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Possibilities to Obtain an Adequate Durability for the Butt Welding Joints of the Temporary Flowlines

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Abstract

This paper presents the main technical solutions highlighted by the authors regarding the durability improvement of butt welding joints of the base components, such as pipes or elbows, of temporary flowlines (low, medium or high pressure) and of end components belonging to quick coupling connections of the Hammer Union type. The solutions presented are based on the results of experimental research for detecting failure causes of such butt welding joints, belonging to a pipe from a temporary flowline of a hydraulic fracturing installation of oil and gas wells.

Key words: *temporary flowline, Hammer Union connectors, butt welding joint durability*

Introduction

Temporary flowlines (low, medium or high pressure) are used in steel mills, chemical and petrochemical installations, ships for dredging navigable waterways, mining installations, equipment for drilling and production of the oil and gas reservoirs, etc.

These temporary flowlines are made of pipes – TFP or elbows – TFE, having components of fittings coupling / quick interconnection mounted at their heads through threaded or welded joints; usually, quick coupling fittings of the type Hammer Union are used, which are made up of three components: a (non-threaded) element with the male sealing surface, called Male (Wing) Sub – MWS, a (threaded) element with sealing surface on the female, called Female (Thread) Sub – FTS and a wing nut tightening, called Wing (Detachable) Nut – WDN, which ensures the rapid coupling of elements FTS and MWS, by making the threaded joint between FTS and WDN. As it can be seen in Figure 1, each component of TFP or TFE type of a temporary flowlines has mounted by threaded joints – TJ or welded joints – WJ at its ends components of MWS and FTS type of quick interconnect couplings, each MWS being assembled with WDN [1-3].

The main technical conditions to be met by temporary flowlines are: a) safe operation, defined as the ability of the pipes to provide mechanical strength and tightness necessary for fluid circulation at the required design pressure; b) durability, expressed by the number of assembly and disassembly of flowlines, without cracking, breaking or inadmissible damaging the components or the connections between them.

The existing experience in the design, manufacture and use of temporary flowlines revealed that the technical specifications presented above are dependent of [1-3]: a) the quality of the components (TFP, TFE, MWS, FTS and WDN), determined by the materials from which they are made of, their dimensional precision and their surface quality; b) the quality of the joints (threaded or welded) between the components; c) the procedures for repeated assembly and disassembly of the flowlines in different sequences of use.

