LINCOLN ELECTRIC
Lincoln Smitweld

GUIDELINES FOR WELDING

ZERON 100

SUPER DUPLEX STAINLESS STEEL

Zeron 100 ® is a super duplex stainless steel offering an excellent combination of corrosion resistance and high strength.

When welding Zeron 100 super duplex stainless steel, there are several factors that must be considered. This pamphlet highlights the main factors that must be taken into account. It relates particularly to welds to be used in this "as-welded" condition and welds that will be manually or submerged are welded. The same principles apply if post weld heat treatment is being applied or if GMAW-STT or orbital GTAW welding is being used.

PREPARATION FOR WELDING ZERON 100

Handling and Storage of Parent Material
All duplex stainless materials should be handled and stored under conditions which prevent contamination from other ferrous and non ferrous alloys.

Use stainless steel protective covers with storage racking, fork lift truck arms, overhead crane slings etc (or wood, plastic or non-metallic materials). Welding should be carried out in a contaminant free work area as recommended for other stainless steel fabrications.
Only qualified duplex stainless steel should be used for temporary attachments at the corrosion side. The minimum number of temporary attachments should be employed.

Handling and Storage of Welding Consumables
Welding consumables for Zeron 100 should be handled and stored in accordance with the manufacture's recommendations. In general, the consumables should be stored in an "electrode" store held at approximately 10°C above ambient temperature and with a relative humidity below 60%.

Opened packs of electrodes and flux should be baked in accordance with the manufacturers recommendations.

Identification of Materials to be Welded
Check against the welding procedure, specifications and drawings that the materials and welding consumables issued are correct and identified. Where it is necessary to mark materials using pens or paint markers, these must be free of chlorides, sulphides, halides and zinc.

Two grades of welding consumables are available.
- Zeron 100 "M" grade has a composition matching that of the parent material and should generally be used for joints to be solution annealed.
- Zeron 100 "X" grade is overalloyed with nickel and is intended for use in joints that are to be put into service in the as "welded" condition.

Autogenous welding of square close butt preparations can only be used under specific circumstances and its use needs to be considered on a case by case basis. Advice on specific situations can be supplied on request.

Welding Preparation
All welding and welding preparation is based on good stainless steel welding practice.

Welding Procedure Specification
Check that an appropriate WPS is available, outlining the welding procedure to be followed.

Tooling
Use only stainless steel grade cutting tools, grinding discs, grinding wheels, wire brushes and polishing wheels. Avoid at the corrosion side the use of power wire brushes so as not to smear the weld zone.

Joint Preparation
Welding bevels should preferably be prepared by cold methods. Where plasma cutting is used the process should be under water and at least 1 mm of material be ground to remove affected zone. When machining preparations, outline machining details are available from WML upon request. Recommended joint configurations for single sided welds are shown below. The recommended root gaps, root faces and joint angle are based on the need to:-

maximise production
minimise parent metal dilution in the root
control the heat input

For this reason control of the root gap is considered an important factor. Compound bevels must be balanced to ensure access whilst minimising joint volume.

TYPICAL JOINT CONFIGURATIONS

Manual Welding
The joints detailed in Fig.1 are for single sided manual welding with the GTAW or GMAW-STT process in the root. Other joints, for example 2 sided, are similar to those applied in general stainless steel practice.

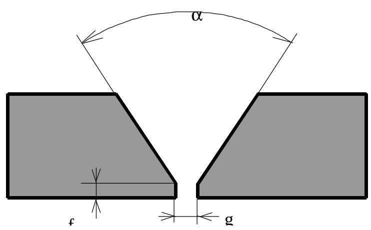
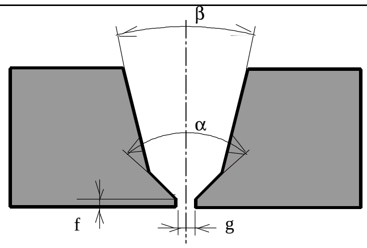
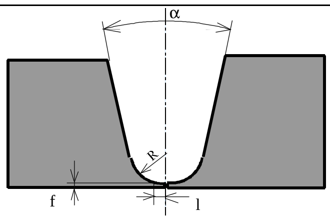
Joint geometry	Wall thickness t [mm]	Included angle [°] α	β	Land l [mm]	Root gap g [mm]	Root face f [mm]
	2 – 3	70 – 90	-	-	2 – 3	0.5 – 1.5
	> 4	70 - 80	-	-	2 - 3	0.5 – 1.5
	> 20	70 - 80	15 - 20	-	2 - 3	0.5 – 1.5
	> 20	15 - 30	R [mm] 4 - 6	0.5 - 2	2 - 3	0.5 – 1.5

