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Experimental Research on Welding Technology of X80 API 5L Steel Pipes

Vlad Ulmanu*, Florentina Mateescu**

* Universitatea Petrol-Gaze din Ploieşti, Bd. Bucuresti, 39, Ploiesti
e-mail:vulmanu@upg-ploiesti.ro
** S.C.COIFER IMPEX S.R.L. Bucuresti
e-mail:florentina.mateescu@coifer.ro

Abstract

As the world's energy demands continue to grow and new sources of fuel are sought, it's no surprise that contracting companies have begun to expand the use of stronger, more cost-effective materials to build longer and more pipelines – both onshore and offshore. Instead of X70 steel pipe, the standard in past years, material like X80 steel grade has become an increasingly common choice. This trend is especially prominent thus far in North America, China, Russia (K60 and K65) and EU (L485 MB and L555 MB) with other areas of the world following closely behind. This investigation presents an experimental research methodology for optimal choice of filler material and welding parameters of Ø 172 x 17.5 mm pipe API 5L-X80 material. The aim of the research was to optimize welding parameters for three types of electrodes for manual metal arc welding (metal-arc welding with covered electrode, 111 as per EN 15609), and two types of solid wire for metal active gas welding, MAG, 135 as per EN 15609.

Key words: *steel pipe,electrodes, welding wire,welding technology*

Materials

The base material used in this experimental research was API 5L - X80. This material have also a correspondence in the European Norms, EN 10208-2:2009, see Table.1

Table1. Standards comparison

Purpose	EN		API 5L	ASTM
	Standard	**Steel Quality**	**Steel Quality**	
Steel pipe for pipelines for combustible fluids	**10208-2: 2009**	L290 NB L360 NB L415 NB **NORMALISED**	Grade X 42 Grade X 52 Grade X 60	A 106 A 106
		L290 MB L360 MB L415 MB L485 MB L555 MB **HOT ROLLED**	Grade X 42 Grade X 52 Grade X 60 Grade X 70 Grade X 80	A 106

The research was conducted on the Ø 172 x 17.5 mm pipe API 5L - X80 material with the following chemical and mechanical properties:

Table 2.Chemical composition of the pipe materials

Steel	Material	C	Si	Mn	P	S	Cech.
X80	Pipe	0.06	0.25	1.85	0.008	0.002	0.42

Table 3. Mechanical properties of the pipe materials

Steel	Material	Mechanical properties on longitudinal direction			
		Yield Strength (MPa)	Tensile strength (MPa)	Elongation (%)	Impact Toughness 0ºC (J)
X80	Pipe	628	713	29,6	172

The welding technology was studied using the following categories of filler metal:

Two types of ESAB welding wire:
- Note S -A - OK Autrod 13.12 wire - DIN 8575 - SG CrMo1 / AWS A5.28 - ER80S-G
- Note S - B - OK Autrod 13.13 wire AWS A5.28 - ER100S-G

Three types of ESAB welding electrodes:
- Note E - A - OK 76.98 electrode - EN 1599 - E Cr Mo 91 B / AWS A5.5 - E9015-B9
- Note E - B - OK 78.16 electrode - AWS A5.5 - E9018-G
- Note E - C - OK 75.75 electrode - EN 757 - E 69 4 Mn 2 NiCrMoB 32 H5 / AWS A5.5 - E11018-G

The chemical composition of filler metal is given in Table 4.

Table 4. Chemical composition of the filler metal, (%)

Type FM	Note	Diameter (mm)	C	Si	Mn	P	S	Cu	Cr	Ni	Mo
Wire	S-A	0.8	0.1	0.7	1.0	0.014	0.008	-	1.1	-	0.5
		1.2	0.15	0.7	0.9	0.012	0.008	-	1.0	-	0.5
	S-B	0.8	0.1	0.7	1.4	0.008	0.002	-	0.6	0.6	0.2
		1.2	0.1	0.7	1.4	0.008	0.002	-	0.6	0.6	0.2
Electrodes	E-A	4.0	0.1	0.35	0.8	0.006	0.006	-	9.0	0.7	1.0
	E-B		0.18	0.4	0.8	0.010	0.002	-	1.0	-	0.2
	E-C		0.055	0.35	1.75	0.014	0.008	-	0.45	2.25	0.45

Welding parameters were tested for metal active gas welding process, 135, and metal-arc welding with covered electrode, 111, butt joint BW, Ø 172 x 17.5 mm pipe API 5L - X80 steel material.