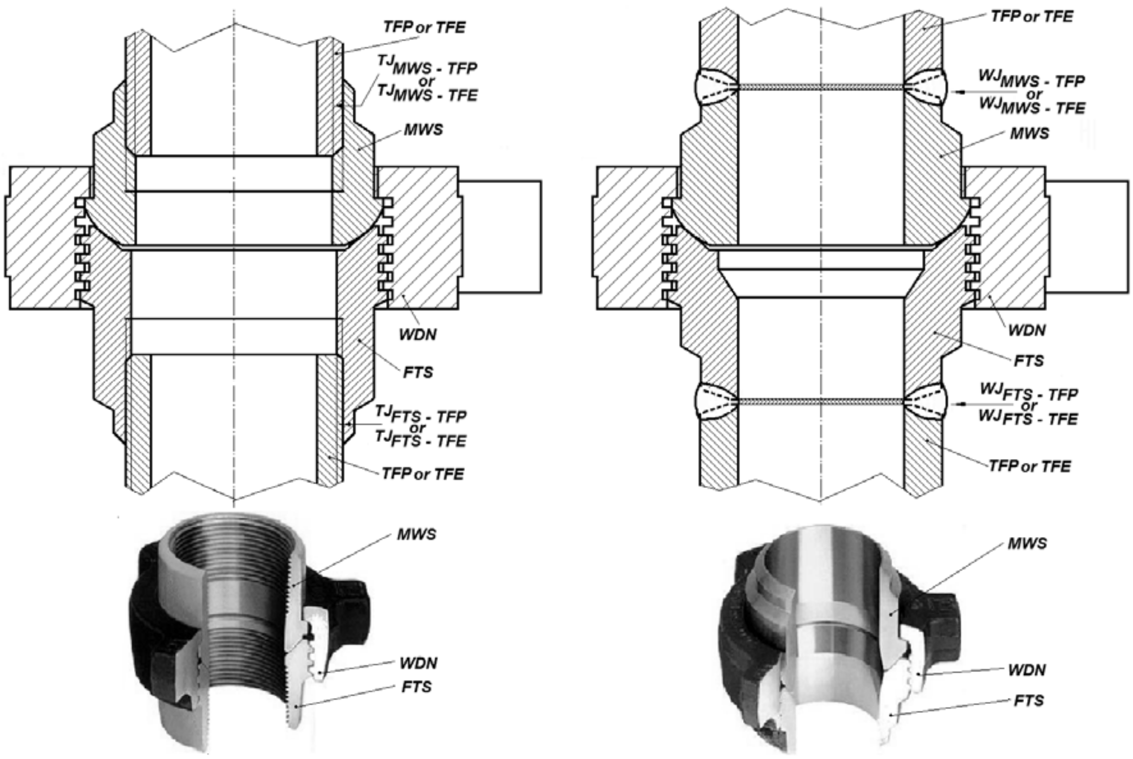

Fig. 1. The main types of Hammer Union fittings
which are mounted on TFE and TFP of temporary flowlines

In this context, the present paper includes the results of experimental researches conducted by the authors when performing a study on the failure causes of the butt welded joint between TFP and MWS, belonging to a pipe (nominal diameter DN80) of a temporary flowline from a hydraulic fracturing installation of oil and gas wells, as well as the technical solutions, highlighted on this base, for ensuring an adequate durability of this type of joint.

Case Study – Failure of a Welded Joint between TFM and MWS

The welded joint which failed in service and has been the subject of the case study, was of the type $WJ_{TFP-MWS}$; as it can be seen in Figure 2, the rupture occurred in the fusion line area from MWS of the butt weld [4]. To perform experimental research for the case study, the following were available: a) fragments resulted from the failure of the welded joint $WJ_{TFP-MWS}$, marked TFP and MWS (see fig. 2); b) the end of the broken pipe that contained the two components, marked TFP and FTS, assembled by welded joint $WJ_{TFP-FTS}$ (see fig. 2); c) an elbow belonging to the same flowline as TFP, with the components marked TFE, MWS_E and FTS_E, assembled by welded joints $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$ (see fig. 3).

The experiments consisted of: a) determining the chemical composition of TFP, MWS, FTS, TFE, MWS_E and FTS_E components; b) the metallographic macroscopic and microscopic examination of welded joints $WJ_{TFP-MWS}$ (which failed), $WJ_{TFP-FTS}$; $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$ (which did not fail); c) determining the hardness in specific areas (welding / seam W, the base materials of welded joint components – MB and Heat Affected Zones – HAZ, from one side to side of the weld) of welded joints $WJ_{TFP-MWS}$, $WJ_{TFP-MWS}$; $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$; d) determining the mechanical strength and toughness of MWS and TFP, by tensile testing and Charpy impact testing [4].

