Fisheries and Oceans Canada
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Canadian Coast Guard
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Ekme#3113928

Integrated Technical Services


Safety First, Service Always


Materials Welding and Weld Inspection for Ship Construction and Repair

Guide

Canada

Published under the Authority of:
Integrated Technical Services Directorate
Fisheries and Oceans Canada
Canadian Coast Guard
Ottawa Ontario, K1A 0E6
http://intra.coast-guard.ca/ITS/Home

Disponible en français: Matériaux, du soudage et inspection des soudures pour la construction et la réparation des navires

MGCE #324469

Record of Amendments

#	Date		Description	Initials
1	May 2015	1st Edition		JK
2	October 2016	revised	enhancements to rolling direction of steel, positive material identification; atomic number limitations expanded for clarification; illustrations improved; technical review for accuracy and bilingual alignment.	LP

Office of Primary Interest (OPI)	Per Joanne Kane	(Tracey Clarke) 01 May 2015 Date:
Manager Hull, Mechanical and Electrical	Anne Marie Sekerka	Date: 01 May 2015
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Document Management

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Section 1 MATERIALS

This Materials Guide for Ship Construction and Repair was developed to assist the Delegated Representatives of the Director, Marine Engineering, Integrated Technical Services, Canadian Coast Guard, Fisheries and Oceans Canada, (hereafter referred to as “Delegated Representative”) to perform their duties more efficiently and accurately by offering frequently required technical information in a compressed format that is easily accessed. The information in this guide has taken into account the mission and responsibilities of Marine Engineering personnel for ship construction, maintenance and repair.

It should be noted, however, that even though the information contained herein has been compiled from the latest editions of the numerous reference materials, standards writing organizations and societies diligently update and improve or reconfirm the content of their documents at regular intervals. As such, the contents of this guide should be reviewed on a frequent basis for technical accuracy and suitability of purpose. For more detailed information than what is provided in this Guide, it is recommended that the user obtain and examine the source document and/or contact the issuing organization directly.

1.1 STEELS

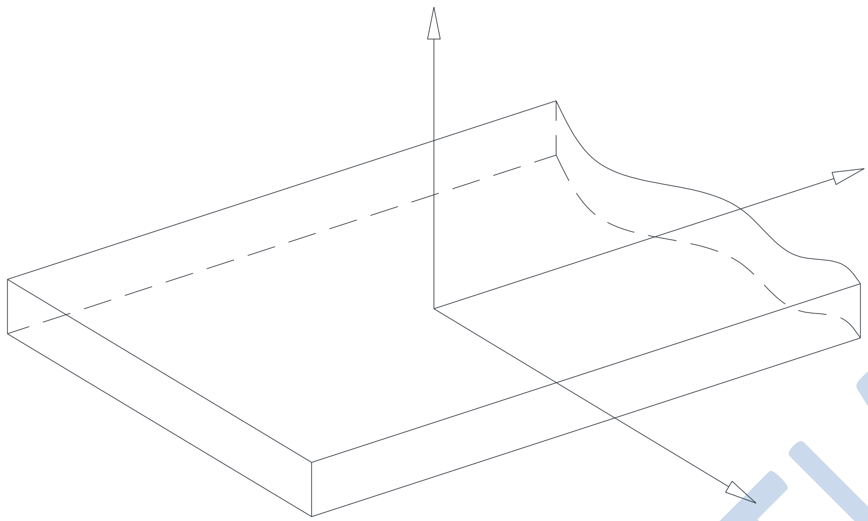
The International Association of Classification Societies (IACS) write and maintain common directives that each member Society is required to adopt by writing the spirit of the directives into their individual rules by a specified date determined by IACS. IACS also prepares guidelines and recommended practices documents which are not necessarily a mandatory unified requirement. As such, not all member Societies adopt the documents.

IACS unified requirements for materials can be found in UR W – Requirements Concerning Materials and Welding. The requirements for low carbon structural steel are located in Section W11 of UR W.

For low carbon structural steel, the designation systems generally categorize shipbuilding grades by the following:

- Deoxidation;
- Chemical composition;
- Condition of supply (heat treatment or mill rolling practice);
- Ultimate Tensile Strength (UTS), Yield Stress (YS) and Elongation;
- Charpy V Notch (CVN) toughness at various temperatures; and,
- Limitations on the maximum carbon equivalent (Ceq) value.

Low carbon structural steels are grouped and categorized as either “normal-strength” or "higher-strength" structural steels. Some Societies have requirements for "extra high-strength" structural steel and for “low temperature service” structural steels. The designation systems of each society are similar. Steels can have a "Z" notation indicating it has met specified through thickness mechanical properties.



1.1.1 Methods of Manufacture (IACS)

As Rolled, AR

This procedure involves the rolling of steel at high temperatures followed by air cooling. The strength and toughness properties of steel produced by this process are generally less than steel heat treated after rolling or than steel produced by advanced processes.

Normalizing, N

Normalizing involves heating rolled steel above the critical temperature followed by air cooling. The process improves the mechanical properties of as rolled steel by refining the grain size.

Controlled Rolling, CR (Normalizing Rolling, NR)

A rolling procedure in which the final deformation is carried out in the normalizing temperature range, resulting in a material condition generally equivalent to that obtained by normalizing.

Thermo-Mechanical Rolling, TM (Thermo-Mechanical Controlled Processing, TCMP)

This is a procedure which involves the strict control of both the steel temperature and the rolling reduction. Unlike controlled rolling, the properties of TM (TCMP) cannot be reproduced by subsequent normalizing or other heat treatment.

Accelerated Cooling, AcC

Accelerated cooling is a process, which aims to improve mechanical properties by controlled cooling with rates higher than air cooling immediately after the final TM-rolling operation. Direct quenching is excluded from accelerated cooling. The properties of TM and AcC cannot be reproduced by subsequent normalizing or other heat treatment.

Quenching and Tempering, QT

Quenching involves a process in which the steel is heated above the critical temperature and then cooled for the purpose of hardening the microstructure. Tempering subsequent to quenching is a process of heating the steel to a specified temperature to restore toughness properties by improving microstructure.

Click this link to watch a video on making steel by US Steel.

Table 1- Normal Strength Steels

Grades	"A"	"B"	"D"	"E"
De-oxidation Practice	For t < 50 mm, any method except rimmed (1) For t > 50 mm killed	For t < 50 mm, any method except rimmed For t > 50 mm killed	For t < 25 mm, killed For t > 25 mm killed & fine grain treated	All thicknesses killed & fine grain treated
Chemical Composition (% wt) (4) (7) (8)				
Carbon (max)	0.21 (2)	0.21	0.21	0.18
Manganese (min)	2.5 x C	0.80 (2)	0.60	0.70
Silicon (max)	0.50	0.35	0.35	0.35
Phosphorous (max)	0.035	0.035	0.035	0.035
Sulphur (max)	0.035	0.035	0.035	0.035
Al (acid soluble min)	-	-	0.015 (5)	0.015 (6)
Al (total content)	-	-	0.020	0.020
Condition Of Supply AR = As Rolled N = Normalizing CR = Controlled Rolling TM = Thermo-Mechanical Rolling	For t ≤ 50 mm, any method For t > 50 mm, N, CR or TM (9)	For t ≤ 50 mm, any method For t > 50 mm, N, CR or TM (9)	For t ≤ 35 mm, any method For t > 35 mm, N, CR or TM (9)	Fort ≤ 100 mm, N or TM (9)
Physical Properties				
Tensile Strength (N/mm^2)	400-520 (11)	400-520	400-520	400-520
Yield Stress (min) (N/mm^2)	235	235	235	235
Elongation	22% min.	22% min.	22% min.	22% min.
Notch Toughness				
Test Temperature	20°C	0°C	-20°C	-40°C
Average Energy (10)		(12)		
t ≤ 50 mm	Not required	27 J	27 J	27 J
50 mm < t ≤ 70 mm	34 J	34 J	34 J	34 J
70 mm < t ≤ 100 mm	41 J	41 J	41 J	41 J

Note 1: Grade A, t < 12.5 mm, may be rimmed subject to Society acceptance.
Note 2: Max 0.23% for sections.
Note 3: For Grade B, impact tested, may be reduced to 0.60%.
Note 4: Variations may be allowed or required for thermo- mechanical rolled condition.
Note 5: For Grade D > t 25 mm.
Note 6: Maximum may be specified by the Society & other grain refining elements may be used with acceptance by the Society.
Note 7: Society may limit amount of residual elements such as Cu and Sn.
Note 8: Content of any additional elements must be indicated.
Note 9: May be supplied As Rolled with Society Approval (see rules).
Note 10: Average minimum for longitudinal direction. For transverse direction, reduce 27 J to 20 J, 34 J to 24 J & 41 J to 27 J.
Note 11: For Grade A upper limit tensile strength may be exceeded at the discretion of the Society and if supplied fine grain practice and normalized or thermo-mechanical rolled impact tests are not required.
Note 12: For Grade B t < 25 mm, charpy-v-notch impact tests are generally not required.

Table 2 - Higher Strength Steels

Grades	"AH-XX"	"DH-XX"	"EH-XX"	"FH-XX"
De-oxidation Practice	Killed and fine grain treated.			
Chemical Composition (% wt) [(4) (6)]				
Carbon (max)	0.18			0.16
Manganese (min)	0.90-1.60 [(1)]			0.90-1.60
Silicon (max)	0.50			0.50
Phosphorous (max)	0.035			0.025
Sulphur (max)	0.035			0.025
Al (acid soluble min)	0.015 [(2) (3)]			0.015 [(2) (3)]
Nb	0.02 - 0.05 [(3)]			0.02 - 0.05 [(3)]
V	0.05 - 0.10 [(3)]			0.05 - 0.10 [(3)]
Al + Nb + V total (max)	0.12			0.12
Ti (max)	0.02			0.02
Cu (max)	0.35			0.35
Cr (max)	0.20			0.20
Ni (max)	0.40			0.80
Mo (max)	0.08			0.08
N (max)	-			0.009 or 0.012 if Al is present
Carbon Equivalent [(5) (7)]				

Note 1: Manganese content may be reduced to 0.70 for t < 12.5 mm.

Note 1: Total aluminum content method not less than 0.020%.

Note 1: In combination with other grain refining elements, the minimum is not applicable.

Note 1: When any grade is supplied in the TM condition, variations in chemical composition may be society allowed or required.

Note 1: When required the Carbon Equivalent (Ceq) value is to be calculated from the ladle analysis using the following formula: Ceq=C+(Mn/6)+ (Cr+Mo+V/5)+(Ni+Cu/15) (%).

Note 1: Other elements not listed herein are to be indicated.

Note 1: Hydrogen induced cold cracking susceptibility can be calculated using the following formula: Pcm=C=(Si/30)+(Mn/20)+(Cu/20)+(Ni/20)+(Cr/20)+(Mo/15)+(V/10)+5B (%).

For Thermo-Mechanical Rolled (TM & TMCP) higher strength steels < 100 mm in thickness, carbon equivalents shall not exceed the following:

Grade	t ≤ 50 mm	50 mm < t ≤ 100 mm
“XX-32”	0.36% max.	0.38% max.
“XX-36”	0.38% max.	0.40% max.
“XX-40”	0.40% max.	0.42% max.

Higher Strength Steels (cont’d) - Condition of Supply

Grades	AH-32/36	DH-32/36	EH-32/36

Grain Refining Elements			
Any	N/A	N/A	t < 100 mm, N or TM
Nb and/or V	t ≤ 12.5 mm, any 12.5 mm < t ≤ 100 mm, N, CR or TM	t ≤ 12.5 mm, any 12.5 mm < t ≤ 100 mm, N, CR or TM	N/A
Al alone or + Ti	t ≤ 20 mm, any 20 mm < t ≤ 35 mm any, AR subject to society approval 35 mm < t ≤ 100 mm, N, CR, TM	t ≤ 20 mm, any 20 mm < t ≤ 25 mm any, AR subject to society approval 25 mm < t ≤ 100 mm, N, CR, TM	N/A

AR=As Rolled	N = Normalizing	CR = Controlled Rolling	TM = Thermo-Mechanical Rolling	QT= Quench and Tempered

For other grades of material consult Table 5 of IACS W11

Grades Physical Properties	AH-XX	DH-XX	EH-XX	FH-XX
Tensile Strength (N/mm²)				
"XX"- 32	440-570			
"XX"- 36	490/630			
"XX"- 40	510/660			
Yield Stress (min) (N/mm²)				
"XX"- 32	315			
"XX"- 36	355			
"XX"- 40	390			
Elongation				
"XX"- 32	22% min.			
"XX"- 36	21% min.			
"XX"- 40	20% min.			

Grades Notch Toughness	AH-XX		DH-XX		EH-XX		FH-XX	
Test Temperature	0°C		-20°C		-40°C		-60°C	
Average Energy (J min)	**Long**	**Trans**	**Long**	**Trans**	**Long**	**Trans**	**Long**	**Trans**
t ≤ 50 mm								
"XX-32"	31	22	31	22	31	22	31	22
"XX-36"	34	24	34	24	34	24	34	24
"XX-40"	39	26	39	26	39	26	39	26
50 mm < t ≤ 70 mm								
"XX-32"	38	26	38	26	38	26	38	26
"XX-36"	41	27	41	27	41	27	41	27
"XX-40"	46	31	46	31	46	31	46	31
70 mm < t ≤ 100 mm								
"XX-32"	46	31	46	31	46	31	46	31
"XX-36"	50	34	50	34	50	34	50	34
"XX-40"	55	37	55	37	55	37	55	37

1.1.2 Substitute Materials

Through the operational life of a ship, modifications and repairs will require the contractor to supply steels of a grade equivalent to the materials fitted at the new build stage. For small quantities of steel, the likelihood of being supplied Classification Society approved shipbuilding grade steels is highly improbable.

Steel mills produce materials that will comply with many materials acceptance or conformity standards which are stock piled by either the mill or distribution partners. As such, contractors often ask the steel distribution partner to supply shipbuilding grade steels or equivalent.

When faced with being offered an equivalent material that is compliant with standards other than those of the Classification Society Rules, the contractor's Quality Assurance Department should supply the following information documents to validate equivalency:

- Rule requirements for the grade of steel originally specified;
- Mill certificate from the source of manufacture, and;
- Copy of the standard of compliance indicated on the mill certificate.

Once obtained, a comparative evaluation record should be prepared by the contractor and supplied to the Delegated Representative by the contractor's Quality Assurance Department.

It is important to note, the determination must ensure that the steel designation to the other standard has the same requirements for all properties listed for the Classification Society Steel designation. Particular attention should be paid to deoxidation, heat treatment and charpy-v-notch toughness requirements of the standard of compliance. Remember, each standard approaches the requirements for these properties in a different manner and sometimes not at all.

The following should be reported on the comparative evaluation record:

1) **The mill certificate from the source of manufacture.** Caution should be exercised if only a statement of compliance from source of supply was used without confirmation from the source of manufacture. Manufacturer trade names should not be considered the only means of evidence.
2) **The deoxidation process** (it should be the same or achieve the same result).

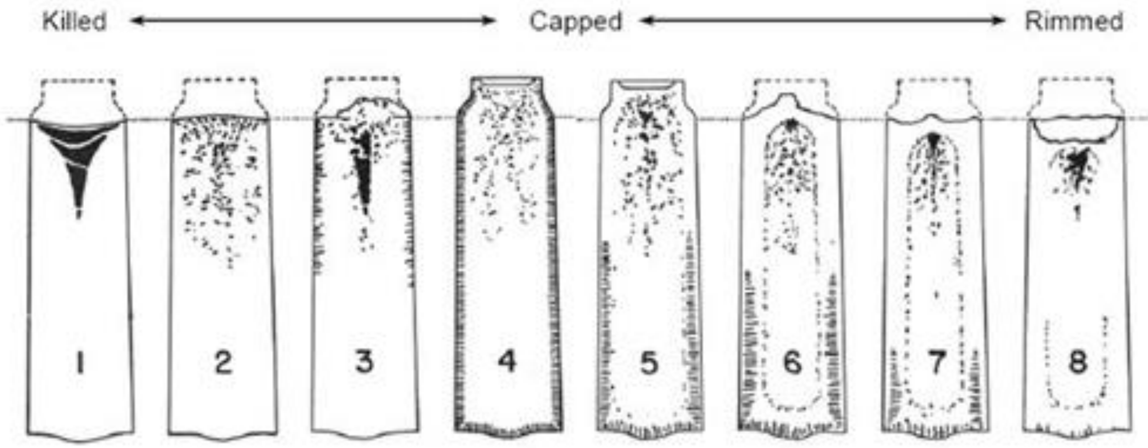
   The following information can be found in the latest edition of CSA Standards G40.20M and G40.21M:

   Rimmed Steel: steel containing sufficient dissolved oxygen to give a controlled, continuous evolution of carbon monoxide while the ingot is solidifying, resulting in a case or rim of metal virtually free of voids.

   Semi-killed Steel: incompletely deoxidized steel containing sufficient dissolved oxygen to form just sufficient carbon monoxide during solidification to offset solidification shrinkage.

   Killed Steel: steel deoxidized either by the addition of strong deoxidizing agents or by vacuum treatment to reduce the dissolved oxygen content to such a level that no reaction occurs between carbon and oxygen during solidification.

Figure 1 - Steel: Killed, Capped, Rimmed



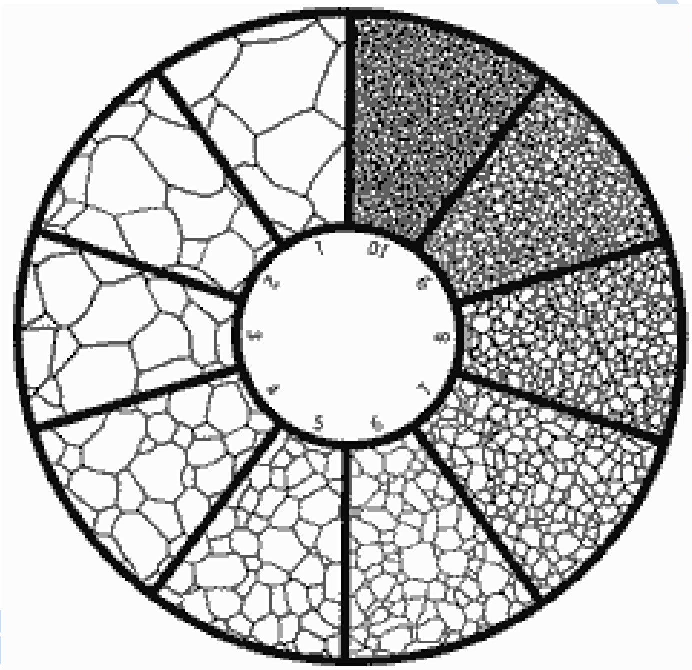


Figure 2 - Fine Grain Steel

Fine grain Steel: material that meets one of the following conditions:

- **a.** the material displays an austenitic grain size of No. 5 or higher for at least 70% of the area examined; or
- **b.** the aluminum content of the reported heat analysis is not less than 0.020% total aluminum or, alternatively, not less than 0.015% acid soluble aluminum.

3) The chemical composition and carbon equivalent. For ordinary strength steels, carbon plus 1/6 manganese should not exceed 0.40%. Classification Society Rule requirements place limits on elements to ensure good weldability. If certain chemical elements are outside rule requirements apply the IIW (1) carbon equivalent formula for normal or ordinary strength steels and the Pcm (2) formula for higher and extra high strength steels to determine weldability. Remember small increases in chromium, molybdenum, vanadium and boron can have a marked effect on hardenability.

Note 1: Ceq=C+ (Mn/6)+ (Cr+Mo+V/5)+(Ni+Cu/15)=%

Note 2: Pcm=C=(Si/30)+(Mn/20)+(Cu/20)+(Ni/20)+(Cr/20)+(Mo/15)+(V/10)+5B=%

4) **The condition of supply.** The strength and toughness properties of as-rolled steels are generally less than normalized, controlled rolled and thermo-mechanical rolled steels.

5) **The yield stress, ultimate tensile strength and elongation properties.** Over and under matching material strength (yield & ultimate) as well as a reduction in elongation properties can have a serious effect on the service life of a structure. Elongation is a measurement of ductility. Low ductility can result in cracks when welding thick plates and joints under high restraint. Also ensure the gage length of the specimens tested and used to calculate % elongation is comparable.

6) **The charpy-v-notch impact properties.** All materials compliance standards approach impact properties differently. First and foremost, when comparing impact properties ensure that the direction of the specimen tested and temperature values are the same. Minimum impact energy values measured in Joules (J) for specimens tested in the longitudinal direction are higher than those in the transverse direction. For shipbuilding grade steels minimum energy values increase based on thickness for the same material grade. Any shipbuilding grade of steel can be appended with a modified notation (M) meaning enhancement of the requirements differ from the Classification Society Rule requirements, for example, the CCGS Terry Fox shell plating in certain ice-belt regions is EH 36-M, where the temperature for charpy impact testing was modified from -40º C to -60º C. All grades of steel may be appended with a "Z" notation. "Z" quality steels have specified through thickness properties such as improved ductility and/or toughness in the "Z" direction.

7) **The test frequency at the source of manufacture.** Not all materials compliance standards are equal in this regard. Determine the frequency (per plate, every so many tons of steel, etc.) in the alternate standard of compliance and determine if it is equivalent to that of the Classification Society Rules.

Approach structural sheet steels with caution. Materials compliance standards classify materials less than 5 mm in thickness as sheet. Most standards for sheet group them as either utility grade or structural grade materials. Utility grade material is not guaranteed to have consistent ultimate tensile strength, yield stress and elongation properties and the chemical composition are not controlled for weldability.

1.1.3 North American Standards Organizations

Most steel substitutes offered by contractors will most likely be in compliance with a standard from one of the following North American standards writing bodies:

Table 3 - North American Standards Organizations

Canadian Standards Association (CSA)	
Structural Steels	CSA G40.20/G40.21- General requirements for rolled or welded structural quality steel / Structural quality steel. SI (metric) units with imperial units in parentheses. These Standards have been harmonized to the maximum possible extent with equivalent ASTM Standards, A6/A6M and A568/A568M.
American Society for Testing & Materials (ASTM)	
Structural Steels	**A6** Carbon Structural Steel. **A131** Standard Specification for Structural Steel for Ships. **A20** General requirements for Steel Plates for Pressure Vessels. **A36** Standard Specification for carbon Structural Steel. **A242** Standard Specification for High Strength Low Alloy Steel. Includes atmospheric corrosion resistant steels. **A516** Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate and Lower-Temperature Service. **A537** Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel.
American Society of Mechanical Engineers (ASME)	
Pressure Vessel Steels	Uses ASTM steel designations. Steels are grouped by "P" number. **P1** = Carbon manganese steels (4 group numbers). **P6** = Martensitic Stainless Steels (6 group numbers). **P7** = Ferritic Stainless Steels (Grade 409, 430). **P8** = Austenitic Stainless Steels: Group 1 - Grades 304, 316, 317, 347; Group 2 - Grades 309, 310; Group 3 - High Manganese Grades; and, Group 4 - High Molybdenum Grades.
American Iron and Steel Institute (AISI) & the Society of Automotive Engineers (SAE)	
Steel Sheets and Bars	Not a detailed specification, a designation system. "XXXX" 1st digit - major class 2nd digit - sub class (alloy content) 3rd & 4th digits - carbon level in hundredths of a percent **10XX** = Plain Carbon **11XX** = Plain Carbon, Resulpherized **12XX** = Plain Carbon, Resulpherized and Rephosphorized **13XX** = Plain Carbon, Manganese 1.75% **15XX** = Plain Carbon, Manganese 1.00 – 1.65%

Note: For more detailed information, see American Society for Metals Handbook, Vol. 1.

1.1.4 CSA Standards G40.20M and CSA G40.21M

Steels in compliance with CSA Standards are most often offered as substitutes. The CSA system categorizes steels by yield stress, type and toughness category.

Table 4 - Mechanical Properties

Grade	Tensile Strength, MPa (1)	Yield Strength, MPa (1)		Elongation, % minimum, Longitudinal		Elongation, % minimum, Transverse	
	≤ 150 mm	t ≤ 65 mm	t > 65 mm	In 200 mm	In 50 mm	In 200 mm	In 50 mm
260 W, WT	410-590	260	250	20	23	18	21
300 W, WT	440-610	300	280	20	23	18	21
350 W, WT	450-650	350	320	19	22	17	20
350 A, AT	480-650	350	350 (3)	19	21	17	19
380 W (2)	480-650	380	350	18	21	-	-
400 W, WT	520-690	400	370	16	18	13	15
400 A, AT	520-690	400	-	18	21	15	18
450 W, WT	550-725	450	420	16	17	12	15
480 W, WT	590-790	480	450	15	17	12	14
480 A, AT	590-790	480	-	15	17	12	14
550 W, WT	620-860	550	520	13	15	10	12
550 A, AT	620-860	550	-	13	15	10	12
700 Q, QT	760-895	700	620 (3)	-	18	-	16

"W" = Weldable steels for general welded construction.

"WT" = Weldable steels for welded construction where good low notch toughness is required. Toughness category (temperature) must be specified by purchaser.

"A" = Atmospheric corrosion resistant weldable structural steel.

"AT" = Atmospheric corrosion resistant weldable notch tough steel. Toughness category (temperature) must be specified by purchaser.

"Q" = Quench and tempered low alloy steel.

"QT" = Quench and tempered low alloy notch tough steels. Toughness category (temperature) must be specified by purchaser.

Note 1: 1 MPa=1 N/mm^{2}.

Note 2: For thicknesses < 8 mm and > 90 mm consult CSA G40.20 test standard clauses 8.3.1.1 & 8.3.1.2.

Note 3: 65 mm < t ≤ 100 mm.

Table 5 - Toughness Category, Longitudinal Specimens

CVN	"1"	"2"	"3"	"4"	"5"
Grade	**Energy**				
260 & 300 WT	20 J	20 J	20 J	20 J	Purchaser specified for all grades
350 - 550 WT	27 J	27 J	27 J	27 J	
350 - 550 AT	27 J	27 J	27 J	27 J	
700 QT	34 J	34 J	34 J	34 J	
Test Temperature	0°C	-20°C	-30°C	-45°C	Purchaser specified

1.2 ALUMINUM

For hull structure, aluminum and aluminum alloys are used for fast rescue craft, search and rescue and fisheries patrol vessels.

The numbering system used to classify aluminum is based on three elements:

1. Heat Treatable or Non-heat Treatable alloys;
2. Temper, and;
3. Chemical Composition.

Unlike steels, while the addition of alloying elements results in greater strength, only with certain of the aluminum casting alloys do the mechanical properties depend on the composition alone.

The non-heat treatable wrought alloys are those in which the mechanical properties are improved by cold working, such as cold rolling and drawing.

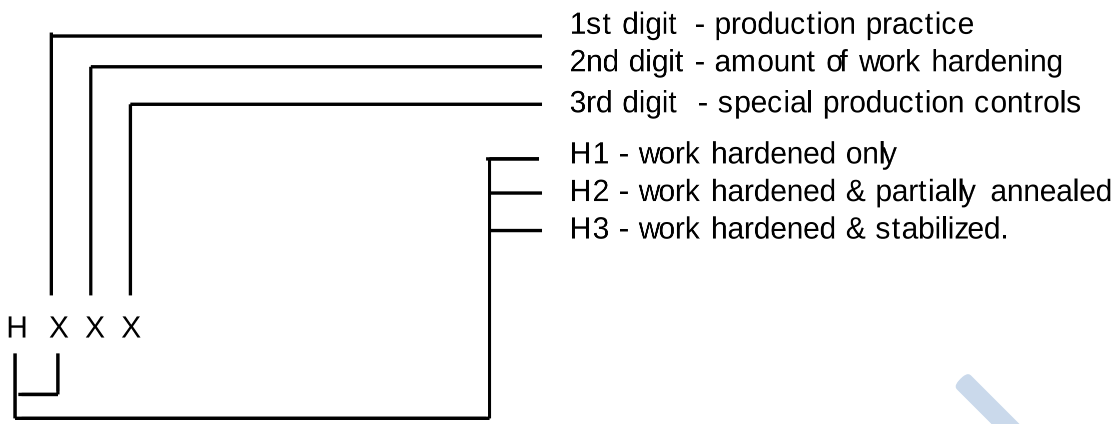
1.2.1 Non-heat Treatable Alloys – Marine Use

Table 6 - Non Heat Treatable Alloys - Marine Use

Alloy	Applications
1050	Chemical and food equipment.
1100	Foil, cooking utensils, forming applications.
5083 **5383** **5059** **5086** **5456** **5754**	Main structural alloys.
5454	Structural alloy at elevated temperatures.

These alloys are produced in several tempers, according to the degree of work hardening.

The second digit denotes the degree of work hardening and the third digit denotes a special degree of control of the basic two-digit temper, which results in an appreciable difference in properties.



1.2.2 Heat Treatable Alloys – Marine Use

Heat treatable alloys of aluminum have the valuable characteristic of responding to heat treatment to allow an increase in strength beyond that permissible by work hardening only.

Table 7 - Heat Treatable Alloys – Marine Use

Alloy	Applications
6005A **6061** **6082** **6351**	Structural extrusions
6063	Architectural and light structural extrusions.

These alloys are also produced in many different tempers, depending on heat treatment.

Table 8 - Tempers

T1	Cooled from an elevated temperature process and naturally aged to a substantially stable condition
T2	Cooled from an elevated temperature process, cold worked, and naturally aged to a substantially stable condition.
T3	Solution heat treated, cold worked, and naturally aged to a substantially stable condition.
T4	Solution heat treated and naturally aged to a substantially stable condition.
T5	Cooled from an elevated temperature process and then artificially aged.
T6	Solution heat treated and then artificially aged.
T7	Solution heat treated and stabilized.
T8	Solution heat treated, cold worked, and then artificially aged.
T9	Solution heat treated, artificially aged, and then cold worked.
T10	Cooled from an elevated temperature process, cold worked, and then artificially aged.

When evaluating the appropriateness of a substitute aluminum alloy, the following should be considered: Corrosion resistance; Physical property performance of the alloy at the temper designation being offered; Weldability & formability; Service temperature, and; Colour match after anodizing.

The following tables summarize the compliance requirements offered in IACS UR W – Materials and Welding, Section W25 – Aluminum Alloys for Hull Construction and Marine Structure. It is very important to note, the temper for a given alloy has a significant effect on physical or mechanical properties.

Table 9 - Chemical Composition (1)

Grade	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti (2)	Other Elements	
									Each	Total
5083	0.40	0.40	0.10	0.40 - 1.0	4.0 - 4.9	0.05 - 0.25	0.25	0.15	0.05	0.15
5383	0.25	0.25	0.20	0.7 - 1.0	4.0 - 5.2	0.25	0.40	0.15	0.05 (5)	0.15 (5)
5059	0.45	0.50	0.25	0.6 - 1.2	5.0 - 6.0	0.25	0.40-0.90	0.20	0.05 (6)	0.15 (6)
5086	0.40	0.50	0.10	0.20 - 0.7	3.5 - 4.5	0.05 - 0.25	0.25	0.15	0.05	0.15
5754	0.40	0.40	0.10	0.50 (3)	2.6 - 3.6	0.30 (3)	0.20	0.15	0.05	0.15
5456	0.25	0.40	0.10	0.50 - 1.0	4.7 - 5.5	0.05 - 0.20	0.25	0.20	0.05	0.15
6005A	0.50 - 0.9	0.35	0.30	0.50 (4)	0.40 - 0.7	0.30 (4)	0.20	0.10	0.05	0.15
6061	0.40 - 0.8	0.7	0.15 - 0.40	0.15	0.8 - 1.2	0.04 - 0.35	0.25	0.15	0.05	0.15
6082	0.7-1.3	0.50	0.10	0.40 - 1.0	0.6 - 1.2	0.25	0.20	0.10	0.05	0.15

Note 1: Composition in percentage mass by mass maximum unless shown as a range or as a minimum.

Note 2: Includes Ni, Ga, V and listed elements for which no specific limit is shown. Regular analysis need not be made.

Note 3: Mn + Cr: 0.10-0.60

Note 4: Mn + Cr: 0.12-0.50

Note 5: Zr: maximum 0.20. The total for other elements does not include Zirconium.

Note 6: Zr: 0.05-0.25. The total for other elements does not include Zirconium.

Table 10 - Mechanical Properties for Rolled Products, 3 mm ≤ t ≤ 50 mm

Grade	Temper (3)	Tensile Strength N/mm2	Yield Strength N/mm2	Elongation % min.(1)		Notes
				A50 mm	A5d	
5083	O	350-275	125	16	14	
	H111	350-275	125	16	14	
	H112	275	125	12	10	
	H116	305	215	10	10	
	H321	305-385	215-295	12	10	
5383	O	290	145	-	17	
	H111	290	145	-	17	
	H116	305	220	10	10	(1) Elongation in 50 mm applies for thicknesses up to and including 12.5 mm and in 5d for thicknesses over 12.5 mm.
	H321	305	220	10	10	
5059	O	330	160	24	24	
	H111	330	160	24	24	
	H116, 3 < t < 20 (mm)	370	270	10	10	
	H116, 20 < t < 50 (mm)	360	260	-	10	(2) 8 % for thicknesses up to and including 6.3 mm.
	H321, 3 < t < 20 (mm)	370	270	10	10	
	H321, 20 < t < 50 (mm)	360	260	-	10	
5086	0	305-240	95	16	14	(3) The mechanical properties for the O and H111 tempers are the same. However, they are separated to discourage dual certification as these tempers represent different processing.
	H111	305-240	95	16	14	
	H112, 3 < t < 12.5 (mm)	250	125	8	-	
	H112, 12.5 < t < 50(mm)	240	105	-	9	
	H116	275	195	10 (2)	9	
5754	0	240-190	80	18	17	
	H111	240-190	80	18	17	
5456	0, 3 < t < 6.3 (mm)	365-290	205-130	16	-	
	0, 6.3 < t < 50 (mm)	360-285	205-125	16	14	
	H116, 3 < t < 30 (mm)	315	230	10	10	
	H116, 30 < t < 40 (mm)	305	215	-	10	
	H116, 40 < t < 50 (mm)	285	200	-	10	
	H321, 3 < t < 12.5 (mm)	405-315	315-215	12	-	
	H321, 12.5 < t < 40(mm)	385-305	305-215	-	10	
	H321, 40 < t < 50 (mm)	370-285	295-200	-	10	

Note: 5456 H111= UTS 320 MPa, YS 230 MPa, Elongation 18%, 5086 H32=UTS 290 MPa, YS 207 MPa, Elongation 12%.

Table 11 - Mechanical properties for extruded products, 3 mm ≤ t ≤ 50 mm

Grade	Temper (3)	Tensile Strength N/mm2	Yield Strength N/mm2	Elongation, % min.(1) (2) A50 mm	Elongation, % min.(1) (2) A5d	Notes
5083	O	350-270	110	14	12	(1) Elongation in 50 mm applies for thicknesses up to and including 12.5 mm and in 5d for thicknesses over 12.5 mm.
	H111	275	165	12	10	
	H112	270	110	12	10	
5383	O	290	145	17	17	
	H111	290	145	17	17	
	H112	310	190	-	13	
5059	H112	330	200	-	10	
5086	O	315-240	95	14	12	(2) The values are applicable for longitudinal and transverse tensile test specimens.
	H111	250	145	12	10	
	H112	240	95	12	10	
6005A	T5	260	215	9	8	
	T6, 3 ≤ t ≤ 10 (mm)	260	215	8	6	
	T6, 10 ≤ t ≤ 50(mm)	250	200	8	6	
6061	T6	260	240	10	8	
	T5	270	230	8	6	
6082	T6, 3 ≤ t ≤ 5 (mm)	290	250	6	-	
	T6, 5 ≤ t ≤ 50 (mm)	310	260	10	8	

Alumina refining video　　Aluminum smelting video　　Aluminum rolling process video

Aluminum casting extrusion billet process video　　Aluminum extrusion process video

1.3 STAINLESS STEELS

Stainless steels are sometimes used in ship construction and repair for fasteners in aluminum, rudder stocks, tail shafts, and part of the structural arrangement of kort nozzles and bow thruster compartment openings.

Stainless steels may be defined as alloy steels containing at least 10% chromium; with or without other elements. They are commonly divided into five groups: Martensitic, Ferritic, Austenitic, Precipitation-hardening, and Duplex stainless steels.

There are a large number of standard types that differ in composition, corrosion resistance, physical properties and mechanical properties. A list of characteristics to be considered is offered below:

- Corrosion Resistance, Resistance to Oxidation and Sulfidation
- Strength and Ductility at Ambient and Service Temperatures
- Stability of Properties in Service
- Toughness
- Abrasion and Erosion Resistance
- Resistance to Galling and Seizing
- Surface Finish and/or Reflectivity
- Magnetic Properties

Credit: The following has been extracted from the Specialty Steel Industry of North America Association's website.

When specifying stainless steels, common names like "316" can be used but it is important to also list the specific Unified Numbering System (UNS) designation for the alloy. This identifies the specific chemistry that is desired. Within the ASTM standards and industry association and company literature, alloys are identified by UNS number and, where one exists, the common name. It has been many years since new AISI numbers have been issued so newer alloys will not have them.

1.3.1 Austenitic Stainless Steel (Fe-Cr-Mn and Fe-Cr-Ni)

Austenitic stainless steel grades or alloys contain either chromium and manganese or chromium and nickel. The carbon content is generally held to a maximum of 0.08% (302, 309 and 310 have slightly higher levels). The chromium content can range from 16.0 to 28.0% with nickel between 3.5 and 32.0%.

These alloys cannot be hardened by heat treatment, but they can develop high strength by cold working. They are non-magnetic in the annealed (heat treated) condition, but cold worked and cast material maybe slightly magnetic.

They exhibit excellent corrosion resistance and molybdenum is added to some grades for additional resistance to chlorides. In some alloys, nitrogen maybe added to improve strength and corrosion resistance. Austenitic stainless steels offer good formability, high ductility and good impact toughness. The most common alloys (e.g. 304 and 304L) are sometimes called 18-8 or 18% chromium and 8% nickel because that is their basic composition. Types 304 and 316 are the most commonly used stainless steels.

Type 304 and Type 316 usually give the best service when exposed to seawater environments. However, in stagnant seawater, all types are likely to pit severely from biofouling. Even Type 316 may be completely unsatisfactory if water velocity is less than 1.5 m/s.

Characteristics

1. Excellent corrosion resistance
2. Typical strength (in the annealed condition) 85 ksi – tensile, 40 ksi – yield and 50% elongation
3. Can't be heat treated but can be hardened by "cold working" (up to 185 ksi–tensile, 140 ksi–yield
4. Non-magnetic
5. Good high and low temperature mechanical properties
6. Excellent formability and weldability
7. All common finishes can be applied

Follow this link for a list of Common Applications.

Examples:

- 200 Series Austenitic (Fe-Cr-Mn): UNS S20100
- 300 Series Austenitic (Fe-Cr-Ni): UNS S30100, S30403, S30500, S30908, S31008, S31603, S31703, S32100

1.3.2 Ferritic Stainless Steels (Fe-Cr)

The ferritic stainless steels are sometimes called "non-hardenable" 400 series grades or alloys, and 409 and 430 are the most common. Alloys of chromium and iron with limited carbon contents that are generally below 0.12% (442, 446 are at 0.20). The chromium content can vary from 10.5 to 30.0%. These grades cannot be hardened by heat treatment but they are magnetic. They have good corrosion resistance (particularly to chloride stress corrosion cracking) but are generally not chosen for toughness.

Characteristics

1. Good corrosion resistance
2. Typical strength 65 - 75 ksi – tensile, 35 - 50 ksi – yield and elongation 20 - 35%
3. Magnetic
4. Limited temperature use
5. Can be polished

Follow this link for a list of Common Applications. **Examples of** Non-hardenable 400 Series Ferritic (Fe-Cr) are: UNS S40500, S40910, S40920, S40930, S43000, S43400, S43600, S43035, S44400, S44660, and S44735.

1.3.3 Martensitic Stainless Steels (Fe-Cr-C)

The martensitic structure results when chromium and higher levels of carbon are added to iron. This structure can be heat treated to higher hardness levels and is sometimes called "hardenable stainless" 400 series. 410, 420 and 440 are the most common grades. Carbon can range from 0.08 to 1.20% with chromium levels between 11.5 and 18.0%. The martensitic structure is also magnetic.