Fig.1. Typical manual welding joint configurations

Automated Welding

For automated GTAW welding, a closed butt (zero root gap) may be used. The joint is designed to maximise the filler addition to the root bead and to achieve adequate root bead thickness. Care must be taken to ensure that there is sufficient filler metal addition. A typical joint is shown in Fig.2.

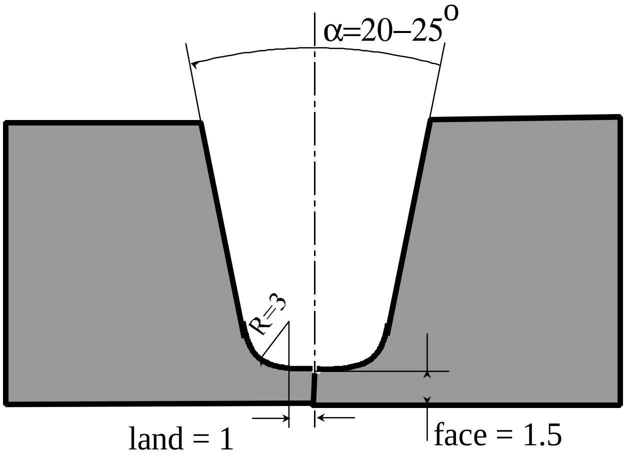


Fig.2 Typical automated weld joint configuration

Welding Equipment

There are no specific welding equipment requirements associated with Zeron 100 over and above good stainless steel welding practice.

As with sophisticated stainless steel welding, slope in/out facilities together with pre and post gas purge are important requirements for GTAW welding plant. Equipment with pulsed arc facilities is considered beneficial for GTAW and GMAW welding of Zeron 100 due to optimal control of heat inputs.

Newer processes where high deposition rates are achieved with lower heat inputs are particularly suited for welding Zeron 100 super duplex stainless steel. Processes such as GMAW-STT®*, GTAW-DSP®** and the use of consumable socket rings are typical of recent developments. Further details are available on request.

Joint Cleanliness

Joint faces and pipe/vessel surfaces 50mm either side of joint seam should be clean and degreased using acetone and lint free cloth. Abrasive cleaning is rarely necessary. Should mechanical cleaning be necessary, light grinding or grit (alumina) blesting may be used.

* STT - Surface Tension Transfer - registrated trade mark of The Lincoln Electric Company

** DSP - Dual Sync Pulse Welding - registrated trade mark of Dimetrics Inc.

WELDING

Joint Fit Up

Line up clamps can be used to ssist joint fit up. The clamp may be either internal or external. Excessive mismatch of abutting joint edges ('Hi-Lo') should be avoided in order to ensure a satisfactory final root underbead profile and weld quality. Counterboring of tubular components should be carried out as normal to achieve the required fit up alignment. Care must be taken to avoid reducing the wall thickness excessively and to taper in the counterbore in accordance with the specification.

Joint fit up, and plate pre-setting, must be related to the normal distortion control techniques including balanced welding and back step welding.