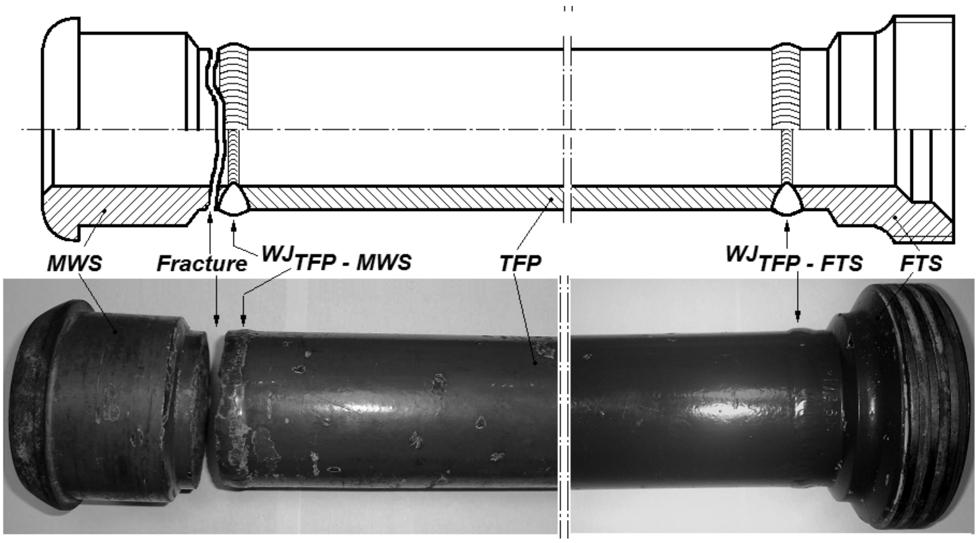

Fig. 2. The welded joint of the temporary flowline which failed during use

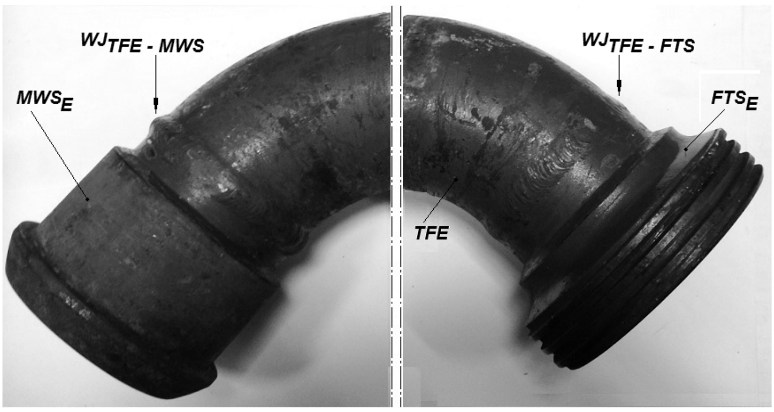

Fig. 3. Temporary flowline elbow used in the experimental program for the case study

Measurements of the chemical composition, performed with the FOUNDRY-MASTER PRO / Oxford Instruments spectrometer, led to the results summarized in Table 1.

Table 1. Results of the measurements of the chemical composition

	Chemical composition, % by mass									CE_{IIW}*	CE_T*
	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%Al		
MWS	0.403	0.246	1.077	0.018	0.013	1.131	0.330	0.153	0.030	0.885	0.604
FTS	0.287	0.275	0.533	0.015	0.005	0.930	0.203	0.011	0.026	0.603	0.407
TFP	0.162	0.215	0.824	0.011	0.016	0.007	0.002	0.001	0.027	0.301	0.245
MWS_E	0.283	0.266	1.054	0.005	0.001	1.095	0.204	0.085	0.026	0.724	0.466
FTS_E	0.266	0.206	0.531	0.009	0.006	0.965	0.178	0.010	0.024	0.584	0.386
TFE	0.194	0.256	0.392	0.002	0.005	0.034	0.003	0.025	0.002	0.269	0.236

* Carbon equivalent $CE_{IIW} = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$; CE_T – see fig. 4.

An analysis of the results presented in Table 1 highlighted the followings: a) MWS, MWS_E, FTS and FTS_E are made of steel with C = 0.27 ... 0.40%, allied with Cr ($\%Cr \cong 1$) and Mo ($\%Mo$ = 0.18...0.33), which is characterized by poor weldability, evidenced by high levels of carbon equivalent (CE_{IIW} = 0.58...0.89 >>0,45 and CE_T = 0.39...0.60); b) TFP and TFE are made of carbon steel, with low carbon content (% C = 0.16 ... 0.19), characterized by good weldability (CE_{IIW} = 0.27...0.30 << 0.45 and CE_T = 0.24...0.25). Appreciation of poor weldability of MWS, MWS_E, FTS and FTS_E was confirmed by applying the methods A and B, recommended by EN 1011-2, to establish the technological measures to be taken into account in order to avoid cracking due to hydrogen when welding carbon steel or low alloy steel. As it can be seen by analyzing the diagrams in Figure 4, constructed considering that the combined thickness of the parts to be joined by welding is s_{CO} = 2s + 4...6 mm = 20...22 mm and the welding is done with fillers with diffusible hydrogen content of less than 5 ml / 100g metal deposited, the avoidance of late cracking overdue at welded joint such $WJ_{TFP-MWS}$, $WJ_{TFP-MWS}$, $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$ requires the use of welding preheating and, possibly, the application of post-weld heat treatment; the implementation of these measures could not be proven because the documentation accompanying the analyzed components (pipe and elbow) of the temporary flowline, subject to investigation, contained no welding procedures used in their manufacture process.

