Duplex Stainless Steel Welding Consumables

FCAW	GMAW/GTAW	SMAW
SFC-2209 SFC-2594	SMG-2209 SMG-2594 STG-2209 STG-2594	SS-2209 SS-2594 SS-2595

Duplex Stainless Steel

A matrix of 50:50 microstructure of austenite with ferrite. 30% ferrite is minimum and balance of austenite as basic organization.

The duplex alloy delivers high strength, ductility, resistance to chloride induced stress corrosion cracking, pitting attack in chloride environments with superior weldability.

Duplex Stainless Steel Welding Consumables

Features

1.	The duplex alloy delivers high strength, ductility, resistance to chloride induced stress corrosion cracking, pitting attack in chloride environments with superior weldability. PREN≒35
2.	Contains higher ferrite than austenite steel, high magnetic, delivers high thermal conductivity and low coefficient of linear expansion.
3.	Normally no preheat, and post heat treatment required, join carbon steel to 18-8 austenite steel dissimilar metal welding also applicable.

Features of supler duplex stainless steel

1.	PREN>40 has higher mechanical properties, resistance of pit corrosion, induced stress corrosion cracking than duplex stainless steel.

PREN(Pitt Resistance Equivalent Number):Cr% + 3.3 x (Mo% + 0.5 x W%) + 16 x N%

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Duplex Stainless Steel Welding Consumables

Applications

Flue Gas Desulfurization System

Desulfurization tower, Absorption tower, Reheater, Flue inlet baffle, Fan& Flue.

Petrochemical Industry

Polyvinyl chloride (PVC) stripper, Heat exchanger, Polyvinyl chloride (PVC) production plant, Methanol Synthesis reactor, Oxo Alcohol loop reactor, acetic acid, Organic acid production equipment, Pipelines for the chemical industry.

Paper Industry

Continuous sulfuric acid digester, batch digester, Chlorine dioxide bleach cartridge, Chlorine dioxide bleach cartridge.




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Duplex Stainless Steel Welding Consumables

Applications

Sea-delivery

Cargo hold, pipe system.

Offshore Industry

Desalination plant heat exchanger and piping system.

Food Industry

Margarine cooling pipes, Vegetable oil heat exchanger, Fermenter heating or cooling pipes, Pharmaceutical Distillation tower.




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SOREX Duplex Stainless Steel SMAW

「SS-2209、SS-2594、SS-2595」

SMAW		AWS	PREN
Duplex	SS-2209	A5.4 E2209-16	35
	Superior corrosion resistance than SS-316L.		
Super duplex	SS-2594	A5.4 E2594-16	42
	Better corrosion resistance than SS-2209 with W.		
Super duplex	SS-2595	A5.4 E2595-16	43
	Better corrosion resistance than SS-2594 with Cu& W.		

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Chemical Composition	C	Mn	Si	Cr	Ni	Mo	Cu	W	N
A5.4 E2209-16	≦0.04	0.5~2.0	≦1.0	21.5~23.5	8.5~10.5	2.5~3.5	≦0.75	--	0.08~0.2
SS-2209	0.035	0.99	0.74	23.09	8.88	2.86	0.117	0.003	0.147
A5.4 E2594-16	≦0.04	0.5~2.0	≦1.0	24~27	8.0~10.5	3.5~4.5	≦0.75	--	0.2~0.3
SS-2594	0.024	0.69	0.81	25.2	9.144	3.81	0.06	0.38	0.25
A5.4 E2595-16	≦0.04	≦2.5	≦1.2	24~27	8.0~10.5	2.5~4.5	0.4~1.5	0.4~1	0.2~0.3
SS-2595	0.027	0.73	0.89	24.98	9.07	3.90	0.64	0.75	0.252

Tension Test :	TS(MPa)	EL(%)
A5.4 E2209-16	≧690	≧20
SS-2209	808	26
A5.4 E2594-16	≧760	≧15
SS-2594	958	26
A5.4 E2595-16	≧760	≧15
SS-2595	909	28

GB/T4334-2008E Intergranular corrosion and bending test		Result
Test solution：$H_2SO_4/CuSO_4$	SS-2209	No crack discovered
Solution temperature：boiling	SS-2594	
Duration：16h	SS-2595	

ASTM G48A corrosion test		Result
Test solution：Fe_2Cl_3	SS-2594	ave. corrosion value: 1.8
Solution temperature：40℃		
Duration：24h	SS-2595	ave. corrosion value: 1.3