Characteristics

1. Adequate corrosion resistance
2. Hardenable by heat treatment
3. Magnetic
4. Somewhat limited temperature use
5. Limited weldability

Common Applications include fasteners, pump shafts, turbine blades, surgical instruments, cutlery, etc. Examples of Hardenable 400 Series Martensitic (Fe-Cr-C) are: UNS S41000, S42000, S44002, and S44004

1.3.4 Precipitation Hardening Steels [Fe-Cr-Ni (Mo-Cu-Al-Nb)- N]

Precipitation hardening stainless steels develop strength by precipitation hardening reactions as the result of heat treatment. With lower carbon levels (0.09 max.), they have good corrosion resistance and are characterized by ease of fabrication. High strengths can be developed at relatively low temperatures (500-800 °C) so distortion is minimized. The chromium is between 12.25 and 18.0%, with nickel levels of 3.0 to 8.5%. Molybdenum, in some grades is between 2 and 3%, with additions of aluminum, copper, rare earth elements and nitrogen.

Common applications include valves, gears, and petrochemical equipment.
Examples of Precipitation Hardening Steels [Fe-Cr-Ni (Mo-Cu-Al-Nb)- N] are: UNS S13800, S15500, S15700, S17400, and S17700.

1.3.5 Duplex Stainless Steels [Fe-Cr-Ni-(Mo)-N]

These stainless steels combine both the austenitic and ferritic microstructures thus earning the name "duplex". The carbon levels are very low (below 0.03%). Generally, the chromium composition is between 19.5 and 30.0% with nickel from 1.0 to 8.0%. They may contain molybdenum contents of up to 5% and nitrogen of up to 0.4%. These alloys are magnetic, and offer increased tensile and yield strength over the other categories. They are more resistant to stress corrosion cracking than austenitic, yet tougher than fully ferritic alloys. Common Applications include pipelines, pressure shafting, structural components, and industrial tanks.

Examples of Duplex Stainless Steels [Fe-Cr-Ni-(Mo)-N are: UNS S32001, S32003, S32101, S32205, S32304, S32507.

1.3.6 Technical Data

To acquire additional technical data for stainless steels from SSINA follow the hyperlinks below.

Physical Properties	Chemical Composition	Mechanical Properties
Fabrication	Life Cycle Costing	High Temperature Properties

More data on stainless alloys can be found in the SSINA handbook
"Design Guideline for the Selection and Use of Stainless Steel".

Fabrication information can be obtained from the stainless steel producers, and

- Stainless Steel Fabrication Guide
- Practical Guidelines for the Fabrication of High Performance Austenitic Stainless Steels
- The Ferritic Solution
- Practical Guidelines for the Fabrication of Duplex Stainless Steels
- Galvanic Corrosion and it's Prevention

There is an immense amount of technical data also available on the following websites:

- Specialty Steel Industry of North America Association (SSINA)
- International Stainless Steel Forum (ISSF)
- Nickel Institute
- International Molybdenum Association (IMOA).
- How "Stainless Steel is made" video.
- "How Stainless Steel Alloy is formed" video.

1.4 COPPER NICKEL

Cu-Ni alloys are widely used for marine applications due to their excellent resistance to seawater corrosion, high inherent resistance to biofouling and ease of fabrication. They have provided reliable service for several decades whilst offering effective solutions to today's technological challenges.

This section is designed to provide a detailed overview of Cu-Ni with data which will allow good practices in design, fabrication and application. Major application areas are covered in detail in System Components and System Design; the latter includes a special section on Fittings.

Table 12 - Material Information Sources

Organization	Contact Information	Web Links
The Aluminum Association Inc	1525 Wilson Blvd.,Suite 600, Arlington, VA 22209 Tel: (703) 358-2960	aluminum.org
American Foundry Society	1695 North Penny Lane, Schaumburg, IL 60173 Tel: (847) 824-0181	afsinc.org
American Iron and Steel Institute	25 Massachusetts Ave., NW, Suite 800; Washington, DC 20001; Tel: (202) 452.7100	steel.org
American Powder Metallurgy Institute	105 College Road East, Princeton, NJ 08540-6692 Tel: (609) 452-7700	mpif.org
American Society for Metals	9639 Kinsman Road, Materials Park, OH 44073-0002 Tel: (440) 338-5151	asm-intl.org
American Society for Testing and Materials	100 Barr Harbor Drive, West Conshohocken, PA Tel: (610) 832-9500	astm.org
American Society of Mechanical Engineers	Two Park Avenue, New York, NY 10016-5990 Tel: (800) 843-2763	asme.org
Canadian Copper & Brass Development Association	65 Overlea Blvd, Suite 210, Toronto, Ontario M4H 1P1, Tel: (416) 391-5599	coppercanada.ca
Canadian Foundry Association	1500 - 1 Nicholas Street, Suite 1500, Ottawa, ON, K1N 7B7; , Tel: (613) 789-4894	foundryassociation.ca
Canadian Institute of Steel Construction	3760 14th Avenue, Suite 200, Markham, ON L3R 3T7 Tel: (905) 946-0864	cisc.ca
Canadian Manufacturers and Exporters	1 Nicholas Street, Suite 1500, Ottawa ON K1N 7B7 Tel: (613) 238-8888	cme-mec.ca
Canadian Standards Association	178 Rexdale Blvd., Toronto, ON M9W 1R3 Tel: (416) 747-4044	csa.ca
Canadian Steel Producers Association	Suite 906, 350 Sparks Street, Ottawa, ON K1R 7S8 Tel: (613) 238-6049	canadiansteel.ca
Copper Development Association	260 Madison Avenue, New York, NY 10016 Tel: (212) 251-7200	copper.org
Forging Industry Association	1111 Superior Ave. Suite 615 Cleveland, OH 44114 Tel: (216) 781-6260	forging.org
Materials Properties Council	PO Box 1942, New York, NY 10156 Tel: (216) 658-3847	forengineers.org
Mining Association of Canada	1105-350 Sparks Street, Ottawa, ON K1R 7S8 Tel: (613) 233-9392	mining.ca
National Association of Corrosion Engineers	4501 Mission Bay Drive, Suite 2G, San Diego, CA 92109 Tel: (858) 768-0828	nace.org
Nickel Institute	161 Bay Street, Suite 2700, Toronto, ON M5J 2S1 Tel: 1 416 591 7999	nickelinstitute.org
Society of Automotive Engineers	400 Commonwealth Dr., Warrendale, PA 15096-0001 Tel: (724) 776-4841	sae.org
Society of Manufacturing Engineers	7100 Woodbine Ave., Suite 312, Markham, ON L3R 5J2 Tel: (905) 752-4415	sme.org
Specialty Steel Industry of North America (SS)	3050 K Street, N.W., Washington, DC 20007 Tel: (202) 342-8630	ssina.com

The following hyperlinks will direct you to an immense amount of technical data that is made available specifically on the Copper Development Association's website.

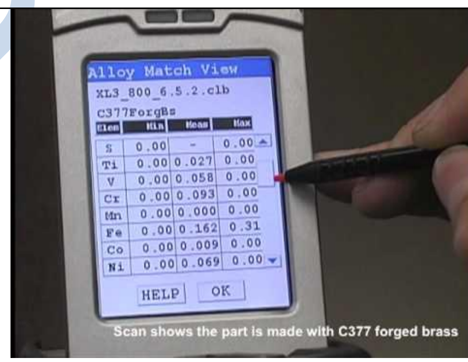
Applications Introduction — Ship Building And Repair Offshore Units — Power Generation Desalination — System Components System Design — Useful Papers	**Resources** Interactive Presentation Supplier Directory Alloy Cross Reference What's New
References Contents to access: — Boat Hulls General Properties — Brake Tubing Fabrication — Condensers & Heat Exchangers Corrosion — Desalination Biofouling — Offshore Sheathing Aquaculture — Seawater Pipework	Technical Information (Contents to access): Alloys — Standards Product Forms — Physical Properties Mechanical Properties — Cryogenic Properties Corrosion Resistance — Biofouling Resistance Welding & Fabrication — Environmental

1.5 TOOLS FOR DETERMINING MATERIAL TYPE & ROLLING DIRECTION

1.5.1 Positive Material Identification

On occasion it may be necessary to determine or verify material type if mill certificates are not easily accessed or available in a docking or repair situation.

A nondestructive method for acquiring the chemistry of a material to assist in determining the material type is X-Ray Fluoroscopy. This process is called Positive Material Identification (PMI). PMI can be performed onsite or in a laboratory. It is common place in industry today and available across Canada and on our coasts.



PMI however does have limitations though not being able to accurately detect atomic elements 22 and below:

1 Hydrogen	2 Helium	3 Lithium	4 Beryllium	5 Boron	6 Carbon	7 Nitrogen	8 Oxygen	9 Fluoride	10 Neon	11 Sodium
12 Magnesium	13 Aluminum	14 Silicon	15 Phosphorus	16 Sulfur	17 Chlorine	18 Argon	19 Potassium	20 Calcium	21 Scandium	22 Titanium

During the docking of an ice-transiting ship weld zone corrosion has occurred to the external shell weld butts and seams to a degree (depth and area of loss) that warrants repair. In order to correctly match weld metals to render a repair deposit that is noble, the exact chemistry of the base plate needs to be known. The mill certificate from the new build is not easily accessed or non-existent for that matter and, the material compliance standard is inadequate in this scenario because there is a large variance permitted for the chemical elements of interest in making the correct decision, primarily manganese (Mg), copper (Cu) and nickel (Ni). You could ask the contractor to drill shavings of each plate and send them off to a laboratory for chemical analysis or ask for onsite PMI which renders results at the time of inspection not days or even weeks later. Since PMI is unable to detect carbon (C), sulphur (S), phosphorous (P), aluminum (Al) and titanium (Ti), the exact grade of shipbuilding steel can't be determined unless shavings were sent out for chemical analysis at a test laboratory.

Similarly, if onboard ship a stainless steel or copper pipe fails and you are not sure what alloy it is, PMI will give you the quick answers needed to make informed decisions. The copper pipe could be alloyed with nickel (Cu Ni) or nickel and iron (Cu Ni Fe) and the wt% of each element may differ, 80/20, 90/10 and so on. For potable water system components and soldered connections, PMI can be used to detect lead (Pb).

PMI is not suitable for determining aluminum (Al) or magnesium (Mg) alloys. A combination of chemical analyst, metallography and physical tests need to be performed to determine alloy and temper or heat treatment. PMI can also be used on many weld metal deposits to validate matching criterion or to locate iron contamination, which is very important when joining stainless steels and cupronickel. [Click to view a video on the use of PMI from Niton UK Limited.]

1.5.2 Rolling Direction

For insert plates that are destined to be located in the shell and strength decks, it is advisable to match rolling direction of the insert plate to the existing plate at ship. For full size plates (≈ 20') this is an easy task if the rolling direction of the insert plate is known. For smaller plates such as those plates located in the stern and bow regions rolling direction cannot not always be determined even by destructive testing.

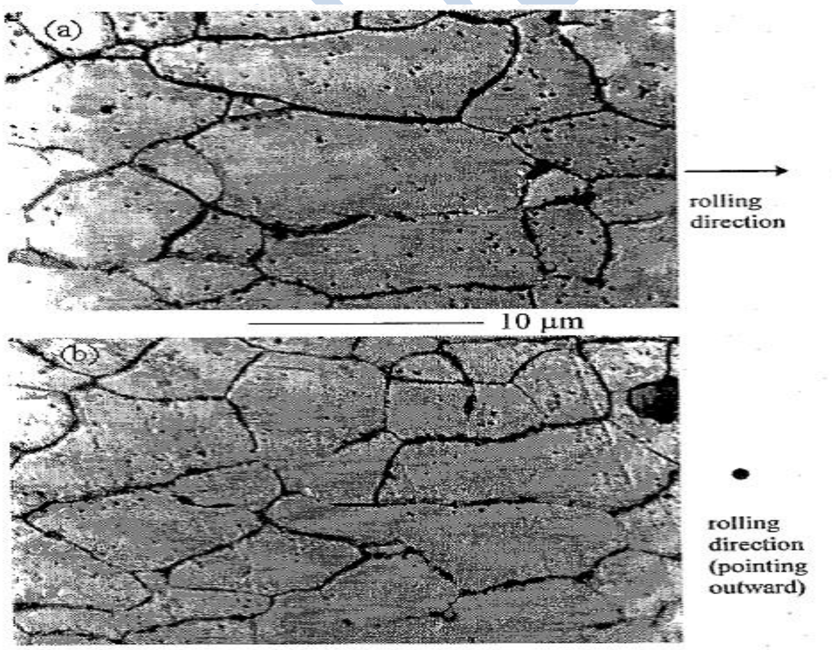


Fig. 4. (a) Optical micrograph shows the elongated grains along the y (rolling) direction on the x directional plane. (b) Optical micrograph shows the elongated grains on the y directional plane.

Figure 3 Optical Micrograph

Metallography offers reliable results for determining rolling direction of steels delivered in the 'as-rolled' condition. An optical micrograph is a reliable method for determining rolling direction of steel plates as illustrated above.

A thin strip of each plate would be sent to a laboratory for testing. Unfortunately, the majority of notch tough shipbuilding steels are normalized and the rolling direction can't be accurately determined by even the most sophisticated metallurgical testing equipment. When removing a piece of steel from the shell envelope for subsequent mechanical testing, ensure the rolling direction is accurately marked on the specimen by marking the fore, aft, top and bottom cut edges and exterior and interior surfaces as well as the frame position and distance above baseline.

1.6 CORROSION BASICS

There are a wide variety of ferrous and nonferrous metals that are used in a marine environment and they are often exposed to harsh elements which results in some form of corrosion overtime. This section offers some corrosion principals information in a condensed format.

1.6.1 Standard Terms

The following common terms related to corrosion have been issued by IACS under Unified Directive No 82 – Surveyor's Glossary, Hull and Hull Survey Terms and are offered herein for information only. For other terms please follow this link to the IACS document.

Abrasion is the removal of material by mechanical, i.e. rubbing or frictional, means.

Active Corrosion means gradual chemical or electrochemical attack on a metal producing loose scale, by atmosphere, moisture or other agents.

Allowable Corrosion or Wastage Limit is the acceptable thickness diminution of structural elements.

Anode is the positively charged metal surface and the corroding part of an electrochemical corrosion cell at which the oxidation or loss of electrons occurs.

Bacterial Corrosion or **Microbially Influenced Corrosion (MIC)** is corrosion which is induced or accelerated by the presence of micro-organisms.

Cathode is the negatively charged metal surface and the non-corroding or protected part of an electrochemical corrosion cell.

Cathodic Protection is the partial or complete protection of a metal from corrosion by making it a cathode, using either a galvanic or an impressed current to bring a metal to a potential where it is thermodynamically stable.

Cavitation Damage is degradation of metal surfaces, characterized by pitting, in which the pit profile is irregular, occurring when very turbulent fluids are in contact with the metal surface, and associated with the formation and collapse of cavities in the liquid at the solid — liquid interface.

Corrosion Fatigue is the process in which a metal fractures prematurely in a trans-crystalline manner under conditions of simultaneous corrosion and repeated cyclic loading of lower stress levels or fewer cycles than would be in the absence of a corrosive environment.

Corrosion is the chemical or electrochemical reaction between a material, usually a metal and its environment that produces a deterioration of material and its properties, usually an oxide is formed.

Corrosion Prevention System is considered a full hard coating; alternatively a full hard coating supplemented by cathodic protection.

Crevice Corrosion is localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from full exposure to the environment because of close proximity between the metal and surface of another material. It is usually associated with small volumes of stagnant water; within lapped joints, under heads of fastenings, under gaskets and packings, under marine organisms and porous deposits.

Deposit Attack is an attack under, or around, the edge of a local deposit formed on a metal surface in the presence of an electrolyte.

Edge Corrosion is local corrosion at the free edges of stiffeners, brackets, flanges, manholes etc.

Electrochemical Corrosion is corrosion associated with the passage of an electric current. If the current is produced by the system itself it is called Galvanic Corrosion and if it results from an impressed current it is called Electrolytic Corrosion.

Erosion Corrosion is a combined action involving corrosion and erosion in the presence of a moving corrosive fluid, leading to the accelerated loss of material. Erosion corrosion is characterized by grooves, gullies, waves, valleys etc., usually with directional pattern and with bright surfaces free from corrosion products.

Erosion Damage is the physical removal of material from a surface by mechanical means such as e.g. flowing liquid and it may be accelerated by corrosion.

Excessive Corrosion is an extent of corrosion that exceeds the Allowable Corrosion.

Extensive Corrosion is an extent of corrosion consisting of hard and/or loose scale, including pitting, over 70% or more of the area under consideration, accompanied by evidence of thickness diminution.

FAIR condition is a term used to describe the condition of a hard coating; with local breakdown at edges of stiffeners and weld connections and/or light rusting over 20% or more of areas under consideration, but less than as defined for Poor condition.

Galvanic Corrosion is electrochemical accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

Galvanizing is the deposition of zinc on to the surface of steel to provide corrosion protection by both protecting the steel from contact with the environment and giving sacrificial protection.

General Corrosion or **Overall Corrosion** appears as non-protective, friable rust of a uniform nature on uncoated surfaces. Rust scale continually breaks off, exposing fresh metal to corrosive attack. Visual judgment of thickness loss is difficult until serious wastage has occurred.

Good condition is a term used to describe condition of hard coating; with only minor spot rusting.

Grooving Corrosion is local corrosion normally adjacent to welding joints along abutting stiffeners and at stiffener or plate butts or seams.

Insignificant Corrosion or **Minor Corrosion** is an extent of corrosion with minor spot rusting and such that an assessment of the corrosion pattern indicates wastage generally not exceeding of 30% of the allowable corrosion limits.

Local Corrosion is by name local in nature, often appearing at areas with local breakdown of coating or at areas with stress concentrations.

Loose Scale is sheets of rust falling off if the surveyor hits the structure with his test hammer. Loose scale can best be removed by hand or power tool cleaning or a combination of these.

Necking Effect is a term describing local corrosion at junction of plating and stiffeners due to flexure effects caused by reverse, cyclic loading with loss of coating or shedding of scale exposing fresh steel to further corrosion. The corrosion rate may be rather high and accelerates with thinning of the material.

Pinholing is tiny, deep holes exposing substrate.

Pinpoint Rusting is local rusting at pinholes or holidays.

Pitguard Anode is a sacrificial anode placed just above tank bottom in order to mitigate the general and pitting corrosion process.

Pitting Corrosion is local, random scattered corrosion mainly on horizontal surfaces and at structural details where water is trapped, particularly at bottom of tanks. For coated areas the attack produces deep and small diameter pits which may lead to perforation. Pitting of uncoated areas in tanks, as it progresses, forms shallow but very wide scabby patches (e.g. 300 mm in diameter) and the appearance resembles condition of general corrosion.

Rust is a visible corrosion product consisting of hydrated oxides of iron and is formed on steel surfaces exposed to moist atmospheric conditions.

Scale is surface oxidation, consisting of partially adherent layers of corrosion products, left on metals by heating or casting in air or in other oxidizing atmospheres and is the product of the corrosion process of steel with a porous surface layer or flakes, in volume greater than the metal from which it was formed.

Stress Corrosion is the preferential attack of areas under tensile stress in a corrosive environment, where such an environment alone would not have caused corrosion. Tensile stresses may be residual stresses from welding or coldworking or applied working stresses.

Substantial Corrosion is an extent of corrosion such that assessment of corrosion pattern indicates wastage in excess of 75% of allowable corrosion, but within allowable corrosion limits.

Suspect Areas are locations showing substantial corrosion and/or are considered to be prone to rapid wastage.

Weld Metal Corrosion is a preferential corrosion of the weld deposit due to an electrolytic action between the weld metal and base metal.

Heat Affected Zone Corrosion (HAZ) is a preferential corrosion of the base plate within 5 mm of the weld toe (edge of the weld). This HAZ definition is not included in the IACS document.

1.6.2 Mechanics of Corrosion

The following contains excerpts from ABS Guidance Notes on the Inspection, Maintenance and Application of Marine Coating Systems – Third Edition 2007. For further information please consult the ABS document.

Corrosion of steel onboard ships can be defined as an electrochemical process in which the steel reacts with its environment to form an oxide, or other compound, similar to the ore from which it was originally obtained.

The majority of metals are found in nature in the mineral state, that is, in their stable oxidized condition as oxides, chlorides, carbonates, sulfates, sulfides, etc. The extraction of a metal from the mineral involves a reduction process which requires a great deal of energy. As a consequence of this large energy input, the metal is in a high energy condition and will try to return to its former stable, oxidized, low energy state as quickly as environmental conditions will allow. It is this energy difference between the pure metal and its oxidized forms which is the driving force for corrosion of the metal. Many corrosion products show a chemical similarity to the corresponding minerals. Iron, for example, is extracted from its ores, mainly oxide and carbonate, by reduction with carbon in a blast furnace. In the presence of moisture and oxygen, the iron metal so obtained is oxidized to rust, which is chemically the same as its ore.

Uncoated Steel and the Corrosion Reaction

During the corrosion process, steel will lose iron atoms into its environment in the form of ions. In return some of the metal ions from the environment will plate out and return to the metallic state. This is known as a reversible reaction. When the rates of the forward and reverse reactions are the same, then the process is in equilibrium and the steel takes up its equilibrium potential.

Metal atoms leave the metal and go into a solution as positively charged metal ions, leaving behind negatively charged electrons. Consequently, the metal becomes more negatively charged. This makes it increasingly difficult or impossible for the remaining metal atoms to escape as positively charged ions as they are being held by the negative charge of the metal. For the process to continue, the excess of electrons in the metal must be consumed elsewhere in another reaction. The manner and speed with which these excess electrons can be removed is one of the factors that determine the rate of corrosion.

One important step in the corrosion of steel is the transformation of an iron atom to an iron ion by the loss of two electrons. This is called the anodic reaction. This reaction can only occur if there is a suitable electron acceptor to combine with the electrons released by the iron atom. Freshwater or seawater contains dissolved atmospheric oxygen which readily serves this purpose. The oxygen is electrochemically reduced to hydroxyl ions in the cathodic reaction.

The heterogeneous character of the metal surface allows for some areas or sites to favor reaction and become anodes and other areas to favor reaction and become cathodes. The whole surface of the metal is therefore divided up into large numbers of anodes and cathodes,

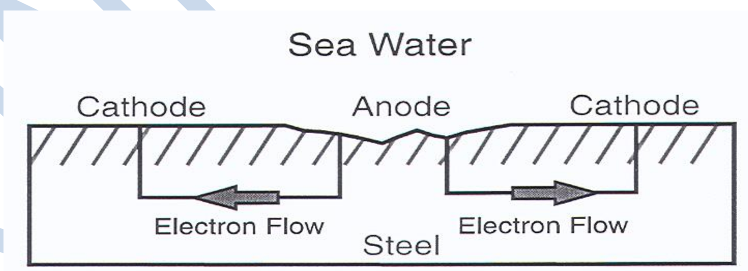


Figure 4 - Anodic & Cathodic Areas Uncoated Steel Surface

as shown in Fig. 4.

As the anodic reaction can take place much more rapidly than the cathodic reaction most of the surface is taken up with the production of hydroxyl ions, as shown in Figure 5.

Figure 5 below shows the progress of corrosion where metal is lost from the anode, causing it to progressively become thinner, accompanied by a flow of electrons from the anode to the cathode which in turn react with both oxygen and water from the environment to form hydroxyl ions.

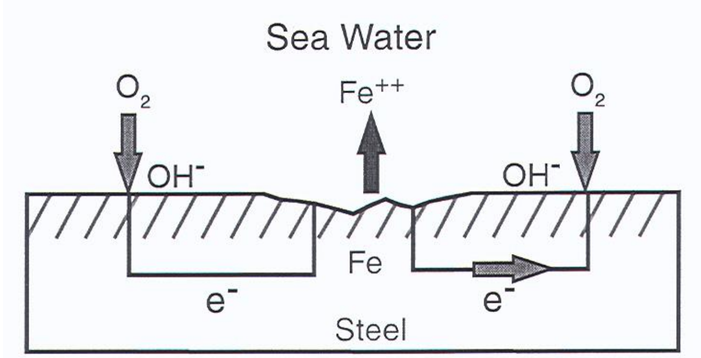


Figure 5 - The Cathode Area is larger than the Anode Area on Uncoated Steels

Both the iron ions and the hydroxyl ions diffuse into the solution and then react together to produce ferrous hydroxide. Ferrous hydroxide in the presence of an abundant supply of oxygen is oxidized to the familiar reddish brown rust.

The previously described reactions are the basic reactions which occur when iron or steel transforms to rust or, more specifically, to hydrated iron oxides. In practical situations the process is not so simple. For instance, corrosion of steel in seawater or in polluted atmospheres results in more rapid and complicated reactions producing corrosion products in association with iron oxide. Some of these iron salts are water soluble and, if not removed before their application, can cause major problems to coatings.

In given environments certain metals will form protective corrosion layers or products, called oxides, which prevent or retard further corrosion. Aluminum and stainless steel are examples of this.

1.6.3 Factors Influencing Corrosion Rates

Diffusion

In the majority of cases, the corrosion rates of metals are controlled by the diffusion of reactants to and from the metal surface. Freshly exposed bare steel surfaces will corrode at a greater rate than those covered with a compact layer of rust.

The corrosion rate is also heavily controlled by the diffusion of oxygen through the water to the steel surface. In areas where oxygen diffusion is prevalent, corrosion appears to occur at faster rates. High flow areas, such as in the vicinity of bell mouths, will tend to exhibit higher corrosion rates because of the increased oxygen levels, although erosion is also a factor. Areas covered by a thin, conducting moisture film, such as the conditions found in ballast tanks after the ballast water is removed and the conditions in cargo tanks after sea water washing, will corrode faster than areas under immersion.

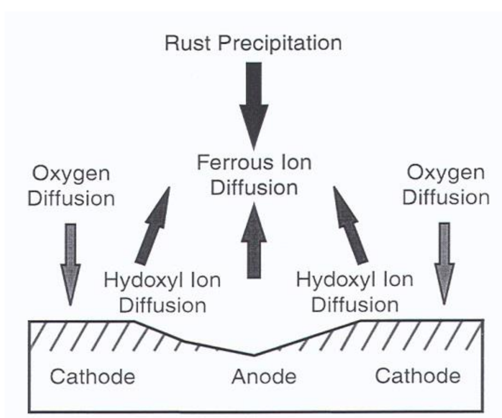


Figure 6 - Diffusion pathways in the corrosion reaction on uncoated steel.

Therefore the ullage space at the top of ballast tanks and at the top of double bottom tanks where air has become trapped, tends to corrode more quickly than deeply submerged areas where there is a lower availability of oxygen, as shown in Figure 6 above.

Temperature

As corrosion rates are determined by diffusion, diffusion rates are also controlled by temperature. Steel and other metals corrode at faster rates at higher temperatures than at lower temperatures. As a result, under-deck areas and regions adjacent to the engine room, or to heated cargo tanks, will tend to corrode faster or preferentially.

One of the features of the modern double hulled tanker with fully segregated ballast tanks is that when the cargo tanks are fully loaded, the empty ballast tanks act as a vacuum flask or thermos-bottle and retain the heat in the cargo for significantly longer periods than the single hull design. This increase in temperature of the cargo/ballast bulkhead combined with the cooler outer shell bulkhead (in the underwater regions) produces a complex set of corrosion conditions and results in an increase in the corrosion rate of the steel in the ballast tanks. Corrosion rates in the cargo tanks themselves will also be higher due to the increased temperature.

Conductivity

For corrosion to occur there must be a conductive medium between the two parts of the corrosion reaction. Corrosion will not occur in distilled water and the rate of corrosion will increase as the conductivity increases due to the presence of more ions in the solution.

The corrosion rate of steel reaches a maximum close to the normal ionic content of sea water. Fresh water corrodes steel to a lesser extent than brackish or estuarine water, with sea water usually being the most corrosive to steel.

Type of Ions

Some types of ions present in sea water or in cargoes are more corrosive than others. Chloride ions are usually the most destructive with sulfate and other sulfur containing ions also presenting major problems.

Chloride ions have a destructive effect on the protective properties of any rusts produced by preventing the formation of the more protective, densely packed oxides. Sulfur containing ions become involved in additional electron generating reactions within the rust itself which in turn forms a cyclic, self-regenerating process. This can produce intensive pitting on the inner bottoms of cargo tanks in oil and product carriers. The sulfur can originate from both the inert gas system and from cargoes containing sulfur, such as sour crude oil.

Acidity and Alkalinity (pH)

pH is a measure of the acidity or alkalinity on a scale of 1 to 14. pH 7 is neutral. In neutral sea water, the pH is around 7.5 which means that the hydrogen ions (acid) and hydroxyl ions (alkali) are almost in balance. Under such circumstances, the reaction that balances the iron dissolution is the reduction of dissolved oxygen to form hydroxyl ions. If however the environment becomes more acidic and the pH falls closer to 1, then there is a greater quantity of hydrogen ions than hydroxyl ions present in the solution. The excess hydrogen ions can become involved in the balancing (cathodic) reaction which results in the evolution of hydrogen gas. As both the hydrogen ions and the hydrogen gas can diffuse very rapidly, the steel can corrode faster. This is a common effect when carrying cargoes such as pet-coke, sulfur and sour crude oils.

Under alkaline conditions, where there is an excess of hydroxyl ions and the pH levels tend towards 14, steel cannot corrode and remains unaffected.

Many of the blisters which are found in ballast tanks, particularly in the double bottoms, are filled with a high pH fluid. When the blister caps are removed, the steel is bright underneath. However, it will begin to corrode once the cap is removed, so once one or two of a group of blisters have been checked and the liquid found to be alkaline, the remainder of the blisters should be left intact.

Electrochemical Potential

Every metal takes up a specific electrochemical potential when immersed in a conducting liquid. This potential is called the half-cell potential as it can only be measured by comparing it to another known reference potential produced by a reference electrode. Common reference electrodes are the Saturated Calomel Electrode (SCE), silver/silver chloride and copper/copper sulfate reference electrodes. The potential that a metal takes up in a solution can determine if and how fast it will corrode.

The potential can be changed by connecting it to another dissimilar metal (as in galvanic corrosion or by using sacrificial anodes) or by applying an external potential, as occurs with an active cathodic protection system of the type employed on the external hull.

1.6.4 Types of Corrosion

Uniform Corrosion

The most common type of corrosion is uniform in nature. The loss of metal is concentrated at the anode sites and there is a continual change in the surface over time. With progressive metal loss, areas which were initially anodic cease to be active and new anodic sites take over. There is a continuous interchange between the anodic and cathodic areas, such that over a period of time the loss of metal over the entire surface is fairly uniform. This is the easiest form of corrosion to combat or allow for because structural lifetime can be predicted.

Pitting Corrosion

The characteristic of this type of corrosion is extremely localized and the penetration is deep in relation to the surrounding area. Pitting is one of the most dangerous forms of corrosion as it often occurs in places where it cannot be readily seen. Pitting corrosion can be intense on mill-scale covered steel which has been left outdoors and has weathered, as shown in Figure 7.

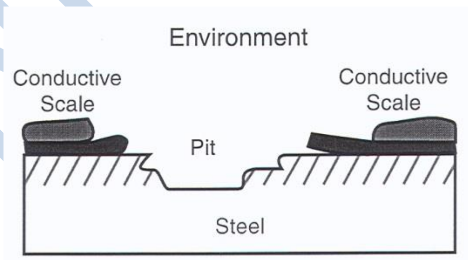


Figure 7 - Pitting Corrosion on Uncoated Steel, showing Layers of Iron Oxides

Pitting corrosion can occur whenever there are suitable localized conditions. Typically pits form where there is a small anodic area which is supported by a large cathodic area. In vessels this can occur at isolated areas where the coating has been damaged. The corrosion occurs at the exposed steel area and the coating becomes the cathodic area. A ring of blisters surrounding an active anodic site are common, as shown in Figure 8.

Before segregated ballast tanks were introduced, cargo tanks with heating coils which were also used as ballast tanks, tended to pit severely.

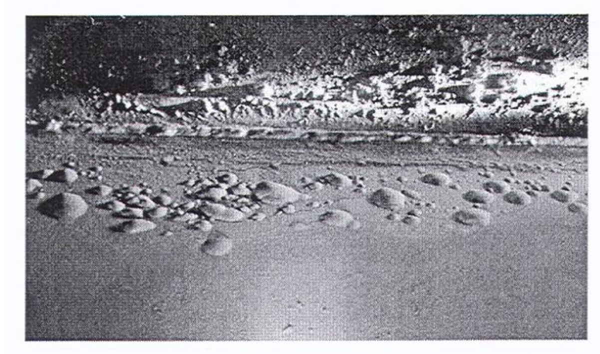


Figure 8 - Cathodic Blisters surrounding an active Anodic Site

On uncoated stainless steel pipe work, for example, pitting can occur where the passive oxide layer becomes damaged and corrosion can initiate at individual sites. If the corrosion products are not washed away from the surface, they will continue to cause corrosion and small pits will form. The materials needed for corrosion become trapped in the bottom of the pits and the rate of corrosion can accelerate as the pit develops. Pits can grow in a variety of shapes, the common ones are V shaped, undercut pits, saucer pits as step sided, as shown in Figure 9.

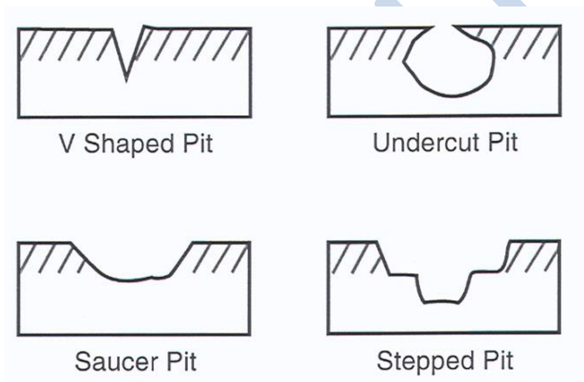


Figure 9 - Different Pit Shapes

V shaped pits are a serious type of pitting, as the rate of penetration through the steel can be very high. Once this type of pit becomes established, it is very difficult to clean the corrosion products from the base of the pit and the corrosion rate can become increasingly rapid.

Undercut pits are also a serious problem as the actual metal loss can be significantly greater than is initially apparent. If the pits are relatively shallow, then the overhang area can break under pressure and cause the pits to “open up”. Over a large area such as inner bottom plating, the effect can be the equivalent of rapid general corrosion. If the pits do not become open, then the rate of corrosion can increase as the pits contain all the constituents necessary for corrosion and the anodic and cathodic areas can separate out within the pit. As with the V shaped pits, these are extremely difficult to clean thoroughly and corrosion rates can be high.

Saucer shaped and stepped pits are the least detrimental, as the rate of metal penetration is relatively low over short time periods as compared with the other types and they are easier to clean and repair.

Crevice Corrosion

Intense localized corrosion, ranging from small pits to extensive attack over the whole surface, can occur within narrow crevices formed by the geometry of a structure, for example: riveted plates or threaded joints. Crevice corrosion is characterized by a geometrical configuration in which the cathode reactant, oxygen, can readily gain access to the metal surface outside the crevice and have less access in way of the crevice. The metal within the crevice is therefore anodic to the surrounding steel and suffers preferential corrosion, see Figure 10.

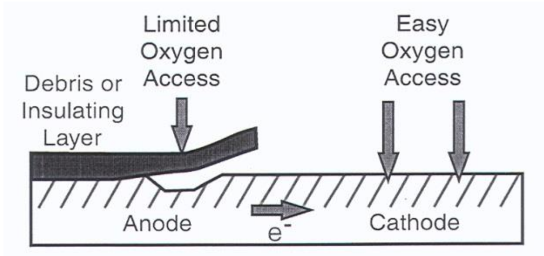


Figure 10 - Crevice Corrosion

When mud, poorly adherent coating, sand and other debris cover a passive surface it undergoes a similar corrosion mechanism to that occurring in crevices. Wherever loose debris collects, there will be a depletion of oxygen in a crevice. Consequently, the corrosion is localized there.

Crevice corrosion and subsequent pitting can also initiate where particles of material such as soot fall on an exposed metal surface. Crevices form where two surfaces are in close contact, for example pipes and pipe support brackets in ballast and cargo tanks can suffer from crevice corrosion where the two items touch. If they are constructed from different metals, one will tend to corrode preferentially. Where they are made from the same metal, both may develop pits where they are in contact.

Crevice corrosion can also form between a metal structure and a non-metallic item, such as a gasket. An example of crevice corrosion forming pits is shown in Figure 11.

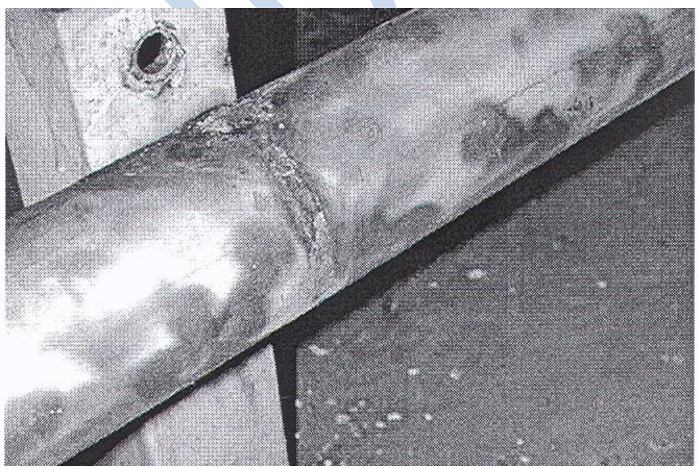


Figure 11 - Pits forming between U Bolt Support and Pipe

Galvanic Corrosion

In the galvanic series shown on the next page the reference potential is a Standard Calomel Electrode (SCE). This is a common reference point in chloride containing environments such as those found in the marine industry. The figure gives the ranking of a number of common engineering materials in the Galvanic Series. The most positive (noble) material will be protected against corrosion at the cost of the most negative (base) material.

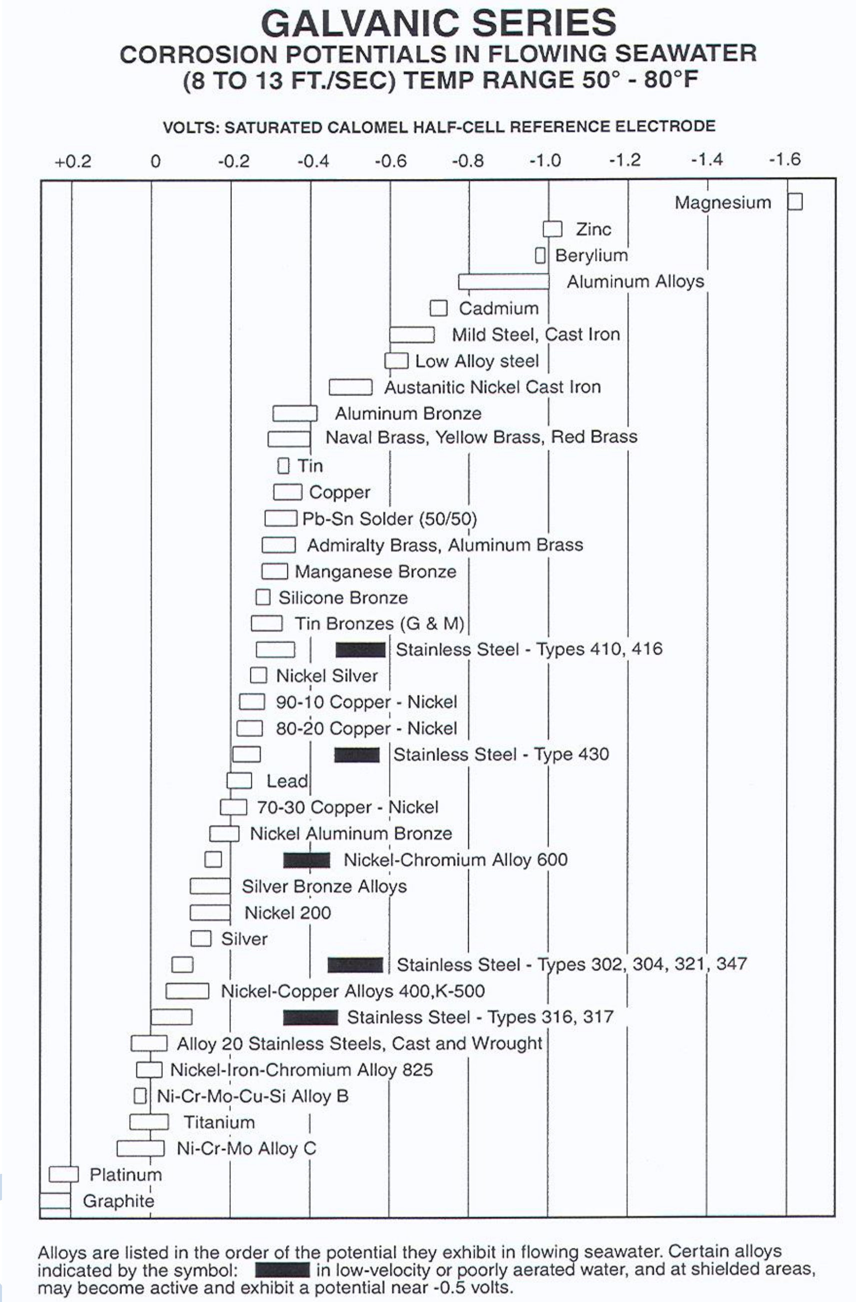


Figure 12 - Galvanic Series

When two different metals in the series are electrically in contact in an electrolyte eg sea water, one of them becomes the anode in the corrosion reaction and the other becomes the cathode. Anodes corrode in preference to cathodes. Cathodes will normally be at the sites of oxygen reduction reaction.

