DEGRADATION OF MECHANICAL PROPERTIES OF SELECTED UHSS STEELS IN HAZ AFTER THEIR WELDING

Igor BARÉNYI[1*]

[1] *Ing. Igor Barényi, PhD., Alexander Dubček University of Trenčín, Faculty of Special Technology, Pri Parku 19, 91106 Trenčín, Slovakia*

**Corresponding author E-mail address: igor.barenyi@tnuni.sk*

Abstract

The paper deals with welding process of ARMOX armoured martensitic steels. The steels are sensitive on temperature above 200°C due to specific processing in their production. The paper describes the level of degradation of mechanical properties at heat affected zone (HAZ) which is created as the consequence of the heat influence by welding process. The paper also includes the experimental parts to determine the level of the degradation of microstructure, tensile strength and microstructure changes in HAZ which cause that.

Keywords: armour steels, martensitic steel, ultra high strength steel, ARMOX, welding,Heat affected zone, mechanical properties, tensile strength, hardness, microstructure

1 Introduction

The Armox steels have lean chemical composition which simplifies welding. Carbon equivalent (CEV) of these steel is low (0,7÷0,8), therefore they have very good weldability. However, their welding is problematic due to significant heat influence during welding process. Armox steels are kind of ultra high strength steel with very high strength, hardness and good toughness. The steels acquire these specific properties due to strict requirements on chemical purity (H, N, P or S content) and specific production process, finalized by very rapid quenching and tempering.

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 about 200°C in order to make the hardened steel tougher [1].

The chemical purity in combination with very rapid cooling brings good toughness of material despite of tempering at very low temperatures. Due to these production process specifics, the producer recommends do not exceed the temperature circa 200°C during the secondary processing of Armox steels as is welding. In a case of breach of this recommendation degradation of mechanical properties level occurs. Most of Armox products aimed to security and protection application are welded from semiproducts plate sheets and therefore the weld joints are serious weaknesses.

2 Experimental samples preparation and used welding process parameters

The shape and dimensions of the sample was designed according to STN EN ISO 6892-1 standard. The samples were prepared from plate sheet by plasma, laser and water jet cutting. All these three technologies were selected because of research described in this paper is a part of bigger project study also about influence of the cutting technologies application to various material properties.

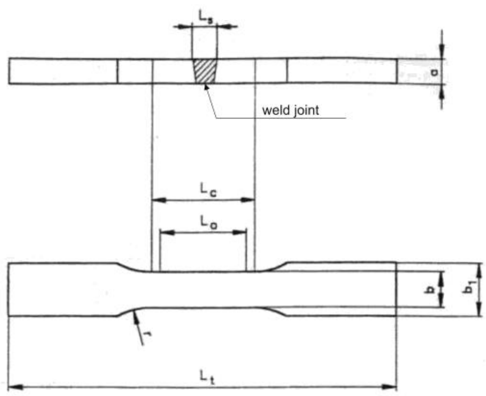

Fig. 1 Experimental specimen (a=4 mm, b=10 mm, L_0=40 mm)

Ultra high strength steel Armox 500 was used for experimental sample preparation. Chemical composition and basic properties of this steel is shown in table 1.

Table 1 Chemical composition and mechanical properties of ARMOX 500 [2]

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

Half of the samples were cut apart in the center point of their length and then welded to next study of material influence by welding. Experimental specimens are welded by Metal active gas method (MAG) with using of the Butt weld (BW) and flat welding position (PA). Thermanit X and DT-SG 600 F (surface bead) are used as a welding consumable. Protect atmosphere consist of 80 % Ar and 20 % CO_2. Detailed information about welding parameters is shown in the table 2.

Table 2 Parameters of used welding process

Weld bead	Welding method	Electric current [A]	Voltage [V]	Type of current Polarity	Wire feed speed [m/min]	Used filler	
						d [mm]	Type
1	MAG	145-155	27-29	= (+)	15-16	Ø 1,0	Thermanit X
2		145-155	27-29	= (+)	15-16	Ø 1,0	Thermanit X
3		160-260	18-26	= (+)	14-15	Ø 1,2	DT-SG 600 F

3 Influence on strength characteristics

All experimental samples were examined by tensile strength test (STN EN ISO 10002-1). Testing device Instron 5500R with automatic evaluation of mechanical characteristics (Tensile and Yield strength) is used. Results of tensile strength test are presented in table 3. The results from every of six presented alternative are average of ten measurements of same parameters sample.