SS-2594：Flat position with slag

SS-2594　Flat position without slag

SS-2594 Horizontal position with slag

SS-2594 Horizontal position without slag

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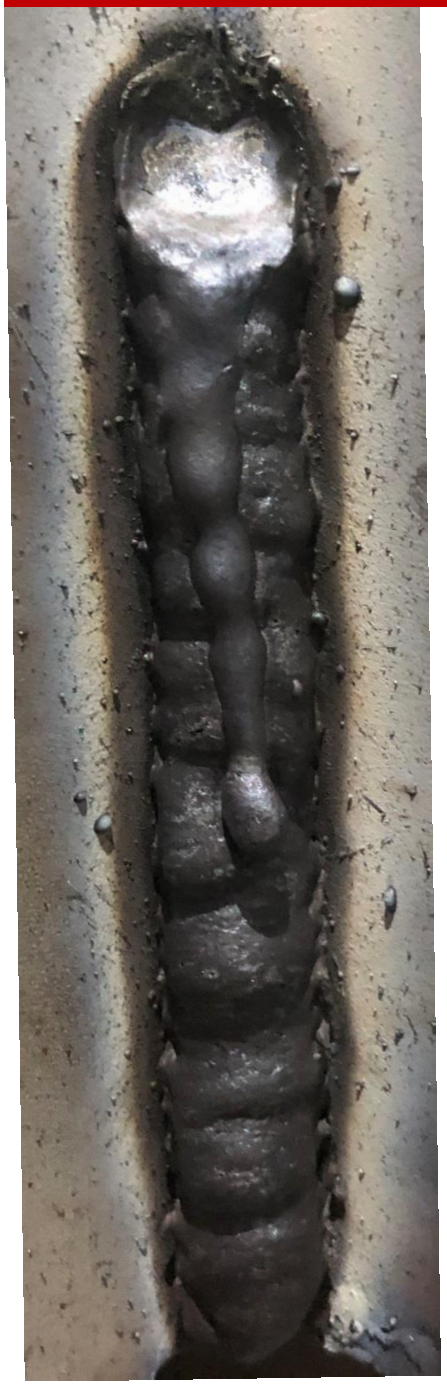
SS-2594 V-up position

With slag



With out slag

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SS-2595 Flat position with slag

SS-2595 Flat position without slag

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SS-2595 Horizontal position with slag

SS-2595 Horizontal position without slag

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SS-2595 V-up position

With slag

Without slag

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SOREX Duplex Stainless Steel SOLID WIRE

「SMG-2209、STG-2209」

「 SMG-2594、STG-2594」

SOLID WIRE		
STG-2209 SMG-2209	AWS	A5.9 ER2209
	EN	ISO 14343-A G/W 22 9 3 N L
STG-2594 SMG-2594	AWS	A5.9 ER2594
	EN	SO 14343-A G/W 25 9 4 N L

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Duplex Stainless Steel SOLID WIRE

Note on usage	
CLEAN	Clean the weld part free from brittle cracking because of oxide or sulfide contamination
TEMPERATURE	Inter pass temp. control at 100~150℃
HEAT INPUT	Keep low heat input at 5-25 KJ/cm for duplex stainless steel, and 5-15 KJ/cm for super duplex stainless steel.
Deformation	High thermal expansion coefficient than carbon steel, more shrinkage occurs on welding. Balanced welding to minimize the deformation is the best way recommended.
MANAGEMENT	To well-control the arc strike & extinction to get avoid of crater crack.
Pollution control	To prevent iron powder from working environment become contamination to the welding.

SMG-2209；STG-2209

Chemical Composition	C	Mn	Si	P	S
AWS A5.9 ER2209	≦0.03	0.50-2.00	≦0.90	≦0.03	≦0.03
SMG-2209 STG-2209	0.01	1.44	0.4	0.017	0.001

Chemical Composition	Cr	Ni	Mo	Cu	N
AWS A5.9 ER2209	21.5-23.5	7.5-9.5	2.5-3.5	≦0.75	0.08-0.20
SMG-2209 STG-2209	23.14	8.63	3.29	0.04	0.16

SMG-2209；STG-2209

Mechanical Properties	Tensile test			Impact test	
	YS	TS	EL	Temp.	Values
AWS A5.9 ER2209-XX	--	≧690MPa	≧20%	--	--
SMG-2209 (98%Ar+2%O2)	620MPa	760Mpa	31%	-40℃	95 J
STG-2209 (100%Ar)	650MPa	790Mpa	34%	-40℃	200 J

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SMG-2594；STG-2594

Chemical Composition	C	Mn	Si	P	S	Cr
AWS A5.9 ER2594	≦0.03	≦2.5	≦1.0	≦0.03	≦0.02	24.0-27.0
SMG-2594 STG-2594	0.01	0.58	0.42	0.019	0.001	25.12

Chemical Composition	Ni	Mo	Cu	N	W
AWS A5.9 ER2594	8.0-10.5	2.5-4.5	≦1.5	0.20-0.30	≦1.0
SMG-2594 STG-2594	9.26	4.02	0.08	0.24	<0.01

SMG-2594；STG-2594

Mechanical Properties	Tensile test			Impact test	
	YS	TS	EL	Temp.	Values
AWS A5.9 ER2594	--	≧760MPa	≧15%	--	--
SMG-2594 (98%Ar+2%O2)	650MPa	840Mpa	24%	-40℃	70 J
STG-2594 (100%Ar)	680MPa	860Mpa	28%	-40℃	120 J

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Recommended welding parameters for MIG

Dia.	Curent	Voltage	Shielding Gas
0.9mm	120~220A	18~25V	98%Ar+2%O2
1.2mm	160~240A	19~26V	
1.6mm	200~300A	24~30V	

Recommended welding parameters for TIG

Dia.	Curent	Voltage	Shielding Gas
1.6mm	90~120A	9~13V	100%Ar
2.0mm	100~130A	14~16V	
2.4mm	120~170	16~18V	
3.2mm	180~250	18~20V	

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SOREX Duplex Stainless Steel FCAW