For instance when steel and copper are connected as in Fig. 13, steel is the less noble and therefore corrodes rapidly, whereas the copper is unaffected apart from its surface becoming more alkaline.

In accordance with the traditional concept, an electrical current travels from the copper to the steel (from the positive cathode to the negative anode). The electron flow is in the opposite direction.

Corrosion of the steel is accelerated through its contact with copper. The steel suffers galvanic corrosion while the copper is protected cathodically. Stainless steel is also cathodic to mild steel. When the two are in direct contact, the mild steel corrodes sacrificially.

Deposition Corrosion

This type of corrosion occurs when the ions of a more noble metal come into contact with a less noble metal and the more noble metal plates out. This results in a local galvanic couple being formed and the less noble metal will corrode. A common example is that of copper ions from pipe work and heating coils being deposited on exposed steel tank tops where rapid pitting corrosion will develop. See Fig.14.

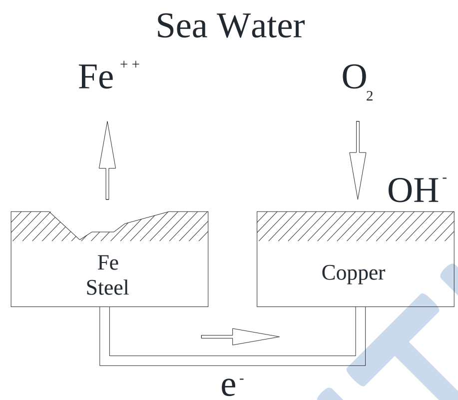


Figure 13 - Flow of Electrons in the Iron/Copper Couple

Figure 14 - Copper Ions Deposited on Aluminum Causing Corrosion

Impingement Corrosion

Impingement corrosion commonly occurs in the way of tank washing and cleaning processes. Areas that are closest to the jets can suffer from a loss of coating and pitting. The force of the jet, whether it is oil or water, is sufficient to remove the protective oxide layers from the metal surface and if the protective oxides cannot reform, localized corrosion (pitting) will occur.

Microbiologically Influenced Corrosion (MIC)

This type of corrosion can very occasionally occur in ballast tanks and has sometimes been blamed for the excessive pitting found on the tank tops of VLCCs. All metals, even stainless steel, can incur corrosion from microbiologically influenced corrosion. It is very difficult to clearly differentiate MIC from other forms of corrosion and opinions differ widely as to its significance. Only when mats or webs of slimy material are present in clearly de-oxygenated environments (zero oxygen) can its presence be definitively confirmed.

The two most common types of bacteria that cause corrosion are acid producing bacteria (APB) and sulfate reducing bacteria (SRB). Both live in colonies attached to the surface of the steel where they assist each other in their growth. Corrosive bacteria, such as SRB which grow in oxygen free environments, rarely thrive over large areas in the conditions on board vessels. On ships, microbes can live in the water layer at the bottom of oil cargo tanks and in the sediment in ballast tanks, but stagnant conditions are usually required for MIC to become wide spread. The exact reaction of microbes and steel is not clear, but they do produce acids, create corrosive cells and produce hydrogen sulfide.

Initial detection of sulfate reducing bacteria is first achieved visually by noting a black slime deposit on the surface of the steel. Additionally, the detection of hydrogen sulfide (as a rotten egg smell) could be noted. Corrosion attributed to MIC is almost always highly localized pitting and the pits are generally filled with a black ferrous product. The walls of the pit can be terraced and the metal surface below the corrosion products is often bright and active. Further confirmation can be obtained by culturing samples.

Similar corrosion effects can also be found where MIC isn't a factor. In crude oil tanks, the corrosion and pitting are driven mainly by sulfur deposits from the cargo or produced by inert gas systems.

All permitted hard coatings used in cargo and ballast tanks are known to be resistant to bacteria with the possible exception of vinyls. The latter are only rarely used in these areas. Supplementing a coating protection system with sacrificial anodes can cause the pH within the tank to increase locally. Bacteria do not usually thrive in areas where the pH level is in the alkaline range of 10 -14.

Note that although sacrificial anodes may be present, the local pH under a bio-film or rust scale may become or remain acidic, if it is shielded from the effects of the sacrificial anode. The use of biocides for treating bacterially affected areas has been tested successfully in small, enclosed tanks, but these have short term effects and are expensive. Biocides such as chlorine, hydrogen peroxide, iodine and quaternary amine have been used.

At the new construction phase, design features should be utilized to minimize or eliminate areas for the accumulation of mud and sediment. Also, proper drainage of all liquids to a common stripping area is desirable to eliminate the possibility of stagnant water accumulating.

Weld Zone Corrosion

This type of corrosion can very occasionally occur in the weld zones of external shell plating of ice transiting ships. Preferential attack can occur in the weld metal deposit or base plate's heat affected zone (HAZ). See Fig. 15 and 16 below.

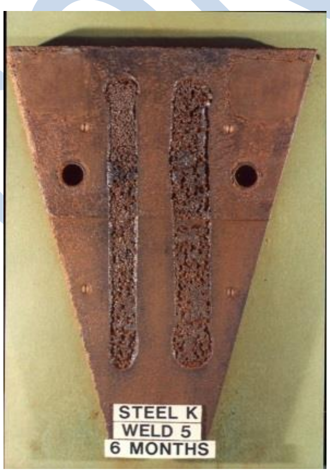


Figure 15 - Weld Metal Corrosion

Figure 16 - HAZ Corrosion

The cause of this form of corrosion was jointly researched by DFO/CCG and CANMET, DNRC a number of years ago. Laboratory tests and field assessments revealed that plain carbon steel weld metal deposits having high silicon content became anodic in relation to the base plate. It was later proven that nobility of weld metal could be improved by either controlling silicon content or alloying the weld metal with small additions of copper and nickel to offset the effects of silicon on nobility.

It was also later discovered that if noble weld metal was deposited in base plates having manganese content greater than 1.2% wt, the morphology switched to HAZ corrosion due to martensitic structure in the HAZ.

These observations were later proven in a three year field assessment study on the MV Arctic which gave a correlation between laboratory test and real-time Arctic exposure corrosion rates.

During the construction of the new bow for the CCGS Louis S. St. Laurent, the mill kept manganese content below 1.30 % wt and the yard filled the seawater side of the groove welds to a depth of 5 mm plus weld crown with a low silicon electrode developed by Air Liquide (E48018-1 RCR). A temper bead technique for capping off is desirable to soften the HAZ as illustrated in Fig. 17.

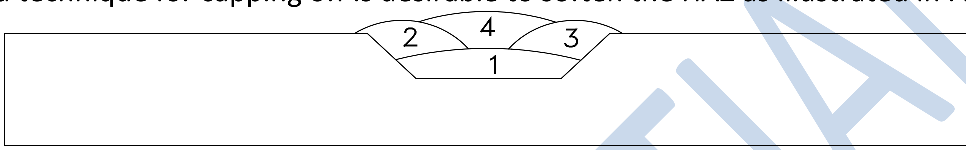


Figure 17 - Temper Bead Technique

Weld metal matching guidance to prevent or repair weld zone corrosion is offered in Sub-Section 5.3.2.10 and Annex B of the 2013 version of the DFO/CCG Welding Specification. As of this date, IACS and their member societies do not offer any guidance or requirements for reducing weld zone corrosion.

1.6.5 Approach to Corrosion Problems

When attempting to solve corrosion problems, the galvanic table should be consulted first to determine the compatibility of the different metals in contact with each other in a marine environment. From a corrosion prevention consideration, simply put, rectification choices available to you are:

- Select materials that are most compatible with each other.
- Isolate materials that are incompatible; coatings or by other means.
- Alter noble/ignoble states by such means as placement of sacrificial anodes, application of sacrificial thermally sprayed metallic coatings or bonding straps.

Example 1, on the Type 1100's in the seawater cooling system, Alpha Laval Titanium Coolers were fitted with an extra heavy wall plain carbon steel pipe between the coolers and the copper nickel iron piping. The carbon steel pipe was intended to be a wastage spool piece (sacrificial anode). Without this sacrificial anode (wastage spool piece), the copper nickel iron pipe would be ignoble in relation to the titanium and corrode.

Example 2, galvanized steel in contact with aluminum initially renders the galvanized steel ignoble until all zinc has been depleted in which case the aluminum reverts to the ignoble state in contact with steel and corrodes.

Example 3, stainless steel bolts were fitted to the sea bay inlet grid plate of the John A MacDonald. At the next docking the steel structure in way of the stainless steel bolts were found severely corroded to an extent requiring repair. A bonding strap between the hull and inlet grid plate would have prevented this.

Example 4, zinc sacrificial anodes are effective for steel but not as effective for aluminum whereas magnesium is effective for aluminum however too ignoble for steel and would waste at a dramatically increased rate.

Section 2 WELDING

Welding dates back to the first working of metal. The first modern welding process was believed to be developed in 1881. One of the first generation welded ships, the HMS Fulagar, was apparently launched in 1920. Welding of steel ships became common in WW II and the lessons learned on the Liberty Ships resulted in better built Victory Ships. Post-war welding became common place, displacing riveting as the primary form of joining.

Due to newness of welding there were issues with its adoption and correct use that posed a risk to public safety in many industrial sectors including marine. As a result, in the 1930's, many nations worldwide, recognized the need for consistent welding standards and the uniform regulation of those standards. The start of WWII temporarily halted further development of standards for welding.

Since the end of WW II, many national and product specific materials, welding and NDT requirements have evolved from a wide variety of sources in the form of specifications, standards, codes, rules, regulations, guides and schemes.

2.1 CANADIAN STANDARDS ASSOCIATION

The Canadian Engineering Standards Association (CESA) formed in 1919 which was later named the Canadian Standards Association (CSA) in 1944. CSA is a not-for-profit membership-based association serving business, industry, government and consumers in Canada and the global marketplace. What began 90 years ago in 1919 as a fledgling operation, striving to make Canada's railways safe, has emerged in the 21st century as a leader in standards development, certification and testing, standards training and consumer product evaluation services.

CSA is an organization that is dedicated to building a better, safer, more sustainable world where standards work for people and business. It is a world class solutions-oriented organization, working diligently to develop standards that address real needs, such as enhancing public safety and health, advancing the quality of life, helping to preserve the environment and facilitating trade. There are 11 CSA Standards Development Programs having multiple categories under each program and many specific standards within each category. CSA Welding Standards are located under the Construction Program, Welding and Structural Metals category.

In 1938 CESA released S-47 which by 1947 evolved into CSA Standard W47 Certification of Companies for Fusion Welding of Steel. The Canadian Welding Bureau (CWB) was established as a division of CSA in 1947 with the mandate of administering the certification requirements of the various CSA Welding Standards.

In 1940 CESA released S-59 which by 1946 evolved into CSA Standard W59 Welded Steel Construction (Metal Arc Welding).CSA Welding Standards are prepared by Technical Committees under the jurisdiction of the Strategic Steering Committee on Welding and Structural Metals, and the standards are formally approved by the Technical Committees.

To promote fairness and to capitalize on the strength and expertise of a broad range of interest groups, each committee is formed using a balanced matrix approach. The composition (matrix) of strategic steering committees and technical committees is set forth with the objective of ensuring that all stakeholder interest categories are represented in reasonable proportion. The matrix establishes a minimum and maximum number of voting members for each interest category and provides a reasonable balance of representation on these committees.

When developing a standard, committee members work toward a consensus of opinion and aim for substantial agreement among the interest groups represented on the committee. The committee considers the views of all participants and develops the content by a consensus process, but not necessarily with unanimity among all committee members. When a draft standard has been agreed upon, it is submitted for public review and amended if necessary.

2.2 CANADIAN WELDING BUREAU (CWB)

The CWB spun off from CSA in 1991 to become CWB Group, a not-for-profit organization that is dedicated to the enhancement of public safety and the success of its clients and members through the provision of welding certification, management systems registration, membership and educational services. CWB Group today is comprised of three business lines and one association:

Canadian Welding Bureau (CWB): Focused on welding certification/ qualification as well as administering of related services (exams, standards, etc.), the CWB provides services for CSA certification as well as international bodies, associations and societies.

CWB Institute (CWBi): Focused on professional development and education, delivers a range of welding and NDE related courses online, in classroom and in hybrid models.

QUASAR: Focused on standards registration, is the only Canadian owned ISO registrar.

Canadian Welding Association (CWA): Focused on advocacy for welding professionals & welding companies, is the largest welding related association in Canada (≈38,000 members & growing).

To this day, the CWB maintains its original 1947 mandate to administer the certification requirements of CSA Welding Standards.

As a technical organization, the CWB is a resource of critical knowledge. From welding procedure reviews and approval to on-site welder qualification to key standards, they are known around the world as a leader in standards administration.

- The CWB is accredited by the Standards Council of Canada as a certification organization.
- The CWB is the Canadian Authorized National Body (ANB) for the International Institute of Welding (IIW) for IIW's Manufacturer's Certification System (ISO 3834) and IIW's Personnel Certification System for welding engineers, technologists, specialists and practitioners.
- The CWBi is accredited by Natural Resources Canada as an NDE training organization
- QUASAR is accredited by the Standards Council of Canada as an ISO registrar.

CWB Group and the CWB serve over 7000 companies in 34 countries worldwide. The CWB presently has over 20 Engineers in various positions of which 7 are dedicated Welding Procedures Engineers. The Procedures Group reviewed 33,443 weld procedure data sheets and supporting welding procedure specifications and, 2,345 procedure qualification test records in 2011. There are presently 20,068 procedure qualification test records stored in the CWB's proprietary weld procedures database and management system.

The CWB has 115 Field Service Representatives. In 2011 the CWB's Field Service Representatives performed over 11,500 Certified Company Audits, tested 43,353 welders, witnessed testing of 89,147 individual test plates and issued 61,622 welder qualification cards; and, administered and witnessed 1,767 welding consumable qualification tests.

The policies and procedures under which CWB Group operates are non-discriminatory and are administered in a non-discriminatory manner. Procedures are not used to impede or inhibit access by applicants, other than as provided for in the standards governing the applicable certification or qualification program.

The structure of CWB is such as to foster confidence in certifications and qualifications granted.

CWB's headquarters is located in Milton, Ontario. The Regional offices are located in Dartmouth, Nova Scotia, Laval, Quebec, Milton, Ontario, Winnipeg, Manitoba, and Edmonton, Alberta. Many of the CWB's Field Service Representatives work out of satellite offices strategically positioned to best serve their clientele.

The CWB presently has 177 accredited welder qualification test centers nationwide where individuals can undergo welder qualification testing to enable them to acquire CWB transferable qualification cards.

BC	Alberta	Mid West	Ontario	Quebec	Atlantic
19	14	14	73	32	25

The CWB presently has 97 companies certified to CSA Standard W178.1 – Certification of Inspection Organizations nationwide of which 47 of these companies are able to perform all methods covered by the standard; VT, LPT, MT, RT, UT, ET and, Metallography and Mechanical testing. These companies may perform the tests required by the test standard to welded test assemblies witnessed by the CWB, with the exception of interpretation of radiographs which is always performed by the CWB.

BC	Alberta	Mid West	Ontario	Quebec	Atlantic
7	19	4	27	27	13

The CWB Group is committed to providing quality certification, qualification and registration services that are reliable, responsive, reputable and competent to ensure the satisfaction of our clients. For over 65 years, the CWB has acted as the administrator of CSA standards (W47.1, W47.2, W55.3, W186 and W48), for 20 years, as a registrar to various international standards (ISO 9001, ISO 14001, OHSAS 18001 and ISO 3834), and as an administrator of industry specific standards (CAN A660, CISC Guideline and CISC Bridge Guideline).

The CWB Group has committed to the implementation and maintenance of a Quality Management System and holds multiple third-party accreditations for the services offered. All employees are encouraged to participate in the system and are responsible to implement and maintain and provide opportunities for improvement of the system.

There are over two hundred certification files at the CWB for companies certified to CSA W47 series standards located in Canada that have indicated to the CWB that either their primary or secondary business is marine.

Complimentary services available from CWB's Office of Public Safety are as follows:

- Educational sessions on:
  - Overview of Canadian standards;
  - Overview of international standards; and
  - Overview of weld quality systems.
- Independent review of project specifications with regard to welding and materials.*

*The service might require a fee based on the extent of the review.

Fee based services available from CWB Group are as follows:

- Project specification development (specific to welding/materials/inspection related issues);
- Supplier evaluations (prior to contract award);
- Review of contractor welding procedures, welder qualifications;
- Review of inspection reports;
- Owners liaison with Classification Societies from a welding/NDE perspective; and,
- Technical advisory service (monthly retainer for on-call advice).

Follow this link for CWB contact information.

2.3 PRESCRIPTIVE WELDING STANDARDS

2.3.1 CSA Standards W47.1 and CSA W47.2

These standards detail the certification requirements of companies for fusion welding of steel (W47.1) and aluminum (W47.2). CSA W47.1 was introduced in 1938 as a preliminary standard and later issued in 1947 as W47. The 2009 edition supersedes the previous editions published in 2003, 1992, 1983 and 1973.

CSA W47.2 was first issued in 1967. The 2011 edition supersedes the previous editions published in 1987 and 1967. These Standards are not intended for applications governed by codes such as the ASME Boiler and Pressure Vessel Code.

The International Association of Classification Societies (IACS) acknowledges that CSA W47.1 and W47.2 are technically equivalent to the standards mentioned in their directives to member societies for welding personnel, welding procedure specification and weld procedure qualification.

These Standards specify the minimum requirements that a company must meet and sustain so as to obtain and retain certification. Certification is granted by the CWB, the administrative body for these Standards.

It is important to understand, certification of a company indicates that it has the organization, personnel, welding procedures, and equipment required to produce satisfactory welds consistent with the Division of Certification.

There are three Divisions. A Division 1 Company is required to employ a full time welding engineer, a Division 2 Company is required to retain a part-time welding engineer and a Division 3 Company is not required to employ or retain the services of a welding engineer.

Production of satisfactory welds is the responsibility of the certified company. It is the responsibility of the purchaser to ensure, through adequate inspection, that the required quality is attained. Although the CWB makes periodic inspections of certified companies to ensure that they continue to comply with the requirements of these Standards, these inspections do not eliminate the need for a certified company's quality control methods or a purchaser's comprehensive inspection program.

CWB issues a letter of validation for each certification standard annually. A company in default has 90 days to rectify the issue(s) to CWB's satisfaction otherwise certification is revoked. Each letter of validation will indicate a period of effectiveness. Caution should be exercised when a current letter of validation cannot be supplied by the contractor. Equally important is ensuring renewals are achieved in an expedient manner when the renewal date lands within a given contract period. A sample letter of validation is offered below

.Figure 18 sample letter of validation

LETTER OF VALIDATION

The CWB acknowledges that

BRIGHTWELD LTD.

123 Arcweld Way, Teejoint, ON Canada

is certified to CSA Standard W47.1

"Certification of Companies for Fusion Welding of Steel"

in **DIVISION 2**

for the period **April 4, 2013** to **May 3, 2014**

Company Code: BRIWL1

Scope: Welding and fabrication of structural steel.

Registrar

The product certification system operated by the Canadian Welding Bureau most closely resembles that described by ISO/IEC Guide 67, Conformity assessment — Fundamentals of product certification, System 6.

8260 Parkhill Drive, Milton, Ontario L9T 5V7
1-800-844-6790 | Int: 905-542-1312 | Fax: 905-542-1318
Email: info@cwbgroup.org | Web: www.cwbgroup.org

Follow this link to search for CWB Certified Companies.

2.3.2 CSA Standards W178.1 and CSA W178.2

These standards detail the certification requirements of welding inspection organizations (W178.1) and welding inspectors (W178.2).

CSA W178.1 was first issued in 1973. The 2008 edition supersedes the previous editions published in 2002, 1996, 1990 and 1973.

CSA W178.1 provides a set of requirements to appraise the capability of organizations supplying services in the welding inspection field. It is to be used in conjunction with CSA W178.2, Certification of welding inspectors.

The requirements of CSA W178.1 are intended to be applied in conjunction with quality management system standards, such as the CAN/CSA-ISO 9000 Standards, and with product category standards.

CSA W178.2 was first issued in 1982. The 2008 edition supersedes the previous editions published in 2001, 1996, 1990, and 1982.

CSA W178.2 provides requirements for certification of welding inspectors independent of where they work. An individual applying for certification under the requirements of this Standard does not have to be employed by an inspection organization.

The effectiveness of welding inspection depends largely on the knowledge and integrity of the individual responsible for carrying out the inspection. As such, there is a definite need for welding inspectors with appropriate knowledge and capability of exercising responsible judgment. This Standard is not intended to replace the employer's final responsibility for the work or a supervisor's judgment of an individual's suitability to perform a given task.

Follow this link to search for CWB certified NDT Companies and Visual Inspectors.

2.3.3 CGSB Standard 48.9712-2006

This Standard defines the certification requirements of NDT personnel. CAN/CGSB 48.9712-2006 has three levels of certification in the Industrial Radiography (RT), Ultrasonic (UT), Magnetic Particle (MT), Liquid Penetrant (PT) and Eddy Current (ET) testing methods.

- Level 1 individuals are permitted to perform tests or assist with the testing under the direct supervision of a Level 2 or 3 individual.
- Level 2 individuals are permitted to perform tests, interpret results and prepare interpretation reports.
- A Level 3 individual is permitted to perform tests, interpret results, prepare interpretation reports and write test procedures.

For the **RT method**,

- EC = Engineering, Materials and Components Sector
- AS = Aerospace Sector
- A = Light Alloy Castings and Forgings
- B = Welds and Weldments
- C = Heavy Metal Castings and Forgings

Certification in the A, B, and C sectors is equivalent to certification in the Engineering, Materials and Components Sector.

For the **UT, MT, PT and ET methods**, all certification is in the Engineering, Materials and Components Sector.

Natural Resources Canada (NRCan) manages Canada's nation-wide program for the certification of individuals performing non-destructive testing. The NRCan National NDT Certification Body (NCB) provides the following services:

- NRCan – CGSB-48.9712 NDT Certification: Certification for NDT Personnel.
- XRF Analyzer Operator Certification: Certification for operators of portable x-Ray tube-based fluorescence (XRF) analyzers in accordance with Health Canada's Safety Code 34 requirements and ISO 20807
- CEDO Written Examination: Qualification for the written examinations for the Canadian Nuclear Safety Commission's (CNSC) certification of Exposure Device Operators (CEDO).

These programs are implemented by the federal government in order to provide the unbiased Canada-wide services required to implement a national program. To ensure that this objective is met, an Advisory Committee composed of individuals knowledgeable about NDT in Canada advises NRCan on the operation of this certification body and its programs.

Follow this link to search for NRCan certified NDT personnel.

The recommended penalties on Code of Conduct breaches are: cheating (on exam) a 1 year minimum suspension of all certifications and misrepresentation (fraud) a 10 year suspension of all certifications. For example, misrepresentation of certification or level of certification on reports, procedures or on copies of wallet sized cards.

2.4 PRODUCT CATEGORY WELDING STANDARDS

2.4.1 CSA Standards W59 and CSA W59.2

These standards detail the welded construction requirements for steel (W59) and aluminum (W59.2).

CSA W59 was first introduced in 1940. The 2003 edition supersedes the previous editions published in 1989, 1984, 1982, 1977, 1970, 1946, and 1940.

CSA W59.2 was first issued in 1991 replacing CSA Standard S244-1969, Welded Design and Workmanship (Inert Gas Shielded Arc Processes). It was given a new number to reflect that it parallels CSA Standard W59. The 1991 Edition was reaffirmed in 2008.

These standards have product requirements in the following areas:

- Design of Welded Connections
- Welding Consumables
- Workmanship
- Acceptance Criterion for Welds
- Weld Inspection

The Annexes of both standards contain guidance information in a number of areas.

CSA W59 has a section on prequalified welding procedures allowing fabricators to obtain approvals if all conditions of the standard have been met without performing weld procedure qualification tests whereas CSA W59.2 does not. All procedures must have the CWB stamp of acceptance.

2.4.2 CCG Welding Specification for Ship Construction and Repair

The Specification establishes the requirements of Marine Engineering, Integrated Technical Services (ITS), Canadian Coast Guard, Fisheries and Oceans Canada. Companies are required to follow and meet the requirements of this Specification whenever required by a contract. It details the requirements for welding and non-destructive inspection of welds for structural steel, aluminum and stainless steel and the wide variety of other materials used for installation of pressure piping, pressure vessels and pressure containment systems and, shipboard equipment.

The Specification relies on the integration of commercial standards with the owner's (CCG ITS) specific or special requirements.

The Specification combines structural materials and pressure piping into one document; structural steel, structural aluminum, structural stainless steel, structural other materials and pressure piping. The Specification is suitable for new construction, mid-life modernization, vessel life extension and repairs.

The Specification defines the authority for technical and inspection as that of the Director, Marine Engineering, ITS-Ottawa and appointed Delegated Representative(s). The Specification also makes reference to the regulatory regime and Transport Canada Marine Safety and Security (TCMSS) Recognized Organizations.

The Specification has been formulated taking into the account the internal desire to procure to the requirements of commercial standards wherever appropriate and sufficient to reduce cost.

As such, the Specification refers to the following commercial standards:

- Welded Structures
    - CSA W47.1 and CSA W59 for steel.
    - CSA W47.2 and W59.2 for aluminum.
    - CSA W47.1 and AWS D1.6 for stainless steel.
    - ASME Section IX and W59 for other materials.
    - IACS Directives for materials, fitted tolerances and welding.
- Pressure Piping, Pressure Vessels and Pressure Containment Systems
    - ASME Section IX and ASME B31.1
- Inspection & NDT
    - CSA W178 and W178.2
    - CGSB 48.9712-2006
    - ASME Section V

The Specification requires companies to be certified by the CWB to CSA Standards W47.1 and W47.2 Division 1 or 2 which has been a requirement of CCG for 30 years now. CWB presently have ≈ 200 files of Canadian certified companies indicating their primary or secondary business is marine.

The Specification refers weld design requirement and welding symbols to CSA Standards W59 and W59.2.

There is a cross reference in the Specification that permits matching the CSA W48 electrode and consumables designations to the various shipbuilding grade steels, higher strength notch tough steels, atmospheric corrosion resistant steels and shell butts and seams of ice transiting ships.

The workmanship section refers to CSA Standards W59 and W59.2 and, IACS No. 47 Shipbuilding and Repair Quality Standard for deformation of plating between stiffeners in addition to a limited number of owner requirements as follows:

5.4.3 Plate forming with heat (heat line bending).
5.4.5 Adjacent weld spacing.
5.4.6 Dimensions for Inserts.
5.4.8 Alignment of Intercostals.
5.4.9 Transition Chamfer between Dissimilar Plate Thicknesses.
5.4.10 Requirements when welds are to be finished flush.
5.4.11 Requirements when welds are to be finished smooth.
5.4.13 Requirements for Welding Sequence and Release Distances.
5.4.15 Requirements regarding temporary welds, lugs and attachments.
5.4.16 Requirements regarding stray arc strikes.

The inspection section refers to CSA Standards W59, W59.2, W178.2 and CGSB 48.9712 in addition to a limited number of owner requirements as follows:

5.5.1 Requirements for requesting the use of ultrasonic inspection in lieu of radiography.
5.5.2 Owner’s requirement for monthly third party audits by CWB.
5.5.3 Owner’s requirement for radiographic film third party audits by NRCan.
5.5.6 The quantity of inspection formula is now the same for new construction of steel and aluminum vessels. Inspection quantities have been defined for maintenance and repair projects.
5.5.7 Requirements for surface preparation prior to inspection.
5.5.8 Delayed inspection requirements for steel > 360 MPa yield strength.
5.5.9.1 & 5.5.9.2 – Level 1 personnel may only observe or assist Level 2 and 3.
5.5.9.3 Qualification certificate requirements for inspectors.

5.5.10 Inspection requirements and acceptance criterion for steel structures.
5.5.11 Inspection requirements and acceptance criterion for aluminum structures.
5.5.12 Double loaded film requirements for radiographic inspection.
5.5.13 – Radiographic film viewer requirements.
5.5.14 – Inspection reports and NDT arrangement drawing requirements.
5.5.15 – Overlapping film requirements.
5.5.16 – Rejected weld or part requirements.

Chapter 6 contains the requirements for welding structural stainless steels by combining the use of CSA W47.1 and AWS D1.6.

Chapter 7 contains the requirements for welding other structural materials not covered by CSA W47.1 and W59, W47.2 and W59.2 and AWS D1.6 by combining the use of ASME Section IX and the acceptance criterion of CSA W59.

Chapter 8 contains the requirements for pressure pipe welding by combining the use of ASME Section IX and ASME B31.1.

Annex A contains a list of referenced codes, standards and publications.

Annex B contains tests for rating corrosion resistance of carbon steel weld metals in seawater.

Annex C contains Hot Forming and Thermal Requirements for Aluminum.

2.5 WELDING ELECTRODES AND CONSUMABLE STANDARDS

2.5.1 CSA Standard W48 - 06

CSA W48 was first issued in 1938. The 2006 edition supersedes the previous editions published between 2001 and 1938. The CWB witnesses all tests required by the standard.

Filler metals standards are intended to provide a generic method of classification and evaluation that allows the end-user to select appropriate welding consumables for a given welding process and product or application. The procedures and tests set out in the Standard, when correctly followed, are designed to produce a consistent product with test results that are as reproducible as possible.

The Technical Committee is also in contact with other organizations, such as the American Welding Society (AWS), European Committee for Standardization (CEN) and the Japan Welding Engineering Society (JWES).

The requirements for solid wire gas metal arc consumables have been replaced by adoption of and reference to CAN/CSA-ISO 14341. Annex A (normative) provides classification equivalencies for the first edition of the Standard.

Non-mandatory annexes in the Standard provide general information and an explanation of the classification system (Annexes B and C); descriptions and intended uses of the welding filler metals and allied materials (Annexes D, E, F, G, and H); information on storage and conditioning of electrodes (Annex I); and information on diffusible hydrogen (Annex J).

Follow this link for a List of CSA W48 CWB approved welding consumables.

2.6 WELD DESIGN

The weld design is the size and type of weld for a given connection; throat or leg size for fillet welds and depth of penetration for other welds.

In the case of new construction of large vessels, the weld design follows the rules of a Recognized Organization (Classification Society). For smaller vessels, the design is often supplied with the construction drawings and plans.

For existing ships, it is always best to follow the original weld design schedule unless the original design has proven to be problematic since the new build stage.

When in doubt the following principles can be applied:

Unless otherwise specified,

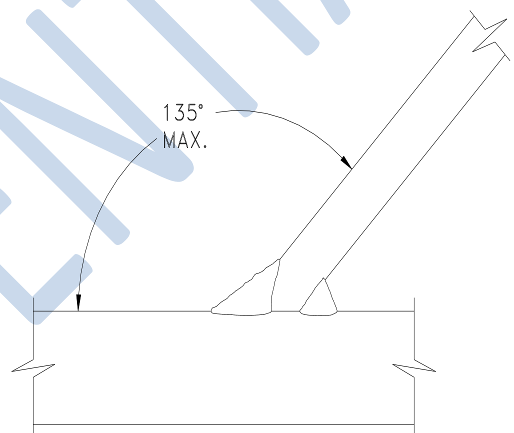
- All fillet welds should be double continuous;
- All butt joints should be full penetration; and,
- All corner joints should be full penetration with a continuous fillet weld.

It is important to know if fillet weld size on the submitted plans is indicating the throat thickness or leg length. Lloyd's and DnV specify fillet size by way of throat thickness, while ABS specifies fillet weld size by leg length. Throat thickness may be converted to leg size by multiplying by a factor of √2. Leg size may be converted to throat thickness by multiplying by a factor of 0.707.

2.7 SKEWED JOINTS

In the case of a skewed joint where one member is not perpendicular to the other, the size of the fillet weld should be determined using the method outlined below.

The deposited leg length of fillet welds need to be adjusted based on the fitted angle using the multiplier in the table below. The calculated fillet size is increased by an amount equal to the gap between the members if present. Gaps less than 1.5 mm may be disregarded. The measured size of each fillet should be the smaller of the two leg sizes. The dihedral angle should not exceed 135°.



Skewed Joints

Dihedral Angle in Degrees	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**
Factor to multiply by	0.71	0.76	0.81	0.86	0.91	0.96	1.00	1.03
Dihedral Angle in Degrees	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**
Factor to multiply by	1.08	1.12	1.16	1.19	1.23	1.25	1.28	1.31

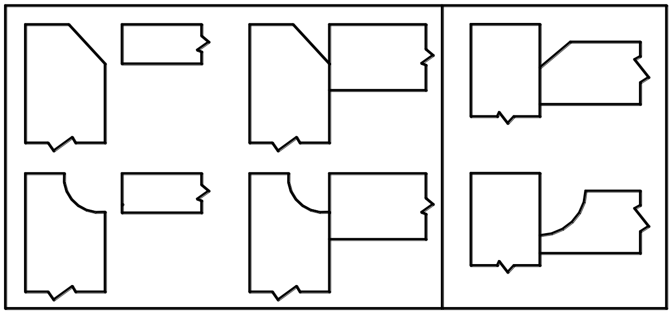
Example: Slab longitudinal in the skewed condition fitted to be 135°. Desired fillet weld in the non-skewed condition (90°) is 5 mm. Leg length required (5 mm x 1.31). If there is a gap when fitted, add the dimension of the gap to the calculated value. Gaps should not exceed 3 mm (e.g. 5 mm x 1.31 + 3 mm). The value should be rounded up to the nearest fillet size.

2.8 PENETRATION WELDS

The Delegated Representative may be requested by the shipyard to approve a reduction in fillet weld size based on the deep penetration that can be obtained through the use of welding processes such as Submerged Arc Welding (SAW) and controlled root openings. This matter should be approached with caution and approval should not be granted until the shipyard has proven, through the use of macro-etch specimens, that the requested reduction in fillet size is being repeatedly replaced by an equivalent penetration into the root of the joint.

2.9 LAMELLAR TEARING

When welding thick plate (t > 19 mm), lamellar tearing can be initiated by poor joint design, particularly in the case of corner joints. The following illustrates desirable and undesirable joint designs when corner joints cannot be avoided.



Desired **Not Desired**

Figure 19 - Joint Design to Avoid Lamellar Tearing

Welding symbols are used to describe the weld required by the designer to provide the necessary joint or connection strength and meet the in-service performance requirements. "Describing" the weld includes, when necessary; defining joint geometry, process to be used, desired contour, finishing process, number and size of welds, non-destructive examination requirements, etc. It is important to realize that a large amount of information can be shown in one welding symbol, information that may not appear elsewhere unless previously requested.

The American Welding Society, working closely with the welding industry in North America, has developed a systematic plan of symbols, which have become standardized industry wide. AWS Standard A2.4, “Standard Symbols for Welding, Brazing, and Non-destructive Examination” describes this system. CSA Standard W59 has adopted the system with some modifications found in the standard.

Before welding symbols can be used and interpreted effectively, the user must understand the basic differences between a joint and a weld as used in the welding industry. The type of joint describes the way in which adjoining members may contact each other and the type of weld describes the weld joint configuration as illustrated below.

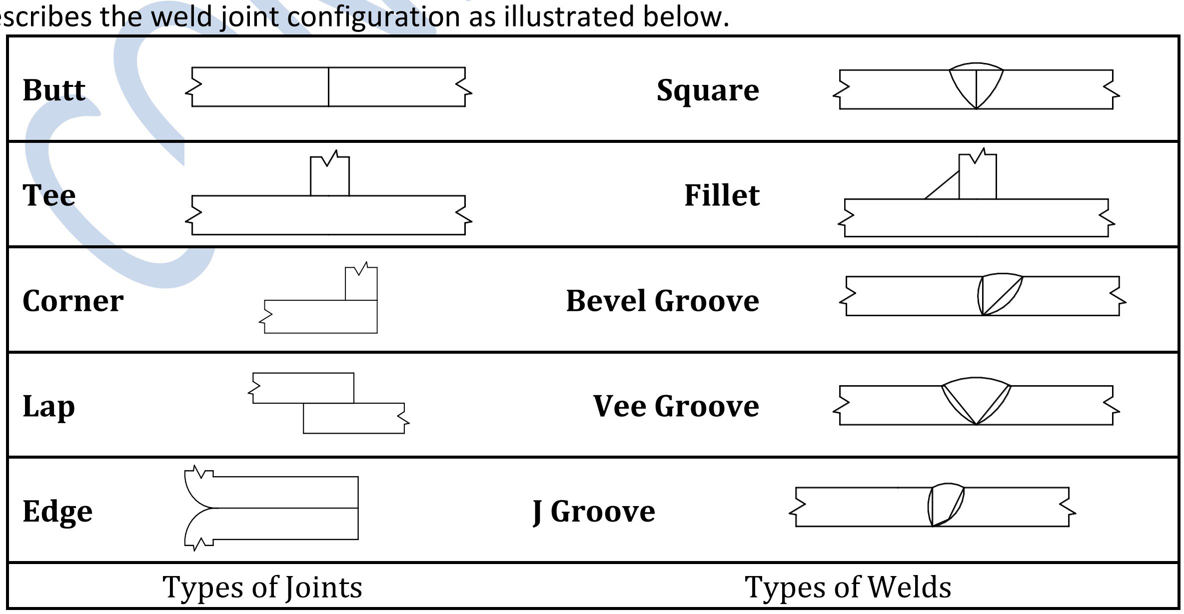
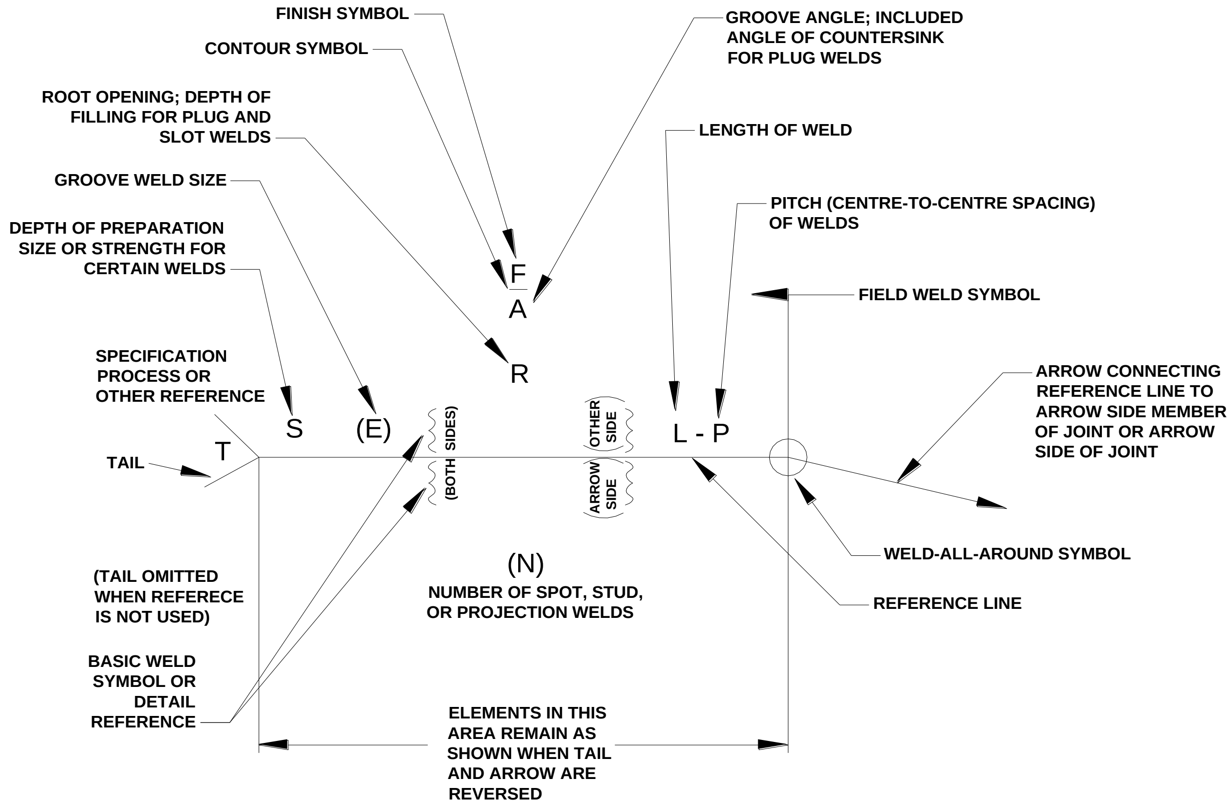


Figure 20 - Types of Joints and Types of Welds

Welding symbols will usually appear on the shop or detail drawings. The standard location of elements of a welding symbol is illustrated below.

