EXPERIMENTAL RESEARCH REGARDING THE BUTT WELDING APPLIED TO THE COILED TUBING THROUGH THE WIG (WOLFRAM INERT GAS) WELDING PROCEDURE

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1 INTRODUCTION

The coiled tubing (a type of oilfield tubular material as a pipe whose length exceeds 4,000 m and a wound on a handling drum) is subject to several complex dynamic and static loadings being generated: either by loads (forces or moments) resulting from various external sources of influence or by existing strains either imposed or prevented.
In addition to those above, the said loadings influencing the condition of the coiled tubing do not depend on the depth accommodating such equipment as the respective loadings occur in any case.
The main kind of damage specific to the coiled tubing is fatigue fracture in those areas where the stress concentration effect is present (defects caused by the manufacture technology or inadequate use conditions). The fatigue fracture of the coiled tubing is preceded by a distention of the pipe (the handling equipment shows an on-line distention of the tubular material). The standards specify that avoiding the loss of the coiled tubing into the hole in case of a distention ranging between 4 and 5 % requires: the damaged segment of coiled tubing to be blocked and removed by cutting (the assembly of blowout preventers being used for such a purpose); the segments being still operational to be butt welded [6].
Taking into account the above-described circumstances, this paper presents the authors's experimental research developed under laboratory conditions and related to the WIG butt welding procedure (WIG – Wolfram Inert Gas) applied to a number of A and QT 700 (X 70) pieces of coiled tubing (QT – Quality Tubing; 700 = 70,000 psi = 482.58 N/mm^2 as yield strength), a permanent metal support of the root being present or not. The same paper also presents the results of the non-destructive tests (penetrating radiation testing) and the destructive ones (tensile tests, flattening tests, hardness tests and microscopic examination) having been applied to this type of oilfield tubular material. The determinations rely upon segments taken from tubing pieces of real dimensions.

2 EXPERIMENTAL RESEARCH REGARDING THE BUTT WELDING TECHNOLOGY APPLIED TO THE COILED TUBING THROUGH THE WIG WELDING PROCEDURE

Sixteen segment-type specimens (see Table 3) are obtained by means of the WIG welding procedure (a manual welding procedure involving the use of non-fusible electrodes and the blast of the inert gas in the space of the electric arc. The supply is feasible both under AC conditions and DC conditions. The above specified procedure is applied to several pieces of coiled tubing characterized by the outer diameter D = 31.75 mm, the wall thickness a = 3.17 mm and manufacture materials (A and X 70 steels, whose chemical composition and mechanical properties are similar).
See Table 1 and Table 2 for the chemical composition and the mechanical properties of the A and X 70 steels as manufacture materials of the coiled tubing used as above.

Table 1 - The chemical composition of the A and X 70 steels

Steel Symbol*	C	Mn	P	S	Si	Cr	Cu	Ni	Mo
	[%]								
A	0.09 - 0.16	0.40 - 0.80	0.04 max. value	0.045 max. value	0.17 - 0.37	-			

X 70**	0.10 - 0.14	0.70 - 0.90	0.025 max. value	0.005 max. value	0.30 - 0.50	0.50-0.70	0.25 max. value	0.20 max. value	0.21 max. value

** According to API classification for line pipe materials [1].*
*** Pipe for coiled tubing QT 700: QT = Quality Tubing;*
700 = 70,000 psi = 482.58 N/mm^2 – specified minimum yield strength [2]

Table 2 - The mechanical composition of the A and X 70 steels.

