FABRICATION AND WELDABILITY OF GRADE 23 TUBING AND PIPING

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ABSTRACT

The need of increased efficiency and reduced emission limits in modern steam generators has required to fabricators worldwide to evaluate new materials. Grade 23 steel has been identified as a potential solution to the requirements mentioned above. TenarisDalmine (TD) has focused on the development of tubes and pipes of this steel grade. Together with the Italian Welding Institute (IIS) and ETC Elettrotermochimica, part of AirLiquide Welding group (ETC), a joint characterization program has been established applying the standard welding processes such as SMAW and SAW.
The tubes and pipes production cycle and the heat treatments have been optimized to guarantee suitable mechanical and creep properties. At the same time, dedicated WPS's have been designed and tested to evaluate the mechanical properties of the welded joints. The joints have been analyzed both in as welded and post weld heat treated conditions.
Creep tests of the various welded joints are on-going to identify the creep resistance limits of this grade.

KEYWORDS

P23, T23, low-alloy steels, welding, PWHT, SMAW, SAW

INTRODUCTION

The energy production is faced with the introduction of increasingly stringent emission regulations to safeguard the health and to preserve the environment for the future generations.
Increasing the thermal efficiency of a power plant is the best way to reduce the emissions.
Thermal efficiency is influenced by several factors, but the adoption of supercritical conditions by increasing steam temperatures and pressures plays a key role: very high temperatures and pressures makes mandatory the use of steels suitable for these severe conditions [1].
For that reason, in the last years the use of new steel grades with enhanced high temperature properties has increased and, accordingly, the need of joining techniques for these materials with comparable high temperature properties [2-4].

In this context it is necessary to investigate deeply the behaviour of these new grades as far as weldability and high temperature base material and welded joints properties concern.
This activity presupposes the development of consumable with a suitable composition and the optimization of the welding procedures.
Grade 23 steel has been identified as a potential solution for its creep and weldability properties.
In the last years Tenaris focused on the development of tubes and pipes of this steel grade; to guarantee optimum mechanical and creep properties, the production cycle and the heat treatment of tubes and pipes have been optimized. On the other hand ALW-ETC Elettrotermochimica developed

and optimized a complete range of welding consumables for all the new advanced materials for power generation.
Now, in order to define the properties of SMAW and SAW joints fabricated from seamless tubolars, Tenaris, the Italian Welding Institute and ETC Elettrotermica, part of Air Liquide Welding Group, have carried out a joint research program.
Dedicated WPSs have been designed and tested, in order to define the properties achievable from welded joints both in the as welded and PWHT conditions.

1. MATERIAL PROPERTIES

Grade 23 is a low alloyed steel (2.25% Cr) derived from grade 22 substituting part of the Mo content with W and adding Nb, V, B.
Mo and W act as solution strengtheners of the metal matrix. V, Nb and Ti form fine precipitates (carbides and nitrides) which obstacle the dislocation movement, thus increasing the mechanical and creep resistance of the material. B stabilizes the $M_{23}C_6$ carbides, retarding their coarsening, which is detrimental for the creep performance.
Seamless pipes and tubes are regulated by the ASTM standards A335 and A213. This material, as per code case 2199-1, conforms also the ASME requirements for the construction of boilers and pressure equipments.
The chemical composition of steel, according to ASTM and ASME, is summarized in table 1.

Table 1 Chemical composition of base material

Grade	C	Mn	P	S	Si	Cr	Mo	W	Nb	V	B	Other
22	0.05 0.15	0.30 0.60	0.025 max	0.025 max	0.50 max	1.90 2.60	0.87 1.13	-	-	-	-	-
23	0.04 0.10	0.10 0.60	0.030 max	0.010 max	0.50 max	1.90 2.60	0.05 0.30	1.45 1.75	0.02 0.08	0.20 0.30	0.0005 0.006	N: 0.03 max

2. PRODUCTION CYCLE

TenarisDalmine tubes and pipes are produced from solid billets, manufactured directly by continuous casting process or manufactured from ingots by hot rolling. All CrMo steels are vacuum degassed to improve the cleanliness and to reduce gas content.
Round bars are heated in a rotary furnace at high temperature before piercing.
Heating parameters depends on the diameter of the bars and on the type of steel: a computerized system controls the thermal cycle, the heating rate and the soaking time at high temperature.
Before piercing, bars are descaled using high pressure water to eliminate the oxide formed during the heating in the furnace.
Tubes and pipes are produced in TenarisDalmine in three different mills, according to the size of the finished products.
Tube sizes with OD up to 88.9 mm are manufactured in a small size continuous mill (FAPI mill); pipes with OD up to 406.4 mm are produced in a multistand pipe mill (MPM) with retained mandrel [5], whereas pipes with OD from 406.4 up to 711 mm are manufactured in a rotary expansion mill [6] (Expander mill). In particular, in the continuous mill, it is possible to produce tubes for Heat Recovery Steam Generator (HRSG) with lengths up to 24 meters.