「SFC-2209」

FCAW		
SFC-2209	AWS	A5.22 E2209T1-1
	JIS	Z3323 TS2209-FC1
	EN	ISO 17633-A T 22 9 3 N L P C/M 2
	GB	T17853 E2209T1-1

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Duplex Stainless steel

Low alloying duplex stainless steel without Mo	
Features	PREN is low, not recommended for chloride environments
Typical Steel	SAF2304
Composition	23%Cr、4%Ni、0.1%N
Recommended consumables	--

Standard Duplex Stainless Steel	
Features	PREN higher than SAF2304, pitting corrosion resistance also improved
Typical Steel	SAF2205
Composition	22%Cr、5%Ni、3%Mo、0.17%N
Recommended consumables	SFC-2209

Super Duplex Stainless Steel	
Features	PREN 40 provides corrosion cracking, pitting attack in chloride environments
Typical Steel	SAF2507
Composition	25%Cr、7%Ni、4%Mo、0.2~0.3%N
Recommended consumables	SFC-2594

Principle of Alloying

Cr	①Ferrite Forming element.
	②Content of Cr higher than 10.5% will enhance Oxide film formation and increase the corrosion resistance and high temperature oxidation resistance.
	③The excessive Cr content will enhance the intermetallic phase.
Ni	①Austenite Forming element.
	②Improve the toughness of steel.
	③Slow down the formation of harmful Intermetallic phase but not as strong as nitrogen.
Mo	①Ferrite Forming element
	②Enhance the corrosion resistance for pitting & crevice.
	③Tend to form harmful Intermetallic phase.
N	①Austenite Forming element is solid solution strengthening ability.
	②Enhance the corrosion resistance for pitting & crevice.
	③Slow down the formation of harmful Intermetallic phase
	④Increase the austenite content can slow down the formation of harmful intermetallic phase and improve the ductility.

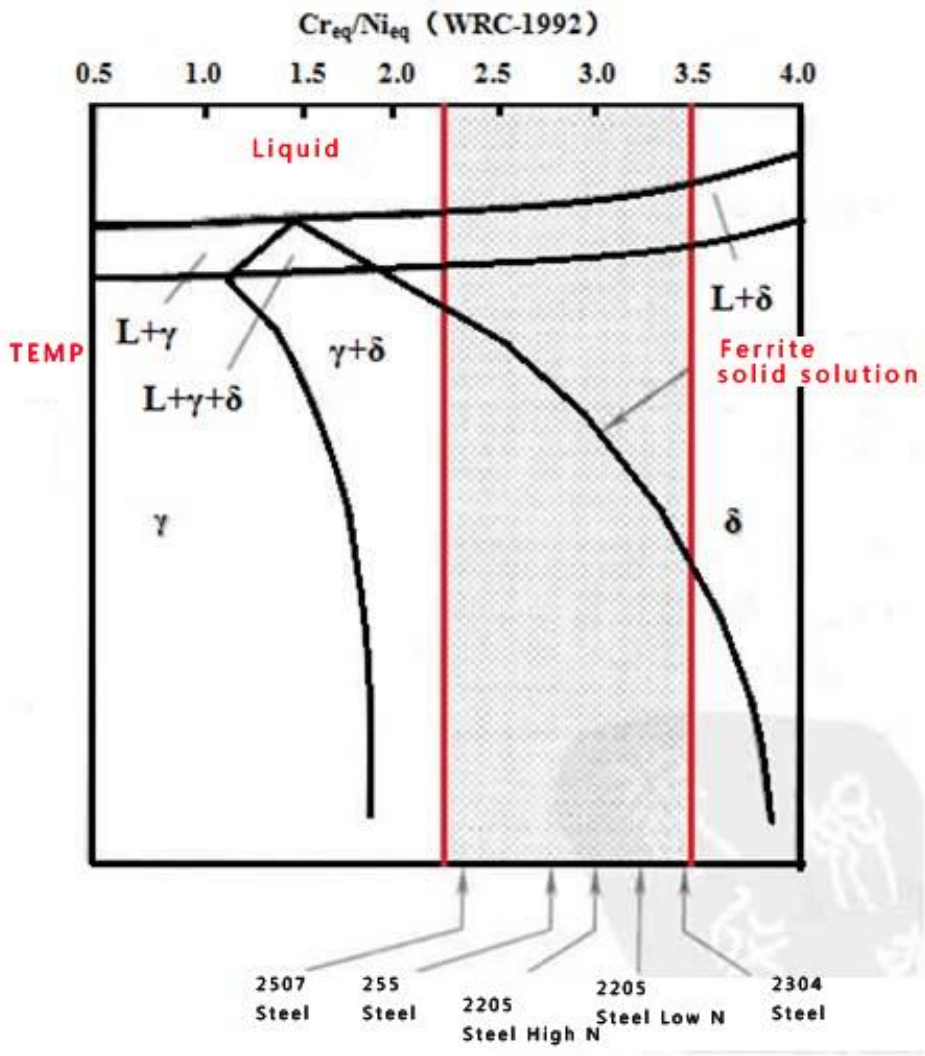
Phase Diagrams

Phase transition sequence L →L+F →F →F+A

①F Solidification mode deliver strong crack resistance

②Typical duplex stainless steel Creq/Nieq generally is 2.25~3.5;