Tack Welding

Several options are available:

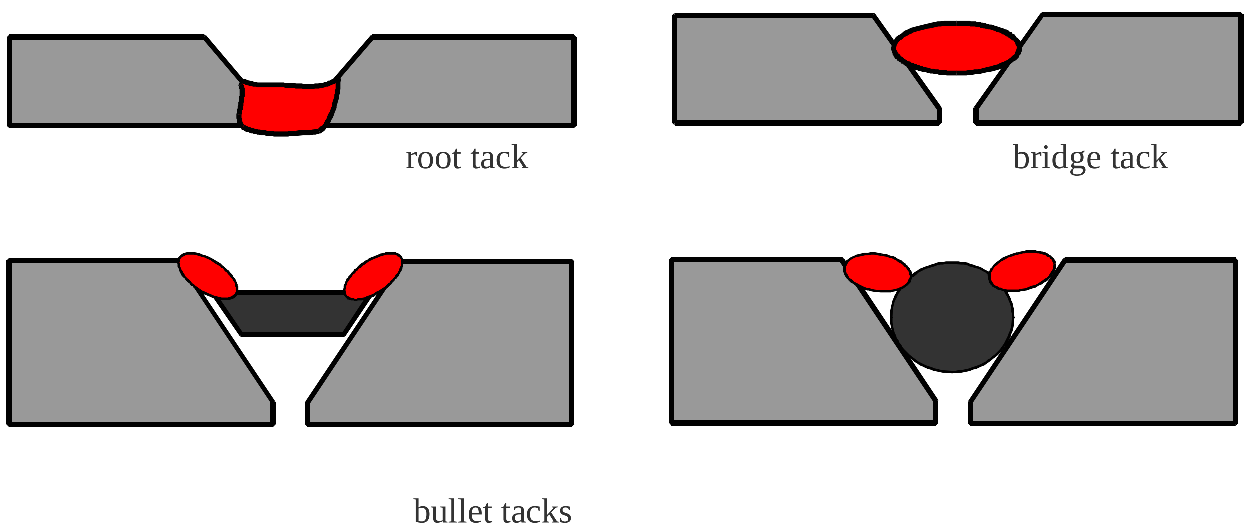


Fig. 3. Tack welding

Bridge tacks or spacer "bullet" blocks are recommended to maintain root gap and joint alignment. Plate joints must be pre-set as normal to couteract distortion. All spacer blocks are to be stainless steel and they should be tacked at a controlled heat input in accordance with the WPS.

Where tack welds are intended to form an integral part of the weld root bead, the root tack welds should be deposited in accordance with the approved WPS and the ends should be taper ground to ensure fusion with subsequent weld runs. Back purging should be employed when GTAW is used to deposit integral tacks

The tack welds should be balanced around the joint in order to maintain the root gap and joint alignment.

Back Purging

When welding Zeron 100, it is recommended that commercial purity argon is used to displace the air behind the joint. The oxygen content of that argon/air mixture must be monitored and controlled to ensure that sufficient nitrogen is retained in the backing gas "mixture" in order to inhibit loss of nitrogen from the weld pool. In practice the oxygen level of this mixture should be controlled at approx. 0.5% oxygen monitered at the start for the welding sequence. In this way, a positive partial pressure of nitrogen is maintained behind the joint thus preventing nitrogen loss from the root bead, whilst the oxidation produced remains acceptable. Subsequent passes to the root pass can be made with minimum oxygen contents.

The backing gas composition should be monitored at the joint line using a protable oxygen monitor immediately prior to starting or re-starting welding in order that consistency can be maintained. Adhesive tape low in sulphur and chloride is used around the open joint seam, and the tape should be removed progressively during the welding sequence.

Care should be taken to regulate the flow rate of the back purge gas to prevent gas turbulence and possible air entrainment through the open weld seam. The flow rate of the backing gas is typically 10-15 l/min although it is necessary to reduce flow rate at the tie-in location to avoid risk of expulsion of molten metal and root underbead concavity.

Gases containing hydrogen, eg., Formier gas, should not be used.

WELDING PROCEDURE

Preheat

Preheat is normally not required. It should only be applied where material is not dry or below 5°C prior to welding. Also in highly restraint constructions preheating up to 150 °C has shown to be benificial. Oxyfuel or carburizing flames should not impinge directly onto the material. Hot spots should not occur.

