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METABK 55(2) 213-216 (2016)
UDC – UDK 669.14.018:612.791.052:539.377:620.17=111

THE INFLUENCE OF TEMPERATURE ON MECHANICAL PROPERTIES OF THE BASE MATERIAL (BM) AND WELDED JOINT (WJ) MADE OF STEEL S690QL

Received – Prispjelo: 2015-04-11
Accepted – Prihvaćeno: 2015-10-10
Preliminary Note – Prethodno priopćenje

This paper presents the analysis of the influence of temperature on mechanic properties of the base material and welded joints made of high strength steel. The joints were welded on S690QL high strength steel plates using the Metal Active Gas (MAG) Welding and two filler materials of different properties. Since the steel S690QL belongs to a group of steels with high strength, the aim of this paper is to determine the temperature at which strength starts to decrease. Experimental tensile testings of the welded joints were performed at five different temperatures in the range from 20 to 550 °C.

Key words: S690QL steel, welded joint, base material, temperature, mechanical properties

INTRODUCTION

With constant advancements in the field of welding technology, there is a growing need for high strength construction steels such as the steel grade S690QL. In order to maintain good weldability, the carbon content in high strength steels has to be as low as possible (max. 0,22 %) and the steel should have good mechanical properties which would make the welded construction reliable and light. When complex welded constructions are made, the steel is often heated (preheated, additionally heated and tempered), leading engineers to a dilemma concerning the maximum temperatures allowed for this process. In the literature, wide ranges of these temperatures can be found, depending on the thickness of the welded plates i.e., their thickness equivalents. The aim of this paper is to determine the maximal temperatures at which both base materials and welded joints keep their high strength values.

Dependance of mechanical properties of the BM and WJ on the temperature has been subject of numerous investigations, [1-6]. The paper [1] analyses the influence of elevated temperatures on the mechanical properties of two high strength steel grades - S460 and S690.

The experiments involved uniaxial tensile testing at 12 different temperatures from 20 to 1 000 °C. The results indicated that the yield stress and tensile strength remain unchanged up to 600 °C. At temperatures higher than 600 °C a significant decrease in yield stress is noticed, particularly with the steel grade S690. The paper [2] studied the influence of elevated temperatures on mechanical properties of construction steel grades S350, S355, S420 and S460, as well as austenitic steel grade X5CrNi18-10. Tensile testings were performed at temperatures in the range from 20 to 900 °C. The decrease in mechanical properties is noticed at 600 °C for construction steels, and at 670 °C for austenitic steel. The paper [3] studied the influence of temperature on mechanical properties of a group of high strength steels including the steel grade S690Q. The results have shown that good mechanical properties can be guaranteed up to the temperature of 540 °C. The paper [4], which also studied the steel grade S690Q at elevated temperatures, reported changes in yield stress, tensile strength and modulus of elasticity. The test temperatures varied from 20 to 700 °C. Unlike with other investigations, [1-3], a significant decrease in properties was noted at 400 °C. In addition to the given results of the papers [1-4], it should be stated that, in their recommendations [5], some of the leading manufactors of the steel grade S690QL do not guarantee its mechanical properties at temperatures higher than 580 °C. Moreover, the maximum recommended preheating temperature is about 200 °C, depending on the equivalent thickness of the parts. The paper [6] analyses mechanical behaviour of materials at elevated temperatures under conditions of thermal stresses, the paper [7] studies the influence of elevated temperatures under conditions of fatigue loading, while the paper [8] measures the level of inner stresses in WJ.

The results shown in the papers [1-4, 6-8] represent a good starting point to understanding the influence of temperature on the base material mechanical properties. However, this influence has not been analysed particularly for the WJ of high strength steels, which are very sensitive not only to local input of heat that ocurrs during the welding process but also to elevated working temperatures. Due to these reasons we have chosen to

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perform complex experimental investigations both of the BM and the WJ. Previously published papers [8, 9] studied the high steel grade S690QL and certain zones of WJ from the aspect of mechanical and metallurgical properties. In these papers different welding processes and different filler metals were used in order to find the optimal welding procedure. In the present paper the GMAW is chosen with two different filler metals. The root pass was done using austenitic filler metal, whereas the subsequent passes were made with the filler metal of the strength similar to the BM strength.

THE WELDING PROCEDURE

Since behaviour of the steel S690QL is studied at elevated temperatures, the welded joints have to be welded using the most suitable welding procedure. The steel S690QL is produced by heating up to the austenite region, followed by rolling and controlled cooling, providing high toughness even at low temperatures, [9]. There are three modifications of this steel that differ only in the guaranteed impact toughness. For the steel grade S690QL it is 47 J at - 40 °C. The chemical composition and mechanical properties of the steel S690QL are given in Tables 1 and 2, [8, 9].

For welding of the steel S690QL, GMAW (135) process was used, with two different filler metals, T 18 8 Mn R M 3 for the root pass and Mn3Ni1CrMo for the filler welds. Chemical composition and mechanical properties of the filler metals are given in Table 3.

