Tenaris

Tenaris TEMPALOY AA-1

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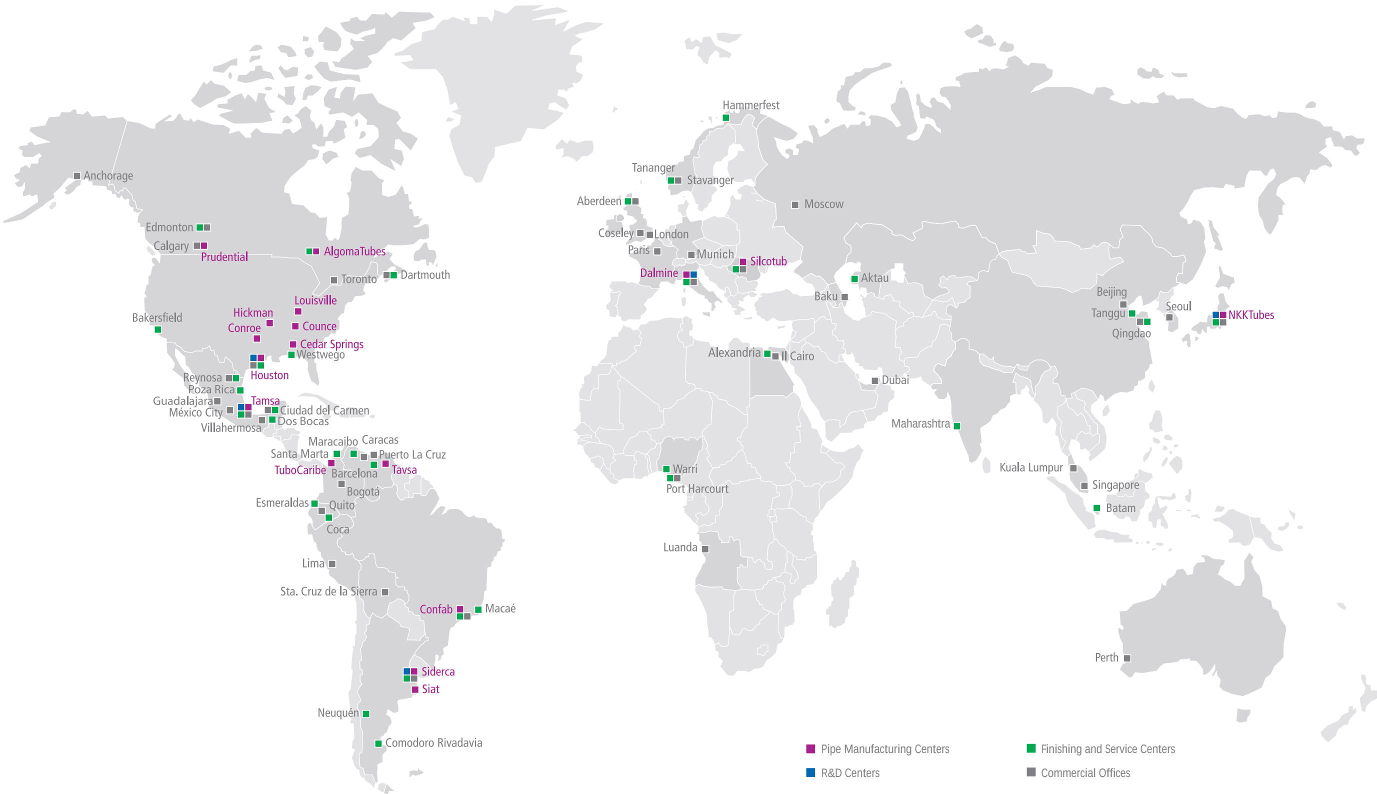


Cover page: Esbjerg power plant. Courtesy of DONG Energy A/S

Technical datasheet of Tenaris TEMPALOY AA-1

Introduction

Tenaris's TEMPALOY AA-1 is a 18Cr-10Ni-3Cu-Ti-Nb-B austenitic stainless steel developed for boiler construction, in particular for the fabrication of superheaters and reheaters.
Its specific chemical composition, developed and tailored by TenarisNKKTubes, produces a steel with extremely high creep and corrosion resistance. This is a key requirement for advanced materials used for super-critical and ultra-supercritical boilers.
Tenaris's TEMPALOY AA-1 is suitable for applications with steam temperatures up to 650°C (1202°F).
TEMPALOY AA-1 tubes are produced for Tenaris by Sanyo Special Steel Co. Ltd. in Japan.

