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Assessment of the hardness of S890QL material welded joins

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Abstract. The need to reduce the mass of products manufactured by welding processes has led to the replacement of the basic steel materials, such as construction steels, by steels with high mechanical properties, such as hard and brittle steels. The increase of the mechanical properties but also of the alloying degree has led to a decrease in the weldability of these materials. The present paper presents the analysis of the welding possibilities with the gas metal arc welding process of S890QL steel. The paper analyzes the hardness values obtained in the case of welding technologies using two preheating temperature values (100 and 1500C) in the context of the variation of the cooling time between 800 and 5000C. The values resulting from the hardness measurements performed indicate that no significant changes in hardness occur in the characteristic areas of the weld bead, the material not being subjected to additional hardening processes. To analyze the weldability of the S890QL material, the results presented in the paper must be correlated with the results of the mechanical tests performed on the welded joints.
Keywords: *high strength steel, weldability, hardness, preheating temperature, cooling time.*

1. Introduction

High strength low alloy steels are a real solution to new industrial requirements. The increase in the mechanical properties of the materials used leads to a reduction in the load-bearing cross-section of the metallic structure used in various industrial fields. This has the direct advantage of reducing the mass of the product and, consequently, reducing production costs [1,2].

High-strength low-alloy steels with low carbon content are fine-grained steels that have been developed to meet the needs of steel construction engineering and in particular of pipelines. They meet the industrial requirements for mechanical properties such as hardness, weldability, strength and corrosion resistance [3…5].

High-strength low-alloy steels are characterized by low carbon contents (0.03-0.12%). They obtain their high mechanical characteristics by thermomechanical treatment (TM). The micro alloyed character is given by the presence of elements such as Nb, Ti or V in sufficient quantities to lead to the formation of carbonitrides.

The evolution of the steels used in this field is illustrated in Figure 1, which shows the effect of metallurgical factors on increasing the yield strength and decreasing the transition temperature [6].

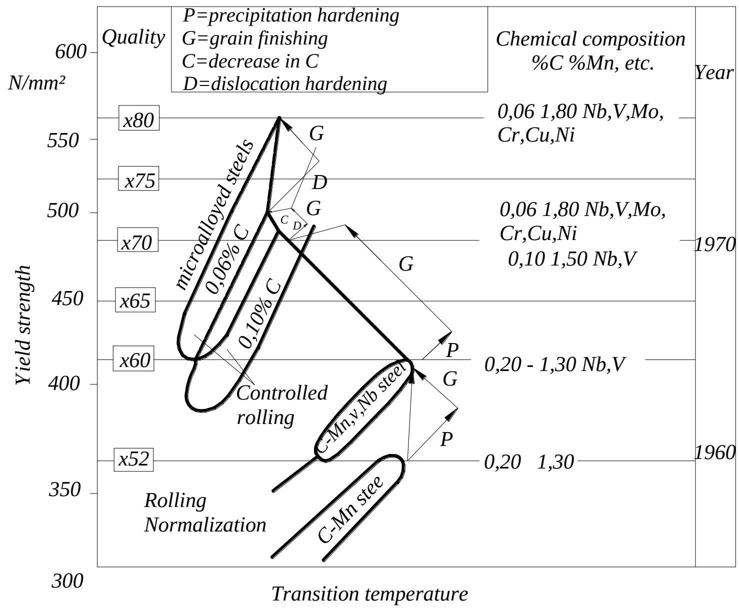

Figure 1. Evolution of microalloyed high strength steels [6].

During the welding of high strength microalloyed steels, the main problem related to weldability is the possible appearance of cold cracks in the heat affected zone. Another problem is the loss of mechanical properties due to changes in the fine grain size caused by overheating of the areas adjacent to the weld bead.

To control these possible problems, it is necessary to pay special attention to the linear energy introduced during the welding process. Linear energy influences the phase transformations that occur during solidification of the molten metal bath.