The as-rolled microstructure is not adequate to ensure mechanical properties and creep resistance suitable for the demanding application of power generation industry. Therefore the as-rolled tubes and pipes are heat treated: in particular the tubes are normalized and tempered, while the pipes with

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larger wall thickness are quenched and tempered. Continuous Cooling Trasformation curves (CCT, see fig. 1) have been used to define the minimum cooling rate to obtain a fully bainitic microstructure after cooling from the austenitizing temperature. Particular attention must be kept to maintain an adequately fast cooling rate, to avoid the formation of a mixed microstucture of ferrite and bainite.

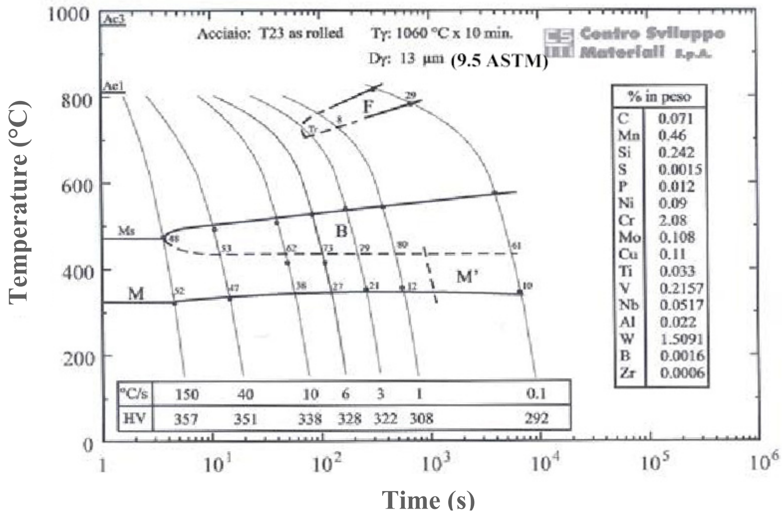

Figure 1 – CCT Diagram of grade 23

The tubes with OD smaller than 168.3 mm are heat treated in a furnace with a special atmosphere which reduces the superficial oxide to metal and at the same time avoids the decarburization. The austenitization temperature range is 1040-1070°C, sufficiently high to put in solution all the carbide forming elements. Tempering is carried out between 750 and 780°C, in order to ensure adequate creep strength and good toughness properties.
Examples of the microstructures are shown in the pictures 2 and 3.

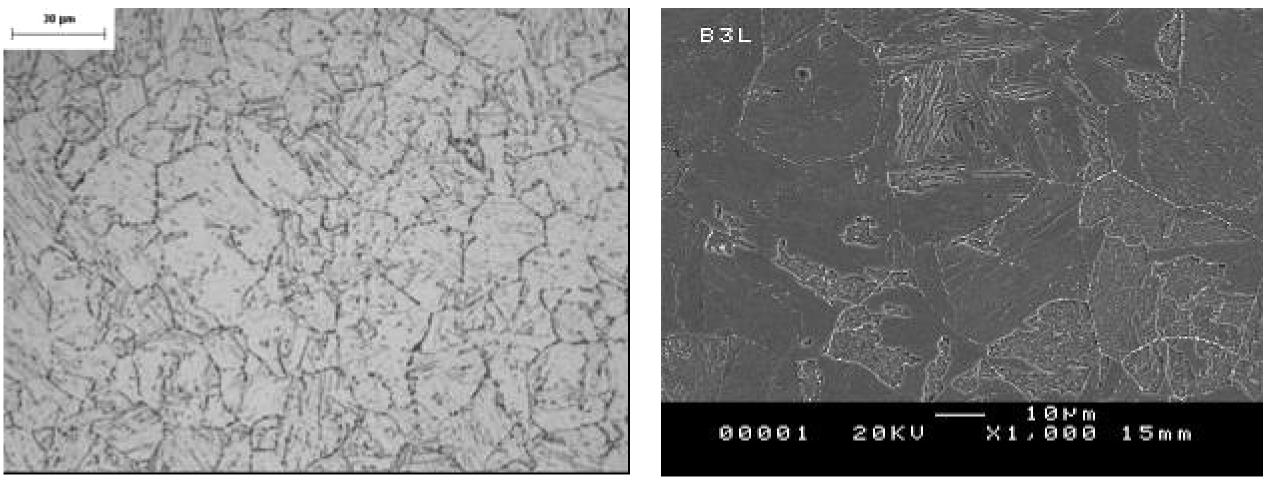

Figure 2 – Tempered bainitic microstructure of a Grade 23 pipe (OD 219mm x WT 31.75mm) after Q+T by LM and SEM