③Solid state phase change F →A



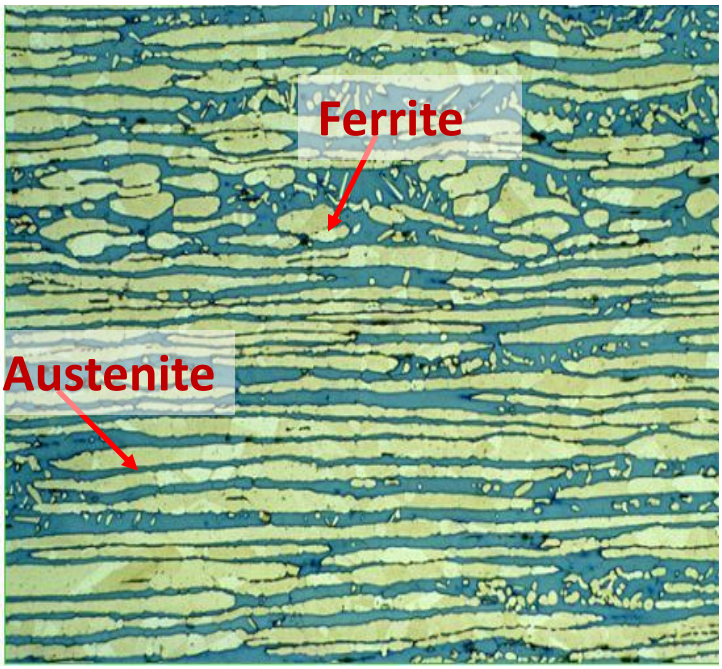
Pseudo-binary phase diagram of duplex composition in high temp. and shadow is representing commercial steel.

Organization and phase balance

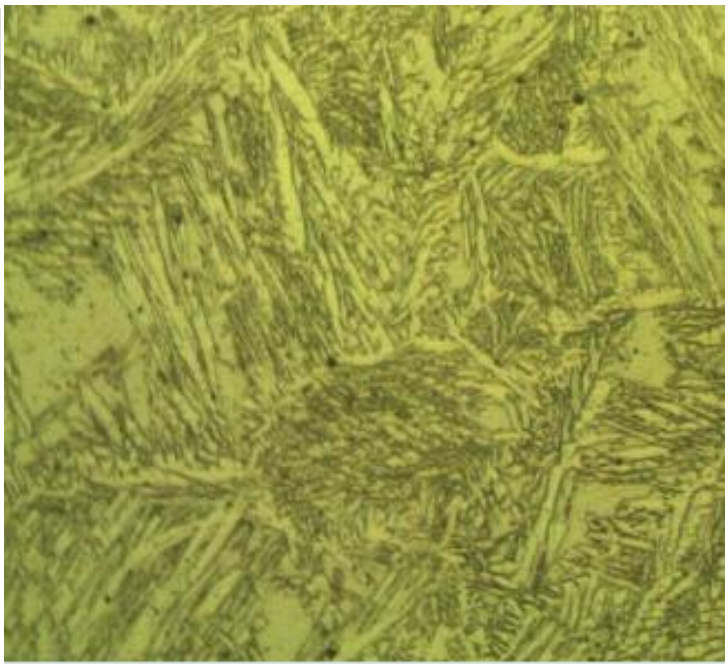
Metallographic

F+A duplex structure

Base metal



Weld bead



Organization and phase balance

Ferrite content Influence on the properties of weld metal

>70%	<25%
Increase HIC	Increase Stress corrosion
Reduce ductility	Reduce strength
Increase Pit corrosion	

Proper ferrite content and its advantages

Here below are the advantages of superior corrosion resistance and mechanical properties which weld bead contains 35~65% ferrite out of the mega data.

1	Can Effectively prevent C, N compound of Cr & austenitic steel secondary precipitation.
2	Can Effectively prevent σ phase precipitation, good for corrosion resistance.
3	Ferrite steel will turn into austenite steel mostly while cooling down, the grain size will refine and two-phase structure to improve the crack resistance and ductility.
4	Austenitic steel dominates, Cr, Ni, Mo appropriate distribution ratio in the two phases.

Properties

1.Mechanical properties

SAF2205 is most popular of duplex steel, here below is the comparison list versus 304L, 316L.

Grade	YS MPa	TS MPa	EL%
2205	510	750	35
304L	280	580	55
316L	280	570	55

High strength is the advantage, especially the yield strength can reduce the work piece size and weight. (environment care)

2.Corrosion resistance

Compared to austenitic stainless steel, duplex stainless steel has：

1	Equivalent or higher corrosion resistance.
2	Superior corrosion resistance for pitting & crevice.
3	Superior induced stress corrosion cracking .
4	Superior grain boundary corrosion resistance.
5	Decreased corrosion resistance under environment contains hydrogen.

Properties

3.Mechanical properties

Duplex stainless steel is more easy to get welding deformation at thinner plate than austenite stainless steel .

Material	Thermal conductivity W/m*℃	Thermal expansion coefficient X10^{-6}/℃
Low carbon steel	47	12
Cr-Ni stainless steel	15	16
Duplex stainless steel	15	13

Properties

（4）Welding performance.

1. Duplex stainless steel has welding performance advantages in comparison to austenite stainless steel and ferrite stainless steel.

