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Using the Hot Brine Hardenability Test for the Qualification of In-Service Welding Procedures for Repairing Natural Gas Transmission Pipelines

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Abstract

In this paper there is presented the proposal of the authors regarding the use of the hot brine hardenability test, usually intended to characterize the hardenability of low-hydrogen steels, for determining the maximum values of the hardness in the heat affected zone of welded joints of steel components, performed while constructing pipes for oil and gas pipelines. Knowing the maximum values of the hardness of the microstructures that can be generated within the heat affected zone of welded joints, there can be made a relevant choice of the hydrogen scale of covered electrodes used during weld repairs and there can be conceived cheap and reliable in-service repair technologies for natural gas transmission pipelines made of steel.

Key words: *hot brine hardenability, gas transmission pipelines, weld repairs, hardness in the heat affected zone*

Technological Issues while Performing Weld Repairs on Pipelines

Many of the technologies, classified and codified in [1-3], used for repairing the defects of natural gas transmission pipelines made of steel include welding operations, which are performed onto in-service or out-of-service pipelines. The welded joints, butt or fillet welded, performed while replacing some damaged pipeline sections or the application onto the pipelines, in the defective areas, of some patches or sleeves, are considered of adequate quality if during their performing the occurrence of hydrogen cracking HC (also known as cold cracking or delayed cracking) is avoided [1-3].

The hydrogen cracking occurs if the following conditions are simultaneously fulfilled: a) hydrogen is present in the welded joint; b) the welded joint reveals areas of crack susceptible structure; c) in the welded joint there are generated tensile stresses. Therefore, in order to avoid this phenomenon, while conceiving weld repair technologies for (in-service or out-of-service) pipelines, there must be taken into account the use of covered low hydrogen electrodes and the possibility to perform welding procedures with low levels of diffusible hydrogen in the welded joints. If these conditions cannot be fulfilled, there must be taken measures that minimize the possibility of the occurrence in the welded joints (in the CUS weld seam and in the heat affected zone – HAZ) of some microstructures that are sensitive to cracking. The most efficient measures that can be taken are: the adequate choosing of the electrode chemical content, the use of some linear welding energies high enough to counteract the fast cooling effect of the circulation of gases under pressure, for instance, while weld repairing in-service pipelines, pre-heat welding (if this is possible and the fast cooling effects produced by the circulation of pressurized gases, if the welding is performed onto in-service pipelines, does not hinder the reaching of the desired pre-heat temperature level), the deposition of some narrow beads at the base of CUS in the corner, on the pipe wall, with electrodes that confer them a low yield strength and a high plasticity (solution known as „temper bead technique) [1-4]. Finally, in order to assure low intensities of the residual stresses generated during welding and low effects of stress concentration at the root of the performed welded joints, there must be used adequate solutions (devices) for positioning and fastening for welding additional elements (patches, sleeves) that are applied onto the pipelines.

Undertaken experimental research led to the prescribing in the actual standards of the correlations shown in figure 1, which have to be provided between the diffusible hydrogen content of covered electrodes used for welding *HD* (stated in milliliters of hydrogen at 100 g deposited weld metal), determined by the diffusible hydrogen level or scale H_S, the maximum hardness *HM* of the crack resistant structures in the presence of a level N_H of the diffusible hydrogen and the crack susceptibility of the structures that can occur in the ZIT of welded joints, which can be described by comparing the maximum value HV_{max} of the hardness of the structures that can occur in the HAZ with the value *HM* corresponding to the conditions in which the welded joints are performed [3-8].