Heat Input

Heat input is the common parameter controlled during the welding process. However, when welding duplex/super duplex it is the cooling rate which controls the microstructure and so heat input should be controlled in conjunction with the joint thickness.
It is more effective in the control of optimum heat inputs to maintain faster welding travel speeds and associated higher welding currents rather than lower welding current and slower travel speeds.

Interpass

Interpass temperature, together with welding heat input, is important in optimising the cooling rate of a joint. Excessively high interpass temperature or heat inputs may impair the corrosion resistance and impact toughness of the joints. The interpass temperature and welding heat input must always be balanced in order to optimise the properties of the joint. If, for example, the heat input cannot be maintained in the appropriate range, it would be necessary to reduce the interpass temperature.

The maximum interpass temperature should be as detailed in the appropriate WPS and certainly less than 150°C.

The interpass temperature is measured immediately prior to any welding directly at the points where a weld run is to commence and where it is proposed to terminate. A contact thermocouple should be used. The weld zone must be below the interpass temperature before restarting welding.

The interpass temperature must be measured at each break in welding and not just when starting a new pass.

Root Pass

The GTAW process is normally specified to enhance control of root bead quality. Whilst fabricator choice and the practices used in a particular shop are very important, it is generally found that:

- 1.6 or 2.0 mm diameter filler wire is often used for material up to 4mm thick.
- 2.4 mm or 3.2 mm diameter filler wire is generallly used for other material thicknesses.

Welder preference can be considered but it should be recognized that it is benificial to deposit larger bead thicknesses within the heat input instructions.

Welding heat input (arc energy), must be controlled to avoid adversely slow weld cooling rates developing during welding cycles. Practical guidelines based on industrial experience are given in the table below:

Table 1 Typical root heat input and layer thicknesses

<table>
<tr><th>Wall thickness (mm)</th><th>Heat input (kJ/mm)</th><th>Typical pass thickness (mm)</th><td rowspan="4">* Heat Input = $\frac{\text{Amps x Volts x 60}}{\text{Travel Speed (mm/min) x 1000}}$ kJ/mm
OR
* Heat Input = $\frac{\text{Amps x Volts x Arc time(s)}}{\text{Run Out Length (mm) x 1000}}$ kJ/mm</td></tr>
<tr><td>2.88</td><td>0.4 – 0.6</td><td>2</td></tr>
<tr><td>7.11</td><td>0.8 – 1.2</td><td>3 – 3.5</td></tr>
<tr><td>17.5</td><td>1.5 – 1.8</td><td>3 – 3.5</td></tr>
</table>

It should be considered that one important variable that is not commonly controlled during manual GTAW welding is filler metal addition. The typical root pass thickness indicated in the table above is based on:

a) Welding into the controlled root gaps specified in figure 1.
b) Addition of maximum and consistent levels of filler metal into the weld pool to promote the optimum cooling rates.

An excessively thick root pass is generally associated with a too high heat input, where as too thin root pass is likely to result in burn through by the second pass. Root beads that are either too thick or too thin do, of course, result in practical welding problems and are likely to result in poor penetration bead profile. The root pass thickness shown is typical for the thickness being welded at the appropriate heat input.

It may be considered advisable to deposit weld beads as a series of balanced segments, for example such as shown in figure 4, as this offers the advantages of:

- Controlling joint gap closure
- Reducing overall joint distortion
- Maximising production whilst maintaining interpass temperature requirement.

The stop and start regions of all weld beads should be taper ground to facilitate smooth tie in. In GTAW welding industrial grade argon (99.995%) is recommended as shielding gas at typical flow rates of 8 - 12 l/min.

