APPLICATION OF HIGH STRENGTH STEELS TO RESPONSIBLE WELDED STRUCTURES ON MOTOR VEHICLES

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UDC:629.021

INTRODUCTION

For considered vehicle several very responsible assemblies are made, and the aim of this paper is to propose welding technology which will ensure obtaining reliable welds. In paper is estimated the weldability of high strength steel on which number of factors have influence. Some of them are chemical composition of the base metal (BM), type of filler material (FM) and welding method, amount of diffusible hydrogen from weld metal into base metal, thickness, type and positions of welds, heat input, type of applied heat treatment, sequence of welding, etc. The optimal welding parameters are based on the results obtained from the mechanical tests performed at room as well as at elevated temperatures, visual inspection of joint and measured hardness and metallographic examinations of some zones of welded joints, and special with regards on results obtained for impact toughness.

WELDABILITY OF THE BASE METAL

The S690QL class steel belongs into a group of special thermo-mechanical (TMO) low alloyed steels. The producer provides declaration of chemical composition on delivery [1-3]. The carbon content is limited to 0.20%, so the steel should possess good weldability. Microalloying elements cause improvement of mechanical properties of those steels;. Especially effective are niobium and boron, which are deoxidizing the steels and cause the fragmentation of metal grains. There are three different modifications of the S690 steels: S690Q, S690QL and S690L1, which only differ with regard to guaranteed impact toughness: S690Q – KV = 27 *J* at -20°C; S690QL – KV = 69 *J* at -40°C, S690QL1 – KV = 27 *J* at -60°C [2, 3]. Mass application of the high strength steel of this class occurred due to exceptional mechanical characteristics (tensile strength and yield stress) as well as favorable impact toughness. Basic data provided by the steel manufacturer can be found in corresponding references [1-3, 5].

It should be emphasized that the commercial mark of this steel is WELDOX 700 (SSAB Sweden).

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It should be emphasized that application of these steels is limited for the working conditions when the temperature does not exceed 580°C, since above this limit the mechanical properties become worse [2, 3].

Weldability of high strength steels can be determined by calculating according to the equivalent carbon (CE) and proneness of the steel towards the cold cracks. Depending on formula for calculating the CE and thickness of the welded parts, the limiting values of CE vary, Table 1.

Table 1 Values of the chemically equivalent carbon [1, 2, 4]

Mark	Thickness, *mm*	chemically equivalent carbon, CE, %	
		$CEV = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15}, \%$	$CET = C + \frac{Mn+Mo}{10} + \frac{Cr+Cu}{20} + \frac{Ni}{40}, \%$
S690QL	20	0.43 - 0.55	0.29 - 0.36
	30	0.46 - 0.55	0.31 - 0.36
	60	0.57 - 0.55	0.35 - 0.36

Based on results from Table 1, steel manufacturers recommend the preheating temperature that enables hydrogen diffusion from the joint zone and extending of the HAZ cooling time, for the purpose of obtaining the softer structure [1, 2, 5]. Besides the chemically equivalent carbon, one can theoretically estimate risk of appearance of cold, hot, lamellar and annealing cracks [1, 5]. According to formulas of different authors, the considered steel is highly prone to appearance of cold cracks. Risk of hot cracks is not so prominent, but risk of lamellar and annealing cracks is [1, 2]. Thus, the manner and procedure of welding should be so chosen that the reliable welded joint can be realized, which during exploitation would not be prone to appearance of any cracks that can cause brittle fracture of the welded structure.

For the S690QL steel the preheating temperature is recommended to be within range 150 – 200°C, and maximum interpass temperature should be $T_{interpass}$ = 250°C in order to prevent porosity in the weld metal caused by air turbulence, as well as worsening of the steel's mechanical properties realized by the thermo-mechanical treatment of steel

SELECTION OF THE OPTIMAL WELDING TECHNOLOGY

Based on manufacturer's recommendation and experience of other users, it was decided, for responsible joints, to apply filler metals of austenitic structure of the smaller strength than the base metal for the root weld layers, while for the rest of the weld layers (filling and cover ones) to apply the filler metals of the strength similar to that of the BM.

