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Mechanical Behaviour of Narrow Gap MAG Welding of API 5L X65M Steel Pipeline

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Abstract. The paper analyzes the main mechanical characteristics of pulsed MAG welded joints obtained from API 5L X65M thermo mechanical treated steel. The results of the tensile strength measurements corroborated with those of toughness tests and metallographic investigations, highlighted the effect of structural changes in the heat affected zone (HAZ) and weld (W) area, on the mechanical behavior of the welded joints.

1. Introduction

Currently, the oil and gas transport are in a constant growth and requires the development of new underground and submarine pipeline networks. Since the costs of achieving these types of pipelines are quite high, the researchers conducted worldwide are oriented towards the following directions [1], [2], [3]:

- selection of low-alloy thermo mechanical treated steels with high mechanical strength characteristics which will allow a reduction in the thickness of the pipe wall and consequently a lower consumption of welding consumables
- implementation of high productivity welding techniques
- use of automated methods for monitoring the quality of welded joints

The matrix requirements for such properties of the steel pipe comprising:
- high mechanical strength characteristics
- good tenacity
- high resistance to fatigue and corrosion
- good metallurgical and technological welding behaviour
- a reasonable cost price

Such steels raise problems that mainly depend on the negative effect of some thermal cycles during the welding operation on the mechanical properties obtained by thermo mechanical treatment.

It is also taken into account that, in order to obtain mechanical characteristics at the base metal level, the welded seam must have an equivalent carbon, Cech. significantly higher than it [3], [4]. A particular aspect is the weakening of the welded joint as a whole due to the softening of some portions of the heat-affected zone, HAZ. The existence of such a portion in the ZIT may reduce the mechanical strength characteristics of the welded joint and this effect becomes more important when the relative width of the softened area is greater; this width is defined as the ratio of the softened portion width and the thickness of the welded element [1].

Taking into consideration the welding process features of thermo mechanically treated steels, this paper studies the performances of the mechanical strength of the joints achieved by applying a high productivity technique.

2. Experimental procedure

Pipelines with a diameter of 42 " (1066.8mm) and a thickness of 31.75mm, made of micro alloyed high-strength steel API5L X65M thermo mechanically treated steel were welded by MAG spray arc the root & hot pass and pulsed current for the fill layers of the welded joint using CRC Evans welding equipment.

The equipment used is composed by an internal welding machine, IWM, for the root pass and two external ones, P625, each one with two welding torches for the fill layers, where the pipe is fix and the welding equipment make an downward vertical orbital movement around the pipe [4].

Welding consumables selected were ER70S-G for the root pass and ER70S-6 for the fill layers.

The geometry of the selected joint is shown in Figure 1.

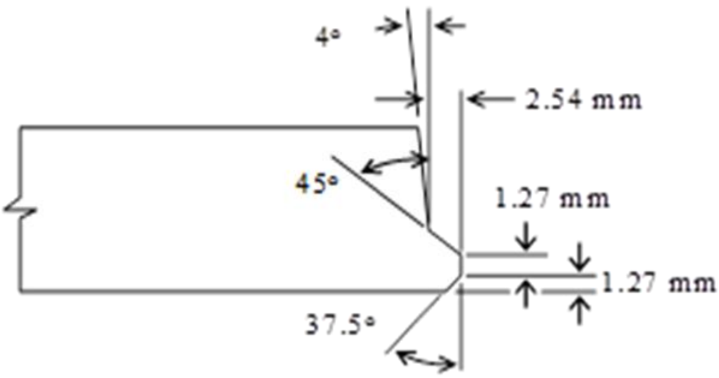


Figure 1. Joint configuration.

The optimal welding parameters of the thermal welding regime were determined experimentally and are presented in Table 1.

Table 1. Welding parameters.

Weld Layers	Current (A)	Voltage (V)	Travel Speed (cm/min)	Heat Input (KJ/cm)
Root	198	20	80	2.97
Hot	282	24.5	128	3.23
Fill	215	22	50	5.67
Cap	132	22.5	48	3.71

From the joints made, samples were taken for mechanical tests and metallographic examinations.

3. Evaluation of experimental results

3.1 Tensile strength test

The purpose of this test is to determine the strength of the welded joint and the location of the fracture.

The specimens used were oxy-gas flame cut followed by machining so that the sides are smooth and parallel.

The location of the tensile specimens is shown in Fig.2 and the shape and dimensions of the specimens (according to API 1104, 2013) are shown in the Fig.3.