A.	Low sensitivity to thermal cracking versus austenite stainless steel.
B.	Increased ductility and low cold cracking tendency versus ferrite stainless steel.

2. Factors of affecting Ferrite content:

Factors	
Weld bead composition	Weld joint cooling rate
1. Consumable composition.	1. Heat input . (welding methods & parameters)
2. Base metal dilution rate. **(welding methods and parameters)**	2.Base metal thickness & joint type.
	3.Temp. of Interpass & layer .

Properties

5.Influence of heating on organization and performance

Precipitation of carbides and nitrides will have negative influence upon mechanical properties and corrosion resistance at the temp. mentioned below.

1	a′ precipitation at 475℃
2	Precipitation of carbides and nitrides at 550-900 ℃
3	χ precipitation at 600-1000 ℃

Thus, duplex stainless steel features ：

1	Not exceeding 300 ℃ working temp. is recommended.
2	Prevent heat treatment, but take solid solution if necessary.

SFC-2209（Φ1.2）

1. All positional welding beads (dual gas)

100%CO_2 FA 220A/32V

80%Ar+20%CO_2 FA 220A/30V

SFC-2209（Φ1.2）

1. All positional welding beads (dual gas)

100%CO_2 VU 140-150A/25V	80%Ar+20%CO_2 VU 140-150A/24V
	

SFC-2209（Φ1.2）

1. All positional welding beads (dual gas)

100%CO2　OH　160-170A/27V

80%Ar+20%CO2 OH 160-170A/26V

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SFC-2209（Φ1.2）

1. All positional welding beads (dual gas)

100%CO2 F 220A/32V(With slag)

100%CO2 F 220A/32V(220A/32V (Without slag)

SFC-2209（Φ1.2）

1. All positional welding beads (dual gas)

80%Ar+20%CO^2 F 220A/30V(With slag)

80%Ar+20%CO^2 F 220A/30V(Without slag)

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2. Deposit metal composition & ferrite content (dual gas)

Chemical Composition	C	Mn	Si	P	S
GB/T STD	0.04	0.5-2.0	1.0	0.04	0.03
AWS STD	0.04	0.5-2.0	1.0	0.04	0.03
100%CO_2	0.037	1.04	0.53	0.026	0.005
80%Ar+ 20%CO_2	0.032	1.12	0.58	0.024	0.003

Chemical Composition	Ni	Cr	Mo	N	PREn
GB/T STD	7.5-10.0	21.0-24.0	2.5-4.0	0.08-0.20	-
AWS STD	7.5-10.0	21.0-24.0	2.5-4.0	0.08-0.20	-
100%CO_2	8.72	22.674	3.38	0.118	35.7
80%Ar+ 20%CO_2	8.65	22.45	3.41	0.12	35.6

Remark: PITTING INDEX(PRE_N)= Cr + 3.3Mo + 16N（The element symbol in the formula represents the quality score of the element in the deposited metal)

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Ferrite content

Shielding Gas	Schaeffler(%F)	WRC-1992(FN)	Measured (FN)	Measured (%F)
100%CO_2	49.4	57.6	44.4	35.4
80%Ar+ 20%CO_2	56.2	66.7	54.8	42.9

3. Deposit metal mechanical properties (Dual gas)

TEST STD	YS (Mpa)	TS (MPa)	EL %	IV(J/℃)	X-ray
GB/T STD	-	690	20	-	Ⅱ
AWS STD	-	690	20	-	-
100%CO_2	645	781	28.0	43/-40	Ⅰ
80%Ar+20%CO_2	645	796	24.5	40/-40	Ⅰ

4. Deposit metal corrosion test (dual gas)

Shielding gas	(1) PITTING CORROSION TEST		
	Test method	Solution temperature	Test result
100%CO_2	ASTM G48 A法	25℃	3.86g/m^2*h
80%Ar+20%CO_2			3.94g/m^2*h
100%CO_2	ASTM G48 C法	21℃	No pitting corrosion discovered
		25℃	Pitting corrosion discovered

①Cosco shipping heavy Ind. Co., ltd. Requested ASTM G48A at 25℃*24hr corrosion rate ＜4g/m2.
②DW-2209 corrosion rate test at 25℃*24hr no pitting corrosion discovered; We test by G48 C STD * 72hr.

4. Deposit metal corrosion test (dual gas)

Shielding gas	（2）Intergranular corrosion test	
	Test Method	Test Result
100%CO_2	GB/T 4334 E STD	Qualified, No crack discovered
80%Ar+ 20%CO_2		Qualified, No crack discovered
100%CO_2	ISO 3651-2 B STD	Qualified, No crack discovered
80%Ar+ 20%CO_2		Qualified, No crack discovered

①GB/T 4334.E STD for stainless steel Sulfuric acid-copper sulfate intergranular corrosion test, specimen bend 180° no surface crack discovered observed by 10 times magnifying glass.

②ISO 3651-2 B STD for intergranular corrosion test corrosion test by using sulfuric acid 35% concentration.

SFC-2209 Welding Procedure Qualification

We proceed the testing on SFC-2209 as following in accordance with the Welding Procedure Qualification provided by customer as per their technical requirements.

