SOME ASPECTS OF ABRASION RESISTANCE STEEL HARDOX 500 PROCESSING BY SELECTED TECHNOLOGIES

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Abstract
The paper deals with some aspects of welding and machining of HARDOX 500 abrasive resistant steel. These technologies are most widely used for processing of the Hardox semiproduct to final component. Part focused on welding assesses the weldability of the steel and decreasing of mechanical properties in HAZ including simulation of processes responsible for degradation. Part targeted on HARDOX 500 machining described condition and requirements on machine tools and its inserts. Experimental test of hard rough face milling with two different types of carbide inserts and acquired technological parameters are also mentioned.

Keywords: Hardox, hard machining, tool wear, tool life.

1 Introduction

The Hardox steels are ultra-high strength martensitic steels with excellent abrasive resistance produced by Swedish company SSAB Oxelosund. The main application fields of these steels are heavy machines in mining or civil engineering industry. The Hardox steels are resistant against sliding, impact and squeezing wear too. [1]. The steels need high hardness and strength to achieve the condition of high wear resistance. These specific properties are achieved by strict requirements on chemical purity (H, N, P or S content) and specific production process, finalized by very rapid quenching and tempering. The chemical purity in combination with very rapid cooling brings good toughness of material despite of tempering at very low temperatures. These specific properties and production processes require the using of special conditions or tools for secondary processing of the Hardox steels semiproduct to final required component. Most used and therefore most important technologies for processing the Hardox ultra high strength steel is specially machining and welding.

2 Basic characteristics of HARDOX 500 steel

There are offered various Hardox steels with different hardness by their producer. Higher hardness also means higher wear resistance. The Hardox 500 was chosen as an experimental material and its chemical composition and basic mechanical properties are shown in table 1. Chemical composition was determined with using of atomic emission spectroscopy by analyser Spectrolab Jr CCD. The Hardox 500 is a bendable and weldable abrasion resistant plate which is used in applications that demand higher wear resistance [1].

***Table 1** Chemical composition and basic mechanical properties of Hardox 500 steel [2]*

HARDOX 500	Chemical compossition [wt. %]	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**B**	**C_E [%]**
		0,27	0,56	1,51	0,019	0,01	1,32	1,42	0,57	0,003	0,58÷0,68
	Basic Mechanical properties	**Tensile strength R_m [MPa]**		**Yield strength $R_{p0.2}$ [MPa]**		**Impact energy KCU [J]**		**Hardness HBW**		**Elongation A_5 [%]**	
		1550		1300		30		499		8	

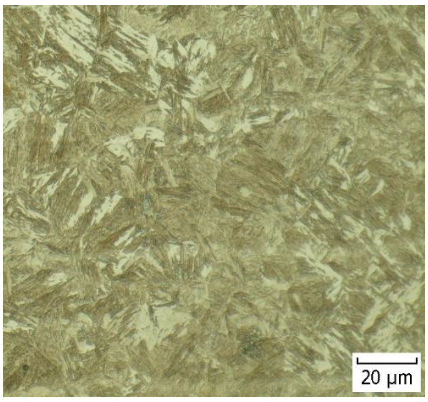

***Fig. 1** Microstructure of Hardox 500 in "as delivered" state*

The HARDOX 500 steel has tempered martensitic structure without clear grain orders of the previous austenite (fig. 1). This microstructure is obvious for martensitic high strength steels. Exposing that microstructure to the temperature above 250°C may lead to its change and consequently to degradation of mechanical properties, strength and hardness mainly [3, 4].

3 Welding of Hardox 500 steel

Welding of the steel of Hardox type (martensitic UHSS steel) is not easy task. Weldability of Hardox 500 steel is good in a view of its chemical composition. Its carbon equivalent determined from formula (1) by specific element content is between 0,58÷0,68 %.

$$\boldsymbol{C_E} = \boldsymbol{C} + \frac{\boldsymbol{Mn}}{\boldsymbol{6}} + \frac{\boldsymbol{Cr+Mo+V}}{\boldsymbol{5}} + \frac{\boldsymbol{Ni+Cu}}{\boldsymbol{15}}\ [\%] \qquad (1)$$

Even though the welding of Hardox steel may brings several problems as are hydrogen induced cracks or liquation cracks in heat affected zone (HAZ). Very important is also heat input thrown into weld during welding process. High heat input leads to widening of HAZ and consequently to degradation of mechanical properties of the steel, its strength and hardness decreased mainly [5, 6]. The choice of appropriate consumable material is also important. High alloyed consumable with properties close to base material is needed to ensure weld joint with high strength.

There were realized two simulations of cooling of the Hardox 500 steel with using of the TTSteel software to determine the decrease ratio of tensile strength at specific conditions occurring in parts of HAZ. First simulation was targeted on changes of mechanical properties in the part of HAZ with full recrystallization of austenite. This regime (A) consist of heating up to temperature in the area of metastabile austenite (up to A_{C3} temperature) followed by free cooling on air (fig. 2, curve 2).

