RESEARCH ON THE QUALITY OF WELDED STEEL PIPE JOINTS

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ABSTRACT: Welding thermal cycles occur due to temperature variations that occur in the base materials and can affect both the mechanical properties and the welded joints and implicitly the integrity of the welded structure. The effects of thermal cycles can be of a microstructural nature but can also affect the mechanical properties of the materials. Through advanced research techniques, which refer to the modeling, simulation and control of the evolution of thermal cycles in welding, it is possible to optimize welding processes to improve the performance of the dewelding process but also the reliability of the material. Taking into account these considerations, the paper contains a study referring to the influence of these factors, combining theoretical notions with practical applications in the welding of 10CrMo9-10 steel pipes, manual electric arc welding with a covered electrode, SEM 111.

KEY WORDS: steel pipes, thermal cycles, welding processes, optimization.

1. INTRODUCTION

Thermal cycling simulation technique has revealed more details about the microstructure and mechanical behavior of the heat-affected zone [1]. It is known that the heat generated during welding induces a significant temperature gradient in and around the weld zone. The region outside the weld joint that is thermally affected by the welding treatment is known as the heat-affected zone (HAZ), [2]
Its properties and microstructure are affected by thermal cycling.
The mechanical properties of the weld metal and the HAZ are closely related to their microstructures, which are dependent on the chemical composition of the material and the thermal history (cycling) due to the welding processes [3], [4].
Welded joints under service conditions can be affected by chemical heterogeneity or the mechanical properties of the base material, the heat-affected zone, and the weld metal. It was concluded that by improving the ZAZ microstructure, the properties of the welded joint can be improved [5]. Excessive heat input could lead to a wide HAZ with low impact strength [6]. As reported by Gu et al. [7], the degradation of the strength and toughness of the welded joint always occurs in the HAZ. For this reason, welding thermal cycle simulation can be used to optimize the welding technology, as it allows some mechanical tests for properties that cannot be performed on real welded joints due to the small width of the HAZ.
Welding thermal cycle simulation facilitates obtaining the necessary results for optimizing the welding parameters of alloy steel, which can be further used for welding under real conditions [8]. This technique consisted of rapid heating and cooling treatments of the base metal in specific simulation equipment. The HAZ can be simulated by heating the base metal to different temperatures, which corresponds to the HAZ temperature of the real welded joint. This technique was used in our previous work [9].

The heat affected zone was studied by simulating the thermal cycle of the welded alloy INC 738 LC [9] and low carbon steel [6]. We found a similarity between the microstructure obtained by simulating the welding thermal cycle and the HAZ microstructure of the real welded joint.

We note that previous works on welding of 304L stainless steel have focused on the microstructure and corrosion behavior of the welding [9] and there is no specific investigation on the heat affected zone of welded 304L stainless steel.

The objective of this investigation is to study the HAZ microstructures of 304L stainless steel by a thermal cycle simulation.

17-4PH stainless steel is a precipitation-hardened martensitic stainless steel and has been widely used in a variety of applications, including chemical process equipment, aircraft turbine blades, pump shafts, and self-lubricating spherical bearings [10], [11].

The most important properties of 17-4PH stainless steel are ease of fabrication, high strength, relatively good ductility, and excellent corrosion resistance.

2. THERMAL CYCLE PARAMETERS IN ELECTRIC ARC WELDING

During welding processes, the electric arc has an influence on all types of transformations: chemical, structural and volume in the welded seam, and for this reason a close correlation of the parameters of the welding regime in relation to its action is required.

The action of the electric arc as a welding source has the effect of distributing heat over the entire surface of the components to be welded, but this is done unevenly, which leads to the appearance of residual stresses after the welding process and implicitly to local or partial deformations of the welded components.

The type of steel used for the development of welding technology is:

10CrMo9-10 (1.7380) - Ø 31.8 x 4.0 mm

Manual electric welding SEM (111) of steel pipes 10CrMo9-10 (1.7380) - 31.8 x 4.0 mm, coated electrodes of type Ø - Crombaz, Ø 2.5 mm were chosen. The chemical and mechanical compositions of the base material are given in Table 2.1 and Table 2.2.

Steel	Chemical compositions %					Obs
	C'	Si	Mn	P'	S'	
	Cr	Mo	Ni	Al	Cu	
	0,88	0,48	0,16	-	0,15	
10CrMo9-10 (1.7380)	0,08 - 0,14	≤ 0,5	0,30 - 0,70	max. 0,025	max. 0,020	SR EN 10216/2 - 2007
	2,00 - 2,50	0,90 - 1,10	≤ 0,30	-	≤ 0,30	
	0,09	0,31	0,44	0,019	0,018	**Exp. determination**
	2,10	0,98	0,19	-	0,10	

Table 2.1. Chemical composition of the base material

If we also take into account the fact that during welding processes the heating rate is very high, the heat is transferred from the electric arc column to the components in a very short time, which means that the transfer process is unstable, because the welding speed is high, the heating temperature of each point changes continuously.