Table 3 Experimental results

Type of Armox steel	Cutting method used for sample preparation	Yield strength $R_{p0,2}$ [MPa]	Tensile strength R_m [MPa]
500 T	Plasma	1359,60	1539,90
500 T	Laser	1392,68	1579,15
500 T	Water jet	1422,09	1614,32
500 T with weld joint	Plasma	593,82	614,65
500 T with weld joint	Laser	818,00	837,35
500 T with weld joint	Water jet	750,56	772,60

Better views on experimental results provide bar graphs in fig. 2 and fig. 3. Yield strength ($R_{p0,2}$) decreases about 44% in the case of plasma cutting, about 42% in the case of laser cutting and about 45% in the case of water jet cutting. Decreases are almost equal; therefore cutting method has no influence on the yield strength level.

The highest decrease of tensile strength (R_m) indicates the alternative with plasma cutting, where the decrease is about 60%. The decrease is about 47% in the case of laser cutting and about 52% in the case of water jet cutting. Significant decrease of Rm at variant with plasma cutting means that affection by heat is so high to appear even after welding application (in contrast to other two cutting technologies).

Decrease of both mechanical properties (Rm and Rp0,2) is obvious at welding joints. The most weak place of welding joint is the weld metal where all of experimental specimens is broken. The level of decrease is in relation to the used welding consumable properties.

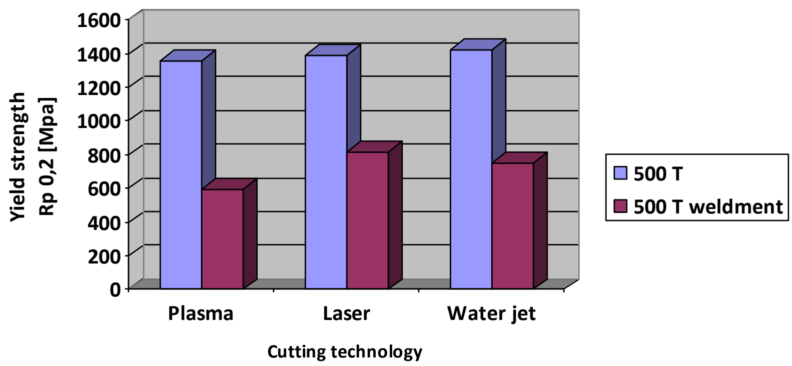

Fig. 2 Experimental results - Yield strength of basic and welded material

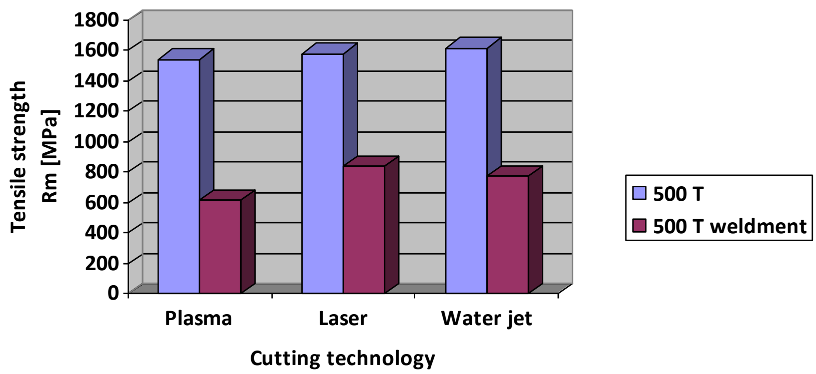

Fig. 3 Experimental results – Tensile strength of basic and welded material

4 Measurement of microhardness across the HAZ area

Experimental measurement of microhardness across heat affected zone was realized to evaluate the influence of Armox 500 welding. 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 welding heat. Measured values are shown in table 3 and graphically presented in figure 4.

Table 4 Values of HV0,5 microhardness across HAZ of Armox 500 welded joint

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	

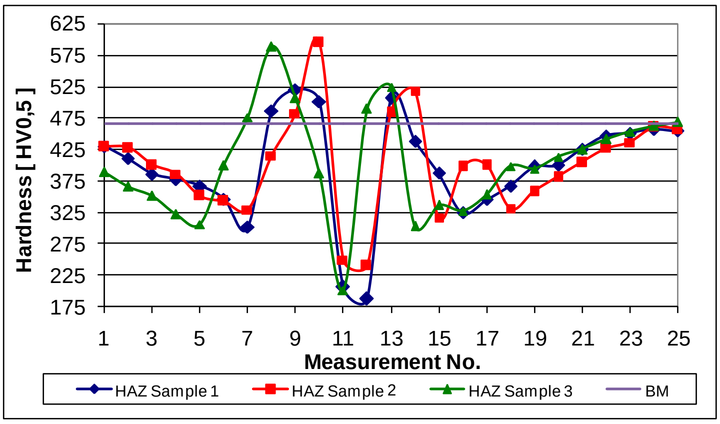

Fig. 4 Microhardness course across HAZ of Armox 500 welded joint

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

Imprints from 8 to 10 (and 13 to 14) were made in area of HAZ affected by temperature above A1. The recrystallization occurs in this area; therefore the microstructure became very coarse martensitic structure (fig. 7). 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.