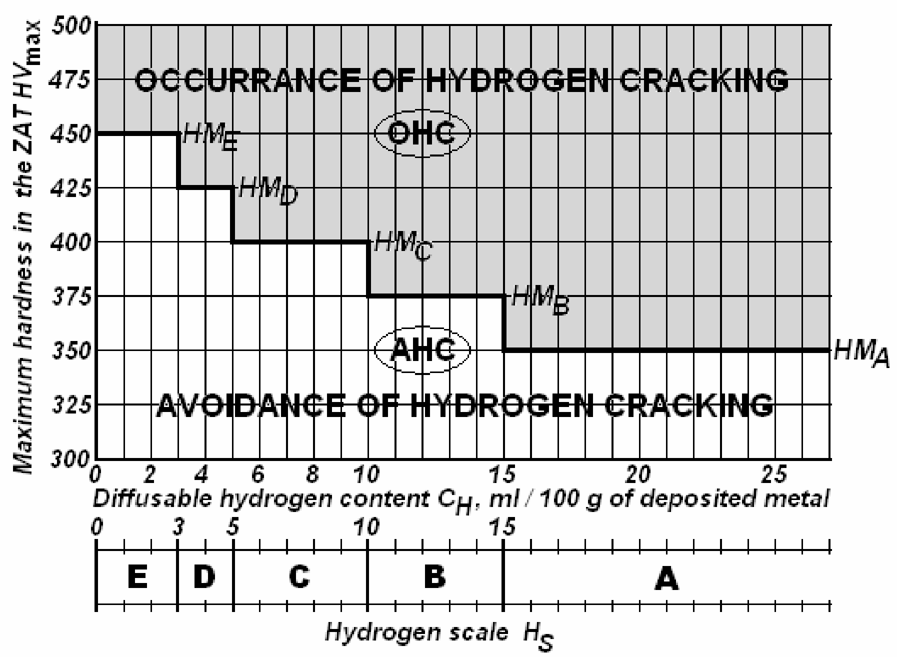

Fig. 1. Diagram of the hydrogen crack susceptibility of welded joints performed while repairing natural gas transmission pipelines

Estimate of HV_{max} in the HAZ while performing weld repairs on pipelines

The maximum value HV_{max} of the hardness of the structures obtained in the HAZ of welded joints is a synthetical characteristic of the way the parent metal of the components to be welded reacts at the thermal cycles produced while welding. This reaction, which involves the modification of the metallographical structure and of the mechanical properties, depends both on the characteristics of the parent metal (chemical content, contaminants, structural state, grain size etc.), and on the characteristics of the thermal cycles produced while welding (temperature and austenitization time and cooling rate, normally determined indirectly by the value of the cooling time from 800 °C to

500 °C, noted $\tau_{8/5}$, which came out to be a constant characteristic for all the strips in the HAZ in which the thermal cycles have the maximum heat temperature above 830...850 °C); the value of $\tau_{8/5}$ depends on the thermophysical characteristics of the parent metal (density, thermal conductivity and specific heat capacity) and on the conditions of the thermal transfer in the welding area (determined mainly by the thickness of the components to be welded), but, especially, on the value of the linear energy while welding *EL* and on the size of the preheat temperature t_p and/or the interpass temperature t_t, in case of multi-run weld. Obviously, for a complete characterization of the reaction of a parent metal at the welding thermal cycles it would be necessary to use, in addition to HV_{max}, which is a characteristic that expresses mainly the mechanical strength, a toughness characteristic (the impact absorbed energy at a reference temperature KV_t or the ductile – brittle impact transition temperature t_{tr}) [1-8,13].

Because HV_{max} characterizes the hardening effect of a parent metal by the action of thermal cycles, the authors of this work suggested the determination of this characteristic by applying the hot brine hardenability test – HBHT, recommended in the technical literature [9-12], instead of the Jominy end-quench test – JEQT, for the characterization of the hardenability of steels (unalloyed, microalloyed and low-alloyed) with a low carbon content (such as weldable steels used for the fabrication of pipes for pipelines). As it can be seen by examining the diagrams in figure 2, in case of low-carbon steels, the use of HBHT instead of JEQT allows a better estimate of their hardenability (fast cooling of austenitic steels) [9,10].

