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THE INFLUENCE OF WELDING ON THE HARDNESS AND WELDABILITY OF THERMALLY HARDENED S620Q STEEL SHEETS

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Abstract

The thermally hardened 12 mm sheets of S620Q steel underwent research. The sheets weldability was examined during semi-automatic welding by MAG method, at the welding conditions usually applied in industry for welding normalized sheets of this steel. The technology of welding was presented. The achievement of metallically continuous joints was confirmed by X-ray examination. For the purpose of usefulness assessment, samples were taken from test joints then the joints hardness distribution measurements were performed. The microstructure was examined and the static tensile tests as well as technological bend tests were carried out. Hardness measurements were performed in three measurement lines for each joint according to PN-EN 1043-1:2000 requirements. Joints microstructures were examined in the joints axis, in SWC and in native materials. Steel microstructures were classified as low carbon tempered martensite of layered construction. Mean values of the selected joints strengths were also presented. The tensile tests values of native materials of metallurgic certificates were given for the sake of comparison. The research results presented in the paper made it possible to determine the weldability of S620Q steel.

Keywords: *low-alloyed quality steels, heat treatment of S620Q steel, welded constructions*

1. Introduction

It is believed that weldable steels of high hardness that are thermally hardened are less weldable than low carbon structural steels. Extra activities aiming at the improvement of weldability are required when welding steels of high strength. However, the designers interest in these steels is caused by the possibility of applying higher static loads or lowering the construction mass. Weldable steels of high hardness that are thermally hardened are high quality steels with micro-additives which disintegrate grain and that were thermally treated (thermally hardened). This treatment is based on hardening steel sheets on a quenching press by double-sided water spraying in the temperatures range of 900-950°C. Sheets tempering is performed in the temperature of 600-700°C with cooling in the air. After this heat treatment sheets gain the structure of tempered layered martensite with carbide and cyanide disperse separations [2]. Steel hardening can also be conducted straight on rollers from the temperature of the rolling finish [1, 4]. It allows reaching desired plasticity border in the steel with lower carbon equivalent C_e, and consequently better weldability than in steel hardened after re-heating [7]. It is assumed that thermal hardening leads to achieving weldable joints of lower weldability. Therefore, the application of such a treatment seems to be legitimate.

The research was undertaken in order to explain whether the thermal treatment allows achieving weldable joints of satisfactory weldability.

2. Research

Thermally hardened 12 mm thick S620Q steel sheets were subjected to research. Tab. 1 presents chemical constitution of an examined steel sheet.

Welding was performed by semi-automatic MAG method. The filler metal, scheme, the welding

Tab. 1. Chemical constitution of the sheet examined according to metallurgic certificates

Steel sign	Chemical constitution, % of mass											
	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V	Nb	Al
S620Q	0.19	1.45	0.29	0.021	0.020	0.02	0.01	0.03	–	0.10	–	0.04

parameters used in the research were identical to the ones used in paper [5]. The butt joints were welded without preheating, at the interlayer temperature of 100°C in a lower position. They were welded semi-automatically in the shield of 80% Ar and 20% CO_2 mixture, on a copper plate, in Y welds. The preparation of sheets segments edges as well as the number and sequence of weld runs is shown in Fig. 1.

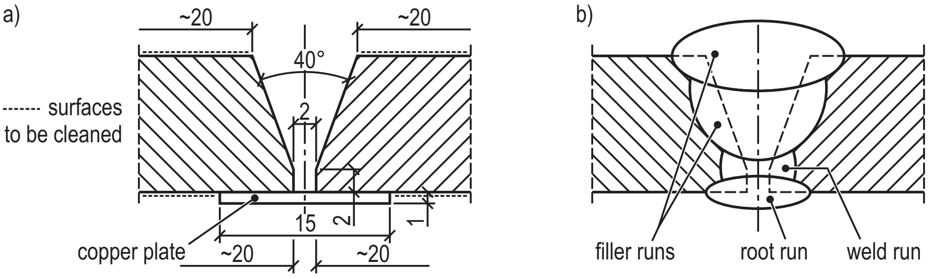

Fig. 1. The diagram of butt weld joints: edges preparation (a) and sequence of weld runs (b)

The achievement of metallically continuous joints was proved by X-ray examination. The correctness of making test joints was confirmed by the measurement of transverse warp and edges of sample sections. However, in order to assess the usefulness, samples were taken from test joints and the hardness distribution measurements were taken in the joints and the microstructure was examined. Moreover, static tensile tests and technological bending tests were carried out.