5 Influence on microstructure

Microstructure of Armox 500 steel in delivered conditions is in fig. 5 [3]. For a comparison, changed microstructure of selected heat affected zones areas is shown in fig. 6 and fig. 7 [4, 5]. Microstructure changes correspond with microhardness course measured in these areas.

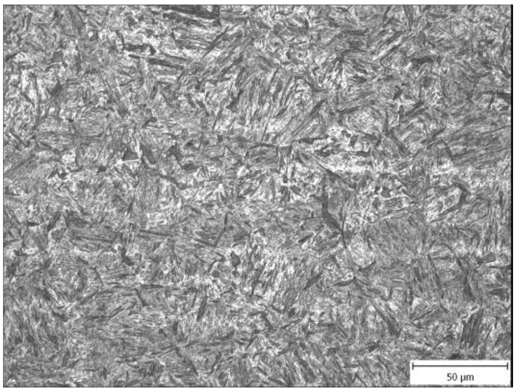

Fig. 5 Microstructure of Armox 500 – delivered conditions (mg. 500x)

Fig. 6 Microstructure of Armox 500 – area of HAZ close to weld metal (mg. 500x)

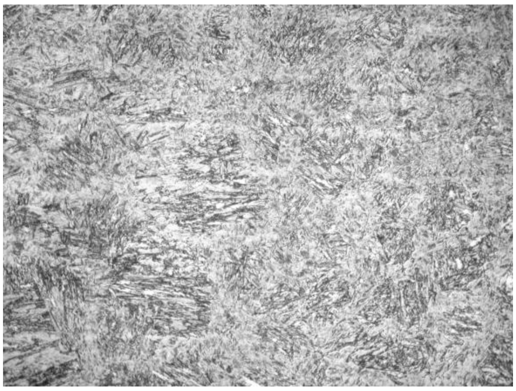

Fig. 7 Microstructure of Armox 500 – area in the middle of HAZ (mg. 500x)

Fig. 6 describes area of HAZ with coarse martensitic needles, where maximum peak of microhardness was observed on the microhardness course. The microstructure area on fig. 7 lay in some distance from weld metal and represents the zone with relatively slower cooling where origin austenite grains transform to banitic or pearlitic structure and ferrite is segregated on the grain boundaries.

Conclusions

Main field of application of Armox type steels is the ballistic and blast protection. Many of these products are made with using of welding technology by Armox semiproducts. The experiments on Armox weld joint describing in the paper could be summarized to the following conclusions:

- The decrease of strength properties (tensile strength, yield point) decrease in range 40÷60% in comparison with standard values given by manufacturer
- Microhardness course through HAZ provide decrease of hardness in all HAZ areas except area with brittle coarse martensitic structure causing maximal hardness peak. The values were compared with micrtohardness measured on unaffected zone.
- Microstructure study of some HAZ areas confirms the conclusions from microhardness measurement and explains the reason of microhardness changes.

Research study described in the paper clearly provides that the weld joint are serious weakness of welded Armox products and is very important to consider these conclusion in a way to provide suitable protection of the product.

Acknowledgements

This publication was created in the frame of the project "Alexander Dubček University of Trenčín wants to offer high-quality and modern education", ITMS code 26110230099, based on the Operational Programme Education.

Modern education for knowledge society / The project si co-funded by European Social Fund.

Európska únia
Európsky sociálny fond
Agentúra
Ministerstva školstva, vedy, výskumu a športu SR
pre štrukturálne fondy EÚ
Operačný program
VZDELÁVANIE

References

[1] SSAB OXELOSUND SWEDEN: The steel book. Sweden, 2008. [online 10.6.2012]. Available: http://www.ssab.com

[2] SSAB, Inc.: ARMOX 440, 500, 600. Datasheets. [on line cited 2010-04-10]. Available from http://www.ssab.com/products-and-solutions/armox/

[3] KULMANN, N.A.: *Metallurgical Characterization of Armor Alloys for the Development and Optimization of Induction Bending Procedures*. The Ohio State University, USA, 2011.

[4] HÍREŠ, O., BARÉNYI, I., BAČÍK, S., VAVRÍK, R., ÚTLY, M.: *Welding of ARMOX Steels: Microhardness Tests*. Výskumná správa č. 8, Trenčín, 2011

[5] SKOČOVSKÝ, P. A KOL.: Náuka o materiáli pre odbory strojnícke.. Universitiy of Zilina (2006).