Shielding gas Ar +18 % CO_2 was used for all passes. The thickness of the welded plates was 15 mm. The root pass (1) was partially grooved using a graphite electrode and arc-air process (Figure 1) in order to correct eventual defects.

Table 1 **Chemical composition of S690QL / wt. % max. [8,9]**

C	0,20
Mn	1,50
Si	0,06
P	0,020
S	0,010
Cr	0,7
Mo	0,7
Ni	2,0
V	0,09
Al	0,015
B	0,005
Cu	0,30
Ti	0,040
Nb	0,040
N	0,010

Table 2 **Mechanical properties and micro structure of the base metal, [8,9]**

Thickness / mm	R_m / MPa	$R_{p0.2}$ / MPa	A_5 / %	Micro structure
4,0 - 53,0	780 – 930	700	14	Interphase tempering structure
53,1 - 100	780 - 930	650	14	
100,1 - 130	710 - 900	630	14	

Table 3 **Chemical composition and mechanical properties of electrode wires**

Wire type	Chemical composition / %						Mechanical properties		
	C	Si	Mn	Cr	Ni	Mo	R_m / MPa	R_p / MPa	A_5 / %
T188MnRM3	0,1	0,8	6,8	19	9	-	600-630	400	35
Mn3Ni1CrMo	0,6	0,6	1,7	0,25	1,5	0,5	770-940	690	17

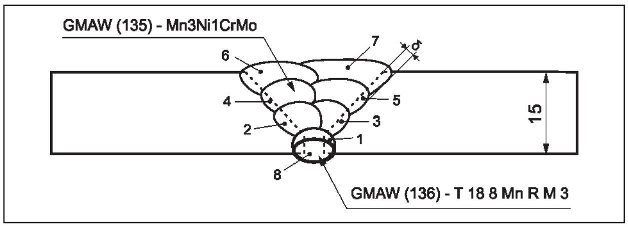


Figure 1 Scheme of welded joint passes

EXPERIMENTAL RESULTS

Figure 2 shows the hardness distribution, while Figure 3 shows the microstructure of characteristic zones of WJ. Specimens for the tensile testing, hardness meas-

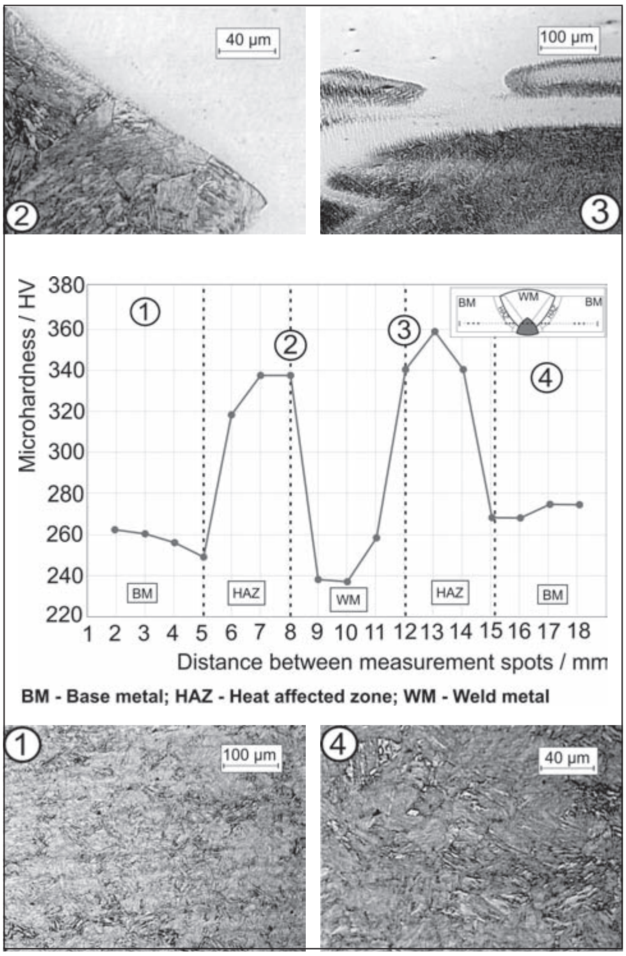
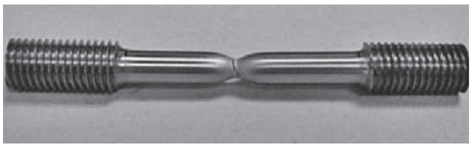


Figure 2 The microhardness and microstructure of WJ. 1) BM, Tempered, non-lamelar martensite. 2) HAZ-WM transition zone, non-lamelar bainite; 3) WM-HAZ transition zone, tempered martensite; 4) BM, Tempered, non-lamelar martensite. Magnification 125 x (100 μm), 300 x (40 μm).



a) base metal

b) welded joint

Figure 3 Tensile specimens after testing

urement and microstructure testing were prepared according to appropriate standards, [10 - 13].