Key features

- 18Cr-10Ni austenitic stainless steel with addition of 3%Cu, Nb, Ti and B to maximise creep strength
- Excellent and long-term stable creep properties up to 750 °C (1382 °F)
- High oxidation and corrosion resistance at elevated temperatures
- Possibility to perform internal shot-blasting to further increase steam oxidation resistance
- Maximum design temperature is 750 °C (1382 °F) according to ASME Code Case 2512
- Balanced chemical composition to avoid embrittlement after long term high temperature exposure.

TEMPALOY AA-1 - CHEMICAL COMPOSITION

TEMPALOY AA-1	C*	Mn	P	S	Si	Cr	Ni	Nb*	Ti*	B	Cu
Min	0.07	–	–	–	–	17.5	9.0	0.10	0.10	0.001	2.50
Max	0.14	2.00	0.040	0.010	1.00	19.5	12.0	0.40	0.25	0.004	3.50

Table 1 - Chemical composition according to ASTM A213 and ASME codes
* 2.0<(Ti+Nb/2)/C<4.0

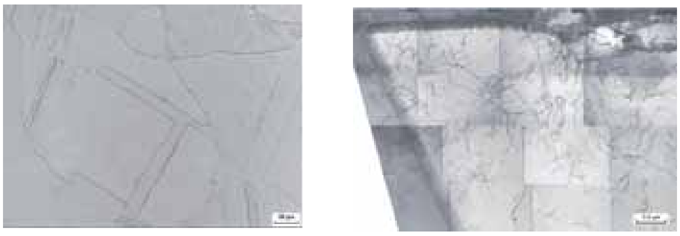


Fig.1 Microstructure of a tube ODxWT 50.8x10.3mm
Left: Optical Microscope; Right: Transmission Electronic Microscope

Applicable international codes and standards

- ASTM A213 S30434
- ASME Code Case 2512
- METI SUS321J2HTB
- TÜV application pending
- EN 10216-5 application pending

Chemical composition, microstructure and mechanical properties

The chemical composition, as specified by ASTM A213 and ASME Code Case 2512, is reported in Table 1.
Table 2 reports the minimum mechanical properties required by ASTM and ASME codes.

The level of Cr and Ni confers a stable austenitic structure free from δ-ferrite, as shown in fig. 1. The addition of Nb and Ti promotes the formation of fine MX type precipitates, besides Cr-rich $M_{23}C_6$.

Through the addition of Cu, a coherent Cu-rich phase precipitates, increasing significantly the creep resistance of the steel.

The studies performed by the R&D centre of TENARIS NKKTubes showed that an addition of 3% of Cu guarantees a significant increase of creep strength of the material (Fig.2).
The microstructure obtained is very stable, as confirmed by the long term creep and ageing tests performed on TEMPALOY AA-1 (Fig. 5).

Not only the creep performances of TEMPALOY AA-1 are outstanding, but this steel maintains also a high toughness after long exposure at service temperature. After ageing tests performed between 650 °C and 750 °C up to 10000h, TEMPALOY AA-1 shows impact values always above 100J/cm^2.
The heat treatment consists of a solution annealing at a temperature above 1160 °C (2120 °F) followed by rapid cooling in water or in other medium.

The heat treatment temperature range has been optimised to maximise the long term creep properties by promoting a fine and diffuse precipitation of MX carbides during exposure at service temperature.

