SUITABILITY ANALYSIS OF THERMALLY HARDENED S620Q STEEL SHEETS USED FOR WELDED CONSTRUCTIONS WORKING IN LOWERED TEMPERATURES

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Abstract

S620Q steel sheets 12 mm thick that were heat treated were subjected to 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 achievement of metallically continuous joints was confirmed by X-ray examination, the correctness of making test joints was confirmed by the measurement of transverse warp and edges of sample sections. Moreover the following tests were carried out: static tensile tests, technological bending tests and impact tests on the samples with V-notch cut in positions S, P, C2 and C5. The joints microstructure was observed 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. The bend tests were carried out by means of bending arbour 36mm in diameter. The impact energy values for test temperatures -60°C, -40°C and -20°C marked in the drawings are the mean values of breaking three samples at a given test temperature. The places of notches cuts applied on welded joints samples are required by Det Norske Veritas regulations for welded joints. Mechanical properties of S620Q steel were given as reference.

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

1. Introduction

Low-alloyed quality steels with micro additives that disintegrate grain and consolidate separated steel, were first developed as steels for the application without heat treatment. The ductility of these steels was satisfactory in the state after hot rolling, for numerous applications. The normalization process of the metallurgic products from theses steels was started and later the thermal hardening was conducted for S620Q sheets 7-40 mm thick. Sheets hardening is carried out on a quenching press by double –sided water spraying in the temperatures range of 900-950ºC. Sheets tempering is performed in the temperature of 600-700ºC with cooling in the air. After this heat treatment sheets gain the structure of tempered layered martensite with carbide and cyanide disperse separations and show good ductility as well as strength [2]. Steel hardening can also be conducted straight on rollers from the temperature of the rolling finish [1, 4]. It primarily aims at the cost reduction by eliminating re-heating sheets for hardening. It also allows the achievement of desired plasticity border in the steel with lower carbon equivalent C_e, and consequently better weldability than in steel hardened after re-heating [7]. My research was conducted in order to clarify if the strength improvement and specifically ductility improvement obtained by heat treatment of S620Q steel sheets makes it possible to meet the requirements for welded constructions working in low temperatures.

2. Research

S620Q steel sheets 12 mm thick that were heat treated were subjected to research. Tab. 1 shows chemical composition of the sheet examined. 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.

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
1	2	3	4	5	6	7	8	9	10	11	12	13
S620Q	.19	1.45	.29	.021	.020	.02	.01	.03	-	.10	-	.04

The scheme, the welding parameters and the filler metal used in the research were identical to the ones used in paper [5]. The achievement of metallically continuous joints was confirmed 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 performed in the joints and the microstructure was examined. Moreover the following tests were carried out: static tensile tests, technological bending tests and impact tests on the samples with V-notch cut in positions S, P, C2 and C5.

Hardness tests were conducted in three measurement lines for each joint, Fig. 1.

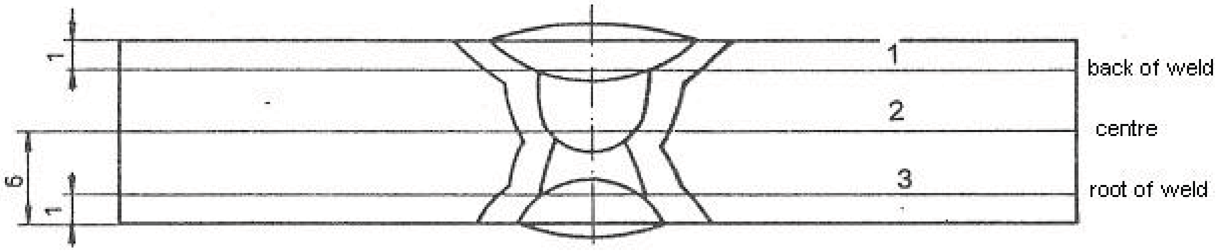

Fig. 1. The location of hardness distribution measurements lines in frontal welded joints

The diagram of hardness distribution in a joint was shown in Fig. 2.

The characteristic hardness in a welded joint is presented in Tab. 2.