Steel Symbol	Min. Yield Strength [N/mm^2]	Min. Tensile Strength, [N/mm^2]	Elongation [%]
A	230	340	26
X 70	482.58	551.51	30

Table 3 - Types of grooves utilized in case of the WIG welding procedure applied to the coiled tubing

Steels	Total Number of Specimens	Number of Specimens		
		"X" – Type Groove wo. Permanent Metal Support	"U" – Type Groove wo. Permanent Metal Support	"U" – Type Groove w. Permanent Metal Support
A	10	3	3	4
X 70	7	2	3	2

Sheets of blotting paper are located at about 300 mm from the ends to stop the water flow into the tubing. All bits generated by the mechanical cutting operation are simply removed if they make use of some chisels. After the removal of the bits, the tubing edges are filled away and then fitted through a turning device. The tubing ends are polished by means of some textile abrasive disks, the polishing operation being applied onto an approximate distance of 50 mm on the outer surface and an approximate distance of 25 mm on the inner one. The tubing edges are machined in compliance with two concurrent directions (because the wall thickness of the tubing pieces is relatively reduced) and "X" and "U" grooves (2 mm opening) required by the need of a root necessary of the welding seam are obtained. After being degreased with alcohol, the surfaces of the grooves must be dried. The selection of the filler metals is based on their compatibility with the base metal, both from the point of view of the chemical composition and that of the mechanical properties.
See Table 4 for the filler metals used in case of the WIG welding procedure applied to the A and X 70 coiled tubing pieces [3].

Table 4 - Filler metals used in case of the WIG welding procedure applied to the A and X 70 coiled tubing pieces

Filler Metal (Electrode)	Protective Gas	Tensile Strength	Unit Loading	Min. Elongation	Impact Energy ("V" - Notch Specimens)
	-	[N/mm^2]	[N/mm^2]	[%]	[J]
ER 70 S-3	Ar or 75 % Ar + 25 % He	410	497	22	27 (at - 18^0 C)
ER 70 S-6		410	497	22	27 (at - 29^0 C)

The welding procedure is specially selected to ensure welding joints being as good as possible, from the point of view of the macrostructure, the microstructure and the mechanical properties.
In case of the WIG welding procedure applied without metal support of the seam, the ends of the tubing pieces are axially aligned; maintaining a constant opening of the groove during the whole welding time interval requires an electrode to be put between the tubing ends; the electrode diameter (d_e) corresponds to the opening (2 mm) of the groove.
The electrode is held between the ends of the coiled tubing pieces, until a circular arc gets welded; after that operation, the electrode must be retrieved to permit the complete welding to be achieved.
Before the welding step the coolers must be positioned (if the coolers are not used, the thermally-influenced zone will get hardened excessively and a premature fracture will occur) on both sides of the tubing pieces to be welded. In case of groove root welding, the coolers are located at 7 mm from the margin of the tubing pieces and then displaced towards the base metal, the weld seam being so feasible.
The specifications of the welding procedure are the spray arc welding, the electrode being pendulated under small-amplitude conditions and the welding current of 52 A (the abrasive cleaning and the increase of the melting rate were favoured; very fine drops of melted metal; great penetration depth).
In case of the WIG welding procedure involving a metal support of the seam, after the axial alignment of the ends of the coiled tubing pieces, a fusible ring is placed at he root of the "U"

groove (the material of the fusible ring and of the coiled tubing to be welded is the same and the pitch diameter of the said ring is equal to the inner diameter of the tube).
See Fig. 1 for the type and the dimensions of the fusible ring and Fig. 2 for the installation of the fusible ring in the "U" groove.
After the cooler installation (as shown for the preceding case), the welding conditions are the spray arc welding, no pendulary motion of the electrode and the welding current of 52 A.
The inner face of the joint becomes approximately even and has no defects; the ring is "sucked" by the groove.
Obtaining an even surface having no cracks requires the coolers to be removed and the seam to be smoothed and then burnished, natural textile fiber disks being used for such a purpose.