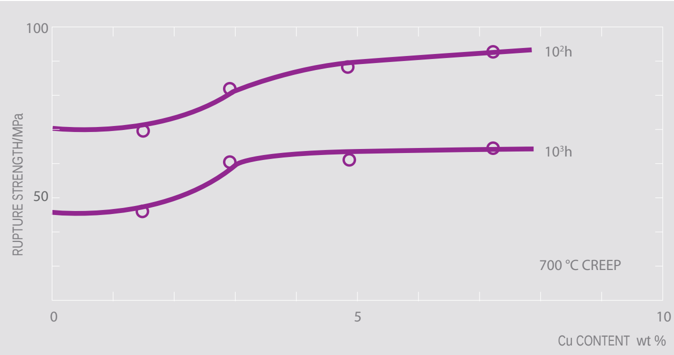


Fig. 2 – Effect of Cu on creep strength

MECHANICAL PROPERTIES

YS, min	205 MPa	30 ksi
UTS, min	500 MPa	73 ksi
Elongation in 2”, min	35%	

Table 2 – Mechanical properties at room temperature, as specified by ASTM A213

Creep properties and allowable stresses

TEMPALOY AA-1 has been extensively characterised regarding creep properties. Creep tests have been performed at 600, 650, 700, 750 and 800°C at different stresses with test durations also longer than 10^5h and with more than 1.5 million broken creep test hours. The ECCC (European Creep Collaborative Committee) guidelines have been followed for the assessment and PATs (Post-Assessment-Tests) have been successfully passed, confirming the quality and the consistency of the results. The assessed values are reported in Table 3.

AVERAGE CREEP RUPTURE STRESSES

TEMPERATURES	Stress (MPa) at Duration (h)					
(°C)	100	10000	30000	100000	150000	*200000
550	442	321	294	266	256	250
560	423	303	277	249	240	234
570	406	287	261	234	225	219
580	388	271	245	218	209	204
590	371	255	230	204	195	189
600	355	240	215	189	181	175
610	338	225	201	175	167	162
620	323	211	187	162	155	149
630	307	197	174	150	142	137
640	292	184	161	137	130	125
650	277	171	149	126	119	114
660	263	158	137	115	108	104
670	249	146	126	105	98	94
680	235	135	115	95	89	84
690	222	124	105	86	80	76
700	209	114	95	77	72	68
710	197	104	86	69	64	61
720	185	94	78	62	57	54
730	173	86	70	55	51	48
740	161	78	63	49	45	43
750	151	70	56	44	40	38

Table 3 – Assessed average creep rupture strength. The lower scatter band is usually defined as the 80% of the average creep strength
* Extrapolation at 200000 h not covered by PATs

The allowable stresses for the design according ASME rules are given in ASME code case 2512. The values are reported in Table 4.

ALLOWABLE STRESSES

Metal Temperature Not Exceeding [°C]	Allowable Stress Values [MPa]	Allowable Stress Values [MPa]	Metal Temperature Not Exceeding [°C]	Allowable Stress Values [MPa]	Allowable Stress Values [MPa]
-30 to 40	138	138	**425**	105	138 *
65	126	138 *	**450**	102	137 *
100	121	138 *	**475**	99.7	135 *
125	118	138 *	**500**	97.1	131 *
150	117	138 *	**525**	94.5	128 *
175	116	138 *	**550**	92.2	124 *
200	116	138 *	**575**	90.0	122 *
225	116	138 *	**600**	88.2	119 *
250	116	138 *	**625**	86.6	102 *
275	115	138 *	**650**	80.7	80.7
300	114	138 *	**675**	63.3	63.3
325	113	138 *	**700**	50.5	50.5
350	111	138 *	**725**	42.5	42.5
375	109	138 *	**750**	35.2	35.2
400	107	138 *			

Table 4 - Allowable stresses from ASME code case 2512 (table 3M)

GENERAL NOTE: The revised criterion of 3.5 on tensile strength was used in establishing these values.

NOTE: (*) Due to the relatively low yield strength of this material, these high stress values were established at temperatures where the short-time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 66 2/3%, but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.
(From ASME code Case 2512)

Physical properties

The main physical properties have been measured and are reported in Table 5.