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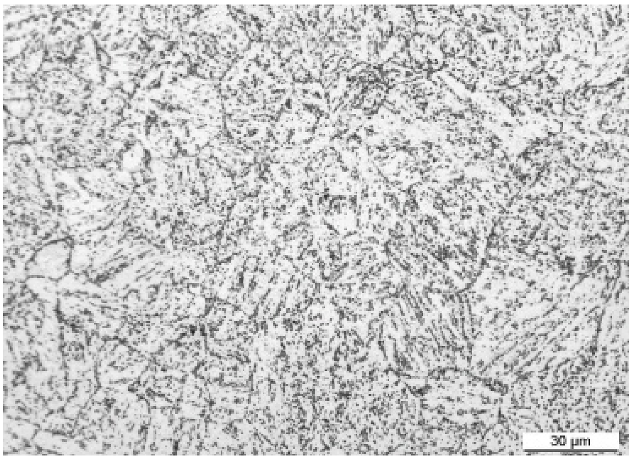

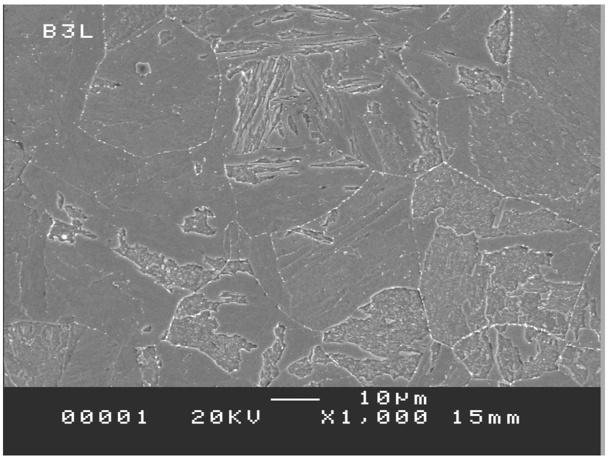

Figure 3 – Tempered bainitic microstructure of a Grade 23 tube (OD 38mm x WT 3.8mm) after N+T by LM and SEM

Table 2 reports the mechanical properties of some TenarisDalmine T23 tubes and P23 pipes of different sizes and the ASTM minimum requirements. Impact properties of a tube ODxWT 38x6.8mm and of a pipe ODxWT 457x17.5mm are listed in table 3 and 4, respectively. Hot tensile tests, carried out up to 700°C on a tube ODxWT 38x6.8mm, are shown in picture 4.

Table 2 – Typical average mechanical properties of selected TenarisDalmine T/P23 tubes and pipes

ASTM grade	Dimension ODxWT [mmxmm]	Hardness (HV_{10})		Yield Strength (MPa)		Ultimate Tensile Strength (MPa)	
		ASTM	TenarisDalmine	ASTM	TenarisDalmine	ASTM	TenarisDalmine
T23	38x3.8	< 230	191	> 400	510	> 510	620
T23	38x6.8	< 230	198	> 400	501	> 510	597
P23	88.9x17	-	214	> 400	517	> 510	620
P23	219x31.75	-	210	>400	511	>510	622
P23	457x17.5	-	208	> 400	458	>510	590

Table 3 – Impact properties of T23 ODxWT 38x6.8mm

Temperature [°C]	J/cm^2	Shear area
20	173	100
0	198	100
-20	181	100
-40	179	97
-60	126	75