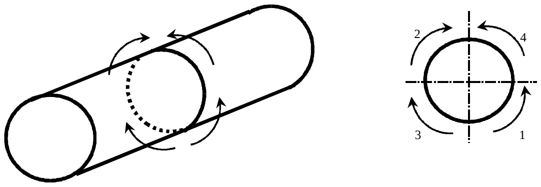


Fig. 4 Balanced joint sequences

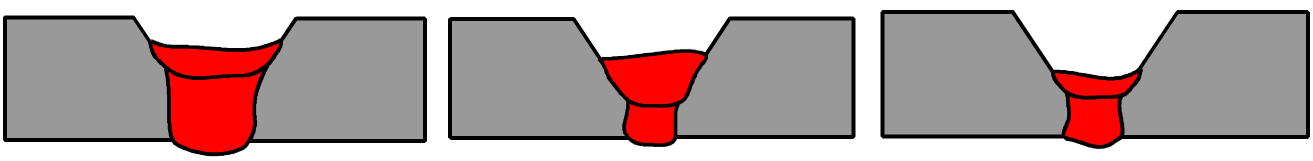
Nozzles incorporating a gas lens ensure good gas coverage and effective weld protection with the avoidance of gas turbulence where extended tungsten electrode stick out is being applied.

Slope down techniques at the termination of a weld to control phase balance should be used.

Second Layer 'Cold Pass'

The root weld bead upper surface should, if necessary, be dressed smooth and stainless steel wire brushed. However, grinding is rarely required.

As a general guide the second "cold" pass is deposited at lower heat inputs than that of the root pass. GTAW welding is normally used. Interpass temperature control as detailed previously must be maintained. It may be necessary to manipulate the weld pool in order to ensure that the pool is "washed in". This can be achieved by "flicking" the weld pool up onto the side wall. Weaving must be minimised. Single bead or split layer welding techniques can be used within heat input and joint configuration requirements. A single bead "cold pass" is prefered. The table below illustrates the effect of different root pass and 2nd "cold" pass heat input combinations.



root passes:			
	BAD: heat input too high	GOOD	GOOD
2nd run			
	GOOD	BAD: heat input too high	GOOD
Overall result			
	BAD: overheat root poor corrosion resistance	BAD: reheated root poor corrosion resistance	GOOD: optimum corrosion resistance

Fig. 5 Options in welding GTAW root and second pass; COLD PASS technique

Joint Filling Passes

Argon back purging of single sided welds should be maintained during welding of pipe and plate with weld deposit thicknesses up to 12mm to avoid progressive root underbead oxidation through reheating. The back purging of double sided welds can be stopped earlier.
Balanced weld sequences should be maintained for the initial 5mm of joint thickness. Control of interpass temperature and heat input should be maintained throughout the welding of the whole joint.

Joint Filling Using SMAW Process

Electrodes should be used directly from unopened containers, vacuum pack containers or from a 150°C minimum storage oven. All other sources of electrodes should be baked for 2hr at 250°C prior to welding.

Electrodes should be issued and stored on the job in heated quivers in quantities suitable for 4 to 5 hours production or consumed within 8 to 10 hours of removal from vacuum packaging.
Welding techniques are based on electrode manipulation avoiding distinct weaving and associated high heat input. Arc strikes should be avoided.

Electrodes should be operated within the amperage range recommended by the manufacturers. These are typically:

Table 2 Range of recommended SMAW electrode current settings

<table>
<tr><th>Electrode diameter [mm]</th><th>Current range DC + [A]</th><td rowspan="2">Zeron 100 is a Ferritic/Austentic Super duplex stainless steel and requires correct electrode handling procedures, in particular protection against mois ture pick-up.</td></tr>
<tr><td>2.5
3.2
4.0</td><td>50 – 65
70 – 90
100 – 140</td></tr>
</table>

Joint Filling Using GMAW Process

Both 1.0mm and 1.2mm diameter wires are available for welding. Multipass weld layers employing minimum weave and controlled heat input are advocated for joint filling. Argon/helium(CO_2) gas mixtures have been successfully used for welding.

Typical parameters for a butt in downhand (1G) position are given below:

Table 3 GMAW parameters for downhand position

Position	Wire diam. [mm]	Current [A]	Arc voltage [V]	Travel speed [mm/min]	Heat input [kJ/mm]	Gas flow [l/min]
1G	1.2	220 – 240	30 – 32	250 – 400	1.0 – 1.5	~ 20
5G/6G	1.0	80 – 95	30 – 32	200 – 300	0.6 – 0.8	~ 20

Welding practice should aim to combine the productivity benefits of the process with maintenance of heat input control.

