REYNOLDS TECHNOLOGY LTD.

TUBE MATERIALS, PROPERTIES AND DIMENSIONS.

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Contents

The contents of this document are provided for general information and should only be used for design and manufacturing after due consideration of the alloy properties required.

Please contact Reynolds Technology Ltd if you have any questions: reytech@reynoldstechnology.biz

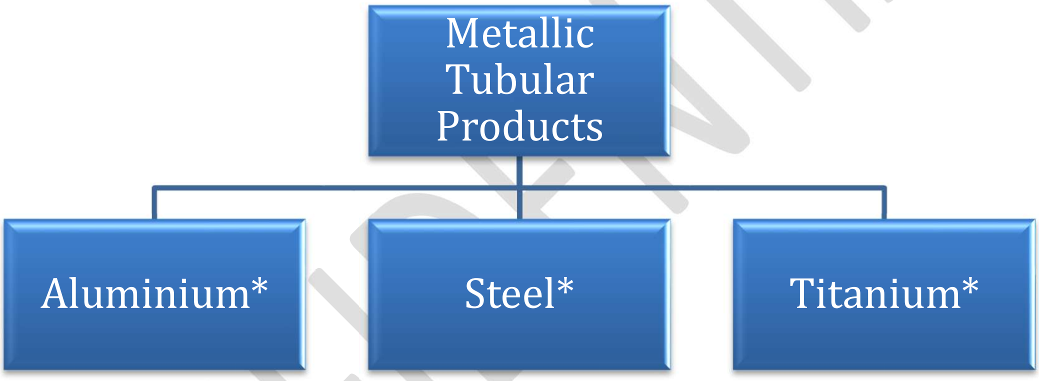
1- Reynolds Technology Ltd

1-1- Background

Birmingham-based **Reynolds Technology Ltd (RTL)** has a long history in the tube making industry. In particular, the Company is world renowned in the bicycle industry, with no fewer than 27 Tour de France champions crossing the finish line atop bicycles built with Reynolds tubing. As part of the TI Group PLC, it supplied "531" tubing to the automotive, motorcycle and wheelchair market.

Now a privately owned business, the company has invested in developing new materials. Reynolds aims to provide innovative, high quality products made from durable advanced materials to the aerospace, automotive, oil and sporting goods sectors.