Figure 21 Welding Symbols



All welding symbols must begin with the reference line and the arrow connecting the reference line to the arrow side member or arrow side of the joint. From that basis, the complexity of the symbol depends upon the amount of information required to produce the necessary weld and subsequent non-destructive examination.

The location significance of the arrow is illustrated below. The arrow side - other side system is used to avoid confusion with regards to which weld is being placed on which side of the joint. The arrow side or other side of the symbol is always as shown, no matter where the arrow is located.

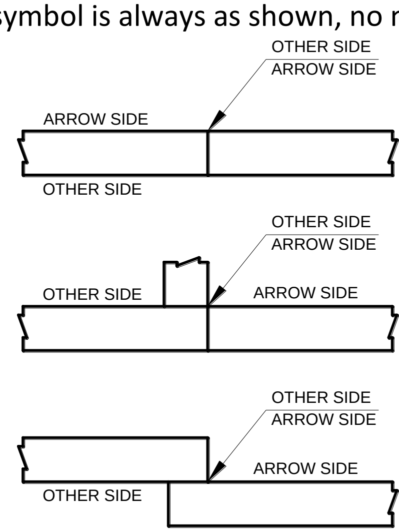


Figure 22 - Location Significance of Arrow

2.10 WELDING PERSONNEL QUALIFICATIONS

CSA Standards W47.1 and W47.2 stipulate the requirements for welding engineers for steel and aluminum, respectively. Division 1 and 2 CWB Certified Companies are required to have a welding engineer; full time for Division 1 and retained for Division 2.

The CWB qualify welding engineers to the requirements of the CSA Standards and maintain a list of qualified welding engineers on their website.

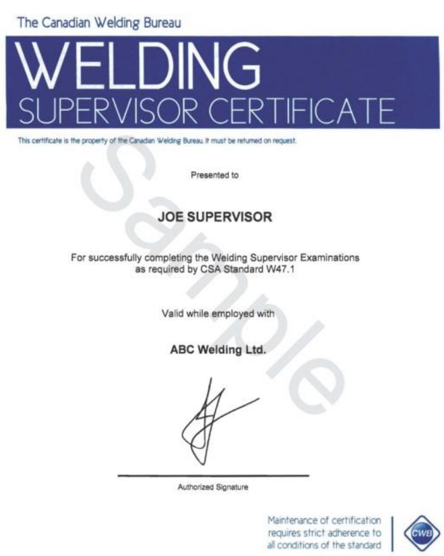
Follow this link to locate CWB qualified welding engineers (select CWB Approved Professional Engineers from the Guide List)

CSA Standards W47.1 and W47.2 stipulate the requirements for welding supervisors for steel and aluminum, respectively. Division 1, 2 and 3 CWB Certified Companies are required to have a qualified welding supervisor.

The CWB qualify welding supervisors to the requirements of the CSA Standards. Welding supervisors must be experienced, have a thorough knowledge of the welding specifications and data sheets for the processes used by the company, be able to read drawings and interpret welding symbols, have knowledge of weld faults, quality control and inspection methods, equipment operation and the codes and standards applicable to the company's operation.

Welding supervisors are issued qualification cards and certificates which can be transferable or non-transferable to another CWB certified company. Sample certificate is illustrated below.

Figure 23 Image courtesy of the CWB. (Use with permission.)



Welding operators, welders and tack welders are issued qualification cards after successful completion of the tests outlined in the applicable standards; CSA W47.1 for Steel and Stainless Steel Structures, CSA W47.2 for Aluminum Structures and ASME Section IX for pressure pipe, pressure vessels and pressure containment systems.

Welding Operator – is a person who operates automatic or machine welding equipment.

- **a.** Automatic Welding – is equipment that performs the welding without adjustment of the controls by a welding operator.
- **b.** Machine Welding – is equipment that performs the welding with constant observation and control by a welding operator.

Welder – is a person who welds by manipulating an electrode holder or welding gun assembly.
Tack Welder – is a person who makes tack welds so as to hold parts to be welded in alignment. The card will indicate if it is transferable or non-transferable and offer the qualified person's name, employer, the qualified thickness range, expiry date, material, welding process, process mode, classification and class, filler alloy group, test standard and other information specific to a given welding process.

1. **Transferable** means the individual's qualification can be transferred to another CWB certified company whereas non-transferable cannot.
2. **Thickness Range** is the range of thicknesses that can be welded under the qualification card.
3. **Material** is the type of material that can be welded under the qualification card (steel, stainless steel or aluminum);
   - **a. Steel** – no divisional categories.
   - **b. Aluminum**
     - **i.** Group 1 – alloys 1050, 1060, 1100, 1350 and 3003.
     - **ii.** Group 2 – alloys 3004, 5005, 5052, 5154, 5254 and 5454.
     - **iii.** Group 3 – 5083, 5086 and 5456.
     - **iv.** Group 4 – 6005, 6061, 6063, 6101 and 6351.
     - **v.** Group 5 – 7004 and 7005.
4. **Welding Process** that can be used under the qualification card;
   - **a.** SMAW is Shielded Metal Arc Welding (stick electrode),
   - **b.** SAW is Submerged Arc Welding (wire and external granular flux),
   - **c.** FCAW is Flux Cored Arc Welding (tubular wire having an internal flux core that is either external gas or self-shielded),
   - **d.** MCAW is Metal Cored Arc Welding (tubular wire having an internal "all metal" core that is external gas shielded),
   - **e.** GMAW is Gas Metal Arc Welding (copper coated or bare solid wire that is external gas shielded), and
   - **f.** GTAW is Gas Tungsten Arc Welding (gas shielded arc drawn between the tungsten and material with or without solid wire filler metal).
   - **g.** PAW is Plasma Arc Welding (plasma gas arc with or without solid wire filler metal).

5. **Mode** of process application offers specifics related to the qualification. The number of electrodes (single/twin) can be appended to any mode listed below;

   - Manual
   - Semi-Automatic
   - Automatic
   - Machine (Mechanized)

6. **Power Source** is indicated for the wire fed and gas tungsten arc welding processes as either conventional and/or pulsed current.

7. **Standard** is the test standard used for the qualification testing; CSA W47.1 for Steel and Stainless Steel and CSA W47.2 for Aluminum.

8. **Class** is the position of welding permitted under the qualification card;

   a. (F) is flat, (H) is horizontal, (V) is vertical up or down, and (O) is overhead.

9. **Classification** under the qualification card is as follows;

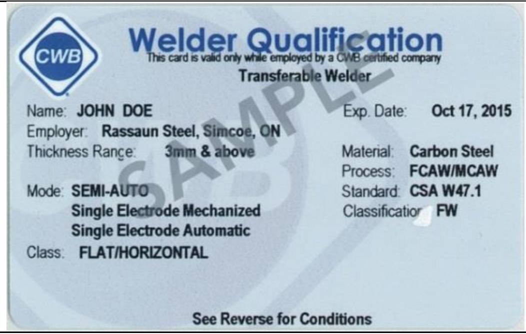
   a. Steel
      i. (T) is full penetration from one side without backing (plate, hollow sections and pipe)
      ii. (S) is full penetration from both sides with back gouging or full penetration from one side with backing material,
      iii. (FW) is fillet and tack welds,
      iv. (WT) is tack welds, and
      v. (ASW) is arc spot welds.

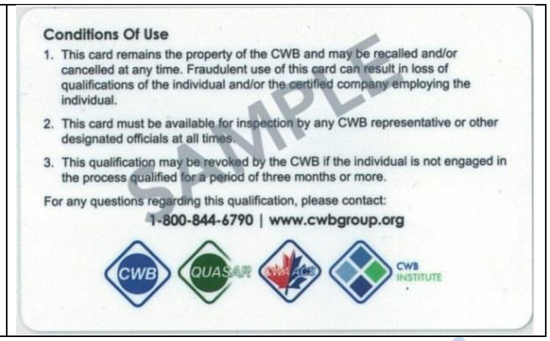
10. **Filler Alloy Group** is the electrode classification for SMAW of steel and GMAW and GTAW of aluminum;

   a. Steel
      i. F4 – EXX 15, 16 and 18.
      ii. F3 – EXX 10 and 11.
      iii. F2 – EXX 12, 13 and 14.
      iv. F1 – EXX 22, 24, 27 and 28.

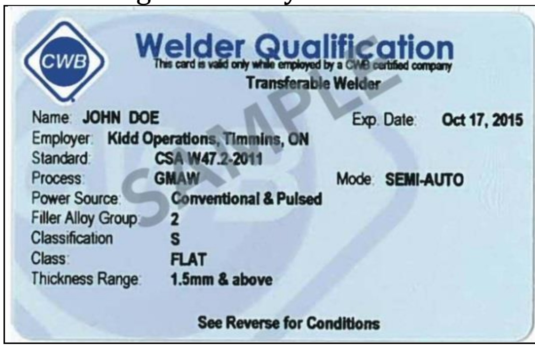
   b. Aluminum
      i. Group 1 – 5183, 5356, 5554, 5556 and 5654.
      ii. Group 2 – 4043, 4047 and 4145.
      iii. Group 3 – 1100.

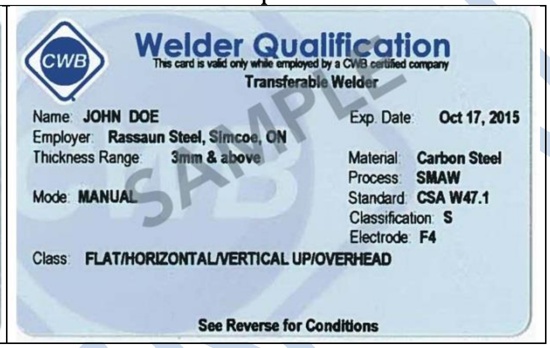
Sample qualification cards are illustrated below.





Images courtesy of the CWB. Use with permission.





Visual welding inspectors are issued qualification cards after successfully meeting the requirements (education, training, experience and testing) of CSA Standard W178.2.

There are three levels of qualification;

Level 1 – performs and assists with visual inspections under the direct supervision of Level 2 and 3 individuals.

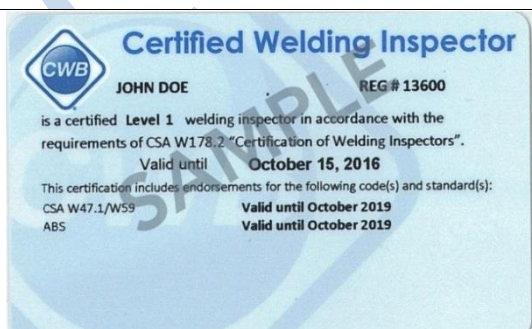
Level 2 – performs and interprets results of visual inspections.

Level 3 – develops procedures, performs and interprets results of visual inspections.

Each qualified inspector is required to acquire code endorsements for the specific industry group where inspections are to be performed.

For general structural work CSA Standards W47.1/W59 is desirable for steel and W47.2/W59.2 for aluminum, ASME for pressure pipe, pressure vessels and pressure containment systems and ABS or IACS for marine.

A sample qualification card is illustrated below.



Images courtesy of the CWB.	Use with permission.

2.11 WELDING PROCEDURE SPECIFICATIONS

The CWB certified company prepares welding procedure specifications for each welding process and material type or group. The welding procedure specifications are supported by a number of welding procedure data sheets (see 2.15 herein). For Division 1 and 2 companies the welding procedure specifications and welding procedure data sheets must be accepted by the company's engineer and CWB by signature and/or stamps in the appropriate box. For a Division 3 company the qualified welding supervisor provides company acceptance in lieu of an engineer.

COMPANY NAME:_______________________________________.

COMPANY ADDRESS:____________________________________.

WELDING PROCEDURE SPECIFICATION
FOR SHIELDED METAL ARC WELDING

SPECIFICATION No.:_________.

Scope

This Welding Procedure Specification covers welding and related operations of steel structures which are fabricated in accordance with the terms outlined in CSA Standards W47.1 and W59, latest revisions. The attached Data Sheets form an essential part of this specification.

A change in any of the essential variables contained in succeeding paragraphs or detailed on applicable Welding Procedure Data Sheet(s) shall require a new Welding Procedure Specification and/or a new Welding Procedure Data Sheet(s).

Welding Procedure

The welding shall be done manually using the SMAW (Shielded Metal Arc Welding) process.

Joints shall be made following the procedural stipulations indicated in CSA Standard W59, and may consist of single or multiple passes in accordance with the accepted Welding Procedure Data Sheets to which this specification refers.

Base Metal

The base metal shall conform to the specifications of steel groups 1, 2, 3 as per Table 11.1 or Table 12.1 of CSA Standard W59. Other groups may be welded providing Welding Procedure Data Sheets are accepted by the Canadian Welding Bureau.

Base Metal Thickness

Base metal thicknesses from 3 mm (1/8") to UNLIMITED THICKNESS inclusive may be welded under this specification providing the respective Welding Procedure Data Sheets have been supplied and accepted for the appropriate weld size.

CWB Acceptance	**Engineer or Supervisor Acceptance**

Figure 24 - Welding Procedure Specification

Samples courtesy of the CWB.	Use with permission.

- 2 -

Filler Metal

The filler metal shall be certified by the Canadian Welding Bureau as conforming to CSA Standard W48.

Storage and Conditioning of Electrodes

Basic Electrodes

The storage and conditioning of electrodes shall be as per CSA Standard W59.

All basic electrodes shall be delivered in hermetically sealed containers that do not show evidence of damage. However, if such containers show evidence of damage, the electrodes shall be reconditioned in accordance with the requirements of CSA Standard W59.

Immediately after being removed from hermetically sealed containers or from reconditioning ovens, electrodes shall be stored in ovens held at a temperature of at least 120°C (250°F).

Basic electrodes of E49XX classification that are not used within 4 hours after removal from ovens shall be reconditioned in accordance with the requirements of CSA Standard W59.

Basic electrodes shall be re-dried no more than once.

Electrodes that have been wet shall be discarded.

Other Than Basic Electrodes

All other than basic electrodes shall be stored in warm and dry conditions and kept free from oil, grease, and other deleterious matter once they have been removed from their containers and packages.

Electrodes that have been wet shall be discarded.

Position

The welding shall be done preferably in the flat position, but other positions such as horizontal, vertical and overhead are permissible providing the proper Data Sheets are supplied and approved.

Preheat

The minimum preheat before welding will comply with Table 5.3 of CSA Standard W59. Minimum preheat to be maintained or exceeded during welding.

If welding is interrupted for some time so that the temperature of the base metal falls below the minimum preheat temperature, then arrangements will be made to preheat again prior to recommencing welding.

The weldment shall be allowed to cool to the ambient temperature, without external quench media being supplied. In other words, do not cool using water or by immediate placement in frigid conditions which will cause a quick temperature change.

Samples courtesy of the CWB.	Use with permission.

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Heat Treatment and Stress Relieving

This will not be applicable to structures welded under this specification, unless a specific Data Sheet showing all the parameters is submitted to the Canadian Welding Bureau and acceptance is obtained.

Electrical Characteristics

Welding equipment will be used having a drooping voltage characteristic. The welding current specified will be direct current (straight or reverse polarity) or alternating current. The current range will be as per electrode manufacturer's instructions and will shown on the Welding Procedure Data Sheet.

Welding Technique

The correct amperage and voltage, speed of travel, thickness of layers, number of passes, position, material electrodes and any special instructions will be as per Data Sheet.

Arc strikes outside of the area of welds should be avoided on any material.

Preparation Of Base Material

The edges or surfaces of parts to be joined by welding shall be prepared by oxy-acetylene machine cutting. Where hand cutting is involved the edge will be ground to a smooth surface. All surfaces and edges shall be free from fins, tears, cracks or any other defects that will adversely affect the quality of the weld.

All loose or thick scale, rust, moisture, grease or other foreign material that would prevent proper welding or produce objectionable fumes, shall be removed.

Quality

Cracks or blow holes that appear on the surface of any pass shall be removed before depositing the next covering pass. The procedure and technique shall be such that undercutting of base metal or adjacent passes is minimized. Fillet and butt welds shall meet the desirable or acceptable fillet weld profiles shown in Figure 5.4 of CSA Standard W59. The reinforcement in groove welds shall not exceed 3 mm (1/8") and shall have a gradual transition to the plane of the base metal surface In general, the weld quality will be such as to meet the requirements of Clause 11.5.4/12.5.4 of CSA Standard W59.

Weld Metal Cleaning

Slag or flux remaining after a pass, shall be removed before applying the next covering pass. Prior to painting, etc., all slag shall be removed and the parts shall be free of loose scale, oil and dirt.

Treatment of Underside of Welding Groove

Prior to depositing weld metal on the underside of a welding groove, the root shall be gouged, or chipped to sound metal, unless otherwise specified on the applicable Data Sheet.

Samples courtesy of the CWB.	Use with permission.

2.12 WELDING PROCEDURE DATA SHEET

The CWB certified company prepares welding procedure data sheets to support a given welding procedure specification. For Division 1 and 2 companies the welding procedure data sheets must be accepted by the company’s engineer and CWB by signature and/or stamps in the appropriate box at the bottom of each page. For a Division 3 company the qualified welding supervisor provides company acceptance in lieu of an engineer.

Figure 25 - Welding Procedure Data Sheet

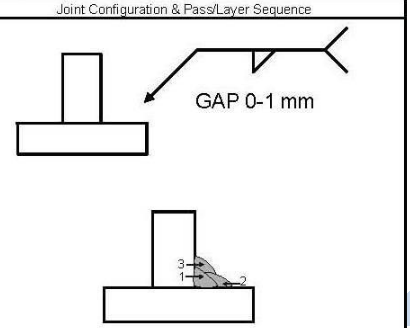
CWB CANADIAN WELDING BUREAU

WELDING PROCEDURE DATA SHEET

WPDS NO.:	GMAW-2F		
DATE:	5/27/2008	Rev.:	0
Company Name:	Canadian Welding Bureau	Ref. Standards:	CSA W47.1/ W59
Address:	7250 West Credit Avenue, Mississauga, ON L5N 5N1	Ref. WPS:	GMAW-1

Welding Processes:	1	GMAW Pulsed: ☐ Yes ☑ No
Shielding Gas Type:		90%Ar/ 10% CO2
	2	Pulsed: ☐ Yes ☐ No
Positions:	Horizontal	
Process Mode:	☐ Manual ☑ Semi-Auto ☐ Machine ☐ Auto	
Joint Type:	☐ Butt ☑ Tee ☐ Corner ☐ Lap ☐ Edge	
Penetration:	☐ Complete ☐ Partial ETT= ☑ Fillet	
Backing:	Material: N/A	Thickness:
Backgouging:	☐ Yes Method:	
	☑ No Depth:	
Electrode Extension:	20 mm	
Nozzle Diameter(s):	16 mm	
Flux Classification:	N/A	
Tungsten Electrode:	Type: N/A	Dia.:
Cleaning Procedures:	Wire brush, clean between passes	
CSA W186 Rebar Splice Type:	☐ Direct Splice ☐ Indirect Splice ☐ Lap Splice ☐ Rebar to Structural Member Only	

Joint Configuration & Pass/Layer Sequence



Identification of Base Material (for CSA W186 indicate carbon equivalent, max. phosphorus & sulphur content)

Part	Specification & Grade	Thickness or Dia.	Special Requirements
I	ASTM A36, A516 Gr. 70 G40.21Gr. 300W, 350 W	6-10 mm	N/A
II	ASTM A36, A516 Gr. 70 G40.21Gr. 300W, 350 W	6-10 mm	N/A

Identification of Filler Material

Process	Trade Name	Classification	Group	Filler Treatment
GMAW	N/A	E[illegible] 4[illegible]A 3 C G6 (ER49S-6)	N/A	Cl. 5.2.4.5, CSA W59

Welding Parameters

Thickness ( )	Weld Size/ ETT	Layer	Pass Number	Welding Process	Dia (mm)	Wire Feed Speed (m/min)	Current A	Volt V	Current Polarity	Welding Speed (mm/min)	Burn-Off Rate ( )	Gas Flow Rate (l/min)	Heat Input ( )
	6	1	1	GMAW	1.2	10.0	260	28	DC+	400-500		20	
	8	1	1	GMAW	1.2	10.0	260	28	DC+	300-400		20	
	10	1	1	GMAW	1.2	10.0	260	28	DC+	400-500		20	
		2	2-3	GMAW	1.2	10.0	260	28	DC+	400-500		20	

Heat treatment :				**CWB Acceptance**	**Company Authorization**
Preheat min:	10° C	Interpasstemp.max.:	250° C		
		Interpasstemp.min.:	10° C		
In accordance with Table 5-3, CSA Standard W59					To be signed by the engineer or supervisor before submission to the CWB
					Date: 5/27/2008

Samples courtesy of the CWB.	Use with permission.

Prior to commencing any welding work, contractor's should submit their CWB stamped welding procedure specifications and welding procedure data sheets that are relevant to the work they are about to perform under the scope of the contract.

2.13 PREQUALIFIED JOINTS

Certain joint configurations that conform to the provisions of CSA Standard W59 are deemed prequalified. Such joints may be approved for use by the CWB without performing procedure qualification tests. As required by Clause 3.1.3.1 of CSA Standard W59 welding procedures must conform to Clauses 4, 5 and 10 of CSA Standard W59 in order for the joint to be considered prequalified. Prequalified joints exist for the shielded metal arc, submerged arc, gas metal arc, gas tungsten arc and flux-cored and metal-cored arc welding processes. Prequalified joints can be approved using more than one process if prequalified conditions of each welding process are met.

Fillet welds conforming to the following Clauses may be designated prequalified:

- Clause 5.5.3 – Submerged Arc Welding (SAW)
- Clause 10.2.3 – Procedures for SMAW
- Clause 10.4.3 – Procedures for Single Electrode MCAW and FCAW
- Clause 10.5.3 – Procedures for Single Electrode GMAW
- Clause 10.6.3 – Procedures for Single Electrode GTAW

Complete penetration groove welds conforming to the following Clauses, Tables and Figures may be designated prequalified:

- SAW – Clause 10.3.1, Figure 10.3 and 10.4 and Clauses 5.1.4, 5.5.1.6, 5.5.2, 5.5.3, 5.7 and 5.13
- SMAW – Clause 10.2.1, Table 10.1, Figure 10.1, Figure 10.2 and Clauses 5.1.4, 5.2.1.2, 5.5.1.6, 5.5.2, 5.7 and 5.13.
- FCAW – Clauses 10.4.1 and 10.4.3, Table 10.2, Figures 10.5 and 10.6 and Clauses 5.1.4, 5.2.3, 5.5.1.6, 5.5.4, 5.7 and 5.13.
- MCAW – Clauses 10.4.1 and 10.4.3, Table 10.2, Figures 10.9 and 10.10 and Clauses 5.1.4, 5.2.3, 5.5.1.6, 5.5.4, 5.7 and 5.13.
- GMAW – Clauses 10.5.1 and 10.5.3, Figures 10.7, 10.8, 10.11 and 10.12 and Clauses 5.1.4, 5.2.3, 5.5.1.6, 5.5.4, 5.7 and 5.13.
- GTAW – Clauses 10.6.1 and 10.6.3, Figure 10.13 and Clauses 5.1.4, 5.2.3, 5.5.1.6, 5.5.4, 5.7 and 5.13

Joint details may depart from those prescribed in Clause 10 of CSA Standard W59. However, in such cases the proposed welding procedure may require qualification testing to be performed in accordance with the requirements of Clause 11 of CSA Standard W47.1.

There are no prequalified joints in CSA Standard W59.2 for aluminum.

Welding procedure data sheets of prequalified joints must display the CWB Stamp of Acceptance and be welded in a manner that meets the Clause 5 workmanship articles listed above.

2.14 WELDING SEQUENCE

To avoid high residual stresses being built-up in the structure by welding and to avoid cracking in weldments and heat affected zones in thick sections or distortion of plating in thin sections, a welding sequence should be developed to systematically control the progression of welding. There are three applications of welding in ship construction or repair that must be considered to determine if the welding sequence offered will be effective:

1) Block construction method.
2) Frame and plate construction method.
3) Inserts in plating or structural built-up sections.

For unit construction methods, a sequence for welding individual unit assemblages should be produced in addition to an erection welding sequence for joining units by welding at the berth. For frame and plate methods of construction however, a welding sequence should be developed for each of the following:

- Panels such as deck, bulkhead, wheelhouse sides and top plating and stiffeners.
- Butts and seams of the shell plating.
- Frames and bulkheads to shell plating.
- Tank top plating to double bottom framing.

- Insert and doubler plates forming part of the primary hull girder.
- "A" frames and stern tubes and similar critical components.

In developing an acceptable welding sequence, these rules are applicable to most fitted conditions:

1) Members to be welded should remain unrestrained during welding.

2) Welds should be deposited in a sequence that balances the heat applied throughout the welding operation.

3) Weld progression should be from points that are fixed to points that have relative freedom of movement.

4) Joints or welds that are oversized or expected to cause significant shrinkage should be welded first.

5) Jigs, fixtures, clamping devices and strong backs must be designed and fixed in such a manner as to avoid high restraint (weld one side/wedge the other).

6) For panels consisting of a number of plates, butts should be welded before seams. Weld progression should progress from the center toward outer edges. Stiffeners fillet welded to plating should remain unwelded a minimum distance of 230 mm at edges of plating.

7) Frames, stiffeners or intercostals should be welded to each other before they are welded to plating.

8) When joining sub-assemblies to each other, joints connecting plating should be welded first, then butt joints of the framing.

9) Welding of shell butts and seams should occur prior to fillet welding frames and bulkheads to shell plating. When they are fillet welded, the traversing member should remain unwelded a minimum distance of 230 mm.

10) When possible, welding should start in the center of the ship progressing outward, forward and aft, welding butts and then seams. Seams should remain unwelded a minimum distance of 230 mm each side of unwelded butts.

Welding sequence for a number of conditions commonly encountered follow:

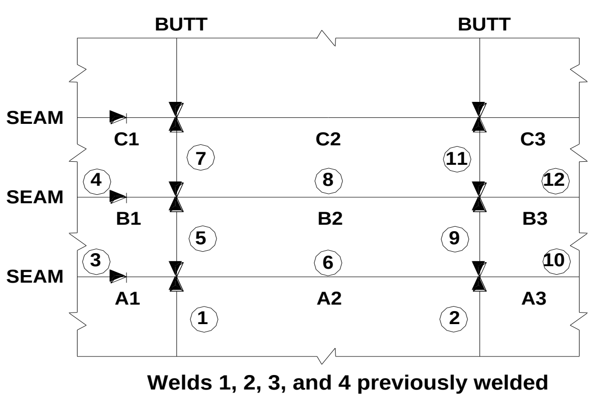


Figure 26 - Typical Welding Sequence / Butts & Seams in Line

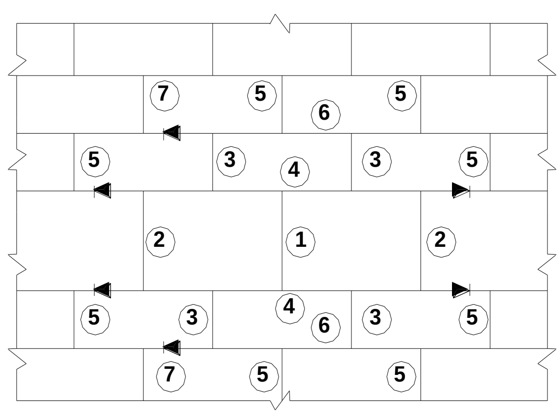


Figure 27 - Typical Welding Sequence / Staggered Butts & Seams

Weld in this sequence:

1) Weld frames and girder to plates within 230 mm of all unwelded butts and seams.
2) Weld butt complete
3) Weld unwelded portion of girder, in way of butt.
4) Weld lower seam to point 230 mm from next butt.
5) Weld unwelded portion of frames in way of lower seam.
6) Weld upper seam to point 230 mm from next butt.
7) Weld unwelded portion of frames in way of upper seam
8) Complete seams.

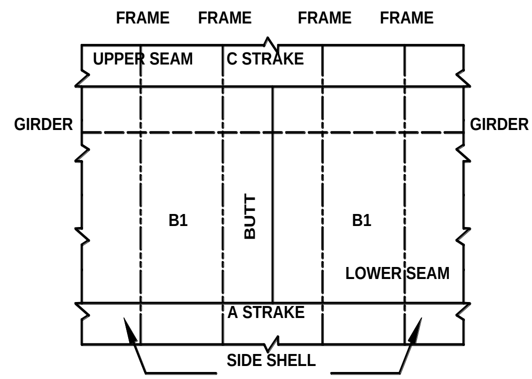
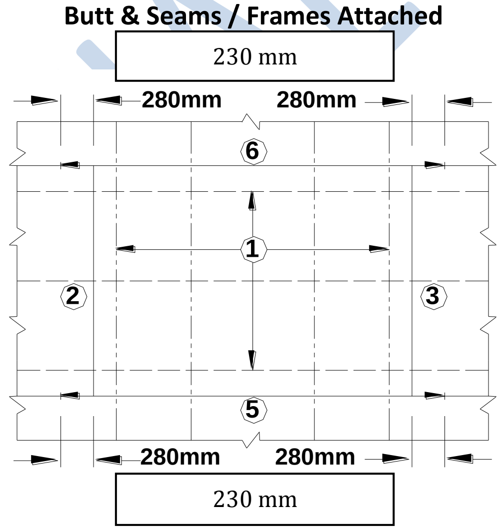


Figure 28 - Typical Welding Sequence for Butt & Seams / Frames Attached

Weld in this sequence:

1) Release framing to within 230 mm of unwelded butts and seams.
2) Vertical butt No. 2 complete.
3) Vertical butt No. 3 complete.
4) Unwelded framing in way of vertical butts.
5) Horizontal seam No. 5 including release lengths.
6) Horizontal seam No. 6 including release lengths.
7) Unwelded framing in way of horizontal seams.

Note: Release length of 230 mm is provided in the horizontal seams at each corner of the insert plate.



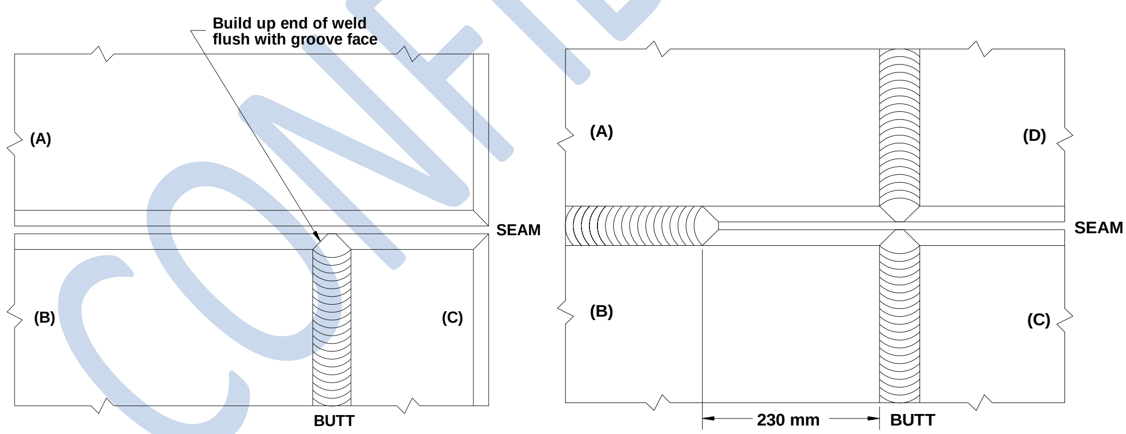


Figure **29** - Typical Welding Sequence for Shell Plate Repair

1. Weld Butt between (B) & (C)
2. Weld seam between (A) & (B)

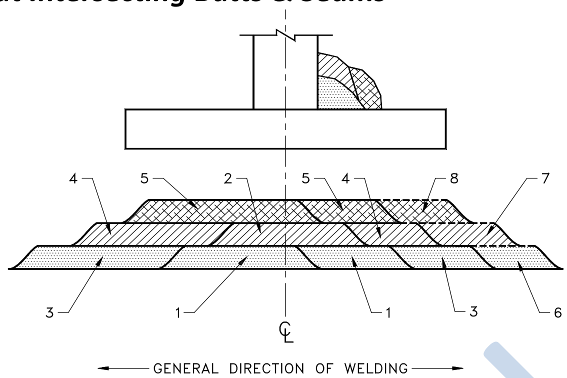
1. Weld seam between (A) & (B) to within 230 mm of butt joint
2. Weld butt between (B) and (C)
3. Weld butt between (A) and (D)
4. Complete welding seam between (AD) and (BC)

When joining thick plates (t $\geq$ 19 mm) by welding, cracking may often be experienced. If the correct sequence for weld passes and layers is systematically developed, cracking may be avoided.

Table 13 - Typical Welding Sequence at Intersecting Butts & Seams

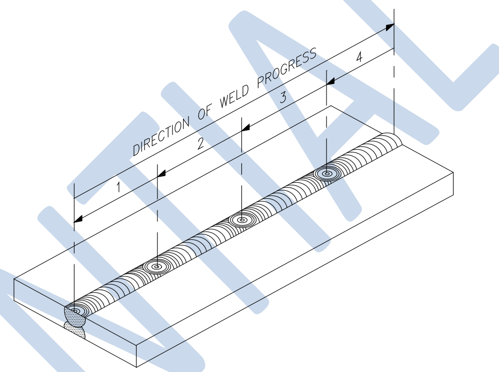
Skip Technique for Fillet Welds

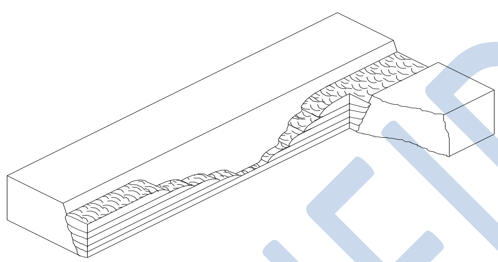
For fillet welds attaching thick plates, the skip technique is effective as illustrated to the right.



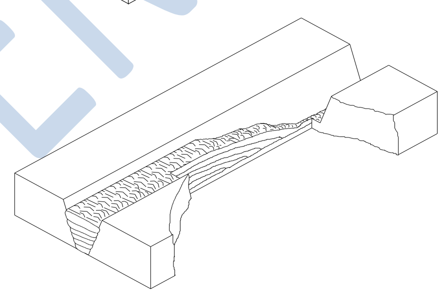
Backstep Technique

For groove welds in butt joints of thick plate, either the backstep (see right), block or cascade techniques are effective as illustrated below.





Block Technique for Groove Welds



Cascade Technique for Groove Welds

It is essential however, independent of the weld pass/layer sequence adopted, that neither the depth nor the width in the cross section of weld metal deposited in each weld pass exceeds the width at the surface of the weld pass as illustrated below.

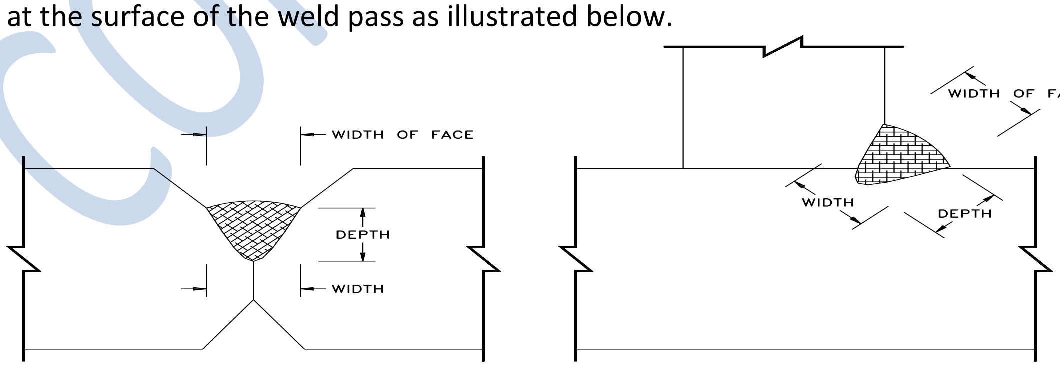


Figure 30 - Depth of Width Ratio

Under high restraint conditions, weld metal should have maximum ductility properties. The ultimate tensile strength of the weld metal should not be overmatched to that of the base plate. Higher preheat temperatures and / or lower retained hydrogen content of the deposited metal may be necessary to avoid hydrogen assisted or induced cold cracking.

2.15 PREHEAT AND POST HEAT

Preheat is generally applied for one of, or a combination of, the following reasons:

1) To control shrinkage stresses when welding highly restrained joints.
2) To reduce the cooling rate through the critical temperature range of the material to avoid the formation of a hardened microstructure. An excessively hardened microstructure reduces the ductility of the heat affected zone and increases susceptibility to hydrogen induced cold cracking.
3) To reduce the cooling rate, increasing the amount of time over 100°C. Increasing the amount of time over 100°C allows more hydrogen to diffuse away from the heat affected zone, reducing the risk of hydrogen induced cold cracking.
4) To remove moisture resulting from high humidity, condensation, rain, snow, or dew.

The main application for preheat is to reduce the probability of hydrogen induced cold cracking (HICC). The following points should be considered:

- Factors controlling HICC typically fall into two main categories:
  - Global factors which can be clearly defined such as chemical composition and thickness; and
  - Local factors that cannot be easily defined such as details of the weld root geometry or local segregation of certain chemical elements.
- Present day methods for reducing the chances of HICC have been carefully developed and in most cases are quite effective without being overly conservative.
- However, there will be cases where local factors predominate, making it extremely difficult to predict precise preheat requirements. These cases are best identified from past experience and must always be approached with caution, applying conservative preheat requirements.
- HICC is very serious and can occur anywhere from 1 hour to six months after welding is completed, so approval and adjustment of preheat values must always be approached with caution.

A contractor may request one of the following:

1) An increase in, or application of, preheat (requested after cracking has occurred); or
2) A reduction of preheat (a shipyard could realize large savings simply by reducing preheat temperatures).

When faced with these requests rely on Annex P of CSA W59 which outlines the two basic methods most widely accepted in the welding industry:

- Heat affected zone (HAZ) hardness control; and
- Hydrogen control.

These methods and their application are outlined herein. For more detailed information and commentary on the determination of preheat consult Annex P of CSA W59.

2.15.1 HAZ Hardness Control Method

The HAZ hardness control method is restricted to fillet welds and is based on the assumption that cracking will not occur if the hardness of the HAZ is kept below a critical value.

This method is applied in the following manner:

- A critical hardness value is selected taking into account steel type, hydrogen level, restraint, and service conditions. The critical value is usually 350VH, 400VH when diffusible hydrogen content is kept low.
- The critical cooling rate that should obtain hardnesses below those mentioned above depends mainly on carbon equivalent. Figure P2 of Annex P of CSA W59 can be used to determine the critical cooling rate on this basis.

The main application for this method comes with being able to determine the minimum heat input (minimum weld size) that may be used without causing excessive hardening.

2.15.2 Hydrogen Control Method

The hydrogen control method allows the estimation of the preheat temperature that is necessary to allow enough hydrogen to diffuse out of the joint to prevent hydrogen induced cracking.

The method is applied in the following manner:

- A modified carbon equivalent formula is used to calculate a value called the composition parameter
- The consumables being used are categorized by hydrogen level, as outlined in Annex P of CSA W59
- A susceptibility index grouping is determined from Annex P of CSA W59, which takes into account the hydrogen level and the composition parameter.

Restraint of the joint is classified according to the following criteria:

Low restraint: Common fillet and groove welded joints with a reasonable freedom of movement

Medium restraint: Fillet and groove welded joints for which freedom of movement is reduced.

High: restraint: Highly restrained welds encountered in repair situations and the joining of thick materials

By taking into account the susceptibility index grouping, material thickness, and restraint level, minimum preheat and interpass temperatures can be determined from Annex P of CSA W59.

Preheat will usually be applied through flame or electric resistance heating. Preheat is most often measured by temperature sensitive crayons or pellets which melt once the required temperature has been met, or through the use of a pyrometer. Whatever preheat method or preheat measurement method is being used; the surfaces of the pieces to be joined should be at or above the minimum required temperature for a distance equal to three inches or the material thickness, whichever is greater, both laterally and in advance of the welding.

