SUITABILITY ANALYSIS OF THERMALLY HARDENED S540Q STEEL SHEETS FOR WELDED CONSTRUCTIONS WORKING IN LOW TEMPERATURES

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Abstract

The conventional heat treatment is being replaced by thermal-plastic treatment. The process of steel hardening is carried out on quenching press with a double-sided water spray at the temperatures ranging from 600 to 700°C. The steel hardening process is conducted at the temperatures of 600-700°C with cooling in the air. After this, thermal hardening the steel sheets obtain the structure of a layered tempered matrensite with carbide and cyanide disperse separations The thermally hardened S540Q steel sheets 12 mm thick underwent examinations. The welding technology was presented. The sheets were welded semi automatically by means of MAG method. The usual welding conditions normally applied in industry were used after steel standardisations. The achievement of joints metallically continuous was confirmed by X-ray tests. The static tensile test was conducted to assess the applicability of this steel. The average values of the welded joints resistance to tensile strength were given. After conducting technological bend, test good ductility was noted. Steel microstructure was defined as low carbon tempered matrensite of layered construction. Microstructure observation was carried out in the joint axis, in heat affected zone and in native material. Hardness measurements were performed according to PN-EN 1043-1:2000 requirements. Impact test was conducted on the samples with a V cut notch at the temperatures of -20, -40, -60 Celsius degrees.

Keywords: *low-alloyed quality steels, heat treatment of S540Q steel, welded constructions*

1. Introduction

Industrial development imposed the application of construction steel of the following plasticity $R_e \geq 420$ MPa. Such requirements were not demanded for welded steel of increased strength. So it was necessary to utilize high strength steel which was thermally hardened. This is steel of a carefully selected chemical composition and of high strength properties, at the same time characterized by good efficiency. Such steel can practically reach the plasticity point of $R_e = 690$ MPa. The products made of high strength steel are delivered after thermal-plastic treatment. The conventional heat treatment is being replaced by thermal-plastic treatment. The process of steel hardening is carried out on quenching press with a double-sided water spray at the temperatures ranging from 600 to 700°C. The steel hardening process is conducted at the temperatures of 600-700°C with cooling in the air. After this, thermal hardening the steel sheets obtain the structure of a layered tempered matrensite 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 mainly aims at reducing the production costs by avoiding further sheets heating for heat hardening. It also 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].

The research was undertaken in order to clarify if the improvement of ductility obtained by thermal treatment of S540Q steel allows it to fulfil the requirements for welded constructions working in lowered temperatures.

2. Research

Thermally hardened 12 mm thick S540Q steel sheets were subjected to research. Tab. 1 presents chemical constitution of an examined steel sheet. The sheets efficiency was tested by means of a semi-automatic MAG method, at the welding parameters usually applied in industry for welding normalized sheets of this steel.

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

Steel	Chemical composition, % weight											
	C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V	Nb	Al
S620Q	0.18	1.36	0.32	0.020	0.016	0.02	0.01	0.02	—	—	0.035	0.04

The filler metal, scheme and welding parameters used in the research were identical to the ones used in paper [5]. The achievement of metallically continuous joints was proved by X-ray examination. The correctness of test joints performance was confirmed by the measurements of transverse warp as well as the 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. The microstructure was examined; the static tensile tests, the technological bend tests and impact tests were carried out on the samples with a V notch cut in positions S, P, C2 and C5.

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

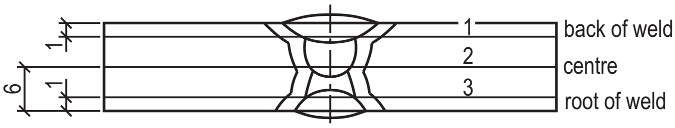

Fig. 1. The location of hardness distribution measurements lines in butt-welded joints

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.

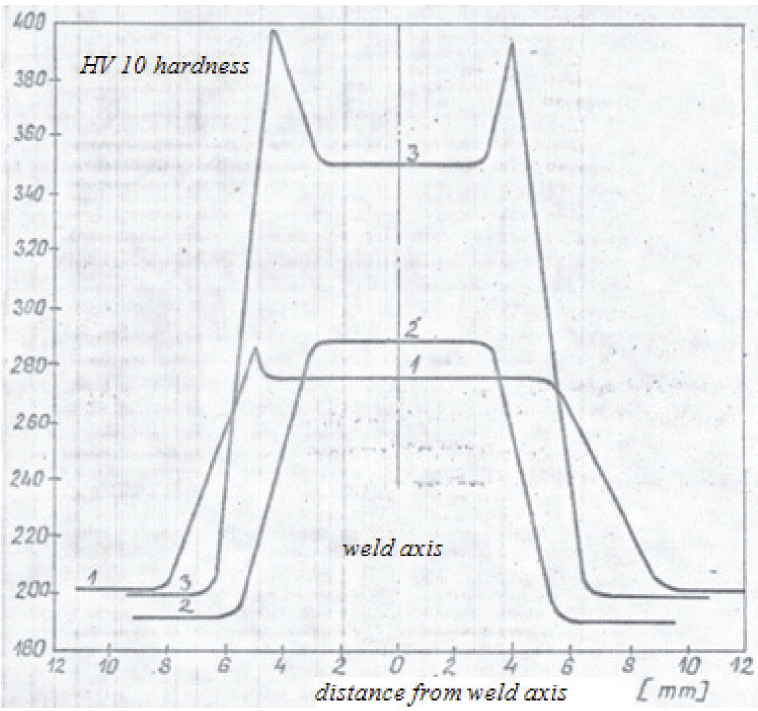

Fig. 2. HV10 hardness distribution in a welded joint of S540Q steel sheet

Tab. 2. Hardness in welded joint of S540Q steel

Steel sign	joint measurement line	HV Hardness				HV10max	
		Weld	Min swc	Max swc	native material	HV10	%
S540Q	back of weld	273	193	283	200	83	41.5
	weld centre	286	183	294	191	103	53.9
	root of weld	351	199	394	200	194	97.0