The paper presents the results of experimental research on the hardness values obtained when analyzing the welding possibilities of S890QL type steel using the Gas Metal Arc Welding (GMAW) process.

The increase of hardness in the welded joint area and in adjacent areas, as a result of the thermal cycling encountered during the welding process, can lead to embrittlement of the material and cold cracking.

In this context, keeping the welding process under control and obtaining hardness values below the limits imposed by the standards in force is an important issue for the technological engineer.

2. Materials and methods

2.1. Materials used

To measure the hardness values in the area of the welded joints obtained with the robotized GMAW welding process, 6 samples were made from 300 x 150 x 12 mm butt-jointed plates of S890QL, low alloy high-strength steel. The filler material used was wire type G 89 4 M21 Mn4Ni2CrMo (according to EN ISO 16834-A), a medium alloy wire electrode for shielded arc welding of quenched and tempered fine grained structural steel [7]. The chemical composition is presented in Table 1 [7,8].

Table 1. Chemical composition of the base and filler materials in wt.%.

Materials	C	Si	Mn	Cr	Ni	Mo	V	N	Nb	Ti	Cu	Zr	S	P
S890QL	0.2	0.8	1.7	1.5	2	0.7	0.12	0.015	0.06	0.05	0.5	0.15	0.01	0.02
G 89 4 M21 Mn4Ni2CrMo	0.1	0.8	1.8	0.35	2.3	0.6	-	-	-	-	-	-	-	-

The chemical composition determines the mechanical properties. These properties can be modified by the structural transformations that occur during welding and are influenced by the thermal cycling introduced during the welding process [9]. In the delivered condition, the mechanical properties of the materials used are shown in Table 2.

Table 2. Mechanical properties of the used materials [7,8]

Materials	Tensile strength (MPa)	Minimum yield strength (MPa)	Elongation (%)
S890QL	940-1100	≥ 890	11
G 89 4 M21 Mn4Ni2CrMo	940 – 1180	≥ 890	≥15

2.2. Equipment used

The robot cell used to realize the welded samples (Figure 2) is composed of the Fanuc ArcMate 100iBe welding robot (Fanuc Corporation, Oshino, Yamanashi, Japan) and the Fronius TPS 4000 welding source (Fronius International GMBH, Pettenbach, Austria). To realize the welded joint, the component edges were machined according to the specifications shown in Figure 3.

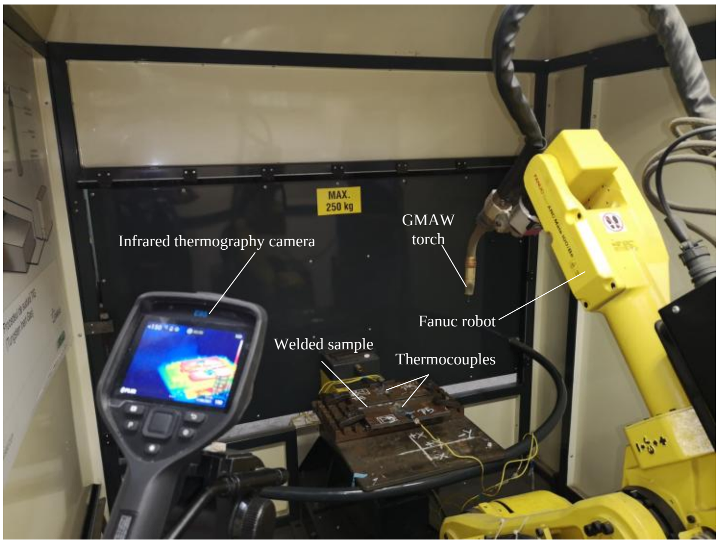

Figure 2. Fanuc robot cell welding workstation

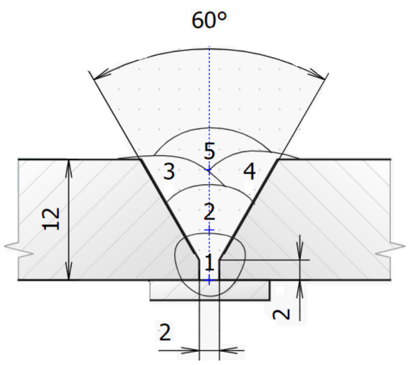

Figure 3. Sketch of the welded joint (1, 2, 3, 4 and 5 – multipass welding)

To perform the welded samples, with the help of the robotized cell, for measuring the hardness in the different areas of the welded joints, the working parameters presented in Table 3 were used.