Chemical composition	Ferrite content	Pitting resistance equivalent number	Charpy at center line of weld bead, fusion line and fusion line +2mm
Mo:3.0~4.0	Measured FN ≥35	PREN ≥34	-20℃ ≥40J

*shielding gas: 100% CO2

Deposited metal composition					
Chemical Composition	C	Mn	Si	P	S
AWS STD	0.04	0.5-2.0	1.0	0.04	0.03
Chemical Composition	Ni	Cr	Mo	N	PREn
AWS STD	7.5-10.0	21.0-24.0	2.5-4.0	0.08-0.20	-
Required	-	-	3.0-4.0	-	34
Result	8.7	22.8	3.45	0.126	34.4

SFC-2209 Welding Procedure Qualification

Ferrite content in butt-joint

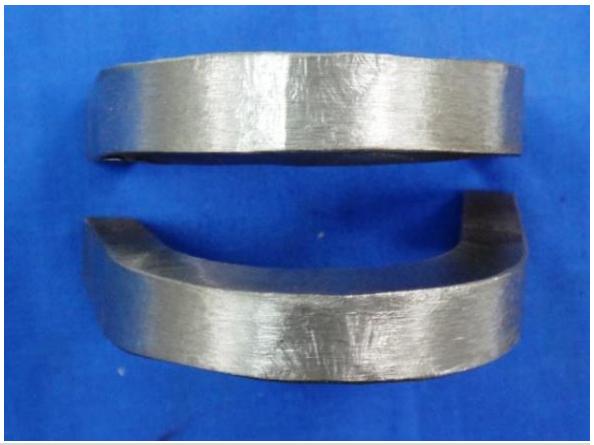
Test	Weld bead	HAZ
Measured FN	38.9	67.2

③ Mechanical properties Butt-joint

Customer requirement						
Horizontal Tensile		Impact		Hardness		Side Bend 4T 180°
T S /MPa	Crack point	CVN at -20℃/J	Sampling point	Hardness /HB	Sampling point	
-	-	≥40	-	-	-	No crack
Test Result						
778	Base metal	41	Weld bead center	220	Weld bead	OK
773	Base metal	59	Fusion line	229	HAZ	
-	-	89	Fusion line +2mm	228	Base metal	

SFC-2209 Welding Procedure Qualification

Horizontal tensile sampling X2



Horirontal side bend X4

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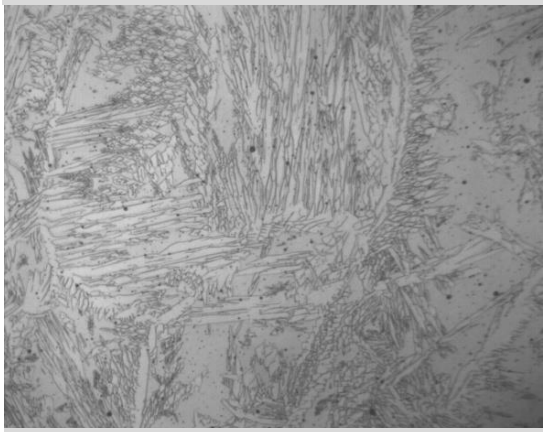
④ Microstructure at Butt-joint (weld bead & HAZ)

Bead metal X200

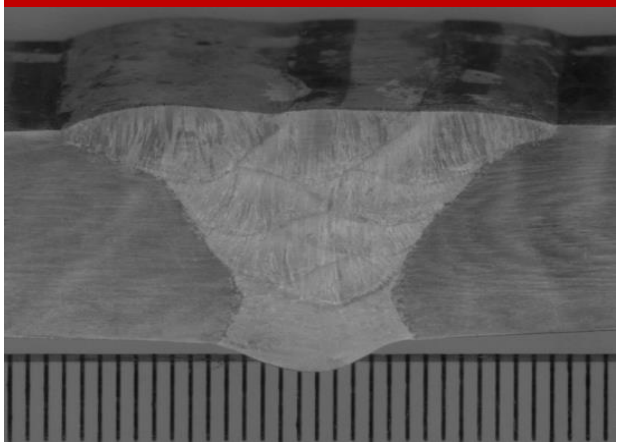
HAZ X200



Bead metal X500

HAZ X500

⑤ BUTT-JOINT SECTIONAL MARCO PHOTO



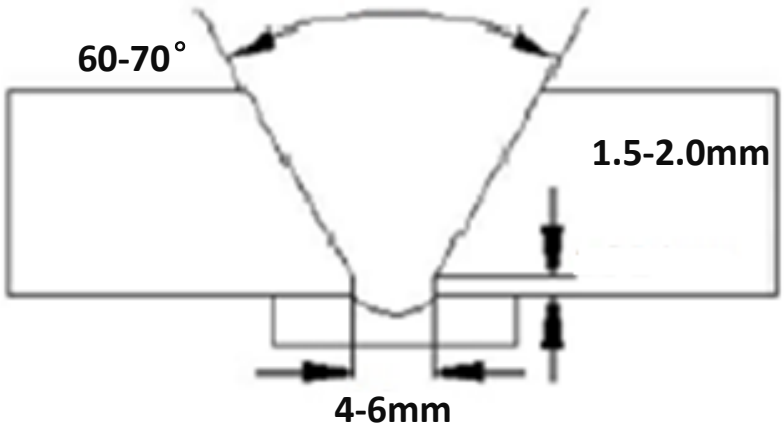
No welding defect discovered .
(slag inclusion, lack of fusion**)**

