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KOBELCO WELDING TODAY

2016 Special Edition

KOBELCO WELDING CONSUMABLES FOR

HEAT-RESISTANT LOW-ALLOY STEEL

KOBELCO

A Quick Guide to Suitable Welding Consumables

For Oil Refinery Reactor

SMAW

Grade (Type of steel)	DCEP		AC	
	AWS Class.	Product name	AWS Class.	Product name
Gr.11 (1.25Cr-0.5Mo)	E8016-B2	**CM-A96** **CM-A96MBD**	E8016-B2	**CM-A96MB**
Gr.22 (2.25Cr-0.1Mo)	E9015-B3	**CM-A105D**	–	–
	E9016-B3	**CM-A106ND**	E9016-B3	**CM-A106N**
Gr.22V (2.25Cr-1Mo-V)	E9016-G	**CM-A106HD**	E9016-G	**CM-A106H**
Gr.5 (5Cr)	E8016-B6	**CM-5**	E8016-B6	**CM-5**
Gr.9 (9Cr)	E8016-B8	**CM-9**	E8016-B8	**CM-9**

SAW

Grade (Type of steel)	DCEP		AC	
	AWS Class.	Product name	AWS Class.	Product name
Gr.11 (1.25Cr-0.5Mo)	F8P2-EG-B2	**PF-200D /US-511ND**	F8P2-EG-B2	**PF-200 /US-511N**
	F8P2-EB2R-B2R	**PF-200D /US-B2R**	–	–
Gr.22 (2.25Cr-0.1Mo)	F9P2-EG-B3	**PF-200D /US-521S**	F9P2-EG-B3	**PF-200 /US-521S**
Gr.22V (2.25Cr-1Mo-V)	F9P2-EG-G	**PF-500D /US-521HD**	F9P2-EG-G	**PF-500 /US-521H**
Gr.5 (5Cr)	–	–	F7P2-EG-B6	**PF-200S /US-502**

GMAW and GTAW

Grade (Type of steel)	AWS Class.	Product name	
		GMAW	GTAW
Gr.11 (1.25Cr-0.5Mo)	ER80S-G	**MG-S1CM**	**TG-S1CM**
Gr.22 (2.25Cr-0.1Mo)	ER90S-G	**MG-S2CM** **MG-S2CMS**	**TG-S2CM**
Gr.22V (2.25Cr-1Mo-V)	ER90S-G	–	**TG-S2CMH**
Gr.5 (5Cr)	ER80S-B6	**MG-S5CM**	**TG-S5CM**
Gr.9 (9Cr)	ER80S-B8	**MG-S9CM**	**TG-S9CM**

For EO Reactor

SMAW

Type of steel	DCEP		AC	
	AWS Class.	Product name	AWS Class.	Product name
Mn-Mo Mn-Mo-Ni	E7016	**BL-76**	E7016	**BL-76**
	E9016-G	**BL-96**	E9016-G	**BL-96**
	E10016-G	**BL-106**	E10016-G	**BL-106**

SAW

Type of steel	DCEP		AC	
	AWS Class.	Product name	AWS Class.	Product name
Mn-Mo Mn-Mo-Ni	F9P4-EG-G	**PF-200 /US-56B**	F9P4-EG-G	**MF-27/US-56B** **PF-200/US-56B**
	F9P8-EF3-F3	**PF-200 /US-F3**	F10P2-EG-G	**PF-200/US-63S**

GMAW and GTAW

Type of steel	AWS Class.	Product name	
		GMAW	GTAW
Mn-Mo Mn-Mo-Ni	ER80S-G	**MG-S56**	**TG-S56**
	ER90S-G	**MG-S63S**	**TG-S63S**

For Oil Refinery Reactor

Process / Polarity	AWS Class.	Product name	Chemical compositions of wires or all weld metal (mass%)																				Mechanical properties of all weld metal (YS=0.2%proof stress)						
			Wire/ W.M.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V		Nb	Al	Ti	Sb	Sn	As	X-bar	J-Factor	AC/DC	YS (MPa)	TS (MPa)	EL (%)	IV (℃)	IV (J)	PWHT (℃×hr)
SMAW / DCEP	E8016-B2	CM-A96	W.M.	0.06	0.29	0.54	0.006	0.001			1.26	0.51											DCEP	484	579	30	−20	84	698×1
	E8016-B2	CM-A96MBD		0.06	0.49	0.79	0.006	0.004	0.02	0.02	1.30	0.56						0.002	0.002	0.002	8	102.4		515	617	27	−20	174	690×1
	E9015-B3	CM-A105D		0.10	0.30	0.74	0.004	0.002	0.03	0.14	2.42	1.03						<0.002	0.002	0.002	<6.0	62		504	644	28	−40	100	690×8
	E9016-B3	CM-A106ND		0.11	0.42	0.84	0.004	0.002	0.031	0.14	2.42	1.03						0.002	0.002	0.002	6	75.6		501	635	26	−40	151	690×8
	E9016-G	CM-A106HD		0.08	0.24	1.12	0.005	0.002			2.48	1.05	0.27		0.012									520	636	24	−18	137	705×26
SMAW / DCEP or AC	E8016-B6	CM-5		0.08	0.36	0.52	0.008	0.002			5.39	0.58											AC	400	560	33	0	150	750×8
	E8016-B8	CM-9		0.08	0.40	0.68	0.007	0.004			9.56	1.03											AC	510	680	26	0	110	740×10
SMAW / AC	E8016-B2	CM-A96MB		0.06	0.45	0.74	0.007	0.003			1.30	0.54											AC	490	590	30	−18	200	690×1
	E9016-B3	CM-A106N		0.11	0.27	0.79	0.008	0.006		0.19	2.42	1.03						0.002	0.003	0.002	10	117		510	650	28	−29	120	690×8
	E9016-G	CM-A106H		0.08	0.31	1.18	0.004	0.001			2.42	1.01	0.29		0.017									612	713	23	−18	147	705×7
SAW / DCEP	F8P2-EG-B2	PF-200D/US-511ND	Wire	0.13	0.09	0.92	0.005	0.003	0.10	0.17	1.49	0.56											DCEP	477	589	27	−29	116	690×4
			W.M.	0.08	0.21	0.82	0.007	0.003	0.09	0.15	1.39	0.56						0.002	0.002	0.002	9	93		522	630	25	−30	150	640×5
	F8P2-EB2R-B2R	PF-200D/US-B2R	Wire	0.14	0.10	0.86	0.004	0.004	0.12	0.15	1.47	0.56	0.004			0.15	0.002	0.001	0.001	0.003									
			W.M.	0.10	0.21	0.86	0.007	0.002	0.10	0.15	1.44	0.55	0.004			0.03	<0.002	<0.001	<0.001	0.003	<8.2	<85.6		497	610	27	0	181	698×1
	F9P2-EG-B3	PF-200D/US-521S	Wire	0.17	0.14	0.96	0.004	0.002	0.13	0.14	2.44	1.07												507	621	26	−29	164	690×6
			W.M.	0.09	0.16	0.81	0.006	0.003	0.13	0.13	2.41	1.07						0.002	0.002	0.002	8	78							
	F9P2-EG-G	PF-500D/US-521HD	Wire	0.16	0.21	1.30	0.003	0.001	0.11		2.54	1.03	0.38		0.022									518	634	26	−30	106	*1
			W.M.	0.07	0.17	1.26	0.007	0.001	0.10		2.44	1.03	0.34		0.011									603	708	24	−18	125	705×8
SAW / AC	F8P2-EG-B2	PF-200/US-511N	Wire	0.13	0.09	0.92	0.005	0.003	0.10	0.17	1.49	0.56											AC	477	589	27	−29	116	690×4
			W.M.	0.08	0.21	0.82	0.007	0.003	0.09	0.15	1.39	0.56																	
	F9P2-EG-B3	PF-200/US-521S	Wire	0.16	0.14	1.00	0.005	0.002	0.12	0.14	2.45	1.05												470	610	27	−29	150	690×8
			W.M.	0.12	0.10	0.82	0.008	0.001	0.12	0.13	2.34	1.04																	
	F9P2-EG-G	PF-500/US-521H	Wire	0.13	0.20	1.27	0.004	0.002	0.12		2.55	0.98	0.39		0.02									616	706	24	−18	106	705×7
			W.M.	0.08	0.14	1.09	0.004	0.004			2.50	1.03	0.33		0.014									620	710	26	−18	150	705×7
	F7P2-EG-B6	PF-200S/US-502	Wire	0.07	0.18	0.50	0.008	0.002	0.12		5.50	0.55	−		−									460	590	32	−29	133	720×1
			W.M.	0.06	0.21	0.78	0.012	0.002	0.12		5.25	0.55	−		−														
GMAW	ER80S-G	MG-S1CM	Wire	0.09	0.55	1.15	0.007	0.009	0.18	−	1.45	0.55											DCEP	570	680	22	0	69	620×1
	ER90S-G	MG-S2CM		0.08	0.56	1.07	0.005	0.009	0.17	−	2.35	1.11												550	670	26	0	110	680×1
	ER90S-G	MG-S2CMS		0.12	0.39	0.85	0.004	0.003	0.14	−	2.27	0.97												600	720	21	−20	120	670×1
	ER80S-B6	MG-S5CM		0.08	0.40	0.53	0.011	0.010	0.18	0.08	5.52	0.55												480	640	26	0	78	700×2
	ER80S-B8	MG-S9CM		0.07	0.40	0.52	0.007	0.008	0.01	0.02	8.99	1.00												480	640	24	0	130	720×2
GTAW	ER80S-G	TG-S1CM		0.06	0.50	0.99	0.007	0.005	0.11	0.02	1.22	0.54											DCEN	540	630	28	0	270	690×1
	ER90S-G	TG-S2CM		0.10	0.26	0.70	0.009	0.008			2.31	1.04						0.004	0.003	0.003	12	115		610	720	28	0	250	690×1
	ER90S-G	TG-S2CMH		0.12	0.16	0.43	0.005	0.008	0.11	0.01	2.31	1.06	0.28		0.037									623	730	22	−18	300	705×7
	ER80S-B6	TG-S5CM		0.09	0.41	0.49	0.006	0.009	0.12	0.04	5.44	0.55												480	600	26	0	280	750×2
	ER80S-B8	TG-S9CM		0.07	0.39	0.52	0.006	0.009	0.01	0.18	8.98	1.00												410	590	32	0	220	750×2

*1 705℃×8h for impact test, 705℃×26h for tensile test

For EO Reactor

Process / Polarity	AWS Class.	Product name	Chemical compositions of wires or all weld metal (mass%)																				Mechanical properties of all weld metal (YS=0.2%proof stress)						
			Wire/ W.M.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V		Nb	Al	Ti	Sb	Sn	As	X-bar	J-Factor	AC/DC	YS (MPa)	TS (MPa)	EL (%)	IV (℃)	IV (J)	PWHT (℃×hr)
SMAW / DCEP or AC	E7016	BL-76	W.M.	0.08	0.63	0.98	0.011	0.005				0.14											AC	440	530	33	0	230	620×10
	E9016-G	BL-96		0.06	0.54	1.30	0.005	0.004		0.37		0.53											AC	540	620	26	−12	31	635×26
	E10016-G	BL-106		0.10	0.53	1.41	0.009	0.005		0.76		0.50											AC	570	670	28	0	120	635×26
SAW / DCEP	F9P8-EF3-F3	PF-200/US-F3	Wire	0.11	0.17	1.65	0.004	0.003	0.09	0.89		0.49											DCEP	568	651	30	−62	78	620×1
			W.M.	0.07	0.23	1.47	0.007	0.002	0.06	0.80		0.49																	
SAW / DCEP or AC	F9P4-EG-G	PF-200/US-56B	Wire	0.10	0.14	1.62	0.007	0.003	0.08	0.84		0.47											AC	490	580	30	−40	182	620×11
			W.M.	0.08	0.11	1.33	0.007	0.003	0.08	0.83		0.43																	
SAW / AC	F9P4-EG-G	MF-27/US-56B	Wire	0.10	0.14	1.62	0.005	0.003	0.08	0.84		0.47											AC	480	560	32	−40	85	635×26
			W.M.	0.08	0.28	1.05	0.009	0.002	0.08	0.87		0.45																	
	F10P2-EG-G	PF-200/US-63S	Wire	0.11	0.14	1.70	0.006	0.004	0.08	1.47	0.16	0.47												620	700	28	−20	170	590×3
			W.M.	0.08	0.10	1.51	0.007	0.004		1.31	0.14	0.47																	
GMAW	ER80S-G	MG-S56	Wire	0.08	0.41	1.50	0.006	0.007	0.17	0.89	−	0.34											DCEP	500	590	29	−40	69	620×40
	ER90S-G	MG-S63S		0.08	0.48	1.76	0.007	0.002	0.12	1.02		0.46												570	650	27	−12	150	630×27
GTAW	ER80S-G	TG-S56		0.10	0.41	1.59	0.007	0.007	0.11	0.66	−	0.50											DCEN	520	590	31	−12	290	620×1
	ER90S-G	TG-S63S		0.10	0.39	1.23	0.008	0.005	0.10	1.58	−	0.39												566	655	27	−12	256	625×15

W.M. = weld metal

X-bar = (10P + 5Sb + 4Sn + As)/100 (ppm), J-Factor = $(Si + Mn) \times (P + Sn) \times 10^4$ (%)

A Quick Guide to Suitable Welding Consumables

For Boiler

SMAW

Grade (Type of steel)	DCEP		AC	
	AWS Class.	Product name	AWS Class.	Product name
P1/T1 (0.5Mo)	E7016-A1	**CM-A76 CM-B76**	E7016-A1	**CM-A76 CM-B76**
P2/T2	E8016-B1	**CM-B86**	–	–
P11/T11 (1.25Cr-0.5Mo)	E7015-B2L	**CM-B95**	–	–
	E8016-B2	**CM-A96 CM-A96MBD**	E8016-B2	**CM-A96 CM-A96MB**
	E8018-B2	**CM-B98**	E8018-B2	**CM-B98**
P22/T22 (2.25Cr-Mo)	E8015-B3L	**CM-B105**	–	–
	E9015-B3	**CM-A105D CM-B105D**	–	–
	E9016-B3	**CM-A106ND**	E9016-B3	**CM-A106N**
	E9018-B3	**CM-B108**	E9018-B3	**CM-B108**
P23/T23	E9016-G	**CM-2CW**	E9016-G	**CM-2CW**
P91/T91 (9Cr)	–	**CM-95B9**	–	–
	–	**CM-96B9**	–	**CM-96B9**
	E9016-G	**CM-9Cb**	E9016-G	**CM-9Cb**
P92/T92 P122/T122	E9016-G	**CR-12S**	E9016-G	**CR-12S**

For Boiler

SAW

Grade (Type of steel)	DCEP		AC	
	AWS Class.	Product name	AWS Class.	Product name
P1/T1 (0.5Mo)	–	–	F8P6-EA3-A3 (F9A6)	**MF-38/US-40**
			F8P6-EA4-A4 (F8A4)	**MF-38/US-A4**
			F8P6-EG-A4 (F8A4)	**MF-38/US-49**
P11/T11 (1.25Cr-0.5Mo)	F7PZ-EB2-B2	**G-80/US-B2**	F7PZ-EB2-B2	**G-80/US-B2**
	F7PZ-EG-B2	**MF-29A/US-511**	F7PZ-EG-B2	**MF-29A/US-511**
	F8P2-EG-B2	**PF-200D/US-511ND**	F8P2-EG-B2	**PF-200/US-511N**
P23/T23	–	**MF-29A/US-2CW**	–	–
P91/T91 (9Cr)	F9PZ-EB9-B9	**PF-90B9/US-90B9**	F10PZ-EG-G	**PF-200S/US-9Cb**
P92/T92 P122/T122	–	**PF-200S/US-12CRSD**	–	–