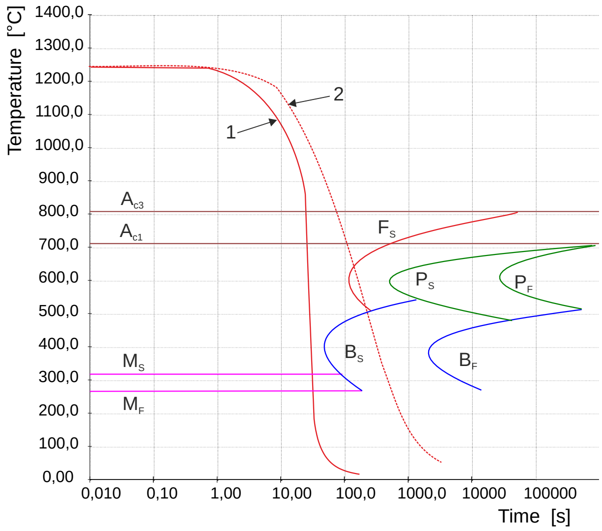

Fig. 2 CCT diagram of Hardox 500 steels with cooling curvers for quenching in water 20°C (1) and free cooling on air (2)

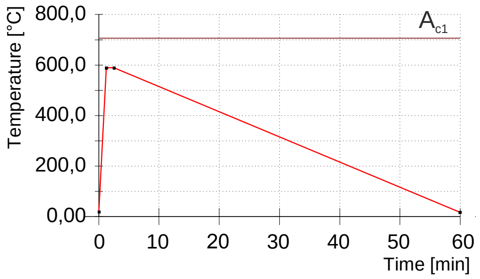

Fig. 3 *Regime (B) used for uncontrolled tempering simulation of HARDOX 500 during welding*

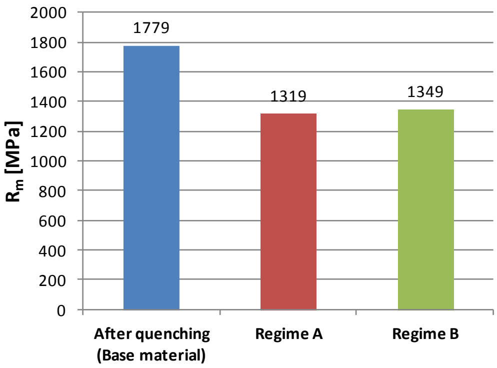

Fig. 4 *Tensile strength of base material Hardox 500 in compare to decreased strength for both simulated regimes*

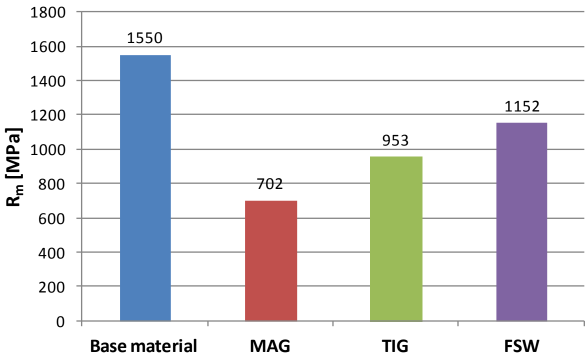

Fig. 5 *Tensile strength of base material in compare with welds strength (in HAZ) made by selected processes for Hardox 500 steel [4]*

Second simulation was targeted on changes of mechanical properties in the part of HAZ without recrystallization, affected by temperature under A_{C1} line. This regime (B) correspond with uncontrolled tempering and consists of heating up to temperature below A_{C1}, short hold-off with next free cooling on air (fig.

3). The decreasing of tensile strength is about 25% in both simulated regimes and is shown in fig. 4 in comparison with base material in „as-delivered” state after quenching.

Real experiments were realized to confirm simulation results. Samples of Hardox 500 weldment made by MAG, TIG and FSW (friction stir welding) were tested with tensile strength test according ISO 6892-1 (fig. 5). There was detected higher degradation of mechanical properties on real tested samples in compare with simulation results.

4 Hard face machining process of Hardox 500 steel

The HARDOX 500 is the abrasion resistance steel verified the fundamental requirements for its hardness [7, 8, 13]. It is important facility against mechanical wear of cutting tool. Very important basic factors from its production process result from high hardness, stiffness and toughness combination. Termomechanical heat treatment causes improvement and increase of the physical-mechanic properties. All of these positive facilities predestinated the HARDOX 500 for large spectrum of application. Especially face rough milling of those materials with defined tool geometry, cutting wedge creates difficulties for high shear stress on the slip plane shear deformations in chips [7, 8].

Through the years, new machining technologies have been developed where these materials can be, in most cases, machined directly into hardened material using new toolpath processing techniques to form hard milling. These materials can range from 45 HRC to as hard as 64 HRC. Advanced moldmakers have realized that adopting new technology can be one of their keys to survival against global competition. According to Zurek [9] and Grzesik [10], the successful hard milling is the result of implementing a system including the machine, cutting tools and toolholders, and the computer aided design/manufacturing system. The machine tool is the key component of the system. The machine must be designed for hard milling, along with having some of the same characteristics found in a high-speed machining center. Coolant is not recommended for hard milling applications with ceramic inserts, but air blast is suggested especially when pocket milling to keep from recutting chips. Reduced coolant usage and disposal cost is an added benefit when using ceramic inserts for hard milling.