Hardness measurements were performed in three measurement lines for each joint according to PN-EN 1043-1:2000 requirements. Fig. 2 shows the location of hardness distribution measurements lines in butt welded joints.

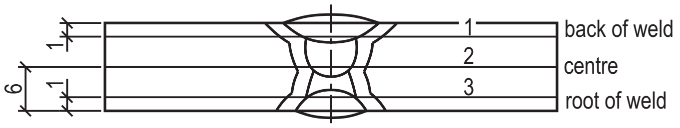

Fig. 2. The location of hardness distribution measurements lines in butt welded joints

The diagram of hardness distribution in a joint was shown in Fig. 3. The characteristic hardness in a welded joint is presented in Tab. 2.

Tab. 2. Hardness in welded joint of S620Q steel

steel sign	joint measurement line	HV Hardness				AHV10$_{max}$	
		Weld	Min swe	Max swe	native material	HV10	%
S620Q	back of weld	308	243	322	265	57	21.7
	centre	269	206	274	262	12	4.6
	root of weld	389	245	409	262	147	56.1

The joints microstructure was examined in the weld axis, in SWC and in native materials with the use of Neophot-2 optical microscope. Steel microstructure was classified as low-carbon tempered martensite of layered construction.

Microstructure differences in particular joints zones were the most clear in the observation lines 1 mm distant from the sheet joints surface. These were dendritic joint structures, typical for welded joints, grown grains in overheating zone, fine-grained normalized zone and partial transformation zone at the SWC entrance to native material. No metal discontinuities in joints were found.

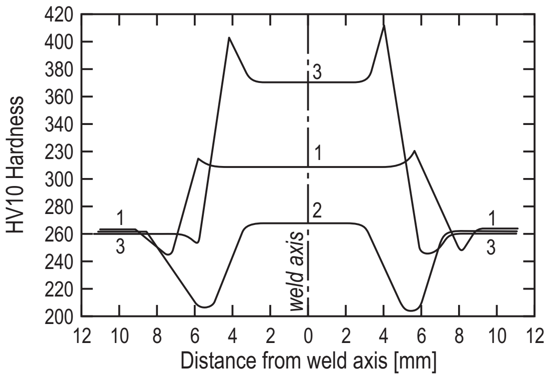

Fig. 3. HV10 hardness distribution in a welded joint of S620Q steel sheet

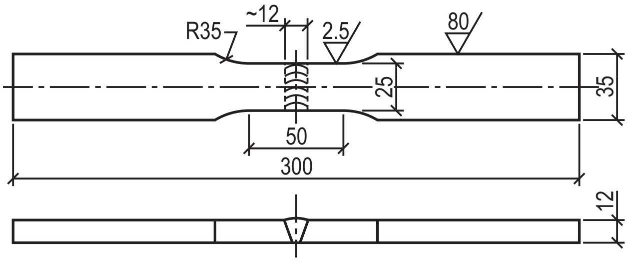

Fig. 4. The sample for the tensile test of welded joint with cut excess weld metal

The joints tensile tests were carried out on samples presented in Fig. 4. The mean values of the selected joints tensile strengths are shown in Tab. 3. The table also contains the tensile strengths of native materials given in metallurgic certificates for the sake of comparison.