Joint Filling with Submerged Arc/SAW Process

Submerged Arc Welding (SAW) combining fast deposition of high quality weld metal with mechanised process productivity, is a very variable alternative for joint filling with:

- Material thickness in excess of 15-20 mm
- Pipe or vessel diameters in excess of 150 mm
- Circumferential or longitudinal seams can be welded in the downhand (ASME: 1G) position.

The welding procedure with Zeron 100 is similar to that with standard austenitic stainless steels (316L etc) although in order to maintain requisite heat input/weld cooling rate control, use of smaller diameter wires (eg 2.4mm) and modest welding parameters is recommended. The comparitively fast travel speed and low heat input conditions facilitate the benefits of continuous (eg full circumferential) welding and a reduced level of interuptions associated with interpass temperature control.

Control of weld bead shape is very important. The depth.width ratio must be less than 1, which requires careful control of arc voltage, to avoid risk of centreline solidification cracking. Avoid too heavy beads per layer. The process is normally introduced to fill out joints following deposition of 8-10mm of TIG (GTAW) and MMA (SMAW) root weld layers. An interpass temperature of 150°C maximum throughout the joint is recommended.

The flux used must be maintained in a reliable dry condition, i.e., either directly from new, unopened, bags/drums or storage ovens operating at 250°C. Unfused flux recovered from the weld should be sieved and re-baked before further use.

With the agglomerated fluxes involved, excessive build-up of fines and a shift in flux grain size balance, resulting from repeated re-cycling, ultimately leads to deterioration in operating characteristics. To counter this effect, re-cycled flux should be diluted with new unused flux in a 1:1 ratio.

The recommended 25-30mm deep flux pile is intended to prevent arc flaring through the flux cover, leading to loss of arc/weld pool stability, possible entrainment of air into the arc cavity, potential risk of weld surface 'gas flats' and, at worst, internal porosity. Above 30mm, flux pile depth will tend to inhibit release of gases generated during welding.
With regard to electrode extensions, 'stick-out', less than 20mm, resistive heating effects and metal droplet detachment may become unstable, resulting in weld bead wander ('slalom effect').
Typical welding parameters are:

Table 4 SAW welding parameters

Wire diameter [mm]	Current DC + [A]	Arc voltage [V]	Travel speed [kJ/mm]	Heat input [kJ/mm]	Electrode extension [mm]	Flux height [mm]
2.4	280 – 350	28 – 30	450 – 500*	0.9 – 1.2	20 – 25	25 - 30

* Travel speeds up to 750mm/min may be required with smaller diameter, eg.6" (150mm) pipe

butt welds.

POST WELD CLEANING

Care should be taken to ensure that all flux or light spatter is removed from the weld zone. Careful light grinding may be used.

HEALTH AND SAFETY

Health and Safety requirements associated with welding Zeron 100 in relation to:

Electrical Equipment
Pressurised Gases
Personnel Protection
Fire
Fume
Arc Radiation

must be observed. If in doubt, your company Safety Officer should be consulted.

SUMMARY

Golden Rules

Many thousands of Zeron 100 joints have been successfully welded utilising and implementing this good welding practice. The main points to be remembered are:

1. Use good stainless steel fabrication practice.
2. Use a consitent joint fit up as detailed in qualified WPS.
3. Control of backing gas composition and flow rate.
4. Correct choice of heat input relative to the joint thickness.
5. Control of heat input during production welding of qualified WPS.
6. Ensure consistent and maximum filler wire additions are made.
7. Monitor and control the interpass temperatures and ensure that the maximum temperature quoted in qualified WPS is not exceeded.

CONTACTS

Technical Support Consumables

	Fred Neessen	Harm Meelker
Telephone:	+31 24 3522282	+31 24 3522411
Fax:	+31 24 3522272	+31 24 3522272
E-mail:	fneessen@lincolnelectric.nl	hmeelker@lincolnelectric.nl