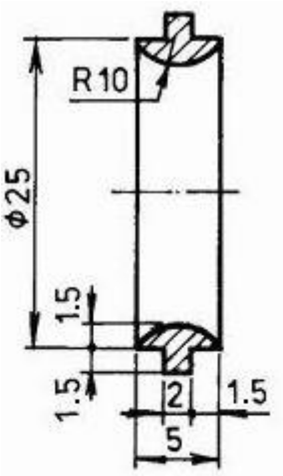

Fig. 1 - The shape and the dimensions of the fusible ring

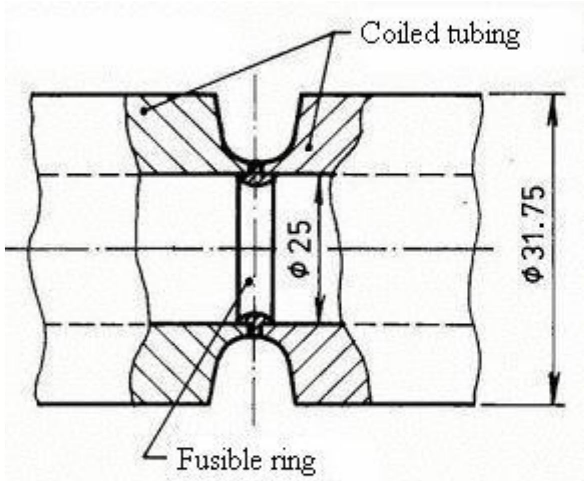

Fig. 2 - How to install the fusible ring in the "U" joint

3 NON-DESTRUCTIVE AND DESTRUCTIVE TESTS APPLIED TO THE COILED TUBING PIECES BUTT WELDED THROUGH THE WIG WELDING PROCEDURE

If no defects exist in conjunction with the welded joints, the integrity of the said joints will be so proved and confirmed incontestably as any defect is known to be dangerous regarding the use performances of the equipment [4,5]. Given the above-specified circumstances, checking the quality of the welded joints requires all section-type specimens (see Table 3) to be subject to non-destructive tests (penetrating radiation testing) as well as destructive tests (tensile / flattening / hardness tests and microscopic estimation). The welded joints having been studied within this research activity do no show any type of defects or flaws.
The tensile tests are performed through a specialized machine, permitting the materials to be statically tested (series 2344/57/18, measurement range 0…30,000 daN and max. travel of 600 mm)
The section-type specimens (see Fig. 3) have been loaded progressively and continually until their fracture.
See Table 5 for the results having been obtained after the tensile tests applied to seven section-type specimens.
The tensile behaviour of the section-type specimens is not influenced by the types of grooves having been utilized ("X", "U" and "U" plus a permanent metal support) and the steel brand used as manufacture material of the section-type specimens of coiled tubing (only 5 % as a max. difference).
The "U" type is recommended to be utilized.
The A section-type specimens get broken in the area of the base metal and the X 70 ones fail in the thermally-influenced zone for values of the tensile strength being approximately equal to those of the unwelded coiled tubing pieces (5 % as a max. difference).

Everything above shows that the welding technologies having been used are adequate and do not influence the tensile behaviour of the welded coiled tubing pieces.
See Fig. 4 for the section-type specimens of coiled tubing after their tensile test.

Table 5 - The results of the tensile test

Steel	Groove Type	Max. Ultimate Strength, F_{max} [daN]	Tensile Strength, R_m [daN/mm^2]	Fracture Location
A	"X"	12,700	44.60	MB
	"U"	12,750	44.82	MB
	"U" – Type groove with a permanent metal support	12,750	44.82	MB
	"U" – Type groove with a permanent metal support	12,750	44.82	MB
X 70	"X"	11,800	41.48	ZIT
	"U"	11,900	44.83	ZIT
	"U" – Type groove with a permanent metal support	11,700	41.10	ZIT

The flattening test of the butt-welded joints afferent to the coiled tubing specimens consists in compressing them between two pressing plates being plane or parallel.
The compression axis is perpendicular to the geneatrix of the tubes, the results of that compression being either a distance H measured under load conditions or a complete flattening (see Fig. 5).
The flattening test uses the same machine as for the static and tensile materials.
The plastic deformation of the section-type specimens is initiated for a compressive force ranging between 5,000 and 5,500 daN.
The macroscopic examination of the flattening-tested specimens (see Fig. 6) does not show any cracks or fractures, even when the specimens are completely flattened, the areas corresponding to the seam or the base metal being free of such defects. As a conclusion, they can say that the metal materials afferent to the manufacture of the coiled tubing and its welded joints behave adequately under compressive load conditions.