The examination of microstructure and hardness measurements (performed in accordance with SR EN ISO 6507-1, on samples from the fragments resulting after failure of $WJ_{TFP-MWS}$, using a DURASCAN 20 / EMCOTEST Vickers micro hardness machine), whose results are summarized in Figure 5, have confirmed the previous presented aspects: a) in HAZ from TFP of the welded joint $WJ_{TFP-MWS}$ (marked $HAZ_{(FTS)}$ in figure 5) were revealed the steady-state structures (ferrite-pearlite) with 160 ... 180 HV hardness, while in the HAZ from MWS of the same joint (abbreviated $HAZ_{(MWS)}$ in figure 5), in which the failure occurred, imbalance structures (structures for quenching, incomplete tempered), with high hardness (630 .. .670 HV) and propensity for brittle behavior, have been observed.

Tensile and Charpy impact tests, performed on specimens taken from TFP and MWS, led to the results presented in Table 2. For tensile testing, standard specimens like pipe strip taken from the TFP (the width l = 20 mm and thickness s = 8 mm) and round specimens axial taken from MWS (with the diameter, of the calibrated portion, d_0 = 6 mm) were used; the test was performed in accordance with SR EN ISO 6892-1, using a LF300 Walter Bai machine for strip pipe specimens and an INSTRON 8801 machine for round specimens. For impact tests, conducted in accordance with SR EN ISO 148-1, we used small samples (7.5 mm × 10 mm × 55 mm) with V-notch (depth h = 2 mm and the angle at peak α = 45°), axially taken from TFP and MWS, and a Charpy pendulum Walter Bai 450, with the initial potential energy W_0 = 150 J; with the results $KV_{R,i}$, i = 1...3, obtained by testing of three specimens from TFP and MWS, the average values were calculated $KV_R = (KV_{R,1} + KV_{R,2} + KV_{R,3})/3$, and by multiplying these values by a factor k_r = 10/7.5 = 4/3, we determined the impact energy values corresponding to normal test specimens (10 mm × 10 mm × 55 mm), KV_1, KV_2, KV_3 and the average $KV = (KV_1 + KV_2 + KV_3)/3$.

The results of the mechanical tests carried out, in conjunction with the results of other tests and examinations, led to the following comments: a) components TFP and MWS, between which $WJ_{TFP-MWS}$ was done, had corresponding strength and toughness characteristics; b) due to its chemical composition, TFP showed a low tendency to modify the structure by the action of welding thermal cycles and, therefore, HAZ from TFP of $WJ_{TFP-MWS}$ had mechanical characteristic related to TFP; c) due to the high concentration of carbon and alloying with Cr and Mo, MWS has radically changed the structure by the action of the welding thermal cycles and, therefore, in the absence of appropriate technological measures during welding (preheating and post welding heat treatment) HAZ from MWS of $WJ_{TFP-MWS}$ presented a structure with high hardness and low toughness, susceptible to brittle cracking.

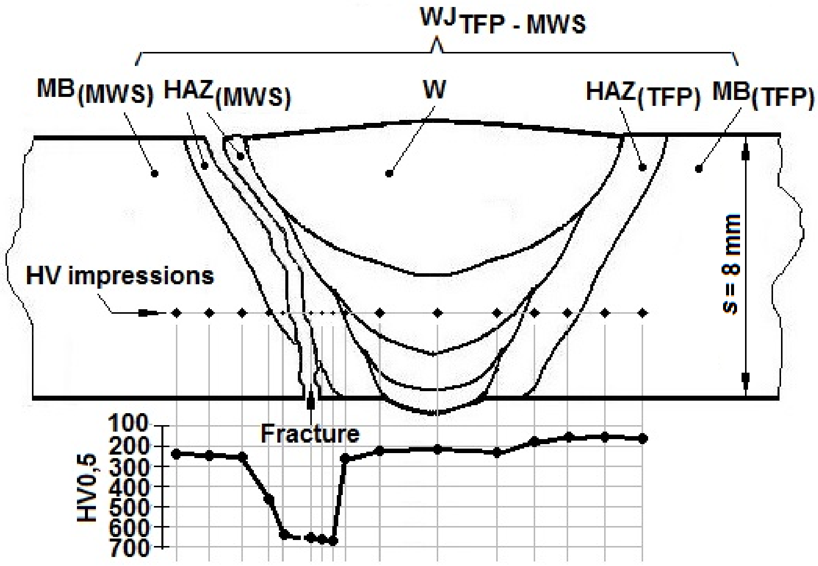

Fig. 5. The results of hardness measurements in specific areas of welded joint $WJ_{TFP-MWS}$