Table 4 – Impact properties of P23 ODxWT 457x17.5mm

Temperature [°C]	J	Shear area
20	399	100
0	415	100
-20	341	100
-40	254	80

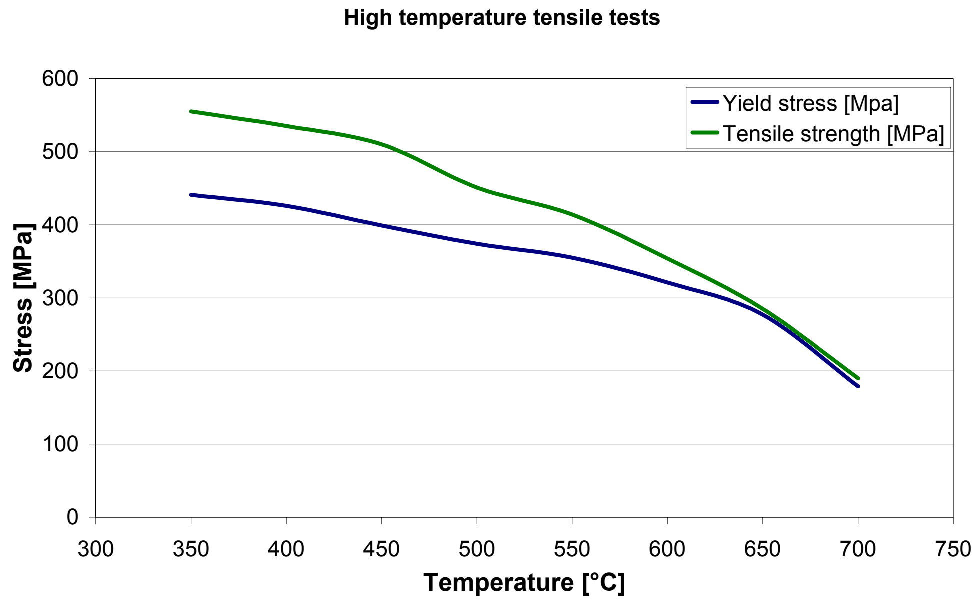

Figure 4 – Tensile properties at high temperature of a tube ODxWT 38x6.8mm

3. GIRTH WELDING OF TUBING AND PIPING

In the construction of a power plant, welding of tubes and pipes takes place in various phases and environments. In particular, all the components that could be assembled in shop will require high efficiency processes such as Submerged Arc Welding (SAW). However, on-site assembly will employ more manageable processes such as Shielded Metal Arc Welding (SMAW).
A dedicated research effort has allowed ALW-ETC to develop a complete set of welding consumables for the above-mentioned processes. The potentialities of flux-coring technologies were employed to design the most appropriate products [7-8] (see table 5). Because of the lack of dedicated Standards (AWS or EN), the chemistry defined by ASTM and ASME Code for the base material has been adopted as a reference to define and develop the chemical composition of the welding consumables.

Table 5 – List of consumables

Consumable	AWS/EN Classification	Type	Diameter
AL CROMO W223	A5.28: ER80 CG	Flux-cored GTAW rod	2,0 mm
AL CROMO E223	A5.5 : E8015 – G	Basic SMAW electrode	2,5; 3,25 and 4,0 mm
AL CROMO SF223	A5.23: F9AZF8PZ ECG-G	Flux-cored SAW wire	3,2
FX 76B	760: SA FB 1 55 AC H5	Basic agglomerated flux	NA

3.1 WELDING ACTIVITIES

ALW–ETC and IIS shared the welding activities in the context of this joint operative research project. Consequently, a series of joints have been chosen to closely represent the most typical ones of power plant assembly conditions. In particular, SMAW was applied in 2G (tube with vertical axis) and 5G PF condition (pipe with fixed horizontal axis). SAW was applied in PA condition (rotating pipe with horizontal axis) – Fig. 5 and 6. The welded joints were tested mechanically and chemically in three different conditions: as-welded (AsW); post weld heat treated at 740°C for 2 hr (PWHT1); post weld heat treated at 710°C for 1.5 hr (PWHT2).

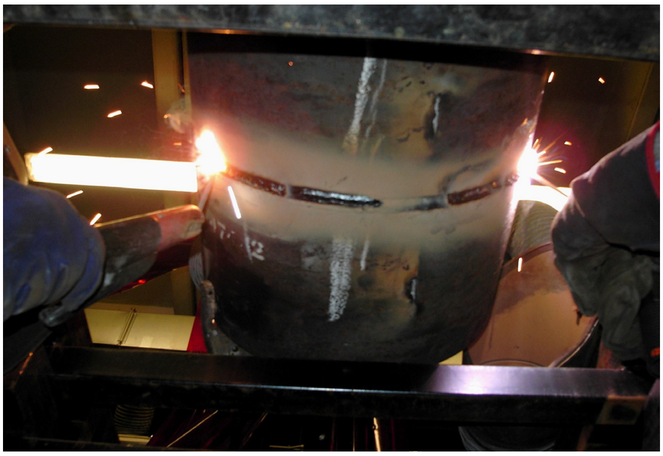

Figure 5 – SMAW welding on P23

Figure 6 – SAW on P23

Table 6 – Welded joints tested (AsW=As-Welded)

Grade	Size ODxWT [mm]	Welding processes	Welding Technique	HI [kJ/mm]	Test conditions
T23	76x12.5	GTAW+SMAW	2G	0.88	AsW
P23	219x31.75	GTAW+SMAW	5G PF	0.92	PWHT2 710°Cx1.5h
P23	219x31.75	GTAW +SMAW+SAW	PA	1.67	PWHT2 710°Cx1.5h
P23	457x17.5	GTAW +SMAW	5G PF	0.92	AsW – PWHT1 740°Cx2h
P23	457x17.5	GTAW +SMAW+SAW	PA	1.67	AsW – PWHT1 740°Cx2h

According to the EN 288-1, each type of joint was defined with a preliminary welding procedure specification (WPS). Upon welding, the operative parameters were collected and a specific WPS was edited.
The welding parameters adopted in the assembly of the girth joints are shortly reported in Table 6. Preheat and interpass temperatures have been selected in the range of the 200-250°C.

3.2 JOINTS CHARACTERIZATION

Each welded joint was X-rayed: non destructive test results show that the joints were sound without any presence of indication. Consequently, a set of specimens were machined to characterize the joints chemically, physically and mechanically.