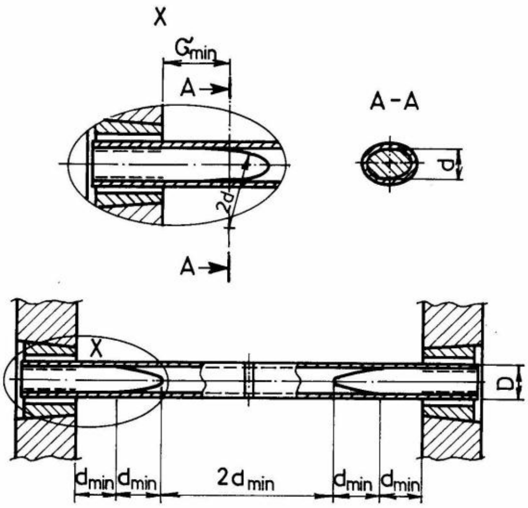

Fig. 3 - The types and the dimensions of the tensile-section specimen

Fig. 4 - Section-type specimens (welded coiled tubing) after the tensile test

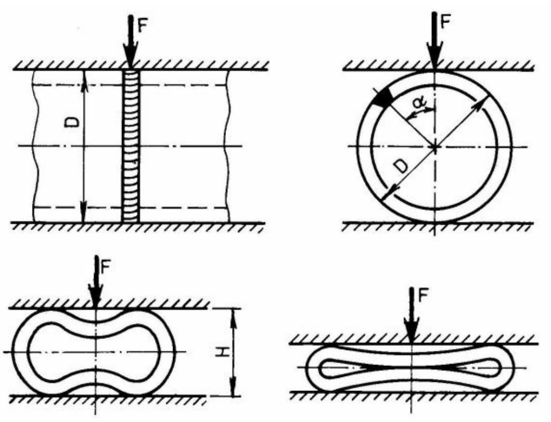

Fig. 5 - The flattening test of the section-type specimens of welded coiled tubing. The principle of the method

See Table 6 for the types and the dimensions of the section-type specimens of welded coiled tubing.

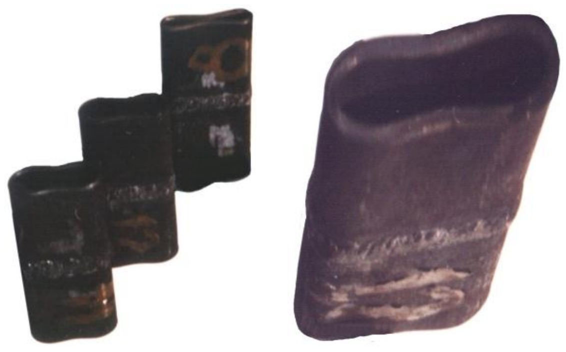

Fig. 6 - Flattened section-type specimen

Table 6 - The types and the dimensions of the section-type specimens of the welded coiled tubing, utilized for the application of the flattening test

<table>
<tr><td rowspan="2">Types and Dimensions</td><td colspan="6">Steels</td></tr>
<tr><td colspan="3">A</td><td colspan="3">X 70</td></tr>
<tr><td>Groove Type</td><td>“X”</td><td>“U”</td><td>“U” – Type with a permanent metal support</td><td>“X”</td><td>“U”</td><td>“U” – Type with a permanent metal support</td></tr>
<tr><td>Diameter [mm]</td><td colspan="3">31.75</td><td colspan="3">31.75</td></tr>
<tr><td>Wall Thickness [mm]</td><td colspan="3">3.17</td><td colspan="3">3.17</td></tr>
<tr><td>Length [mm]</td><td colspan="3">100</td><td colspan="3">100</td></tr>
</table>