All weldings were made without pipe rotation, in the following manner:
135 semi-automatic welding was performed with a Selco installation, without preheating (outside temperature was about 24 ° C). 135 welding parameters were established after testing nine welded test pieces.
111 welding parameters were established after testing six welded test pieces.

Welding Technology

Technological problems in API 5L-X80 material welding

Due to its high yield strength, the addition of various alloys (manganese, copper, molybdenum and nickel among other) and a relatively low carbon content, X80 steel has an inherent susceptibility to hydrogen-induced cracking when welded. The pipelines made from these materials are almost always subject to extreme environmental conditions – to temperatures as low as -50 degrees Celsius.

X80 steel pipe is more difficult to weld than lower strength materials. Welding procedure variables such as pre-heat and interpass temperatures, along with the overall welding parameters (amperage, voltage, etc.), are much more stringent and must be very carefully controled. Finally, the filler metals used to weld X80 steel must meet the base material's strength requirements, provide the ductility to resist cracking and compensate for the extreme temperatures to which these pipelines are subject.

Experimental research on the development of welding technology in metal active gas welding procedure, 135, and metal-arc welding with covered electrode procedure, 111

Different combinations of welding process parameters were obtained by varying the heat input of welding, the geometry of the joint, the number of passes and the size of filler metal.

The conditions for metal active gas welding procedure, 135, and metal-arc welding with covered electrode, 111, are shown in Tables 5 and 6.

Table 5. Welding conditions for procedure 135

Welding Process	Heat input (kJ/mm)	Joint's preparation schema	Pass number	Filler metal MA	Size of filler metal(mm)
135	0.9	V – 20º	6	S-A ER80S-G	0.8
				S-B ER100S-G	
	1.0	V - 40º	7	S-A ER80S-G	1.2
				S-B ER100S-G	
	1.2	V - 40º	6	S-A ER80S-G	
				S-B ER100S-G	
	1.4	V - 40º	5	S-A ER80S-G	
		V - 60º	7	S-A ER80S-G	
	1.5	V - 60º	6	S-A ER80S-G	
				S-B ER100S-G	
	2.0	V - 60º	6	S-A ER80S-G	

Table 6. Welding conditions for procedure 111

Welding Process	Filler metal, Electrod	Heat input (kJ/mm)	Joint's preparation schema	Pass number
111	E – A E9015-B9	1.4	V - 60º	7
		3.8	V - 60º	4
	E-B E9018-G	1.4	V - 60º	9
		4.3	V - 60º	3
	E-C E11018-G	0.8	V - 60º	14
		3.8	V - 60º	5

Research regarding the mechanical properties of the welds by applying nondestructive and destructive tests

The nondestructive quality control of the welds was performed based on the visual test, VT, penetrant liquid inspection, PT and penetrant radiation test, RT. The destructive quality control of the welds was performed based on the determination of the mechanical characteristics of welds by destructive testings.

Nondestructive tests, NDT

Visual inspection, VT, has been done according to SR EN 970, with interpretation as "B" class of ISO 5817 standard.

Liquid dye penetrant inspection check has been made according to SR EN 571-1, with interpretation as "B" class of ISO 5817 standard.

Penetrating radiation test, RT, has been done according to SR EN 1435, with interpretation as " B "class of ISO 5817 standard.

Destructive tests

Location of samples for destructive control

The location of samples was selected in accordance with SR EN 15614-1 and Figure 1.

Area 1 is for:
- 1 tensile test specimen;
- bend test specimens.

Area 2 is for:
- impact and additional test specimens if required.

Area 3 is for:
- 1 tensile test specimen;
- bend test specimens.

Area 4 is for:
- 1 macro test specimen;
- 1 hardness test specimen.

