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## Microstructure and residual stress analysis of Strenx 700 MC welded joint

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### Abstract

High strength low alloy (HSLA) steels are a new generation of plain carbon steels with significantly improved mechanical properties while maintaining good weldability with common commercial techniques. Residual stress and microstructural analysis of welded HSLA Strenx 700 MC was carried out in this research. Results have shown that the welding process causes significant grain coarsening in the heat affected zone. The microstructural changes are also accompanied with creation of tensile residual stress field in the weld metal and heat affected zone, reaching up-to depth of 4 mm. Tensile residual stresses are well known for acceleration of fatigue crack initiation and together with coarse grains can lead to significant decrease of the fatigue properties of the welded structure.

JEL: L69, M11

## 1. Introduction

Welding process is currently one of the most common methods of joining steel, aluminium and even plastic components in industry. The possibility to weld a steel and the final weld quality is related to a so called carbon equivalent, in which is represented influence of each alloying element on the weldability. To ensure high quality of the welded joint, C, Mn, Cr, Mo, V, Ni and Cu content has to be kept very low. This obviously limits the possibility of use steels with higher mechanical properties for welding, since the higher yield point and ultimate tensile strength is mostly obtained by increasing of carbon content.

Requirements of increasing safety and efficiency in modern industry forced steel factories to focus on development of the special High Strength Low Alloy (HSLA) steels, which exhibit excellent mechanical properties, while maintaining good weldability with conventional technologies, due to their low content of alloying elements. The improvement of mechanical properties is based on special thermo-mechanical processing providing extremely fine-grained microstructures, microstructures strengthened by precipitation hardening or solid solution

strengthening (Shao et al., 2018; Park et al., 2013; Bakkaloğlu, 2002; Charleux et al., 2001).

The main problem of welding of the HSLA steels is, that during the welding, part of the material is fully re-melted and certain material volume around the weld is locally annealed, what leads to partial loss of the superior mechanical properties due to changes of the microstructure (Jesus Jorge et al., 2018). Also the crystallization of weld metal and thermal expansion due to high amount of heat introduced into the material can significantly change the residual stress state of the welded joint. Macroscopic effect of high stresses can be seen as deflection of welded joint – this occurs when the stresses exceed the yield point. However, high value elastic residual stresses still remain in the material. These stresses attribute to the loading stresses during the component operation, what can lead to initiation and propagation of fatigue cracks. It is true, that stress relieving can be carried out by heat treatment or special vibration techniques, however both processes are expensive and impossible to perform on large structures. This is the main reason, why for wide application of HSLA steels for series production, it is necessary to understand the residual stress

state in the weld and then search for optimal welding parameters to provide balanced mechanical properties and low residual stress state (Lago et al., 2019).

## 2. Experimental material and welding process

Strenx 700 MC is a thermomechanically rolled steel with precisely controlled heating, rolling and cooling process. Chemical composition (Tab. 1) is characterized by low carbon and manganese contents to ensure good weldability and addition of small amounts of elements such as Niobe, Titanium and Vanadium (together, their content must not exceed 0.22 wt. %) to ensure grain refinement of the final steel. Grain refinement together with high micropurity results in UTS and yield point values (Tab. 2) which are commonly achieved in low alloy steels after heat treatment, however the steel is still suitable for cold forming and welding. According to the EN-10149-2 standard, the EN S700 MC steels rank in the category of extra high strength steels used for various application as the truck frames, cranes and mining machines.

**Table 1.** Chemical composition of experimental material Strenx 700 MC (wt. %) obtained by OES analysis

C	Si	Mn	S	P	Al	Nb	V	Ti
0.11	0.093	0.64	0.017	0.009	0.017	0.088	0.19	0.14

**Table 2.** Mechanical properties of Strenx 700 MC obtained by tensile test and Charpy impact test

Yield point [MPa]	UTS [MPa]	A5 [%]	KV [J]		
			+20 °C	-20 °C	-30 °C
741	823	11.5	76	51	49

For experimental works were used welded joints manufactured by welding of two 10 mm thick Strenx 700MC sheet metals with the MAG method. Before the welding, the edges of the sheet metal were machined to a 30° bevel to create a 60° V shape channel. Welding has been carried out with use of one root bead and two filling beads and one covering bead as sketched in Fig. 1. As filler material was used ESAB OK Aristod wire with chemical composition and mechanical properties as listed in Tab. 3.