Welding dual phase stainless steel chemical boat

1. Welding procedure and technics

Preheating	Generally no preheating required, only if the environment is wet, can preheat the groove to remove the moisture ≤40 ℃ by thermo instead of flame
layer temp	Layer temp to be controlled under 150 ℃ (better under 100 ℃)
control, PWHT	Not proceed PWHT
	Thermal straightening is not recommend, No flame heating to prevent the C

Thickness	Joint type	Welding position	Welding method	Welding consumables
8-15mm	V	PA,PF	FCAW	SFC-2209
Remark	**PA: Flat position ;PF: Vertical-up position**			



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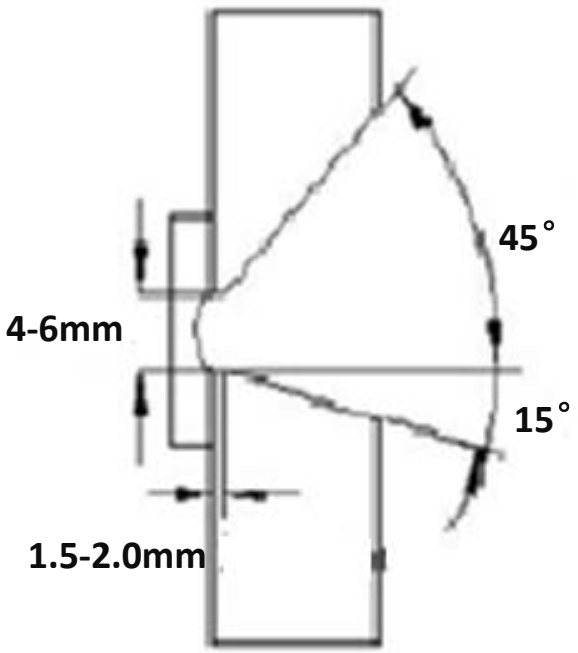
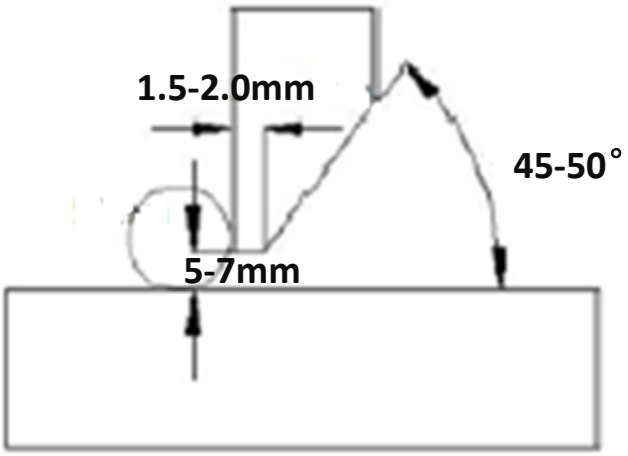
Welding dual phase stainless steel chemical boat

Thickness	8-15mm
Joint type	V
Welding position	PC
Welding method	FCAW
Welding consumables	SFC-2209
Remark	PC:Horizontal position



Thickness	Joint type	Welding position	Welding method	Welding consumables
8-15mm	Half K	PB,PD,PF	FCAW	SFC-2209
Remark	PB: Horizontal position; PD: Overhead position; PF: Vertical-up position			



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Welding procedure

1	Follow procedure to reduce stress & deformation.
2	Not to arc strike & extinction at the bead cross position.

Welding technics

1	Torch to target at stainless steel base metal side to reduce the dilution of carbon steel on dissimilar welding.
2	Root pass is recommended to use ceramic tape for single phase welding for complete fusion with defect.
3	To conduct high efficiency welding.
4	To complete bead appearance with minimum post weld cleaning
5	To grind the last arc extinction point before welding if the weld toe shape is over convex.
6	To Use tooling clamp and weighting for assembly positioning, suitable welding method and welding procedure is recommended to prevent deformation.
7	Cold working method is recommended to correct deformation.

Notes on welding

1	Suitable groove angle and gap design. ：To prevent narrow gap or small groove angle and incomplete fusion or slag inclusion, because of dual phase stainless steel liquid metal has less liquidity and light penetration.
2	To avoid hot crack due to poor butt-joint.
3	To avoid blow hole due to moisture absorption or poor protection.
4	To avoid the corrosion resistance drop, proceed welding repair upon welding scar, scratch and improper grinding.

Welding Inspection & Welding repair

1	Welding parameters control (Current, Voltage, Travel Speed, Gas flow Rate, Inter-pass temp.)
2	Deposit metal Ferrite content (Magnetic, Graphic, metallographic method)
3	NDT (Visual inspection, coloring, ultrasound, radiation)
4	Defect repair ①To remove the defect by plasma arc or polishing.
	②To prevent spatter, protect the around area to be repaired.
	③To adopt the suitable way for repair.
	④To inspect repair is completed.
	⑤Can repeat defect repair if the base metal function remain still.