To hardness of 50 HRC can be used even cutting tools HSS-Co, but with low productivity and low durability. In practice, the best certified cemented carbide (HW) without coating, or better with CVD and PVD coatings (with the HC cutting material). Fine-grained and ultra fine grain cemented carbide structure with grain size of 0.3÷0.5 μm increases the hardness and flexural strength, and thus the cutting tool properties [11, 12].

Experimental testing methods of the HARDOX 500 face milling were realized by The DORMERPRAMET milling cutter with 8230 changeable carbide inserts of type SNHF 1204EN-SR-M1. Parameters, tools and conditions of experiment are sumarized in table 2.

Table 2 *Paramaters, tools and conditions of experiment*

Material:	HARDOX 500 steel
Sample Dimensions:	20x150x705mm created by laser (TRUMATIC L3030 – STELLIT Company)
Machine tool:	The FA3V vertical console milling machine tool, P = 45 kW
Cutting tool:	The NAREX milling cutter with carbide changeable inserts, D = 50 mm, PN 222460.12, z = 4, K_r = 75 deg, rake angle γ = -7 deg, cutting clearance angle α = 7 deg, λ_s angle = - 4 deg (Fig. 4).
Changeable cutting insert:	SNHF 1204ENSR-M1-8230 DORMERPRAMET (see on Fig.2a,b)
Workpiece material clamping:	two pieces of sheet clamped in double grippers on machine tool support for 150 mm highness
Milling parameters:	for T = f (v_c) – where T is a function of cutting speed to Taylors ratio.
The time of the rough face milling process and reached cutting tool life:	t_{AS1} = 8,86 min, t_{AS2} = 6,29 min, t_{AS3} = 4,40 min T_1 = 223 min, T_2 = 135 min, T_3 = 39,6 min

The overall results from measured cutting times, tool life of inserts but at various feed rate motions f_{z1} = 0.039 mm.tooth^{-1} ; f_{z2} = 0,056 mm.tooth^{-1} ; f_{z3} =0,078 mm.tooth^{-1} ; f_{z4} =0,112 mm.tooth^{-1} ; f_{z5} = 0,15 mm.tooth^{-1} were graphically executed. Then from these measured values at constant revolutions n = 355/min were designated T = f (f_z) by the square method to the final form: $T = C_T/ f_z^{\ y}$.$T = 7{,}551/f_z^{\ 0{,}99}$. The reached average surface roughness was reached by the feed motion growth in the range from R_a = 0,6÷0,95 μm to R_a = 1,2÷1,6 μm. The auxiliary cutting edge was also worn to the VB = 0,1 ÷ 0,12 mm.

These experimental hard face milling process with DORMERPRAMET 8230 and 8240 show us that carbide insert 8230 has cutting tool life of T = 223 min whereas 8240 only T = 132 min, what is 68% more than with 8240. Both two types of coated cemented carbide inserts (shown in Fig. 2 and 3) are desirable for hard machining technology application of the HARDOX 500 with 46÷50 Rockwell hardness.

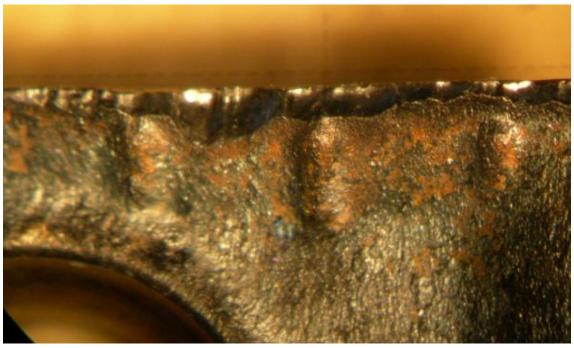

Fig. 2 *A picture of worn carbide insert of type 8230 carbide insert*

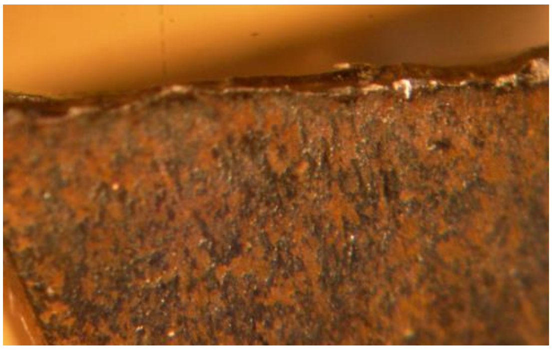

Fig. 3 *Tool wear after rough face milling process with 8240 carbide insert*

5 Conclusions

Two ways of the HARDOX 500 steel processing and important influencing parameters are described in particular chapters. The HARDOX 500 steel arc welding problematic and decreasing of mechanical properties in HAZ during the process could be summarizing to these following critical factors: heat input control, consumable material and eventual pre-heat. The Hardox 500 steel hard machining was considered in a view of used cutting tools and its carbide inserts. The face milling process is convenient without coolant usage in the 8230 and the 8240 type of used carbide. In a case of the 8240 type, lower cutting conditions are achieved.

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