B M	Mechanical characteristics					Observations
	R_m, N/mm²	$R_{p0.2}$, N/mm²	A_5, %	KV, J	T, ⁰C	
10CrMo9-10 (1.7380)	480…630	280	22	40	+ 20	SR EN 10216/2 - 2007
	607	483	23,1	-	+ 20	Experimental determination

Tabel 2.2. Caracteristici mecanice ale materialului de bază

In the case of steel, brand 10CrMo9-10, for the chemical elements chromium (Cr) and molybdenum (Mo), the composition variation graphs were represented in eight areas on the pipe thickness 42.4 x 5.4 mm. The composition is quite homogeneous on the pipe thickness of the 10CrMo9-10 alloy steel, the average values of the chemical elements (2% Cr and 1% Mo) do not differ significantly from the individual values determined experimentally, ferlito-pearlitic structures with fine carbides of Cr and Mo placed inter-intragranularly.

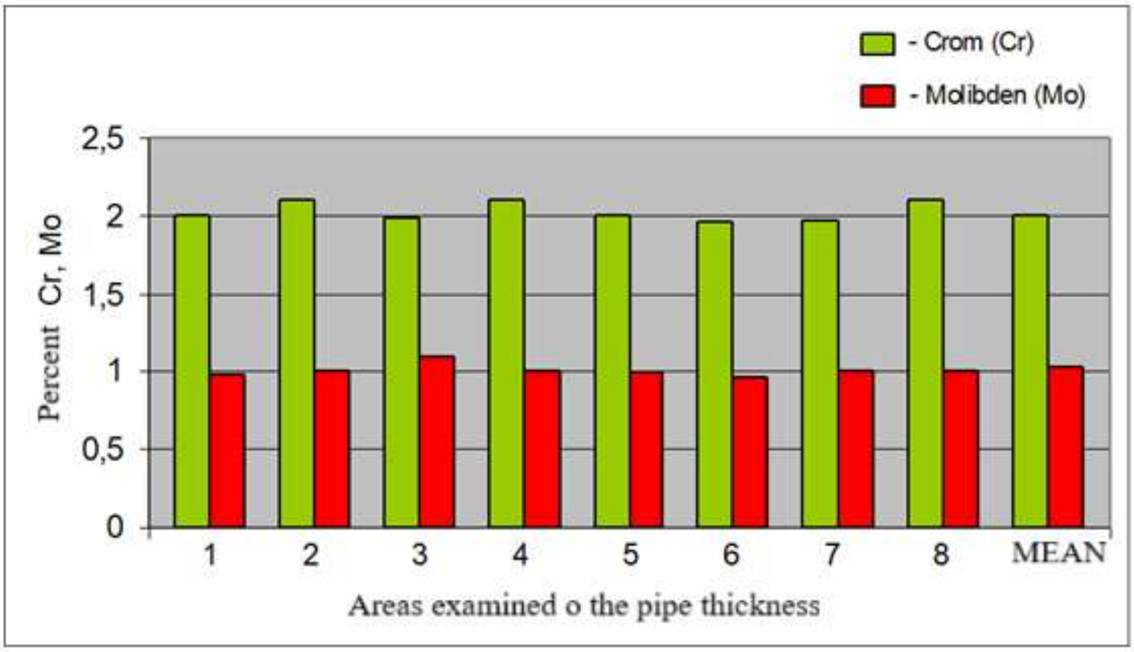

Figure 2.1. Graphs of variation of Cr and Mo elements in areas distributed over the thickness of the steel pipe 13CrMo4-5 mm

3. MECHANICAL TESTS TO DETERMINE THE QUALITY OF WELDED SEAMS

From the 10CrMo9-10 steel pipes, samples with dimensions of 110 x 18 mm and the calibrated portion with dimensions of 50 x 6 mm were mechanically taken, the weld being placed in the middle of this area.

The hardness tests were performed on the cross-section of the sample, by the Vickers method, the test force had the value F=100N, using the Vickers HV hardness tester type ZWICK 3212, fig. 3.1.

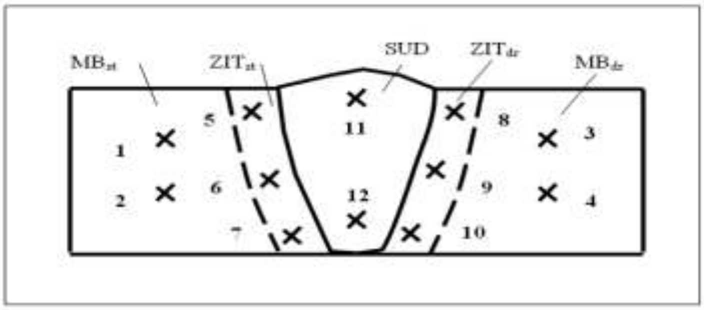

Figure 3.1. Positioning of Vickers HV10 hardness indentations.
Vickers HV10 hardness tests

Since during the thermal cycle of welding, large temperature variations occur along the welded seam, the application of stress relief heat treatments was aimed at reducing internal stresses in the welded seams and also at normalizing the welded structure in the heat-affected zone.