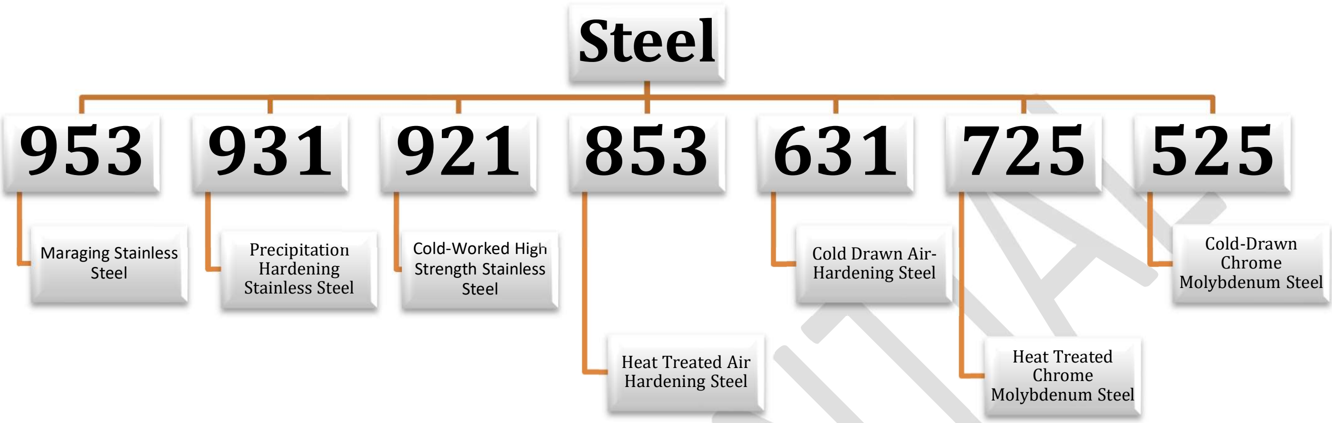
1-2- Materials/Process Capability



** For information please refer to our website (www.reynoldstechnology.biz OR www.rtl.cc)*

- MANUFACTURING BASE IN THE UK for specialist low volume alloys or custom-made steel and titanium tubing applications. Can include "**butted**" (variable wall thickness) tubes – see page 6.
- EXTRUSION of Aluminium profiles, made under license in South Africa and Taiwan.
- HYDROFORMED aluminium (6061/7005), made under license in China, with possible options in titanium and 4130 steel.
- OFFSHORE PRODUCTION of tubing for volume markets in mild steel, 4130 seamless and cold-drawn/welded Cr-Mo, 6061 and 7005 grade aluminium, made under license in Taiwan and China.

2- Materials: Reynolds Weldable Steel Brands Overview



Reynolds branding started with the legendary “531” used for cycle, motorcycle, automotive and aviation use commencing in 1935. For our steel products, the increasing brand number generally indicates higher strength based on the alloy content.

Reynolds 953: Stainless Maraging Steel, currently used as premium-melted, precision welded and cold-drawn tube with maximum tensile strength at 2000MPa. The combination of stainless properties and martensitic-aging makes this a great engineering alloy with very high specific strength.

Reynolds 931: Stainless Precipitation Hardening Steel based on the Custom 630/17-4PH grade alloy composition. Tubes can be either welded or seamless depending on the application. For 2022 this is now drawn and butted in the UK.

Reynolds 921: Cold worked, high strength austenitic stainless steel based on 21-6-9 grade alloy composition. High levels of manganese and nickel provide toughness whilst a high nitrogen content increases yield strength. Our raw material is a precision welded and cold-drawn tube made to aviation standards.

Reynolds 853: Seamless Air-hardening Steel, mainly cold-drawn and heat-treated. The air-hardening effect in the weld zone creates a fine grain structure, allied to the bainitic microstructure for this alloy, leading to fatigue life improvement.

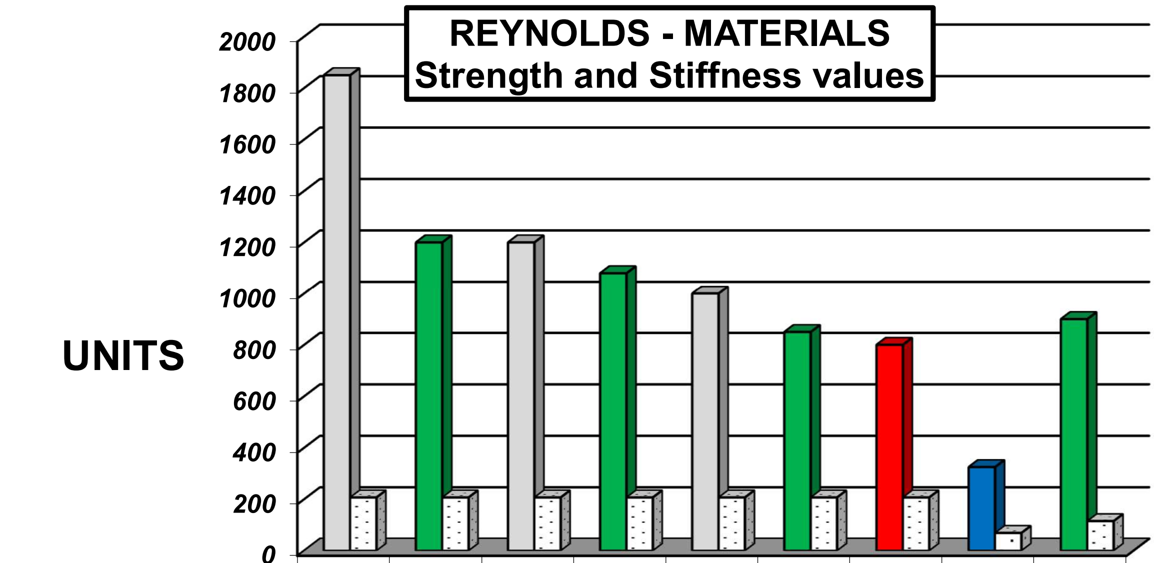
Reynolds 631: is the cold-drawn version of the 853, with similar air-hardening advantages in the weld zone.

Reynolds 725: Chrome-moly steel, based on the industry standard 4130 steel alloy. This tube range is heat-treated.