3.2.1 WELDMENT CHARACTERISATION

Macro graphic examinations were performed to evaluate the beads sequence and joint quality. In addition, the chemical composition of the joints was analyzed using a mass spectrometer. A matching weld metal chemical composition has been developed for SMAW and SAW welding process. The weld metal chemical analysis shown in Table 7 matches the ASTM and ASME requirements for the parent metal (see also table 1).

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Table 7 – Chemical analysis of the joints in different locations (WM and BM)

T23 ODxWT 76x12.5 SMAW

	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Sn	V	Nb	W
ASME	0,04	0,10	0,50	0,03	0,010	-	1,90	0,05	-	-	0,20	0,020	1,45
Req	0,10	0,60	max	max	max		2,60	0,30			0,30	0,080	1,75
BM	0,06	0,47	0,26	0,020	0,004	0,14	2,08	0,10	0,15	0,013	0,21	0,048	1,47
WM	0,05	0,51	0,24	0,011	0,006	0,45	1,94	0,05	0,03	0,005	0,20	0,013	1,28

P23 ODxWT 457x17.5 SMAW

	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Sn	V	Nb	W
ASME	0,04	0,10	0,50	0,03	0,010	-	1,90	0,05	-	-	0,20	0,020	1,45
Req	0,10	0,60	max	max	max		2,60	0,30			0,30	0,080	1,75
BM	0,06	0,46	0,23	0,008	0,002	0,09	2,09	0,13	0,13	0,011	0,23	0,055	1,54
WM	0,05	0,51	0,23	0,010	0,006	0,49	2,03	0,06	0,03	0,005	0,21	0,015	1,32

P23 ODxWT 457x17.5 SAW

	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Sn	V	Nb	W
ASME	0,04	0,10	0,50	0,03	0,010	-	1,90	0,05	-	-	0,20	0,020	1,45
Req	0,10	0,60	max	max	max		2,60	0,30			0,30	0,080	1,75
BM	0,06	0,46	0,23	0,008	0,002	0,09	2,09	0,13	0,13	0,011	0,23	0,055	1,54
WM	0,05	0,51	0,23	0,010	0,006	0,49	2,03	0,06	0,03	0,005	0,21	0,015	1,32

P23 ODxWT 219x31.75 SAW

	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Sn	V	Nb	W
ASME	0,04	0,10	0,50	0,03	0,010	-	1,90	0,05	-	-	0,20	0,020	1,45
Req	0,10	0,60	max	max	max		2,60	0,30			0,30	0,080	1,75
BM	0,06	0,46	0,23	0,008	0,002	0,09	2,09	0,13	0,13	0,011	0,23	0,055	1,54
WM	0,05	0,51	0,23	0,010	0,006	0,49	2,03	0,06	0,03	0,005	0,21	0,015	1,32

3.2.2 CHARACTERIZATION OF MECHANICAL PROPERTIES

The mechanical characteristics were assessed by means of hardness, tensile, impact toughness and bend tests.

To better understand the hardness trends in the joint, the pattern in figure 7 was adopted. Results measured on five different types of joints are reported in the graph of figure 8 for the weld metal and the heat affected zone.

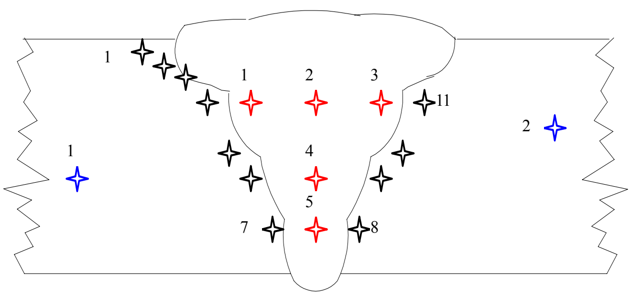

Figure 7 – Hardness test pattern

Tensile tests were carried out both in transversal (or cross weld, CW) and longitudinal (or all weld AW) direction. CW specimen gauge length contains the fusion zone at the centre, and heat affected zone and parent material at the two sides, while AW specimens are cut from weld metal only. Tests were carried out at two different temperatures: room temperature and 550°C.

Impact characteristics were assessed for the various joints at room temperature, 0°C and –20°C.

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Test results are reported together with the relevant acceptance criteria in the tables 8, 9 and 10 for different types of joints.
Hot tensile CW tests at 550°C were carried to quickly assess the behaviour of the joints at high temperature: all the ruptures occurred in the parent material