In tab. 3.1. the parameters of the heat treatment regimes were synthesized.

Stress relief heat treatment option	Parameters of heat treatment regimes							Steel grade
	Temp. min, ^{0}C	Temp. max, ^{0}C	Heating rate V_{inc}, ^{0}C/oră	Cooling rate $V_{răc}$, ^{0}C/oră	Heating time T_{inc}, ore	Holding time T_{men}, ore	Cooling time $T_{răc}$, ore	
TD3	20	650	150	200	4,20	0,50	3,15	10CrMo9-10

Table 3.1. Parameters of stress relief heat treatment regimes

Table 3.2 shows the results obtained from the tensile tests on two butt-welded samples, SEM welding, without heat treatment and with heat treatment..

Nr. sample	Nr. sample	Sample dimens. (S_0 x B_0), mm	F_{max}, N	R_m, N/mm^2	Place of rupture
E3	E3.1	4,0 x 6,4	14050	549	MB
	E3.2	3,9 x 6,4	13920	557	MB
E3T	E3.1T	4,0 x 6,4	14100	552	MB
	E3.2T	4,0 x 6,4	14080	550	MB

Table 3.2. Tensile test results on butt-welded samples with and without stress relief heat treatment

Macroscopic examination of the cross-sections of the welded joints did not reveal macrocracks (Fig. 3.2 and 3.3) on both the welded samples without heat treatment and those with heat treatment (TD3).

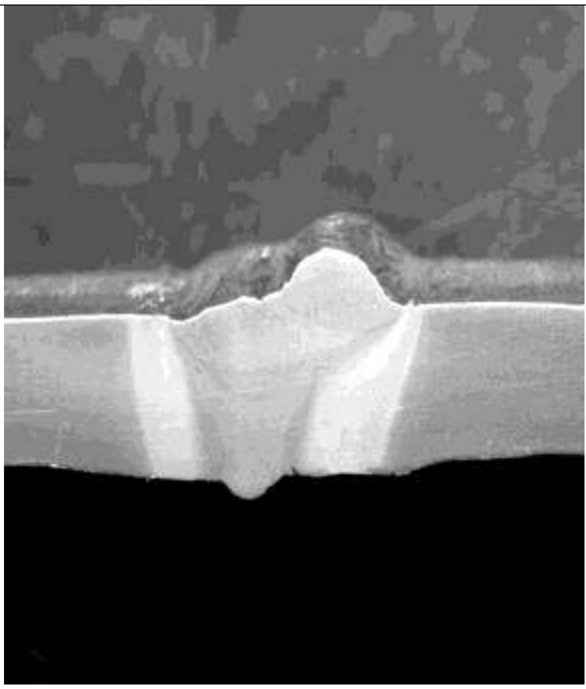

Figure 3.2. Sample E3 without heat treatment, 10% Nital attack

Figure 3.3. Sample E3 heat treatment applied Nital attack 10%

4. CONCLUSIONS

For the 10CrMo9-10 alloy steel, all the tensile strength values determined are higher than the minimum required value (480 N/mm2) and fall within the range (480...630) N/mm2, attesting to a high mechanical strength of the joints welded by the three welding processes.
The application of post-weld heat treatment in the TD3 variant generally leads to an increase in the tensile strength by a maximum of 6.4% compared to the non-heat-treated variant.
The structural characterization of the areas of the welded joints analyzed (MB, ZIT and SUD) confirms the presence of specific microstructures that are in direct correlation with the Vickers HV10 hardnesses of these areas.
The chosen post-welding heat treatments lead to structural modification, in the sense of developing structural transformations specific to tempering, with a general decrease in Vickers HV10 hardness values and sometimes in Rm tensile strength.
The application of both the welding process, 111 and the thermal cycles specific to post-welding treatments in the variants with stress relief heat treatment and without treatment, of the welded joints, did not lead to the appearance of welding or heat treatment defects, attesting that the welding and heat treatment of the 10CrMo9-10 steel was carried out under appropriate conditions.
The hardening of the solid solution due to the presence of dislocations, precipitations and foreign atoms in the network represents a particularly important element that must be taken into account when determining the structural and mechanical characteristics of weldable unalloyed and alloyed heat-resistant steels.
Secondary phase particles, such as carbides of alloying elements (Cr, Mo, V) have a determining role on the heat resistance characteristics of weldable heat-resistant alloyed steels, both in shape and size, as well as in their quantity and dispersion.
The stress-relieving heat treatment applied post-welding to heat-resistant steels must ensure the optimal reduction of the level of residual stresses, the restoration of the ductility of the embrittled areas and the minimum degradation of the mechanical characteristics of the steels in the non-embrittled areas.

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