Postheat is employed on some heavy weldments, often when castings have been incorporated into a weldment that will be in highly stressed portions of the structure such as rudders, rudder posts, and stern frames. Postheat is most often used to:

a) Reduce residual stresses to a desired level; or
b) Return the weldment to dimensions necessary for fitting or machining.

Caution should be exercised when approving the application of postheat to many of the low alloy, quenched and tempered steels, or other materials that attain their properties through use of thermal or thermal-mechanical treatments, as postheat operations may impair these properties. For plain carbon steel, usual treatment is one hour for every inch of maximum thickness at a temperature of 620 ± 28°C.

2.16 WELDING HEALTH AND SAFE PRACTICES

Welding operations present certain potential hazards, which can result in physical injury, short or long term health effects, discomfort, and, in severe circumstances, even death. Health hazards commonly associated with welding operations are intensified in the ship repair or ship construction environment due to space restrictions and the presence of flammable and explosive materials. Individuals should always take steps to protect themselves from the hazards that follow.

2.16.1 Radiation

Radiant energy may originate from the welding arc or be reflected from other surfaces and consists of ultraviolet, visible light, and infrared radiation. Infrared radiation can cause operator discomfort, and when severe, result in skin burns. Ultraviolet radiation causes skin burns and eye irritation. Be certain to cover all exposed skin and use appropriate headgear as illustrated in Figures 4 and 5 of CSA Standard W117.2, to protect the face and eyes when monitoring welding in progress. Filter lenses should be selected after consulting the lens shade selector table. (See CSA Standard W117.2, Table 7)

A condition often called "arc eye" or "arc flash" is the result of severe exposure to the eyes from ultraviolet radiation of the welding arc. At the time of exposure, the effects may not be noticeable. However, hours later the individual experiences a feeling of sand or grit in the eye. Medical attention should be sought in cases of severe discomfort.

2.16.2 Burns

Be on the lookout for hot materials. Welding, cutting, and allied processes produce molten metal, sparks, slag, and hot work surfaces. The best protection from severe burns from sparks and molten metal is careful dressing prior to entering the jobsite. Always ensure that:

- Clothing is made of cotton or denim at the minimum. Synthetic clothing such as nylon should be avoided. These materials will fuse to skin upon melting and offer little protection in the event of fire. Only synthetic clothing approved for high temperature use, such as Nomex, should be worn.
- Leather work boots are laced to the top.
- Remove or close pockets and roll all cuffs down.
- Fire resistant earplugs and skullcaps are worn when there is a risk of sparks or slag falling on the head.

2.16.3 Fumes and Gases

Welding operations can produce smoke-like fumes and gaseous by-products. The amount and composition of these fumes and gases depend upon the composition of the filler metal and the base material, welding process, current level, arc length and other factors. Coatings such as paint, epoxy, vinyl, zinc, etc., produce hazardous gases when subjected to high temperatures. Gas shielded welding processes are dangerous in confined spaces because of oxygen displacement. Always position yourself in a manner, which allows you to keep your face out of the direct plume of fumes and gases being generated by the process being used when witnessing welding. In confined spaces or in compartments where adequate ventilation is not available, fume extraction equipment and/or breathing apparatus should be used.

2.16.4 Electric Shock

Use of electricity is a common and integral part of many welding operations. Electric shock may result from faulty or improperly maintained equipment combined with a lack of awareness or familiarity by the operator. Extra precautions should be taken against electric shock by ensuring that protective clothing and footwear remain as dry as possible and that footwear has non-conductive soles.

2.16.5 Fires and Explosions

The very nature of the shipboard environment; oily bilges, relatively confined spaces, inaccessible void spaces, painted surfaces, an abundance of chemicals and combustibles; makes fires and explosions of great concern when welding operations are being performed. Always be aware of the operations going on around you that may initiate a fire or explosion.

2.16.6 Noise

The Canadian Labor Code, Marine Occupational Safety and Health Regulation, Part 12-161, “Levels of Sound” govern noise level exposure. Grinding, cutting, and gouging operations often produce noise levels above acceptable exposure limits. The risk of hearing damage increases further when these operations are performed in a confined space. The accepted practice is to use hearing protectors that meet the safety standards outlined in CSA Standard Z94.2, Hearing Protectors, to reduce the level of sound exposure to 85 dB or less.

2.16.7 Chemicals

In addition to chemical hazards common to the shipboard environment, welding operations can result in exposure to chemical hazards from anti-spatter compounds, fluxes, pickling solutions and gases formed from solvent fumes. When heat and light are applied to usually harmless substances, chemical reactions can occur which produces a toxic substance that can be absorbed through the skin or enter the body by inhalation and can cause serious short or long-term health effects.

2.16.8 Tripping and Falling

Ships are designed to utilize all available space. Hotwork operations often require the stringing of hoses, cables, and rigging in tight quarters. This increases the risk of tripping and falling both for personnel performing hotwork and for individuals entering the work area. Always be aware of your environment and look before you step.

For further information regarding safe welding practices, refer to CSA Standard W117.2, "Safety in Welding, Cutting, and Allied Processes" and CCG TP11515E, "Welding Health and Safety Technical Program".

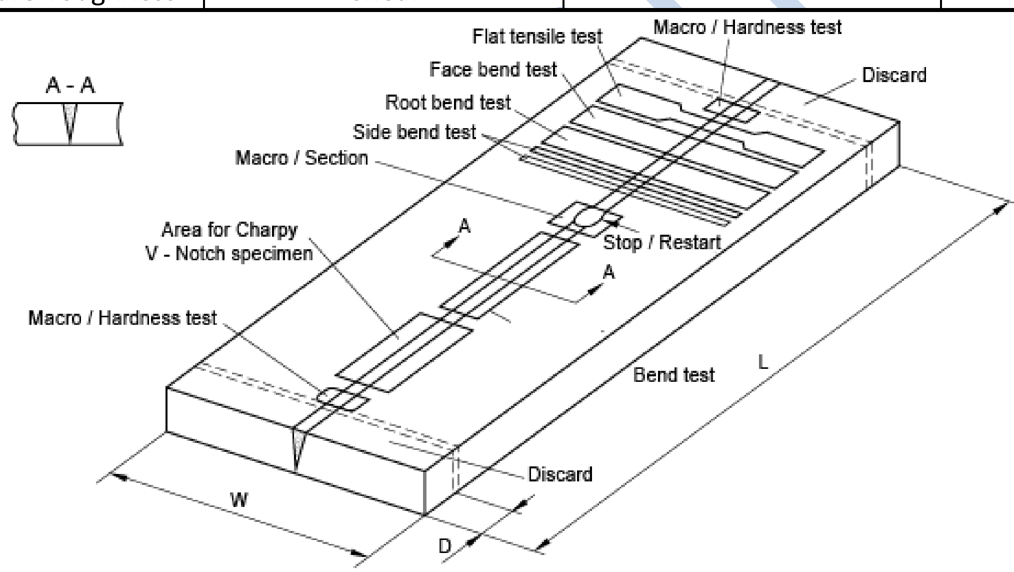
Section 3 MECHANICAL TESTING OF WELDS

The inspector is occasionally called upon to audit mechanical testing of weldments and review test results. Recognized Organizations all have requirements in their respective rules for mechanical testing which form part of their schemes for approving materials and welding electrodes and consumables.

Most rule requirements for mechanical tests of weldments follow either international or national recognized standards. In North America, the American Society for Testing and Materials (ASTM) Standard Methods publication specifies how to use mechanical test methods when testing weldments. It takes into consideration the various properties that can occur between different regions (base metal, heat affected zone and weld metal) of a weldment.

ANSI/AWS B4.0-XX, which is published by the American Welding Society, offers a compilation of all mechanical test methods for weldments in a single document. Mechanical tests may be categorized and grouped as follows:

Groove Welds Tests	Fillet Welds Tests	Groove & Fillet Welds Test	Stud Welds Test
Bend	Longitudinal Guided Bend	Nick Break	Bend
Tension	Soundness	Hardness	Tensile Pull
Fracture Toughness	Shear	---	---



ANSI/AWS B4.0-XX gives requirements for specimen preparation, test parameters, and testing procedures but does not specify acceptance criterion or bend radius, etc. Such requirements should be located in the product design or workmanship standards. Methods of testing are grouped either quantitative, qualitative or both.

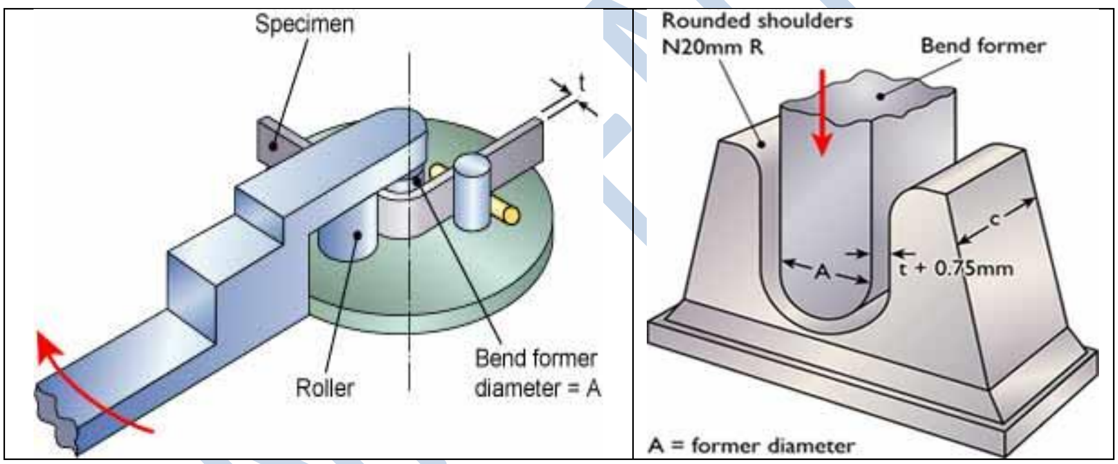
[Follow this link to view an educational video on mechanical testing from TWI.]

3.1 BEND TESTS FOR GROOVE WELDS

For groove welds there are seven different bend tests:

1. **Transverse Side Bend**
   The longitudinal axis of the specimen is perpendicular to the weld, and the specimen is bent so that one of the side surfaces becomes the tension surface of the specimen.
2. ***Transverse Face Bend***
   The longitudinal axis of the specimen is perpendicular to the weld and the specimen is bent so that the face of the weld becomes the tension surface of the specimen.

3. ***Transverse Root Bend***
   The longitudinal axis of the specimen is perpendicular to the weld and the specimen is bent so that the root of the weld becomes the tension surface of the specimen.
4. ***Longitudinal Face Bend***
   The longitudinal axis of the specimen is parallel to the weld and the specimen is bent so that the face of the weld becomes the tension surface of the specimen.
5. ***Longitudinal Root Bend***
   The longitudinal axis of the specimen is parallel to the weld and the specimen is bent so that the root of the weld becomes the tension surface of the specimen.
6. ***Fillet Weld Root Bend***
   The root of the weld shall be the tension surface of the specimen. In some codes and specifications, this test is an alternate to the fillet weld break test. The joint is a square butt with backing and an opening that allows placement of two 9.5 mm single pass fillet welds. The joint is filled by welding, backing material removed and bent.
7. ***Weld Surfaced Bend Specimens***
   Designed for testing bead overlay for hard surfacing and cladding applications of welding. Test method has provisions for face and side bends.



3.2 TENSION TESTS FOR GROOVE WELDS

There are three basic tension tests for groove welds as follows:

1. ***Round Tension Test***
   All Weld Metal: *Used for evaluation of deposited weld metal ultimate tensile strength, yield strength, elongation and reduction of area. Joint is designed to test undiluted weld metal.*

   Transverse Weld Specimen: *Used together with base metal to evaluate joint efficiency. Only ultimate tensile strength is normally determined.*
2. ***Rectangular Tension Test***
   Transverse or Longitudinal: *Used to test joint efficiency. Only tensile strength is normally determined. If thickness of test specimen is beyond the capacity of test equipment, the weld is divided into as many specimens as required to cover the full thickness. Results of partial thickness are averaged.*
3. ***Tubular Tension Test***
   For pipe > 50 mm in nominal diameter, reduced rectangular tension test specimens are used. For pipe or tubing ≤ 50 mm a full section specimen is used for testing welds.

[Click on this link to view a tensile test educational video.]

3.3 FRACTURE TOUGHNESS TESTS FOR GROOVE WELDS

Fracture toughness testing methods and applicable test standards for groove welds are:

Test Method	Applicable Standard
Charpy V Notch	ANSI/ASTM E23
Dynamic Tear	ANSI/ASTM E604
Plane-Strain Fracture Toughness	ANSI/ASTM E399
Drop Weight Nil-Ductility Temperature	ANSI/ASTM E208

The apparatus for conducting the various fracture tests, specimen preparation and test procedure for measuring fracture toughness of a weldment are included in the indicated ANSI/ASTM Standard. [Click on this link to view a charpy impact test educational video.]

3.4 SOUNDNESS TESTS FOR FILLET WELDS

The purpose of this test is to determine the soundness of fillet welds. The test is qualitative in nature with acceptance being based on the extent and nature of any unacceptable discontinuities discover.

One leg of a T-joint is bent upon the other so as to place the weld in tension. In order for this test to be effective, only one side of the joint is welded and the resulting leg length must be small enough in size in relation to the base plate thickness to allow a clean fracture through the center of the fillet weld.

This test is commonly used for the following applications:

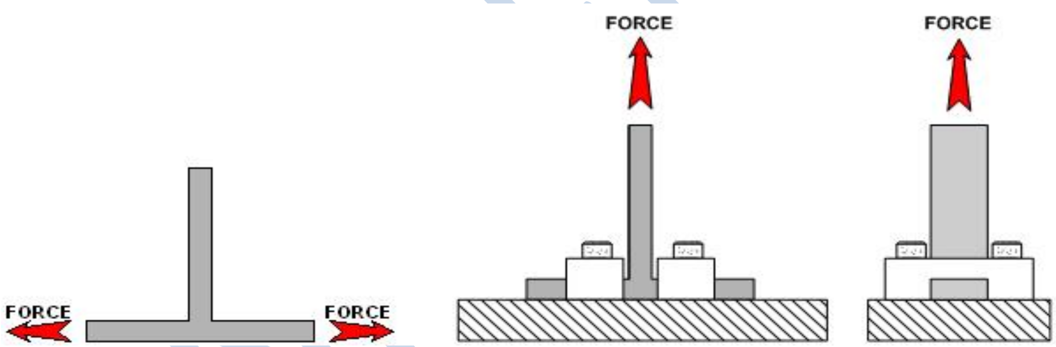
- Fillet Weld Procedure Qualification
- Primer Coated Procedure Qualification
- Galvanized Procedure Qualification
- Welder Qualification
- Tack Welder Qualification

3.5 SHEAR TESTS FOR FILLET WELDS

The fillet weld shear test places a tensile load on a specimen prepared so that the load shears the fillet welds. For a weld that has failed, the weld shearing strength is reported as load per unit length of weld, and shear stress on the throat of the weld. The data obtained from fillet weld shear tests may include:

- Unit shear load
- Shear strength
- Location and mode of fracture.

The test method allows for testing shear in longitudinal and transverse directions. The specimen is loaded in tension until the welds are sheared. The test is disregarded if failure occurs in the base metal. Unit shear load per unit length of weld is determined by dividing the maximum load by the total length of the weld under test. Shear strength acting on the throat of the fillet weld, is determined by dividing the unit shear load per linear mm by the average throat dimensions of welds that sheared.



3.6 NICK BREAK TESTS FOR GROOVE OR FILLET WELDS

The nick break test is an inexpensive test that is used to evaluate the proper technique and welding parameters necessary to obtain sound groove or fillet welded joints in pipe or plate. No significance should be attached to the magnitude of load necessary to create fracture.

In this test, the specimen is fractured by one of three methods:

1) Supporting the ends and striking one in the center with a hammer or by supporting one end and striking the other with a hammer.
2) Specimens are loaded in tension until fracture.
3) Supporting the ends and applying a load at the center of the opposite side.

In each case, a notch is placed in the center of the weld on both sides and ends. Notch depth (1.5-3 mm) and orientation varies with the type of specimen being tested. (See ANSI/AWS B4.0-XX.) The fractured surface is examined for unacceptable discontinuities.

3.7 HARDNESS TESTING OF WELDS

Hardness tests provide qualitative data, which can be used in the design of welding procedures and in the analysis of, weld failures. The Brinell and Rockwell hardness tests produce relatively large indentations and consequently are used for evaluating large weld joint areas. The Vickers and Knoop hardness tests, which produce relatively small indentations, are widely used for hardness measurements in cross sections of small welds or extremely localized weld areas.

For hardness testing, a calibrated machine forces an indenter into the surface of the test specimen and some measure of the resultant impression is expressed as a specific measure of hardness. The indenter is of a specified geometry and it is forced into the material under a specified load.

A list of ASTM Standard Test Methods for hardness testing is offered:

ASTM Standard	Description of Test
E10	Standard Test Method for Brinell Hardness of Metallic Materials
E18	Standard Test Method for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
E92	Standard Test Method for Vickers Hardness of Metallic Materials
E110	Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers

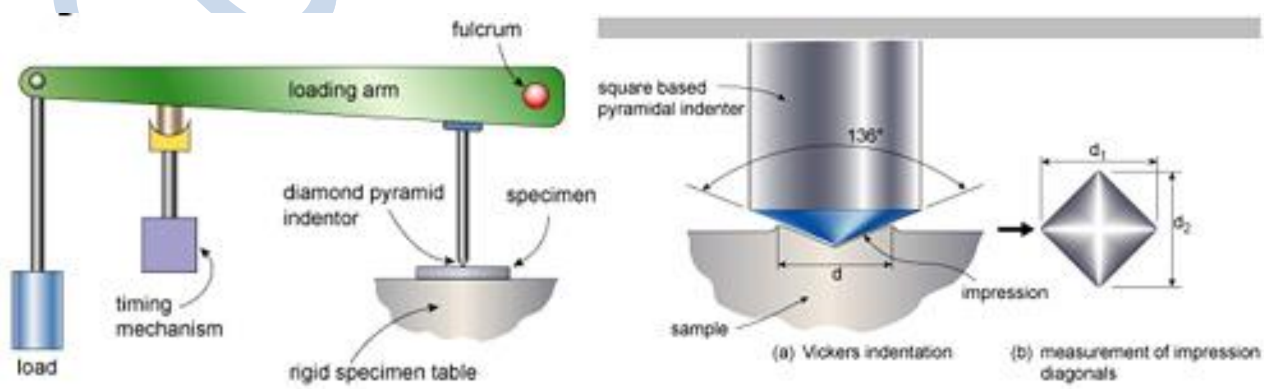


Figure 31 - Schematic Principle of Vickers Hardness machine

The following limitations for hardness testing should apply:

1) Portable hardness test methods should only be permitted for base metal evaluation.
2) Brinell and Rockwell hardness test methods should only be permitted for base metal and weld metal evaluation.
3) Vickers and Knoop hardness test methods should be the only test method used for fine scale traverse across single or multiple regions of weld metal or heat affected zones.

Hardness conversion numbers comparing the test results of the different hardness test methods, indenter type and load can be found in CSA Standard W47.1, Table D1.

3.8 TESTING OF STUDS

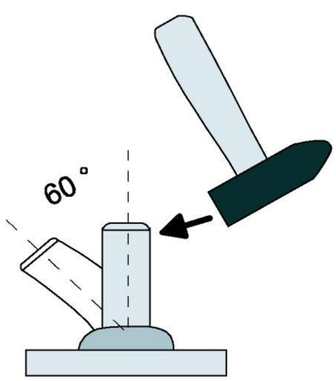
Mechanical testing of arc welded studs is used to evaluate weld soundness, tensile properties, and ductility of the stud weld. These tests are primarily used as a weld procedure qualification method to evaluate welding parameters and surface preparation.

A stud welded specimen is tested in one of two methods:

1) The stud is bent by striking it with a hammer or bending it using a length of tube or pipe.
2) A tensile load is applied to the stud by appropriate fixturing. This is most often accomplished by use of a torque wrench and a stand off sleeve.

A list of codes and standards containing detailed requirements for welding and testing welded studs are as follows:

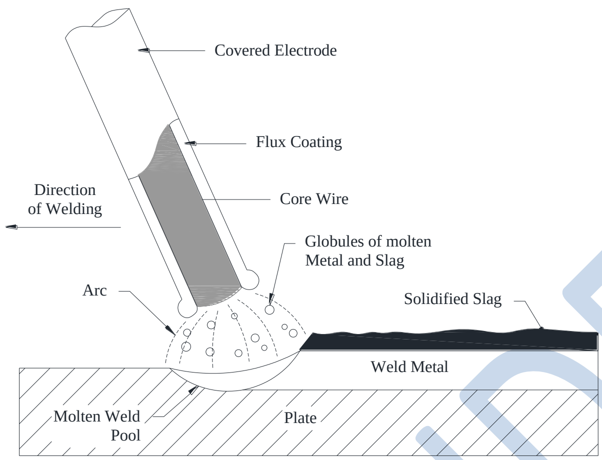
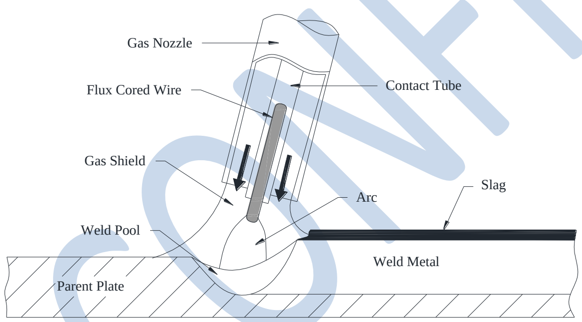
Standard	Description
CSA W59, Clause 6 and Appendix H	• Welded Steel Construction
CSA W59.2, Clause 9 and Appendix E	• Welded Aluminum Construction



Section 4 WELD INSPECTION

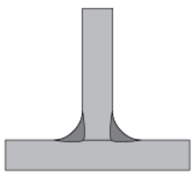
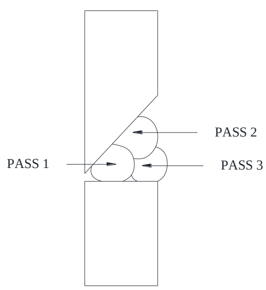
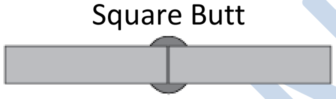
4.1 WELD FAULTS

The results of in-process and final inspection of welds can alert the Delegated Representative responsible for inspection to the type of defects that may result allowing the individual to choose points for spot examination by other nondestructive inspection methods. It is very important to note, that each welding process is prone to certain defects when the parameters used are outside the essential variables for that process.

<table>
<tr><th>Process</th><th>Typical Defects</th></tr>
<tr><td>SMAW

</td><td>Most prone to slag inclusions and incomplete penetration. Dependent on electrode coating condition gross porosity can be encountered. Hydrogen induced cracking can be experienced if electrodes are not dry, cooling rate is too fast and joint is under high restraint. Rutile and cellulosic coatings tolerate the presence of pre-construction primers very well. Basic low hydrogen electrodes do not tolerate primers.</td></tr>
<tr><td>FCAW

</td><td>Most prone to undercut, slag inclusions and porosity. Solidification cracking along weld centerline can be experienced if travel speed is too fast resulting in teardrop shaped molten weld pool. Very low tolerance to the presence of pre-construction primers.</td></tr>
<tr><td>GMAW
</td><td>Most prone to nonfusion, porosity and incomplete penetration. Dependent on wire/gas combinations ductility can be poor. No tolerance to the presence of pre-construction primers.</td></tr>
</table>

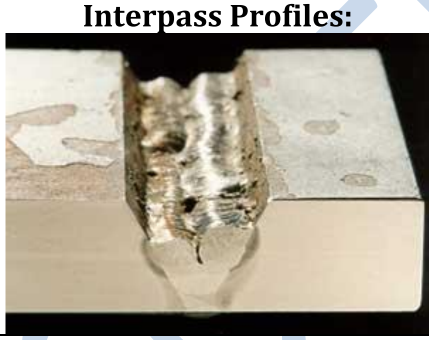
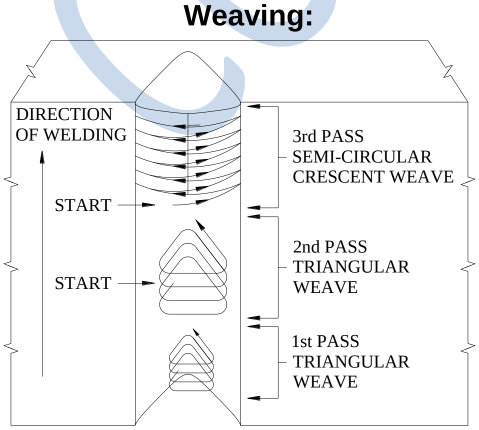
SAW 	Most prone to continuous defects along entire weld length. Incomplete penetration common when root face too thick or when gouge depth insufficient. Low tolerance to the presence of pre-construction primers.

Edge preparation and fit-up conditions can contribute to the probability of acquiring certain defects in a weld if the conditions are outside the essential variable parameters for a given welding process.

Condition	Typical Defects
Joint Type:	
Tee/Fillet Weld 	Undercut, incomplete fusion at root and unequal leg for all welding processes in the horizontal fillet and overhead positions.
Butt/Single Bevel  	Nonfusion along square edge. Incomplete penetration when not back gouged. Nonfusion and slag inclusions with permanent backing bars. Undercut and concavity at root when nonmetallic temporary backing materials used.
Square Butt 	Incomplete penetration when not gouged to sound metal and welded from both sides.
Condition	**Typical Defects**
Included Angle:	
Too Small	Slag inclusions and incomplete penetration for slag generating processes. Nonfusion and incomplete penetration for GMAW. Increased gouge depth may assist in avoiding incomplete penetration.
Too Large	Increases cross sectional area of joint requiring more weld passes and layers. Increased risk of accumulated defects because more welding is involved. Angular distortion on thin plate and high residual stresses on thick plate. Increased risk of cracking when joints are under high restraint and weld metal ductility is low.
Root Face:	
Too Thin	Burn through, convex root profile and gross porosity in first pass/layer of weld. If welded from two sides, gouge depth may be increased to totally remove unsound weld metal.
Too Thick	Incomplete penetration if welded from two sides without gouging. Incomplete penetration and concavity if welded from one side. If welded from two sides and gouged, depth of gouge may be increased to totally remove unfused metal.

Root Opening:	
Too Narrow	Incomplete penetration if welded from one side with or without permanent backing bars.
Too Wide	Burn through, convex root profile and gross porosity in first pass/layer of weld. If welded form two sides, gouge depth may be increased to totally remove unsound weld metal. Increases cross sectional area of joint requiring more weld passes and layers. Increased risk of accumulated defects because more welding is involved. Angular distortion on thin plate and high residual stresses on thick plate. Increased risk of cracking when joints are under high restraint and weld metal ductility is low.
Gouged Profile:	
Too Shallow	Incomplete penetration.
Too Small or No Radius	Incomplete penetration and slag inclusions for SMAW, FCAW and SAW. Nonfusion and incomplete penetration for GMAW.
Too Deep or Wide	Burn through on thin materials and aluminum. Increases cross sectional area of joint requiring more weld passes and layers. Increased risk of accumulated defects because more welding is involved. Angular distortion on thin plate and high residual stresses on thick plate.

Welding technique can also contribute to the probability of acquiring certain defects in a weld if the conditions are outside the essential variable parameters for a given welding process.

Condition	Typical Defects
Interpass Profiles: 	For SMAW, FCAW and SAW, slag may be tightly adhered at weld toes and if not removed slag inclusions may be trapped. For GMAW, silicate may be tightly adhered at weld toes and if not removed nonmetallic inclusions may be trapped. If overlap is present at weld toes, nonfusion may occur. If a weld pass crowds the plate edge in multi pass weld layers, slag inclusions and /or nonfusion may result.
Weaving: 	Weaving should not be employed for joining aluminum or when GMAW is used. Weaving is permitted for steel and most commonly used for SMAW and FCAW. For SMAW, weave width should not exceed 1.5 times electrode coating diameter and should not result in single pass widths or depths exceeding that listed herein. Improper weave techniques can result in nonfusion and slag inclusions. However, it is less prone to these defects in the vertical up position.

4.2 STANDARDS OF ACCEPTANCE FOR WELDS

Welds may contain profiles and/or discontinuities which can be ruled acceptable or unacceptable by the acceptance criterion defined in the standards of acceptance. Discontinuities may be visible on the surface or located below the surface within the weld cross section which is often referred to as structural in nature and only detectable by some form of nondestructive examination. The CCG Welding Specification sets the standards of acceptance for weld profiles and visible and structural discontinuities by reference to the acceptance criterion written within commercial standards.

A good weld may be considered a weld that meets the acceptance standards for its thickness or size which can contain a variety of acceptable discontinuities in numerous forms and orientation but no unacceptable profile conditions or visible and/or structural discontinuities.

4.2.1 Profiles

For fillet welds, convexity, concavity and how the toe of the fillet weld blends into the base metal is evaluated against the acceptance criterion of the standards of acceptance. Typical unacceptable conditions may include:

- Insufficient throat size.
- Insufficient leg length.
- Convexity over the acceptable limit.
- Undercut over the acceptable limit.
- Overlap at the weld toe.

For groove welds, reinforcement and how the toe of the fillet weld blends into the base metal is evaluated against the acceptance criterion of the standards of acceptance as well as the tolerances for welds requiring to be prepared smooth or flush with the base metal. Typical unacceptable conditions may include:

- Insufficient throat (concavity or suck-back).
- Convexity over the acceptable limit.
- Undercut over the acceptable limit.
- Overlap at weld toe.
- Unacceptable smooth tolerance.
- Unacceptable flush tolerance.

4.2.2 Visible Discontinuities

In addition to the profile requirements of the acceptance criterion of the standards of acceptance, the following visible discontinuities open to the surface are permitted within the limits of the acceptance criterion of the standards of acceptance:

- Isolated porosity for fillet welds in locations other than wet and fuel tanks.

The following visible discontinuities open to the surface are not permitted in any length per the requirements of the acceptance criterion of the standards of acceptance:

- Cracks in any orientation.
- Nonfusion between the weld and base metal.
- Porosity open to the surface in groove welds.

4.2.3 Structural Discontinuities

In addition to the profile and visible discontinuities requirements of the acceptance criterion of the standards of acceptance, the following discontinuities below the surface and within the weld cross section are permitted within the limits of the acceptance criterion of the standards of acceptance:

- Porosity.
- Nonfusion.
- Incomplete penetration.
- Nonmetallic inclusions (slag).
- Globular metallic inclusions (tungsten).

The following discontinuities below the surface and within the weld cross section are not permitted in any length per the requirements of the acceptance criterion of the standards of acceptance:

- Cracks in any orientation.

The CCG Welding Specification assigns the following standards of acceptance for welds:

Structural Steel – CSA Standard W59	Structural Stainless Steel – AWS D1.6
Structural Aluminum – CSA Standard W59.2	Other Structural Materials – CSA W59
Pressure Piping – ASME B31.1	

4.3 VISUAL INSPECTION

The basic steps of visual inspection may be categorized as periodical inspections prior to welding, during welding and after welding. Ideally the shipyard should employ the services of a certified welding inspector who has been approved by CWB to CSA Standard W178.2 Level 2 or 3. Level 1 personnel can observe or assist a Level II or III individual with the inspections under CCG's Welding Specification requirements. Individuals are required to hold code endorsements for CSA W47/W59 and Marine (ABS or IACS).

At the outset, the Delegated Representative responsible for inspection should request an inspection and test plan from the shipyard's Quality Assurance (QA) and/or Quality Control (QC) departments that addresses the following as a minimum:

1) Colour coded chalk to be used by each party for marking defects in workmanship requiring repair (shipyard's inspector, TCMSS or Registered Organization and Classification Society Surveyor as appropriate.

2) Safe access and lighting requirements.

3) Reporting, signing off and disposition of reported defects in workmanship.

4) Inspection hold points in the production plan.

5) Inspection schedule based on the method of construction (block or frame & plate) and types of inspections (visual, other NDT, hydrostatic, leak tests, etc.).

6) Minimum advance notice required for scheduled inspections.

4.3.1 Prior to Welded Fabrication or Repair

As a minimum, the shipyard's QA and QC processes should address the following in sufficient detail to facilitate periodic audit by the Delegated Representative responsible for inspection.

1) Materials

- Verification that the materials indicated on purchase orders to suppliers are what has been specified by the design and is of a grade that complies with the applicable classification society rules.

- Verification that mill certificates are compliant with purchase orders and classification society rule requirements. Determination if a statement of compliance from the mill or supplier satisfies the material certification requirements.
- Verification that the material markings from the mill are traceable to the mill certificates and purchase orders.
- Verification that the material is acceptable without the presence of damage from handling & shipping, rust or pitting, heavy scaling, de-lamination, nicks and gouges and that it is the required thickness within the rule requirement mill tolerance.
- Verification that the material storage practice is adequate and will render the material in an acceptable condition when needed for the job.

2) Joint Design

- Verification that the joint design has been checked for suitability for stress, welding and access to weld.
- Verification that edge preparations have been carefully selected for thick plates where there is a risk of lamellar tearing.
- Verification that weld bunching has been avoided by application of suitable transition pieces.

3) Weld Design

- Structural drawings indicate the shipyard's convention with respect to fillet weld size (throat or leg length). ABS Rules list leg length, while others list throat size.
- The weld factors in classification society rules have been followed for the type of member being joined by fillet welds.
- All welds in butt joints are full penetration unless the effective throat size is indicated and classification society rule requirements permit partial penetration welds.

4) Welding Electrodes & Consumables

- The welding electrodes to be used on the job for each base metal grade and welding process involved have been identified and listed.
- Welding electrodes and consumables are approved by the governing codes.
- Welding electrode and consumable storage and handling procedures and facilities are suitable in accordance with the requirements and applicable codes. This is to address permanently installed and portable holding ovens and welder's quivers.
- Procedures for the authorization and use of substitute materials approved to other codes and standards.

5) Welding Procedures

- Based on the project requirements and drawings, produce and supply a list of materials, thicknesses, joint types, and edge preparations for the job. List the welding processes to be used for the job and combine this list with the welding consumable list previously prepared.
- Determine the position of welding for the various parameters based on the production method (i.e., block construction or frame and plate method).

- Examine the welding procedure data sheets and identify welds not covered by approved data sheets. Inform the Delegated Representative of shortcomings and plan of action to produce new weld procedure data sheets approved by the required authorities.

6) Welders, Welding Operators & Tack Welders

- Define the number of welders that will be employed to meet the production schedule and supply a list of each individual's qualifications and mandatory re-testing dates. At random, request copies of certificates for at least 25% of the welder work force and check these against the list provided.
- Ensure the qualifications of individuals are suited to the project production requirements in terms of material type, welding processes, welding electrodes, positions of welding, technique (i.e. one or two sided welding, pipe or plate, open root or backing bar, manual, semi-automatic or automatic etc.). Advise the Delegated Representative of shortcomings and scheduled test dates.
- Produce monthly reports on welding work force qualification status including re-test.

7) Welding Sequence

- Assurance that adequate welding sequences have been prepared and reviewed in advance of any welding operations:
- Block construction sequences for fabrication of panels, blocks and joining blocks at the berth.
- Frame and plate construction sequences for welding panels, tank top, transverse and longitudinal bulkheads, and shell plating to framing.
- Insert plates, partial or full shell plate renewals, a welding sequence for each different arrangement that exists (i.e., fitting and tying in to existing butts & seams, oval, circular or rectangular or square with rounded corners, etc.).

4.3.2 During Welded Fabrication or Repair

As a minimum, the shipyard's QC and QA processes should address the following in sufficient detail to facilitate periodic audit by the Delegated Representative responsible for inspection.

1) Materials

- Verification that the material grades are fitted where they should be.
- Verification that flame cut edges are free of nicks, gouges, unacceptable surface roughness, and de-lamination.
- Verification that the materials have not been damaged by handling, are free of corrosion and pitting and any scars caused by removal of welded lugs and temporary attachments have been repaired and proven sound.
- Verification that the materials are free of adhered spatter and slag from welding and flame cutting operations.
- Verification that any scars on the seawater side of the shell envelope and inside wet tanks have been repaired by welding using the correct corrosion resistant weld metal.

2) Joint Design

- Verification that joint geometries match those appearing on approved on drawings.
- Verification that that structural tolerances of fitted plates are being met (i.e., alignment, fairness, etc.).
- Verification that the root openings, included angles, root faces, and backing bars are within tolerance.

3) Weld Design

- Verification that weld sizes and dimensions match those appearing on approved drawings and/or the classification society rule requirements.

4) Welding Electrodes & Consumables

- Verification that the environment of the welding electrode stores has been suitable and electrodes in damaged packaging have been quarantined.
- Verification that electrode ovens are functional and maintained at the correct temperature for the types of electrodes being held and checked for the presence of undesirable matter that may produce moisture.
- Verification that quarantined materials records are prepared and filed.
- Verification that the welding electrodes and consumables in the welders' possession are the correct type and have not exceeded the allowable exposure time.
- Verification that correct grade of electrodes and consumables are being used for the grades of base metal being welded.
- Verification that wet over exposed or damaged electrodes are quarantined and discarded.
- Verification that the correct gas or gas mixtures are being used.

5) Welders, Welding Operators & Tack Welders

- Verification that current qualifications are held for the material, welding process, electrodes and positions of welding at the work site.

6) Welding Procedures

- Verification that welding procedure data sheets for the job are available for reference by floor welding personnel.
- Verification that procedures have been approved and properly qualified by test (PQR) when required.
- Verification that welding is being performed by welders to the approved procedures.
- Verification of technique:
    - Weld layer and pass sequence;
    - Maximum size single pass fillet weld;
    - Maximum single pass bead width and layer depth;
    - Remove to sound metal profiles; and,
    - Tack welds destined to be incorporated in the final weld.

- Verification that preheat, interpass temperature and post heat is being performed as required by the weld procedure data sheets, methods used for measuring temperature are accurate and the temperature of plate is being measured both laterally and in advance of the welding arc.

1) Welding Sequence

Verification that the approved welding sequence and minimum release distances for butts, seams and internals are followed.

Verification that proper techniques are employed at intersecting butts and seams.

2) Repair of Distortion

Verification that approved procedures are being used and followed for repair of distortion.

4.3.3 After Welded Fabrication or Repair

1) Surface Preparation

Verification that prior to inspection the surfaces of welds and the adjacent base metal was cleaned adequately to allow for accurate interpretation of the area of interest (weld zone) and that paint was not applied over the weld zone until final inspection and acceptance occurred.

2) Staging and Access

Verification that staging for safe access was provided for the inspections that allowed direct visual inspection within 610 mm of the surface to be examined and at an angle not less than 30° to the surface to be examined.

3) Lighting

Verification that the specific part or section under examination was illuminated when necessary with a flashlight or other auxiliary lighting to attain a minimum of 160 lx for general examination and 540 lx for detection or study of small anomalies.

4) Materials

Verification that detailed inspections for deformation, cracks, scars, spatter and surface profile have been undertaken.

5) Welds

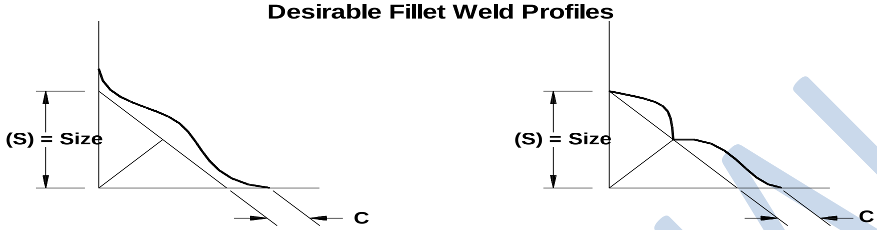
- Verification that all welds have been completed.
- Verification that the required weld design has been complied with in terms of weld size (leg and throat), weld length and / or spacing (continuous, double continuous, intermittent or staggered intermittent), return around ends of members fillet welded, splices in permanently fixed backing bars and fillet welds attaching backing bars in wet spaces.
- Verification that welds have been checked for profile, reinforcement and the presence of discontinuities such as undercut, overlap, nonfusion, craters, pores open to the surface, melt-through, root penetration and cracks.

Follow this link to view a CWB visual welding inspector video.

4.3.4 Weld Acceptance Criterion

The CCG Welding Specification refers to CSA Standards for acceptable and unacceptable profiles which are summarized in this sub-section.