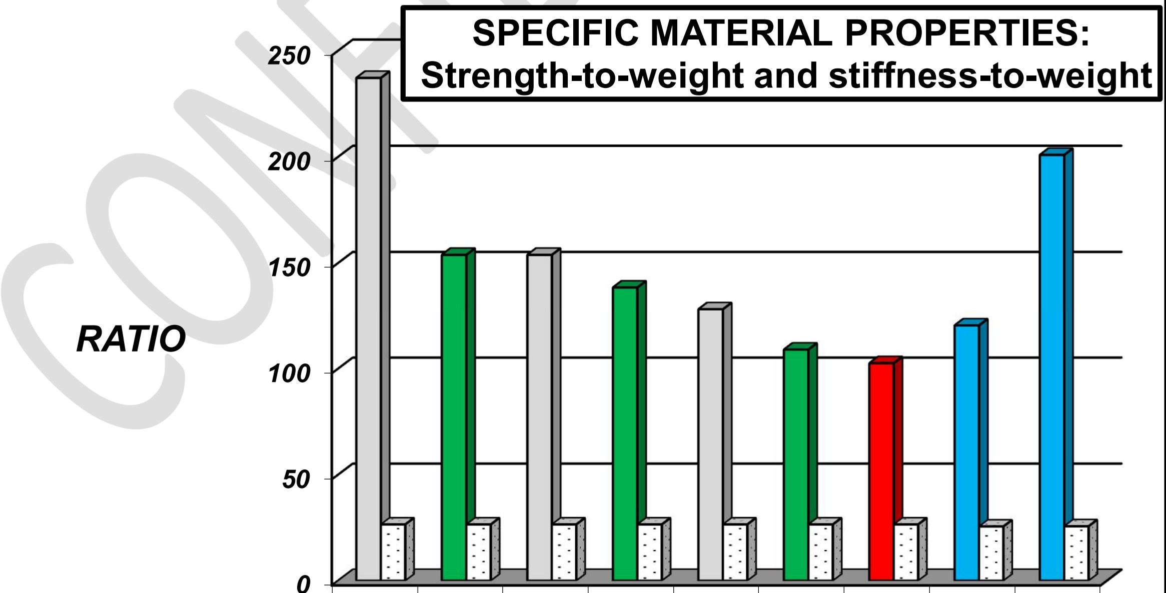
Reynolds 525: Also based on the 4130 steel. Our Reynolds 520 series is normally a welded, cold-drawn version.

2-1- Mechanical Properties – Reynolds Materials

Comparative values for UTS in MPa and Stiffness in GPa for metals used by Reynolds in previous applications to date including 6061-T6 Aluminium and 3Al-2.5V titanium.



	953	853	931	725	921	631	525	6061	3AL-2.5V
STRENGTH (MPa)	1850	1200	1200	1080	1000	850	800	325	900
STIFFNESS (GPa)	207	207	207	207	207	207	207	69	115



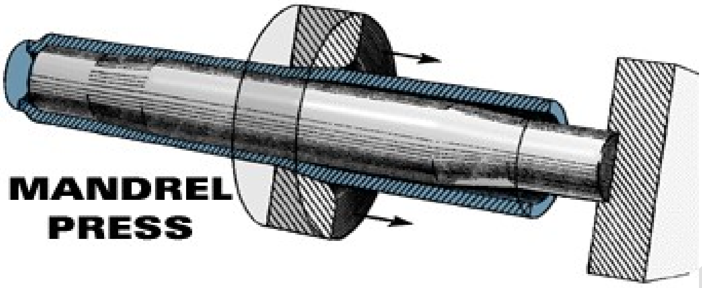
	953	853	931	725	921	631	525	6061	3AL-2.5V
STRENGTH	237	154	154	138	128	109	103	120	201
STIFFNESS	27	27	27	27	27	27	27	26	26