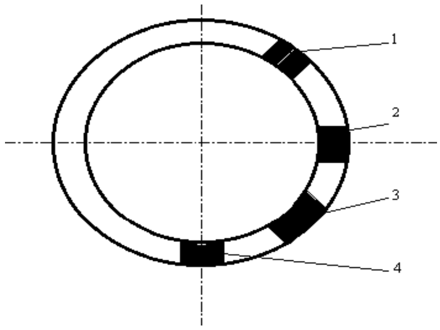


Fig. 1. Location of test specimens for a pipe butt joint

Mechanical tests

Mechanical tests have been performed as follows:
- Impact test in accordance with SR EN 875;
- Transverse tensile test in accordance with SR EN 895;
- Bend test in accordance with SR EN 910.

Welds made by the procedure 135, metal active gas welding

Transverse tensile test

All specimens were broken in the base material.

Figure 2 and 3 show the heat input effects on yield strength and the ultimate strength of the weld.

It is observed that both yield strength and tensile strength decrease with the increase of heat input, but all measured values have higher values than the limit of the base material (yield strength = 552 ÷ 650 MPa; tensile strength = min.650 MPa).

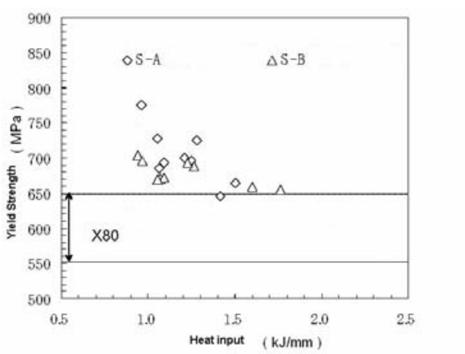


Fig.2. The relationship between yield strength and heat input

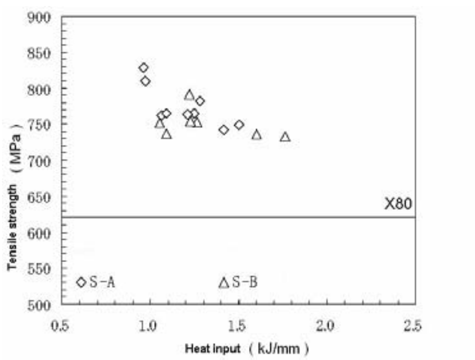


Fig.3. The relationship between tensile strength and heat input

Charpy impact energy

Figures 4 and 5 show the Charpy impact energy, at 0 °C, in the welding and respectively in HAZ.

It may be noted that, in the HAZ, the impact energy values are much higher than those of the weld.

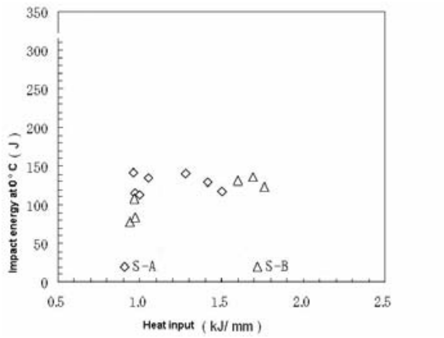


Fig.4. The relationship between Charpy impact energy of the welds, at 0 °C, and heat input

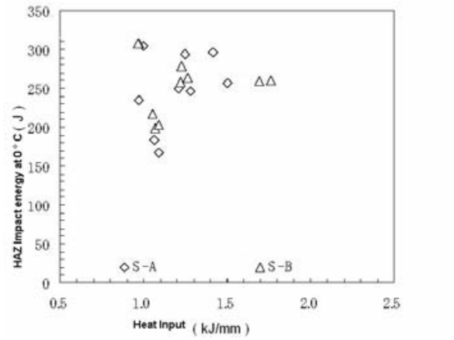


Fig.5. The relationship between HAZ Charpy impact energy, at 0 ° C, and heat input

Hardness

Figure 6 shows some hardness values for measurements made at 4 mm from the outer surface and inner surface of the pipe. The hardness of the weld (WM) was HV280. The minimum and maximum values in all samples examined were obtained.

