OPPORTUNITIES OF NARROW GAP MAG WELDING OF API 5L X65M STEEL PIPELINE

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Abstract

Since thermomechanical treatments favors increased mechanical resistance characteristics of steels, their degree of alloying is lower than that of any found in normalized steel with the same strength.

This is extremely beneficial for the weldability of steel.

To prevent the emergence of unwanted micro-structural transformations in welded joint areas (softening HAZ, excessive growth of grain, cold cracking), the present paper aims to implement the narrow gap MAG welding of steel X65M intended for the fabrication of pipeline used for the transportation of natural gases and liquid hydrocarbons.Root and hot layers have been welded using MAG spray arc and the fill layers in pulsed current.

The equipment used is composed by an internal welding machine for the root pass and external 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.

Assessments of the quality of the welds are done through macro- and micrographic analyzes in conjunction with sclerometer examinations.

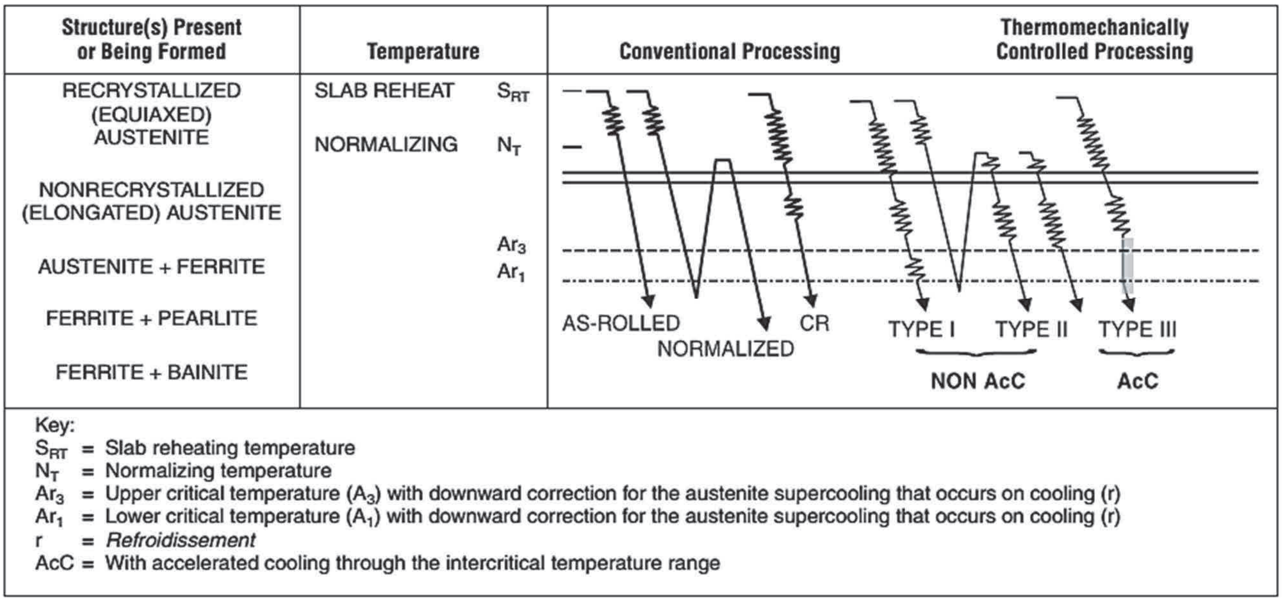
Keywords: Thermomechanical treatment, steel, MAG welding, narrow gap

1. PROBLEMS THAT OCCURS DURING THE WELDING OF THE THERMOMECHANICAL STEELS

Processing the steels through thermomechanical treatment in the first stage involves heating them at a temperature of approximately 1200°C, their plastic deformation in a normal way and then a final reduction of the section achieved at a lower temperature than specific conventional processing.