REYNOLDS Steel Brands		853	631	725	525	953	931	921
Elements								
Carbon	C	0.14-0.18	0.14-0.18	0.28-0.33	0.28-0.33	max 0.02	max 0.07	max 0.08
Silicon	Si	0.15-0.30	0.15-0.30	0.15-0.35	0.15-0.35	max 0.25	max 1.0	max 1.0
Manganese	Mn	1.6-1.8	1.6-1.8	0.40-0.60	0.40-0.60	Max 0.25	max 1.0	8.0-10.0
Phosphorus	P	max 0.025	max 0.025	max 0.035	max 0.035	max 0.015	max 0.04	max 0.06
Sulphur	S	max 0.025	max 0.025	max 0.04	max 0.04	max 0.01	max 0.03	max 0.03
Chromium	Cr	1.90-2.10	1.90-2.10	0.80-1.10	0.80-1.10	11.0-12.5	15.5-17.5	19.0-21.5
Molybdenum	Mo	0.45-0.60	0.45-0.60	0.15-0.25	0.15-0.25	0.75-1.25	0	0
Nickel	Ni	max 0.20	max 0.20	0	0	10.8-11.3	3.0-5.0	5.5-7.5
Copper	Cu	max 0.30	max 0.30	0	0	0	3.0-5.0	3.0-5.0
Tin	Sn	max 0.020	max 0.020	0	0	0	0	0
Aluminium	Al	0.02-0.040	0.02-0.040	0	0	0	0	0
Titanium	Ti	0	0	0	0	1.5-1.8	(Nb+Ta max 0.45)	0
Nitrogen	N	0	0	0	0	0	0	0.15-0.4

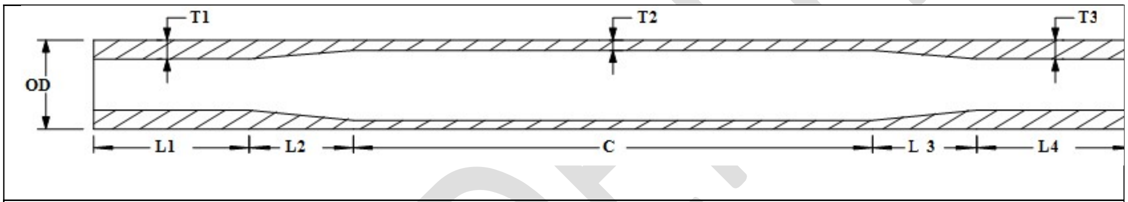
REYNOLDS Steel Brands	853	631	725	525	953	931	921
Mechanical Properties							
UTS (min) (MPa)	1200	800	1050	750	1650	1100	1000
YS (min) (MPa)	1000	650	800	600	1450	1000	800
E% min	8	10	8	10	8	8	20
Poisson's Ratio	0.34	0.34	0.34	0.34	0.30	0.32	0.29
Density (gms/cc)	7.8	7.8	7.8	7.8	7.8	7.8	7.8

N.B. SUBJECT to draw-pass method and heat-treatment

3- TUBE BUTTING: Invented by Reynolds in 1898 !



Tubes are cold-drawn through a die over a shaped mandrel, so that the tube has a constant OD and a variable ID. The wall thickness profile options depend on the material and route chosen including inter-pass annealing.



4- Dimensional Options for Steel Tubing.

Current production dimensional options for steel tubing ex UK factory:

- Butting draw bench (drawn over a shaped mandrel)- max length 750-780mm depending on diameter
- Conventional plug bar draw bench : plain gauge tubes to 4M.
- For low volume production using custom made mandrels, butted tubes can be made to ~ 1.2-1.4M depending on diameter requirements.

Based on the type of steel, raw materials and production system used typical dimensions for Reynolds tubular products are shown in the following table:

- ***Mechanical and Materials Properties***

Steel Type	**MARAGING STAINLESS STEEL**	**COLD-WORKED HIGH STRENGTH STAINLESS STEEL**	**AIR-HARDENING STEEL**		**CHROME-MOLY STEEL**		**3AL-2.5V TITANIUM**
Comment	Cold-Worked and Heat-Treated	Cold-Worked	Cold-Worked	Heat-Treated	Cold-Worked	Heat-Treated	Cold-Worked
Reynolds Brand	953	921	631	853	525	725	-
Maximum UTS (MPa)	2000	800-1000	850	1400	800	1200	900