Table 3. The welding parameters used in the experiments.

Test number	Transfer mode	T_{pr} * [^{0}C]	$t_{8/5}$ [s]	Q** [KJ/mm]	I [A]	U [V]	v [mm/s]
1.	SHORT-ARC	100	8	0,84	165	18	3
2.		150	8	0,72	180	18,7	4
3.		100	12	1,03	190	19,2	3
4.		150	12	0,88	200	20,7	4
5.		100	17	1,23	206	21	3
6.		150	17	1,04	194	19	3

T_{pr} – preheating temperature, $t_{8/5}$ – cooling time between 800 and 500^{0}C, Q – heat input (calculated with relation 1) [10]

$$Q = k \cdot \frac{I \cdot U}{v} \cdot 10^{-3} \ [kJ/mm] \quad (1)$$

Where:
- k – thermal efficiency [-]; the value of k for GMAW is 0.8 (acc. to EN ISO 1011-1:2009),
- I – welding current [A],
- U – arc voltage [V],
- v – travel speed [mm/s].

To measure the hardness in the characteristic areas of the welded joints, the samples were processed in the LAMET laboratory of the Faculty of Industrial Engineering and Robotics. Initially, the samples were cut to initial dimensions using Buehler ISOMET 4000 cutting equipment. After cutting, the samples were polished using Buehler's Vector and Alpha Beta polisher (Buehler, Leinfelden-Echterdingen, Germany) automatic metallographic sample grinding and polishing equipment. The hardness measurement was carried out using Shimadzu HMV2T Microdurimeter (Kyoto, Japan).

The Vickers hardness test with HV 0.2 load was carried out in accordance with EN ISO 9015-1:2011 [11]. Hardness measurements were performed in the weld bead, in the heat affected zone and in the base metal. The layout of the measurement points is shown in Figure 4. To obtain the most representative results for the analyzed welded joints, 3 measurements were performed for each area of interest.

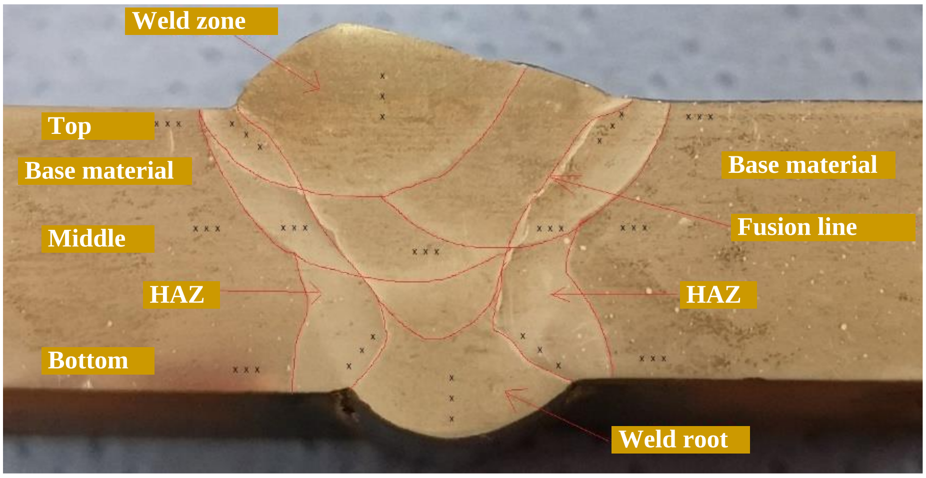

Figure 4. Welded joint measurement areas

To avoid the occurrence of welding defects, according to the requirements of international standards (EN ISO 15614-1:2017), the hardness values in the welded joint area must not exceed certain maximum acceptable limits (450 HV10, in the case of non-heat-treated steels, respectively 380 HV 10 units, in the case of heat-treated steels) [12]. Considering the nature of the base material as well as its high mechanical properties, when developing welding technologies, special attention will be paid to the hardness values obtained in the characteristic zones of the welded joints.