By carrying out plastic deformation at a lower temperature is promoting a finishing of crystal grains and a delay of precipitation phenomenon of secondary phases. The final hot deformation processing may continue at temperatures below the critical point Ar_3, the transformation of austenite to ferrite. Obviously, this requires powerful equipment which is capable of deforming the steel to lower working temperature. Research has shown that the optimal size of precipitation of secondary phases and their high degree of dispersion is achieved when the final rolling temperature is about 775 °C [1, 2]. For some thermomechanically treated steels last cooling stage (during which the transformation is completed) is conducted with a cooling rate higher than that specific for the air, but below the critical speed of hardening of steel considered to favor the formation of bainite and, or in place of formation of the ferrite.

There are many thermomechanically methods of treatment, three of which are illustrated in (**Figure 1**). The first two (types I and II **Figure 1**) do not contain an accelerated cooling from the end of deformation and they mainly differ by the temperature range in which this happens. A third method (type III **Figure 1**) comprises an accelerated cooling after controlled rolling process.



Key:
S_{RT} = Slab reheating temperature
N_T = Normalizing temperature
Ar_3 = Upper critical temperature (A_3) with downward correction for the austenite supercooling that occurs on cooling (r)
Ar_1 = Lower critical temperature (A_1) with downward correction for the austenite supercooling that occurs on cooling (r)
r = *Refroidissement*
AcC = With accelerated cooling through the intercritical temperature range

Figure 1 Cycles of conventional and thermomechanically controlled processing

High strength microalloyed steels are characterized by low carbon content (0.03 - 0.12 %) and microalloying with TI, Nb, V in sufficient amounts to cause the formation of carbonitrides. The thermomechanical treatment applied ensures high mechanical characteristic compensating the effect of lower carbon content through a hardening by precipitation and a finishing of crystalline grain size.

Effective combination of thermal and mechanical strictly controlled procedures was increased by accelerated cooling method development (AC / ACC) which allows the control of microstructural transformations not only during the hot deformation, but until the final stage of product development. As a result, the mechanical strength characteristics of thermomechanical steel are superior to those with specific structural state obtained by normalization. Therefore, the degree of alloying of thermomechanical steel is lower than of a normalized steel of the same strength. This is extremely beneficial for the weldability of the steels. It is previsioned at some grades of steel, toughness characteristics of the heat affected zone can become even better than the normalized state, and they can be obtained at higher values of welding heat input. Therefore, it is considered that some of the thermomechanical steels with a low carbon content (0.03-0.12 %) and the alloying elements (< 0.1 %), resulting in a carbon equivalent Ce (IIW) < 0.40 %, compared to the specific one of the low alloy steels, Ce ≥ 0.40 %, they have a better welding behavior than many of low alloy steels. As results of a lower Ce, welding preheat temperature is lower by 75 °C compared to the conventionally processed steels [3, 4]. However, in the majority of thermomechanical steels welded, there is a certain degree of softening of the heat affected zone. Recommended welding conditions to avoid the risk of cold cracking is determined taking into consideration besides the equivalent carbon equivalent Ce, hydrogen level and geometry of the weldment. In many cases it is used as assessment criterion the value of hardness.

This paper aims to find a way to limit unwanted microstructural transformations in welds concomitant with increasing productivity by implementing a narrow gap MAG welding of a thermomechanical steel intended for the pipeline fabrication used in the oil and gas industry.

2. EXPERIMENTAL PROCEDURE

The objective of the research aims to achieve narrow gap welds, with multiple layers, one pass per layer for pipelines with a diameter of 42 " (1066.8mm) and a wall thickness of 31.75mm.

The chemical composition of the base metal is shown in (**Table 1**), and the filler materials selected in the (**Table 2**) and (**Table 3**).