GMAW and GTAW

Grade (Type of steel)	AWS Class.	Product name	
		GMAW	GTAW
P1/T1 (0.5Mo)	ER70S-A1	**MG-S70SA1**	**TG-S70SA1**
	ER80S-G	**MG-SM**	**TG-SM**
P2/T2	ER80S-G	**MG-CM**	–
	–	–	**TG-SCM**
P11/T11 (1.25Cr-0.5Mo)	ER80S-B2	**MG-S80B2F** ∗	**TG-S80B2**
	ER80S-G	**MG-S1CM**	**TG-S1CM**
P22/T22 (2.25Cr-1Mo)	ER90S-B3	–	**TG-S90B3**
	ER90S-G	**MG-S2CM MG-S2CMS**	**TG-S2CM**
P23/T23	ER90S-G	**MG-S2CW**	**TG-S2CW** (ER80S-G)
P91/T91 (9Cr)	ER90S-B9	**MG-S90B9**	**TG-S90B9**
	ER90S-G	**MG-S9Cb**	**TG-S9Cb**
P92/T92 P122/T122	ER90S-G	**MG-S12CRS**	**TG-S12CRS**

∗ Single pass only

For Boiler

Process / Polarity	AWS Class.	Product name	Chemical compositions of wires or all weld metal (mass%) Wire/ W.M.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V		Nb	Al	N	Mn+Ni	W	Co	X-bar	J-Factor	Mechanical properties of all weld metal (YS=0.2%proof stress) AC/DC	YS (MPa)	TS (MPa)	EL (%)	IV (℃)	IV (J)	PWHT (℃×hr)
SMAW / DCEP	E8016-B1	CM-B86	W.M.	0.07	0.48	0.79	0.012	0.006			0.48	0.48											DCEP	590	680	28	0	98	620×1
	E7015-B2L	CM-B95		0.03	0.87	0.71	0.005	0.004			1.20	0.49												470	580	29	0	78	690×1
	E8016-B2	CM-A96MBD		0.06	0.49	0.79	0.006	0.004	0.02	0.02	1.30	0.56									8	102.4		515	617	27	−20	174	690×1
	E8015-B3L	CM-B105		0.03	0.85	0.87	0.006	0.004			2.14	0.95												550	650	25	0	79	690×1
	E9015-B3	CM-A105D		0.10	0.30	0.74	0.004	0.002	0.03	0.14	2.42	1.03									<6.0	62		504	644	28	−40	100	690×8
	E9015-B3	CM-B105D		0.06	0.66	0.73	0.011	0.005	0.02	0.01	2.24	0.95									11.4			566	677	27	−20	56	696×1
	E9016-B3	CM-A106ND		0.11	0.42	0.84	0.004	0.002	0.031	0.14	2.42	1.03									6	75.6		501	635	26	−40	151	690×8
	−	CM-95B9		0.10	0.22	0.84	0.007	0.002	0.02	0.51	8.94	1.02	0.23		0.04	0.002	0.039	1.35						651	768	22	20	74	760×2
SMAW / DCEP or AC	E7016-A1	CM-A76		0.06	0.49	0.79	0.006	0.002	−	−	−	0.49											AC	550	630	29	0	210	620×1
	E7016-A1	CM-B76		0.07	0.46	0.77	0.011	0.004			−	0.53											AC	540	620	26	0	200	620×1
	E8016-B2	CM-A96		0.06	0.38	0.72	0.008	0.004			1.31	0.54											AC	570	650	26	0	210	690×1
	E8018-B2	CM-B98		0.07	0.68	0.75	0.012	0.006			1.29	0.52											AC	590	690	26	0	66	690×1
	E9018-B3	CM-B108		0.07	0.68	0.70	0.012	0.007			2.14	0.95											AC	610	720	23	0	106	690×1
	E9016-G	CM-2CW		0.04	0.27	0.84	0.009	0.006	0.02	−	2.39	0.07	0.21		0.02				1.70				DCEP	473	582	28	0	158	747×2
	−	CM-96B9		0.10	0.19	0.85	0.007	0.004	0.03	0.52	9.01	1.05	0.24		0.04	0.002	0.038	1.37					DCEP	657	771	21	20	71	760×2
	E9016-G	CM-9Cb		0.06	0.31	1.51	0.006	0.003	−	0.94	9.11	1.06	0.18		0.03	−	0.030						AC	600	750	25	0	81	750×5
	E9016-G	CR-12S		0.08	0.41	0.94	0.008	0.001	0.02	0.52	9.62	0.23	0.37		0.030		0.05		1.63	1.57			DCEP	645	771	22	0	40	740×8
SMAW / AC	E8016-B2	CM-A96MB		0.06	0.45	0.74	0.007	0.003			1.30	0.54											AC	490	590	30	−18	200	690×1
	E9016-B3	CM-A106N		0.11	0.27	0.79	0.008	0.006		0.19	2.42	1.03									10	117		510	650	28	−29	120	690×8
SAW / DCEP	F8P2-EG-B2	PF-200D/US-511ND	Wire	0.13	0.09	0.92	0.005	0.003	0.10	0.17	1.49	0.56											DCEP	477	589	27	−29	116	690×4
			W.M.	0.08	0.21	0.82	0.007	0.003	0.09	0.15	1.39	0.56																	
	F9PZ-EB9-B9	PF-90B9/US-90B9	Wire	0.11	0.26	0.74	0.004	0.005	0.01	0.51	9.30	1.05	0.23		0.06	<0.001	0.04							582	716	23	20	37	760×2
			W.M.	0.10	0.21	0.92	0.009	0.004	0.01	0.50	9.00	0.97	0.21		0.04	0.01	0.04	1.42											
	−	MF-29A/US-2CW	Wire	0.04	0.14	1.17	0.006	0.005	0.16	−	2.29	0.12	0.26		0.03				1.80					495	596	28	0	128	747×2
			W.M.	0.03	0.23	1.14	0.008	0.004	0.16	−	2.28	0.11	0.23		0.02				1.80										
	−	PF-200S/US-12CRSD	Wire	0.07	0.35	0.74	0.004	0.003	0.01	0.51	9.92	0.35	0.21		0.035		0.040		1.45	1.01				652	775	23	20	31	745×8
			W.M.	0.06	0.24	0.88	0.008	0.004	0.02	0.52	9.48	0.32	0.20		0.03		0.04		1.36	0.98									
SAW / DCEP or AC	F7PZ-EB2-B2	G-80/US-B2	Wire	0.11	0.13	0.57	0.007	0.006	0.11		1.49	0.53											DCEP	425	545	27	20	37	690×1
			W.M.	0.06	0.45	0.83	0.009	0.005	0.12		1.29	0.54																	
	F7PZ-EG-B2	MF-29A/US-511	Wire	0.09	0.19	0.60	0.008	0.009			1.51	0.54											AC	440	580	28	0	98	650×20
			W.M.	0.09	0.25	0.78	0.010	0.007			1.32	0.52																	
SAW / AC	F8P6-EA3-A3	MF-38/US-40	Wire	0.13	0.04	1.80	0.008	0.010	0.12			0.52											AC	560	630	29	−51	58	620×1
			W.M.	0.08	0.34	1.58	0.017	0.009	0.12			0.45																	
	F8P6-EA4-A4	MF-38/US-A4	Wire	0.09	0.04	1.59	0.010	0.014	0.10			0.52												510	600	29	−51	40	620×1
			W.M.	0.10	0.39	1.35	0.013	0.013	0.11			0.52																	
	F8P6-EG-A4	MF-38/US-49	Wire	0.09	0.03	1.58	0.014	0.013	0.10			0.52												510	600	29	−51	40	600×3
			W.M.	0.10	0.37	1.35	0.014	0.014	0.09			0.53																	
	F8P2-EG-B2	PF-200/US-511N	Wire	0.08	0.30	0.90	0.004	0.002	0.14	0.17	1.45	0.52												450	560	31	−29	120	690×8
			W.M.	0.08	0.20	0.88	0.007	0.002	0.11	0.15	1.39	0.55																	
	F10PZ-EG-G	PF-200S/US-9Cb	Wire	0.08	0.13	1.73	0.007	0.005		0.60	8.91	0.90	0.23		0.05									580	710	24	0	68	740×8
			W.M.	0.06	0.12	1.58	0.008	0.004		0.55	8.31	0.88	0.21		0.03														
GMAW	ER70S-A1	MG-S70SA1	Wire	0.04	0.51	0.99	0.009	0.012	0.16	0.03		0.49											DCEP	454	531	33	−20	118	620×1
	ER80S-G	MG-SM		0.07	0.59	1.10	0.006	0.009	0.17	−	−	0.55												520	610	25	0	98	AW
	ER80S-G	MG-CM		0.06	0.72	1.62	0.005	0.008	0.22		0.53	0.55								Ti:0.18				510	600	25	0	78	620×1
	ER80S-B2	MG-S80B2F		0.09	0.51	0.59	0.003	0.005	0.26	0.03	1.32	0.52												549	649	28	−18	144	620×1
	ER80S-G	MG-S1CM		0.09	0.55	1.15	0.007	0.009	0.18	−	1.45	0.55												570	680	22	0	69	620×1
	ER90S-G	MG-S2CM		0.08	0.56	1.07	0.005	0.009	0.17	−	2.35	1.11												550	670	26	0	110	680×1
	ER90S-G	MG-S2CMS		0.12	0.39	0.85	0.004	0.003	0.14	−	2.27	0.97												600	720	21	−20	120	670×1
	ER90S-G	MG-S2CW		0.04	0.39	1.17	0.003	0.007	0.21	0.50	2.29	0.10	0.29		0.04				1.79					551	644	28	0	150	747×2
	ER90S-B9	MG-S90B9		0.13	0.23	0.71	0.003	0.004	0.02	0.46	8.34	0.93	0.25		0.05	0.01	0.04	1.17						568	716	23	20	64	760×4
	ER90S-G	MG-S9Cb		0.08	0.35	1.59	0.007	0.008	0.01	0.45	8.79	0.88	0.17		0.02									570	700	27	0	98	740×8
	ER90S-G	MG-S12CRS		0.04	0.40	1.19	0.004	0.006	0.01	0.52	10.10	0.40			0.04		0.04		1.59	1.59				592	721	25	20	72	750×8
GTAW	ER70S-A1	TG-S70SA1		0.07	0.58	1.08	0.005	0.008	0.13	0.03	−	0.56	0.30										DCEN	534	611	32	0	267	620×1
	ER80S-G	TG-SM		0.08	0.54	1.04	0.004	0.007	0.12	0.02	−	0.53												500	580	32	0	280	620×1
	ER80S-G	TG-SCM		0.08	0.22	0.58	0.004	0.008	0.21	0.01	0.64	0.56												470	570	31	0	190	620×1
	ER80S-B2	TG-S80B2		0.11	0.50	0.67	0.004	0.004	0.15	0.01	1.40	0.55												490	625	32	−20	246	620×1
	ER80S-G	TG-S1CM		0.06	0.50	0.99	0.007	0.005	0.11	0.02	1.22	0.54												540	630	28	0	270	690×1
	ER90S-B3	TG-S90B3		0.11	0.64	0.67	0.006	0.006	0.14	0.01	2.44	1.09												596	725	27	−20	237	690×1
	ER90S-G	TG-S2CM		0.10	0.26	0.70	0.009	0.008			2.31	1.04									12	115		610	720	28	0	250	690×1
	ER80S-G	TG-S2CW		0.06	0.42	0.43	0.006	0.008	0.17	−	2.34	0.48	0.34		0.03				1.19					494	627	31	0	289	747×2
	ER90S-B9	TG-S90B9		0.11	0.24	0.69	0.004	0.004	0.01	0.53	8.91	0.94	0.23		0.05	0.003	0.042	1.22						706	809	22	0	160	760×2
	ER90S-G	TG-S9Cb		0.07	0.16	0.99	0.008	0.006	−	0.68	8.97	0.90	0.18		0.04	−	0.022							700	780	24	0	240	740×8
	ER90S-G	TG-S12CRS		0.07	0.35	0.74	0.004	0.003	0.01	0.51	9.92	0.35	0.21		0.04				1.45	1.01				686	790	23	0	44	740×8

W.M. = weld metal

X-bar = (10P + 5Sb + 4Sn + As)/100 (ppm), J-Factor = $(Si + Mn) \times (P + Sn) \times 10^4$ (%)

TRUSTARC™

CM-A96

AWS A5.5 E8016-B2

A world-class 1.25Cr-0.5Mo electrode of persistent quality since 1952.

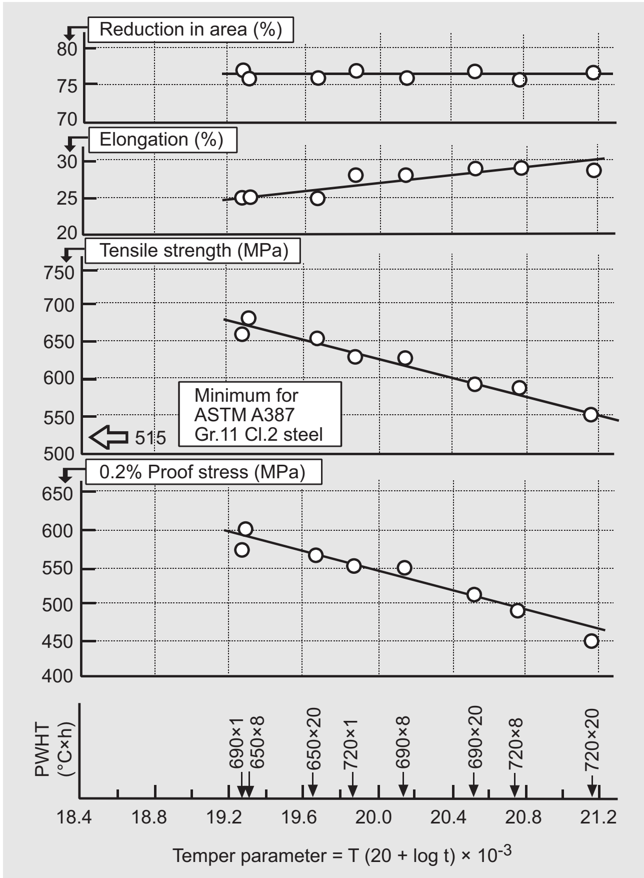
Since its inception, CM-A96 has persistently earned a good reputation in the high-temperature high-pressure fields such as boilers and refineries in which 1.25Cr-0.5Mo steel is used at a large consumption ratio for steam power generating equipment and reactor vessels.

Heat-resistant low alloy steel is a main material for coal firing power plants.

In welding Cr-Mo steel, the weld metal should have the essential qualities: (1) low susceptibility to cold cracking, (2) low susceptibility to hot cracking, (3) resistibility to extended postweld heat treatment for better mechanical properties, and (4) stable microscopic structure for better creep resistance at elevated temperatures.

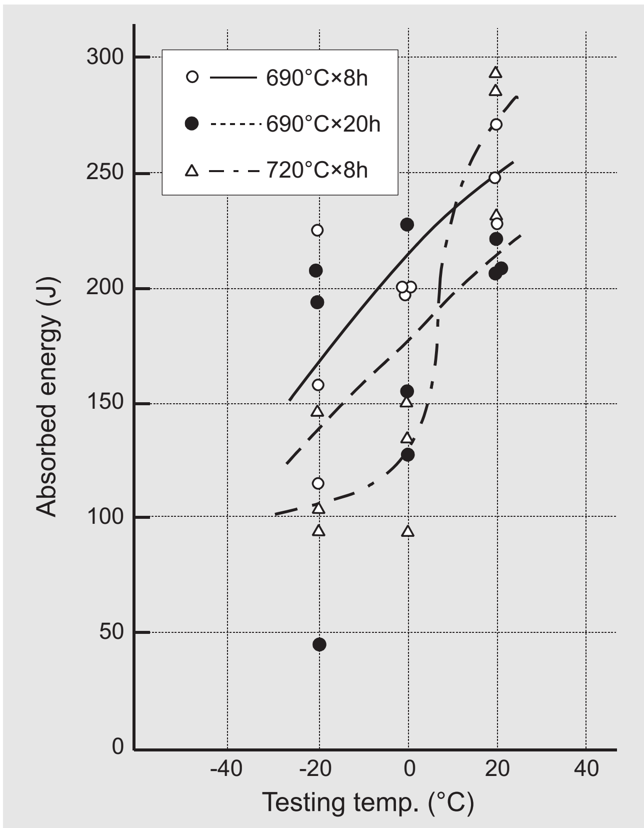
In order to fulfill these essential requirements, CM-A96 is ingeniously designed. First, it is of the extra-low hydrogen type; consequently, the amount of diffusible hydrogen in the weld metal can be kept lower than with conventional low hydrogen type electrodes, thereby reducing the susceptibility to cold cracking. Second, the phosphorous and sulfur content of the weld metal is kept low to decrease the susceptibility to hot cracking. Thirdly, the elaborate chemical composition of CM-A96 provides a stable weld metal microstructure, which allows the weld metal to maintain adequate mechanical properties over extended postweld heat treatment (PWHT) of high temper parameter (Figures 1 and 2) and to increase creep resistance.