Table 7 - The experimental results of the hardness tests applied to the welded joints of the coiled tubing

<table>
<tr><td rowspan="2">Steels</td><td rowspan="2">Groove Type</td><td colspan="3">Hardness HV_{10}</td></tr>
<tr><td>Base Material</td><td>Thermally - Influenced Area</td><td>The joint</td></tr>
<tr><td rowspan="3">A</td><td>“X”</td><td>148.3-146
146-146</td><td>165-167-161
167-165-161</td><td>175-178</td></tr>
<tr><td>“X”</td><td>149.5-148.3
147.2-147.2</td><td>172-169-167
175-169-165</td><td>185-183</td></tr>
<tr><td>“U”</td><td>148.3-147.2
147.2-146</td><td>175-171-168
175-169-167</td><td>187-185</td></tr>
<tr><td>X 70</td><td>“U”</td><td>182-180
180-180</td><td>195-192-190
197-195-192</td><td>227-227-221</td></tr>
</table>

The hardness test is performed by means of a Vickers apparatus (series 308; measurement range: 30 kgf, 10 kgf and 5 kgf). A load of 10 kgf is applied. Preparing the specimens for the hardness test of the welded joints requires sections of A and X 70 specimens of coiled tubing (D = 31.75 mm; a = 3.17 mm) to be taken along an axis perpendicular to the “X” – welded joint by means of a mechanical device for cutting. The mechanical cutting as well as the operations following it (surface dressing and attack by making use of reagents) affects the specimen face to be tested if the problem is metalurgically taken into consideration. The specimen wall thickness being less than 4 mm, the test is performed as mark rows along the median line of the face to be tested in, the area of the base metal, the area of the seam and the thermally-influenced area.
See Table 7 for the experimental values afferent to the hardness test. The hardness values for the X 70 specimens are greater than those specific to the A specimens, the approximate difference ranging between 13 and 20 %, indifferently from the point of view of the mark area.

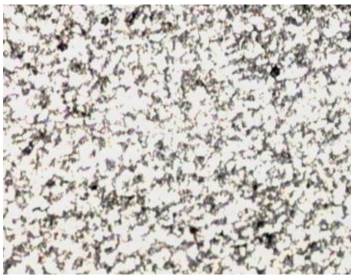

Fig. 7 - The crystalline structure of the seam in case of coiled tubing samples

The microscopic examination is applied to samples taken from section-type specimens of A and X 70 coiled tubing to see the crystalline structures in case of the base metal, the thermally influenced zone and the seam.

The welded pieces taken from the section-type specimens of A and X 70 coiled tubing show similar structures. Their structures are a crystalline structure of ferrite and pearlite, which is uniform – in case of the seam and fine – in the thermally-influenced area and oriented crystals of ferrite and pearlite under normal granulation conditions – in the area of the base metal (Fig. 7).

4 CONCLUSIONS

The standards regarding the use of the systems handling coiled tubing recommend the removal of the coiled tubing segments having been damaged during the working process, which are to be cut through the system of blowout preventers.

The segments of coiled tubing still operational must be butt-welded under field conditions. As a result of the research having been developed, the authors recommends the performance of the butt-welding in case of A and X 70 coiled tubing to be achieved through the WIG welding procedure (WIG – Wolfram Inert Gas) applied either with or without a metal support of the "U" – type groove root.

SUMMARY

This paper describes the results of the authors's experimental research regarding the WIG butt-welding procedure (WIG – Wolfram Inert Gas) applied to a number of A and QT 700 (X 70) specimens of coiled tubing under laboratory conditions (QT = Quality Tubing; 700 = 70,000 psi = 482.58 N/mm^2 as their yield strength), the two possible options (presence or absence of a permanent metal support of the root) being equally taken into account and the results of the non-destructive tests (penetrating radiation testing) as well as those of the destructive ones (tensile / flattening / hardness tests and microscopic examination) applied to the coiled tubing in its position of oilfield tubular materials.

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