Table 1 Chemical composition of the base metal API 5L X65MS

X65MS	C%	Si%	P%	S%	Ti%	Mn%	Ni%	Cr%	Al%	Mo%	V%	Nb%
Actual values	0.043	0.32	0.007	0.0009	0.013	1.53	0.018	0.19	0.038	0.008	0.004	0.044
Composition as per API 5L	0.1	0.4	0.016	0.002	0.04	1.6	0.3	0.3	0.06	0.15	0.08	0.05

Note: API Specification 5L: Specification for Line Pipe (API 2012) - American Petroleum Institute Standard

Table 2 Chemical composition of welding consumable for root passes

ER70S-G	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Cu%	V%	Ti%
Actual values	0.07	0.74	1.57	0.013	0.008	0.04	0.01	0.04	0.11	0.01	0.05

Note: ASME Sect.II Part.C does not specify the chemical composition

Table 3 Chemical composition of the welding consumable for fill layers

ER70S-6	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Cu%	V%
Actual values	0.07	0.95	1.69	0.011	0.010	0.03	0.01	0.05%	0.10	0.01
Composition as per ASME Sect.II Part.C	0.06-015	0.8-1.15	1.4-1.85	0.025	0.035	0.15	0.15	0.15	0.50	0.03

General note: single values represent the maximum values of each component

Selected joint configuration is shown in (**Figure 2**).

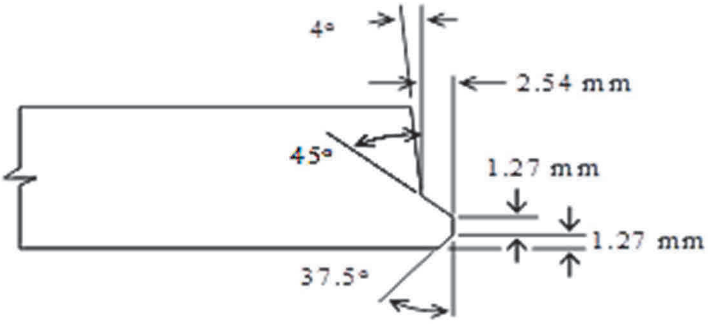


Figure 2 Joint configuration

The basic characteristics of this welding process can be summarized as follows:

- Narrow gap, the groove faces are slightly open
- Reduced deformations due to the joint configuration
- Multiple welding layers with one pass per layer
- The heat affected zone (HAZ) is reduced due to low welding heat input
- The process offers a lower cost due to decreasing consumption of filler metal and welding time

The main disadvantages of narrow gap MAG welding are:

- Welding equipment is more expensive due to the welding head control and of the wire feeding system
- Increasing the risk of defects (lack of fusion) as increasing the thickness of components
- The difficulty of removing defects due to limited accessibility

The welding process used is MAG in arc spray for the root & hot passes and pulsed current for the fill passes. Welding operation was done with the welding equipment from CRC Evans, composed of a internal welding machine, IWM and a welding machine for the exterior of the pipe, P625, with two wires for filling, where the pipe is fix and the welding equipment produce an orbital vertical downward movement around the pipe.

Internal Welding machine IWM used to weld of the root pass inside the pipe, uses 6 welding heads, from each 3 heads welding simultaneously and produce also an orbital vertical downward movement around the pipe (**Figure 3**).

Figure 3 Internal welding of the root pass using 3 welding heads simultaneously

Figure 4 External welding using 2 welding heads

External welding machine, P625, produce an orbital vertical downward movement around the pipe being provided with two welding heads where the pipe is fixed (**Figure 4**).

Welding parameter values are shown in the **(Table 4)** below:

Table 4 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

3. EXPERIMENTAL RESULTS

3.1. Metallographic examinations

To emphasize the structure of the welded joints it was applied macroscopic test for overall examination and microscopic test for detailed examination. To carry out the respective tests, the test coupons were cut transversally that is perpendicular to the longitudinal axis of the weld. Such samples allow getting information regarding the welding configuration, HAZ expansion, areas with segregation and welding defects onto the length direction. In (**Figure 5)** is exemplified a macroscopic image of a cross-section of the welded joint, remarking that both the weld and HAZ have a suitable geometry and they are free of defects such as porosity, cracks, lack of fusion etc. HAZ's width is uniform throughout the section and the direction of crystallization in welding is the normal one that coincides with the heat dissipation.