- ***Dimensions***

	953/931		***921***		***631 / 853***		***525 / 725***		**TITANIUM**	
Draw Bench	Butting Draw Bench	Conventional Plug Bar Draw Bench**	Butting Draw Bench	Conventional Plug Bar Draw Bench	Butting Draw Bench	Conventional Plug Bar Draw Bench	Butting Draw Bench	Conventional Plug Bar Draw Bench	Butting Draw Bench	Conventional Plug Bar Draw Bench
Maximum Length (mm)	740	*	740	3000	740	3000*	740	Large Range* (up to 4000)	740	Various Sizes* (up to 3000)
OD Range (mm)	16 – 38.1	16-38.1	16-44.5	16-44.5	22.2-44.5	19.0-44.5*	19-41.3	Various Sizes* (16-44.5)	16.0-41.3	Various Sizes* (16-44.5)
Wall Thickness Range (mm)	0.35-0.7	0.7-0.8**	0.9-2.0	0.8-1.25	0.4 -2.2	0.9-2.5**	0.6-1.2	Various Sizes* (0.7-0.9)	0.65-1.00	Various Sizes* (0.7-0.9)

* Only used for custom applications and subject to Annealing/Heat-Treatment restrictions – 2-4M lengths.

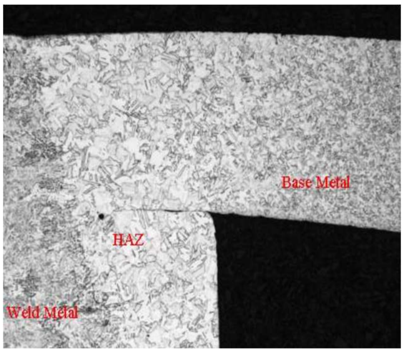
** wall thickness options depend on the raw material used, diameters and cold-working operations required.

Shape options e.g. ovals; square, conical are possible depending on material, tooling and design. OD/wall thickness combinations depend on the process route, maximum reduction in area limits and if interpass annealing (at sub-contractors) can be achieved for some products

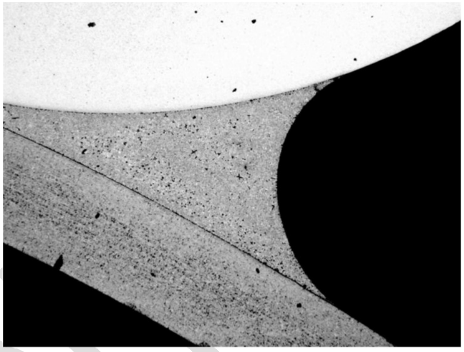
5- Tube Welding/Brazing Guidelines

5-1- Estimated Tube Yield Strength in Welded/Brazed Joints

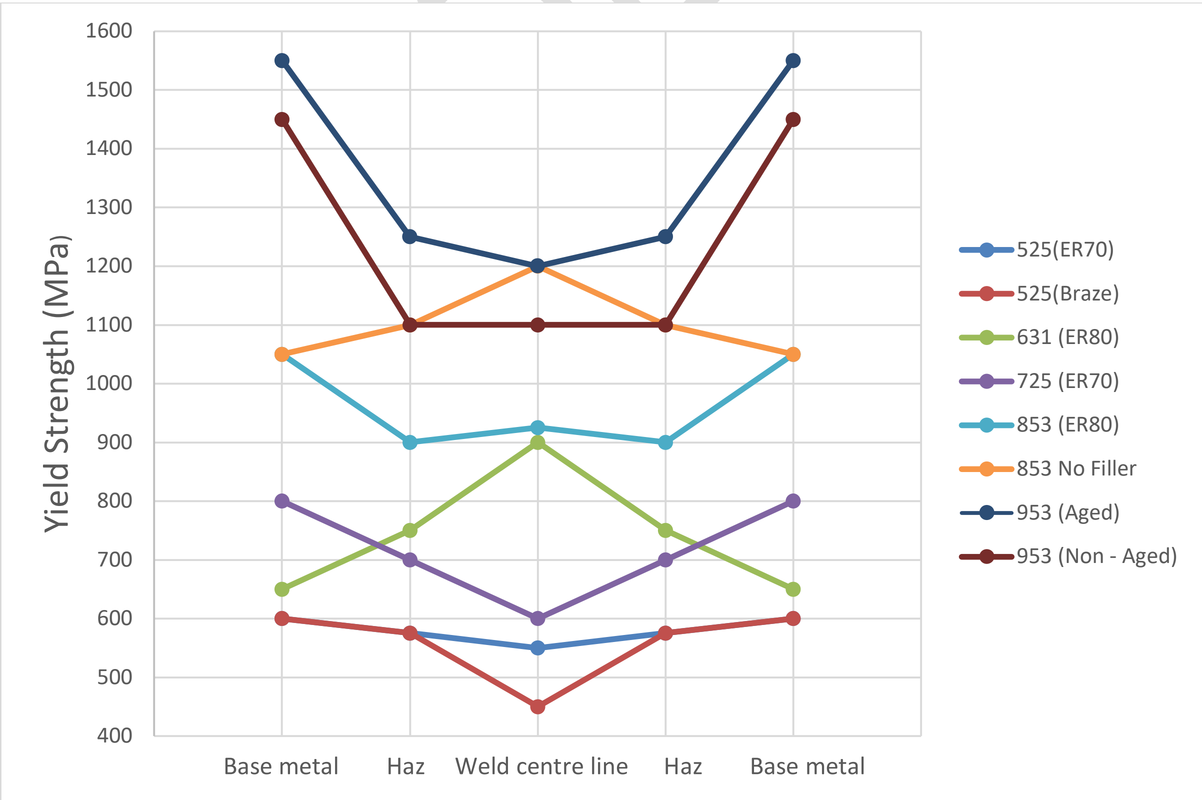
(Yield strength data is subject to validation but estimates are based on current knowledge and volume fraction data. In general, RTL expect a correlation between high strength in the edge of the HAZ and fatigue life). See page 9 for weld/braze guidelines.