3. Results and discussion

The results obtained after hardness measurements in the characteristic areas of the welded joints are presented in Table 4. To obtain the most accurate results and to eliminate the probable errors caused by the way the measurements were carried out and by the measurement area, 3 measurement points were chosen for each characteristic area. Table 4 shows the average values of the 3 measurements performed in each area of interest. On the basis of the values presented in Table 4, variation graphs were drawn (Figures 5...7), for the 6 samples analyzed. The variation of the values was analyzed in the characteristic areas (left base material, HAZ, weld bead) transversally across the weld bead, at the top, middle and root.

Table 4. Hardness values measured in characteristic weld zones.

Semple number	Measurement Position	Measurement areas (HV 0,2)*				
		BML	HAZL	WM	HAZR	BMR
Semple 1	up	338	356	334	349	334
	centre	337	321	322	338	336
	root	323	330	329	337	326
Semple 2	up	327	347	346	350	334
	centre	335	336	344	366	348
	root	331	328	334	338	346
Semple 3	up	321	356	347	349	335
	centre	330	284	273	279	330
	root	338	277	272	282	335
Semple 4	up	322	385	361	365	322
	centre	325	368	337	349	326
	root	340	318	311	338	345
Semple 5	up	334	338	343	330	334
	centre	344	391	314	330	349
	root	347	309	304	342	346
Semple 6	up	333	381	348	340	333
	centre	333	334	326	326	343
	root	334	386	348	344	332

* where: BML – left base material, BMR - right base material, HAZL – left heat affected zone, HAZR – right heat affected zone, WM – weld material.