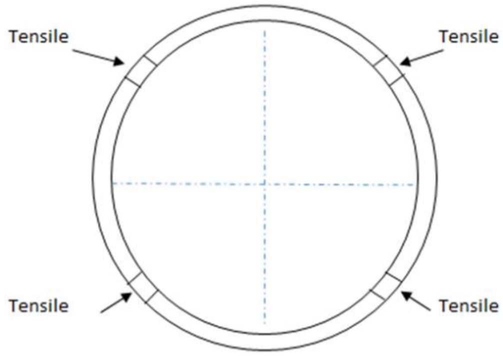


Figure 2. Location of tensile specimens.

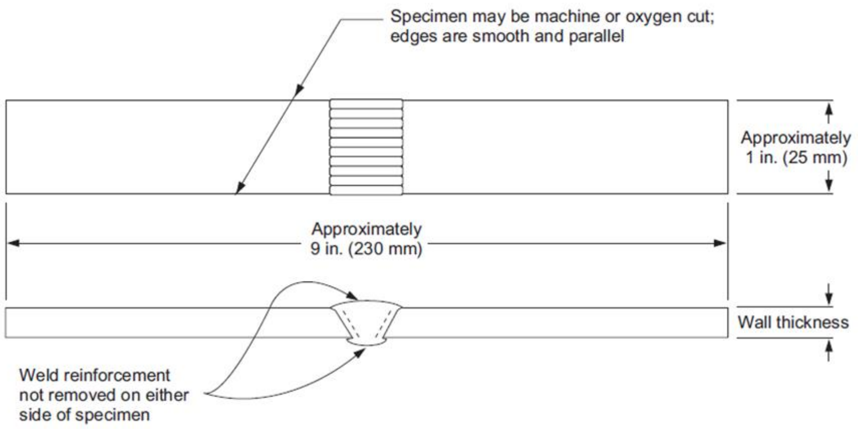


Figure 3. Tensile strength test specimen.

Tensile test was performed using a universal hydraulic machine, type Satec 5500R 200BTE (fig.4).

Figure 4. Universal machine type Satec 5500R 200BTE.

The results of the tensile tests are shown in Table 2 and the appearance of a test specimen is shown in fig. 5.

Table 2 Experimental results.

Specimen ID	So (mm^2)	Fmax (N)	Rm (N/mm^2)	Fracture Location
TT1	800.87	476226	595	Base metal
TT2	796.45	476126	598	Base metal
TT3	801.24	469729	586	Base metal
TT4	799.22	460440	576	Base metal

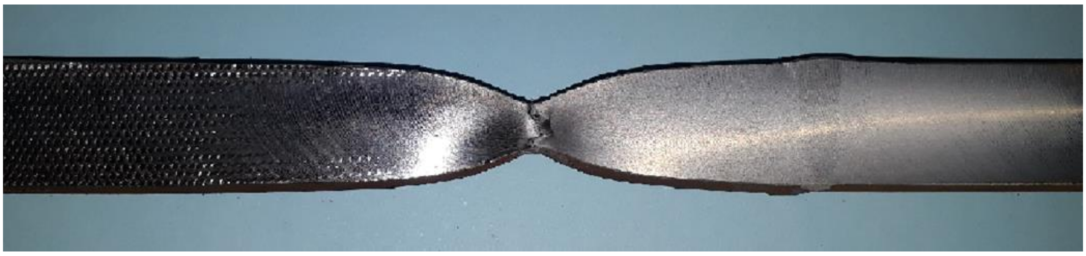


Figure 5. Fracture location of the tensile strength test specimen.

The analysis of the obtained data show that, each time, the fracture occurred in the base material (MB) and the values of the tensile strength for all 4 sets of tensile specimens are superior to the minimum required for the basic material (in accordance with API 5L, 2012), which is 535 N/mm^2. According with API 1104, 2013, the tensile strength of the weld, including the fusion zone of each specimen has to be greater than or equal to the specified minimum tensile strength of the pipe material.

3.2 Charpy Impact Testing

The charpy impact test seeks the appreciation of the welded joint toughness. The Charpy method uses prismatic specimens with a U-shaped or V-shaped notch in the middle of the specimen. V- notch specimens are preferred to those with U-shaped notches because the absorbed energy is mostly accredited for crack propagation; in U-shape notch specimens the absorbed energy mainly characterizes the crack initiating.

The experiments were conducted on samples with a V-shaped notch (ASTM E23, 2012), and the test temperatures were: + 20 ° C, 0 ° C, -30 ° C and -50 ° C.

For the tests performed at low temperature the used media was a refrigerant (dry ice) and a moderating liquid (ethanol). This combination (dry ice and ethanol) is used for the range: + 20 °C…-75° C.

