Education and Culture

Leonardo da Vinci

Course: 141 - TIG WELDING OF STAINLESS STEEL

Module 7

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MODULE 7

Inspection and testing

In order to guarantee the application of all the fabrication procedures and the required properties for the product, appropriate inspections and tests shall be implemented during the manufacturing process

Location and frequency of such inspections and/or tests will depend on the contract and/or product standard, on the welding process and on the type of construction. As a general rule the state of inspection and testing of the welded product have to be indicated in some way. Such a means shall be adequate to the type of product; as an example, a Fabrication and Control Plan may be required for big products (on which the testing activities are marked); while routing cards or confined space inside the manufacturing plant shall be sufficient for small series product to indicate the inspection and testing status. Table 5 reports a typical chart for tests to be carried out before, during and after welding operations.

In some situations, the signature of the inspector[1] shall be required in order to enhance the traceability of the welding and related process activities. Moreover, the reference number of the relevant test report shall be included, if required.

All the procedures or instructions relevant to inspection and testing shall be made available to the inspection personnel, and properly controlled.

As to NDT, testing activities (method, technique and extension) shall be carried out in consideration of and in accordance with the quality level of the product. Some of those parameters are reported in the manufacturing codes, where the designer chooses the class of the weld taking into consideration all of the above mentioned factors. All these aspects should be considered during the design review phase by the welding coordinator.

[1] For some tests or checks (e.g. welding parameters, dimensional checks, visual testing, etc.) the welder or welding operator itself shall be considered as inspector.

TEST		Checked (date)	Signature of the inspector	Reference report
Tests before welding operations	**Reference procedure**			
Suitability and validity of welders qualification certificates				
Suitability of welding procedure specification				
Identity of parent material				
Identity of welding consumables				
Joint preparation (e.g. Shape and dimensions)				
Fit-up, jigging and tacking				
Special requirements in the welding procedure specification (e.g. Prevention of distortion)				
Arrangement for any production test				
Suitability of working conditions for welding, including environment				
Tests during welding operations				
Preheating / interpass temperature				
Welding parameters				
Cleaning and shape of runs and layers of weld metal;				
Back gouging;				
Welding sequence;				
Correct use and handling of welding consumables;				
Control of distortion;				
Dimensional check				
Tests after welding operations				
Compliance with acceptance criteria for Visual Testing				
Compliance with acceptance criteria for other NDT examinations (e.g. Radiographic or Ultrasonic Testing)				
Compliance for destructive testing (when applicable)				
Results and records of post-welding operations (e.g. PWHT)				
Dimensional checking.				

Template for testing and inspection chart.

Survey of specific weld imperfections and their cause (B5)

The main national and European norms and standards that can be applied for establishing the level of acceptance of the imperfections, depending on the used control process, are synthetically presented below.

Following will be presented the possible causes of imperfections' appearance, in relation with the welding process that was used:

111 - SMAW troubleshooting

PROBLEM	PROBABLE CAUSE	REMEDY
1. Arc weak, difficult to strike	a. Insufficient Amperage a. Faulty connection	a. Increase amp setting a. Check and secure all connections including work (ground) clamp
2. Electrode sticks to the plate	b. Insufficient Amperage c. Improper technique	b. Increase amp setting c. Review how to strike the arc
3. Lack of fusion	d. Insufficient Amperage e. Travel speed too high	d. Increase amp settings e. Reduce travel speed
4. Burn-through	f. Excessive Amperage g. Arc length too short h. Travel speed to slow i. Root opening too wide	f. Reduce amp setting g. Maintain 1/16-in. arc length h. Increase travel speed i. Reduce root opening, use a backup material
5. Inclusions	j. Insufficient Amperage k. Excessive arc length l. Uneven oscillations and/or travel speed m. Dirty plate	j. Increase amp settings k. Maintain 1/16-in. arc length l. Move electrode uniformly m. Remove rust, grease, paint, etc.
6. Porosity	m. Dirty plate n. Excessive amperage o. Excessive arc length	m. Remove rust, grease, paint, etc. n. Lower amp setting o. Maintain 1/16-in. arc length
7. Undercut	q. Excessive arc length r. Improper electrode angle s. Travel speed too high t. Excessive amperage	q. Maintain 1/16-in. arc length r. Direct electrode more into area of undercut s. Reduce travel speed t. Lower amp setting
8. Overlap	u. Improper electrode angle v. Travel speed too slow	u. Lower electrode angle v. Increase travel speed
9. Cracking	w. Bend too small or too concave x. Failure to fill craters y. Wet or dirty plate z. Wet or dirty electrode	w. Reduce travel speed x. Circle electrode at end of bead, re-strike to fill as required y. Dry or clean plate as needed