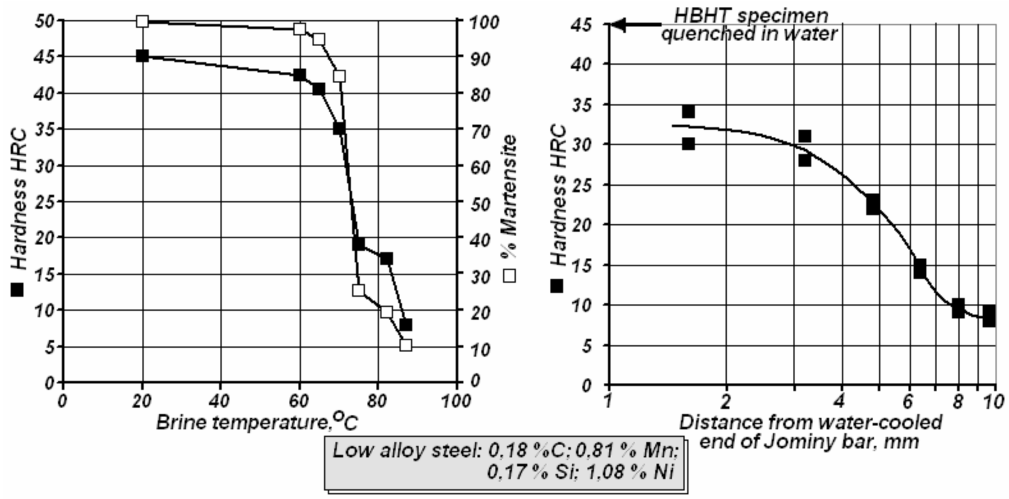

Fig. 2. Comparison of the results obtained by the HBHT and JEQT methods regarding the hardenability of a steel

HBHT, adjusted by the authors of this work in order to be used for the determination of the HV_{max} characteristic in case of pipe steels, is performed by following the next steps:

- Specimens are taken from the steel to be analyzed, with the dimensions and form presented in figure 3; there are prepared n = 4 sets of specimens from the same steel, each set, including m = 2...3 specimens, will be subjected to a thermal cycle characterized by a certain cooling rate.
- The specimens are subjected to austenitization at the temperature t_i = 925 °C, for a period of τ_m = 10 minutes. At the end of this stage the structure of all specimens will be of homogenous austenite, with a certain grain size.
- Each set of specimens j = 1...n is subjected to cooling (from the austenitization temperature) in a medium that provides a certain cooling rate $v_{r,j}$, j = 1...n. The original methodology for performing a HBHT implied the use of some cooling baths of sodium chloride solution in water (where the concentration of the solutions was 10...12 % NaCl), kept at various temperatures $t_{r,j}$, j = 1...n [10]. The methodology suggested by the authors of this work (called HBHT modified) implies the use of cooling alternatives of the specimens specified in table 1.

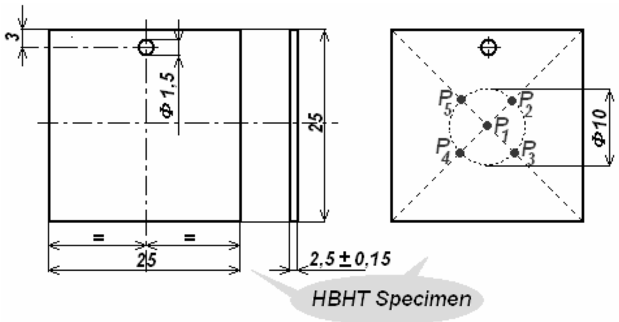

Fig. 3. Configuration and dimensions of the specimens used for HBHT

Table 1. Cooling alternatives of the specimens from the austenitization temperature

Cooling conditions		Cooling alternative A	Cooling alternative B	Cooling alternative C
$j = 1$	Cooling medium	water +12 % NaCl	water with ice	refrigerated air
	Temperature of the cooling medium	$t_{r,1} = 0$ °C	$t_{r,1} = 0$ °C	$t_{r,1} = 0$ °C
$j = 2$	Cooling medium	air	water	air
	Temperature of the cooling medium	$t_{r,2} = 20$ °C	$t_{r,2} = 20$ °C	$t_{r,2} = 20$ °C
$j = 3$	Cooling medium	water +12 % NaCl	water	heated air
	Temperature of the cooling medium	$t_{r,3} = 60$ °C	$t_{r,3} = 50$ °C	$t_{r,3} = 100$ °C
$j = 4$	Cooling medium	bath of melted Sn	water boiling	heated air
	Temperature of the cooling medium	$t_{r,4} \cong 250$ °C	$t_{r,4} = 98...100$ °C	$t_{r,3} = 200$ °C