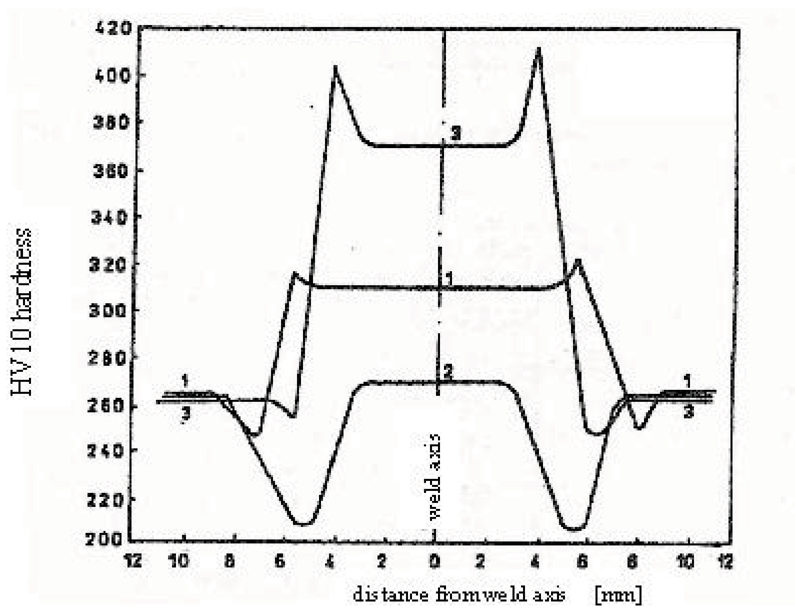

Fig. 2. HV10 hardness distribution in a welded joint of S620Q steel sheet

Tab. 2. Hardness in welded joint of S620Q steel

	joint measurement line	HV Hardness				$AHV10_{max}$	
steel sign		Weld	Min	Max	native	HV10	%
			swe	swe	mat		
1.	2	3	4	5	6	7	8
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 observed 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.

The joints tensile tests were carried out on samples presented in Fig. 3. The mean values of the joints tensile strengths that were chosen are shown in Tab. 3. The table also contains the tensile strengths of native materials given in metallurgic certificates for the sake of comparison. As can be seen in the table the joints tensile strength was not worse than the native material tensile strength. High plasticity border of the native material can be noticed, as it constitutes 86.5-96.1% of its tensile strength. As a result the increase of safety coefficients is to be considered when defining permitted stresses of these sheets in a construction.

Tab. 3. Mechanical properties of S620Q steel

Steel sign	Samples	Re	^{R}m	A_5	Re/Rm	Rmz/R_{mr}
		MPa	MPa	%		
1	2	3	4	5	6	7
S620Q	native mat.	638	715	16.0	0.892	-
	welded joint	-	745	-	-	1,04

The bend tests were carried out by means of bending arbor 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°, while when 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 side of bent sample in the zones of weld transition, which is an area of welded joints that has the lowest plasticity.

The impact energy used when breaking the samples is shown in Fig. 4 in relation to test temperature. The impact energy values for test temperatures -60°C, -40°C and -20°C marked in the drawings are the mean values of breaking three samples at a given test temperature.

The places of notches cuts applied on welded joints samples are required by Det Norske Veritas regulations [6] for welded joints.

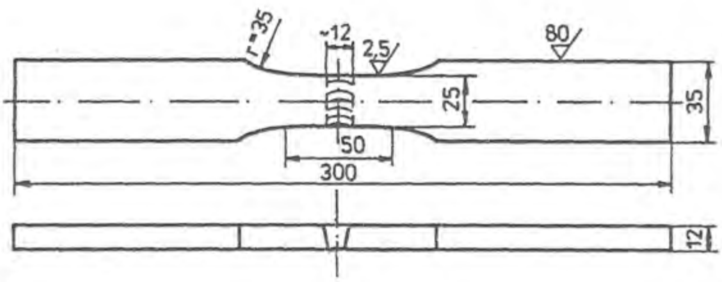

Fig. 3. The sample for the tensile test of welded joint with cut welds notches

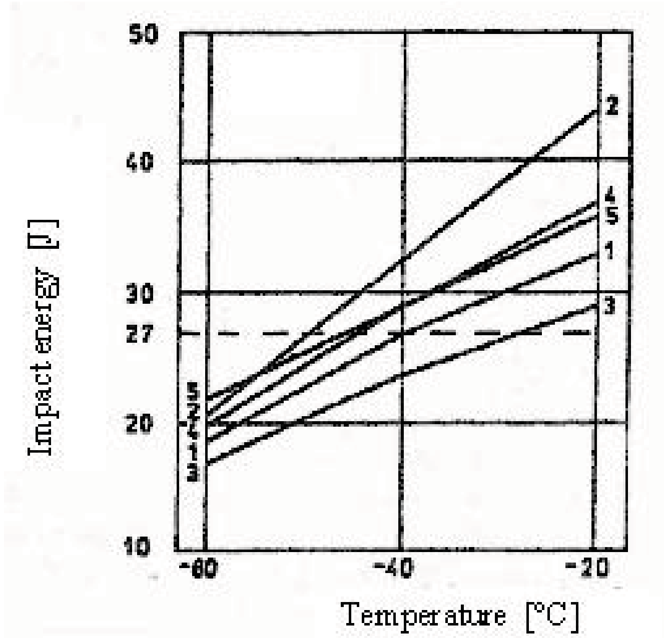

Fig. 4. KV impact energy at breaking welded joint samples made of S620Q steel

The places of notches cuts: 1-native material, 2- weld axis, 3-transition zone , 4- SWC 2 mm from transition zone , 5- SWC 5mm from transition zone.