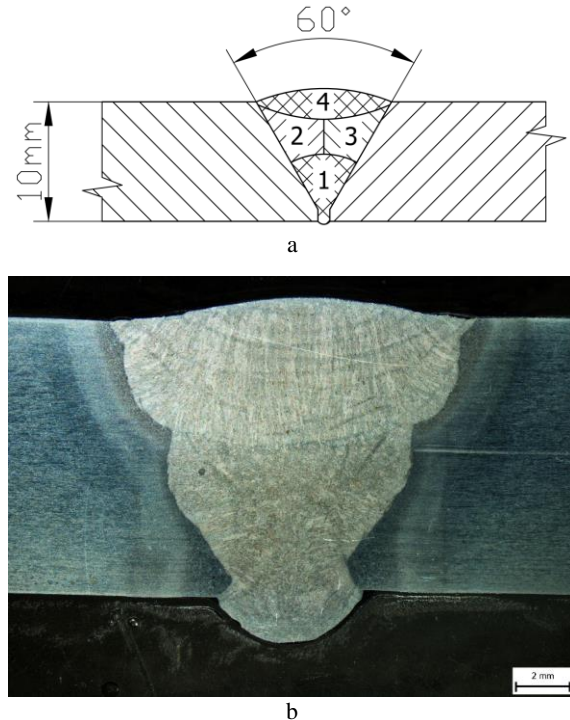
**Table 3** ESAB OK Aristod 69 chemical composition (wt. %) and mechanical properties

C	Si	Mn	Mo	Cr	Ni	V
0.08	0.60	1.60	0.25	0.30	1.40	0.07
Yield point min. (MPa)		Ultimate tensile strength min. (MPa)			Elongation A5 min. (%)	
730		800			19	

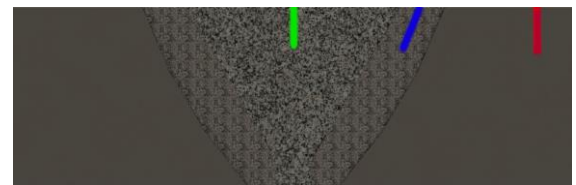
## 3. Experimental results and discussion

Residual stress analysis was carried out with use of X-Ray diffraction method, which is based on measuring of the position of a diffraction peak, when the material is exposed to X-Ray radiation (Cullity, 2002). The used experimental set-up

was: Proto iXRD device, Cr K $\alpha$  radiation, 1 mm<sup>2</sup> irradiated area and sin<sup>2</sup> $\psi$  evaluation method. The depth-profile was obtained by material removal with use of electrochemical polishing with electrolyte of saturated NaCl water solution. The measurements were performed in the weld metal (WM), heat affected zone (HAZ) and base material (BM) – Fig. 2, and the measurement vector was along the weld axis.



**Fig. 1.** Welding process of the Strenx 700 MC steel: sequence of the beads (a), macro-etched cross-section of the final weld (b).



**Fig. 2.** Position of measured residual stresses in the welded joint

The surface layers of the Strenx 700 MC sheet metal are characterized by compressive residual stresses (Fig. 3) with value of approx. -200 MPa. With increase of measurement depth, the value slowly decreases and saturates at approx -50 MPa in 4 mm depth under the original surface. In contrary, residual stresses in the weld metal and heat affected zone have opposite character. In the surface layers the tensile residual stresses reach approx. 150 ÷ 200 MPa and with increasing measurement depth, they slowly decrease. They reach values close to zero in approx. 3 ÷ 3.5 mm under the surface and again saturate at a depth of 4 mm with value close to -50 MPa.

Presence of compressive residual stress state in sheet metal is a common result of the sheet rolling process and these