Thus, the proposed welding technology assumes deposition of the root welds by the MMAW electrode E 18 8 Mn B 22 – diameter Ø 3.25 mm; deposition of the filling layers is done by the GMAW electrode wire Mn3Ni1CrMo – diameter Ø1.2 mm (Figure 1). For deposition of the covering layers the GMAW procedure was selected due to better productivity with respect to the MMAW [1, 2]. The welded plate dimensions were 400×200×15 mm. After deposition of the root pass 1 it was subsequently partially grooved by the graphite electrode arc-air procedure and the new root pass was deposited in the complete argon protected atmosphere by the austenite electrode 8.

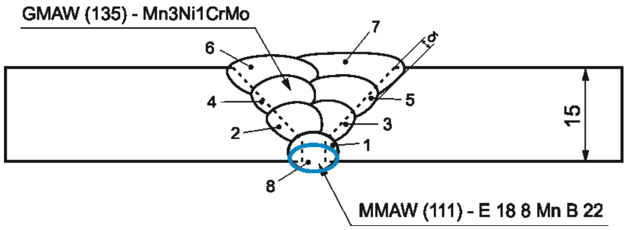


Figure 1 Combined MMAW/GMAW deposition of weld layers

Table 2 Chemical composition and mechanical properties of the filler metals [1, 2].

Electrode type	Chemical composition, %						Mechanical properties of weld metal			
	C	Si	Mn	Cr	Ni	Mo	R_m, MPa	R_p, MPa	A_5, %	KV, J
E 18 8 Mn B 22 *	0.12	0.8	7	19	9	-	590 - 690	> 350	> 40	>80 (+20ºC)
Mn3Ni1CrMo **	0.6	0.6	1.7	0.25	1.5	0.5	770 - 940	> 690	> 17	>47 (-40ºC)

Table 3 Welding parameters [1]

Parameters	I, A	U, V	v_z, cm/s	v_t, m/min	q_l, J/cm	δ, mm	Shielding gas	The flow of shielding gas, l/min
Root weld (MMAW)	120	24.5	0.2	-	12000	1.7	-	-
Filler welds (GMAW)	240	25	0.35	8	14885	2	Ar/18% CO_2	14

EXPERIMENATAL INVESTIGATION OF THE WELDED JOINTS

Tensile testing

Experimental tests of the S690QL steel specimen consisted of both mechanical tensile test and impact toughness test. The tensile test was performed on specimens prepared from the 15 *mm* thick plate; 4 specimens were prepared for the Base Metal (BM) tests and 4 specimens were aimed for testing the welded joint material (Figures 2 and 3) [5, 6]. Tests were performed according to standard SRPS EN 10002-1 [8].

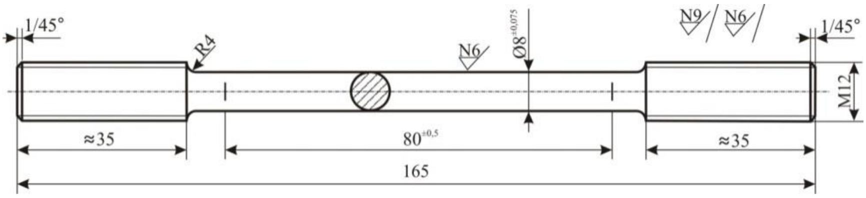
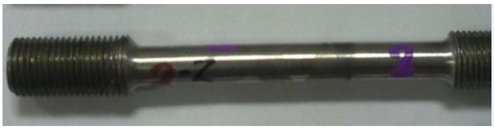


***Figure 2** Specimen for tensile testing*

Specimen before testing - BM

Specimen afrer testing - BM



Specimen before testing - WJ

Specimen after testing - WJ

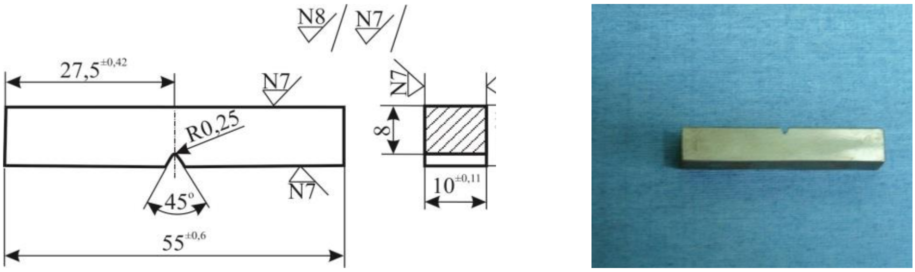
Figure 3 Specimen appearance before and after testing