Figure 1: Tensile properties of CM-A96 (5ϕ) weld metal vs. temper parameter by AC welding in flat position.



T: K (=°C+273.15); t: hours

Figure 2: Charpy impact properties of CM-A96 (5ϕ) weld metal in the PWHT condition by AC welding in flat position.

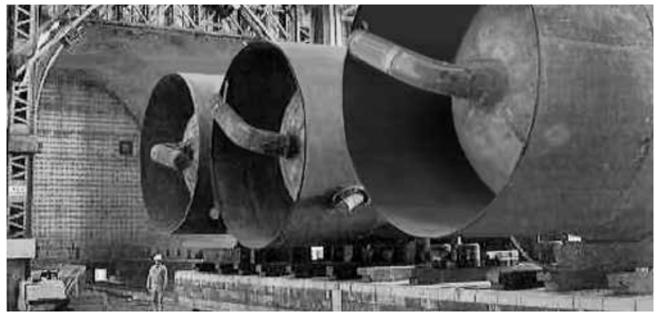


TRUSTARC™

CM-A96MB

AWS A5.5 E8016-B2

The best choice for moderate-PWHT fabrication of 1.25Cr-0.5Mo components to strict notch toughness and hardness restriction.



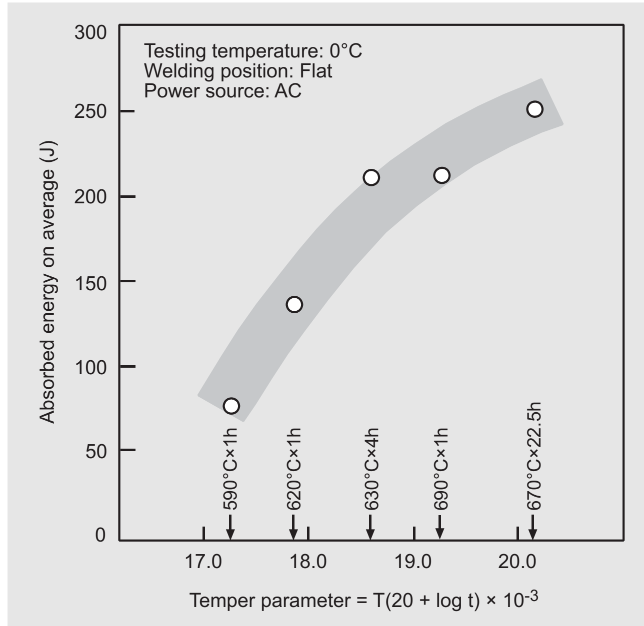
CM-A96MB shines in the fabrication of pressure components where PWHT uses lower temper parameters and strict control of temper embrittlement is required.

With lower temper parameters (either with lower PWHT temperature or with shorter PWHT time), weld hardness is prone to be higher — hence lower ductility — and notch toughness tends to be lower in general. The temper parameter of PWHT will necessarily be lower depending on the thickness of the weldment, the specification or code to follow, and the base metal used.

In contrast to CM-A96, CM-A96MB is more suitable for moderate PWHT of lower temper parameter. With moderate PWHT, CM-A96MB provides better notch toughness and lower hardness — thus higher ductility — compared with CM-A96. In addition, CM-A96MB more strictly controls impurity elements such as phosphorous (P), tin (Sn), antimony (Sb), and arsenic (As) to minimize temper embrittlement. Figure 1 shows results of Charpy impact tests of CM-A96MB weld metal that sustained low temper parameter PWHT. The weld metal exhibits adequate notch toughness over the range of temper parameters.

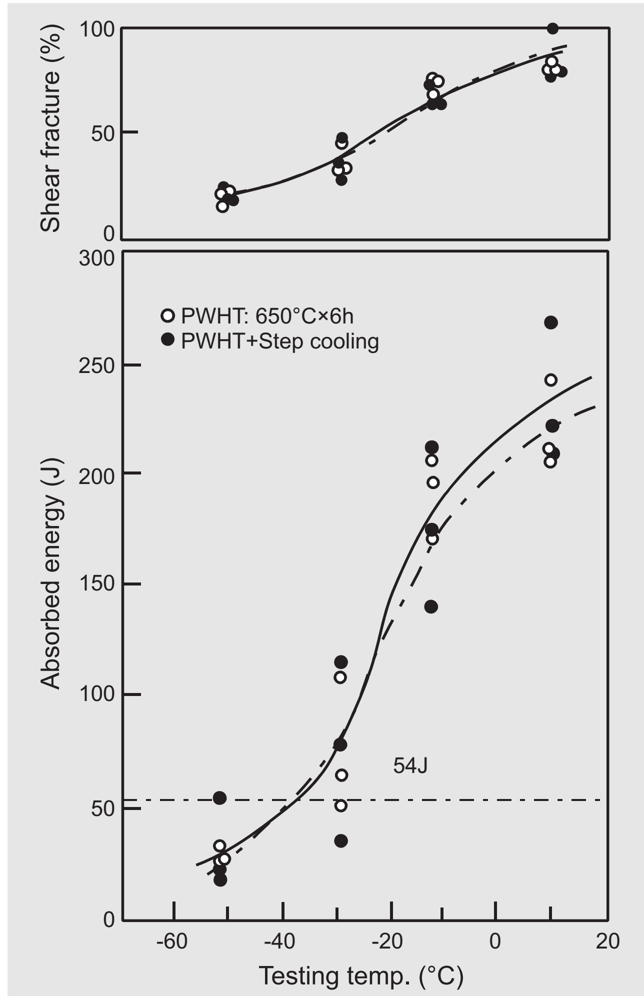
As shown in Figure 2, the susceptibility to temper embrittlement of CM-A96MB weld metal is quite low with almost no temperature shift at the standard absorbed energy of 54 J specified for fabricating pressure vessels for high temperature service.

Figure 1: Charpy impact absorbed energy of CM-A96MB (5ϕ) weld metal as a function of temper parameter.



T: K (=°C+273.15); t: hours

Figure 2: Temper embrittlement test results of CM-A96MB (6ϕ) weld metal by AC welding in flat position (Step cooling is a heat treatment to accelerate temper embrittlement).



TRUSTARC™

TG-S1CM

AWS A5.28 ER80S-G

A 1.25Cr-0.5Mo GTAW filler wire, unbeatable in pipe welding in refineries and boilers.

1.25Cr-0.5Mo steel is used for the equipment operated at the temperatures from 350-550℃. For such high-temperature applications, the materials must metallurgically be stable, resisting elevated temperature oxidation and creep rupture. Kobe Steel has used its accumulated technical expertise to pursue quality control of TG-S1CM, maintaining its high performance for the piping of oil refineries and power boilers.

Unlike conventional 1.25Cr-0.5Mo GTAW filler wires classified as AWS E5.28 ER80S-B2, TG-S1CM is classified necessarily as ER80S-G because of its unique chemical composition. TG-S1CM weld metal contains, as shown in Table 1, comparatively low carbon, phosphorous and sulfur along with a higher manganese content. This improves usability (better fluidity of the molten pool) and the resistance to hot cracking that is likely to occur in root-pass welding of pipes.

Table 1: Typical chemical composition of weld metal with pure argon gas shielding (mass%)

C	Si	Mn	P	S	Cr	Mo
0.06	0.50	0.99	0.007	0.005	1.22	0.54

The mechanical properties of TG-S1CM weld metal are sufficient for tubular steel base metals such as ASTM A199 Gr.T11, A213 Gr.T11, A250 Gr.T11, and A335 Gr.P11 after extended PWHT ― Table 2.

Table 2: Typical mechanical properties of weld metal with pure argon gas shielding

PWHT (℃× h)	0.2% PS (MPa)	TS (MPa)	El (%)	IV [1] (J)
650 × 1	550	620	25	270
690 × 1	540	630	28	270
700 × 5	510	590	25	260
ASTM A335P11 [2]	205 min	415 min	22 min	−

1. IV: Charpy impact energy on average at 0℃.
2. A335P11: 1.25Cr-0.5Mo seamless pipe.

Tips for welding

(1) Use direct current with electrode negative polarity.

(2) Pure argon gas is suitable for both torch shielding and back shielding. The shielding gas flow rate should be 10-15 liter/min. In apparent ambient wind over 1 m/sec, use a windscreen to protect the molten pool from the wind, or the wind may cause porosity, oxidation, and poor reverse bead formation.

(3) In the use of an automatic GTAW process, the welding procedure should be determined in accordance with the quality of the weld in advance. This is because, with a high feeding rate of filler wire ― hence a high deposition rate ― in automatic GTAW, the notch toughness of the weld metal tends to decrease because of coarser crystal grains.

(4) Preheating and interpass temperature should be 150-200℃ to decrease the cooling speed and thereby minimize the hardness of weld and prevent cold cracking.

(5) Postweld heat treatment temperature should be 650-700℃ to remove residual stresses, decrease the hardness of weld and improve the mechanical properties.

(6) Heat input should be properly controlled because excessive heat input can cause hot cracking, and deteriorate the tensile properties and notch toughness of weld.

TRUSTARC™

TG-S80B2

AWS A5.28 ER80S-B2

A 1.25Cr-0.5Mo GTAW filler wire, unbeatable in pipe welding in refineries and boilers.

This new brand has been developed by modifying the chemical composition of traditional TG-S1CM (AWS ER80S-G) to make it easier for international customers to select a suitable filler wire per the AWS chemical requirement designation (B2) for welding 1Cr-0.5Mo and 1.25Cr-0.5Mo steels. The welding usability, mechanical properties and crack resistibility of this new brand are comparable to the traditional brand. Table 1 shows typical chemical composition.

Table 1: Typical chemical composition of wire (mass%)

Elements	Wire	AWS A5.28 ER80S-B2
C	0.11	0.07-0.12
Si	0.50	0.40-0.70
Mn	0.67	0.40-0.70
P	0.004	0.025 max.
S	0.004	0.025 max.
Cu	0.15	0.35 max.
Ni	0.01	0.25 max.
Cr	1.40	1.20-1.50
Mo	0.55	0.40-0.65

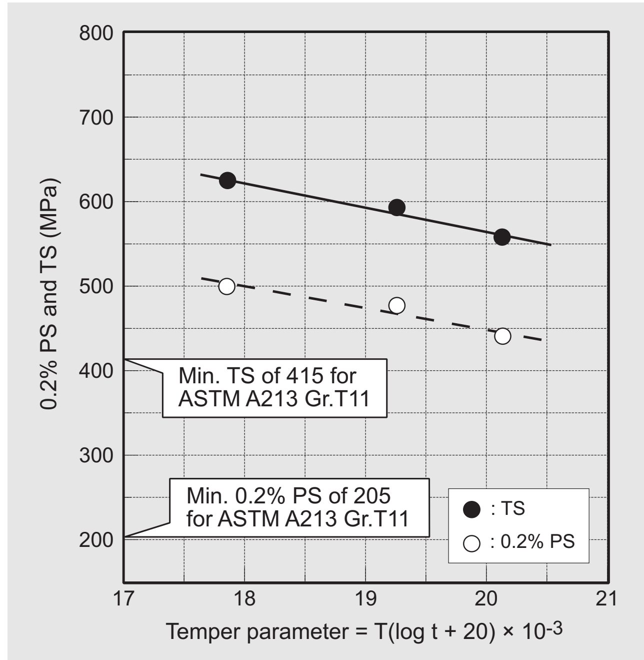
The mechanical properties of TG-S80B2 weld metal match the AWS requirements as shown in Table 2. In addition, as illustrated in Figure 1, this filler wire satisfies the ASTM requirement for tubular steels such as A213 Gr.T11 (1.25Cr-0.5Mo) after extended postweld heat treatment (PWHT).

Table 2: Typical mechanical properties of weld metal

	0.2% PS (MPa)	TS (MPa)	El (%)	IV at −20℃(J)	PWHT (℃×h)
Weld metal	499	625	32	Av. 246	620×1
	476	593	32	Av. 256	690×1
	440	558	34	Av. 242	690×8
ER80S-B2	470min	550min	19min	−	620±15×1

The soundness and bead appearance of the root pass welds by GTAW are essential performances of filler wires. TG-S80B2 offers good weldability and usability in root-pass welding, exhibiting good weld-pool washing on the groove faces and thereby resulting in excellent penetration bead appearance on the reverse side of the root pass weld with argon gas back shielding.

Figure 1: Tensile properties of weld metal as a function of PWHT (Temper parameter: 17.86 for 620℃×1h; 19.26 for 690℃×1h; 20.13 for 690℃×8h.

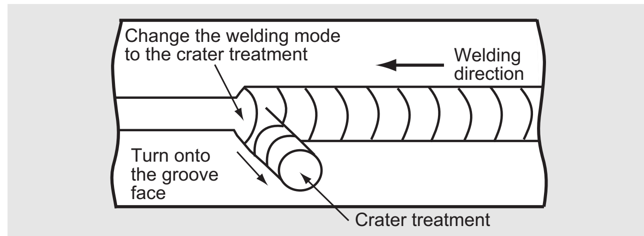


T: K (=℃+273.15); t: hours

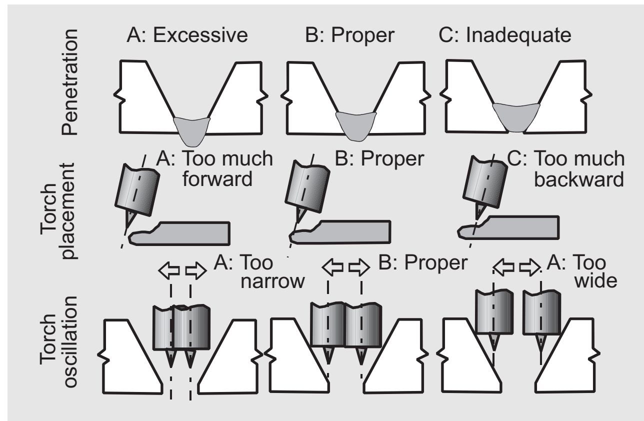
Tips for higher workmanship

In addition to the aforementioned tips for TG-S1CM, the following techniques are effective to prevent weld imperfections in root-pass welding of tubular work.

(1) The weld crater should be terminated on the groove face in order to prevent hot cracks in the crater.



(2) Use proper torch placement and oscillation for making good penetration.



TRUSTARC™

PF-200D/US-B2R

AWS A5.23 F8P2-EB2R-B2R

A low-impurity SAW flux/wire combination for DC welding, classified as AWS A5.23 F8P2-EB2R-B2R

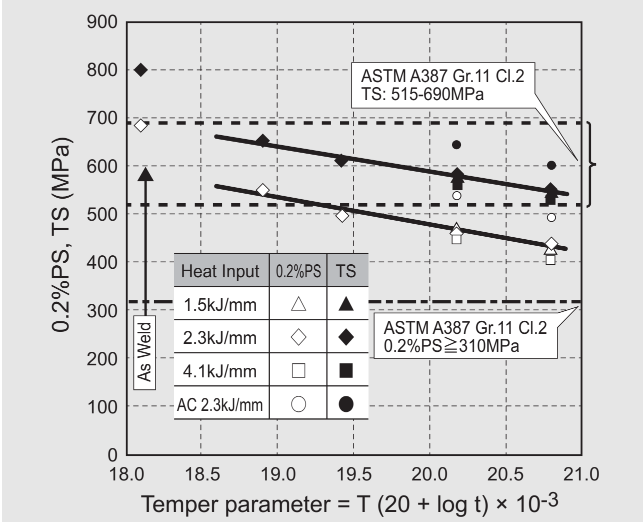
According to the AWS A5.23 standard, SAW filler metals, such as those for oil reactors, may include an R suffix in their designation if they satisfy the impurity elements index (X-factor ≦ 15) for applications that require a step-cooling test to evaluate susceptibility to temper embrittlement. As such, this wire can be designated as EB2R and the weld metal as B2R. PF-200D/US-B2R is a SAW flux/wire combination intended for DC welding, whose raw materials contain only traces of such impurities as P, Sb, Sn, As, Cu, and S to meet the requirements of F8P2-EB2R-B2R. The room-temperature tensile strength of the deposited metal can satisfy the specified range for the base metal of ASME A387 Gr.11 Cl.2 steel under the postweld heat treatment within the temper parameters, 19.0-20.5. Though this flux/wire combination excels in low-temperature toughness, the welding heat input should be limited to 2.5kJ/mm or lower for better temper embrittlement resistance.