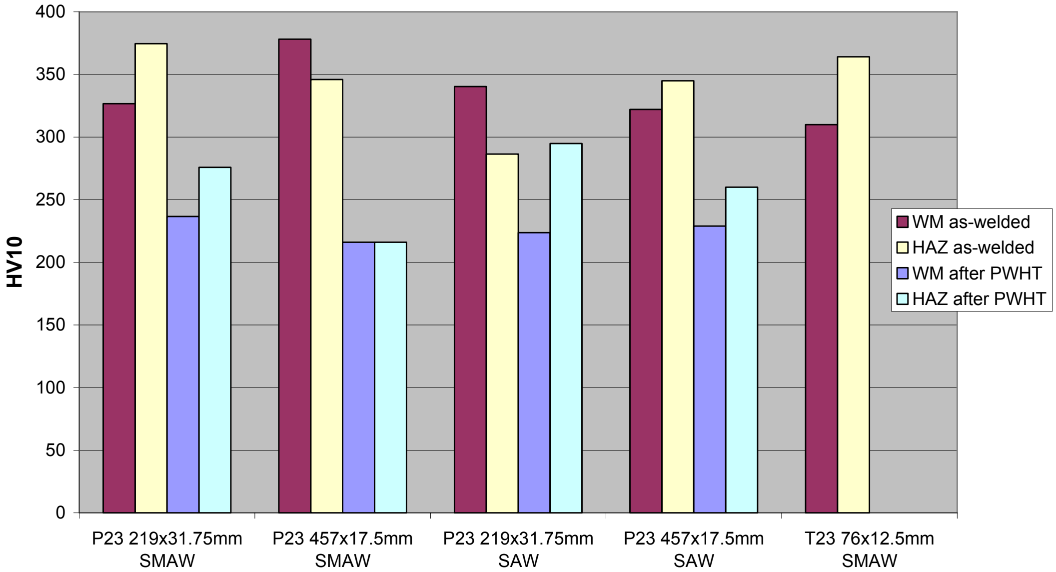

Figure 8 – Maximum Hardness values in the different types of joint

Table 8 - Mechanical Characteristics of T23 ODxWT 76x12.5 mm SMAW girth welded joint in the as-welded condition

Test	Zone	Acceptance Criteria	Results
Tensile at RT		UTS >510 MPa	UTS 652 (CW)*
KVC at RT [J]	weld metal	>27J at RT	32
	Fusion line		30
	FL+2mm		201
	PM		222
HV10 max	WM	NA	310
	HAZ		364
	PM	Max 230 HV	214

Table 9 - Mechanical Characteristics of P23 ODxWT 219x31.75 mm SMAW and SAW girth welded joints in the as-welded and PWHT conditions;

Joint condition	Test	Zone	Acceptance Criteria	SMAW	SAW
As-welded	Tensile RT		UTS > 510 MPa	641 (CW)*	628 (CW)*
	KVC at RT [J]	Weld metal	>27 J at RT	17	20
		HAZ		242	215
		PM		395	395
PWHT 1.5h 710°C	Tensile RT		UTS > 510 MPa	595 (CW)*	615 (CW)*
	KVC at RT [J]	Weld metal	>27 J at RT	147	53
		HAZ		243	237
		PM		395	395
	KVC at 0°C [J]	Weld metal		113	22
		HAZ		231	158
		PM		377	377

Note: * specimen broken in parent metal

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Table 10 - Mechanical Characteristics of P23 ODxWT 457x17.5 mm SMAW and SAW girth welded joint in the as-welded and PWHT conditions;

Joint condition	Test	Zone	Acceptance Criteria	SMAW	SAW
As-welded	Tensile RT		YS > 400 MPa	786 (AW)	762 (AW)
			UTS > 510 MPa	868 (AW) 601 (CW)*	877 (AW) 615 (CW)*
			E > 20%	11 (AW)	19 (AW)
	KVC at RT [J]	Weld metal	>27 J at RT	12	20
		Fusion line		30	215
		HAZ		190	219
		PM		399	399
PWHT 2h 740°C	Tensile RT		YS > 400 MPa	511 (AW)	534 (AW)
			UTS > 510 MPa	601 (AW) 555(CW)*	629 (AW) 585 (CW)*
			E > 20%	20.4 (AW)	23.1 (AW)
	KVC at RT [J]	Weld metal	>27 J at RT	161	89
		Fusion line		197	127
		HAZ		226	183
		PM		399	399
	KVC at -20°C [J]	Weld metal		39	15
		Fusion line		61	31
		HAZ		196	24
		PM		238	238
	Tensile 550°C		YS	339 (AW)	348 (AW)
			UTS	359 (AW) 343 (CW)*	374 (AW) 341 (CW)*

Note: * specimen broken in parent metal

3.3 BEND TESTS

According to ISO 5173, side bend test specimens were taken from all the P23 joints. No evident ruptures, tearing or cracking occurred, even with bending angles up to 180°, as can be seen in picture 9.