Desirable Fillet Weld Profiles



Acceptable Fillet Weld Profiles

Convexity, C, of a weld or individual surface bead should not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 1.6 mm (1/16 in).	Convexity, C, of a weld should not exceed 0.10S + 1.5 mm.
Acceptance Criterion – Steel See CSA Standard W59, Clause 5.9	Acceptance Criterion – Aluminum See CSA Standard W59.2, Clause 6.0

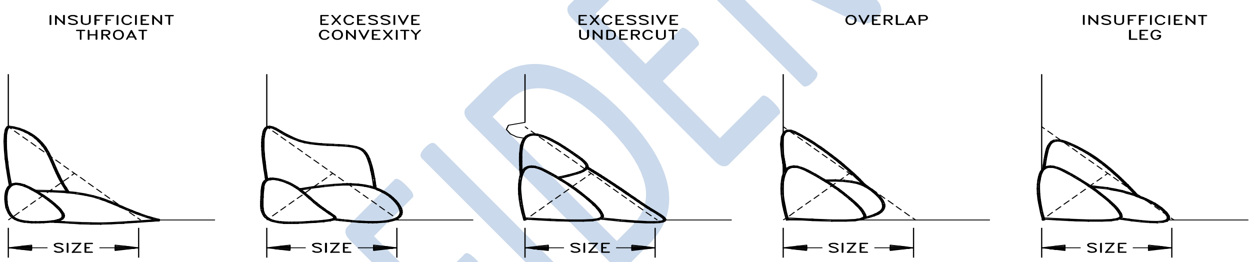
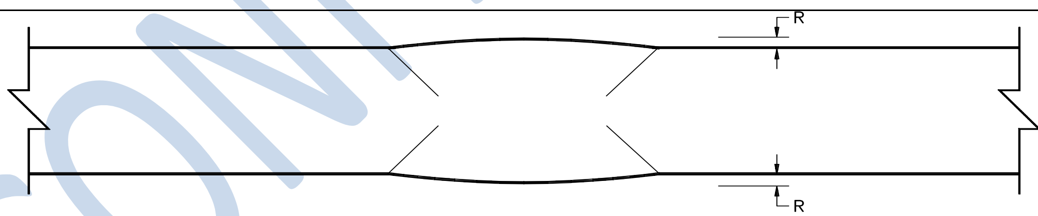


Figure 32 - Unacceptable Fillet Weld Profiles



Reinforcement "R" should not exceed 3mm.	Statically loaded structures: Reinforcement "R" should not exceed 1.5 mm + 20% of face width. Dynamically loaded structures: Reinforcement "R" should not exceed 1.5 mm + 15% of face width
Acceptance Criterion – Steel	Acceptance Criterion – Aluminum
See CSA Standard W59, Clause 5.9	See CSA Standard W59.2, Clause 6.0

Figure 33 - Acceptable Groove Weld Profile

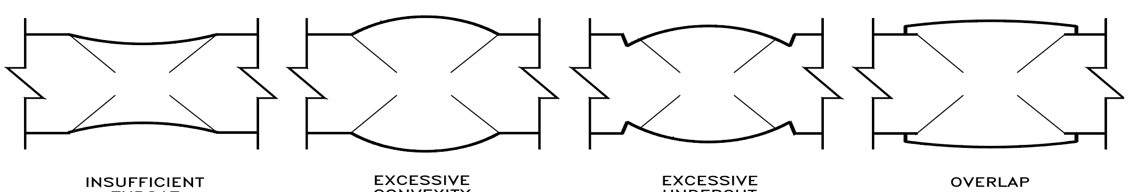


Figure 34 - Unacceptable Groove Weld Profiles

Follow this link to view Part #1 – Alignment, Measurement and Weld Measuring Gauges.

Follow this link to view Part #2 – Alignment, Measurement and Weld Measuring Gauges.

• Insufficient throat is not permitted • No overlap • Undercut parallel to primary stress does not exceed 1 mm in depth. • Undercut transverse to primary stress does not exceed 0.25 mm in depth. • No visible cracks. • No lack of fusion between the base metal & weld. • No visible porosity for groove welds. • No more than 1 visible pore < 2.5 mm in diameter in each 100 mm length of fillet weld. • Acceptable profiles. • Single continuous fillet welds are allowed to under run the nominal fillet leg length by 2.0 mm without correction provided the undersize portion does not exceed 10% of the length of the weld. On web to flange welds, no under run is permitted at the ends for a length equal to twice the width of the flange.	• Insufficient throat is not permitted • No overlap • Continuous undercut does not exceed the smaller of t/5 or 1 mm in depth, where t is the member thickness • Isolated undercut does not exceed 2 mm in depth, nor should the length of undercut greater than 1 mm in depth exceed 15 mm. The intervals between such isolated cases of undercut should exceed 100 mm. • No visible cracks. • No lack of fusion between the base metal & weld. • If there is visible porosity, internal inspection is required. • Acceptable profiles. • Single continuous fillet welds are allowed to under run the nominal fillet leg length by 1.5 mm without correction provided the undersize portion does not exceed 10% of the length of the weld. On web to flange welds, no under run is permitted at the ends for a length equal to twice the width of the flange.
Acceptance Criterion – Steel See CSA Standard W59, Clauses 5.9 & 12.5.4.1	**Acceptance Criterion – Aluminum** See CSA Standard W59.2, Clause 6.0

The acceptance criterion for stainless steel can be found in AWS D1.6, Clauses 5.11 and 6.29.1.

Pores open to the surface are undesirable for shell butts and seams and any weld located in a wet tank or space and definitely not those that carry fuel.

Pores open to the surface in welds of aluminum are a good indication of gross porosity within the weld cross-section and these zones should be further examined by other nondestructive inspection methods such as radiography.

There are three basic finishes to groove welds that may be required in ship construction or repair: As-welded, smooth or flush.

In the as-welded condition, toes of the weld should blend smoothly into the base metal without interruption. For multi pass finishing layers of weld metal, each pass should blend smoothly with each other so that there are no objectionable ripples or valleys between individual passes.

When low friction coatings are applied to icebreakers it desirable to at least grind welds smooth or possibly flush.

Surfaces of groove welds required to be smooth should be finished so as to ensure the weld reinforcement does not exceed 2 mm; that there are no valleys or grooves between individual weld beads (stringer technique); and, that the weld toe blends very smoothly into the base metal without undercut or overlap.

Surfaces of groove welds required to be flush should meet the following requirements:

Reinforcement: 1 mm maximum.	Reinforcement: No requirement.
Concavity: 5% plate thickness to a 1 mm maximum.	Concavity: Test standard mill tolerance.
Roughness Parallel to Primary Stress: 6 µm maximum.	Roughness Parallel to Primary Stress: 12 µm maximum.
Maximum Roughness any direction: 3 µm maximum.	Maximum Roughness any direction: 6 µm maximum.
Acceptance Criterion – Steel See CSA Standard W59, Clause 5.9	Acceptance Criterion – Aluminum See CSA Standard W59.2, Clause 6.0

4.3.5 Audit Checklist for Visual Inspection

The following audit checklist for visual inspection is offered for guidance only.

Table 14 - Visual Inspection Check List

Materials	Inspector's Qualifications	• Formal qualification system or • Education • Training • Experience
	Procedures	• Acceptable formal procedures • Systematic approach • Document review (mill test certificates, heat treat records) • Material identification and transfer • Examination of condition (shipping, handling and storage damage)
	Report	• Documentation for traceability • Condition reports
Welding	Inspector's Qualifications	• Currently certified by CWB to CSA W178.2 (Level 2 or 3 for interpretation & assessment) with code endorsement appropriate to the work being inspected.
	Procedures	• Written checklist or status sheet • Verifying welder following approved procedure • Verifying type and handling of consumables • Verifying fit up and surfaces to be welded • After welding, geometry and workmanship
	Report	• Welder, weld procedure and materials documents • Results including details of repairs requested

Follow this link to view a TWI Video Introduction to Non-destructive Testing.

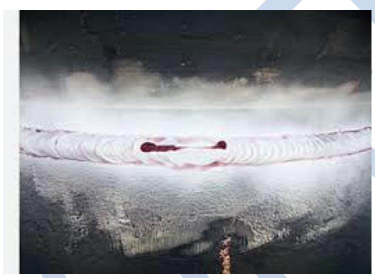
4.4 PENETRANT TESTING (PT)

Penetrant inspection (PT) is a sensitive method of detecting and locating discontinuities that are open to the surface. The method employs a penetrating liquid dye, which is applied to the surface under examination. If a discontinuity is open to the surface, the dye enters the discontinuity. After a suitable dwell time, the excess penetrant is removed from the surface and the part is dried. A developer is applied which acts as a blotter, drawing the penetrant out of the discontinuity. The penetrant drawn from an opening on the surface indicates the presence and location of a discontinuity.

There are two varieties of the test method:

	
Visible Penetrant, usually red in colour to provide contrast against the white background from the developer.	**Fluorescent Penetrant,** usually greenish yellow in colour to provide contrast against a dark background when viewed in a darkened area under a black (ultraviolet) light source.

There are three different penetrants used with both methods:

	
Solvent Removable Used for "on location" inspections. Removed by a solvent cleaner with a hand wiping technique.	**Water Washable** Used for "station inspections of small parts". Somewhat restricted because facilities for water, disposal and drying are needed.

Post Emulsifiable

- Used for detection of very minute discontinuities.
- Removed by a separate emulsifier. Same facilities as water washable is needed.

Penetrant inspection can be performed on magnetic and non-magnetic materials. Surface condition must be smooth. For marine, the inspection process is most commonly used for detection of cracks and surface discontinuities in shafts, pump casings, etc. It should be pointed out that some substances in penetrants can have a deleterious effect on either welds or base metals on which they are used.

4.4.1 Qualification of Personnel

In Canada, personnel performing and interpreting penetrant testing are qualified by the Certifying Agency of Department on Natural Resources Canada (NRCan) to CGSB Standard 48.9712. The individual may be qualified to Level 1, Level 2 or Level 3.

Level 1 personnel can observe or assist a Level 2 or 3 individual with the inspections under CCG's Welding Specification requirements. Level 2 and 3 may write procedures and interpret results. A Level 3 individual has demonstrated better knowledge of the inspection method and as such may be called upon for supervision, writing of more complex procedures and techniques, and for settlement of disputed interpretation.

Each certified individual is issued a pocket size certificate that indicates his/her qualifications and level. Follow this link to search for NRCan certified NDT personnel.

4.4.2 Procedures

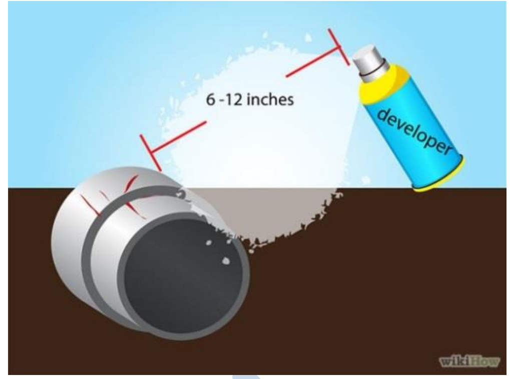
The following general processing procedures apply to both the fluorescent and visible inspection methods using solvent removable penetrant materials.

1) ***Pre-clean:*** The surface must be dry and free of any rust, scale, welding flux, spatter, grease, paint, oily films, etc.

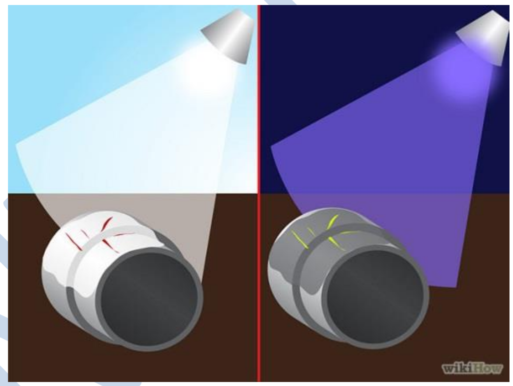
2) ***Penetrate:*** Part temperature must be between 16°-50°C. Spray penetrant evenly on area of interest and allow to drain. Care should be taken to prevent pools of penetrant. Set dwell time in accordance with the penetrant manufacturer's recommendation.

3) ***Remove:*** Remove using wipes of clean, lint free material until most traces of penetrant are removed. Lightly moisten a new wipe with solvent and wipe surface until all remaining traces of excess penetrant have been removed. Use solvent type recommended by manufacturer and avoid soaking wipe with solvent. Allow solvent to evaporate.

4) ***Develop:*** Apply non-aqueous wet developer by spraying in a manner that assures complete coverage with a thin, even film. The length of time before the coated area is visually observed for indications should not be less than 7 minutes, or as recommended by the manufacturer. Development time begins as soon as the non-aqueous developer is dry. If bleed out does not alter the inspection results, development periods of over 30 minutes are permitted.



5) ***Inspect:*** Visible penetrant indications can be inspected in either natural or artificial white light at a minimum light intensity of 350 lx at the surface under inspection. Fluorescent penetrant indications are inspected in darkened areas. Maximum ambient light of about 32 lx is allowed. Black light intensity should be a minimum of 800 $\mu W/cm^3$ measured at the surface.



6) ***Post Clean:*** Developers should be removed a short time after inspection is complete. A suitable technique, such as solvent soaking or ultrasonic cleaning may be employed.

For other penetrant processes, refer to ASTM E165, Standard Recommended Practice for Penetrant Inspection Method.

4.4.3 Acceptance Criterion

When examining welds by penetrant testing, the acceptance criterion should be that adopted for visual inspection see Section 3.2.0 herein and; CSA Standard W59, Clauses 5.9 and 12.5.4.1 for steel, AWS D1.6, Clauses 6.7.6 and 6.29.4 for Stainless Steel and CSA Standard W59.2, Clause 6.0 for aluminum.

4.4.4 Interpretation Reports

An interpretation report should contain as a minimum:

1) Date the test was performed.
2) Inspection organization's name.
3) Method, manufacturer & trade name.
4) Dwell time.
5) Reference to a procedure or technique sheet.
6) Performing inspector's name, CGSB Level and signature.

7) Interpreter's name, CGSB Level and signature.
8) The code of acceptance criterion.
9) Interpretation report number.
10) Individual part or weld identification number.
11) Reported discontinuities, their location, their individual and accumulated length and acceptability or rejection.

A technique sheet should contain:

1) Reference to a penetrant procedure.
2) Penetrant system (manufacturer and materials)
3) Surface cleanliness.
4) Dwell time.
5) Fluorescent or colour contrast.
6) Cleaning method, penetrant removal method.
7) General viewing conditions.
8) Calibration of black light, if used.

4.4.5 Audit Checklist for Penetrant Testing

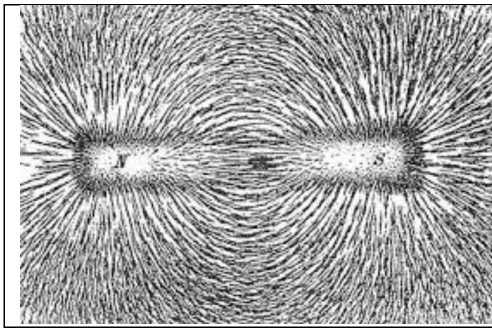
Follow this link to view a CWBi Video on Penetrant Inspection.
The following audit checklist for penetrant testing is offered for guidance only.

Table 15 - Penetrant Testing Checklist

Inspector's Qualifications	• CGSB 48.9712 Level 2 or 3
Procedure	• Approved written procedure • Conformance to ASTM E165
Equipment & Materials	• Penetrant system (manufacturer and materials) • Surface cleanliness • Dwell time • Fluorescent or colour contrast • Cleaning method, penetrant removal method • General viewing conditions • Calibration of black light, if used
Report	• Method • Manufacturer and trade name • Penetrant dwell time • Results

4.5 MAGNETIC PARTICLE TESTING (MT)

Magnetic particle testing is used to detect surface or near surface discontinuities in magnetic materials. The test method is based on the principle that magnetic lines of force, when present in ferromagnetic materials, will be distorted by an interruption in material continuity, such as a discontinuity or a sharp dimensional change. If a discontinuity in a magnetized material is open or close to the surface, the magnetic flux lines will be distorted at the surface, a condition termed flux leakage. When fine magnetic particles are distributed over the area of the discontinuity while the magnetic flux leakage exists, they will collect at the discontinuity and be held in place. There are three essential requirements for the test method:

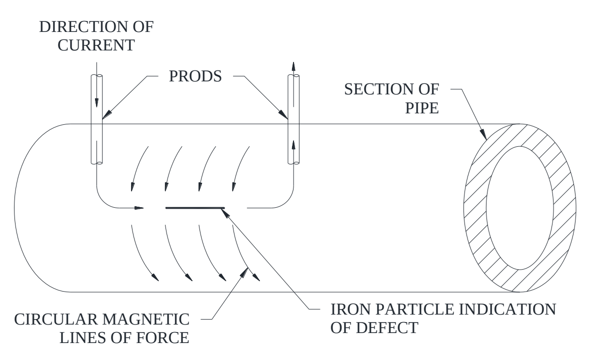
	
1) The part must be magnetized.	**2)** Magnetic particles must be applied while the part is magnetized.


3) Any collection of magnetic particles must be observed and interpreted.

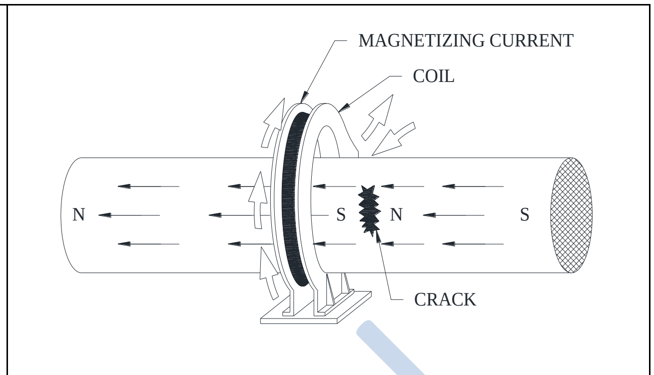
A ferromagnetic material can be magnetized by:

	
1) Passing an electric current through the material.	**2)** Placing the material within a magnetic field originated by an external source.

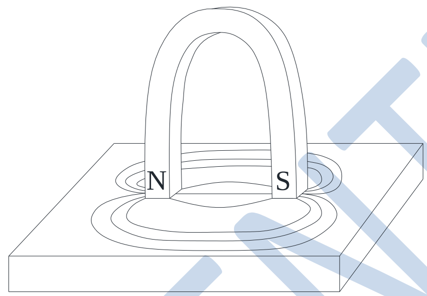
There are three orientations of the magnetic field that can be used for testing:



Circular magnetization.

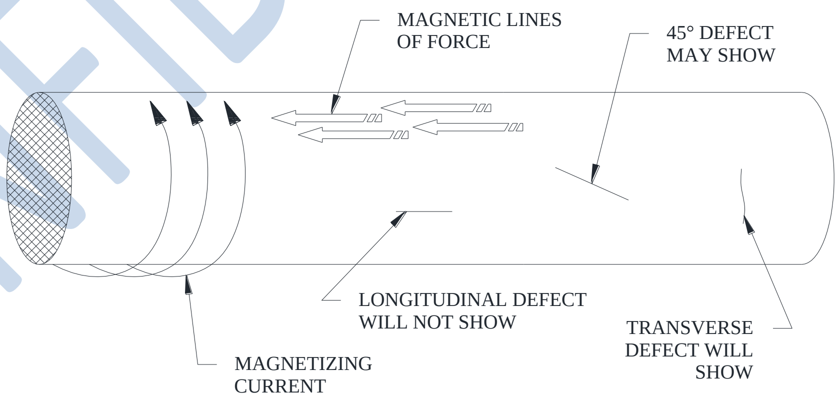


Longitudinal magnetization.



3) Localized magnetization.

If a discontinuity is oriented parallel to the lines of force, it will be essentially undetectable. As such, the selection of the orientation of magnetization is dependent on part shape and position of potential discontinuities with respect to the lines of force.



4.5.1 Qualification of Personnel

In Canada, personnel performing and interpreting penetrant testing are qualified by the Certifying Agency of Department on Natural Resources Canada (NRCan) to CGSB Standard 48.9712. The individual may be qualified to Level 1, Level 2 or Level 3.

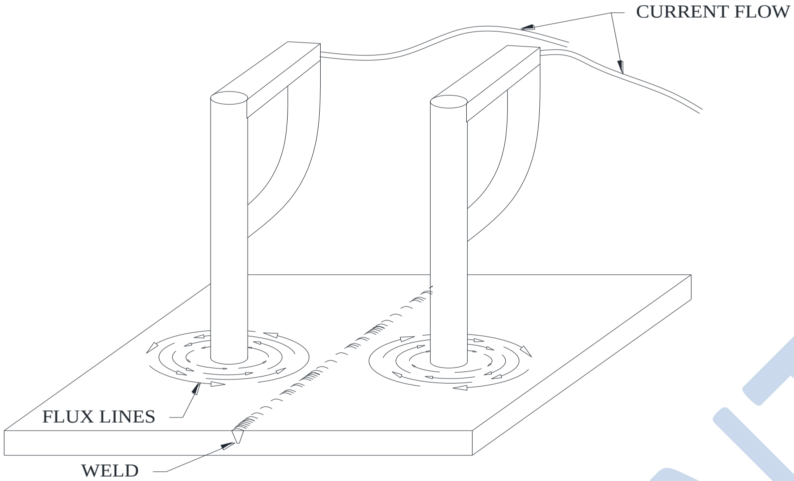
Level 1 personnel can observe or assist a Level 2 or 3 individual with the inspections under CCG's Welding Specification requirements. Level 2 and 3 may write procedures and interpret results. A Level 3 individual has demonstrated better knowledge of the inspection method and as such may be called upon for supervision, writing of more complex procedures and techniques, and for settlement of disputed interpretation.

Each certified individual is issued a pocket size certificate that indicates his/her qualifications and level. [Follow this link to search for NRCan certified NDT personnel.]

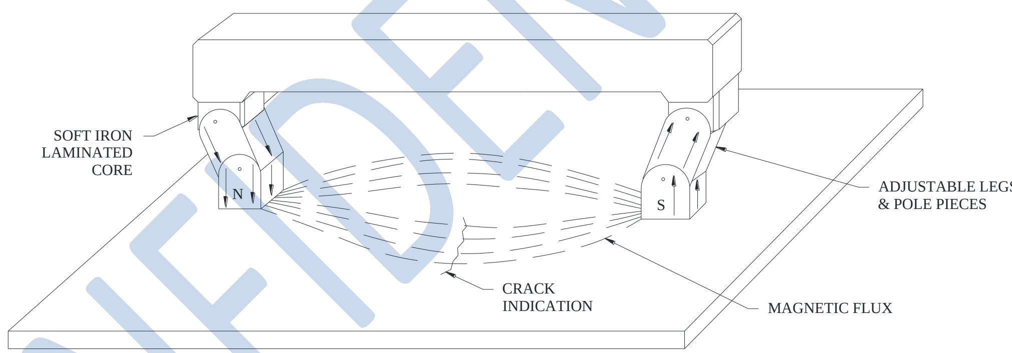
4.5.2 Procedures

For inspection of welds, localized magnetization is used in one of two forms:

1) Direct magnetization, using DC prods.



2) Indirect magnetization, using a Yoke (AC or DC).



DC Prods or DC Yoke	• Used extensively for examining weld zones. • Prods must be securely held or arcing of plate will occur. • Necessary to re-orient prods at about 90° for complete inspection. • More sensitive than AC for detecting subsurface discontinuities. • Half wave rectified, single-phase current provides maximum sensitivity because of particle mobility.
AC Yoke	• Used for finding surface discontinuities. • Only the surface of the metal is magnetized. • It may be used to inspect welds where subsurface evaluation is not required.

Table 16 - Approximate amperage ranges for various magnetized methods

Longitudinal	• 3,000 to 10,000 ampere-turns dependent on ratio of coil and part diameter
Circular	• Overall magnetization: 100 to 1,000 amperes per inch of part diameter.
Prod	• 90-125 amperes per inch of prod spacing depending on metal thickness.
Yoke	• Sufficient current to lift 40 lb. with DC and 10 lb. with AC.

Magnetic particles of various colours, mobility, and luminescence can be selected that will provide the greatest test sensitivity for each specific test situation. The condition of the test surface as well as the types of flaws suspected impact on the type of inspection media selected.

Dry Method	• Ferromagnetic particles coated to enhance mobility. • Dyed various colours for distinct contrast with differing backgrounds. • Applied uniformly by particle dispenser, an atomizer, or a spray gun in low velocity cloud • Greatest portability and more satisfactory for rough surfaces.
Wet Method	• Ferromagnetic particles of smaller size suspended in light petroleum distillate. Available in red or black and coated with a dye that fluoresces brilliantly under black (ultraviolet) light. • Can be used in either an oil or water bath and aerosol can sprayed on part. • Best suited for fine surface flaws on smooth surfaces. Less likely to reveal sub-surface flaw. Fluorescent particles can indicate very fine flaws and permit rapid inspection of irregular or dark surfaces.

For further information on magnetic particle testing procedures and techniques, refer to ASTM E709, Standard Recommended Practice for Magnetic Particle Examination and ASTM E125, Magnetic Particle Indications on Ferrous Castings.

4.5.3 Acceptance Criterion

When examining welds by magnetic particle testing, the acceptance criterion should be that of CSA Standard W59, Clauses 5.9, 12.5.4.1 and 12.5.4.4 for steel and AWS D1.6, Clauses 6.7.7 and 6.29.2 for Stainless Steel.

4.5.4 Interpretation Reports

An interpretation report should contain as a minimum:

1. Date the test was performed.
2. Inspection organization's name.
3. Method and level of magnetization.
4. Contrasting agents' properties.
5. Properties of magnetic particles - colour, size and viscosity of particles and fluid.
6. Viewing conditions and lighting arrangements.
7. Reference to a procedure or technique sheet.
8. Performing inspector's name, CGSB Level and signature.
9. Interpreter's name, CGSB Level and signature.
10. The code of acceptance criterion.
11. Interpretation report number.
12. Individual part or weld identification number.
13. Part geometry and shape, surface condition.
14. Reported discontinuities, their location, their individual and accumulated length and acceptability or rejection.

A procedure or technique sheet should contain:

1. Reference to a magnetic particle procedure.
2. Type of magnetization equipment.
3. Type and magnitude of current.
4. Continuous or residual magnetization.
5. Direction (s) of magnetization.
6. Fluorescent suspension sensitivity check.
7. Black light calibration, if used.

4.5.5 Audit Checklist for Magnetic Particle Testing

The following audit checklist for magnetic particle testing is offered for guidance only.

Follow this link to view a CWBi Video on Magnetic Particle Inspection.

Table 17 - Magnetic Particle Testing Checklist

Inspector's Qualifications	• CGSB 48.9712 Level 2 or 3
Procedure	• ASTM E709 • Approved Inspection Procedure
Equipment & Materials	• Type Of Magnetization Equipment • Type And Magnitude Of Current • Continuous Or Residual Magnetization • Direction(S) Of Magnetization • Indicating Medium • Fluorescent Suspension Sensitivity Check • Black Light Calibration
Report	• Procedure Details • Results

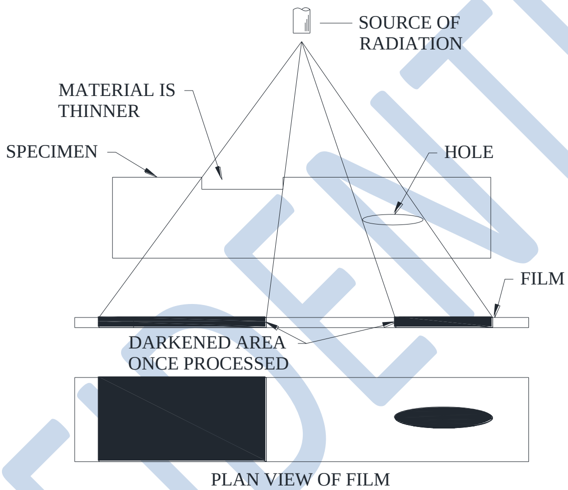
4.6 RADIOGRAPHIC TESTING (RT)

The most common method of examining welds in ship structures is radiographic inspection. This is in part a result of there being physical evidence in the form of a developed film that may be reviewed by the surveyor.

RT is good for measuring porosity, incomplete penetration and slag inclusions however, the inspection method has a few limitations with respect to its ability to locate side wall nonfusion and cracks parallel to the plate surface during normal inspection techniques where the source of radiation is placed 90° to the plate surface.

There are two basic sources of radiation: gamma rays, emitted by radioactive materials such as iridium 192 or cobalt 60, and x-rays.

In either case, the rays pass through the weld and are recorded on a special film as a shadow picture. Only relative densities of the material are shown on the developed film.



Discontinuities such as cracks, porosity, slag inclusions, and incomplete penetration are indicated by darker areas, contrasting with the lighter areas, which depict more dense, sound metal. Tungsten electrode inclusions and stainless steel wire brush strands however, appear lighter on the film because these materials are more dense than plain carbon steel or aluminum.

The clarity of film achieved with x-ray is better than gamma ray. X-ray must be used for examining welds in aluminum and is the preferred source of radiation for welds in steel having a thickness < 6 mm. Although x-ray is preferred over gamma ray for all steel thicknesses, the bulk and weight of x-ray tubes renders its use impractical for ship construction and repair.

X-Ray Tube

Gamma Ray

4.6.1 Qualification of Personnel

In Canada, personnel performing and interpreting penetrant testing are qualified by the Certifying Agency of Department on Natural Resources Canada (NRCan) to CGSB Standard 48.9712. The individual may be qualified to Level 1, Level 2 or Level 3.

Level 1 personnel can observe or assist a Level 2 or 3 individual with the inspections under CCG's Welding Specification requirements. Level 2 and 3 may write procedures and interpret results. A Level 3 individual has demonstrated better knowledge of the inspection method and as such may be called upon for supervision, writing of more complex procedures and techniques, and for settlement of disputed interpretation. Each certified individual is issued a pocket size certificate, indicating qualification.

Follow this link to search for NRCan certified NDT personnel.

4.6.2 Image Quality Indicators (Penetrameters)

Image Quality Indicators (IQI) are placed on the source side of the part to be examined to allow measurement of the sensitivity of the radiographic technique by the individual reviewing the film.

The quality of a radiographic image can be assessed in three ways:

- Image Sharpness – usually, in radiography, the inverse of sharpness - unsharpness or blurring is used.
- Image Contrast – the density change on a film for a given thickness change in the specimen. If a small image detail shows only faintly, this is a low contrast image; if the detail is easily seen, this is a higher contrast image.
- Image Noise – for radiography, on film, this is effectively graininess. In radioscopy, there are additional features affecting image noise.

A good IQI design should be able to show changes in all of the above factors.

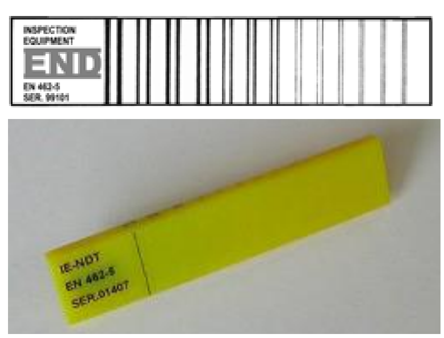
 Hole Type	 Wire Type
 Step/Hole Type	 Duplex Wire Type

Figure 35 - Four types of IQIs in use today

The hole, step/hole and wire types are widely specified in many Standards for film radiography.

The duplex wire type IQI, is not often used for routine film radiography, largely because of its high production cost. It consists of a series of pairs of wires of high density material (tungsten and platinum) where each pair of wires of diameter (d) is spaced at a distance (d) apart.

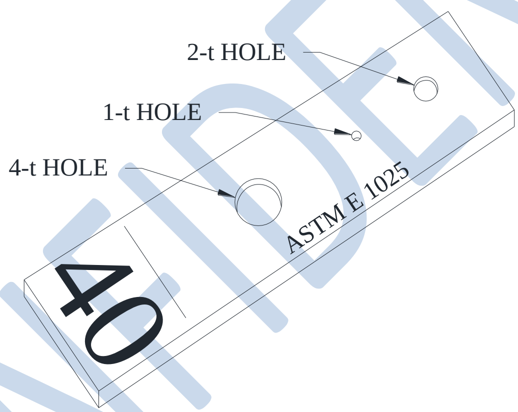
As one looks along the images of these wire pairs, one reaches a pair where the individual wire images are merged and one can no longer see two separate wires. The diameter (d) of this pair is a measure of the total effective unsharpness of the radiographic image.

This duplex wire IQI measures only unsharpness and is easy to use. At present, its principal use is to measure the total unsharpness of radioscopic (real-time radioscopy) screen images where there are many causes of unsharpness acting simultaneously, and in laboratory experiments.

Hole type IQIs are commonly used in North America whereas wire type are in widespread use elsewhere. CSA and AWS welding standards permit the use of either hole or wire type IQIs, however in Canada hole type are most often used.

A hole type IQI is:

- made of similar material to that which is being examined.
- designed such that its thickness is equal to 2% of the thickness of the part under examination.
- designed to contain three essential holes; 2-1t, 2-2t and 2-4t, where t is equal to the thickness of the IQI



If the specified essential hole is projected clearly on to the film, the technique has demonstrated an ability to project a discontinuity equal to the diameter and depth of the specified essential hole through the material thickness under examination. For equal thicknesses, one IQI is placed at each film end as illustrated below:

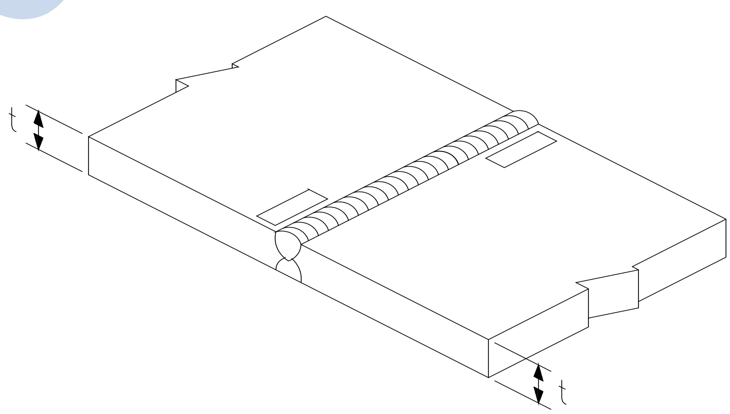


Figure 36 - IQI Placement for Equal Thickness

For unequal thicknesses, one additional IQI is placed on the thicker part as illustrated below:

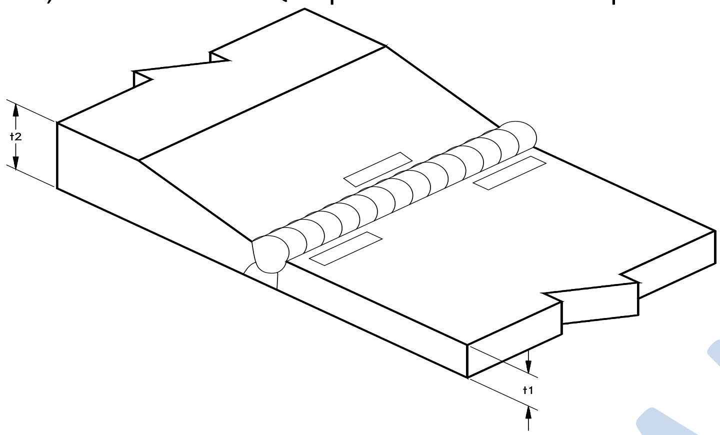


Figure 37 - IQI Placement for Unequal Thickness

IQI's should be placed as close as possible to the weld toe without inhibiting the interpretation of the area of interest (weld zone).

If the weld reinforcement has not been removed by grinding or machining, then a shim that is of a thickness equal to the reinforcement (both weld crowns) must be placed under the IQI. Recommended shim dimensions are illustrated below.

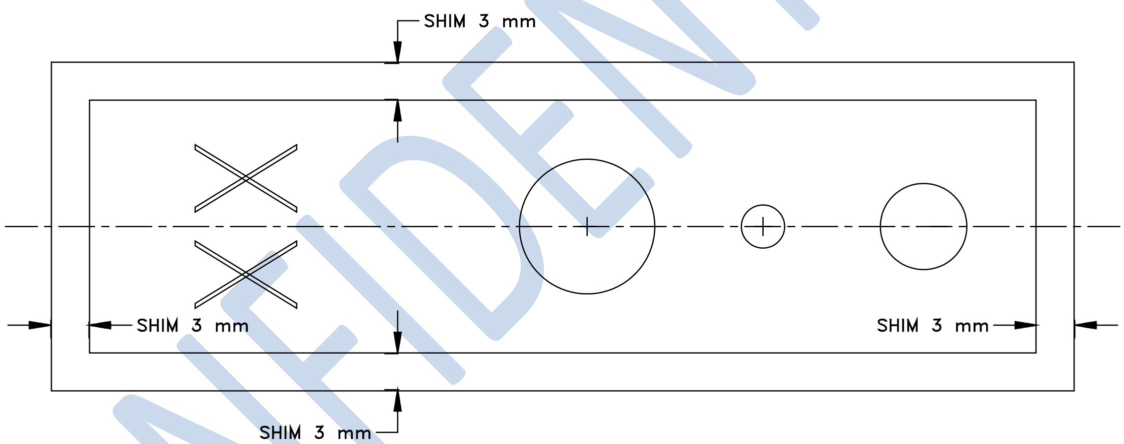


Figure 38 - Shim Dimension and Placement

In accordance with the CCG Welding Specification, an exposed radiograph should show the outline of the IQI, the outline of the shim, the IQI identification number, and the image of the essential hole as follows:

Material Thickness (mm)	Material Thickness (inches)	IQI Identification Number
≤ 6	≤ 0.25	10
> 6 to 10	> 0.25 to 0.375	12
> 10 to 16	> 0.375 to 0.625	15
> 16 to 20	> 0.625 to 0.75	17
> 20 to 25	> 0.75 to 1.0	20
> 25 to 32	> 1.0 to 1.25	25
> 32 to 38	> 1.25 to 1.50	30
> 38 to 50	> 1.50 to 2.0	35
> 50 to 65	> 2.0 to 2.5	40
> 65 to 75	> 2.5 to 3.0	45

Source of Radiation	Material Thickness	Essential Hole
X-Ray	All thicknesses in aluminum and ≤ 6 mm in steel.	2-2t
Gamma Ray	For steel thicknesses > 6 mm and < 12.5 mm using Class 1 film	2-2t
Gamma Ray	For steel thicknesses ≥ 12.5 mm and ≤ 30 mm.	2-4t
Gamma Ray	For steel thicknesses > 30 mm.	2-2t

4.6.3 Film Densities

The transmitted film density through the radiographic image of the body of the appropriate IQI and the adjacent area of interest (weld zone) should be: 1.8- 3.5 for X-Ray, and 2.0- 3.5 for Gamma Ray.

If the density of the radiographs through the area of interest (weld zone) varies by more than minus 15% or plus 30% from the density through the body of the IQI within the minimum/maximum recommended density ranges, an additional IQI should be used for each exceptional area or areas and the radiograph should be retaken.

4.6.4 Geometric Unsharpness

Geometric unsharpness of the radiograph should not exceed the following values:

Material Thickness		Geometric Unsharpness	
Metric	Imperial	Metric	Imperial
Up to 25mm	Up to 1"	0.125mm	0.005"
25 to 50mm	1 to 2"	0.250mm	0.010"
50 to 75 mm	2 to 3"	0.375mm	0.015"

4.6.5 Quality of Developed Film

The area of interest (weld zone) being inspected should not be inhibited for interpretation with interference from IQI's or lead markers. They should also be free of mechanical, chemical and/or other blemishes to the extent that they do not mask potential discontinuities located in the area of interest. Films that display water stains, blotches, streaks, fingerprints, sharp lines, milky zones, brownish tones and fog should be retaken.

4.6.6 Interpretation

An interpretation report should contain as a minimum:

1) Date the radiograph was taken.
2) Inspection organization's name.
3) Reference to a procedure or technique sheet.
4) Performing radiographer's name, CGSB Level and signature.
5) Interpreter's name, CGSB Level and signature.
6) The code of acceptance criterion.
7) Interpretation report number.
8) Individual film identification number.
9) Reported discontinuities, their location on the film, their individual and accumulated length and acceptability or rejection.

A technique sheet should contain:

1) Reference to a radiographic procedure.
2) IQI design and identification number.
3) Type of source radiation.
4) Source to film distance.
5) Angle of incident radiation.
6) Intensification screen design if used.
7) Material type, thickness, joint type and geometry.