PHYSICAL PROPERTIES

T [°C]	Cp [J/g*°C]	k [W/(mK)]	[10^{-6}/K] *
25	0,4552	14,75541	-
50	0,4602	14,97312	14,82
100	0,4702	15,47386	16,00
200	0,4902	16,63865	17,95
300	0,5102	17,92392	18,85
400	0,5302	19,27374	19,10
500	0,5502	20,66138	19,20
550	0,5602	21,36465	19,20
600	0,5702	22,07259	19,30
650	0,5802	22,97524	19,25
700	0,5902	23,86783	19,15
750	0,6002	24,22722	19,30
800	0,6102	24,53322	19,40

Table 5 – Main physical properties of TEMPALOY AA-1 (Tenaris data)

* Measured between 20 °C and the reference temperature

Steam oxidation and corrosion resistance

High temperature corrosion and steam oxidation resistance are key-parameters for the selection of boiler materials.
Specific tests were performed on TEMPALOY AA-1 to evaluate the corrosion resistance in simulated coal ash and heavy oil combustion atmospheres.

The results achieved show good corrosion resistance thanks to its high Cr content. Steam oxidation properties have also been evaluated at different temperatures.
The results of laboratory steam oxidation tests performed at different temperatures for 1000h are reported in Fig. 3 compared with the benchmark material, a type 321H stainless steel.

The optional shot-blasting operation on the inner tube surface increases significantly the steam oxidation resistance.
The cold working caused by the shot-blasting promotes a fast diffusion of Cr towards the inside surface, increasing locally the Cr concentration and consequently the oxidation resistance.

STEAM OXIDATION RESISTANCE

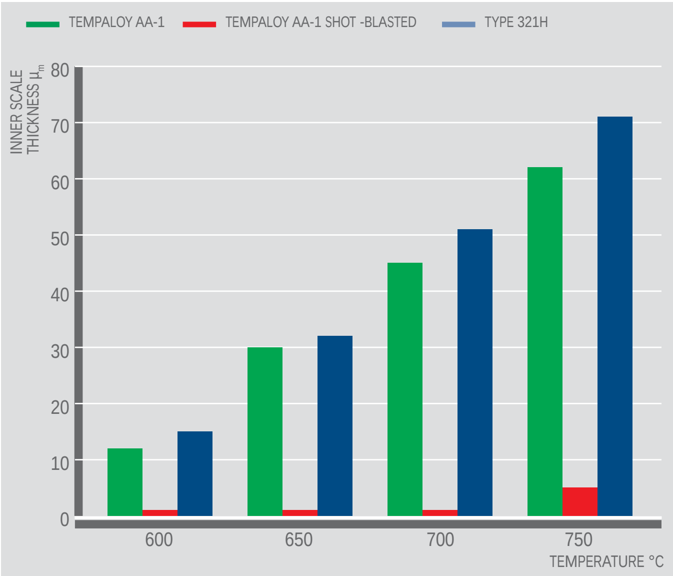


Fig. 3 - Steam oxidation of TEMPALOY AA-1 in standard and shot-blasted condition

Cold forming of TEMPALOY AA-1 tubes

Rules for heat treatment of cold bent TEMPALOY AA-1 tubes are given by ASME 2007 Section 1 PG-19.
If the finishing-forming temperature is below 1160 °C (2120 °F) or if percentage strain calculated as:

$$\% \text{ strain} = \frac{100\ r}{R}$$

(where r is the nominal radius of the tube and R the bending radius) exceeds the values indicated in table 6, a solubilization heat treatment is necessary.
The soaking time shall be 20 minutes per inch of thickness or 10 minutes, whichever is greater.
The minimum solubilization temperature shall be 1160 °C (2120 °F), while the maximum temperature shall be 1245 °C (2270 °F).