Table 2. The results of mechanical tests performed on samples taken from TFP and MWS

Results of tensile testing					
	Specimen marking	Tensile strength R_m, MPa	Yield strength $R_{t0.5}$, MPa	$R_{t0.5} / R_m$	Elongation A, %
FTP	T1 – FTP	487	360	0.74	25.5
	T2 – FTP	485	367	0.76	23.8
MWS	T1 – MWS	817	655	0.80	21.5
	T2 – MWS	810	649	0.80	-

Results of impact testing					
	Specimen marking	Impact energy, J			
		$KV_{R,i}$	KV_R	KV_i	KV
FTP	K1 – FTP	23.1	22.1	30.8	29.4 > 27
	K2 – FTP	22.0		29.3	
	K3 – FTP	21.1		28.1	
MWS	K1 – MWS	102.3	99.6	136.4	132.8 >> 27
	K2 – MWS	96.2		128.3	
	K3 – MWS	100.2		133.6	

The microstructure examination and the hardness measurements, performed on samples made of pipe strips, taken from areas welded joints $WJ_{TFP-FTS}$, $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$, together with the results of the chemical composition determinations (see Table 1), have revealed the following issues: a) Hammer Union fittings components are made of steel for hardening and tempering treatment ($\% C \geq 0.25$), which ensures the durability and safety in use, prescribed for temporary flowlines; b) in most cases, if the components for the connections of the Hammer Union are joined by welding with TFP or TFE elements, TFS and MWS are used with mass concentration of carbon $\% C = 0.25 ... 0.30$; obtaining MWS and TFS from steel with higher carbon concentrations ($\% C = 0.35 ... 0.40$) is probably only indicated when these components are assembled with TFP or TFE by threaded joint; in the case study performed, 3 of the 4 components of MWS and TFS examined complied with these rules (FTS, FTS_E and MWS_E were made of steel with $\%C = 0.27...0.29 < 0.3$ – see Table 1), while the fourth, assembled with TFP through $WJ_{TFP-MWS}$, had $\% C = 0.40 >> 0.25$, and a very low weldability, which resulted in premature failure of $WJ_{TFP-MWS}$; c) low weldability of MWS had to be compensated by using preheating at welding, a judicious choice of welding regime and linear energy *EL*, and applying an adequate post welding heat treatment; d) as it can be seen by examining the diagrams in Figure 6, obtained from hardness measurements performed on welded joints $WJ_{TFP-FTS}$, $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$, the right choice (% C = 0.25 ... 0.30) of MWS and FTS components used to make temporary flowlines elements, together with the use of proper welding technologies (with preheating and post welding heat treatment), can lead to proper welded joints without high peaks of hardness values in the HAZ and with good toughness; this hypothesis can be verified and confirmed, as it is shown in Figure 6, through the determination of hardness on strip type samples, taken from areas of welded joints $WJ_{TFP-FTS}$, $WJ_{TFE-MWS}$ and $WJ_{TFE-FTS}$, which were subjected, in laboratory, to a heat treatment – HT (for annealing, tempering and stress relieving) with heating temperature t_i = 600...680 °C, holding time τ_m = 0.5 hours and cooling in air [4].