4.6.7 Acceptance Criterion

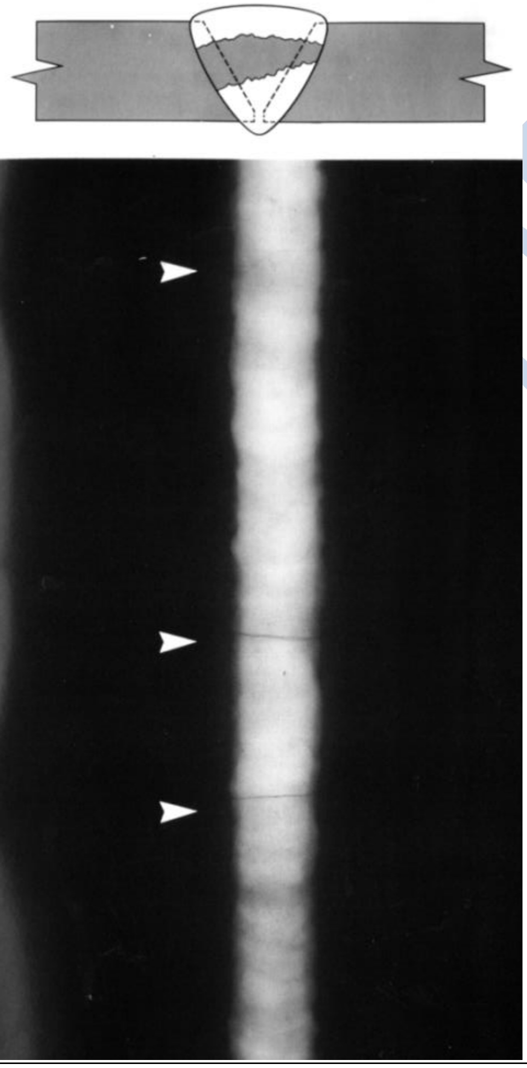
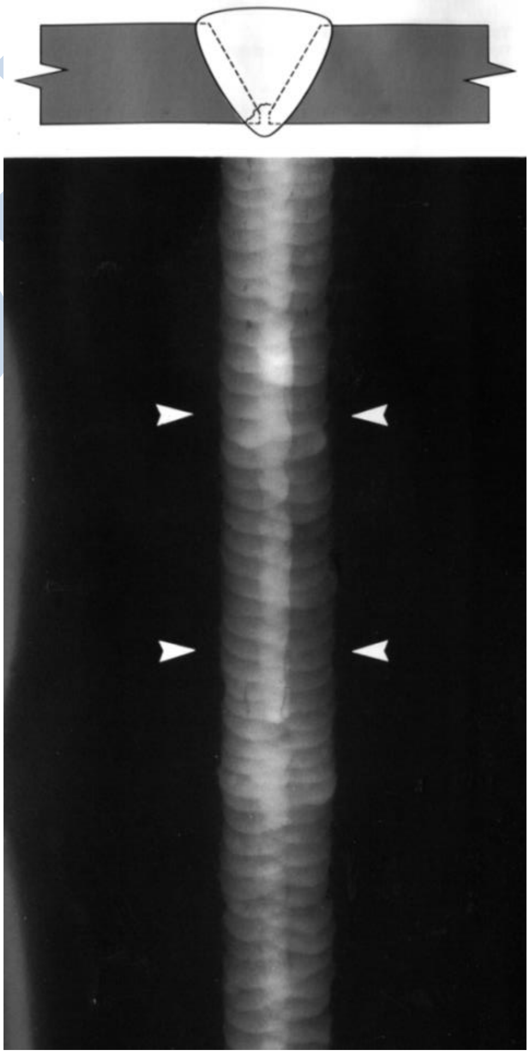
When examining welds by radiographic inspection the acceptance criterion should be that of CSA Standard W59, Clauses 5.9, 12.5.1 and 12.5.4.3 for steel, AWS D1.6, Clauses 6.9, 6.10 and 6.29.2 for stainless steel and CSA Standard W59.2, Clause 6.0 for aluminum.

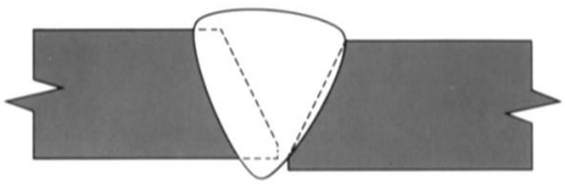
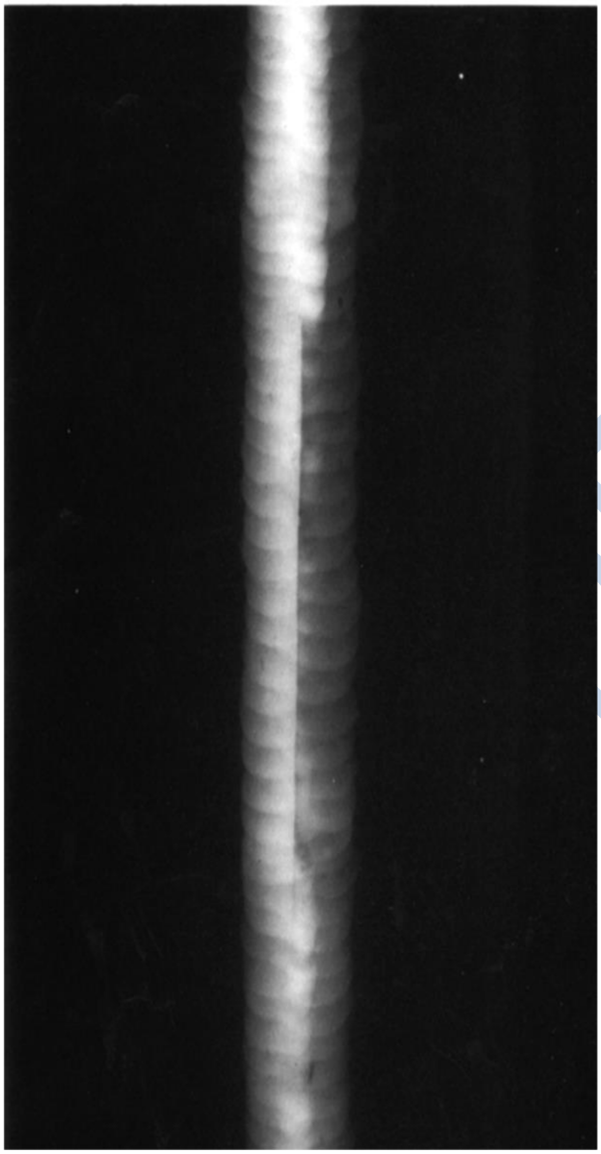
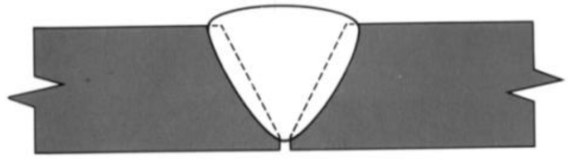
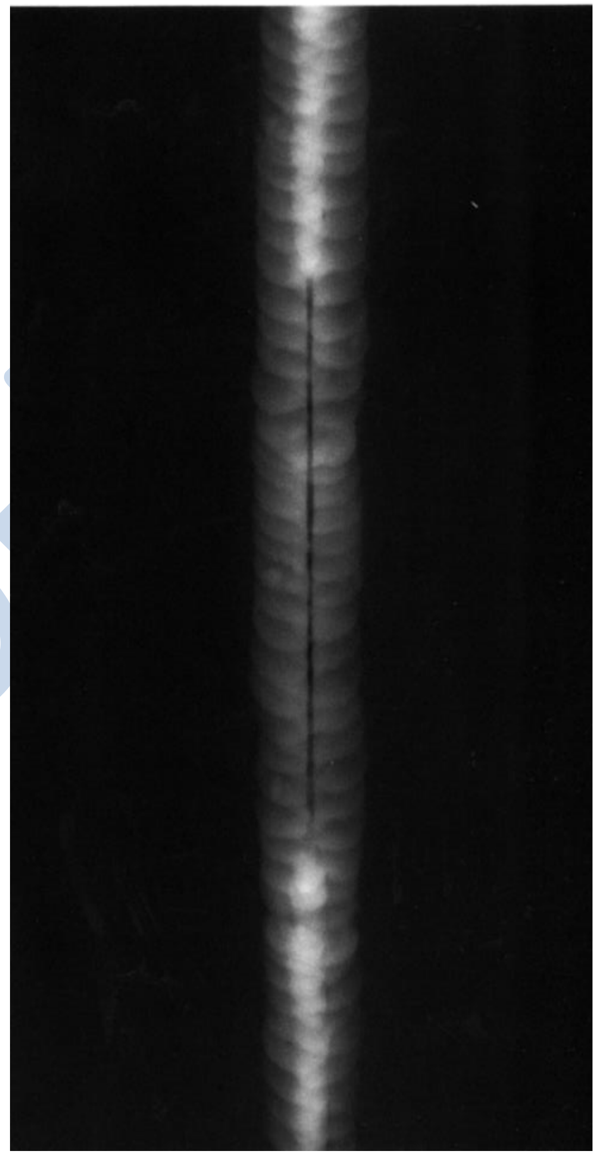
Defects appearing on the film that are noted to be on the surface should be repaired and the radiograph should be retaken. It is always advisable to subject the location selected for radiographic inspection to visual examination prior to the taking of the radiograph.

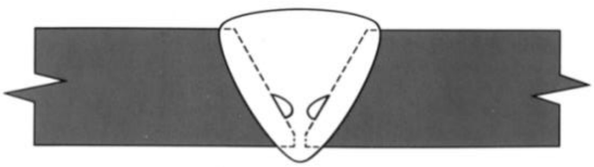
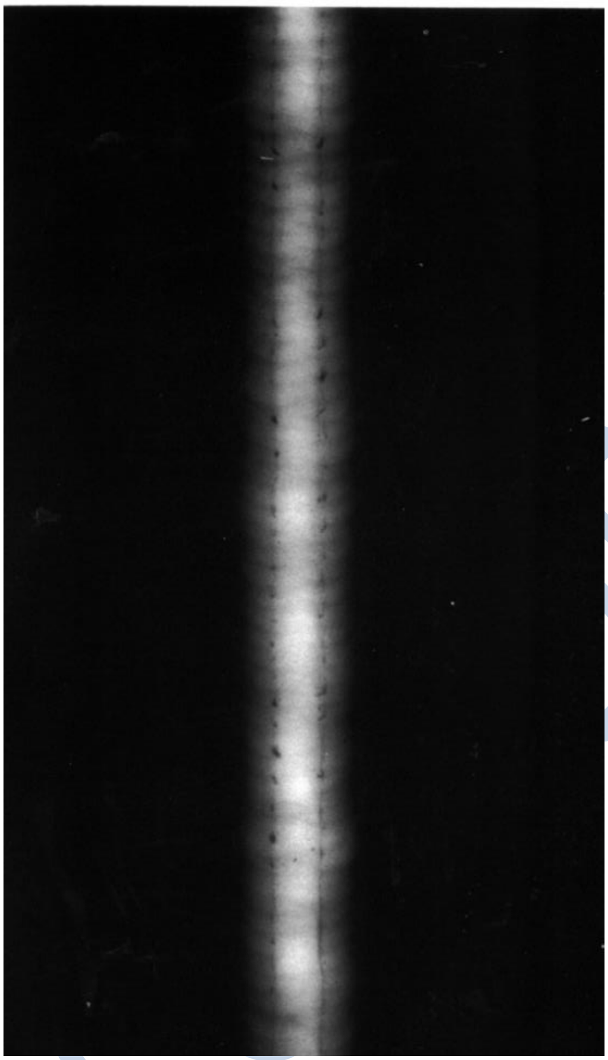
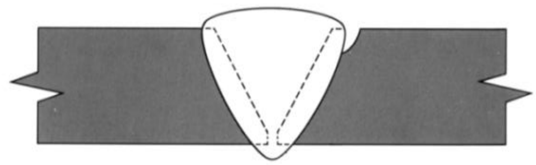
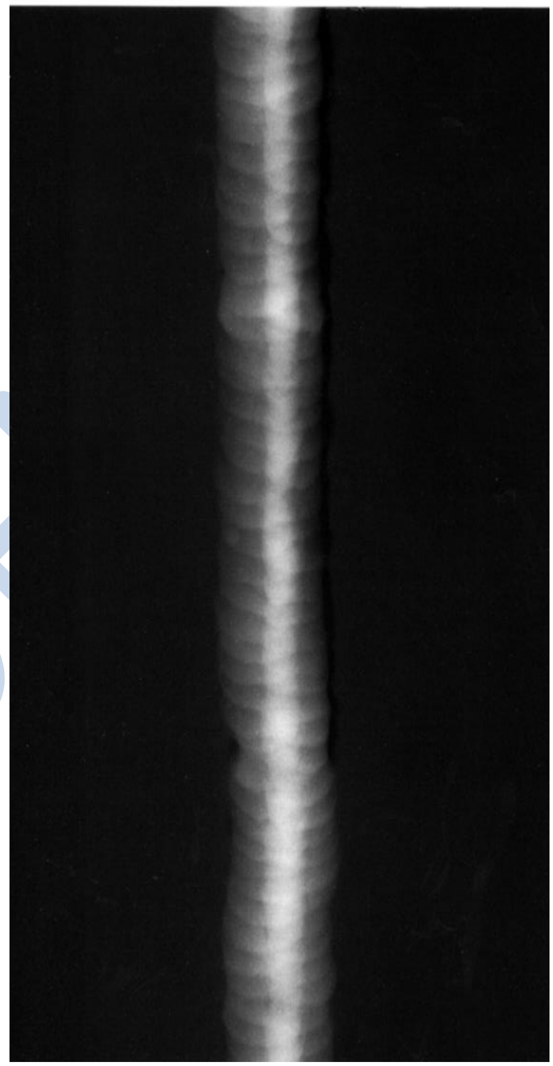
IIW reference radiographs for steel and aluminum should be consulted if there is a question with respect to how defects should appear on radiographic film. In the case of disputed interpretation, a third party Level 3 evaluation through the Certifying Agency of NRCan should be sought.

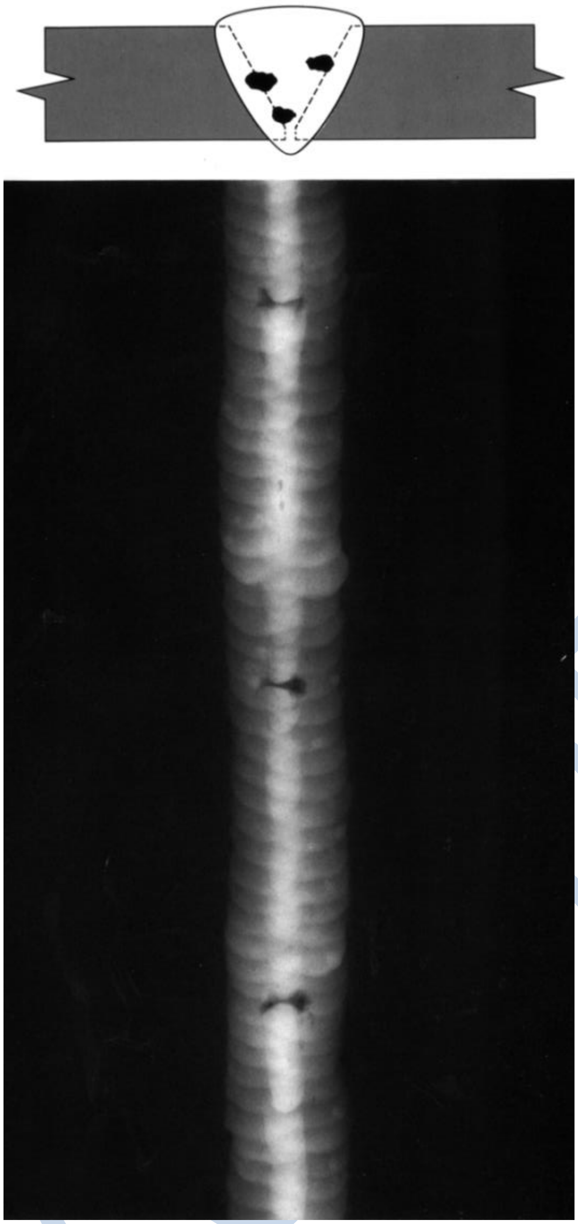
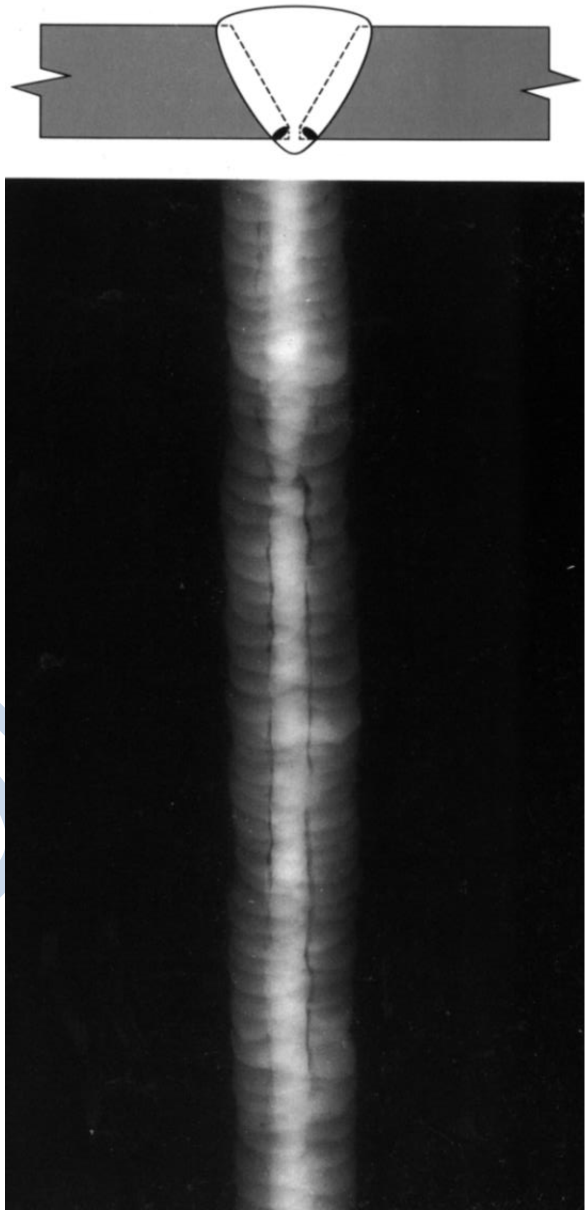
4.6.8 Appearance of Weld Faults on Radiographic Film

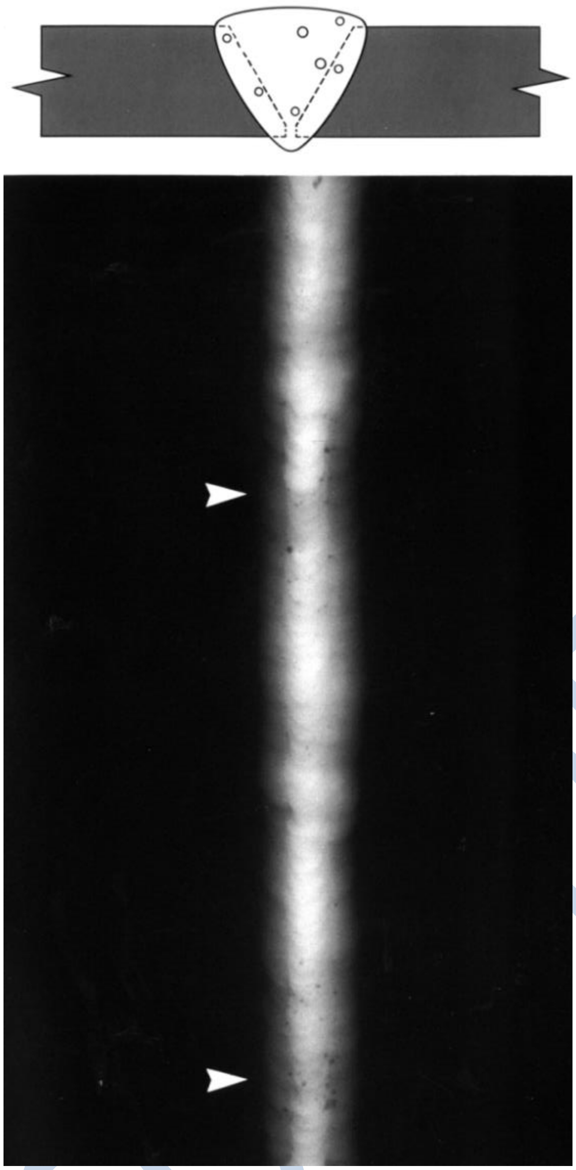
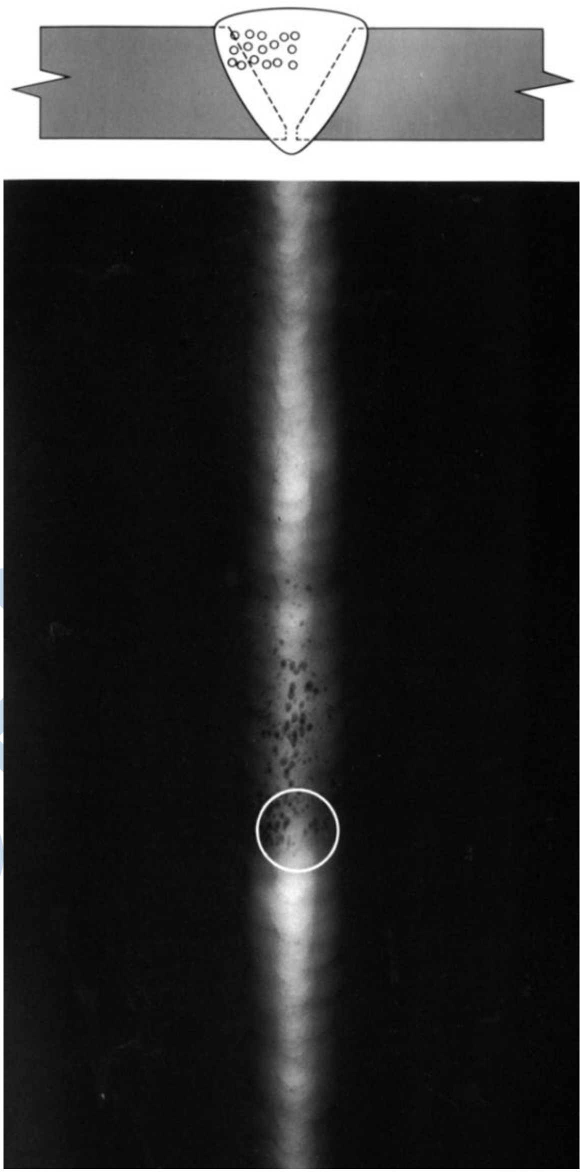
The following offers guidance on how some different types of discontinuities in welds will appear on a radiographic film.

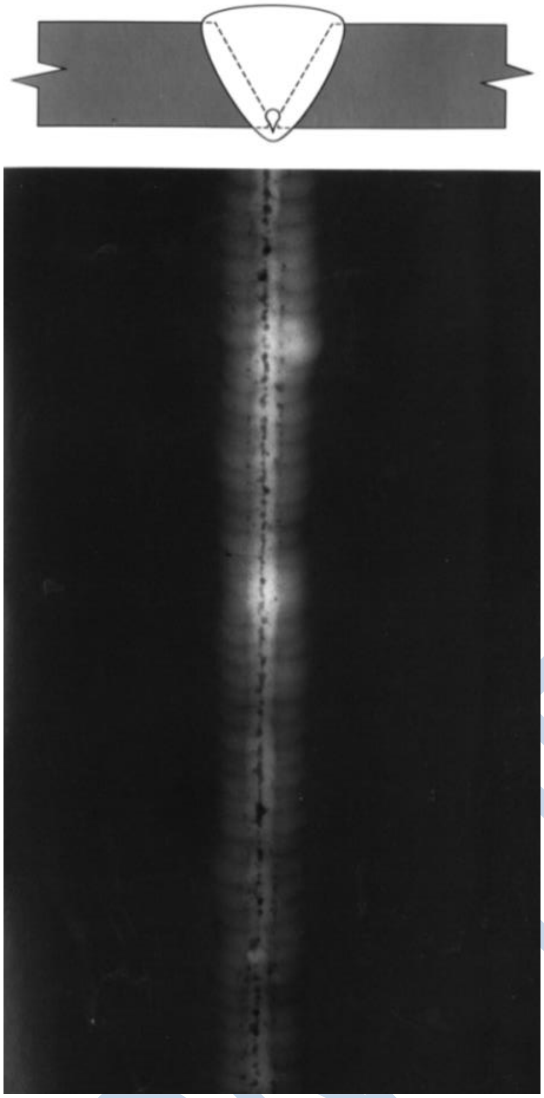
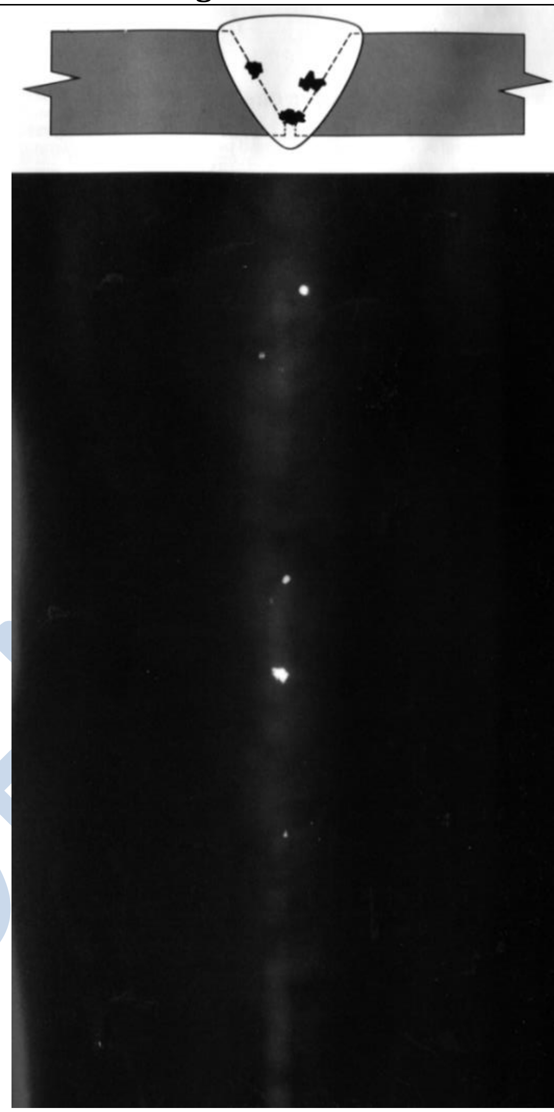
Transverse Cracks	Longitudinal Root Crack
	
A fracture in the weld metal running across the weld.	A fracture in the weld metal at the edge of the root pass.

Offset or Mismatch with Lack of Penetration	**Incomplete or Lack of Penetration**
 	 
A misalignment of the pieces to be welded and insufficient filling of the bottom of the weld or "root area".	The edges of the pieces have not been welded together, usually at the bottom of single V-groove welds.

Lack of Side Wall Fusion	**Undercut**
 	 
Elongated voids between the weld beads and the joint surfaces.	A gouging out of the piece to be welded, alongside the edge of the top or "external" surface of the weld.

Interpass Slag Inclusions	Elongated Slag Lines (Wagon Tracks)
	
Usually non-metallic impurities that solidified on the weld surface and were not removed between weld passes.	Impurities that solidify on the surface after welding and were not removed between passes.

Scattered Porosity	**Clustered Porosity**
	
Rounded voids random in size and location.	Rounded or slightly elongated voids grouped together.

Root Pass Aligned Porosity	Tungsten Inclusions
	
Rounded and elongated voids in the bottom of the weld aligned along the weld centerline.	Random bits of tungsten fused into but not melted into the weld metal

4.6.9 Managing the Selection of Locations to be examined

It's not uncommon for contractors to request the Delegated Representative to identify where inspections will occur well in advance of completed work. Zones of structure should be identified to the shipyard but not necessarily the exact locations for spot examination.

A typical plan may be as follows:

Strength Members:	Shell Plating:	Others:
• Flat and Vertical Keel • Tank Margin Plates • Sheer Strakes • Bilge Strake • Deck Stringer Plates	• Intersection of Butts and Seams • Transverse Prefabricated Block Butts • Transverse Block Butts at the Berth • Longitudinal Seams Prefabricated, Block and at the Berth	• Inserts and Closure Plates • Cruciform Welds • Terminal Welds

Of the number of radiographs available for selection, it is wise to retain at least 30% for examining connections that are submerged arc welded in the prefabrication phase and those connections that are cause for concern as a result of in-process visual inspection findings (i.e., poor fit-up, poor included angle, excessive root openings, etc.).

Results of tests should be turned over to the Delegated Representative within an agreed to and reasonable time frame. When the completed joint to be examined is under high restraint and /or when the yield strength is equal to or greater than 42 kg/mm², tests should be delayed at least 48 hrs.

When a discontinuity extends to either or both ends of a film, additional inspection should be taken. The new film should overlap the original film end where discontinuities appeared.

If discontinuities are continuous along the film length, overlapping film should be taken to determine the extent of such conditions. If the shipyard elects to repair and not take overlapping radiographs, overlapping films should be positioned at both ends of the completed repair.

4.6.10 Audit Checklist for Radiographic Inspection

Follow this link to view a CWBi Video on Radiographic Inspection.

The following Audit Checklist is offered for information purposes only.

Table 18 - Radiographic Testing Checklist

Procedure	❑ Approved written procedure ❑ ASTM E94
Inspector's Qualifications	❑ CGSB 48.9712 Level II ❑ AECB Operator's License
Equipment &Materials	❑ Source of radiation ❑ Geometry of exposure (shooting sketch) ❑ Type of film ❑ Exposure times ❑ Identification ❑ Visible penetrameter (IQI)
Report	❑ Procedure details ❑ Interpretation report ❑ Results

4.7 ULTRASONIC TESTING (UT)

Ultrasonic testing is a means of examining weldments in ferrous and nonferrous metals, castings, forgings, composites, etc. It is also widely used for measuring thickness variances in most metals caused by corrosion.

By using the same principles as sonar, a short pulse of energy is transmitted by a transducer and when coupled to an inspection material it sets up a sound wave. The wave travels through the material until it strikes a boundary of different acoustic velocity (porosity, cracks, inclusions, etc.). The sound is then reflected back to the transducer where the sound energy is transformed to an electrical signal and displayed on a cathode ray tube or LED read out.

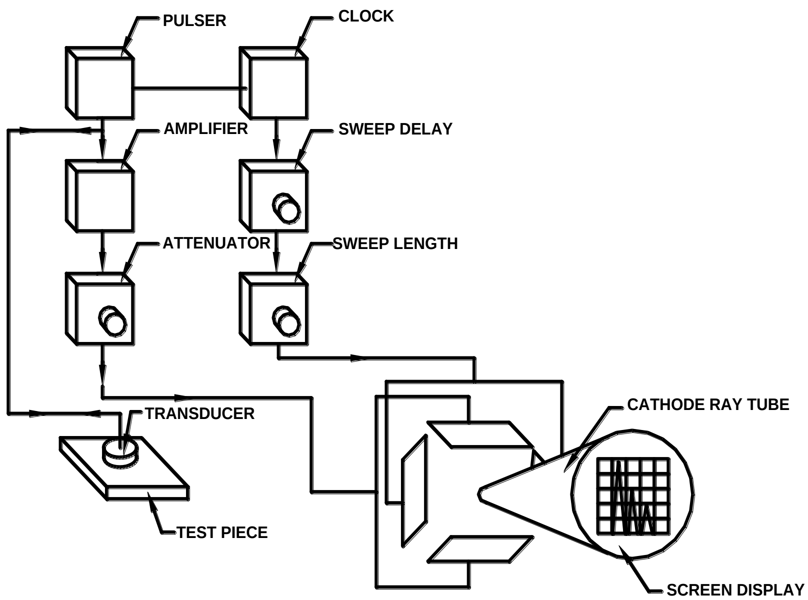


Figure 39 - Block Diagram, Pulse Echo Flaw Detector

The results are instantaneous, reliable and can be easily stored for future reference. Ultrasonic inspection is usually performed with either longitudinal waves (straight beam) or shear waves (angle beam). The most commonly used frequencies are between 1 and 5 MHz, at angles of 45°, 60° and 70°.

4.7.1 Longitudinal Waves

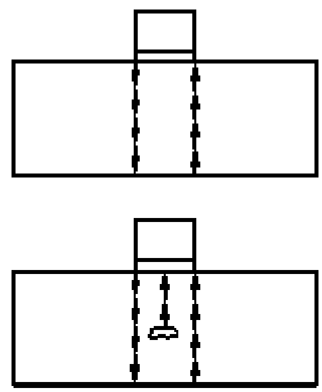


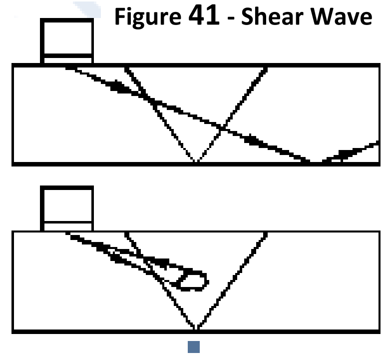
Figure 40 - Longitudinal

Longitudinal beam is most commonly used for examining base metals for de-laminations, laminations, inclusions and thickness. In longitudinal beam testing, sound is projected into the part perpendicular to the entry surface by a straight beam search unit.

For flaw detection, when the entry surface and the back surface are parallel, a back reflection will appear on the CRT. A discontinuity lying between the front and back surfaces will also be displayed.

A thickness reading is in fact a measurement of the time delay for the ultrasound to travel from its inception point, to a distant point from which that sound has been reflected. The time delay of this travel is then compared to the time delay of known thickness and the test specimen's thickness is assumed to be proportional to that known.

Figure 41 - Shear Wave



4.7.2 Shear Wave

Discontinuities such as cracks, porosity, inclusions, incomplete penetration, nonfusion, metallic and nonmetallic inclusions and undercut can be detected by the angle beam shear wave method.

With this method sound travels through the weld at a specified angle, by moving the probe transverse and longitudinally along the length of the weld, a thorough inspection can be achieved.

Ideally, only discontinuities should appear on the CRT during angle beam inspection. This is not always the case, however, since the geometrical boundaries of the part being inspected often reflect sound back just as a discontinuity would. Therefore, caution should be exercised when inspecting complex geometries such as welds with permanently fixed backing bars.

Since it is important to intercept the discontinuity at near 90°, it is common for more than one angle search unit to be used to inspect a particular weld.

When testing welds it is important to firstly search the adjacent base metal with longitudinal wave for lamellar reflectors that may inhibit proper inspection of the weld.

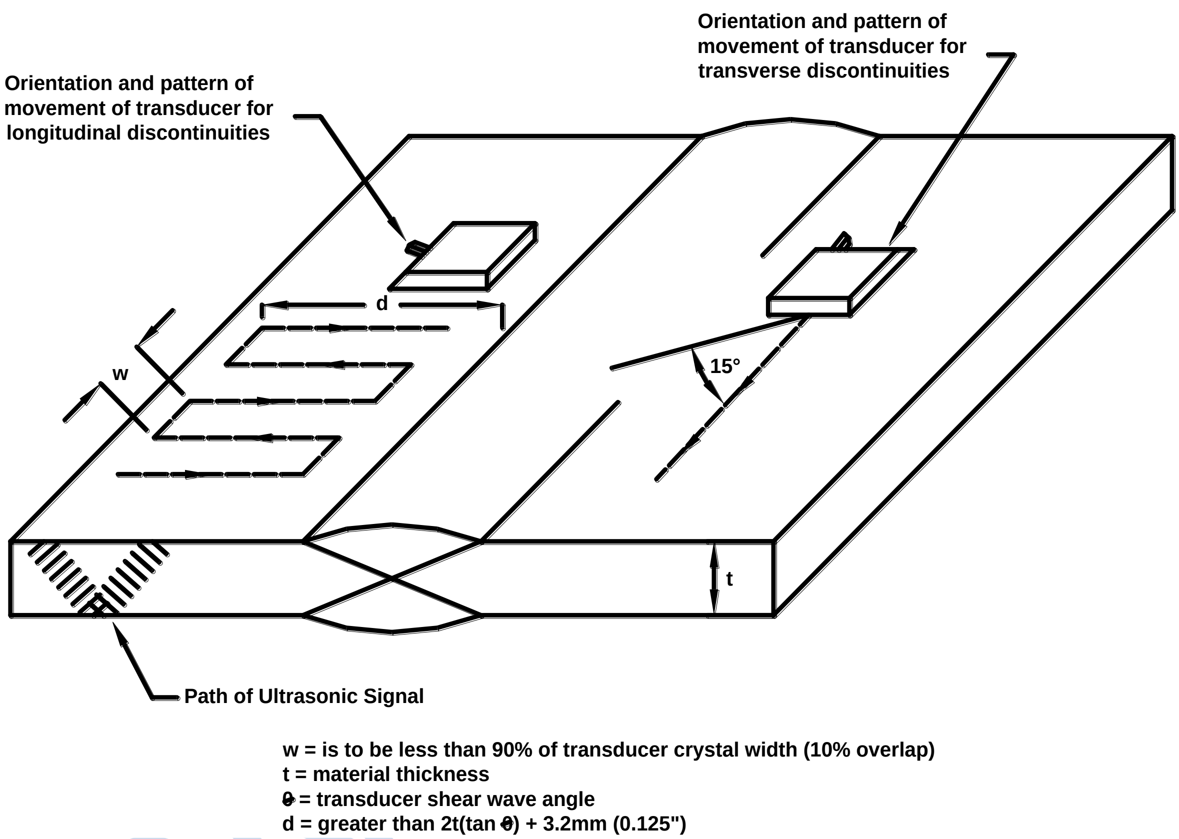


Figure 42 - Typical Scanning Technique & Transducer Movement

4.7.3 Advantages

1. Greater accuracy in determining the position of internal discontinuities, estimating their size and characterizing their orientation, shape and nature. High sensitivity permits detecting very small discontinuities.
2. Only requires access from one side of the part being examined.
3. Inspection data is instantaneous.
4. Equipment is portable and its operation represents no safety hazards to workers in the immediate area of inspection.
5. Method permits inspection of a volume of metal extending from the front surface to the back surface of the weld.
6. Superior penetrating power allows detection of discontinuities deep in the part.

4.7.4 Disadvantages

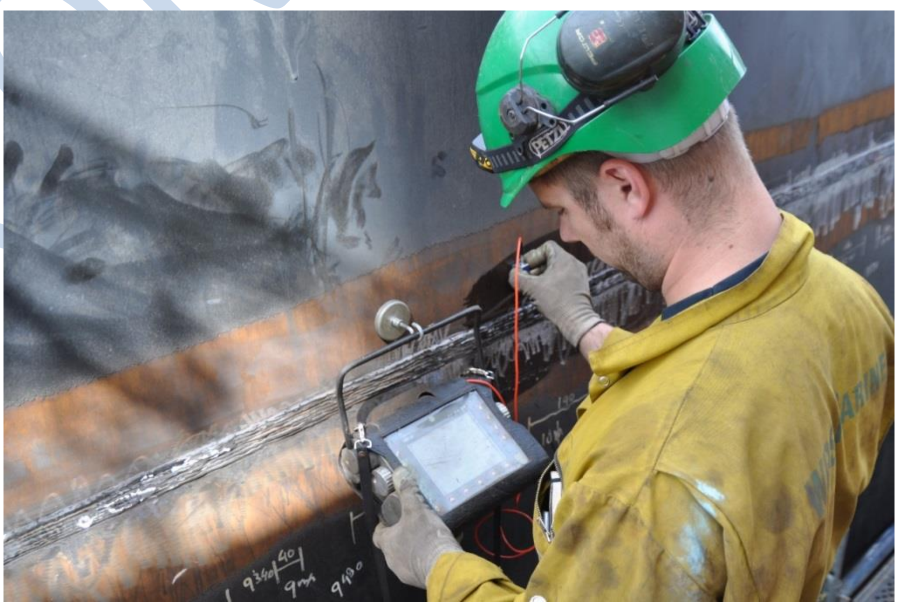
1. Inspection method reliant on careful attention by experienced technicians and extensive technical knowledge to develop procedures.
2. Parts that are rough, irregular in shape, small or thin, or inhomogeneous are difficult and expensive to inspect.
3. Internal structure may inhibit inspection (i.e. grain size, porosity, inclusions or fine dispersed precipitates).
4. If access only allows the inspection to be carried out from one side it is possible a larger defect may shadow a smaller defect, making it undetectable.
5. Shallow defects may not be detected.
6. Calibration procedures and reference standards are required for varying test conditions.