		z. Use only dry and clean electrodes
10. Excess spatter	aa. Excessive amperage (fine sized spatter) bb. Excessive arc length (large sized spatter)	aa. Lower amp setting bb. Maintain 1/16-in. arc length
11. Rough appearance	cc. Oscillations spaced too far apart dd. Improper travel angle	cc. Use more oscillations per inch of travel dd. Reduce travel angle
12. Arc blow	ee. Work (ground) clamp improperly located ff. Direct current	ee. Move clamp to different place relative to weld ff. Use ac if possible
13. Finger nailing (of flux)	gg. Flux coating cracked or chipped hh. Flux coating not concentric with rod	gg. Use undamaged electrode hh. Exchange for quality electrode

141 - TIG welding

Discontinuities and defects

Discontinuities are interruptions in the typical structure of a weldment, and they may occur in the base metal, weld metal, and heat-affected zones. Discontinuities in a weldment that do not satisfy the requirements of an applicable fabrication code or specification are classified as defects, and are required to be removed because they could impair the performance of that weldment in service.

Problems and corrections

Tungsten Inclusions

One discontinuity found only in gas tungsten arc welds is tungsten inclusions. Particles of tungsten from the electrode can be embedded in weld when improper welding procedure is used with 141 - TIG process. Typical causes are the following:

•contact of electrode tip with molten weld pool
•contact of filler metal wit hot tip of electrode
•contamination of electrode tip by spatter from the weld pool
•exceeding the current limit for a given electrode size or type
•extension of electrodes beyond their normal distances from the collet (as with long nozzles) resulting in overheating of the electrode
•inadequate tightening of the holding collet or electrode chuck
•inadequate shielding gas flow rates or excessive wind drafts resulting in oxidation of the electrode tip
•defects such as splits or cracks in the electrode
•use of improper shielding gases such as argon-oxygen or argon-CO_2 mixtures that are used for gas metal arc welding

•corrective steps are obvious once the causes are recognized and the welder is adequately trained.

Lack of Shielding

Discontinuities related to the loss of inert gas shielding are tungsten inclusions previously described, porosity, oxide films and inclusions, incomplete fusion, and cracking. The extent to which they occur is strongly related to the characteristics of the metal being welded. In addition, the mechanical properties of titanium, aluminum, nickel, and high-strength alloys can be seriously impaired with loss of inert gas shielding. Gas shielding effectiveness can often be evaluated prior to production welding by making a spot weld and continuing gas flow until the weld has cooled to a low temperature. A bright, silvery spot will be evident if shielding is effective.

Welding Problems and Remedies

Numerous welding problems may develop while setting up or operating a 141 - TIG operation. Their solution will require careful evaluation of the material, the fixturing, the welding equipment, and the procedures. Some problems that may be encountered and possible remedies are listed in the following table:

PROBLEM	PROBABLE CAUSE	REMEDY
1. Porosity	a. Entrapped gas impurities (hydrogen, nitrogen, air, water vapor a. Defective gas hose or loose hose connections a. Oil film on base metal	a. Blow out air from all lines before striking arc; remove condensed moisture from lines; use welding grade (99.99%) inert gas a. Check hose and connections for leaks a. Clean with chemical cleaner not prone to break up in arc; DO NOT WELD WHILE BASE METAL IS WET
2. Tungsten contamination of workpiece	Contact starting with electrode Electrode melting and alloying with base metal Touching tungsten to molten pool	Use high frequency starter; use copper striker plate Use less current or larger electrode; use thoriated or zirconium-tungsten electrode Keep tungsten out of molten pool

131/135 MIG/MAG

Hydrogen Embrittlement

An awareness of the potential problems of hydrogen embrittlement is important, even though it is less likely to occur with 131/135 MIG/MAG, since no hygroscopic flux or coating is used. However other hydrogen sources must be considered. For example, shielding gas must be sufficiently low in moisture content. This should be well controlled by the gas supplier, but may need to be checked. Oil, grease, and drawing compounds on the electrode or the base metal may become potential sources for hydrogen pick-up in the weld metal. Electrode manufacturers are aware of the need for cleanliness and normally take special care to provide a clean electrode. Contaminants may be introduced during handling in the user's facility. Users who are aware of such possibilities take steps to avoid serous problems, particularly in welding hardenable steels. The same awareness is necessary in welding aluminum, except that the potential problem is porosity caused by relatively low solubility of hydrogen in solidified aluminum, rather than hydrogen embrittlement.