3. Discussion on the research results

X-ray radiographic and metallographic examinations showed that the weld achieved was metallically continuous, so the basic condition of recognising the sheets examined ad weldable was fulfilled. However, in case of joints applicability the DnV regulations [6] state that the tensile strength of welded frontal joints with cut weld notches located across the direction of sample lengthening are not to 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 quenching 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.

In the welds examined, the smallest 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.

Five grades were assumed for evaluating welding in paper [8], depending on maximum SWC hardness of welded joints , and are as follows:

- 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.

Considering 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. The modification of the conditions of welding sequence setting in order to decrease the cooling speed of this sequence makes it possible to reduce HV_{max} in the joints.

In case of frontal welded joints, cracks appeared at bending to the angle of 70°.

DnV regulations [6] require that the welded joints do not show cracks bigger than 3 mm in any direction when bending 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 bending tests only to an angle of 120°.

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

Classification Societies regulations were used to analyze the resistance to brittle cracking and the possibility of service in low temperatures.

According to DnV regulations [6] mean energy values of breaking three samples and energy values of breaking one impact sample taken from frontal welded joint of steel sheets, should normally be in accordance with the values required for transversal impact samples of native material at test temperature assigned to it. Mean energy values of breaking three samples and energy values of breaking one impact sample type P, C2 and C5 taken from these joints, should normally be in accordance with the values required for transversal or longitudinal samples of native material depending on how the samples of sheet sections were taken for welding the test joint in relation to the direction of sheet rolling. As the test joints used for the research were welded from sheets sections whose rolling direction was parallel to welding line, the impact test results of the samples type P, C2 and C5 should be in accordance with the values required for transversal samples of native material. Mean energy values of breaking three samples should not be lower than 27J, and the energy value of breaking a single sample should not be lower than 20J.

Accepting these criteria and on the basis of the achieved impact test results for frontal welded joints it is possible to state that frontal joints welded of a thermally treated steel 12 mm thick fulfill the requirements for steel with D plasticity form.

In comparison with the results of impact test of native material (line 1 in Fig. 4.) the welding conditions applied in the research reduced the plasticity of thermally hardened sheets 12 mm in diameter from form E to D.

Summing up the research results it is possible to state that welded joints examined showed full applicability for low temperature conditions.

4. Summary

- X-ray and metallographic examinations have shown that the joints are weldable.
- Welds made of S620Q steel have satisfactory ductility.
- Welding conditions that were applied reduced the plasticity from E to D form.
- Welded joints that were examined showed full suitability for service in low temperatures such as: –20 and –40°C.

References

[1] Polski Rejestr Statków, *Przepisy klasyfikacji i budowy statków morskich 1990*, T. 7, Części IX, Zmiany Nr 1, Gdańsk 2009.

[2] Cicholska, M., *Analiza przydatności ulepszonych cieplnie stali 15G2Anb, 18G2AV-1 i 14HNMBCu na konstrukcje koparek*, Rozprawa doktorska, Politechnika Gdańska, Gdańsk 1994.

[3] Brózda, J., *Spawalność stali o wysokiej wytrzymałości*, Opracowanie Instytutu spawalnictwa w ramach SPUB, 2005.

[4] Miller, Ch., *The metallurgy & welding of high strength steels*, Doc. TWI Nr WTC84hss, 2004.

[5] Cicholska, M., Piaseczny, L., *Ulepszenie wytrzymałości na zmęczenie przez obróbkę brzegów doczołowych złączy spawanych*, Zeszyty Naukowe AMW 1996.

[6] Det norske Veritas, *Rules for classification steel ships*, Part 2, Chapter 3, Section 2, Welding procedure and approwal of welders, Oslo 2010.

[7] Basu, B., *Microstructural variations in high-strengh structural steel weld under isohead input conditions*, Welding Jurnal, Nr 11, 2002.

[8] Reumont, G. H., *Die Schweisseingnung hochfester Feinkornbaustähle - ihre Ermittlung und Bedeutung*, DVS-Berichte, H. 22, 1971.