Table1: Chemical composition of wire and all weld metal (mass%)

Elements	Wire	AWS A5.23 EB2R	All weld metal	AWS A5.23 B2R
C	0.14	0.07-0.15	0.10	0.05-0.15
Si	0.10	0.05-0.30	0.21	≦0.80
Mn	0.86	0.45-1.00	0.86	≦1.20
P	0.004	≦0.010	0.007	≦0.010
S	0.004	≦0.010	0.002	≦0.010
Cr	1.47	1.00-1.75	1.44	1.00-1.50
Mo	0.56	0.45-0.65	0.55	0.40-0.65
Cu	0.12	≦0.15	0.10	≦0.15
As	0.003	≦0.005	0.003	≦0.005
Sn	0.001	≦0.005	<0.001	≦0.005
Sb	0.001	≦0.005	<0.001	≦0.005
Ni	0.15	−	0.15	−
Al	0.15	−	0.03	−
V	0.004	−	0.004	−
Ti	0.002	−	<0.002	−
X-bar [1]	−	−	<8.2	−
J-Factor [2]	−	−	<85.6	−

1. X-bar = (10P + 5Sb + 4Sn + As)/100 (ppm)
2. J-Factor = (Si + Mn) × (P + Sn) × 10⁴ (%)

Figure 1: Tension test results of all weld metal at room temperature



T: K (=℃+273.15); t: hours

Figure 2: Tension test results of all weld metal at elevated temperature by PWHT condition (Heat input 2.3kJ/mm)

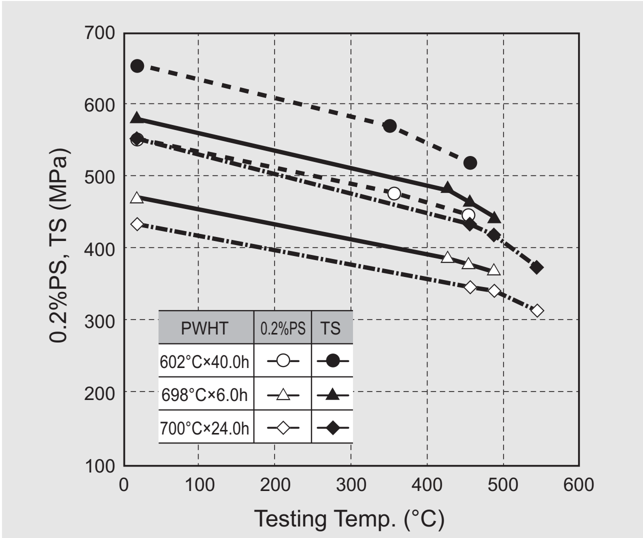
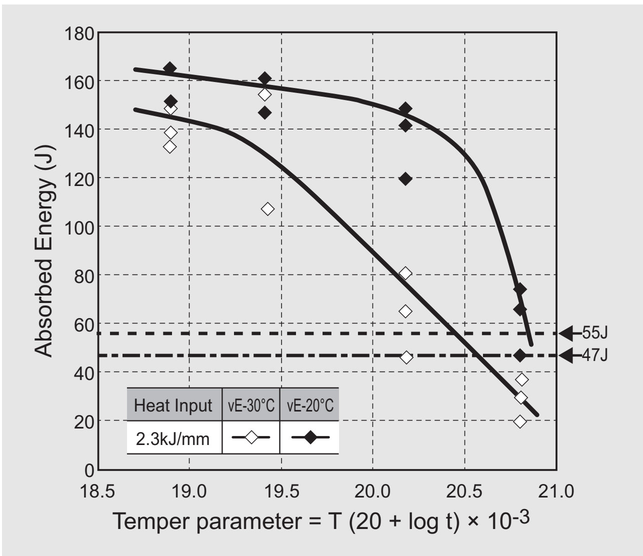


Figure 3: Notch toughness of all weld metal



T: K (=℃+273.15); t: hours

TRUSTARC™

G-80/US-B2

AWS A5.23 F7PZ-EB2-B2

A usability-refined SAW flux/wire combination corresponding to AWS A5.23 F7PZ-EB2-B2

Welding consumables for one-pass fillet welding of 1.25Cr-0.5Mo fin tube panels for boilers. Conforming with F7PZ-EB2-B2 requirements, G-80/US-B2 is a SAW flux/wire combination for 1.25Cr-0.5Mo steel. This brand offers excellent usability, providing good bead appearance and slag removability, and is suitable for both one-pass and multi-pass welding. In one-pass fillet welding, the use of a flux size of 12×65 mesh produces a good weld bead at carriage speeds up to 100cm/min under the current and voltage conditions of 460-500A and 24-28V. G-80 is a neutral fused flux that absorbs little moisture because it is glassy. However, as moisture in the form of condensation may deposit on the flux surface, it is recommended to dry the flux by heating before use.

Table 1: Chemical composition of wire (mass%)

Elements	Wire	A5.23 EB2	Weld metal (DCEP)	A5.23 B2
C	0.11	0.07-0.15	0.06	0.05-0.15
Si	0.13	0.05-0.30	0.45	≦0.80
Mn	0.57	0.45-1.00	0.83	≦1.20
P	0.007	≦0.025	0.009	≦0.030
S	0.006	≦0.025	0.005	≦0.030
Cu	0.11	≦0.35	0.12	≦0.35
Cr	1.49	1.00-1.75	1.29	1.00-1.50
Mo	0.53	0.45-0.65	0.54	0.40-0.65

Table 2: Welding condition and setup for fillet weld

Polarity	Welding Current	Arc Voltage	Carriage speed
DCEP	420-500A	24-28V	50, 100cpm

Preheat, Interpass temperature	Mesh size of flux
Room temperature	12×65

* Dia. of wire : ϕ2.4mm
* Distance between contact tip and base metal : 20mm
* Forehand / Backhand angle : 0°

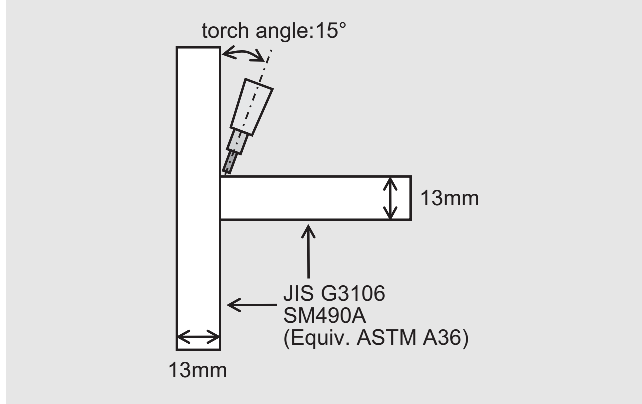
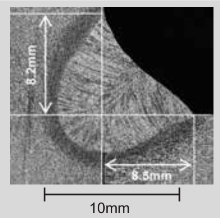
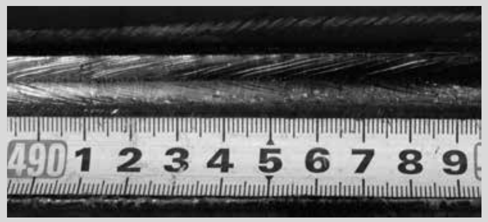
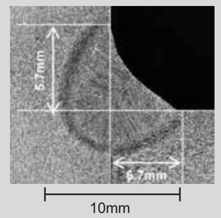


Table 3: Weldability in fillet welding

Flux mesh size	Carriage speed	Slug detouchability	Bead ripple	Pockmark generation
12×65	50cpm	Good	Good	Excellent
	100cpm	Good	Good	Good

* Welding current : 460A, Arc voltage : 28V

Table 4: An example of bead appearance and cross-sectional shape of fillet weld

Carriage speed	Bead appearance	Cross-sectional shape
50cpm		
100cpm		

* Welding condition : 460A - 28V

TRUSTARC™

MG-S80B2F

AWS A5.28 ER80S-B2

A one-pass fillet GMAW wire corresponding to AWS A5.28 ER80S-B2

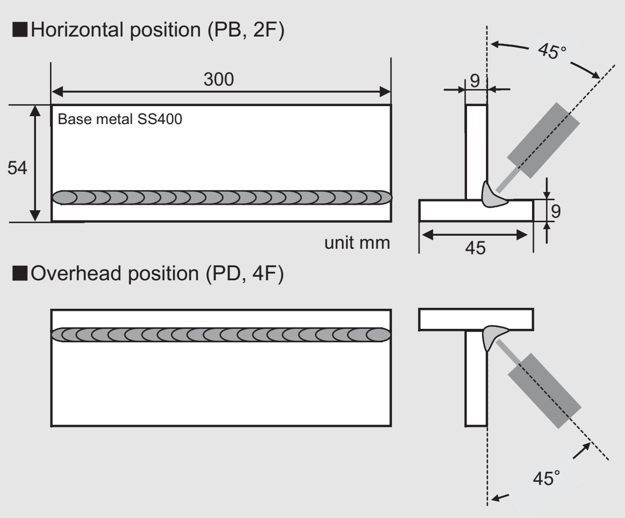
MG-S80B2F conforms with the ER80S-B2 requirement and uses 80%Ar-20%CO_2 shielding gas in the gas metal arc welding (GMAW) of 1.25Cr-0.5Mo steel. Because this wire may generate porosity in multiple-pass welding, its use should be limited to single-pass fillet welding, which is likely to be defect-free. MG-S80B2F can be used at travel speeds of up to about 80 cm/min to produce a fillet weld with a leg length of 5 mm at approximately 300 A in the horizontal and overhead positions.

Table1: Welding condition

Product name	Current (A)	Voltage (V)	Travel speed (cm/min)	Heat input (kJ/mm)
MG-S80B2F ϕ1. 2mm	280~320	29~31	80	0.6~0.7

Polarity	Preheat temp.	Pass sequence	Welding positions
DCEP	None	1	Horizontal, Overhead

Shielding gas	Flow rate (L/min)	Welding equipment
Ar-20%CO_2	25	PICOMAX-2Z



PB, PD: ISO 6947
2F, 4F: AWS/ASME A3.0

Table 3:Fillet size (PB, 2F)

Current (A)	Voltage (V)	Travel speed (cm/min)	Leg length (mm)	Penetlation depth (mm)
280	29	80	5.1	1.8
320	31		6.1	3.1

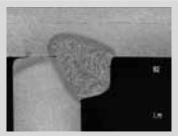
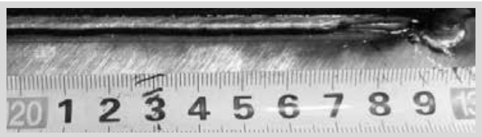
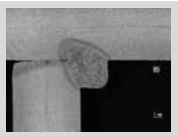
Table 5:Fillet size (PD, 4F)

Current (A)	Voltage (V)	Travel speed (cm/min)	Leg length (mm)	Penetlation depth (mm)
280	29	80	5.0	3.2
320			3.4	2.3

Table 2:Bead appearance and macrostructure (PB, 2F)

Current (A)	Voltage (V)	Travel speed (cm/min)	Bead appearance	Macrostructure
280	29	80		
320	31			

Table 4:Bead appearance and macrostructure (PD, 4F)

Current (A)	Voltage (V)	Travel speed (cm/min)	Bead appearance	Macrostructure
280	29	80		
320				

TRUSTARC™

CM-A106N

AWS A5.5 E9016-B3

Where temper embrittlement resistance is strictly required, CM-A106N is an unbeatable covered electrode.

Hydro-desulfurization reactor is a typical pressure vessel for which temper embrittlement resistance is strictly required.

Temper embrittlement, which occurs in low-alloy steels, such as Cr-Mo steels, is a decrease in impact toughness (or an increase in the ductile-to-brittle transition temperature) after long service at high temperatures in the 371 to 593℃ range. Temper embrittlement is a primary concern in the fabrication of 2.25Cr-1Mo steel pressure vessels that are operated at about 454℃, a temperature at which temper embrittlement is most likely to occur.

In principal, this form of brittleness is believed to occur due to the segregation of phosphorous (P), antimony (Sb), tin (Sn), and arsenic (As) at the grain boundaries of the steel and weld metal. Manganese (Mn) and silicon (Si) are also believed to affect the embrittlement. Based on these common theories on the causes of temper embrittlement, Kobe Steel has researched extensively to develop CM-A106N that fulfills the strict requirement for heavy-wall pressure vessels. Table 1 shows the typical chemical composition of weld metal designed to minimize temper embrittlement.

Table 1:Typical chemical composition of weld metal by AC welding in the flat position (mass%)

C	Si	Mn	P	S	Ni	Cr
0.11	0.27	0.79	0.008	0.006	0.19	2.42
Mo	Sb	Sn	As	X-bar [1]		J-Factor [2]
1.03	0.002	0.003	0.002	10		117

1. X-bar = (10P + 5Sb + 4Sn + As) / 100 (ppm)
2. J-Factor = (Si + Mn) × (P + Sn) × 10^4 (%)

In addition to the chemical elements, the microstructure of the weld metal is an essential factor in temper embrittlement. CM-A106N is designed so as to possess a fine microstructure in the weld metal after postweld heat treatment to minimize temper embrittlement — Figure 1.

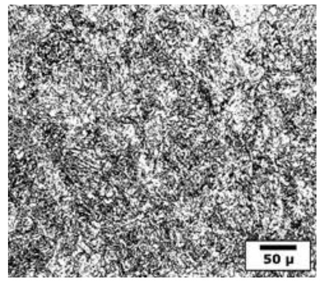


Figure 1: A very fine bainitic microstructure of weld metal after PWHT.

The susceptibility to temper embrittlement is evaluated with a step-cooling test using cyclical thermal aging as shown in Figure 2. Typical test results are shown in Figure 3, revealing excellent notch toughness with a very little shift of impact energy between the as-SR and SR+SC conditions.

Figure 2: A typical step cooling cycle for detecting the susceptibility to temper embrittlement.

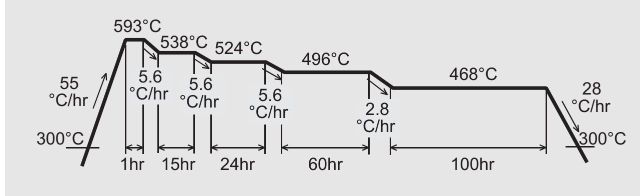
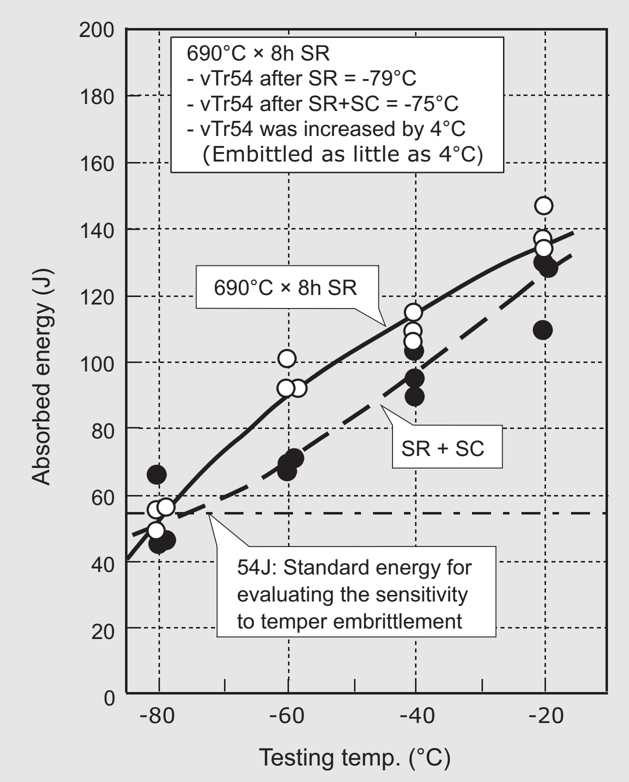


Figure 3: Temper embrittlement test results of weld metal by Charpy impact test (AC, flat welding position).