Oxygen and Nitrogen Contamination

Oxygen and Nitrogen Contamination are potentially greater problems than hydrogen in the 131/135 MIG/MAG process. If the shielding gas is not completely inert or adequately protective, these elements may be readily absorbed from the atmosphere. Both oxides and nitrides can reduce weld metal notch toughness. Weld metal deposited by 131/135 MIG/MAG is not tough as weld metal deposited by gas tungsten arc welding. It should be noted here, however, that oxygen in percentages of up to 5 percent and more can be added to the shielding gas without adversely affecting weld quality.

Cleanliness

Base metal cleanliness when using 131/135 MIG/MAG is more critical than with 111 - SMAW or submerged arc welding (121 SAW). The fluxing compounds present is 111 - SMAW and 121 SAW scavenge and cleanse the molten weld deposit of oxides and gas-forming compounds. Such fluxing slags are not present in 131/135 MIG/MAG. This places a premium on doing a thorough job of preweld and interpass cleaning. This is particularly true for aluminum, where elaborate procedures for chemical cleaning or mechanical removal of metallic oxides, or both, are applied.

Incomplete fusion

The reduced heat input common to the short-circuiting mode of 131/135 MIG/MAG results in low penetration into the base metal. This desirable on thin gauge materials and for out-of-position welding. However, an improper welding technique may result in incomplete fusion, especially in root areas or longer groove faces.

Weld Discontinuities

Some of the more common weld discontinuities that may occur with the 131/135 MIG/MAG process are listed in the following paragraphs.

Undercutting

The following are possible causes of undercutting and their corrective actions:

POSSIBLE CAUSES	CORRECTIVE ACTIONS
1. Travel speed to high	Use slower travel speed
2. Welding voltage too high	Reduce the voltage
3. Excessive welding current	Reduce wire feed speed
4. Insufficient dwell	Increase dwell at edge of molten weld puddle
5. Torch angle	Change angle so arc force can aid in metal placement

Porosity

The following are the possible causes of porosity and their corrective actions:

POSSIBLE CAUSES	CORRECTIVE ACTIONS
1. Inadequate shielding gas coverage	Optimize the gas flow. Increase gas flow to displace all air from the weld zone. Decrease excessive gas flow to avoid turbulence and the entrapment of air in the weld zone. Eliminate any leaks in the gas line. Eliminate drafts (from fans, open doors, etc.) blowing into the welding arc. Eliminate frozen (clogged) regulators in CO_2 welding by using heaters. Reduce travel speed. Reduce nozzle-to-work distance. Hold gun at the end of weld until molten metal solidifies.
2. Gas contamination	Use welding grade shielding gas.
3. Electrode contamination	Use only clean and dry electrode.
4. Workpiece contamination	Remove all grease, oil, moisture, rust, paint, and dirt from work surface before welding. Use more highly deoxidizing electrode.
5. Arc voltage too high	Reduce voltage
6. Excess contact tube-to-work distance	Reduce stick-out

Incomplete fusion

The following are the possible causes of incomplete fusion and their corrective actions:

POSSIBLE CAUSES	CORRECTIVE ACTIONS
1. Weld zone surfaces not free of film or excessive oxides	Clean all groove faces and weld zone surfaces of any mill scale impurities prior to welding.
2. Insufficient heat input	Increase the wire feed speed and the arc voltage.

	Reduce electrode extension.
3. Too large a weld puddle	Minimize excessive weaving to produce a more controllable weld puddle. Increase the travel speed.
4. Improper weld technique	When using a weaving technique, dwell momentarily on the sidewalls of the groove. Provide improved access at root of joints. Keep electrode directed at the leading edge of puddle.
5. Improper joint design	Use angle groove large enough to allow access to bottom of the groove and sidewalls with proper electrode extension, or use a "J" or "U" groove.
6. Excessive travel speed	Reduce travel speed.

Incomplete joint penetration

Possible causes of incomplete joint penetration and their corrective actions are:

POSSIBLE CAUSES	CORRECTIVE ACTIONS
1. Improper joint preparation	Joint design must provide proper access to the bottom of the groove while maintaining proper electrode extension. Reduce excessively large root gap in butt joints, and increase depth of back gouge.
2. Improper weld technique	Maintain electrode angle normal to work surface to achieve maximum penetration. Keep arc on leading edge of the puddle.
3. Inadequate welding current	Increase the wire feed speed (welding current).