SOREX
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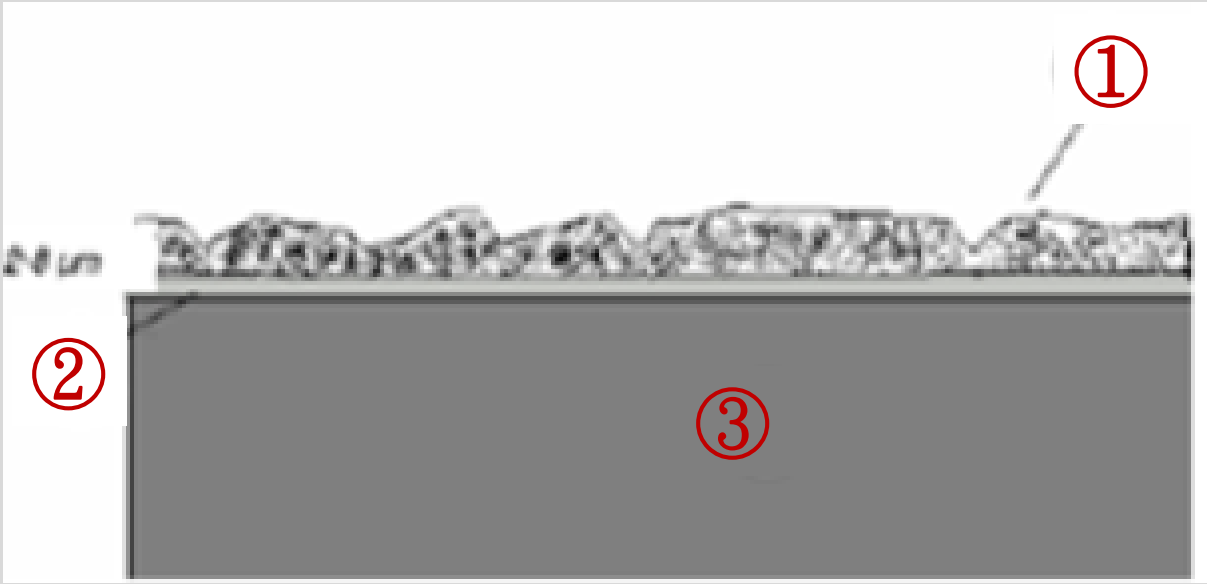
Surface cleaning post welding.

HAZ Surface



From outside layer to inside：

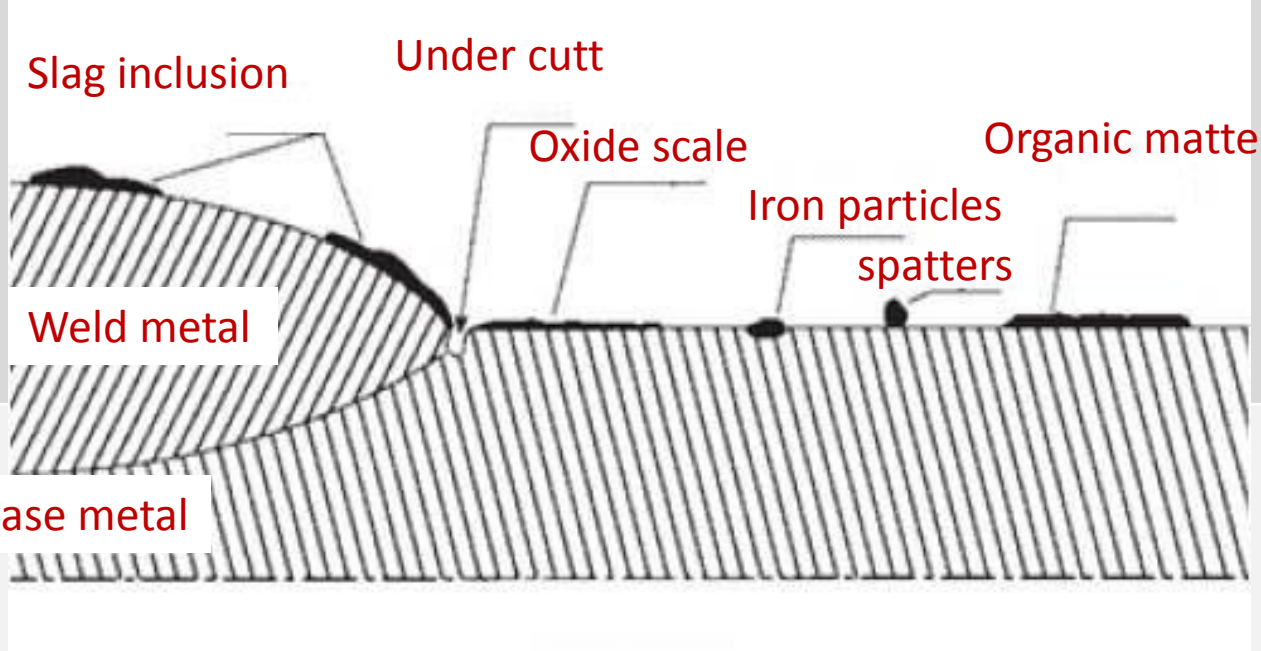
①Oxide scale 50-60%Cr.

②Cr-poor layer <10%Cr.

③ Base metal＞18％Cr Remove Oxide and Cr-poor layer after welding.

Surface cleaning post welding.

Butt-Joint defects on surface.



Surface treatment

① **Stainless steel brush.**

② **Grinding, Polishing.**

③ **Pickling/ Passivation.**

Pickling/ Passivation has the best effect above.