The specimens were kept at the test temperature, T ± 1 ° C, for a period of 5 minutes. The Charpy impact machine was a Charpy pendulum with hammer, type PSW30 which had an available energy of 300J.

Impact test specimens location is shown in fig.6.

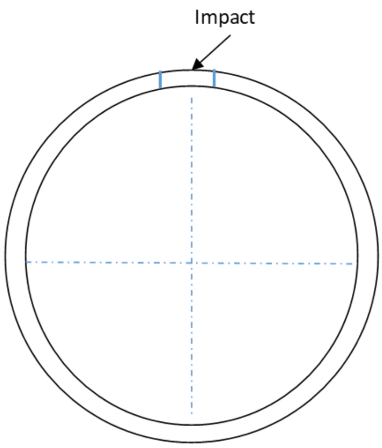


Figure 6. Location of impact specimens.

The notch axis was normal to material surface, as shown in fig.7.

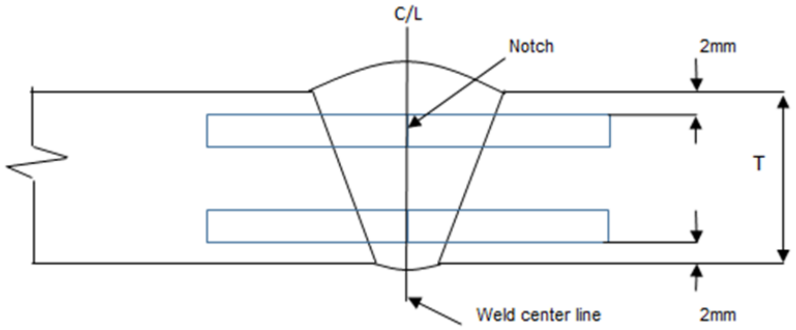


Figure 7. Notch location of impact specimens.

For each test temperature and each location of the notch, at least 3 specimens were used. The results obtained are shown in Table 3 and graphically represented in fig.8.

Table 3. The values of the breaking energy KV.

Notch Location	Specimen size, mm	Temp.°C	Absorbed Energy, Joules			
			A	B	C	Average
WCL Cap	10 x 10 x 55	+20°	178	176	190	181
WCL Root	10 x 10 x 55	+20°	220	220	208	216
WCL Cap	10 x 10 x 55	0°	150	138	150	146
WCL Root	10 x 10 x 55	0°	198	188	226	204
WCL Cap	10 x 10 x 55	-30°	102	110	116	109
WCL Root	10 x 10 x 55	-30°	130	150	138	139
WCL Cap	10 x 10 x 55	-50°	80	50	62	64
WCL Root	10 x 10 x 55	-50°	44	56	50	50

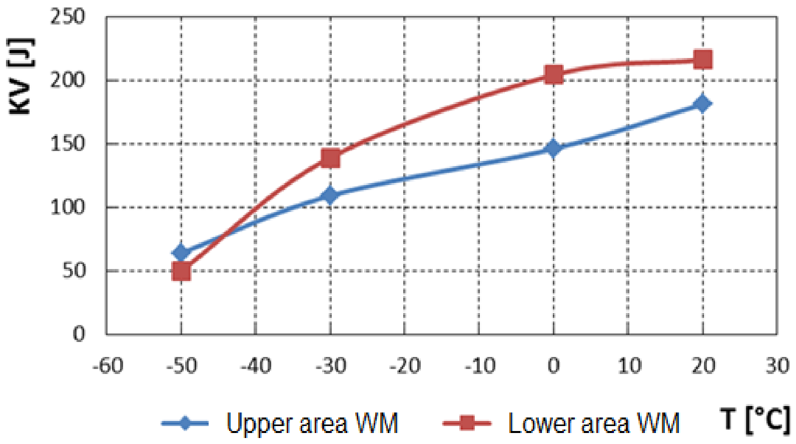


Figure 8. Absorbed energy variation KV with the test temperature T [°C].

Analysing the variation of the absorbed energy KV with the test temperature (Fig. 8), it can be observed that the welded joint has a high resistance to brittle fracture, its behaviour being ductile in a wide range of temperatures (-50 ° C - + 20 ° C).

The appearance of the fracture surface (fig. 9) is matte - fibrous, characteristic of the ductile fracture, which are preceded by large plastic deformations, respectively high values of the absorbed energy for crack propagation.

Towards the edges of the fracture surface where the shear stress is predominant, the fracture develops on the inclined surface to the core of the fracture surface.

Figure 9. Halves of broken Charpy V-Notch Impact specimen.