Excessive Melt-Through

The following are possible causes of excessive melt-through and their corrective actions:

POSSIBLE CAUSES	CORRECTIVE ACTIONS
1. Excessive heat input	Reduce wire feed speed (welding current) and the voltage. Increase the travel speed.
2. Improper joint penetration	Reduce root opening. Increase root face dimension.

Weld Metal Cracks

The following are possible causes of weld metal cracks and their corrective actions:

POSSIBLE CAUSES	CORRECTIVE ACTIONS

1. Improper joint design	Maintain proper groove dimensions to allow deposition of adequate filler metal or weld cross section to overcome restraint conditions.
2. Too high a weld depth-to width ratio	Either increase arc voltage or decrease the current or both to widen the weld bead or decrease the penetration.
3. Too small a weld bead (particularly fillet and root beads)	Decrease travel speed to increase cross section of deposit.
4. Heat input too high, causing excessive shrinkage and distortion	Reduce either current or voltage, or both. Increase travel speed.
5. Hot-shortness	Use electrode with higher manganese content (use shorter arc length to minimize loss of manganese across the arc). Adjust the groove angle to allow adequate percentage of filler metal addition. Adjust pass sequence to reduce restrain on weld during cooling. Change to another filler metal providing desired characteristics.
6. High restraint of the joint members	Use preheat to reduce magnitude of residual stresses. Adjust welding sequence to reduce restraint conditions.
7. Rapid cooling in the crater at the en of the joint	Eliminate craters by backstepping technique.

Heat-Affected Zone Cracks

Cracking in HAZ is almost always associated with hardenable steels.

POSSIBLE CAUSES	CORRECTIVE ACTIONS
1. Hardening in the heat-affected zone	Preheat to retard cooling rate.
2. Residual stresses too high	Use stress relief heat treatment.
3. Hydrogen embrittlement	Use clean electrode and dry shielding gas. Remove contaminants from the base metal. Hold weld at elevated temperatures for several hours before cooling (temperature and time required to diffuse hydrogen are dependent on base metal type).

Flux Cored Arc Welding (136 - FCAW) Troubleshooting

PROBLEM	PROBABLE CAUSE	REMEDY

1. Porosity	a. Low gas flow	Increase gas flowmeter setting clean spatter clogged nozzle.
	b. High gas flow	Decrease to eliminate turbulence
	c. Excessive wind drafts	Shield weld zone from draft/wind
	d. Contaminated gas	Check gas source Check for leak in hoses/fittings
	e. Contaminated base metal	Clean weld joint faces
	f. Contaminated filler wire	Remove drawing compound on wire Clean oil from rollers Avoid shop dirt Rebake filler wire
	g. Insufficient flux in core	Change electrode
	h. Excessive voltage	Reset voltage
	i. Excess electrode stick out	Reset stickout & balance current
	j. Insufficient electrode stick out (self-shielded electrodes)	Reset stickout & balance current
	k. Excessive travel speed	Adjust speed
2. Incomplete fusion or penetration	l. Improper manipulation	Direct electrode to the joint root
	m. Improper parameters	Increase current Reduce travel speed Decrease stickout Reduce wire size Increase travel speed (self-shielded electrodes)
	n. Improper joint design	Increase root opening Increase root face
3. Cracking	o. Excessive joint restrain	Reduce restraint Preheat Use more ductile weld metal Employ peening
	p. Improper electrode	Check formulation and content of the flux
	q. Insufficient deoxidizers or inconsistent flux fill in core	Check formulation and content of the flux

111 - SMAW

Porosity problems

Submerged arc deposited weld metal is usually clean and free of injurious porosity because of the excellent protection offered by the blanket of molten slag. When porosity does occur, it may be found on the weld bead surface or beneath a sound surface. Various factors that may cause porosity are the following:

- contaminants in the joint
- electrode contamination
- contaminants in the flux
- insufficient flux coverage
- entrapped flux at the bottom of the joint
- segregation of constituents in the weld metal
- excessive travel speed
- slag residue from tack welds made with covered electrodes

As with other welding processes, the base metal and electrode must be clean and dry. High travel speeds and associated fast weld metal solidification do not provide time for gas to escape from the molten weld metal. The travel speed can be reduced, but other solutions should be investigated first to avoid higher welding costs. Porosity from covered electrode tack welds can be avoided by using electrodes that will not leave a porosity-causing residue.

Cracking Problems

Cracking of welds in steel is usually associated with liquid metal cracking (hot cracking). This cause may be traced to the joint geometry, welding variables, or stresses at the point where the weld metal is solidifying. This problem can occur in both butt welds and fillet welds, including grooves and fillet welds simultaneously welded from two sides.