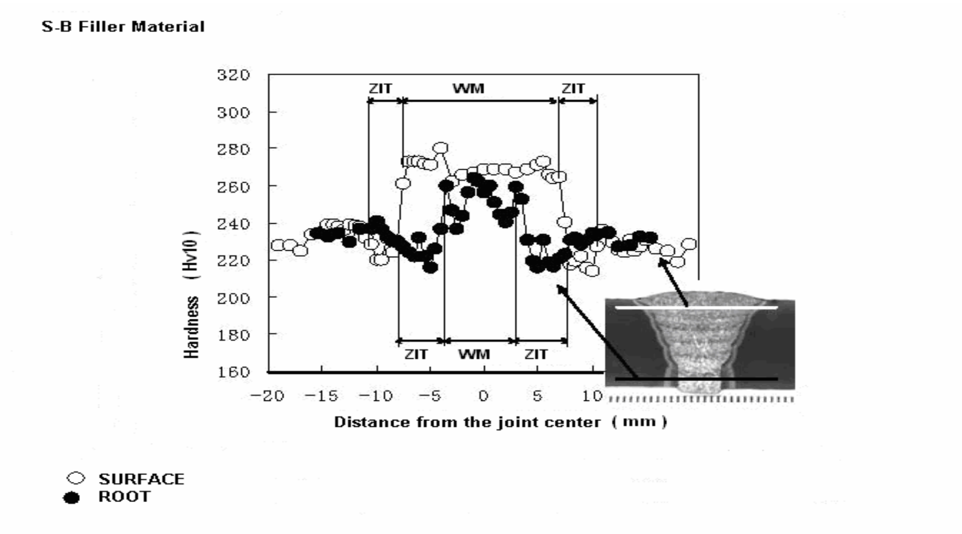


Fig 6. Hardness of weld joints

Welds produced by the procedure 111, metal-arc welding with covered electrode

Transverse tensile test

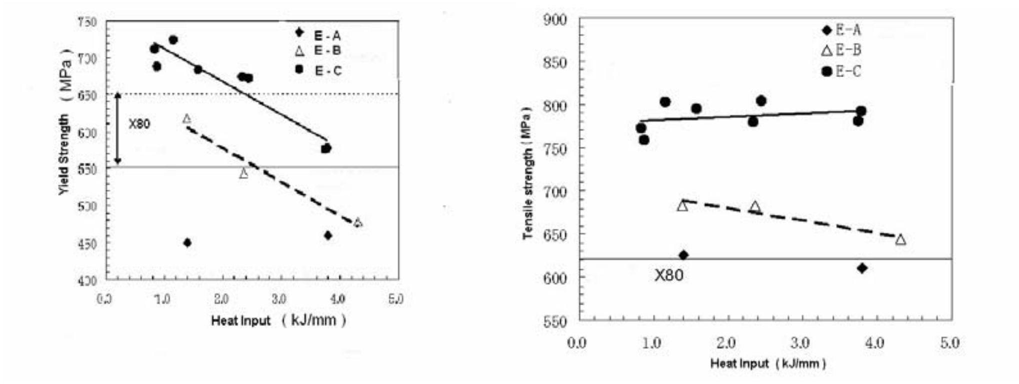
All specimens were broken in the base material.

Figures 7 indicates the effects of welding heat input on yield strength and tensile strength.

It is observed that both yield strength and tensile strength decrease with the increase of welding heat input, but no measured value is below the limit of the material yield strength equal to 552 ÷ 650 MPa; ultimate strength equal to min.650 MPa.

It may be noted that the yield strenght of the weld linearly decreases with the increase of the heat input, excepting for electrode EA - E9015-B9.

Taking into consideration the condition of obtaining a yield strenght value at least equal to the base metal’s value it is clear that the only proper electrode for welding of X80, with any welding heat input, is EC - E11018-G.



a b

Fig.7. The relationship between yield strength (a), tensile strength (b) and heat input

Charpy impact energy

Figures 8 and 9 show the effects of welding heat input on Charpy impact strenght of welded joints.