Weld



Braze



Tube Yield Strength

5-2- TIG welding for Low Carbon and Air Hardening Steels (525/725/631/853)

For Reynolds 853/631 three typical rods are shown below.

The weld rods are typically as used for Cr-mo (e.g. our 525/725 brands) TIG welding:

Weld Rod	Reynolds Steel Brand	Weld Yield Strength (MPa)	Comment
ER70S-2	525/725	550-650	For Higher Strength Welds (Aircraft Frames), TIG.
	631/853	650-750	
ER70S-6	525/725	450-500	Including Mild Steels, and MIG welding
	631/853	500-550	
ER80S-2	525/725	700-800	For Higher Strength, Lower Ductility Welds
	631/853	900 -1000	

Note: Weld Wire for TIG process includes ER70S2 or ER80SD2.

Note that although the filler wire is less strong than the base metal, these wires are known to have good ductility after welding. Cr-Mo weld hardness typically average around 700-800 MPa, whilst 853/631 welds with the same wire can average over 1000 MPa due to the air-hardening benefit. Welding Cr-mo to our air-hardening steels is also common practice in the cycle industry, using TIG welding settings similar to those used for Cr-Mo steel. Mild steel plate can also be welded to 525/631/853 but check the weld joint strength will meet your design specifications.

For Motorsport applications, mild steel or Cr-Mo fittings can be welded to 631/853 tubing but care should be taken with thin walled fabrications.

5-3 TIG Welding for 921

For TIG welding of 921 it is recommended that Nitronic 40/50 wire is used. Welding of 921 to other stainless materials can be carried out as long as all other parts/fittings are to the 17-4 over-aged condition. Since the coefficient of thermal expansion for austenitic stainless steels is relatively high. Tube fit up and weld sequence should be considered to minimise distortion. As with any stainless. Use of a suitable purge gas is recommended to prevent oxidation of the weld.

5-4 Brazing for 921

Austenitic stainless steels such as 921 can be susceptible of inter-crystalline cracking when brazed at high temperatures. It is for this reason that Reynolds do not recommend fillet brazing recommends the use of silver braze alloys with working temperatures of between 670 and 750°C. Both oxy acetylene and oxy propane torch set ups can be used, though techniques should be modified to ensure heat input is kept to a minimum.

Reynolds hold stock of suitable silver filler and flux (Meta-braze™ 140 wire and Meta-braze™ LT 21 flux respectively).

5–5 Flux guidelines

Before commencing fluxing, The joint should be free from contamination (oil, grease and oxide scale should be all be mechanically removed). A layer of flux should then be applied to the joint surfaces before assembly of the parts.

Further flux should be applied externally either side of the joint mouth.

Tubes should then be heated slowly and evenly to brazing temperature without local overheating. During heating the flux will bubble as water is boiled off. The flux will turn from opaque to clear as the brazing temperature is reached.