One solution to this problem is to keep the depth of the weld bead less than or equal to the width of the face of the weld. Weld bead dimensions may best be measured by sectioning and etching a sample weld. To correct the problem, the welding variables or the joint geometry must be changed. To decrease the depth of penetration compared to the width of the face of the joint, the welding travel speed as well as the welding current can be reduced.

Cracking in the weld metal or the heat-affected zone may be caused by diffusible hydrogen in the weld metal. The hydrogen may enter the molten weld pool from the following sources: flux, grease or dirt on the electrode or base metal. Cracking due to diffusible hydrogen in the weld metal is usually associated with low alloy steels and with increasing tensile and yield strengths. It sometimes can occur in carbon steels. There is always some hydrogen present in deposited weld metal, but it must be limited to relatively small amounts. As tensile strength increases, the amount of diffusible hydrogen that can be tolerated in the deposited weld decreases.

Cracking due to excessive hydrogen in the weld is called delayed cracking; it usually occurs several hours, up to approximately 72 hours, after the weld has cooled to ambient temperature. It is at ambient temperatures that hydrogen accumulated at small defects in the weld metal or base metal results in cracking.

To keep the hydrogen content of the weld metal low:
•remove moisture from the flux by baking in an oven (follow the manufacturer's recommendations).
•remove oil, grease, or dirt from the electrode and base material.
•increase the work temperature to allow more hydrogen to escape during the welding operation. This may be done by preheating or by post heating the weld joint.

Electroslag troubleshooting

LOCATION	PROBLEM	CAUSES	REMEDY
Weld	1. Porosity	1. Insufficient slag depth 1. Moisture, oil, or rust 1. Contaminated or wet flux	1. Increase flux additions 1. Dry or clean workpiece 1. Dry or replace flux
	2. Cracking	2. Excessive welding speed 3. Poor form factor 4. Excessive center-to-center distance between electrodes or guide tubes	2. Slow electrode feed rate 3. Reduce current; raise voltage; decrease oscillation speed 4. Decrease spacing between electrodes or guide tubes
	3.Nonmetallic inclusions	5. Rough plate surface 6. Unfused nonmetallics from plate lamination	5.Grind plate surfaces 6. Use better quality plate

Fusion line	4. Lack of fusion	7. Low voltage 8. Excessive welding speed 9. Excessive slag depth 10. Misaligned electrodes or guide tubes 11. Inadequate dwell time 12. Excessive oscillation speed 13. Excessive electrode to shoe distance	7. Increase voltage 8. Decrease electrode feed rate 9. Decrease flux addition; allow slag to overflow 10. Realign electrodes or guide tubes 11. Increase dwell time 12. Slow oscillation speed 13. Increase oscillation width or add another electrode 14. Decrease spacing between electrodes
	5. Undercut	14. Too slow welding speed 15. Excessive voltage 16. Excessive dwell time 17. Inadequate cooling of shoes 18. Poor shoe design 19. Poor fit-up	15. Increase electrode feed rate 16. Decrease voltage 17. Decrease dwell time 18. Increase cooling water flow to shoes or use larger shoe 19. Redesign groove in shoe 20. Improve fit-up; seal gap with refractory cement dam
Heat-affected zone	6. Cracking	20. High restraint 21. Crack-sensitive material 22. Excessive inclusions in plate	21. Modify fixturing 22. Determine cause of cracking 23. Use better quality plate

Oxyfuel gas welding

Weld quality

The appearance of a weld does not necessarily indicate its quality. It discontinuities exist in a weld, they can be grouped into two broad classifications: those that are apparent to visual inspection and those that are not. Visual examination of the underside of a weld will determine whether there is complete penetration and whether there are excessive globules of metal. Inadequate joint penetration may be due to insufficient beveling of the edges, too thick a root face, too high a welding speed, or poor torch and welding rod manipulation.

Oversized and undersized welds can be observed readily. Weld gages are available to determine whether a weld has excessive or insufficient reinforcement. Undercut or overlap at the sides of the welds can usually be detected by visual examination.

Although other discontinuities, such as incomplete fusion, porosity, and cracking, may not be externally apparent, excessive grain growth and the presence of hard spots cannot be determined visually. Incomplete fusion may be caused by insufficient heating of the base metal, too rapid weld travel, or gas or dirt inclusions. Porosity is a result of entrapped gases, usually carbon monoxide, which may be avoided by careful flame manipulation and adequate fluxing where needed. Hard spots and cracking are result of metallurgical characteristics of the weldment.