- After the cooling, the specimens of each set are processed by grinding them on one of the side square parts, where there is traced centrally a circle having the diameter of 10 mm; the centre of the circle and its intersections with the diagonals of the square surface delimits the points $P_1...P_5$, as it can be seen in figure 2.
- The hardness Vickers is measured in the points $P_1...P_5$ marked on the specimens and the hardness of each specimen is calculated as arithmetical mean of the values measured in the points $P_1...P_5$. The maximum hardness determined this way HV_{HBHT} can be considered to be the upper bound of the values $HV_{\max}$ that can be obtained in the HAZ of welded joints performed onto pipes made of the examined steel ($HV_{\max} \le HV_{\mathrm{HBHT}}$).

The method suggested for estimating $HV_{\max}$ in the HAZ while performing weld repairs on pipelines has been tested by using specimens taken from pipes made of two different steel grades: a) specimens marked T1, processed from a X52 steel pipe, having the composition: %C = 0,183; %Si = 0,223; %Mn = 1,262; %P = 0,0278 and %S = 0,0306; b) specimens marked T2, processed from a X60 steel pipe, having the composition: %C = 0,227; %Si = 0,352; %Mn = 1,458; %P = 0,0320 and %S = 0,0257; the equivalent carbon *CE*, calculated by means of the simplified IIW formula *CE* = %C +%Mn/6, had the following values: a) for the specimens T1, of X52 steel, $CE_{\mathrm{T1}} = 0{,}393$ %; b) for the specimens T2, of X60 steel, $CE_{\mathrm{T2}} = 0{,}470$ %, and the microstructures of the pipes the specimens were taken from were those shown in figure 3. The results obtained using the A cooling alternative of specimens from the austenitization temperature, synthesized in figure 4, were interpreted this way:

- The thermal cycles applied to the parent metal of X52 steel pipes can determine the occurrence of some structures characterized by hardness values under the value $HV_{\mathrm{HBHT}} = 368$ SV40, if the cooling rates are very high (of a size corresponding to the cooling in brine at 0 °C, or to the value $HV_{\mathrm{HBHT}} =$ 206 HV10, if the cooling is performed with moderate or low rates (under the air cooling rate). On this basis it can be estimated that during weld repairs, with or without pre-heating, of pipelines made of this type of pipes, the effects of thermal cycles can determine the occurrence in the HAZ of welded joints of some microstructures with the maximum hardness $HV_{\max} \le HV_{\mathrm{HBHT}} = 206$ HV10, if the welding is performed on out-of-service pipelines, or with the maximum hardness $HV_{\max} \le HV_{\mathrm{HBHT}} = 368$ HV10, if the welding is performed on in-service pipelines (when the effect of cooling rate intensification interferes, due to the circulation within the pipeline of pressurized gases). Consequently, for weld repairs performed on out-of-service pipelines it is recommended to choose covered electrodes having the hydrogen scale H_S = A, and for weld repairs performed on pressurized pipelines – to choose electrodes with H_S = B.

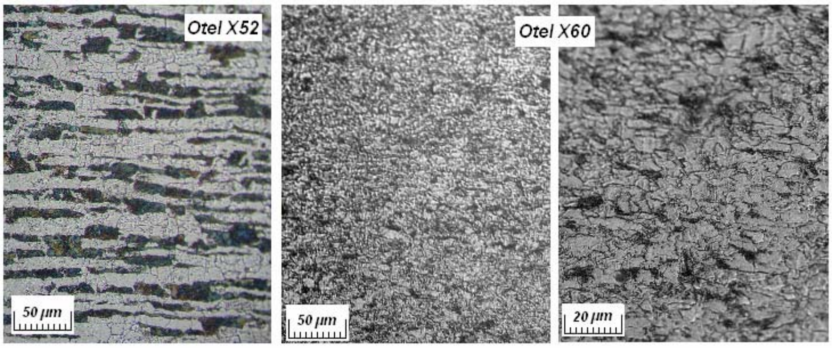

Fig. 3. Microstructure of the pipes the specimens for applying HBHT modified were taken from