Tab. 3. Mechanical properties of S620Q steel

Steel sign	Samples	R_e [MPa]	R_m [MPa]	A_5 [%]	R_e/R_m [–]	R_{mz}/R_{mr} [–]
18G2AV-1	native material / welded joint	638 / –	715 / 745	16.0 / –	0.892 / –	– / 1.04

The bend tests were conducted by means of bending arbour 36 mm in diameter. The cracks on the lengthened surfaces of samples, that exceeded the dimensions by 3 mm in any direction, appeared at the joints bending angle value when bent from the back of weld at the bend angle of 70°. When being lengthened from the root of weld – no cracks were observed at the bend angle of 180°. In the majority of samples bent, the cracks appeared on the bent side of the sample in the zones of weld transition, which is an area of welded joints that shows the lowest plasticity.

3. Discussion on the research results

X-ray radiographic and metallographic examinations showed that the welds obtained were metallically continuous, so the basic condition of recognising the sheets examined as weldable was fulfilled. However, in case of joints applicability the DnV regulations [6] state that the tensile strength of butt weld joints with cut excess weld metal located across the sample lengthening direction should not be worse than tensile strength of native material. The results of tensile tests presented in Tab. 3 show that this condition was met at the applied welding conditions.

The occurrence of cold cracks in the joints depends on the chemical composition of steel and weld, the amount of heat and hydrogen introduced during welding, the speed of joints cooling and the values of the remaining stresses [3]. If the joint cooling speed after welding is too high, the excessive hardening can occur in the SWC. On this account, it is possible to assume that the joint maximum hardness is a sure measure of sheets weldability in given welding conditions. Sheets weldability is better if the SWC hardness is lower.

As seen in Tab. 4, the joints tensile strength was not lower than the strength of native material. High limit of native material plasticity is notable, and constitutes 86.5-96.1% of its tensile strength. Therefore, it seems worthwhile to increase the safety coefficients when determining permissible sheets stresses in constructions.

In the welds examined , the lowest SWC hardness increase was observed in the measurements line in the centre of joints thickness. This zone was formed during setting the first weld layer and was tempered by heat introduced when setting the second layer of welds. Hence, the considerable drop of HV_{max} hardness in the SWC area.

For the purpose of weldability assessment in the paper [8] , the following 5 grades were assumed depending on maximum SWC hardness of welded joints:

- grade 0 for HV_{max} = 110-280,
- grade 1 for HV_{max} = 281-340,
- grade 2 for HV_{max} = 341-400,
- grade 3 for HV_{max} = 401-460,
- grade 4 for HV_{max} > 460.

Taking into account the above criteria and SWC hardness measurements results in line from the root of weld, where HV_{max} was the highest , it is possible to assign welding grades to the sheets examined, that is grade 3 for S620Q steel sheet. However, if mean HV_{max} value of 3 measurement lines was assumed – the sheets examined would have grade 1. It is also worth noticing that the biggest SWC hardness occurs in measurement line from the root of weld, where the highest weld cooling speed was observed. A modification of the conditions of welding sequence in order to decrease the cooling speed of this run makes it possible to reduce HV_{max} in the joints. In case of butt weld joints, cracks appeared at bending to the angle of 70°.

DNV regulations [6] require the welded joints not to show cracks bigger than 3 mm in any direction when being bent to an angle of 180°, however lower bending angles are permitted for welded joints of steel having E 420-690 hardness category. And so when accepting a weld, DnV regulations [6] as well as PRS regulations [1] require performing weld bend tests only to an angle of 120°.

In the view of the results obtained from bend tests it can be stated that satisfactory plasticity was observed.

3. Summary

1. X-ray and metallographic examinations have shown that the welding technology applied allowed to produce a joint of satisfactory weldability.
2. The highest SWC hardness appears in the measurement line at the root of weld, where the highest weld cooling speed was observed. A modification of the conditions of welding sequence in order to decrease the cooling speed of this run makes it possible to reduce HVmax in the joints.
3. Welded joints tensile test showed that their tensile strength is not lower than that of a native material.
4. Welds made of S620Q steel show satisfactory ductility.

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