SOLUBILIZATION HT AFTER BENDING

Limitations in lower temperature range					Limitations in higher temperature range			Minimum heat treatment temperature when design temperature and forming strains are exceeded	
For design temperature				Forming strain exceeding	For design temperature exceeding		Forming strain exceeding		
Exceeding		But less than or equal to							
°F	°C	°F	°C		°F	°C		°F	°C
1000	540	1250	675	15% *	1250	675	10%	2120	1160

*: for simple bends of tube and pipes whose outside diameter is less than 3.5 in. (89mm), this limit is 20%

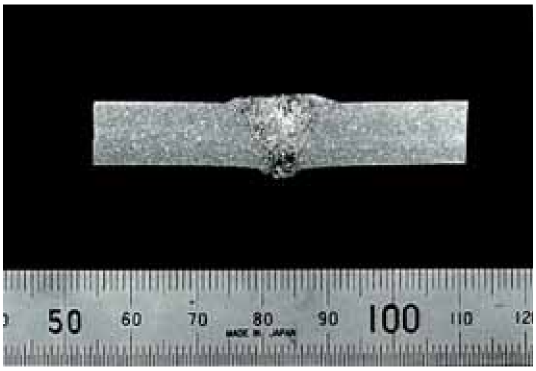
Table 6 – Rules for heat treatment of cold bent TEMPALOY AA-1 tubes, from ASME 2007 Section 1 PG-19.

Welding

TEMPALOY AA-1 tubes can be welded without pre-heating and PWHT. Specific similar welding consumables for GTAW and SMAW processes have been developed by Kobelco and are currently available on the market as TG-S1AS and NC-B1AS respectively.

The use of approved fillers guarantees optimum welding results and enhanced creep resistance of the welded joints.

Creep tests on cross welded joints produced with Kobelco welding consumables show a creep resistance of the welded joint perfectly in line with that of base material (Fig. 5)



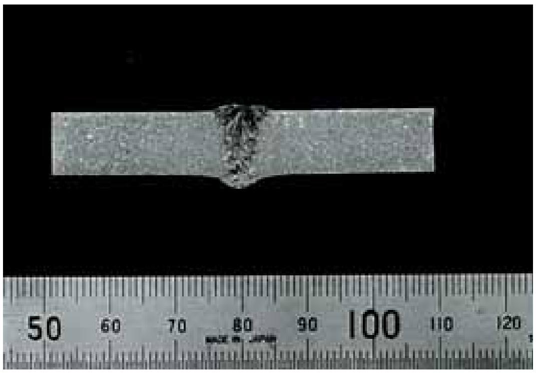


Fig. 4 – Macro sections of welded joints manufactured by GTAW process (left) and GTAW+SMAW (right)