TRUSTARC™ CM-A105D

AWS A5.5 E9015-B3

A new stick electrode for DCEP polarity, corresponding to the AWS A 5.5 E 9015-B 3 classification

CM-A105D is a 2.25Cr-1Mo stick electrode for DC that was derived from CM-A106ND (E9016-B3) but has been reformulated to meet the E 9015-B 3 requirement.

This brand offers good low-temperature toughness and temper embrittlement resistance similar to CM-A106 ND (for DC) as well as CM-A106N (E9016-B3) for AC, and the tensile strength of the all weld metal can meet the specified range for the base metal of ASME A 387 Gr.22 Cl.2 steel under the postweld heat treatment at the temper parameter range of 19.5-20.5.

Table1: Welding condition

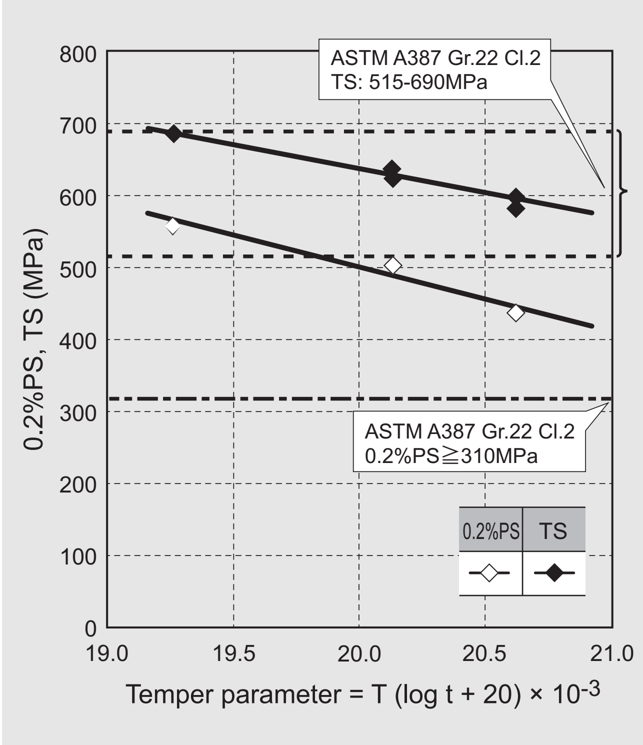
Dia. (mmϕ)	5.0
Polarity	DCEP
Welding Position	Flat
Current (A)	210
Voltage (V)	25
Travel Speed (cm/min)	Avg. 11
Heat Input (kJ/mm)	Avg. 2.9
Preheat and Interpass temp. (℃)	160-190

Table2: Chemical composition of all weld metal (mass%)

Elements	Weld metal	AWS A5.5 E9015-B3
C	0.10	0.05-0.12
Si	0.30	≦1.00
Mn	0.74	≦0.90
P	0.004	≦0.03
S	0.002	≦0.03
Cr	2.42	2.00-2.50
Mo	1.03	0.90-1.20
Cu	0.03	–
Ni	0.14	–
Sn	0.002	–
Sb	＜0.002	–
As	0.002	–
X-bar [1]	＜6.0	–
J-Factor [2]	62	–

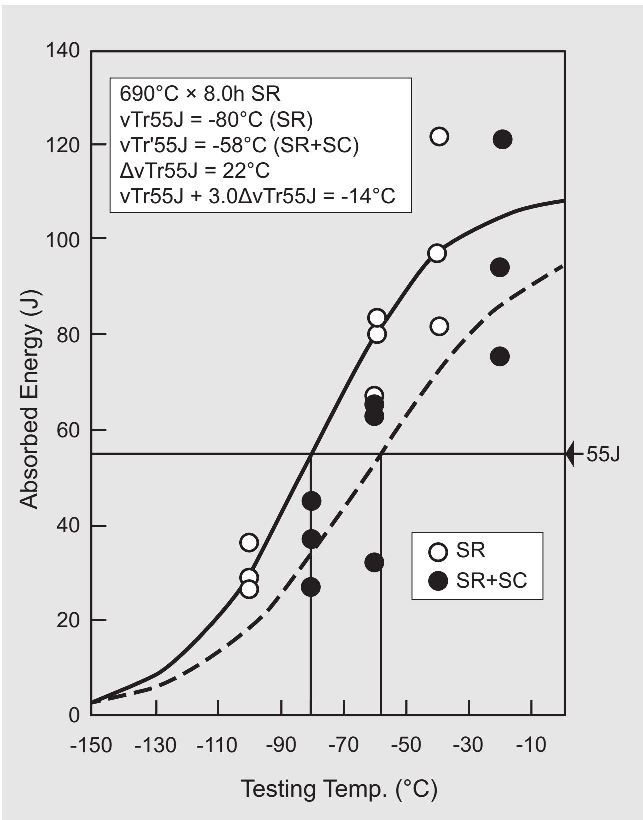
1. X-bar = (10P + 5Sb + 4Sn + As)/100 (ppm)
2. J-Factor = (Si + Mn) × (P + Sn) × 10^4 (%)

Figure 1: Tension test results of all weld metal at room temperature



T: K (=℃+273.15); t: hours

Figure 2: Notch toughness of all weld metal (PWHT: 690℃×8.0h)



TRUSTARC™ TG-S2CM

AWS A5.28 ER90S-G

A highly reputed GTAW wire for 2.25Cr-1Mo tubes and pipes.

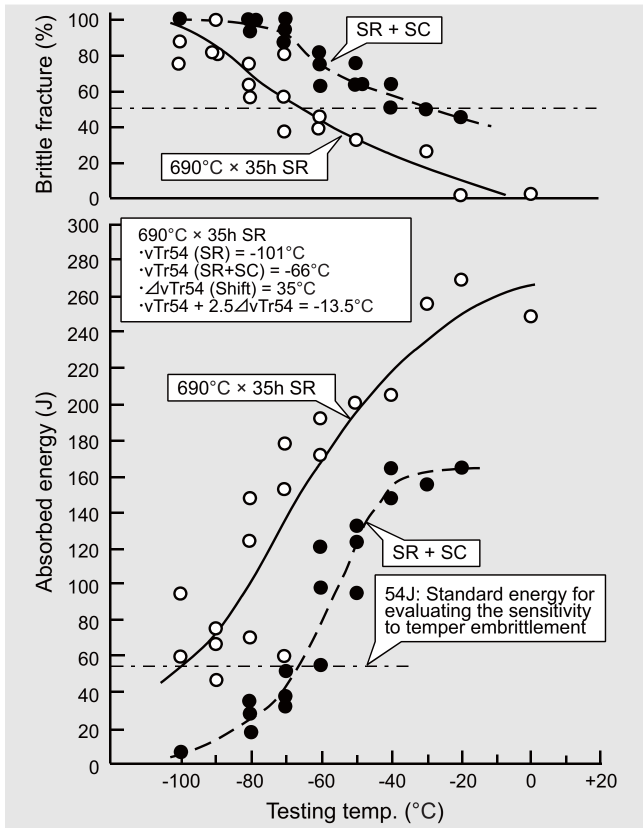
Unlike conventional 2.25Cr-1Mo filler wires classified as ER90S-B3, TG-S2CM is classified necessarily as ER90S-G due to its unique chemical composition. As shown in Table 1, TG-S2CM weld metal contains comparatively low silicon (Si) compared with conventional ER90S-B3 wires. In addition, TG-S2CM restricts phosphorous (P), antimony (Sb), tin (Sn), and arsenic (As). This elaborate chemical composition reduces temper embrittlement (Figure 1) and improves resistance to hot cracking that is likely to occur in root-pass welding of tubes and pipes.

Table 1: Typical chemical composition of weld metal with pure argon gas shielding (mass%)

C	Si	Mn	P	S	Cr	Mo
0.10	0.26	0.70	0.009	0.008	2.31	1.04
Sb	Sn	As	X-bar [1]		J-Factor [2]	
0.004	0.003	0.003	12		115	

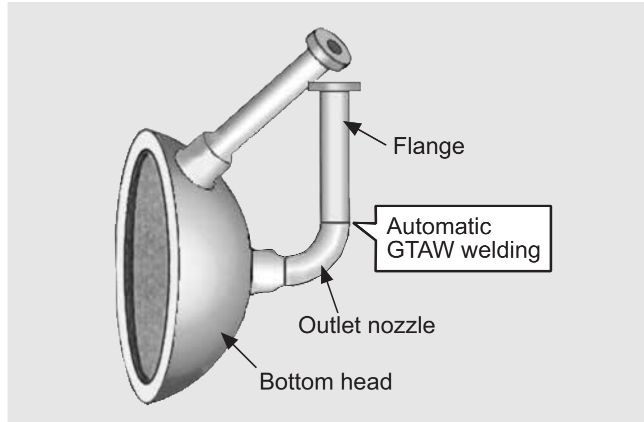
1. X-bar = (10P + 5Sb + 4Sn + As)/100 (ppm).
2. J-Factor = (Si + Mn) × (P + Sn) × 10^4 (%).

Figure 1: Temper embrittlement test results of weld metal by Charpy impact testing.



TG-S2CM is available in both cut rod and spooled wire. Spooled wires are suitable for mechanized gas tungsten arc welding. Bend-to-flange joints of reactors, tube-to-tubesheet joints of heat exchangers and pipe-to-pipe joints of process piping are typical applications for the automatic GTAW.

Figure 2: An example of automatic GTAW application for joining the 90-degree bend and flange extended from the bottom head of a reactor pressure vessel.



Tips for welding

(1) Back shielding with argon gas is indispensable to provide a smooth root-pass bead with regular penetration. The torch shielding gas flow rate should be 10-15 liter/min. In apparent ambient wind over 1m/sec, use a windscreen to protect the weld pool from the wind, or the wind may cause porosity.

(2) In mechanized GTAW, the welding procedure should be determined in consideration of the quality requirements for the weld beforehand. This is because, with a high feeding rate of filler wire — thus a high deposition rate — in automatic GTAW, the notch toughness of weld tends to decrease because of coarser crystal grains.

(3) Preheat and interpass temperature should be 200-250℃ to decrease the cooling speed and thereby minimize the hardness of weld and prevent cold cracking.

(4) Postweld heat treatment temperature should be 680-730℃ to remove residual welding stresses, decrease hardness and improve the mechanical properties of weld.

(5) Heat input should be controlled to prevent hot cracking and ensure the mechanical properties of weldment.

TRUSTARC™

TG-S90B3

AWS A5.28 ER90S-B3

An AWS-type new brand of GTAW filler wire for international customers.

This brand has been developed by modifying the chemical composition of traditional TG-S2CM (ER90 S-G) to make it easier for international customers to select a suitable filler wire per the AWS chemical requirement designation (B3) for welding 2.25Cr-1Mo steels. The welding usability, mechanical properties and crack resistance of the brand are comparable to the traditional brand. Table 1 shows typical chemical composition.

Table 1: Typical chemical composition of filler wire (mass%)

Elements	Wire	AWS A5.28 ER90S-B3
C	0.11	0.07-0.12
Si	0.64	0.40-0.70
Mn	0.67	0.40-0.70
P	0.006	0.025 max.
S	0.006	0.025 max.
Cu	0.14	0.35 max.
Ni	0.01	0.25 max.
Cr	2.44	2.30-2.70
Mo	1.09	0.90-1.20

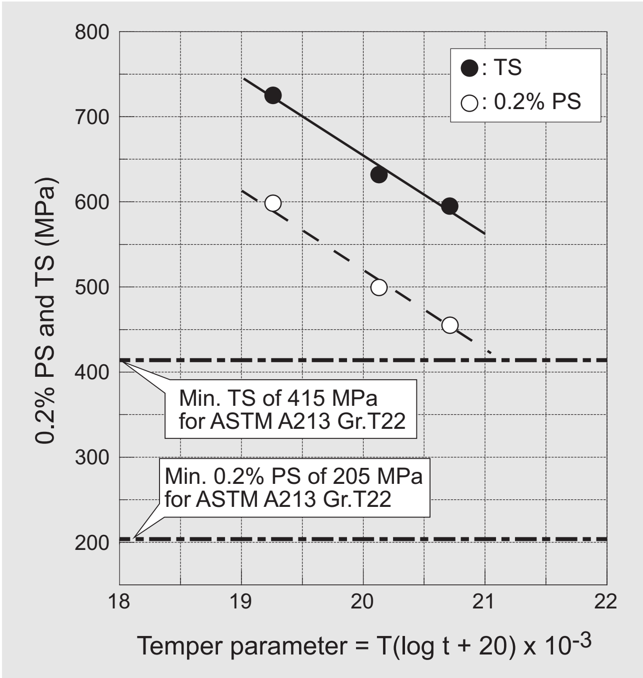
The mechanical properties of weld metal match the AWS requirements as shown in Table 2. In addition, as illustrated in Figure 1, this filler wire satisfies the ASTM requirement for tubular steels such as A213 Gr. T22 (2.25Cr-1Mo), after extended postweld heat treatment (PWHT).

Table 2: Typical mechanical properties of weld metal

	0.2% PS (MPa)	TS (MPa)	El (%)	IV at −20℃ (J)	PWHT (℃ × h)
Weld metal	596	725	27	Av. 237	690 × 1
	497	632	30	Av. 169	690 × 8
	452	595	30	Av. 156	690 × 32
ER90S-B3	540 min.	620 min.	17 min.	–	690 ± 15 × 1

The soundness and bead appearance of the root pass weld by GTAW are essential performances of filler wires. TG-S90B3 offers good weldability and usability in the root-pass welding, exhibiting a regular penetration bead appearance — Figure 2.

Figure 1: Tensile properties of weld metal as a function of PWHT.



T: K (=℃+273.15); t: hours

(Temper parameter: 19.26 for 690℃× 1h; 20.13 for 690℃ × 8h; 20.71 for 690℃ × 32h)

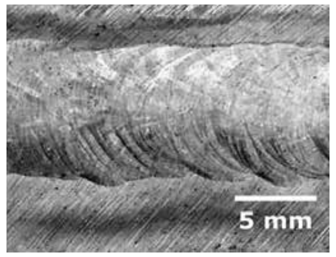
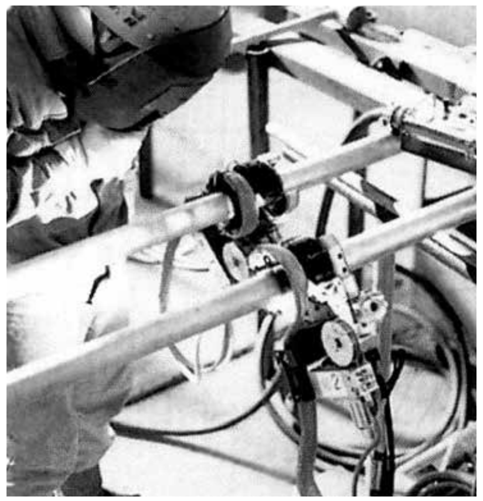


Figure 2: A bead appearance protruded on the reverse side of the root pass weld with argon gas back shielding.

Spooled TG-S90B3 is available in addition to cut rod. Spooled wires are suitable for automatic GTAW (Figure 3). Tube-to-tubesheet joints of heat exchangers and tube-to-tube and tube-to-bend joints of steam boilers are typical applications for automatic GTAW.

Figure 3: Automatic GTAW of tube-to- tube butt joints is a typical application for TG-S90B3.