The joints microstructure was observed in the welds axis, in HAZ 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 HAZ entrance into native material. No metal discontinuities in joints were detected. The joints tensile tests attempts were carried out on samples presented in Fig. 3. The average values of the joints tensile strengths that were chosen are shown in Tab. 3. For the sake of comparison, the table also contains the tensile strengths of native materials given in metallurgic certificates. As can be seen from 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% 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 S540Q steel

Steel sign	Samples	YS [MPa]	UTS [MPa]	EL [%]	YS/UTS [%]	R_{mz}/R_{mr}
S540Q	native material	545	630	23.5	86.5	—
	welded joint	—	652	—	—	1.03

The bend tests were carried out by means of bending arbour with the diameter of 36 mm. 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. No cracks were observed at the bend angle of 180°. The impact energy used when breaking the samples is shown in Fig. 4 with 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.

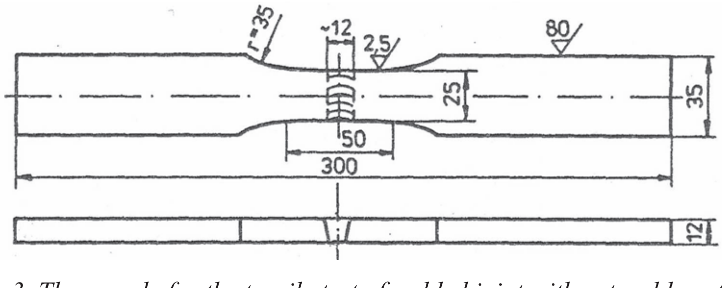

Fig. 3. The sample for the tensile test of welded joint with cut welds notches

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

3. Discussion on research results

X-ray radiographic and metallographic examinations showed that the welds achieved were metallically continuous, so the basic condition for recognising the sheets examined as weldable

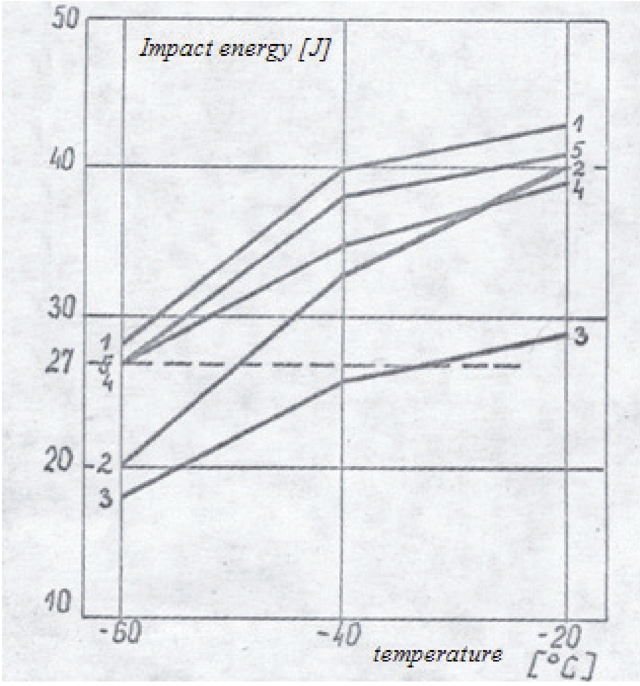

Fig. 4. KV impact energy at breaking welded joint samples made of S540Q steel. The places of notches cuts: 1 – native material, 2 – weld axis, 3 – transition zone, 4 – HAZ 2 mm from transition zone, 5 – SWC 5 mm from transition zone

was fulfilled. However, in case of joints applicability the DnV regulations [6] state that the tensile strength of butt-welded joints with cut weld notches situated across the direction of sample lengthening are not to be worse than tensile strength of native material. The results of tensile tests presented in Table 3 show that this condition was also 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 HAZ. 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 will be better if the SWC hardness is lower.

Five grades were assumed for evaluating steel weldability in the paper [8], depending on maximum HAZ hardness of welded joints, and are the following:

– 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.

Bearing in mind the above criteria it is possible to assign welding grade 2 to S540Q steel sheet. It is also worth noticing that the biggest HAZ 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 butt welded joints, no cracks appeared 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 . Therefore, when accepting a weld, DnV regulations [6] as well as PRS regulations [1] require performing weld-bending tests to an angle of 120° only. In the view of the results obtained from bending tests it can be stated that satisfactory plasticity was observed. Classification Societies regulations were also used to analyse the resistance to brittle cracking and the possibility of service in low temperatures.

As far as DnV regulations [6] are concerned, the average energy values of breaking three samples and energy values of breaking one impact sample taken from butt-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 according to PN-89/M-69733 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 according to PN-89/M-69733 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, while the energy value of breaking a single sample should not be lower than 20 J]9].

Assuming these criteria and basing on the obtained impact test results for butt-welded joints it is possible to state that butt joints welded of a thermally treated steel 12 mm thick fulfil the requirements for steel with E plasticity form.

When compared with the results of impact test of native material (line 1 in Fig. 4.) the welding conditions applied in the research decreased the plasticity of thermally hardened sheets 12 mm in diameter from form F to E.

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

Summary

- X-ray and metallographic examinations have shown that the joints obtained are weldable.
- Welds made of S540Q steel show satisfactory ductility.
- Welding conditions that were applied reduced the plasticity from F to E.
- Welded joints that were examined showed full suitability for service in low temperatures such as -20, -40 and -60°C.

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