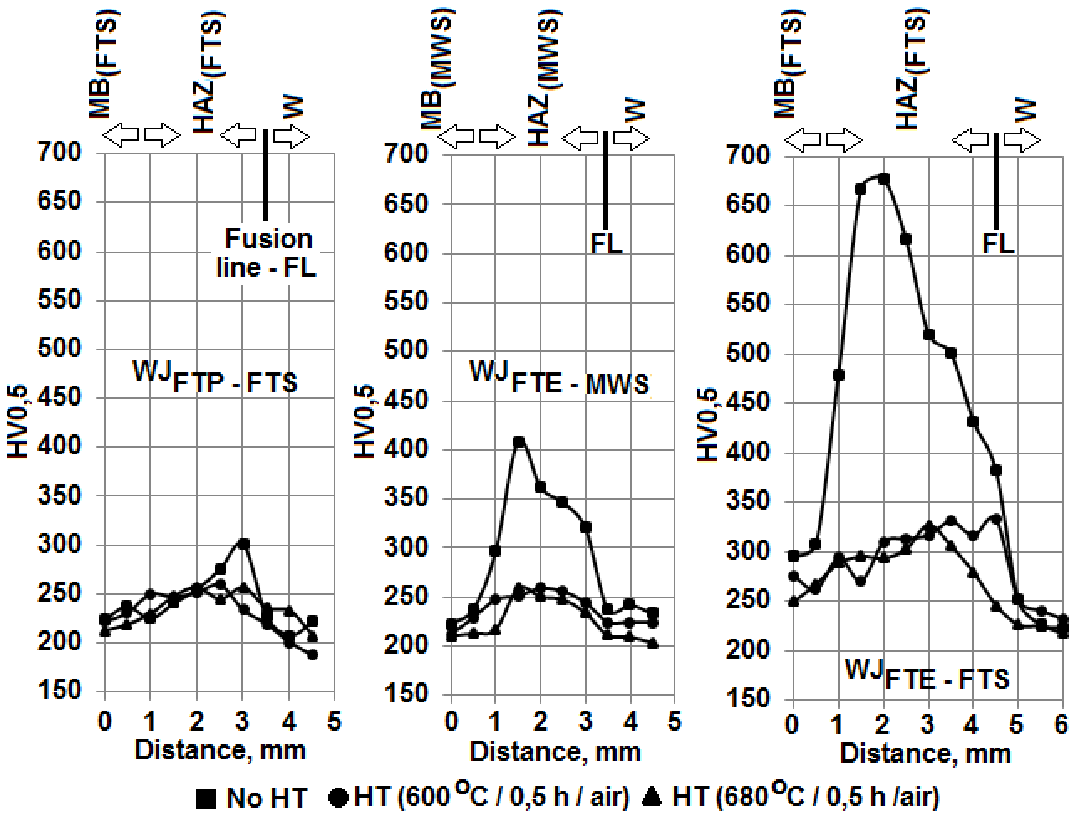

Fig. 6. The result of hardness testing in characteristic areas of welded joint WJT_{FP-FTS}; WJT_{FE-MWS} and WJT_{FE-FTS}, with and without post welding heat treatment

The results of experimental researches for the analyzed case study, revealed that one of the main causes of failure in service of the butt welded joints, between MWS and FTS components of rapid interconnection fittings and of the TFP and FTS type components of temporary flowlines, consists of obtaining improper structures in these joints with high hardness and pronounced brittleness in HAZ, from MWS and FTS components. The case study cannot be completed without mentioning that another major cause of failure for these welded joints is the incorrect assembly and disassembly (repeated) of temporary piping (by tightening and loosening of threaded joints between FTS and WDN components) consisting of dynamic (by hitting, with shock) and uncontrolled (as intensity and orientation) application of forces conducting necessary tightening or loosening torque of threated joints between FTS and WDN, which causes overload of these welded joints on circumferential direction and supplementary load on axial direction, at bending and/or tensile. Applying technical solutions summarized in Figure 7 may increase security of operation and durability of temporary flowlines [5,6].