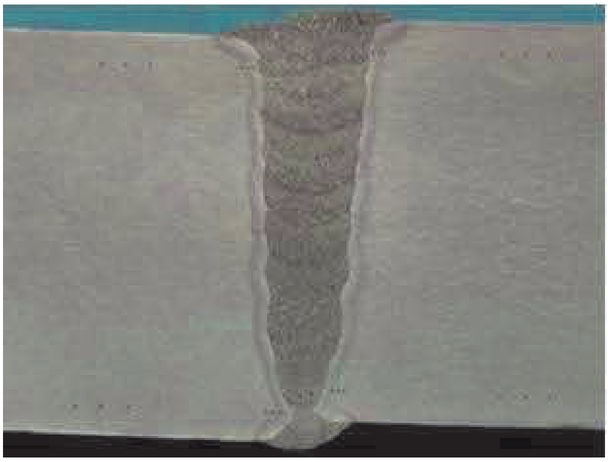


Figure 5 Macroscopic cross-sectional image of the welded joint. Chemical reagent: NITAL (10cm^3 HNO3, 100 cm^3 ethyl alcohol)

Microscopic investigation in the welding areas demonstrate that in the welding a dendritic structure is formed, the grains growth are produced in a columnar manner (**Figure 6**), and in the HAZ occurs ferritic-bainitic structure with a fine precipitation of second phase (**Figure 7**).

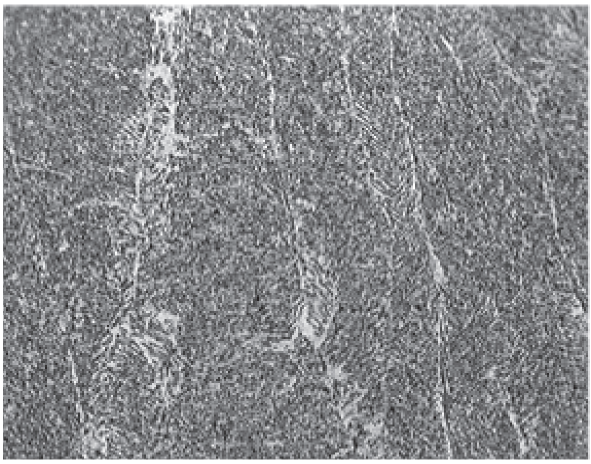


Figure 6 Welded seam microstructure x 200

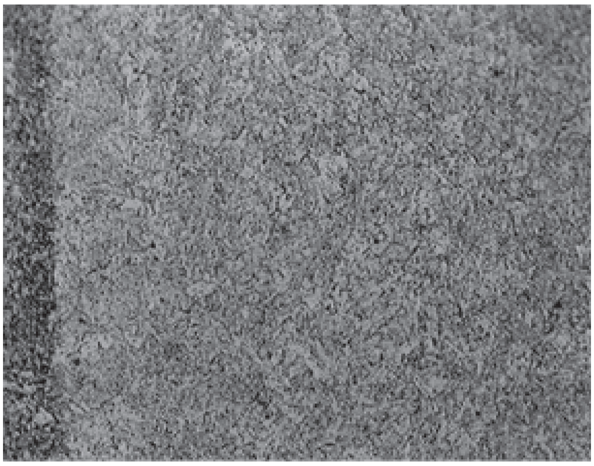


Figure 7 HAZ microstructure x 200

The processes that occur on heating for welding are determined by the heating rate, the maximum temperature reached in each area and the holding time above the critical points Ac$_3$ and Ac$_1$. Increasing the heating rate and reducing the holding time above the critical temperature Ac$_3$ limits the diffusion processes and conditions or keeping undissolved carbonitrides particles in austenite or formation of a non-homogenous austenite. The presence of undissolved carbonitrides or chemical non-homogenous of austenite decreases its stability at transformation during the subsequent cooling, favoring the apparition of ferrite (**Figure 7**). At the same time, due to the large thickness of the pipe wall, the rate of cooling increases, so that local, some micro-areas of non-homogeneous austenite is transformed into bainite (**Figure 7**).

3.2. Sclerometric examination

Vickers hardness measurements on the cross section of the welded joint were made at a distance of 2 mm from the bottom **(Figure 8)** and top **(Figure 9)** of the pipe. Their degree of scattering confirms the structure heterogeneities in the weld and HAZ. Slightly higher values of hardness in the weld are explained by a larger content of carbon equivalent of the weld metal as compared with the parent metal.