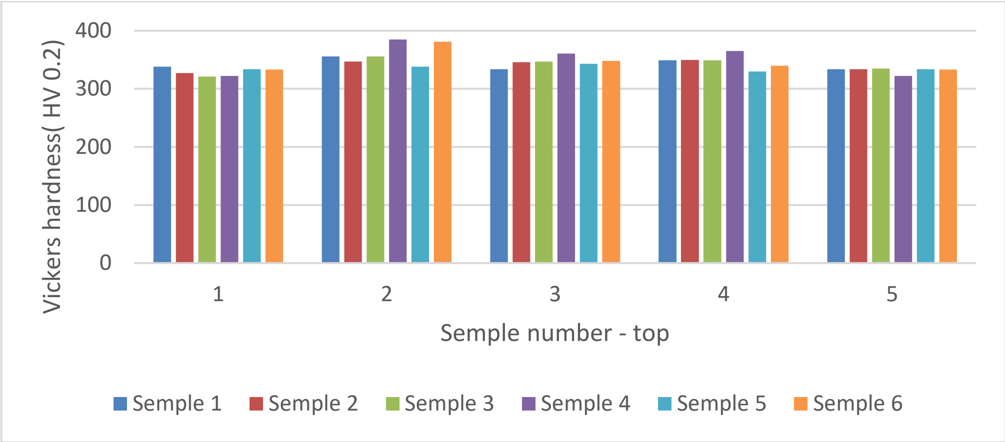

Figure 5. Vickers hardness measurements in the top of weld areas

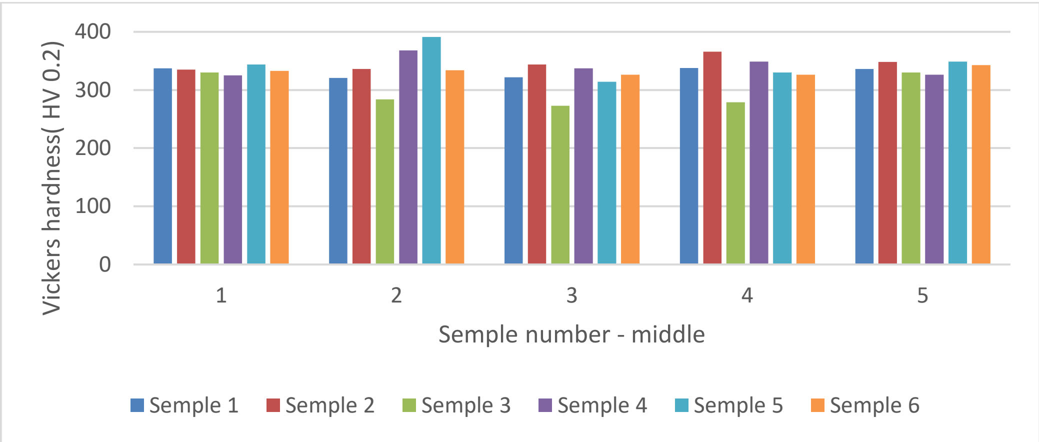

Figure 6. Vickers hardness measurements in the middle of weld areas

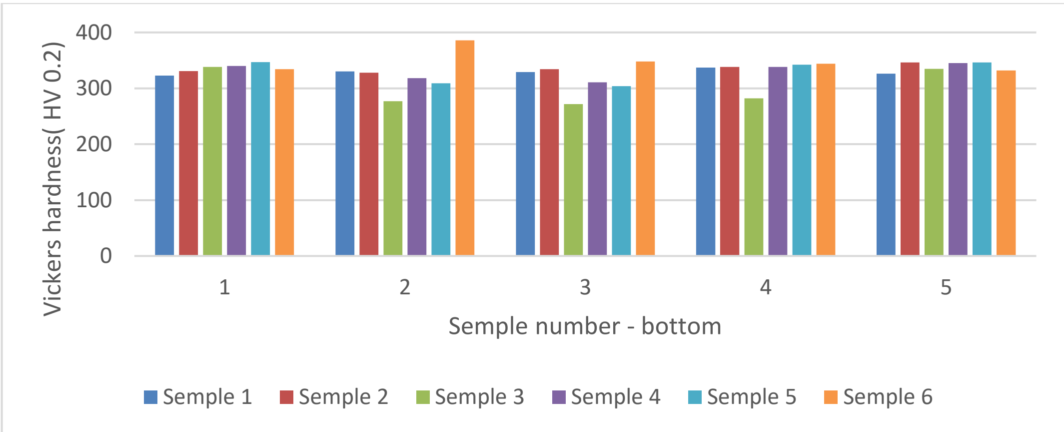

Figure 7. Vickers hardness measurements in the bottom of weld areas

From the analysis of the hardness values presented in Table 4 and Figures 5 to 7 one can observe that there is no significant variation in their values. The thermal cycles used in the experiments do not lead to any significant change in the hardness values compared to the values of the base material. When working on site, there is a risk of increased hardness and cracking due to the hard and brittle structure, internal tension of the structure and diffusible hydrogen. An increase in the preheating temperature or linear energy can lead to an increase in the grain size of the material in the welded joint areas, which leads to a reduction in mechanical properties.

4. Conclusions

Material properties influence the behavior of the product during operation. The thermal cycle during the welding process influences the resulting structure of the welded joint and the adjacent area and, consequently, the mechanical properties of the material.

After analyzing the results of the hardness measurements, one can observe that there is a small change in their values in HAZ and WM compared to the BM hardness values.

From the analysis of the values in Table 3, one can observe that, when using cooling times between 800 and 500^{0}C between 8s and 17s, no significant changes in hardness values occur. Hardness decrease for S890QL steel can be realized at higher cooling times or by post welding heat treatments.

There is, however, the danger of a significant increase in hardness values when welding processes are carried out under site conditions, in case the technological recommendations are not followed.

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