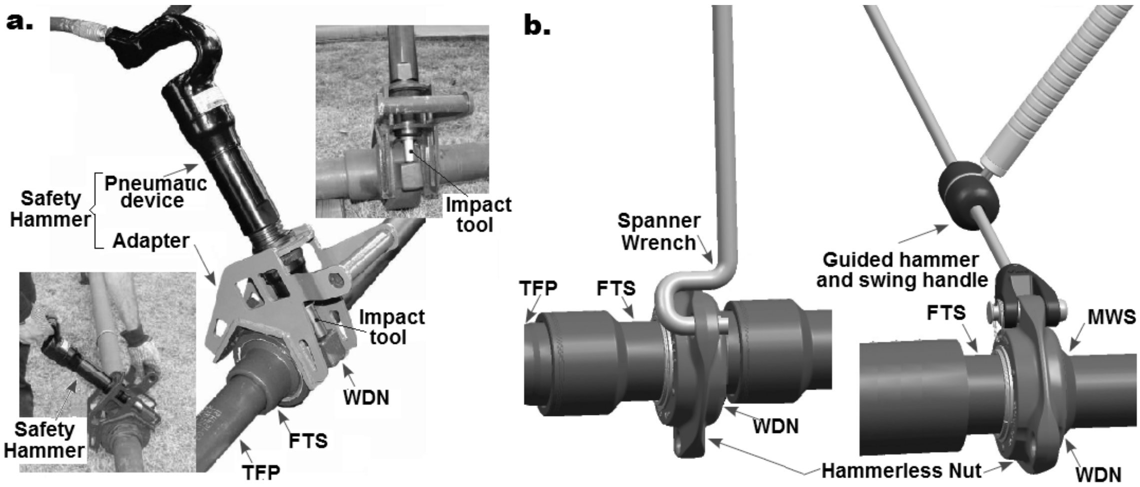

Fig. 7. Solutions to increase operational safety and durability for temporary flowlines:
a. using existing WDN and Safety Hammer drive equipment type;
b. using new design solutions for WDN and controlled clamping devices

Conclusions

The aspects presented in this paper led to the following conclusions regarding the durability increase for temporary flowlines components, in general, of welded butt joints between elements of Union Hammer rapid connections fittings and pipes or elbows used in these pipelines, in particular:

- MWS and FTS type components, which combine, through butt weld, with components like pipe or elbow from temporary flowlines must, simultaneously, fulfill two conditions: a) ensure a higher durability of the sealing surfaces and threaded areas, which implies using low and medium alloy steels (hardening and tempering steel with %C $\geq$ 0.25), b) provide a good weldability, so that welded joints grant good and convenient characteristic of mechanical strength and toughness, which involves their manufacturing from steels with low carbon content (%C $<$ 0.2) and the alloying elements (Cr, Mo etc.).

- Satisfying the two necessary conditions imposes the adoption of compromise technical solutions: a) the use (as currently practiced) of hardening and tempering steels (with %C $\geq$ 0.25, alloyed with 1% Cr and 0.2 ... 0.3% Mo), which ensure that the first requirement is respected and the use of appropriate welding technologies compensate for the lack of weldability of these steels, consisting of choosing a suitable welding process and procedure, the use of preheating and post welding heat treatment; b) the use of steels (carbon steel or micro-alloyed, with fine grain and high strength) which has good weldability and local hardening, through appropriate technological procedures (superficial heat treatment, plating, etc.) of sealing surfaces and threads.

- Controlled operation, using equipment of the type presented in this paper for temporary flowlines components, to avoid their overload and / or additional loading (tensile, bending, etc.) during repeated assembly and disassembly.

- The use of proactive maintenance systems for existing temporary flowlines components, which includes periodic verification for cracks in the HAZ of welded joints and restoration of joints where such defects are detected. The hardness (on existing components) in the HAZ of welded joints can also be controlled and, where hardness values are greater than 350 HV, one can make the decision to apply local heat treatment, as described in this paper.

Acknowledgements

This study was performed using equipment (Laboratory spectrometer with optical emission FOUNDRY-MASTER PRO / OXFORD Instruments, Micro-hardness testers DURASCAN 20 / EMCOTEST, Static and dynamic universal testing machine Walter Bai LF300 and Charpy pendulum impact testing machines Walter Bai 450) acquired within the project "**Regional centre for the determination of the characteristics and monitoring of the technical state of OCTG – oil country tubular goods – CRDPMTP**", co-financed by the **European Regional Development Fund**, on the basis of a financing contract from **European funds**, **POSCCE-A2-O2.2.1-2009-4.**

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Posibilități de obținere a unei durabilități adecvate pentru îmbinările sudate cap la cap ale conductelor temporare

Rezumat

Lucrarea prezintă principalele soluții tehnice evidențiate de autori privind îmbunătățirea durabilității îmbinărilor sudate cap la cap dintre componentele de bază, de tipul țevilor sau coturilor, ale conductelor temporare (de joasă, medie sau înaltă presiune) şi componentele racordurilor de cuplare rapidă, de tipul Hammer Union, amplasate la capetele componentelor de bază. Soluțiile prezentate au rezultat în urma efectuării unui amplu program de cercetare experimentală, destinat depistării cauzelor cedării unei astfel de îmbinări sudate, de pe una din țevile care alcătuiesc conducta temporară utilizată într-o instalație de fisurare hidraulică a sondelor de petrol şi gaze.