Table 4 Experimental results of the tensile test [1-5]

Sample No	L_0, *mm*	S_0, *mm*^{2}	$R_{p0.2}$, *MPa*	R_m, *MPa*	$A_{11.3}$, %
Base material – S690QL					
1	89.28	50.27	781.94	797.81	14.19
2	89.28	50.27	809.40	839.92	11.30
3	88.42	50.01	800.41	835.52	9.98
4	88.29	50.27	811.95	842.45	10.92
Welded joint – plate 1 (REL/MAG)					
1	89.28	50.27	809	840	11.30
2	88.42	50.27	764	831	9.77
3	86.96	49.39	760	812	5.49
4	86.96	49.39	740	804	5.38

IMPACT TOUGHNESS TESTING

Specimens were prepared for the impact toughness tests (Figure 4), according to the similar procedure as for the tensile test specimens; six aimed for testing the BM and three for testing the impact toughness of the weld metal, root metal and HAZ. Tests were done on the Charpy pendulum, both at room and lower temperatures, according to standard EN 10045-1 [9]. Table 5 gives results of the impact tests.



a) b)

Figure 4 Appearance of specimen for impact toughness testing: drawing (a) and photo of the specimen (b)

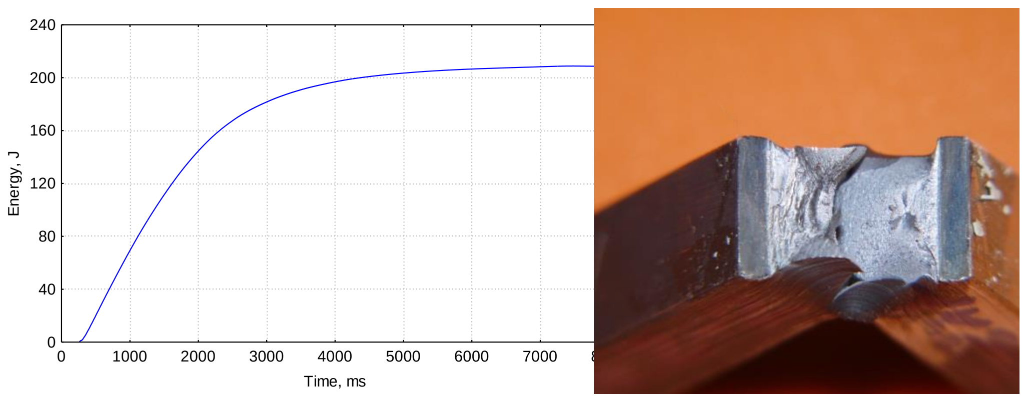
Table 5 Impact energy absorbed at room and lower temperatures [2, 3]

Steel mark	Temperature, ºC	Impact energy, J			
		Base material	Weld metal	Root weld metal	HAZ
S690QL	+20	235.2; 222.4; 234.7	24.2; 45.5; 34.7	85.8; 89.5; 54.1	189.2; 172.8; 209.7*
	-40	219.6; 19.8; 206.1	-	-	-

*Marked value is shown on diagram in Figure 5.

In figure 5a is shown the impact energy vs. time diagram and in figure 5b fracture surfaces appearance. Figure 5 is related to one representative specimen.

Besides the presented results, in favor of selected welding technology, were deciding also the plastic properties of the executed welded joints, estimated according to the share of the plastic fracture in the total fracture surface (Figure 2b), which was, in all the zones of the executed joint, within range 92.41 – 99.81%. That represents exceptional results from the aspect of the welded joints plasticity.



