 6 Simulation results for Armox 500 steel

Conditions	Armox 500T – mechanical properties			
	R_m [MPa]	$R_{p0,2}$ [MPa]	Hardness [HV]	Microstructure
After quenching	1839	1548	559	100% martensite
After cooling on air	1339	1081	412	80% bainite, 20% martensite
Difference [%]	-27 %	-30 %	-26 %	

Table 7 Simulation results for Armox 600T steel

Conditions	Armox 600T – mechanical properties			
	R_m [MPa]	$R_{p0,2}$ [MPa]	Hardness [HV]	Microstructure
After quenching	1963	1664	595	100% martensite
After cooling on air	1557	1284	477	84% bainite, 16% martensite
Difference [%]	-21 %	-23 %	-20 %	

4 Simulation of Armox steels cooling after their heat up below A_1 temperature

The subject of this simulation is the heating up to the temperature below A_1 (600°C, see table 4), short stay on the temperature (1÷2 min) and cooling on air. This way of sample „treatment" is schematically depicted in the fig. 3. This mode corresponds e.g. to thermal influence at cutting of Armox steel by laser or plasma in HAZ where the temperature do not exceed A_1 and then also the austenitization do not occurs.

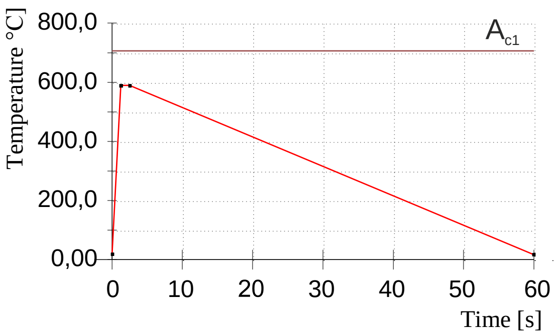

Fig.3 *Thermal treatment mode suggested for simulation*

Described thermal mode could be describe as uncontrolled tempering therefore the tool of TTSteel software for tempering simulation was used to simulate it. The shape and dimension of the simulation sample was the same like in previous case (see fig. 1). Also the chemical composition determined by spectral analysis was used for this simulation too (see tables 1, 2 and 3).

Table 8 Simulation results for Armox 440 steel

Conditions	Armox 440T - mechanical properties		
	R_m [MPa]	Hardness [HV]	Tvrdosť HV
After quenching	1603	1328	490
After uncontrolled tempering	1373	1113	423
Difference [%]	-14 %	-16 %	-14 %

The results of the simulation are shown in tables 8, 9 and 10 for each of simulated steels. The Parameters acquired by quenching simulation is again considered as base values in comparison with the values from the simulation of uncontrolled tempering. The degradation of mechanical properties was noticed as expected and appropriate differences are show in the last row of tables 8, 9 and 10. According to simulation, condition the degradation is in a range 14÷19 % where the most decrease occurs at Armox 500 steel. The degradation of tensile strength, yield point and hardness is also almost uniform for each of simulated steels.

Table 9 Simulation results for Armox 500 steel

Conditions	Armox 500T - mechanical properties		
	R_m [MPa]	$R_{p0,2}$ [MPa]	Hardness [HV]
After quenching	1839	1548	559
After uncontrolled tempering	1516	1247	465
Difference [%]	-18 %	-19 %	-17 %

Table 10 Simulation results for Armox 600 steel

Conditions	Armox 600T - mechanical properties		
	R_m [MPa]	$R_{p0,2}$ [MPa]	Hardness [HV]
After quenching	1963	1664	595
After uncontrolled tempering	1688	1407	515
Difference [%]	-14 %	-15 %	-13 %

5 Conclusion

Both realized simulation of processes in HAZ after thermal cutting confirm the degradation of mechanical properties as expected. Presupposed degradation in part of HAZ with heating up above the A_1 temperature is in range 20-30% and in part of HAZ with heating up just below the A_1 temperature in range 14-19%.

Presented simulation will be used for wider experimental study of influence in HAZ after selected thermal cutting processes as a scope to limit and effectively plan experimental sources as are materials, devices and also for saving the experimental time. As a another part of the study, simulation results will be confirmed by real experiments.

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