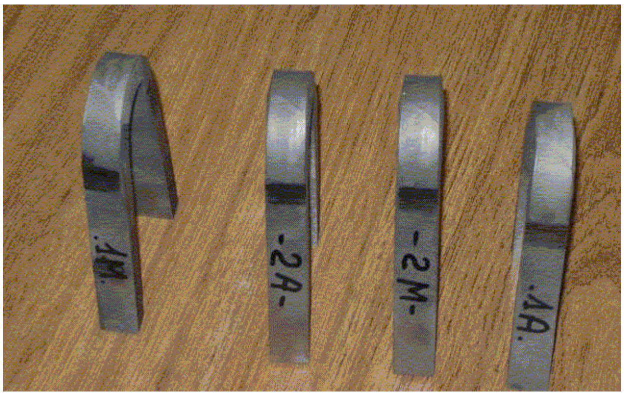

Figure 9 – Bend test specimens after bending

3.4 CREEP TESTS

Creep strength is of utmost importance for the materials used for high temperature applications. It can be affected by many factors but the most important are the chemical composition, the heat treatment parameters and the microstructure.

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The welding process affects all of these factors and therefore the creep strength of the welded joints must be assessed in order to obtain safety factors for the design and to ensure safe working conditions of the components. Creep specimens from the welded joints were tested at three different temperatures near the typical working condition of this grade, testing joints both in the as-welded and in the PWHT condition. The results on welded joints are compared with creep results on grade 23 TenarisDalmine parent material. All the ruptures of welded joints are within the 80% scatter band of the parent material mean line (Figure 10) and occur in the parent material near the HAZ.

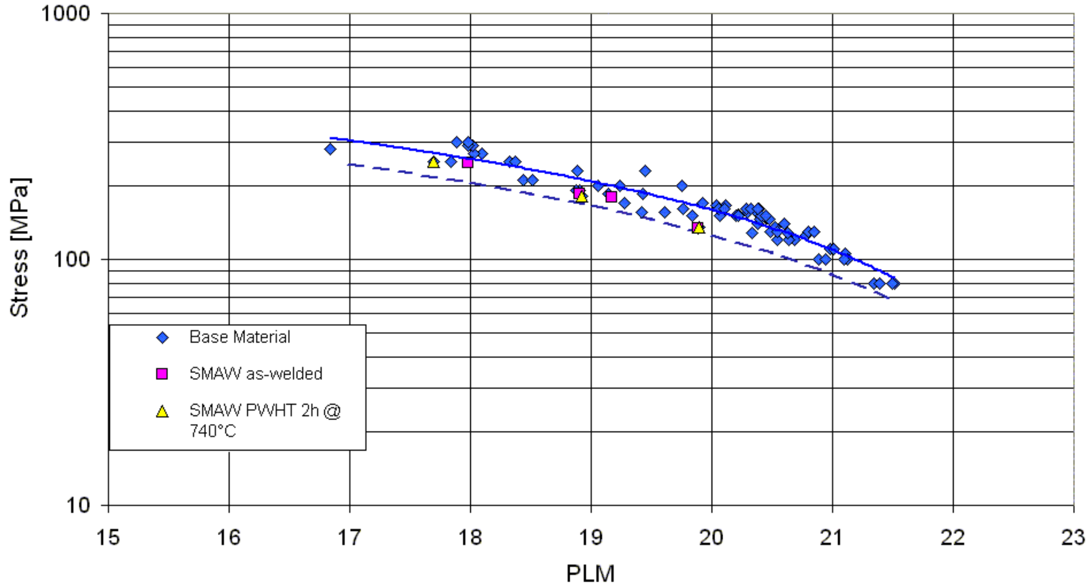

Figure 10 – Welded joints and parent material creep properties (CLM=20)

4. DISCUSSION

The chemical composition of the material and the high cooling rate typical of the welding process determine a martensitic microstructure in the weld metal and in the parts of the joints which during welding transform into austenite. As a consequence, in the as-welded condition high values of hardness and rather low toughness values are obtained in the weld metal and in the coarse grain HAZ.
In the as-welded joint with a thickness of 12.5 mm, the impact properties are acceptable even if they are just over the minimum requirements (32J in the WM, 30J in the HAZ).

Increasing the thickness of the pipe, the impact properties of the weld metal decrease, while hardness increases in the weld metal and in the heat affected zone. A PWHT was necessary to restore toughness and hardness properties on the pipes with wall thickness 17.5 mm and 31.75 mm (for example, in the SMAW joint ODxWT 457x17.5mm, the impact energy in the WM increased from 12J to 161J at RT (from 6J to 39J at -20°C) and the maximum hardness in the HAZ decreased from 346 to 216 HV10).
Therefore a PWHT should be necessary for its beneficial effect on the impact properties of the joint on heavy wall thickness pipes.

A simulation with a numerical code [9] has been carried out in order to evaluate the cooling rates varying the wall-thickness of the pipe and the welding parameters: on the basis of the results a maximum thickness of 6-7 mm seems suitable to avoid the PWHT without affecting the mechanical properties and the safety.
Further welding tests on these small sizes will be done to verify the results of the numerical simulations.

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Both PWHT conditions (PWHT1 and PWHT2) are sufficient to restore the toughness to satisfactory levels even at low temperature (-20 °C) and to decrease the hardness in WM and in HAZ to acceptable values in the examined SMAW joints.