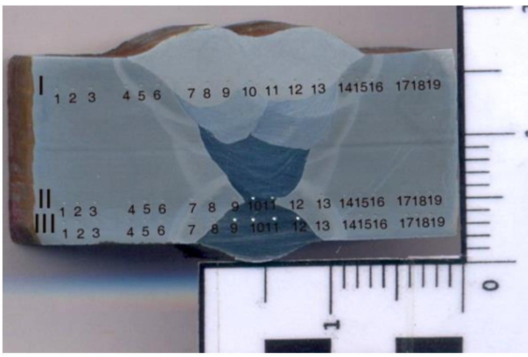
a) *b)*

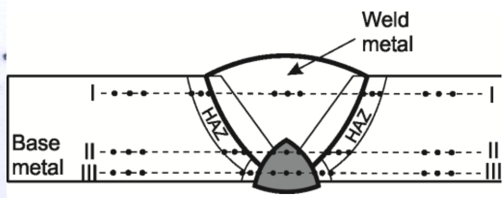
Figure 5 Representative specimen – HAZ – sample 3: a) impact energy vs. time diagram; b) fracture surfaces appearance

HARDNESS MEASUREMENT

For hardness measurements of individual welded joints' zones, special metallographic samples were prepared, 2 per each plate (Figure 6), on which the microstructure of characteristic zones was red-off as well. Hardness was measured by the Vickers method, indentation force was 100 N, according to standard SRPS EN 1043-1:2007 [2-4].

Hardness was measured of the base metal (BM), in the HAZ and weld metal (WM) along the straight lines perpendicular to the welded joint, Figure 16. Along a single line hardness was to be measured at least at three points for each of the characteristic zones, WM, HAZ (both sides) and BM (both sides). The first indent in HAZ ought to be as close as possible to the melting zone (border WM – HAZ). This also applied for the root. Obtained results show slight deviations of values for the homogeneous zones (BM, WM), but those deviations are somewhat larger for the HAZ, as well as for the melting zone.

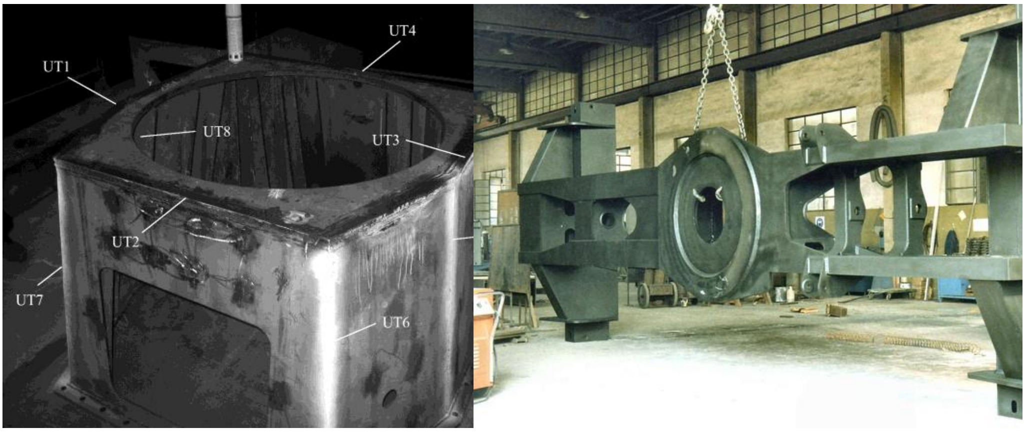




a) *b)*

Figure 6 Metallographic sample for hardness measurement and microstructure estimate (a) and hardness measurement directions (b)

In Figure 7 are shown some examples of welded construction made according to proposed welding technology and also some details from production process.



a) *b)*

Figure 7 Details from motor vehicle production process: a) ultrasonic defectoscopy and b) rear axle of a truck

CONCLUSION

After detail analysis of the most important properties of base material and estimation of its weldability, choosing the optimal combination of filler materials, welding method and technology, and extensive model investigation, the optimal welding technology was established which has been applied on real construction. That welded construction is than installed on vehicle and was subjected to rigorous tests and it fulfilled all the requirements necessary for field work, where it turned as a very reliable one.

In establishing the optimal technology experimental results of the sample welds tensile and impact tests were used as indicators. During the tensile tests samples' fractures occurred outside the welded joint zone, what means that strength of the welded joint was higher than the base metal strength. Impact toughness was within limits required by the appropriate standards, especially in the HAZ as the most critical zone of the joint. The recorded metallographic structure revealed that appearance of the brittle martensitic structure of the welded metal was avoided.

Due to all quoted in paper, the required properties of welded joint, similar to properties of the base material, it is recommended to use this particular steel for production very responsible welded constructions.

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