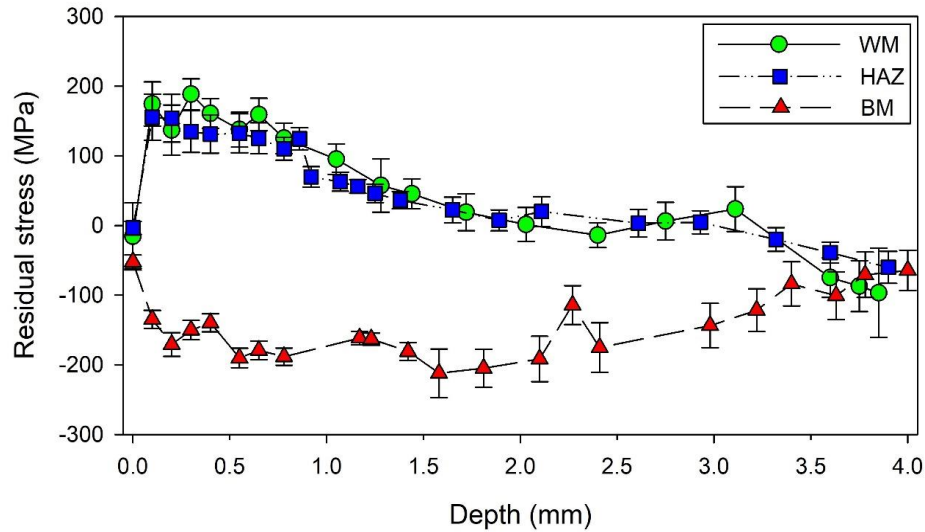


Fig. 3. Residual stress in the zones of Strenx 700 MC welded joint

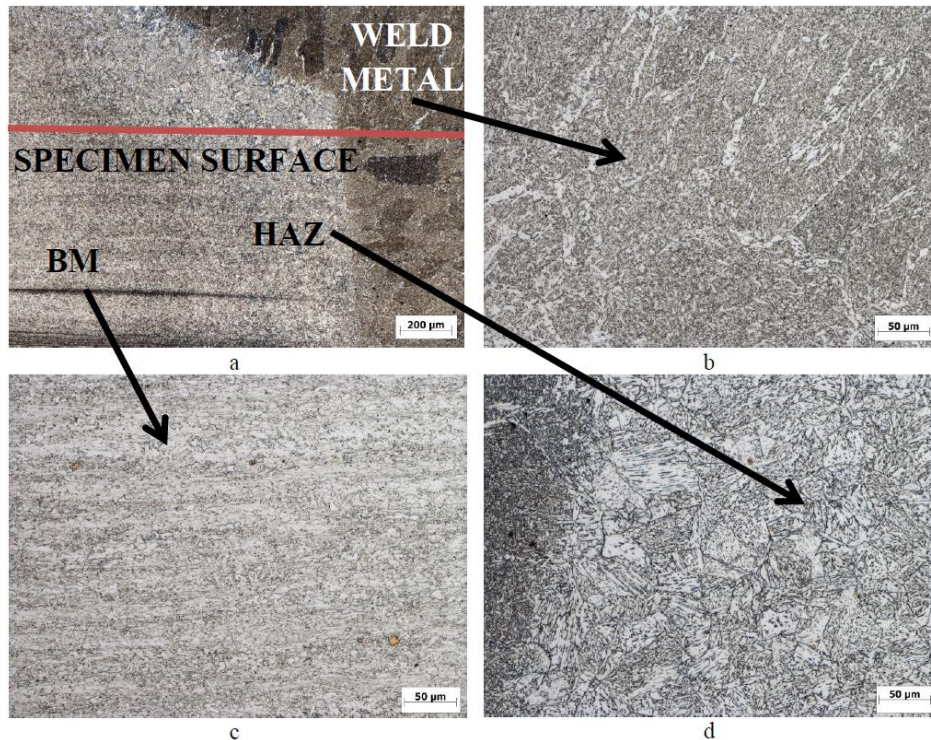


Fig. 4. Microstructure of Strenx welded joint: welded joint overview (a); weld metal (b); base metal (c); heat affected zone (d), transversal section, etch. Nital 2%

stresses are usually considered as beneficial, since they are able to close the initiated fatigue cracks and slow their propagation.

On contrary, introduction of tensile residual stresses tends to open both, existing cracks and cracks created by external loading. This is the reason why presence of tensile residual stresses is usually considered unsuitable for components and constructions loaded by alternating stresses (Noyan and Cohen, 1987).

The microstructural analysis was performed on a transversal section of the welded joint (Fig. 4a). The weld metal consists

from fine acicular ferrite without visible inclusions or irregularities (Fig. 4b). The grain orientation is in the direction of the thermal output, towards to the HAZ. Base metal, Fig. 4c, in the region far from the weld, which was not thermally influenced, consists from fine grain rolled structure with Ti, Nb and V carbides. However, due to their small size, these carbides are hard to identify by optical metallography methods, but their presence is expected due to the chemical composition of the steel and the corresponding phase diagrams. The purpose of these carbides is better grain refinement in the Strenx steel manufacturing process, as has been mentioned before. It is

well noticeable that HAZ is not wider than 1 mm and significant grain coarsening can be observed. The grain size in the HAZ is approx. ten times bigger than in the BM and the microstructure is consisting from coarsen polyedric ferrite grains with the Ti, Nb and V carbides.

#### 4. Summary and conclusion

Welding process introduced changes to microstructure and residual stress state of the Strenx 700 MC HSLA steel. Besides the fact, that between the two sheet metal plates was added another material in form of the filler metal, the thermal input caused grain coarsening of the surrounding area (HAZ). Since the superior mechanical properties of the experimental material is mainly achieved by fine-grained microstructure, the material of the weld metal and in the heat affected zone will not have the same parameters as the rest of the component.

The welding process also introduced tensile residual stress state in the weld metal and heat affected zone (approx. 150 ÷ 200 MPa vs. -200 in the as-rolled condition). Tensile residual stresses are in most applications considered dangerous due to their influence on accelerating the fatigue crack initiation and propagation. It has to be noted, that tensile residual stresses after welding are quite common, however, they have to be considered when designing a construction from HSLA steel, since this construction is expected to resist higher loading.

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## Strenx 700 MC焊接接头的组织和残余应力分析

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#### 關鍵詞

残余应力  
高强度钢  
焊接  
微观结构  
晶粒粗化

#### 摘要

高强度低合金 (HSLA) 钢是新一代的普通碳素钢, 具有显著改善的机械性能, 同时又通过常用的商业技术保持了良好的可焊性。本研究对焊接的HSLA Strenx 700 MC的残余应力和显微组织进行了分析。结果表明, 焊接过程会在热影响区引起明显的晶粒粗化。显微组织的变化还伴随着在焊接金属和热影响区中产生拉伸残余应力场, 直至达到4 mm的深度。拉伸残余应力对于加速疲劳裂纹萌生是众所周知的, 并且与粗大晶粒一起可导致焊接结构的疲劳性能显著降低。