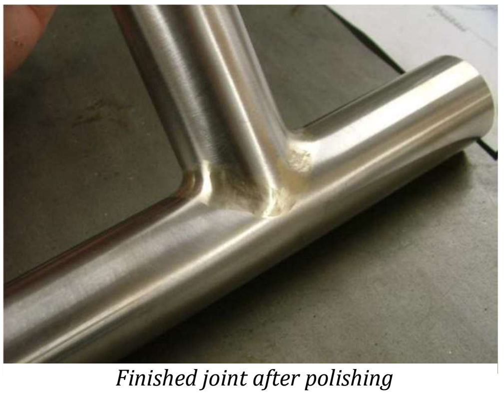
Tacked joint ready for fillet build up

Extra flux may need to be added after tacking and before the fillet is built up. Passes should be planned to minimize the total number of heat cycles experienced.

Tubes post brazing and prior to flux removal

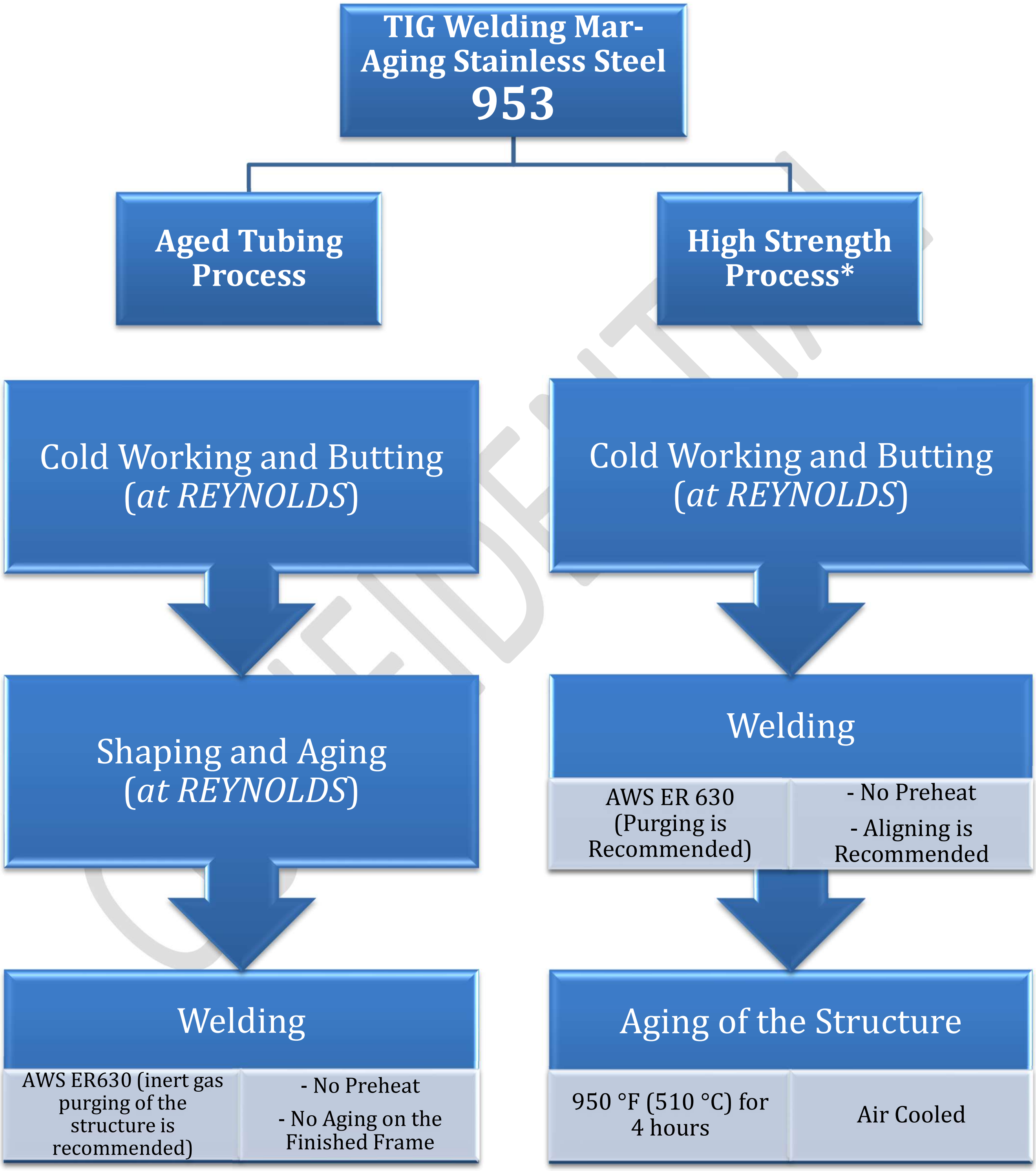
The residues of silver brazing fluxes, including Meta-braze™ LT 21, are corrosive and must be removed before any further processing of the parts take place. They should not be left on the parts after brazing. Soaking components in warm or hot water at ~60°C for >30 mins should be sufficient though, scrubbing in a stream of water will help remove stubborn residues.