TRUSTARC™

MG-S2CMS

AWS A5.28 ER90S-G

A time-proven GMAW wire with higher performance over AWS A5.28 ER90S-B3 wires: used frequently in heat-resistant low-alloy applications in Japan since the 1980s

MG-S2CMS is a solid wire for gas metal arc welding (GMAW) of conventional 2.25Cr-1Mo steel that offers its best performance in spray transfer mode with a shielding gas mixture of 80% Ar-20% CO_2. The chemistry of the wire is classified as AWS A5.28 ER90 S-G as shown in Table 1; however, it beats ER90S-B3 class GMAW wire in porosity resistance and X-ray soundness in multi-layer welds and is thus applicable for thick-section work. This wire can also exert higher impact values and lower susceptibility against temper embrittlement compared with the traditional 2.25Cr-1 Mo GMAW wire, MG-S2CM.

Table1: Typical chemical composition of wire (mass%)

Elements	Wire	AWS A5.28 ER90S-B3
C	0.12	0.07-0.12
Si	0.39	0.40-0.70
Mn	0.85	0.40-0.70
P	0.004	0.025 max.
S	0.003	0.025 max.
Cu	0.14	0.35 max.
Cr	2.27	2.30-2.70
Mo	0.97	0.90-1.20

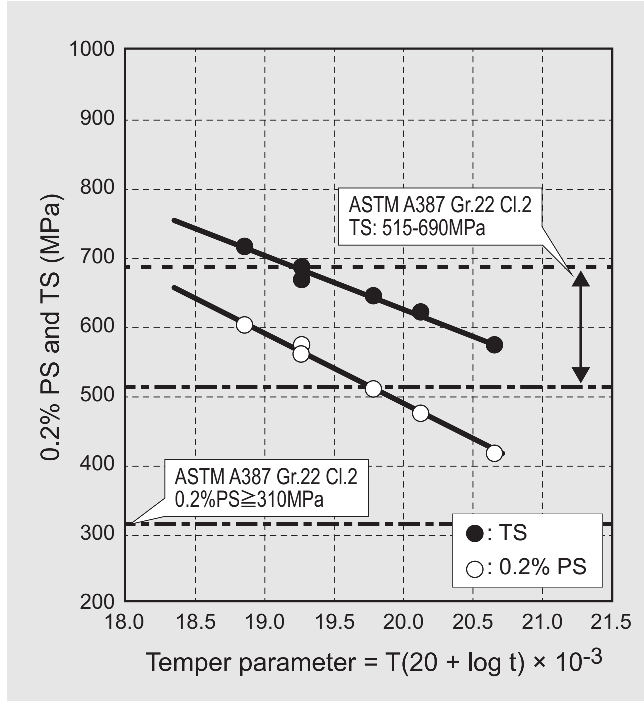
This wire can produce weld metal that offers excellent temper embrittlement resistance to meet the API RP 934-A requirements: CvTr40+2.5 Δ CvTr40 ≤ 50° F (10℃), where CvTr40 is the 40ft-lbt (55J) transition temperature. The weld metal also experiences little temperature shift by temper embrittlement.

[Notes on usage]

(1) The room-temperature tensile strength of deposited metal can satisfy the requirements for the base metal of ASME A387 Gr.22 Cl.2 steel under the postweld heat treatment at temper parameters from 19.5-20.5.

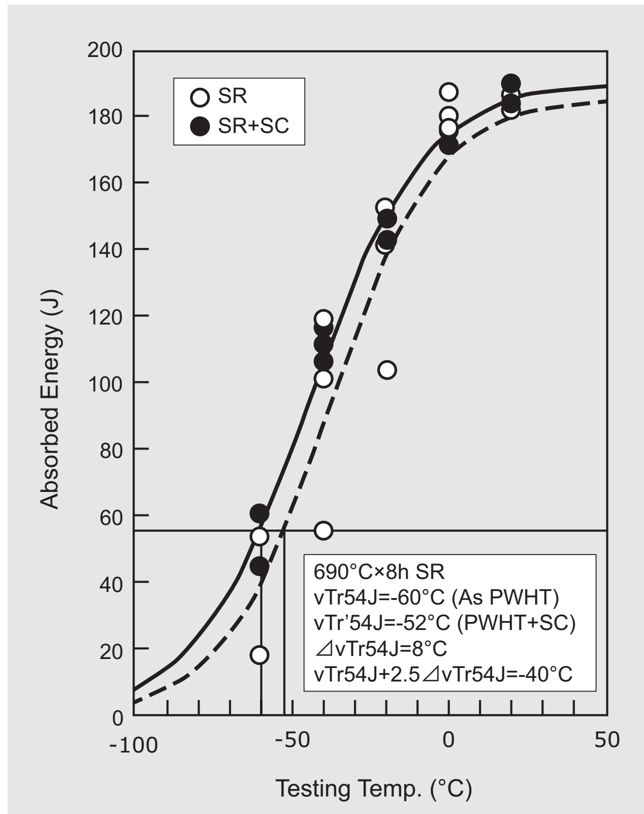
(2) For obtaining good toughness in multiple-layer welds, weld thickness of no more than 3-4 mm per layer is recommended in order for each preceding layer to contain a larger reheated zone that is produced by the heat of the succeeding layer. The welding heat input should also be controlled up to 3.5kJ/mm.

Figure 1: Tensile properties of weld metal vs. temper parameter



T: K (=℃+273.15); t: hours

Figure 2: Notch toughness of weld metal



TRUSTARC™

CM-A96MBD PF-200D/US-511ND

AWS A5.5 E8016-B2 AWS A5.23 F8P2-EG-B2

CM-A106ND PF-200D/US-521S

AWS A5.5 E9016-B3 AWS A5.23 F9P2-EG-B3

Stricter requirements for weld metal quality increasingly demanded for DC-spec. Cr-Mo filler metals.

Most filler metals suitable for AC may be used with DC, unless the quality requirement is strict. When requirements are strict, the matter is treated seriously, even when a particular filler metal is classified by the AWS as an AC-or-DCEP type. This is because the polarity of welding current affects the chemical composition (C, Si, Mn, and O in particular) — thus the mechanical properties — of the weld metal.

Kobe Steel has long been producing Cr-Mo steel filler metals for oil refinery reactor vessels and heat exchangers, which include CM-A96MB, PF-200/US-511N, CM-A106N and PF-200/US-521S. These filler metals have a high reputation in the domestic and overseas markets. Unlike in the domestic market, DC power sources are often used overseas, increasing demand for filler metals designed for DC current use with better performance in notch toughness, resistance to temper embrittlement and high-temperature strength. To meet this demand, Kobe Steel has developed brand new DC-spec. filler metals that are more suitable for DCEP welding and able to meet stringent requirements.

SMAW stick electrodes

With the elaborate chemical composition of the weld metal, CM-A 96 MBD and CM-A 106 ND exhibit excellent tensile properties, low-temperature impact toughness and resistance to temper embrittlement, as well as good usability, with DCEP currents. Typical chemical and mechanical properties are shown in Tables 1 and 2, respectively.

X-bar and J-Factor, shown in Table 1, are the index of control against the susceptibility to temper embrittlement of the weld metal: the higher the index, the more susceptible the weld metal becomes, according to the most commonly accepted embrittlement mechanism. To confirm the temper embrittlement susceptibility, Charpy impact testing is conducted for the weld metal in the SR and SR + step-cooling (Figure 1) conditions. Figure 2 shows typical Charpy impact test results of weld metals that confirm their high resistance to temper embrittlement.

Table 1: Typical chemical properties of weld metals (mass%) [1]

Product names	CM-A96MBD		CM-A106ND	
Elements	45-deg. vertical-up	Flat	45-deg. vertical-up	Flat
C	0.06	0.06	0.11	0.11
Si	0.37	0.49	0.32	0.42
Mn	0.76	0.79	0.84	0.84
P	0.006	0.006	0.004	0.004
S	0.004	0.004	0.002	0.002
Cu	0.01	0.02	0.032	0.031
Ni	0.03	0.02	0.13	0.14
Cr	1.29	1.30	2.41	2.42
Mo	0.57	0.56	1.04	1.03
Sb	0.002	0.002	0.002	0.002
Sn	0.002	0.002	0.002	0.002
As	0.002	0.002	0.002	0.002
X-bar [2]	8	8	6	6
J-Factor [3]	90.4	102.4	69.6	75.6

1. Base metal: ASTM A387 Gr.11 Cl.2; A387 Gr.22 Cl.2, Plate thickness: 19 mm
2. X-bar = (10P + 5Sb + 4Sn + As) /100 (ppm)
3. J-Factor = (Si + Mn) × (P + Sn) × 10^4 (%)

Table 2: Typical tensile properties of weld metals [1]

Product names	Welding position	PWHT (℃× h)	Test temp. (℃)	0.2% PS (MPa)	TS (MPa)	El [2] (%)	RA (%)
CM-A96MBD	45-deg. vertical-up	690 × 1	RT	515	617	27	76
			454	394	484	19	73
		690 × 8	RT	469	583	29	76
			454	368	456	25	76
	Flat	690 × 1	RT	476	588	29	77
			454	371	468	24	76
		690 × 8	RT	435	557	30	76
			454	342	438	24	78
CM-A106ND	45-deg. vertical-up	690 × 8	RT	501	635	26	72
			454	402	483	19	73
		690 × 26	RT	440	588	28	72
			454	343	446	23	73
	Flat	690 × 8	RT	504	644	28	71
			454	405	489	20	73
		690 × 26	RT	435	594	30	72
			454	344	449	23	73

1. Base metal: ASTM A387 Gr.11 Cl.2; A387 Gr.22 Cl.2, Plate thickness: 19 mm
2. Gauge length: 4D for RT, 5D for 454℃

Figure 1: Step-cooling (SC) heat treatment.

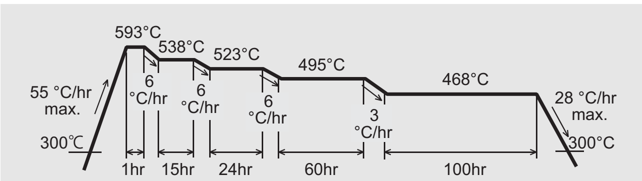
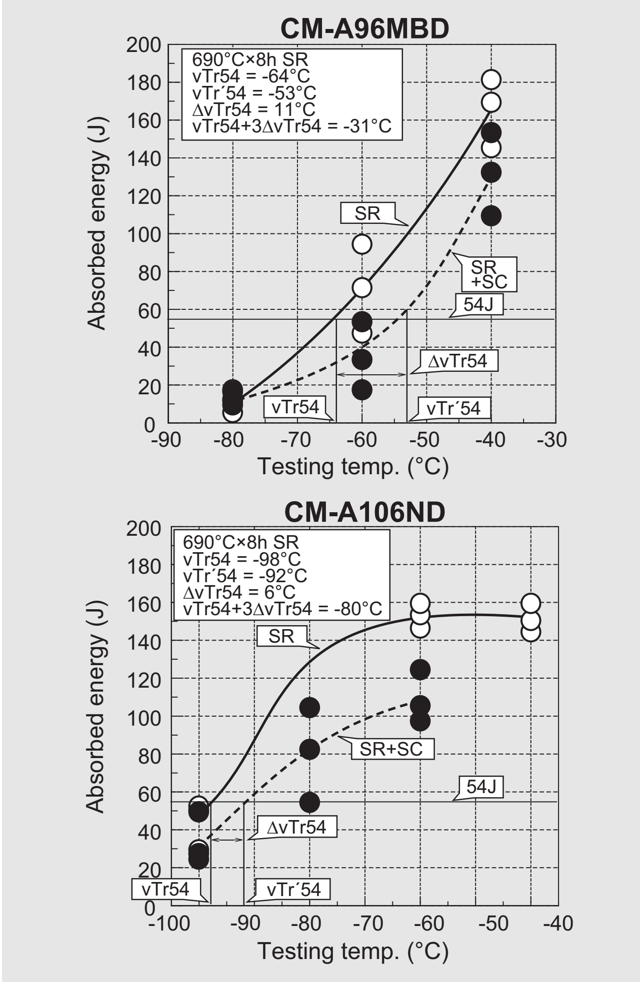


Figure 2: Temper embrittlement test results (4ϕ, 45-deg. vertical-up position).



SAW flux/wire combinations

With sophisticated wire electrode chemistry and a unique bonded flux, PF-200D/US-511ND and PF-200 D/US-521S offer first-class performance in tensile strength and ductility, low-temperature notch toughness and resistance to temper embrittlement, as well as outstanding usability, with DCEP currents.

Figure 3: Temper embrittlement test results (Wire: 4ϕ).

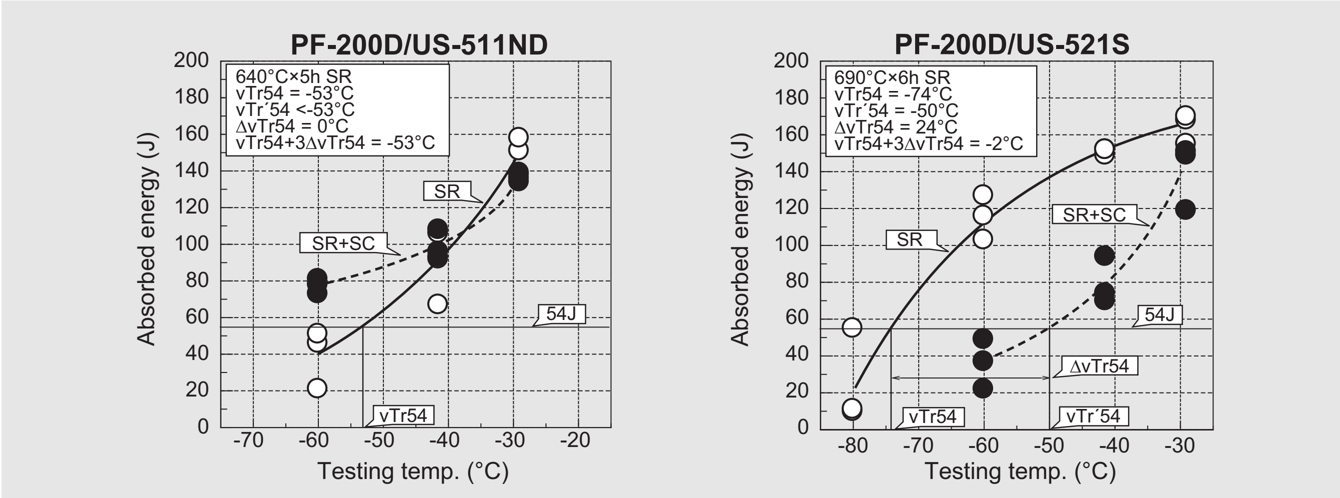


Table 3 shows typical chemical properties of the weld metals. Table 4 presents typical tensile properties of the weld metals. Figure 3 exhibits the unsurpassed resistance of the weld metals against temper embrittlement, with a comparison of 54-J absorbed energy transition temperatures in the SR and SR + SC conditions.

Table 3: Typical chemical properties of weld metals (mass%) [1]

Elements	PF-200D/US-511ND	PF-200D/US-521S
C	0.08	0.09
Si	0.21	0.16
Mn	0.82	0.81
P	0.007	0.006
S	0.003	0.003
Cu	0.09	0.13
Ni	0.15	0.13
Cr	1.39	2.41
Mo	0.56	1.07
Sb	0.002	0.002
Sn	0.002	0.002
As	0.002	0.002
X-bar	9	8
J-Factor	93	78

1. Base metal: ASTM A387 Gr.11 Cl.2, A387 Gr.22 Cl.2, Plate thickness: 20 mm; Wire size: 4ϕ.

Table 4: Typical tensile properties of weld metals [1]

Product names	PWHT (℃ × h)	Test temp. (℃)	0.2% PS (MPa)	TS (MPa)	El [2] (%)	RA (%)
PF-200D/ US-511ND	640 × 5	RT	522	630	25	69
		454	408	491	17	64
	690 × 4	RT	477	589	27	73
		454	376	465	17	72
	691 × 20	RT	424	546	29	73
		454	336	437	21	73
PF-200D/ US-521S	690 × 6	RT	507	621	26	75
		454	414	485	17	70
	690 × 13	RT	484	602	28	73
		454	403	472	17	72
	690 × 28	RT	468	584	28	72
		454	380	452	20	72

1. Base metal: ASTM A387 Gr.11 Cl.2, A387 Gr.22 Cl.2, Plate thickness: 20 mm; Wire size: 4ϕ.
2. Gauge length: 4D for RT, 5D for 454℃.