In the SAW joints, the hardness values after PWHT reach acceptable levels. The impact properties at RT are acceptable and over the minimum requirements, although a little bit lower than the values obtained in the SMAW joints, as a probable consequence of the slightly coarser microstructure developed (figures 11 and 12).
The impact test results on SAW weld metal obtained on the 17,5 and 31,75 mm wall thickness pipes show that a PWHT at higher temperature seems to be more beneficial to improve the toughness of the weldments (89J (740°Cx2h) vs. 56J (710°Cx1,5h) at RT).

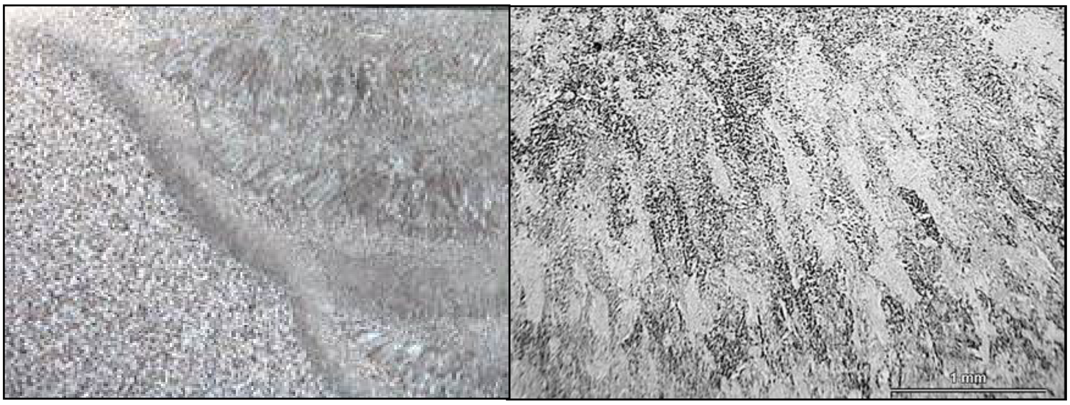

Figure 11 – P23 ODxWT 219x31.75 mm SMAW– left: macro; right: microstructure

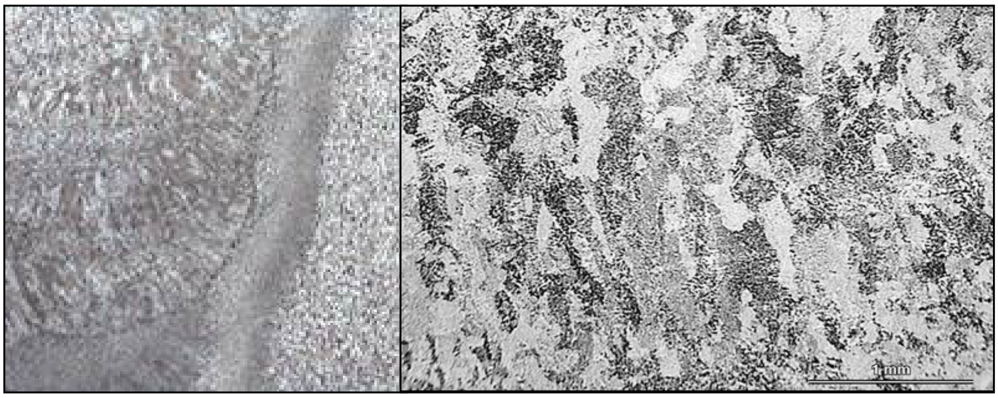

Figure 12 – P23 ODxWT 219x31.75 mm SAW – left: macro; right: microstructure

The welded joints creep tested fail within the 80% scattering band of the parent material. No significant differences between creep behaviour of as-welded and PWHT materials are observed.

5. CONCLUSION

Weldability tests were carried out on different sizes of grade 23 seamless pipes and tubes. The wall thicknesses covered in this study range from 12.5 to 31.75 mm. Both as-welded joints and PWHT joints were characterized.
The results obtained show that only the tubes ODxWT 76x12.5mm could be welded without PWHT, because impact energy in the weld metal is above the threshold of 27 J at room temperature even if the highest hardness reading in the heat affected zone is above 350HV10.

For larger wall thicknesses the PWHT is necessary and beneficial because reduces the hardness under 220 HV in SMAW joints and under 260 HV in SAW joints. Impact energy in the weld metal after PWHT of both SMAW and SAW joints satisfy the requirements of 27J at RT; SMAW weld metal is above 27 J even at -20°C.
These differences between SMAW and SAW joints are probably due to the coarser microstructure obtained in SAW joints: further tests are on-going in order to enhance the properties of SAW joints.
The creep strength of the welded joint was also characterized and lies within the 80% scatter band of the parent material mean line; long-term tests on welded joints are on-going.
The results obtained in the first part of this research activity, conducted on materials already available on the market, show that tubes, pipes and weld metal present satisfactory performances according to the relevant current standards.

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