4.7.5 Personnel Qualifications

In Canada, personnel performing and interpreting penetrant testing are qualified by the Certifying Agency of Department on Natural Resources Canada (NRCan) to CGSB Standard 48.9712. The individual may be qualified to Level 1, Level 2 or Level 3.

Level 1 personnel can observe or assist a Level 2 or 3 individual with the inspections under CCG's Welding Specification requirements. Level 2 and 3 may write procedures and interpret results. A Level 3 individual has demonstrated better knowledge of the inspection method and as such may be called upon for supervision, writing of more complex procedures and techniques, and for settlement of disputed interpretation. Each certified individual is issued a pocket size certificate, indicating qualification. Follow this link to search for NRCan certified NDT personnel.

Because of the wide range of applications and the variety of defects sought with ultrasonic testing, it is very difficult to gain expertise in all areas of application of the test method. Most often, a qualified operator will specialize in specific types of inspection using ultrasonics. To become knowledgeable and proficient in weld inspection, it requires years of dedication and experience on the part of an operator.



4.7.6 Standardization of Test Equipment

It is essential that interpretation results can be duplicated under both field and shop conditions. Using one or both ASTM standards E 164 or E 317 will enable an operator to achieve two important goals:

1) The performance characteristics of the complete testing system including the search unit, couplant, interconnectors, and instrument can be evaluated; and,

2) The interpretation results can be duplicated, enabling identical inspections to be carried out at two different locations producing the same results.

Couplants play an important part of any ultrasonic inspection. When equipment calibration checks are performed they should be carried out with the intended use couplant and at field condition temperatures. The transducer and couplant planned to be used for the inspection should be used for equipment calibration checks.

4.7.7 CSA Standard W59 requirements for Ultrasonic Testing of Welds in Steel

Ultrasonic testing is a suitable method of testing for steel and some grades of stainless steels however not suitable for coarse grain materials and many weldments in nonferrous metals such as aluminum as a result of finely dispersed porosity.

For welds made in structural steel, the requirements for ultrasonic examination are clearly stated in Clauses 7 and 8 of CSA Standard W59. It is important to note that the CCG Welding Specification cautions against the use of ultrasonic testing as the primary means of determining weld quality unless it is supplemented initially and periodically by a reasonable amount of radiographic examinations.

Prior to the use of ultrasonic testing for the required examinations, the shipyard's QA and QC departments should verify and satisfy the Delegated Representative of the following:

1. Ultrasonic examination is being performed to acceptable materials within the thickness range of 9 mm and 200 mm.

2. Operator training and qualifying practices are acceptable.

3. Test results are reliable and reproducible.

4. The equipment is suitable, calibrated and well maintained.

5. There is proper application of calibration and examination procedures, techniques and acceptance standards to the contract test standards such as CSA Standard W59 for steel.

6. Records are kept concerning the nature and severity of indications and, the extent and amount of repairs to unacceptable welds.

Clause 8.2.4 of CSA Standard W59 offers the requirements for Ultrasonic Examination Equipment. A summary of the requirements of this Clause are offered in the following table:

Clause	Summary of Equipment Requirements
8.2.4.1	Pulse Echo Type and able to generate, receive and display on screen pulses within the frequency range of 1 to 5 MHz.
8.2.4.2	Horizontal linearity within + or - 5% over the linear range, 90% of the sweep length presented on screen for the longest sound path.

8.2.4.3	Internal stabilization, no variation in response > + or - 1 dB with supply voltage changes within 15% or for battery powered over the battery charge operating life. Low supply voltage signal or alarm is required.
8.2.4.4	Attenuator (calibrated gain control) that is adjustable in 1 or 2 dB steps over at least 60 dB range. Gain control accuracy within 1 dB, by methods offered in ASTM E317.
8.2.4.5	Display dynamic range is such that a difference of 1 dB of amplitude is easily detected on the display.
8.2.4.6	Square straight beam search unit transducers with an active area ≥ 323 square mm and < 645 square mm in the 2 to 5 MHz range capable of resolving three reflections.
8.2.4.7	Angle beam search units can be two separate elements or an integral unit having a frequency between 2 and 2.5 MHz, can be square or rectangular varying in size, producing a sound beam within the range of + or - 2° of 45°, 60° or 70° angles. Search units must display frequency, nominal angle of refraction, and index point. For other requirements see CSA Standard W59.

Clause 8.2.5 of CSA Standard W59 offers the requirements for Calibration Standards. A summary of the requirements of this Clause are offered in the following table:

Clause	Calibration Standards
8.2.5.1	The IIW ultrasonic reference block in ISO 2400 is for both distance and sensitivity calibration. An IIW-type block with dimensions as shown in Figure 8.9 of CSA Standard W59 can be used for imperial units of measure provided conformity to all other aspects of ISO 2400. Other blocks may be used if reference level sensitivity for instrument/search unit combination is equivalent to that achieved with an IIW block.
8.2.5.2	A corner reflector for calibration is not permitted.

Clause 8.2.6 of CSA Standard W59 offers the requirements for Equipment Calibration. A summary of the requirements of this Clause are offered in the following table:

Clause	Equipment Calibration
8.2.6.1	The attenuator (gain control) must be checked for correct calibration at two-month Intervals and meet the requirements of Clause 8.2.4.4 of CSA Standard W59.
8.2.6.2	In each of the distance ranges used, the horizontal linearity must be checked by techniques prescribed in Clause 8.2.4.2 of CSA Standard W59 at specified intervals; the shorter of, 40 hours of instrument use and/or 2 month intervals.
8.2.6.3	After each 8 hours of use, using a calibration block, each angle beam search unit must be checked for contact face flatness, correct sound entry point and beam angle tolerance (+ or - 2°). Search units that do not meet the requirements must be corrected or replaced.
8.2.6.4	The holes in calibration blocks must be kept clean and free any foreign matter and fluids that could affect calibration and repeatability.

Clause 8.2.7 of CSA Standard W59 offers the requirements for Calibration for Examination. A summary of the requirements of this Clause are offered in the following table:

Clause	Calibration for Examination
8.2.7.1	Calibration for sensitivity and horizontal sweep and recalibration.
8.2.7.2	Calibration for straight beam examination.
8.2.7.3	Calibration for angle beam examination.

Clause 8.2.8 of CSA Standard W59 offers the requirements for Testing Procedure. A summary of the requirements of this Clause are offered in the following table:

Clause	Testing Procedure
8.2.8.1	Identification Number
8.2.8.2	Surface Condition
8.2.8.3	Couplant
8.2.8.4	Reliable Evaluation
8.2.8.5	Laminar Reflectors
8.2.8.6	Angle Beam Testing Requirements
8.2.8.7	Marking Rejectable Defects

Clause 8.2.9 of CSA Standard W59 offers the requirements for Reports. A summary of the requirements of this Clause are offered in the following table:

Clause	Preparation and Disposition of Reports
8.2.9.1	Report Content
8.2.9.2	Prior to Acceptance
8.2.8.3	Delivery to Owner/Contractor's Responsibility

Clause 8.2.10 of CSA Standard W59 offers the requirements for Calibration of the Ultrasonic Unit, Clause 8.2.11 Scanning Patterns and 8.2.12 Alternate Ultrasonic Systems. A summary of the requirements of these Clauses are offered in the following table:

Clause	Calibration of the Ultrasonic Unit
8.2.10.1	Longitudinal Mode • 8.2.10.1.1 Distance Calibration • 8.2.10.1.2 Amplitude • 8.2.10.1.3 Resolution
8.2.10.2	Shear Wave Mode • 8.2.10.2.1 Sound Entry Point • 8.2.10.2.2 Sound Path Angle
8.2.10.3	Distance Calibration: 8.2.10.3.1 IIW Block
8.2.10.4	Amplitude Calibration

8.2.10.5	Resolution
8.2.10.6	Approach Distance of Search Unit
8.2.11	Scanning Patterns for Ultrasonic Examination • 8.2.11.1 To Seek Longitudinal Indications • 8.2.11.2 To Seek Transverse Indications
8.2.12	Alternate Ultrasonic Systems

4.7.8 Acceptance Criterion and Reports

When examining welds by ultrasonic inspection the acceptance criterion should be that of CSA Standard W59, Clauses 5.9, 12.5.1 and 12.5.4.5 for steel and AWS D1.6, Clause 6, Part "C" and Clause 6.29.3 for stainless steel. Radiography is the preferred inspection method for aluminum.

Defects appearing on the report that are noted to be on the surface should be repaired and the examination performed again after repair. It is always advisable to subject the location selected for ultrasonic examination to visual inspection prior to performing ultrasonic examination.

In the case of disputed interpretation, a third party Level 3 evaluation through the Certifying Agency of NRCan should be sought.

4.7.9 Audit Checklist for Ultrasonic Inspection

Inspector's Qualifications
The person assessing the test results should be certified by NRCan to CGSB standard 48.9712 Level 2 or 3. Under CCG Welding Specification requirements Level I personnel can only observe or assist Level 2 or 3 personnel.

Procedure
General UT procedure should follow ASTM E164, E317 and CSA Standard W59. The inspector should also have available to them a copy of Level 3 personnel approved inspection procedure. The QA and QC departments should verify that the inspector is following this procedure.

Equipment and Materials
The written procedure will define the type of instrument to be used, the frequency, size and angle of the transducer, the calibration procedure, the scanning procedure, the procedure for assessing and evaluating indications and the acceptance/rejection levels in terms of instrument parameters (% of screen height or dB).

Report
The report should show the details of the procedure used and the results, usually classified into reportable indications and rejectable indications. The sensitivity of the method is such that the inspection may reveal internal indications that are below the rejection level, however for future reference, it is desirable to have a record of their existence. The following is desirable:

- Hull number.
- Dates of inspections and personnel qualifications and signatures.
- Exact location and length of welds examined.
- Base metal type and thickness.
- Joint design and edge preparation.

- Welding process and any unusual condition of weld bead (ground, undercut, etc.).
- A copy of the visual inspection report should be attached or at least referenced.
- Standard to which examination is being carried out.
- Reference to the Inspection Procedure and Technique followed.
- Equipment characteristics - range and resolution, pulse shape etc.
- Probe characteristics - frequency, beam spread, near zone.
- Couplant characteristics - acoustic impedance.
- Equipment calibration - procedure and calibration blocks.
- Scanning procedure.
- Reflections that are interpreted as passing and failing to meet the specified requirements
- Interpretation of results.
- Recording, evaluation and reporting.

Follow this link to view a CWBi Video on Ultrasonic Inspection.

Table 19 - Ultrasonic Testing Checklist

Inspector's Qualifications	CGSB 48.9712 Level 2 or 3
Procedure	Approved written procedure ASTM E164/E317 & W59
Equipment & Materials	Type of instrument (digital/analog) Transducer frequency, size, angle Calibration blocks, procedure Scanning procedure Evaluation and assessment procedure Acceptance/rejection criteria
Report	Procedure details Instrument and transducer serial numbers and details Reportable and rejectable indications Results

Section 5 QUALITY PROGRAMS

Quality Assurance (QA) is adherence to written direction and standard operating procedures (SOP's) within an organization. A company can establish a QA manual complete with reporting structures and instructions on how to do specialized work right down to the shop level and can even be registered to an outside agency that will audit them on a regular basis. These audits are performed to ensure customers that they will always receive a consistent level of quality and, to confirm to the auditor that management and workers alike understand the procedures. QA procedures are owned by the company and can be altered to reflect changes in communication, technology or how processes are carried out, but the QA manual must then be altered to reflect these changes.

Most Quality Assurance (QA) Program Standards view welding as a specialized manufacturing process that requires company developed controls outside the scope of the Quality Assurance Program Standards. Recently developed ISO 3834 QA Program Standard recognizes welding as an important manufacturing process and offers QA requirements specifically formulated to control welding operations. The CWB is IIW's authorized national body and registrar for ISO 3834 in Canada.

Quality Control (QC) is about metrics, and the physical measurement of things. If workers adhere to set processes, the quality of the end product will always be the same, (this is often called reproducibility). If tolerances or results change with a product, repeated measurements that have been saved over time will indicate where the problems lie. This data is called objective evidence.

In summary, QA is about adherence to internal procedures within the company and QC is about metrics and the collection of objective evidence.

Annex A GUIDELINES FOR THE REPAIR OF CORRODED WELDS IN KORT NOZZLES

A.1 SCOPE

This Annex only applies to connections attaching IACS Grades A, D, E, DH36 and EH36 steels to 316 stainless steels (SS). Independent of steel grade, this Annex "does not apply" to base plates having manganese content "greater than 1.25 wt %".

A.2 WELDING ELECTRODES AND CONSUMABLES

Welding electrodes for repair build-up should be a combination of E309-16 and E5518-C3.

A.3 WELD PROCEDURE QUALIFICATION TESTS

Weld repair build-up should only be performed using qualified procedures. Weld procedures should be qualified in accordance with the requirements of this Clause.

A test should be required in the flat (1G), vertical (3G) and overhead (4G) positions. Vertical-down progression should not be permitted. Tests should be made with the largest diameter electrode intended for repair at a representative heat input (kJ/mm).

Base plates should be Grade A and 316 SS having an as-fitted dimension of at least 500 mm in length and 250 mm in width.

Test plate assemblies should be as illustrated in Figure A1.

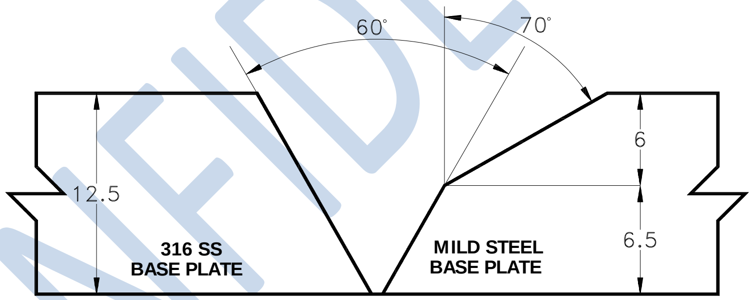


Figure A1 - Preparation for Weld Procedure Test

The groove should be welded following the technique illustrated in Figure A2. The exact bead sequence should be followed.

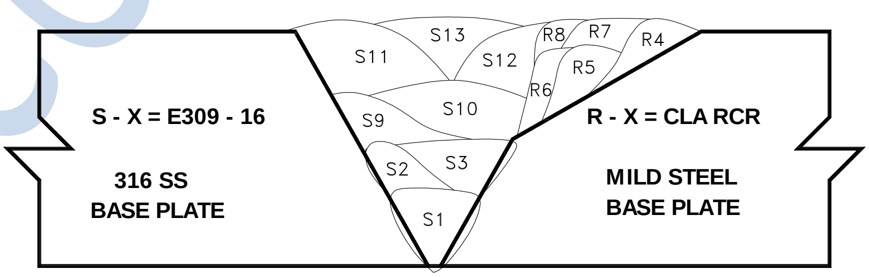


Figure A2 - Bead Sequence for Weld Procedure Test

The contractor may adjust the number of layers and passes to suit conditions. The completed weld should be subjected to visual and radiographic inspection. The acceptance standard for weld procedure qualification tests should be in accordance with the requirements of AWS D1.6

or CSA Standard W47.1. A welder that has successfully completed a weld procedure qualification test may be considered qualified to the requirements of Clause A4.0 of this Annex for the position(s) the test was completed in.

A.4 WELDER QUALIFICATION TESTS

Weld repair build-up should only be performed using qualified welders. Each welder should be tested using a combination of E5518-C3 and E309-16 SS weld metals. Tests should be conducted in the positions necessary for actual repair conditions. Completed welds should be examined by visual and radiographic inspection. The acceptance standard should be in accordance with the requirements of AWS D1.6 or CSA Standard W47.1.

A.5 REMOVAL OF PROTECTIVE COATINGS

Protective coatings should be removed exposing the steel and stainless steel substrate to a width of 150 mm across the corroded weld. The technique employed for removal of protective coatings, especially epoxy based low friction types, should not cause grooving or damage the metallurgical structure of either base metal.

A.6 PREPARATION FOR WELDING

All corrosion product, grooves and valleys should be washed to a smooth profile by the carbon arc air gouging method and finished by grinding. The finished profile should offer a transition from carbon steel to stainless steel weld metal as illustrated in Figure A3.

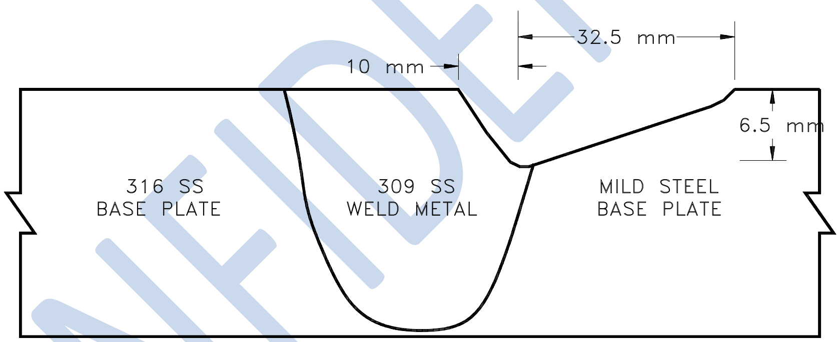


Figure A3 - Required Preparation Geometry

A.7 TECHNIQUE

The maximum size of electrode should be 4 mm. No single pass should be weaved more than 1.5 times the electrode diameter. No individual layer should exceed 5 mm in thickness. For buttering layers with E5518-C3, the bead sequence illustrated in Figure A4 should be employed in all positions of welding to reduce the risk of heat affected zone corrosion at the weld toe transition to carbon steel.

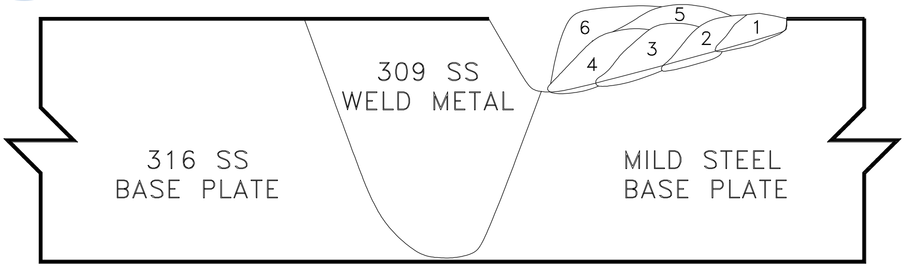


Figure A4 - Weld Sequence for Buttering Layer

Once the buttering layers of E5518-C3 are in place the joint should be prepared by grinding to a profile equivalent to that illustrated in Figure A5.

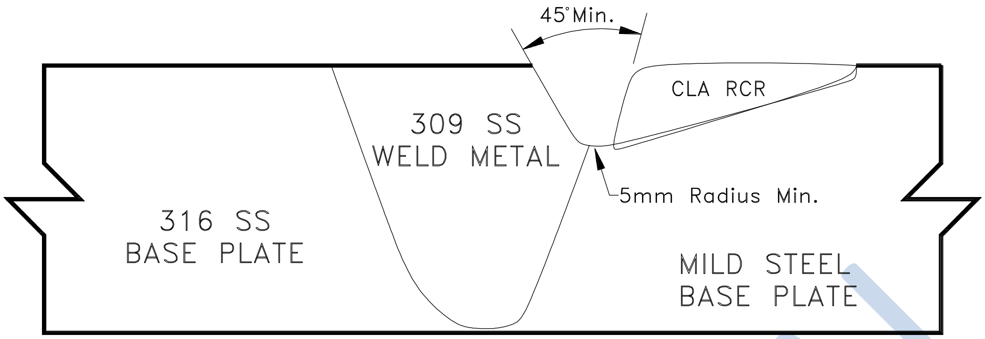


Figure A5 - Required Preparation for Stainless Steel Weld Metal

Welding should proceed using E309-16 SS electrodes following the bead sequence detailed in Figure A6.

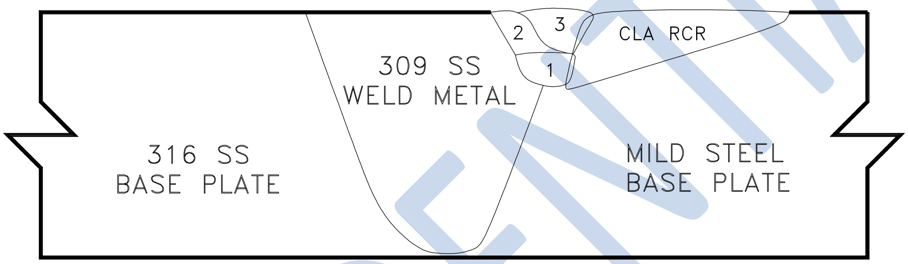


Figure A6 - Bead Sequence for Stainless Steel Weld Metal

Completed welds should be ground flush.

A.8 INSPECTION REQUIREMENTS

All welds should be visually examined along their entire length for undercut, profile and discontinuities open to the surface. Acceptance standards should be in accordance with the requirements of AWS D1.6 or CSA Standard W59. Undercut having a dimension not exceeding 1.0 mm in depth, should be carefully repaired by grinding to a profile suitable for fatigue enhancement that blends the area smoothly into the surrounding material without interruption. Undercut exceeding 1.0 mm in depth and other unacceptable conditions should be repaired by welding. After repair welding, temper bead(s) should be reapplied and the resulting profile ground flush. Any zones repaired by welding should be inspected by visual and penetrant inspection their entire length.

Annex B REPAIR OF TRIPPING DAMAGE WITHOUT PREHEAT

B.1 SCOPE

This Annex provides guidance for repairing tripping damage to stiffeners attached to the shell plating of ice-transiting ships. This Annex applies to all fillet welds connecting stiffeners to shell plating for repairs above and below the waterline without preheat when the ambient temperature is above -20°C.

B.2 LIMITATIONS OF USE

The provisions of this Annex do not apply when ambient temperatures are less than -20°C. The provisions of this Annex apply to steel shell plate thicknesses equal to or greater than 12.5 mm.

The ship's shell and replacement steel plate chemistries should be known. This Annex does not apply to ship's shell plates having a carbon equivalent greater than 0.50 (see Table B1), quench and tempered steels or steels manufactured by the thermo-mechanical controlled process (TMCP).

Table B1 - Carbon Equivalent

$$\text{Carbon Equivalent (CE)} = \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

This Annex does not apply to groove welding shell plates.

All welding and tacking should be performed using the Shielded Metal Arc Welding (SMAW) process and only those electrodes approved in Clause B4 of this Annex.

B.3 PERSONNEL REQUIREMENTS

All welders should be currently certified by the Canadian Welding Bureau to the requirements of CSA Standard W47.1 for Shielded Metal Arc Welding with F4 electrodes in all welding positions. In addition, the individual should demonstrate to the satisfaction of the Delegated Representative, they are capable of depositing acceptable single pass fillet welds in the positions of welding listed in Table B2.

Table B2 - Single Pass Fillet Size

Position	Fillet Size (mm)
horizontal	8
vertical	8
overhead	6

Welder qualification test assembly dimensions, requirements and acceptance criterion should be as described in Figure B1. Welding electrodes should be those listed in Clause B4 of this Annex or equivalent.

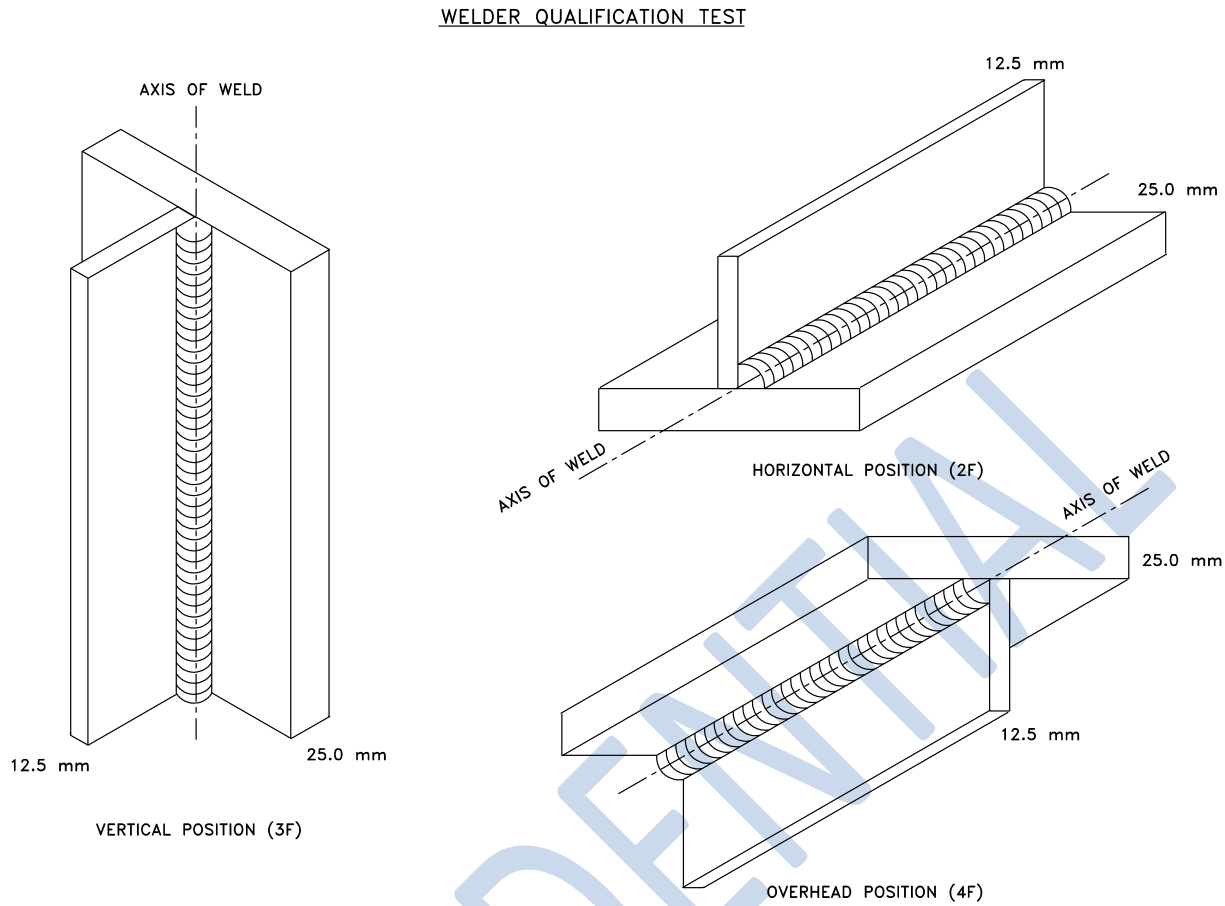


Figure B1 - Qualification Test Positions of Welding

B.4 WELDER QUALIFICATION TEST REQUIREMENTS

Test Conditions

1) All test welds should be deposited using a 4 mm diameter electrode.
2) The type of electrode should be approved (refer to Table B3).
3) The test weld length should be 500 mm.
4) Test welds produced in each position should incorporate 1 stop and restart location.
5) The minimum test weld size should be 6 mm for the 4F position and 8 mm for the 2F and 3F positions.
6) The power source output characteristics should be similar to that intended for actual repairs.

Acceptance Criterion

- Weld leg lengths should be the minimum as defined for the position with a tolerance of + 2 mm only.
- The weld profiles should meet the requirements of CSA Standard W59.
- The maximum depth of undercut permitted is 0.5 mm.
- Welds including stop and restart locations, should be free from visible porosity.
- Two macro sections should be taken in areas selected by the Delegated Representative. The macro sections should show full fusion to the root and meet the requirements of CSA Standard W59.

B.5 EQUIPMENT AND MATERIALS

This Annex does not apply to ship's shell plates having a carbon equivalent greater than 0.50 (see Table B1), quench and tempered steels or steels manufactured by the thermo-mechanical controlled process.

The carbon equivalent of replacement plates should not exceed 0.40.

The chemistry of all plates being welded must be known. A chemical analysis of replacement steel and ship's shell plates should be made available to the Delegated Representatives.

Air Heaters: Forced air heaters should be used to raise the ambient air temperature of the compartment to 10°C minimum.

Welding Electrodes: Only approved shielded metal arc welding electrodes should be used for all welding including tack welding. The minimum diameter should be 4.0 mm. Approved electrodes are specified in Table B3.

Table B3 - Approved Shielded Metal Arc Consumables

Electrode Manufacturer	Trade Name	Classified	Minimum Diameter
Metrode	Ultramild	E4318 (AWS E6018)	4.00 mm

Electrode Storage Oven: All electrodes should be stored in close proximity to the repair in electric ovens. Portable electrode holders should be used to transport electrodes from the electric oven to the repair location.

Temperature Indicator: The temperature of steels to be welded should be continuously monitored by a suitable surface temperature probe recording temperatures below -20°C and to an accuracy of ± 2°C.

Flame Heating Torch (for moisture removal): Although this Annex does not include the use of preheat before welding, a heating torch using a rosette pre-heating tip is necessary to remove all moisture, grease and other sources of hydrogen from steel surfaces. Tips designed for cutting should not be used for pre-heating.

B.6 WORKMANSHIP AND PROCEDURES

B.6.1 Removing Damaged Material

All damaged material requiring replacement should be removed by oxy-fuel cutting and grinding. Special care should be taken to not scar or damage shell plates. Air carbon arc gouging should not be used without approval of the Delegated Representative.

B.6.2 Preparing Edges for Welding

All surfaces to be welded should be cleaned thoroughly to remove any foreign matter for a distance of at least 50 mm each side of the weld toe. Paint film must be completely removed from areas to be welded. Edges that are to be welded must be ground smooth to remove all notches and surface oxides.

B.6.3 Storage and Conditioning of Electrodes

Electrodes should be supplied in the manufacturer's approved containers. If the container shows evidence of damage, all electrodes from the container should be discarded.

Electrodes should be stored in an electric oven set at a minimum temperature of 125°C. The oven should be preheated for a minimum of 30 minutes before receiving electrodes from the manufacturer's containers. Electrodes should be placed in the electric oven immediately after breaking the electrode container's seal.

When transferring electrodes from the oven to portable containers, electrodes should be handled so that the coating is not contaminated by oil, dirt, grease, moisture or any other substance.

Storing the electrodes with the bare end at the oven/holder opening will help ensure contamination from soiled gloves does not occur. The electrode end must not be handled with soiled or wet gloves. Electrodes should be removed from portable holders, one at a time, closing the lid each time.

B.6.4 Fit-up and Assembly

Parts to be welded should be brought into alignment and held in position for welding so that the maximum gap does not exceed 2 mm.

Members should be brought into alignment and held for welding using bolts, clamps, wedges, struts or other approved devices.

Stiffeners brought into alignment with force should not have alignment devices removed until all repairs are completed and the welded area has cooled to ambient conditions.

If attachments or temporary welds are made on the ship's hull, these welds must be applied in accordance with all of the requirements of this Annex. Temporary welds made on the shell plates should be ground smooth after removal and inspected by the magnetic particle methods. Any repairs should be made in accordance with all of the requirements of this Annex.

B.6.5 Minimum Fillet Weld Size

All fillet weld beads should be applied at a minimum leg size of 6 mm. For horizontal and vertical welding, a minimum single pass fillet weld size of 8.0 mm is preferred and should be stipulated in the weld procedure. Weaving and other means of arc manipulation is permitted; however, the maximum single pass fillet weld size should not exceed 10 mm.

For large multipass fillet welding, the final passes of the last layer progress from the shell plate to the stiffener following a temper bead sequence.

B.6.6 Welding Parameters

All welding parameters should be as per those used in the Welder Qualification Test (see Clause H3). These parameters should be documented on a Welding Data Sheet (WDS) and approved by the Delegated Representative. The Welding Data Sheet should be available on site for reference.

The objective during welding is to apply a defined amount of energy into the joint by depositing large fillet weld beads in order that the weld cooling rate is controlled. The amperage and electrode size must, therefore, be at a maximum while permitting the deposition of fillet weld free of notches, undercut or undesirable profiles. The minimum heat input for all welding should be 2.0 kJ/mm.

B.7 INSPECTION

B.7.1 Visual Inspection

All fillet welds should be 100% visually inspected in accordance with the methods set forth in ASME Section V.

B.7.2 Magnetic Particle Inspection

All permanent fillet welds and temporary weld locations should be completely inspected for cracks using magnetic particle inspection methods not less than 72 hours after the completion of repairs. Magnetic particle inspection procedures and techniques should be in accordance with the methods set forth in ASTM Standard E709.

B.8 ACCEPTANCE CRITERION

Personnel qualifications and acceptance criterion for visual and magnetic particle inspection methods should be in accordance with AWS D1.6 or CSA Standard W59.

B.9 CORRECTIONS AND REPAIRS

All undercut or undesirable weld profiles should be corrected using small hand-held grinders. Corrections should be strictly controlled. Areas showing linear indications such as cracks and incomplete fusion should be carefully repaired with repair welding procedures approved by the Delegated Representative.

Annex C PRINTED LIST OF HYPERLINKS

C.1 SECTION 1.0 MATERIALS

1.1	International Association of Classification Societies http://www.iacs.org.uk/ guidelines and recommended practices http://www.iacs.org.uk/publications/publications.aspx?pageid=4&sectionid=5 UR W – Requirements Concerning Materials and Welding http://www.iacs.org.uk/publications/publications.aspx?pageid=4&sectionid=3
1.1.1	Click this link to watch a video on making steel by US Steel. http://www.youtube.com/watch?v=9l7JqonyoKA
1.2.2	Alumina refining video http://www.youtube.com/watch?v=UUpdEdULxu8&list=PLadeEB9Jmj0KJ0g1WkHRY6KRg0U1HCa3b Aluminum smelting video http://www.youtube.com/watch?v=zDDbVnlDJfw&list=PLadeEB9Jmj0KJ0g1WkHRY6KRg0U1HCa3b Aluminum rolling process video http://www.youtube.com/watch?v=HfY-B6emEz8 Aluminum casting extrusion billet process video http://www.youtube.com/watch?v=aiDg4M3cWUI Aluminum extrusion process video http://www.youtube.com/watch?v=s99aSFkV2aY
1.3	Specialty Steel Industry of North America Association's website http://www.ssina.com/about/index.html
1.3.1 1.3.2	Common Applications http://www.ssina.com/overview/sheetstrip.html
1.3.6	Physical Properties http://www.ssina.com/composition/physical.html Chemical Composition http://www.ssina.com/composition/chemical.html Fabrication http://www.ssina.com/shopfabrication/stainless.html Mechanical Properties http://www.ssina.com/composition/mechanical.html Life Cycle Costing http://www.ssina.com/lifecycle/index.html High Temperature Properties http://www.ssina.com/composition/temperature.html
1.3.6	"Design Guideline for the Selection and Use of Stainless Steel". http://www.ssina.com/publications/design.html Stainless Steel Fabrication Guide http://www.ssina.com/publications/fabricat.html Practical Guidelines for the Fabrication of High Performance Austenitic Stainless Steels http://www.nickelinstitute.org/TechnicalLiterature/Other%20Series/PracticalGuidelinesForTheFabricationofHighPerformanceAusteniticStainlessSteels_16001_.aspx The Ferritic Solution http://www.worldstainless.org/publications/brochures_and_posters Practical Guidelines for the Fabrication of Duplex Stainless Steels http://www.imoa.info/molybdenum-media-centre/downloads/molybdenum-use-by-material/duplex-stainless-steel/duplex-stainless-steel.php

	Galvanic Corrosion and it's Prevention http://www.nickelinstitute.org/en/TechnicalLiterature/Other%20Series/StainlessSteelinWaters-GalvanicCorrosionanditsPrevention.aspx Specialty Steel Industry of North America Association (SSINA) http://www.ssina.com/about/index.html International Stainless Steel Forum (ISSF) http://www.worldstainless.org/ International Molybdenum Association (IMOA). http://www.imoa.info/molybdenum-media-centre/downloads/molybdenum-use-by-material/stainless-steel/stainless-steel.php "How Stainless Steel Alloy is formed" video. http://www.youtube.com/watch?v=gLNltMtBjc8 How "Stainless Steel is made" video. http://www.youtube.com/watch?v=5zwgI-pQ6kE
1.4	Introduction http://www.copper.org/applications/marine/cuni/homepage.html Ship Building And Repair http://www.copper.org/applications/marine/cuni/app_shipping.html Offshore Units http://www.copper.org/applications/marine/cuni/app_offshore.html Power Generation http://www.copper.org/applications/marine/cuni/app_power.html Desalination http://www.copper.org/applications/marine/cuni/app_desal.html System Components http://www.copper.org/applications/marine/cuni/app_syscomp.html System Design http://www.copper.org/applications/marine/cuni/txt_sea_water_system_design.html Useful Papers http://www.copper.org/publications/pub_list/marine.html
1.4	Contents http://www.copper.org/applications/marine/cuni/txt_properties.html
1.4	Contents http://www.copper.org/applications/marine/cuni/txt_references.html
1.4	Interactive Presentation http://www.copper.org/applications/marine/cuni/visual_overview/index.html Supplier Directory http://www.copper.org/applications/marine/cuni/suppliers/CuniFabricatorSearch.html Alloy Cross Reference https://www.kupferinstitut.de/en/arbeitsmittel/kupferschluessel.html What's New http://www.copper.org/applications/marine/cuni/whats_new/
1.5.1	Click to view a video on the use of PMI from Niton UK Limited. http://www.youtube.com/watch?v=pnnwoqDviRw
1.6.1	For other terms please follow this link to the IACS document. http://www.iacs.org.uk/document/public/Publications/Guidelines_and_recommendations/PDF/REC_82_pdf221.pdf
1.6.2	ABS Guidance Notes on the Inspection, Maintenance and Application of Marine Coating Systems – Third Edition 2007. http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/Rules&Guides/Current/49_InspMaint&ApplofMarineCoatingSystems/Pub49_CoatingsNov07

C.2 SECTION 2.0 WELDING

2.2	Follow this link for CWB contact information. https://www.cwbgroup.org/about/contact-us
2.3.1	Follow this link to search for CWB Certified Companies. https://www.cwbgroup.org/services/certified-directory-search/companies
2.3.2	Follow these links to search for CWB certified NDT Companies and Visual Inspectors. https://www.cwbgroup.org/services/ certified-directory-search/inspection-companies and https://www.cwbgroup.org/services/ certified-directory-search/inspectors
2.3.3	Follow this link to search for NRCan certified NDT personnel. http://www.nrcan.gc.ca/minerals-metals/non-destructive-testing/3164
2.5.1	Follow this link for a List of CSA W48 CWB approved welding consumables. https://www.cwbgroup.org/services/certified-directory-search/consumables
2.10	Follow this link to locate CWB qualified welding engineers. https://www.cwbgroup.org/services/documents-forms (select CWB Approved Professional Engineers from the Guide List)
2.16.6	Canadian Labor Code, Marine Occupational Safety and Health Regulation, Part 12-161, http://laws-lois.justice.gc.ca/eng/regulations/sor-2010-120/index.html

C.3 SECTION 4.0 WELD INSPECTION

4.3.3	Follow this link to view a CWB visual welding inspector video. http://www.youtube.com/watch?v=UVWTnHXR2AY
4.3.4	Follow this link to view Part #1 – Alignment, Measurement and Weld Measuring Gauges http://www.youtube.com/watch?v=vzYj0qsLbVY Follow this link to view Part #2 – Alignment, Measurement and Weld Measuring Gauges. http://www.youtube.com/watch?v=WT1wzeXs3Yw
4.3.5	Follow this link to view a TWI Video Introduction to Non-destructive Testing. http://www.youtube.com/watch?v=tlE3eK0g6vU
4.4.1 4.5.1 4.6.1 4.7.6	Follow this link to search for NRCan certified NDT personnel. http://www.nrcan.gc.ca/minerals-metals/non-destructive-testing/3164
4.5.5	Follow this link to view a CWBi Video on Penetrant Inspection. http://www.youtube.com/watch?v=QpU5JyhNVgQ&list=PL1133F1151BA4901B
4.5.6	Follow this link to view a CWBi Video on Magnetic Particle Inspection. http://www.youtube.com/watch?v=N1emHJD0-1E

4.6.10	Follow this link to view a CWBi Video on Radiographic Inspection. http://www.youtube.com/watch?v=VscasN8jgfo
4.7.9	Follow this link to view a CWBi Video on Ultrasonic Inspection. http://www.youtube.com/watch?v=41i0ciqqYYM

C.4 SECTION 3.0 MECHANICAL TESTING

3.0	Follow this link to view an educational video on mechanical testing from TWI. http://www.youtube.com/watch?v=0WMWUP5ZHSY
3.2	Follow this link to view a tensile test educational video. http://www.youtube.com/watch?v=D8U4G5kcpcM
3.3	Follow this link to view a charpy impact test educational video. http://www.youtube.com/watch?v=tpGhqQvftAo