3.3 Metallographic examinations

Investigation of the weld macrostructure (Fig.10), reveals a full penetrated weld which interpenetrates correctly in the base metal without the appearance of metallic continuity defects.

The weld microstructure (fig.11a) consists of columnar grains oriented in the thermal gradient direction, and a heat-affected zone, HAZ, (Figure 11b) of ferrite, bainite and fine precipitations of secondary phases which impede the dimensional growth of crystalline grains in a purely mechanical manner. The base metal has a ferrite-bainitic microstructure (Fig. 11c).

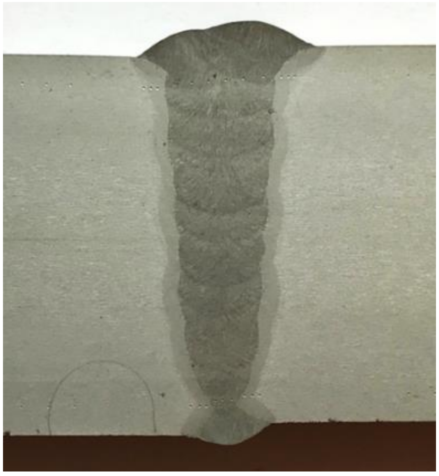
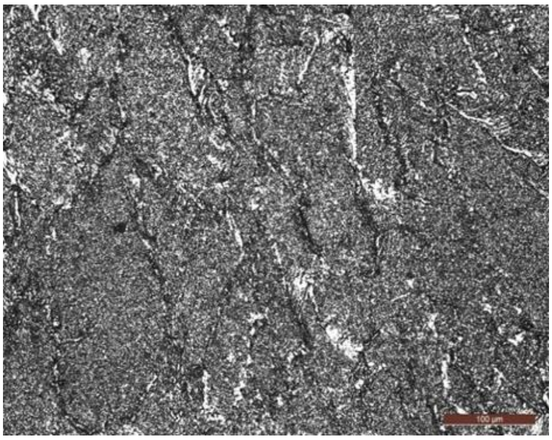
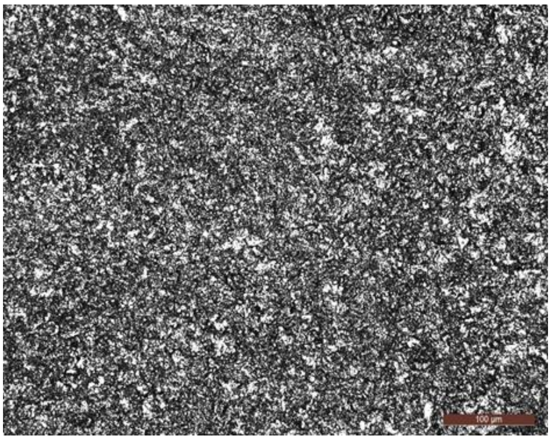


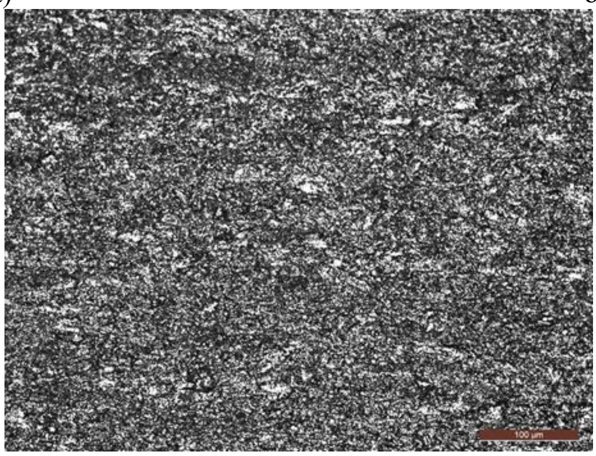
Figure 10. Welded joint macrograph.
Chemical Reagent: NITAL ($10cm^3$ HNO_3, $100cm^3$ Ethyl Alcohol)



a)



b)



c)

Figure 11. Microstructure of welded joint zones: a) weld metal; b) HAZ; c) base metal.
Chemical Reagent: NITAL ($10cm^3$ HNO3, $100cm^3$ Ethyl Alcohol)

4. Conclusions

MAG welded joints of low-alloy thermo mechanical treated steels API 5L X65M, presents tensile strengths values Rm = 576…598 N/mm^2 higher than those required for base metal Rm ≥ 535 N/mm^2.

At the lowest charpy impact test temperature, (-50 ° C), the absorbed energy KV from the upper and lower metal deposited exceeds the minimum value of 38 J imposed by the DNV-OS-F 101 standard for this base material.

5. References

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