Figure 3 shows the test specimens from BM and WJ after the tensile testing.

Experimental determination of mechanical properties at elevated temperatures [14] was performed on the universal testing machine Zwick Roell Z100 equipped with a special chamber for heating specimens. A homogenous temperature field was formed within the chamber using the controller. Three thermocouples were used to maintain the temperature and a homogenous temperature field.

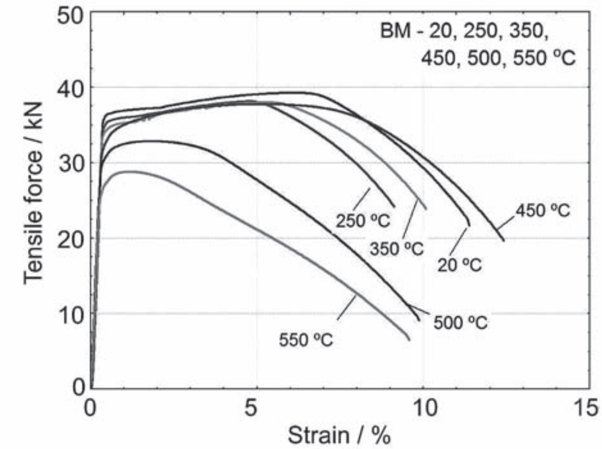
For each testing temperature, two test specimens were prepared, for the base material and for the welded joint. The tests were initially conducted at 20 °C, 250 °C, 350 °C, 450 °C, and then, only for the BM, at 500 °C and 550 °C. The obtained results are shown in Table 4.

Table 4 **Experimental results obtained by tensile testing of the BM and the welded joints**

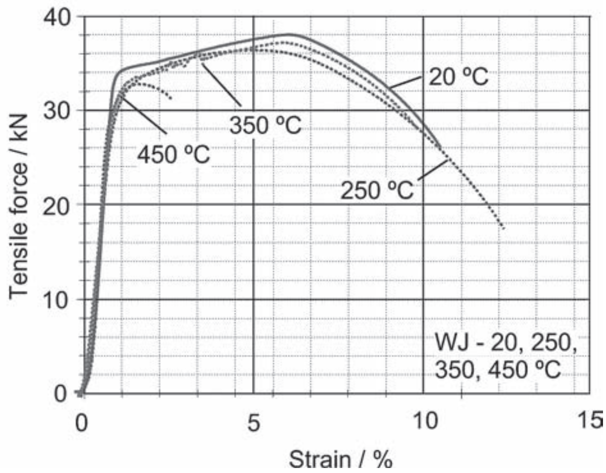
Testing temperature / °C	Specimens			
	Base material		Welded joint	
	$R_{p0,2}$	R_m	$R_{p0,2}$	R_m
20	769,8 779,6	835,5 850,5	736,7 736,7	793,0 794,3
250	715,1 718,9	725,1 785,7	691,3 702,2	742,8 754,7
350	727,9 728,3	804,1 806,3	665,3 678,9	727,4 748,4
450	656,0 671,2	754,5 756,4	634,2 650,2	718,9 749,4
500	612,5 617,1 650,2	658,4 662,5 749,4	-	-
550	532,9 547,8 577,3	560,1 583,0 611,5	-	-

Graphic presentation of the obtained results is given in form of diagrams - curves (Figure 4). It should be emphasized that fracture of the welded joint specimens occurred out of welded joint and heat affected zone, what is parameter for good welding technology.

Testing of the base metal has shown that a significant decrease in mechanical properties occurs at the temperatures higher than 450 °C (Figure 4a). With further increase in temperatures this decrease is more and more evident (Table 4). As for the welded joints, the



a) base metal



b) welded joint

Figure 4 Diagrams of tensile testing

decrease in mechanical properties occurs at temperatures higher than 450 °C (Figure 4b). Small decrease in ductility of the welded joint, is registered at the temperature of 450 °C, is attributed to the non-metal inclusions, noticed in the cross-sections of the broken specimens, [15].

CONCLUSIONS

The obtained experimental results have shown a significant decrease in the yield stress and tensile strength of the base material at temperatures higher than 450 °C. The welded specimens also exhibited a decrease in their mechanical properties at 450 °C. This decrease can be explained by carbon diffusion and transformation of martensite into a phase with lower strength and higher plasticity. One should keep in mind that the steel producer recommends for this steel not to be exposed to temperatures higher than 200 ºC. We have shown here that the temperature range can be extended up to 400 ºC, as it was also shown in [1-4].

Since the obtained results for the base material and the welded joints are similar, it can be concluded that the choice of welding procedure was right. One should keep in mind that it was not a random choice; rather, the large number of tests was carried out in order to select the optimal welding technology , as shown in [9, 10].

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Note: Responsible person for English translation is prof. Martina Šuto (J. J. Strossmayer University of Osijek) and prof. Marina Karšić