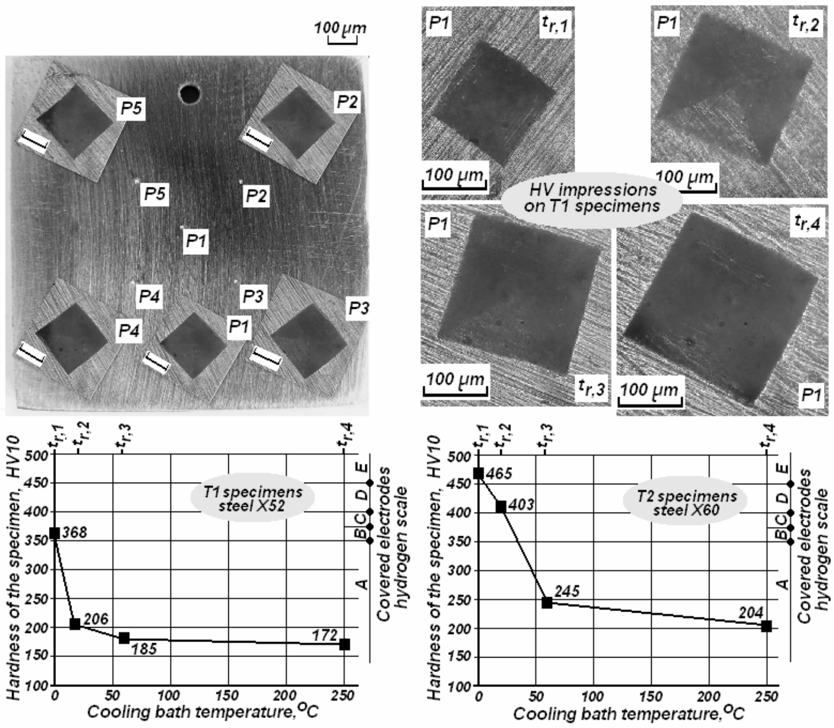

Fig. 4. Results obtained by applying HBHT modified for X52 and X60 steel pipes

➢ By a reasoning identical to the previous one, it can be estimated that for weld repairs, with or without pre-heating, of pipelines made of X60 steel pipes, the effects of the thermal cycles can determine the occurrence in the HAZ of welded joints of some microstructures with the maximum hardness $HV_{\max} \le HV_{\mathrm{HBHT}}$ = 403 HV10, if the weld repair is performed onto out-of-service pipelines or with the maximum hardness $HV_{\max} \le HV_{\mathrm{HBHT}}$ = 465 HV10, if the weld repair is performed onto in-service pipelines. Consequently, for weld repairing out-of-service pipelines it is recommended to choose covered electrodes with the hydrogen scale H_S = C, while for weld repairing pressurized pipelines – to choose electrodes with H_S = D or E.

Conclusions

This work highlighted the following issues as conclusions:

- In order to avoid the hydrogen cracking, the hydrogen scale H_S of covered electrodes for weld repairs performed onto natural gas transmission pipelines should be chosen correlated with the maximum hardness HV_{max} of the microstructures which can be obtained in the HAZ under the action of weld thermal cycles.
- In the absence of a thermal cycle simulator for estimating the value HV_{max} there can be used the hot brine hardenability test – HBHT modified, a simple test that can emphasize the ability of the parent metal of pipes to harden under the action of thermal cycles.

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Utilizarea încercării de durificare prin răcire în băi de săruri la stabilirea tehnologiilor de reparare prin sudare a conductelor de transport al gazelor naturale

Rezumat

În lucrare se prezintă propunerea autorilor privind utilizarea încercării de durificare prin răcire în băi de săruri, utilizată în mod obişnuit pentru caracterizarea călibilității oțelurilor cu conținut scăzut de carbon, pentru determinarea valorilor maxime ale durității în zona influențata termic a îmbinărilor sudate care se realizează între componente din oțeluri destinate fabricării țevilor pentru conducte petroliere. Cunoscând valorile maxime ale durității microstructurilor care pot fi generate în ZIT a îmbinărilor sudate, se poate face o alegere pertinentă a scalei de hidrogen a electrozilor înveliți folosiți la repararea prin sudare şi se pot concepe tehnologii ieftine şi sigure de reparare fără scoaterea din exploatare a conductelor din oțel destinate transportului gazelor naturale.