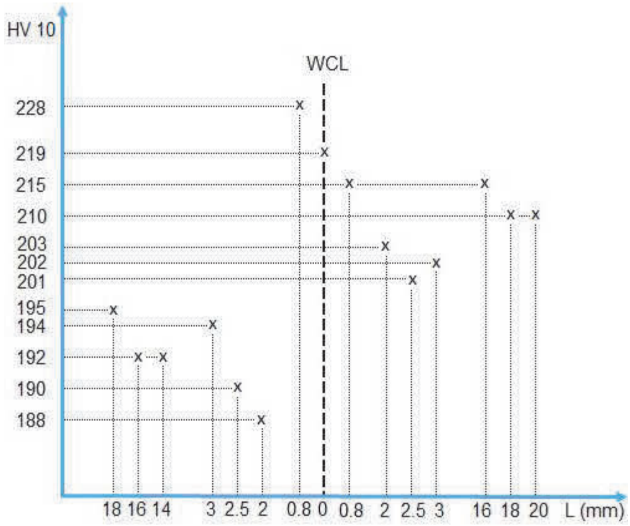


Figure 8 Variation of the hardness along the cross section of the weld from the internal region of the pipe

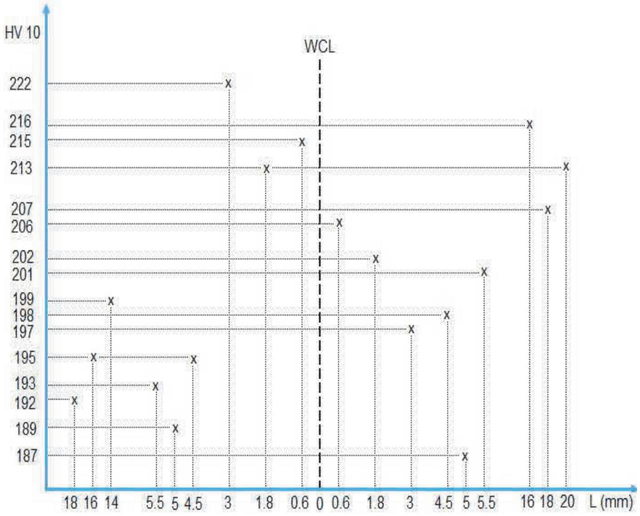


Figure 9 Variation of the hardness along the cross section of the weld from the external region of the pipe

4. CONCLUSIONS

Technological version of narrow gap MAG welding allows use a low energy input, low distortion, a small HAZ and a flawless macrostructure of metal continuity.

The microstructure of the weld metal has a dendritic appearance with a columnar crystal grain oriented and HAZ is constituted by a ferrite matrix with small amounts of bainite and carbonitrides of alloying elements.

Hardness gradient on the cross section of the welded joint demonstrates that technological regime adopted prevents the softening of HAZ and assures good mechanical properties.

REFERENCES

[1] NISHIOKA K. Market requirements of thermomechanically processed steel for the 21st century. *Steel World*, 2000, vol. 5, no.1, pp. 61-67.

[2] BANG, K.S., KIM, W.Y. Estimation and prediction of HAZ soft-ening in thermomechanically controlled - rolled and accelerated - cooled steel. *Welding Journal* **, 2002, vol. 81**, no. 8, pp. 174-179.

[3] HILDEBRAND, J. WERNER, F. Change of structural condition of welded joints between high-strength fine-grained and structural steels. Journal of Civil Engineering and *Management*, vol. 2, pp. 87-95.

[4] OPIELA, M. Elaboration of thermomechanical treatment conditions of Ti-V and Ti-Nb-V microalloyed forging steels. *Archives of Metallurgy and Materials,* 2014, vol.**59**, no. 3, pp. 1181-1188.

[5] YAJIMA, J. Extensive Application of TMCP-manufactured High Tensile Steel Plates to Ship Hulls and Offshore Structures. *Mitsubishi Heavy Industries Technical Review*, 1987, vol. 24, no. 2, pp. 54-59.