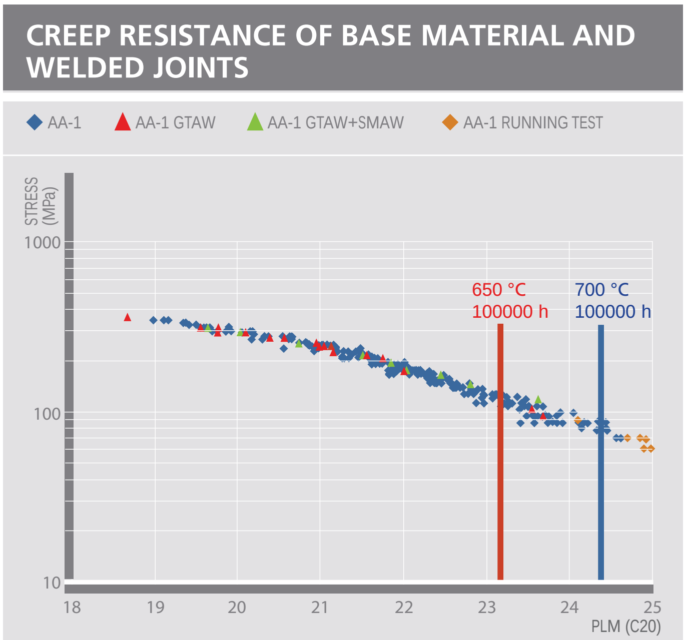
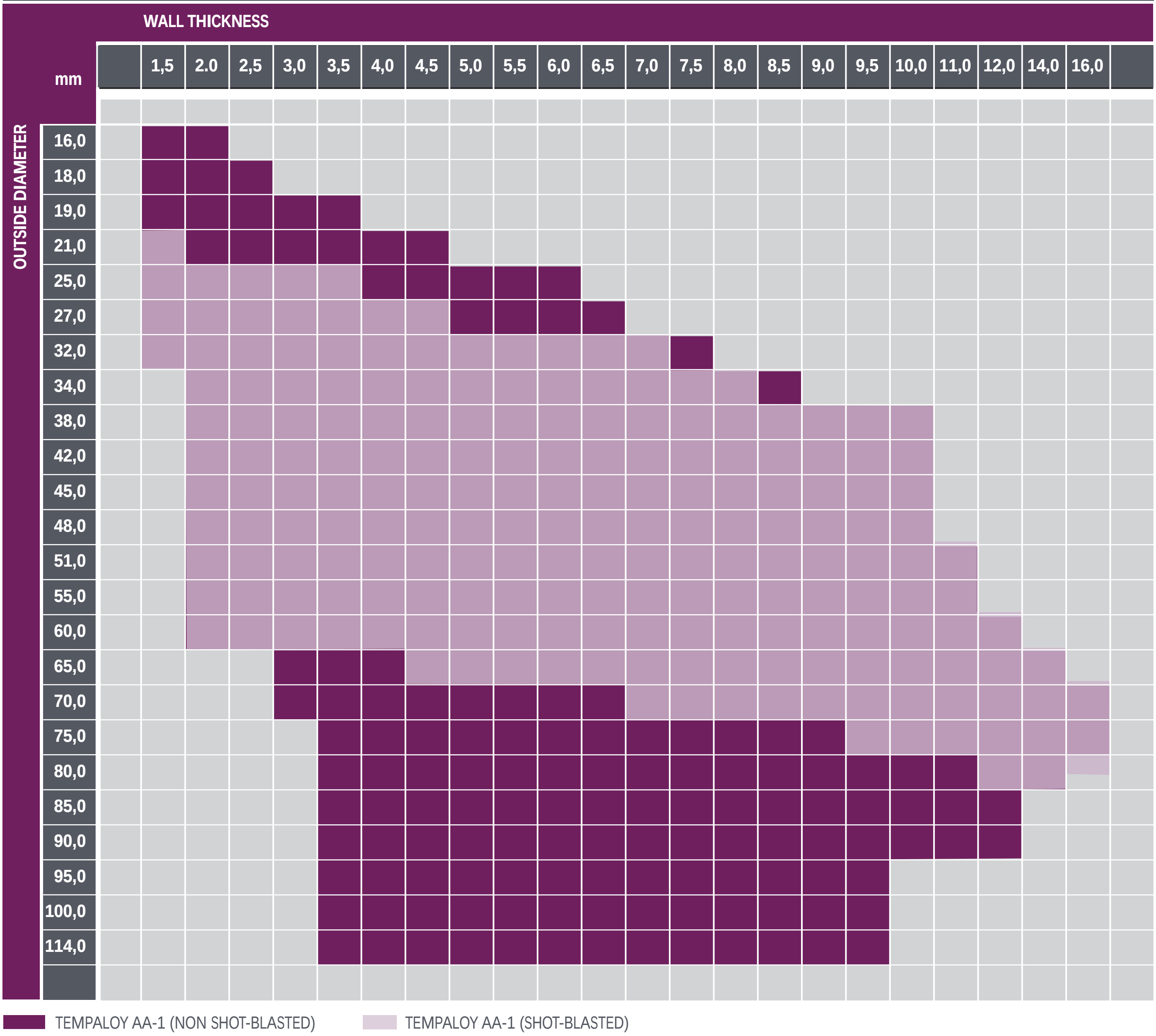


Fig. 5 – Tenaris creep data for TEMPALOY AA-1 base material and cross weld joints

FEASIBLE SIZE RANGE



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