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CM-A106H PF-500/US-521H

AWS A5.5 E9016-G AWS A5.23 F9P2-EG-G

CM-A106HD PF-500D/US-521HD TG-S2CMH

AWS A5.5 E9016-G AWS A5.23 F9P2-EG-G AWS A5.28 ER90S-G

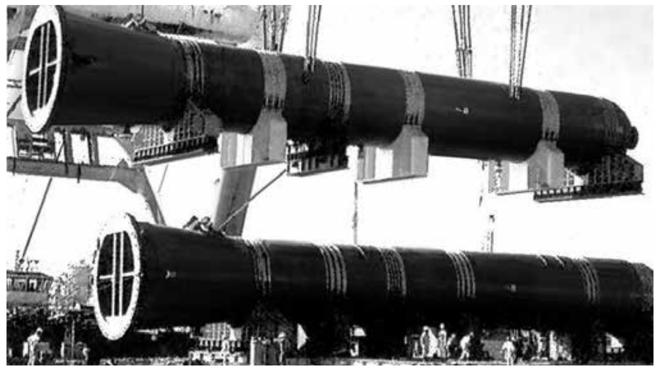
Why high-strength 2.25Cr-1Mo-V steel is needed

Desulfurization reactors are thick heavy section pressure vessels that remove, by chemical reaction, sulfur impurities contained in crude oil in the refining of heavy hydrocarbons into lighter, more valuable products in refineries (Figure 1).

Figure 1: Refineries are composed of a variety of such sophisticated equipment as reactors, towers, heat exchangers, and pipelines.

The reactors for refineries are operated in a high-temperature high-pressure hydrogen atmosphere. In order to efficiently carry out the desulfurization reaction, the service temperature and pressure are increased, causing increases in thickness and scale of the reactor. The world's largest heavy oil desulfurization reactor that uses high strength 2.25Cr-1 Mo-V steel has a shell of 330-mm thick and weighs 1400 tons (Figure 2).

Figure 2: The world's largest heavy oil desulfurization reactor vessel (Photo source: Welding Techniques Vol.47, The Japan Welding Engineering Society).



This explains the need for specific steels — advanced steel with higher strength and resistance to hydrogen at higher operation temperatures — that are superior to conventional 2.25Cr-1Mo steel. The high-strength 2.25 Cr-1Mo-V steel is the one for this application; it has been used to fabricate reactors since 1998.

How high-strength 2.25Cr-1Mo-V steel and the matching welding filler metals are specified in ASME

Table 1 shows steel grades and requirements for chemical composition and mechanical properties of 2.25Cr-1Mo-V steel, as specified by ASME Boiler and Pressure Vessel Code Sec. Ⅷ Div. 1 Appendix 31 and Div. 2 Appendix 26. In using these specific materials for the fabrication of pressure vessels, these ASME Code Appendixes require to use welding filler metals that satisfy the requirements of chemical composition and mechanical properties of weld metal, as shown in Table 1.

What are the advantages of high-strength 2.25Cr-1Mo-V steel and filler metal?

As shown in Table 1, the high-strength 2.25Cr-1Mo-V steel and matching filler metals contain small amounts of vanadium and niobium.

Alloying these elements is, first, to strengthen the Cr-Mo steel by the precipitation of vanadium and niobium carbides in the matrix. Second, stable vanadium and niobium carbides improve resistance to high temperature hydrogen attack. High temperature hydrogen attack is believed to be one form of hydrogen damage, where molecular hydrogen dissociates into the atomic form, atomic hydrogen readily enters and diffuses through the steel rapidly, and hydrogen may react with carbon in the steel ($Fe_3C + 4H \rightarrow CH_4 + Fe$) to cause either surface decarburization or internal decarburization and fissuring. Thirdly, fine particles of vanadium carbide improve resistance to hydrogen embrittlement, by trapping diffusible hydrogen to prevent its concentration at crack tips.

With higher strength, the wall thickness of a 2.25Cr-1 Mo-V steel pressure vessel can be reduced by about 12% when compared with conventional 2.25Cr-1Mo steel because the allowable stress can be increased by about 12%. Thinner material means welding can be finished faster and time for postweld heat treatment soaking can be reduced, thereby reducing fabrication costs. Superior resistance to high temperature hydrogen attack and hydrogen embrittlement facilitates more efficient operation of the reactor vessel at higher temperatures (482℃ max. for operation temperature) and higher atmospheres of hydrogen pressure.

Table 1: Requirements of chemical composition and mechanical properties of high-strength 2.25Cr-1Mo-V steel and weld metal (ASME BPVC Sec. Ⅷ Div. 1 Appendix 31 and Div. 2 Appendix 26)

Steel spec, and grade	Chemical composition of steel (%) 1													
	C	Mn	P	S	Si	Cr	Mo	Cu	Ni	V	Nb	Ti	B	Ca
SA-182, F22V SA-336, F22V	0.11-0.15	0.30-0.60	0.015	0.010	0.10	2.00-2.50	0.90-1.10	0.20	0.25	0.25-0.35	0.07	0.030	0.0020	0.015
SA-541,22V	Mechanical properties of steel 2													
SA-542, D-4a	- Tensile strength (MPa): 585-760						- Elongation (%): 18 min.							
SA-832, 22V	- 0.2% offset strength (MPa): 415 min.						- Impact energy at −18℃ (J): 54/47 min. 3							

Welding process	Chemical composition of weld metal (%) 1								
	C	Mn	P	S	Si	Cr	Mo	V	Nb
SMAW	0.05-0.15	0.50-1.30	0.015	0.015	0.20-0.50	2.00-2.60	0.90-1.20	0.20-0.40	0.010-0.040
SAW	0.05-0.15	0.50-1.30	0.015	0.015	0.05-0.35	2.00-2.60	0.90-1.20	0.20-0.40	0.010-0.040
GTAW	0.05-0.15	0.30-1.10	0.015	0.015	0.05-0.35	2.00-2.60	0.90-1.20	0.20-0.40	0.010-0.040
	Mechanical properties of weld metal 2								
SMAW	- Tensile strength (MPa): 585-760				- Impact energy at −18 ℃ (J): 54/47 min. 3				
SAW	- 0.2% offset strength (MPa): 415 min.				- Creep rupture life at 538℃ and 205 MPa: 4 Exceed 900h				
GTAW	- Elongation (%): 18 min.								

1. Single values are the maximum.
2. The heat treatment conditions for tensile test are specified based on the maximum and minimum vessel-portion temperatures and holding time. The heat treatment condition for impact test is specified based on the minimum vessel-portion temperature and holding time in fabrication. The heat treatment condition for creep rupture tests is specified based on the maximum vessel-portion temperature and holding time.
3. For Charpy impact energy requirement, 54J is for three-specimen average and 47 J is for one specimen.
4. Specified by ASME Sec. Ⅷ Div. 2 Appendix 26 for category A welds (both all weld metal and welded joint).

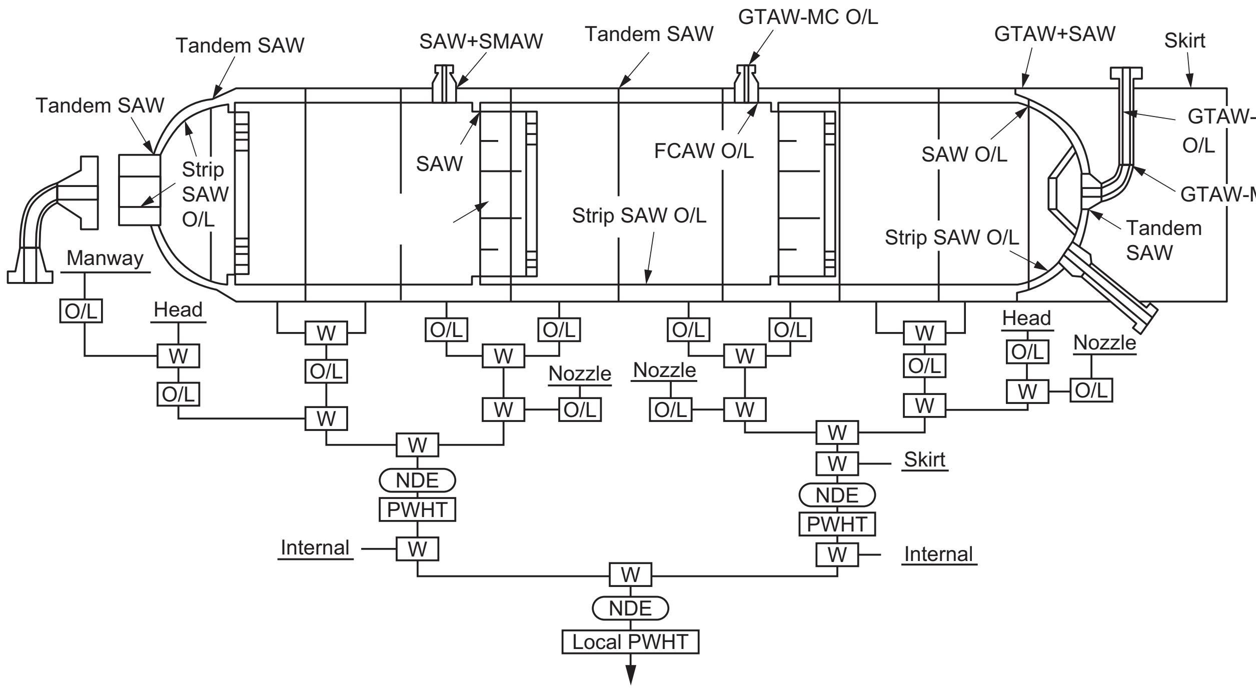
How reactor vessels are fabricated

Figure 3 shows a fabrication procedure for reactor pressure vessels. Stainless steel overlay welding of the internal surfaces of the Cr-Mo shell ring forgings is carried out on a single ring forging or two ring forgings joined by circumferential welding.

Overlay stainless steel welds protect the Cr-Mo base metal and weld metal from high-temperature high-pressure hydrogen during desulfurization. After this process, the shell ring forgings are joined by circumferential SAW welding accompanied by SAW and SMAW of nozzles in the shell rings. The heads of a reactor have a thickness about one half of that of the shell, and they are produced by hot pressing Cr-Mo steel plates without joints. The heads are processed by stainless steel overlay welding on their internal surfaces, followed by SAW of nozzles and SAW of head-to-shell circumferential joints. Bend pipe-to-nozzle neck and bend pipe-to-flange pipe girth joints are welded by automatic GTAW.

All the welds are subjected to nondestructive examinations (NDE) such as X-ray, ultrasonic, magnetic particle and liquid penetrant tests, followed by postweld heat treatment (PWHT). After PWHT, the soundness of the welds is again checked by NDE to ensure no cracking has developed. Next, the vessel is subjected to a pressure test, followed by the final NDE. The completed pressure vessel is then shipped. More than 95% of the welding operations in fabrication of reactor vessels are reportedly automated to assure consistent quality.

Figure 3: An example of fabrication procedure for reactor vessels by arc welding.
(Source: Welding Technique Vol.47, The Japan Welding Engineering Society)



SAW: Submerged arc welding
Strip SAW: SAW with strip electrodes
GTAW-MC: Automatic gas tungsten arc welding
FCAW: Flux cored arc welding (CO_2 shielding)
SMAW: Shielded metal arc welding
W: Joint welding
O/L: Overlay welding
NDE: Nondestructive examination
PWHT: Postweld heat treatment

Unbeatable characteristics of Kobelco 2.25Cr-1Mo-V filler metals

Kobe Steel has long carried out research in welding metallurgy of Cr-Mo weld metals and has developed innovative filler metals suited specifically for 2.25Cr-1 Mo-V steel. These filler metals are SMAW stick electrode of CM-A106H and CM-A106HD, SAW flux and wire of PF-500/US-521H and PF-500D/US-521 HD, and GTAW filler wire of TGS2CMH. These filler metals fulfill the requirements of ASME Sec. Ⅷ Div. 1 Appendix 31 and Div. 2 Appendix 26, which can be verified with the weld metal chemical and mechanical properties shown in Tables 2 and 3. These advanced filler metals are characterized by a sophisticated chemical composition that provides the weld metal with sufficient impact toughness and minimized temper embrittlement. The resulting weld metal also contains adequate amounts of vanadium and niobium to ensure tensile strength, creep rupture strength and resistance to high temperature hydrogen attack and hydrogen embrittlement.

In addition, the coating fluxes of CM-A106H and CM-A106HD are designed so as to perform sufficient usability in all position welding. The coating fluxes are of extra-low hydrogen type; therefore, these covered electrodes deposit very low hydrogen weld metal, thereby minimizing the susceptibility to delayed cracking.

PF-500 and PF-500D are ultra-low hydrogen bonded type fluxes for SAW. PF-500 and PF-500D pick up moisture at slower rates as compared with conventional bonded type fluxes. Furthermore, these SAW fluxes offer unsurpassed usability providing self-peeling slag removability in the narrow groove of heavy thick section work. TG-S2CMH offers excellent usability with sufficient wetting of the weld pool in narrow groove work, which ensures good performance in automatic or mechanized welding processes.

Table 2: Typical chemical compositions of weld metals

Product names	Polarity	Chemical composition (mass%)								
		C	Mn	Si	P	S	Cr	Mo	V	Nb
CM-A106H	AC	0.08	1.15	0.29	0.007	0.003	2.41	1.00	0.28	0.016
PF-500/US-521H		0.08	1.09	0.14	0.004	0.004	2.50	1.03	0.33	0.014
CM-A106HD	DCEP	0.08	1.12	0.24	0.005	0.002	2.48	1.05	0.27	0.012
PF-500D/US-521HD		0.07	1.26	0.17	0.007	0.001	2.44	1.03	0.34	0.011
TG-S2CMH	DCEN	0.10	0.38	0.14	0.003	0.004	2.21	1.02	0.21	0.025

Table 3: Typical mechanical properties of weld metals

Product names	Polarity	PWHT (℃ × h)	0.2% PS (MPa)	TS (MPa)	EL (%)	IV at −18℃ (J)
CM-A106H	AC	705 × 7	612	713	23	147
PF-500/US-521H		705 × 7	616	706	24	106
		705 × 26	533	639	26	142
CM-A106HD	DCEP	705 × 26	520	636	24	137
		705 × 8	598	713	21	121
PF-500D/US-521HD		705 × 26	518	634	26	142
		705 × 8	603	708	24	125
TG-S2CMH	DCEN	705 × 7	623	730	22	300

Figure 4: Microstructure of the dendritic zone of weld metal of fine bainite (CM-A106H).

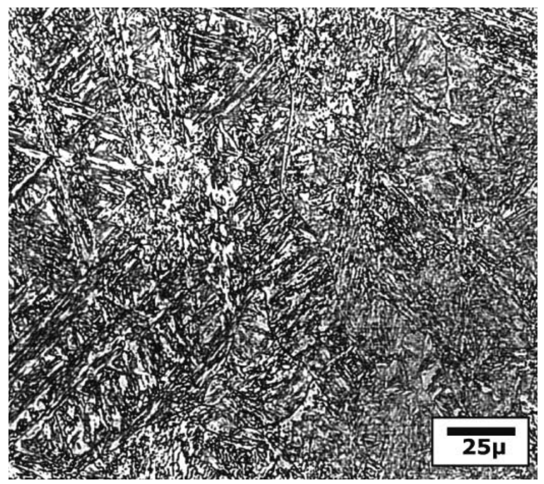
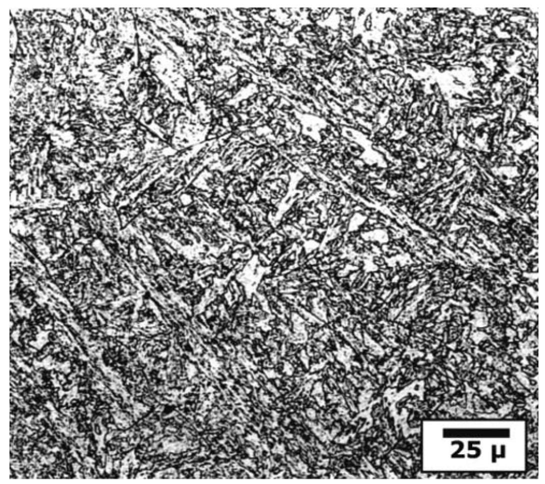


Figure 5: Microstructure of the dendritic zone of weld metal of fine bainite (PF-500/US-521H).