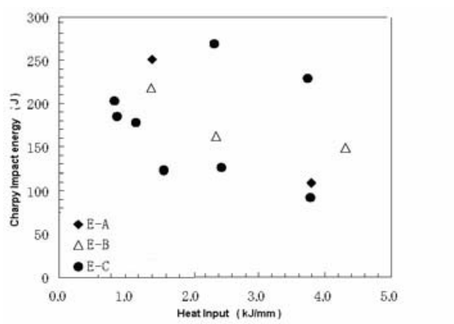


Fig.8. The relationship between weld Charpy impact energy and heat input

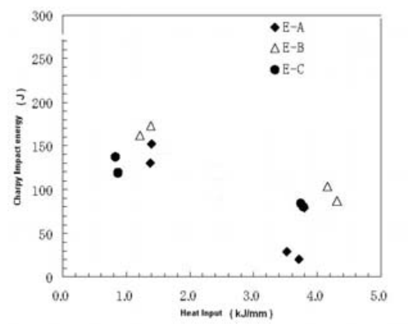


Fig.9. The relationship between HAZ Charpy impact energy and heat input

Charpy impact energy of the weld was strongly influenced by welding heat input for all the electrodes used in this study. All welding conditions ensure strong welds.

Charpy impact energy of the weld should be analyzed in parallel with the tensile strength and yield strength of the base material, X80. In this case, the tensile strength of the weld should not exceed the 827 MPa limit specified in API 5L standard for this type of base material.

When weld Charpy impact energy increase, heat input decrease for all electrodes. The tests showed relatively high values for Charpy impact energy which exceeded 50J for all cases studied (except electrode E-A at high heat input).

As noted in the foregoing, the electrode E - C provides a superior yield strength comparing with the X80 pipe material yield strength with a heat input less than 2.5kJ/mm. In addition, the E -C electrode provides good Charpy impact energy even at 3.8kJ/mm heat input. These results indicate electrode E - C as the optimal choice for X80 pipe welding.

Conclusions

1. All welding conditions have provided high values for yield strength and tensile strength of the welds for 135, metal active gas welding, procedure. Considering X80 pipe material yield strength, the values higher than 650 MPa were obtained only for low heat input, smaller than 2.5kJ/mm.
2. Transverse tensile strength of the weld decreases with the increase of heat input for all materials studied (using the 135 procedure).

3. All welding conditions for 135 procedure have provided an acceptable Charpy impact energy.
4. All samples taken from the welded joints failed in the base material, not in the HAZ or in the weld.
5. The 111 welding procedure, metal-arc welding with covered electrode, electrode EC, E11016-G class, provides tensile strength higher than 780 MPa and yield strength higher than 650 MPa with an acceptable Charpy impact energy, when welding X80 pipe material with a heat input less than 2.5kJ/mm.

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Cercetări privind tehnologia de sudare a coductelor executate din oţel de înaltă rezistenţă X80 - API 5L

Rezumat

Creşterea continuă a nevoilor energetice ale lumii moderne a dus la căutarea de noi resurse naturale şi implicit la dezvoltarea de materiale noi necesare industriei extractive şi transportului acestor materii prime. Progresele în domeniul ştiinţelor materialelor conduc anual la îmbunătăţirea proprietăţilor unor materiale, respectiv la apariţia de noi materiale cu proprietăţi adaptate pentru a satisface exigenţele specifice acestei industrii. Astfel s-a trecut la înlocuirea ţevilor din oţeluri de clasa X65, X70, API 5L cu ţevi din otel de clasa X80 si X100, oteluri cu proprietăţi fizico-mecanice mult îmbunătăţite. Această tendinţă se manifestă atât in America de Nord, China, Rusia (K60 şi K65) cât şi în Uniunea Europeana (MB L485 şi L555 MB). Lucrare de faţă prezintă metodologia de cercetare experimentală folosită pentru alegerea tehnologiei optime de sudare a ţevilor Ø 172 x 17.5 mm din material X80, API 5L. Scopul cercetării a fost de a optimiza parametrii de sudare pentru trei tipuri de electrozi, pentru sudare manuala cu arc electric cu electrod invelit, 111 conform EN 15609, şi două tipuri de sârme pline pentru sudarea cu arc electric în mediu protector de gaz activ, MAG, 135 conform EN 15609.