post flux removal



Finished joint after polishing

5-6 TIG Welding for 953 - 2 options possible



** Suitable for thicker walls 0.7+mm and when additional strength in the weld zone is important. Note that the aging temperature can be altered to provide improved ductility where required.*

Final Properties of Structure;

Welding Process	Weld Rod	Weld Yield Strength (MPa)	Comment
Aged Tubing Process	AWS ER630	1100	Cold worked tubes will have cold worked plus age properties-around 1700-1950 MPA Tensile
High Strength Process*	AWS ER630	1200	Cold worked tube areas will have cold worked plus age properties - 1700-2050 MPA Tensile Strength

* Please note that for this process, there can be some titanium pickup in the weld zone after ageing that reduces ductility in this zone. We recommend full testing of fabricated structures for this method.

Final properties of each structure will depend on the tubes used, the wall thickness chosen and the welding method employed. Where lower strength/fatigue is acceptable for the design/fittings, 953 can be welded to lower strength 316L type stainless steel parts using suitable weld rods, or the higher strength 17-4PH grade stainless steel can be used where high tensile strength is required.

Brazed or lugged frames can be made; Reynolds recommends the use of silver braze alloys with working temperatures of between 670 and 750°C. Reynolds hold stock of suitable silver filler and flux (Meta-braze™ 140 wire and Meta-braze™ LT 025 flux respectively).

Machining of aged 953 tubing will be more difficult than lower strength alloys as tools will wear. Use plenty of coolant, sharp tooling and slow feed rates. Experiment with holesaw rpm, higher speeds seem to work better compared to the standard recommended stainless steel values.

5-7- TIG Welding for 931

The TIG process used will be similar to 853 but gas purge on the ID of the welded tubular structure is recommended for stainless steels. Although the optimum strength weld zone/structure will be achieved by heat-treatment within an aging oven (H900-H1050 options), this may not be practical. Good fatigue results can be achieved by using pre-aged tubes and welding with 17-4PH wire.

5-8- Brazing for 931

Reynolds 931 can be used for both lugged and fillet brazed construction. Reynolds recommends the use of silver braze alloys with working temperatures of between 670 and 750°C. Reynolds hold stock of suitable silver filler and flux for fillet brazing (Meta-braze™ 140 wire and Meta-braze™ LT 21 flux respectively.

6- Welding/brazing for dissimilar metals

Reynolds have undertaken testing on TIG welding of carbon steel (853) to stainless steel (921) using stainless 309 weld filler rods. As a bike frame, this combination in one typical frame design has passed EN fatigue testing. We are also aware that some builders have used 312 wire (non-stainless) for mild steel to lower strength 304/316 stainless steel fabrications. These options appear to be possible but each combination of materials used should be tested before commercial use.

Reynolds have also successfully brazed carbon steel parts to stainless steels using the Meta-Braze system.

7- Bending Guidelines

The following bending options are available at Reynolds Technology as an indication of bend radii and angles possible with 631 and 921 thin wall tubing without a mandrel bender:

O.D.	Wall Thickness (mm)	Bend Radius* CLR (mm)	Bend Degree	Comment
22.2	1.2	100	180°	“As-drawn” tube
31.8	1.15	150	90°	“As-drawn” tube
34.9	1.15	170	35°	“As-drawn” tube

* Specialist tube bending companies using mandrel/CNC bending and appropriate tooling should achieve smaller bend radii and/or higher “wraparound”

TC/23-12-21.