The high strength 2.25Cr-1Mo-V weld metals have fine bainitic structures as shown in Figure 4 for CM-A 106H and in Figure 5 for PF-500/US-521H. This is the reason why the weld metal exhibits high tensile strength, adequate creep rupture strength, sufficient impact toughness, and low susceptibility to temper embrittlement. As shown in Tables 2 and 3, AC-spec filler metals and DC-spec filler metals are comparable to each other about chemical and mechanical properties due to consistent fine microstructure.

Resistance to temper embrittlement is essential for filler metals for reactor vessels

Figures 6, 7 and 8 show Charpy impact and temper embrittlement test results of CM-A106H, PF-500/US-521 H and TG-S 2 CMH weld metals, respectively. These test results exhibit quite high notch toughness satisfying the ASME Code requirement of Charpy impact absorbed energy at −18℃ in the SR condition and sufficiently low susceptibility to the temper embrittlement by step cooling heat treatment.

Figure 6: Charpy impact test results of CM-A106H (4ϕ) weld metal after SR and SR + Step Cooling (Welding position: flat).

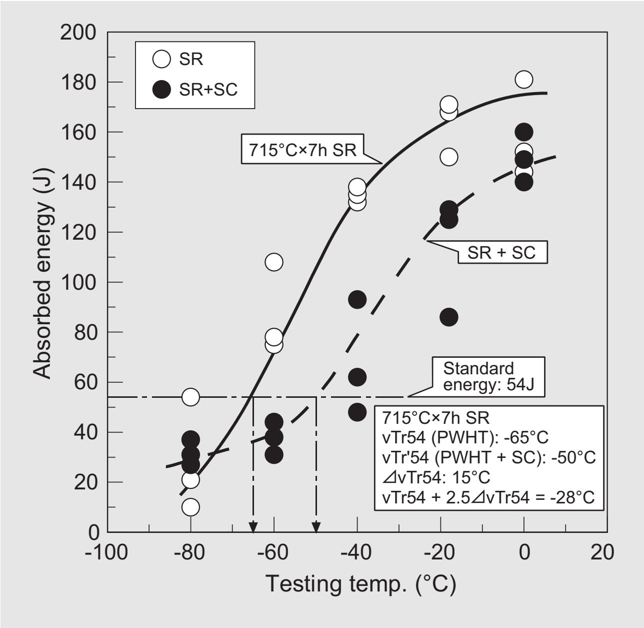


Figure 7: Charpy impact test results of PF-500/US-521H weld metal after SR and SR + Step Cooling

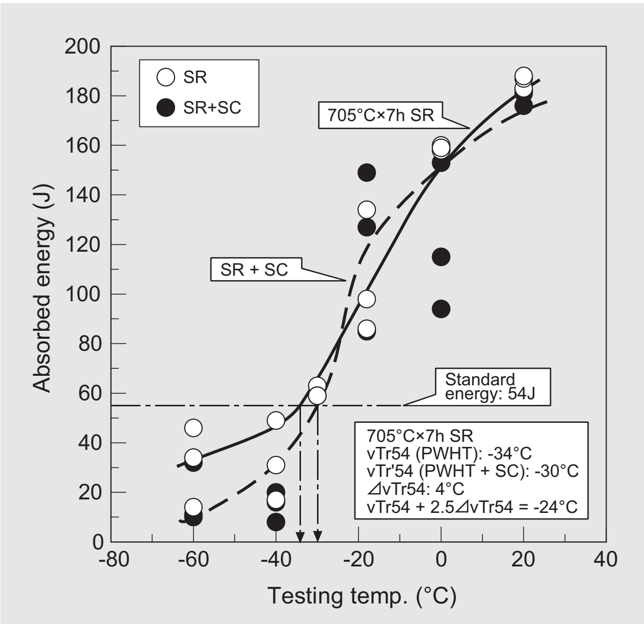


Figure 8: Charpy impact test results of TG-S2CMH weld metal after SR and SR + Step Cooling (Welding position: flat; Ar shielding).

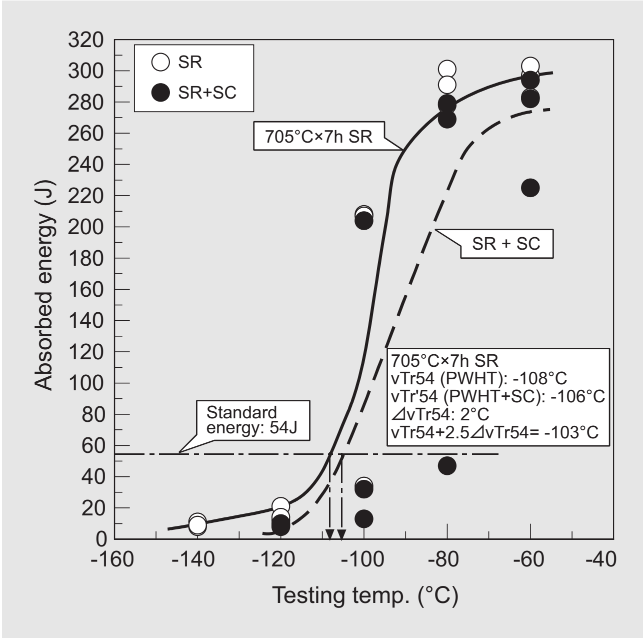
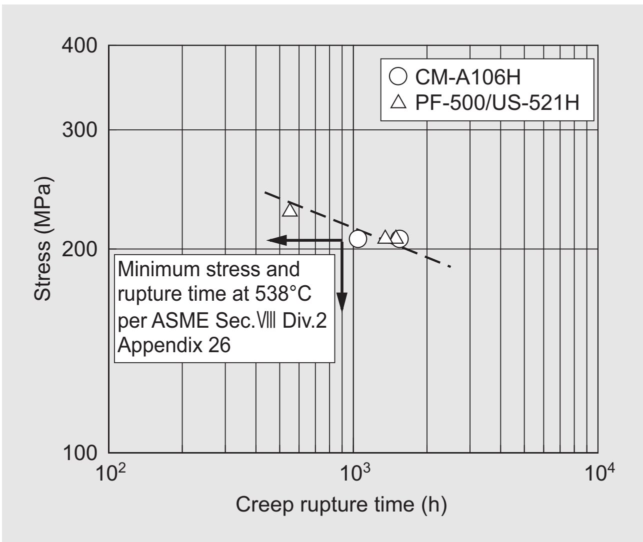


Figure 9 shows creep rupture test results of CM-A106 H and PF-500/US-521H weld metals after SR. It is obvious that the test results satisfy the ASME Code requirement. In this test, the testing temperature is 538 ℃ that is higher than the permissible maximum operation temperature (482℃) as per the ASME Code. The use of higher temperature is to know the creep rupture strength with shorter hours, by accelerating creep of the specimen.

Figure 9: Creep rupture test results of CM-A106H and PF-500/US-521H weld metals after SR (705℃ × 26h) (Polarity: AC; Testing temperature: 538℃).



※Please note that AWS A5.5 in this chapter refers to 2006 Edition.

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CM-9Cb AWS A5.5 E9016-G
TG-S9Cb AWS A5.28 ER90S-G
CM-96B9 AWS A5.5 E9016-B9 (2006Edit.)
CM-95B9 AWS A5.5 E9015-B9 (2006Edit.)
TG-S90B9 AWS A5.28 ER90S-B9

How advanced 9Cr filler metals help innovate power boilers

Steam boilers (Figure 1) produce high-temperature high-pressure steam by heating pressurized water contained in hermetically sealed vessels through combustion of such fuels as coal, LNG, and oil. Steam boilers are widely used for such various applications as power plants, ships, steel mills, textile processes, chemical processes, and oil refineries.

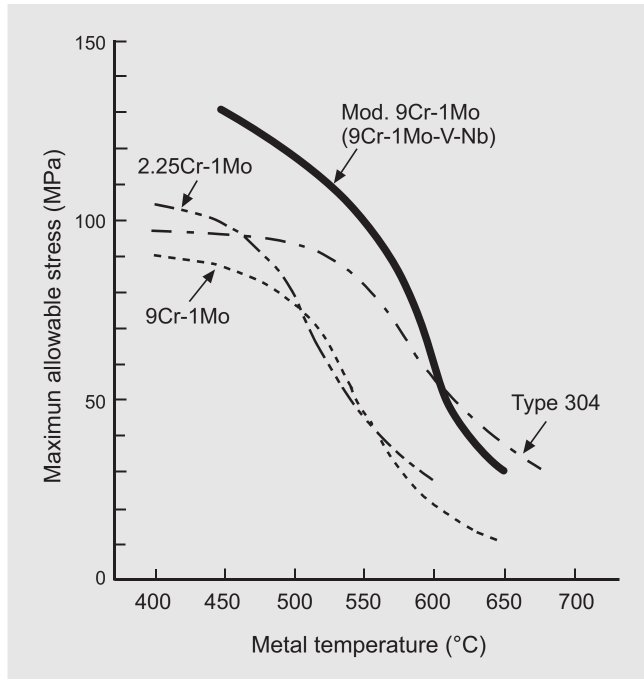
Figure 1: A coal-fired steam boiler consisting of the sophisticated piping system fabricated with tens of thousands of tubes and pipes made from carbon steel, Cr-Mo steel, and stainless steel.

Steam boilers, also known as power boilers, used in power plants generate high-temperature high-pressure steam for better power generation efficiency. The steam temperatures and pressures of coal-fired power boilers have been increasing to improve thermal efficiency. As the efficiency becomes higher, the consumption of fuels for generating unit electrical power can be decreased, thereby helping to combat global warming.

Among power boilers, supercritical pressure boilers are operated at high temperatures (e.g. 538℃) and high pressures (e.g. 24.1 MPa). Ultra-supercritical (USC) pressure boilers are operated at even higher steam temperatures (e.g. 593℃) and pressures (e.g. 31.4 MPa). Steam temperature and pressure are apt to be higher for more efficient power generation for the future.

As a factor in the technology of advanced power boilers, modified 9Cr-1Mo steel (9Cr-1Mo-V-Nb) is highlighted due to its superior high temperature performance relative to conventional 9Cr-1Mo steel and Type 304 stainless steel. That is, 9Cr-1Mo-V-Nb steel can be used with a higher allowable stress in comparison with 9Cr-1Mo and, up to 600℃, in comparison with Type 304, as shown in Figure 2.

Figure 2: A comparison between 9Cr-1Mo-V-Nb and other steels on the maximum allowable stress for high-temperature equipment over a range of metal temperatures.



The use of 9Cr-1Mo-V-Nb steel is expanding for ultra-supercritical pressure boilers. With ferritic 9Cr-1Mo-V-Nb steel, the countermeasures (e.g. use of expansion joints) to release thermal stresses in the tube bundle structures of steam boilers can be lessened than with austenitic Type 304, because the thermal expansion and contraction of ferritic 9Cr steels are less. The thermal stresses are raised by the thermal cycle during operation accompanied by the fluctuation of power generation in a day.

How to select suitable advanced 9Cr filler metals that match the base metal

Table 1 is a quick guide to suitable filler metals for shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW) of 9Cr-1Mo-V-Nb steels. The base metal grades are in accordance with the ASTM standard but this guidance can also be used for other equivalent base metal grades per other national standards.

Table 1: A quick guide to matching filler metals for the 9Cr-1 Mo-V-Nb base metal grades

Grade of steel (ASTM)			SMAW (AWS A5.5)	GTAW (AWS A5.28)
Plate	Tube/Pipe	Forging		
A387 Gr.91 Cl.2	A199 Gr. T91 A213 Gr. T91 A234 Gr.WP91 A335 Gr. P91	A182 Gr.F91 A336 Gr.F91	**CM-9Cb** (E9016-G)	**TG-S9Cb** (ER90S-G)
			CM-96B9 (E9016-B9)※ **CM-95B9** (E9015-B9)※	**TG-S90B9** (ER90S-B9)

※AWS A5.5-2006

There are two choices for 9Cr-1Mo-V-Nb steel. One is the Kobelco original type (CM-9Cb, TG-S9Cb), which satisfies the mechanical properties requirement of the AWS standard but its chemical composition is unique and it has been used for many ultra-supercritical pressure boilers fabricated by Japanese manufacturers. The other one is the AWS type (CM-96B9, CM-95B9, TG-S90B9), which has been developed by modifying the original type so as to conform with both the mechanical and chemical requirements of the AWS standard (2006 Edition), taking into account the usual requirements of international customers.

CM-9Cb and TG-S9Cb: filler metals for ultra-supercritical pressure boilers

In the early 1980's when the research and development of coal-fired, ultra-supercritical pressure boilers began among the leading steel producers and boiler fabricators in Japan, Kobe Steel developed suitable filler metals for the modified 9Cr-1Mo steel.

This advanced steel is alloyed with considerable amounts of vanadium, niobium and nitrogen in addition to chromium and molybdenum to improve elevated-temperature strength. However, filler metals, inherently, cannot accommodate as much niobium and nitrogen as contained in the steel because such elements result in poor weldability. This is why CM-9Cb and TG-S9Cb have unique chemical compositions that provide good performance in mechanical properties and welding workability in out-of-position welding. Table 2 shows the typical chemical compositions of these filler metals, in comparison with the chemical requirements for a 9Cr-1Mo-V-Nb steel tube of ASTM A213 T91.

Table 2: Typical chemical compositions of CM-9Cb and TG-S9Cb weld metals in comparison with the A213 T91 tube chemistry range (mass%)

Elements	CM-9Cb	TG-S9Cb	ASTM A213 T91
	AC	DCEN	
C	0.06	0.07	0.08-0.12
Mn	1.51	0.99	0.30-0.60
Si	0.31	0.16	0.20-0.50
P	0.006	0.008	0.020 max
S	0.003	0.006	0.010 max
Cr	9.11	8.97	8.00-9.50
Mo	1.06	0.90	0.85-1.05
Ni	0.94	0.68	0.40 max
V	0.18	0.18	0.18-0.25
Nb	0.03	0.04	0.06-0.1
N	0.030	0.022	0.030-0.070
Al	−	−	0.04 max

Simple alloying of conventional 9Cr-1Mo filler metal with vanadium and niobium creates a heterogeneous microstructure consisting of coarse, polygonal ferrite precipitates in the martensitic matrix, thereby decreasing strength and impact toughness. However, CM-9Cb and TG-S9Cb offer fine, homogeneous microstructures (Figure 3) created by the elaborate chemical compositions.

Figure 3: CM-9Cb deposits homogeneous microstructure consisting of tempered martensite with the absence of polygonal ferrite after PWHT (750℃ × 5h), exhibiting a dendritic zone (upper) and a pass-to-pass tempered zone (under).

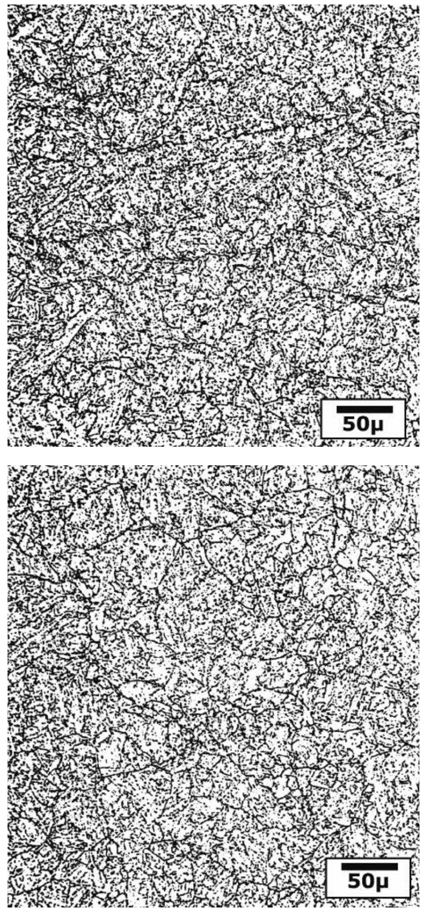


Figure 4: High-temperature strength of CM-9Cb (4ϕ) weld metal, satisfying the minimum strength of modified 9Cr-1Mo steel.

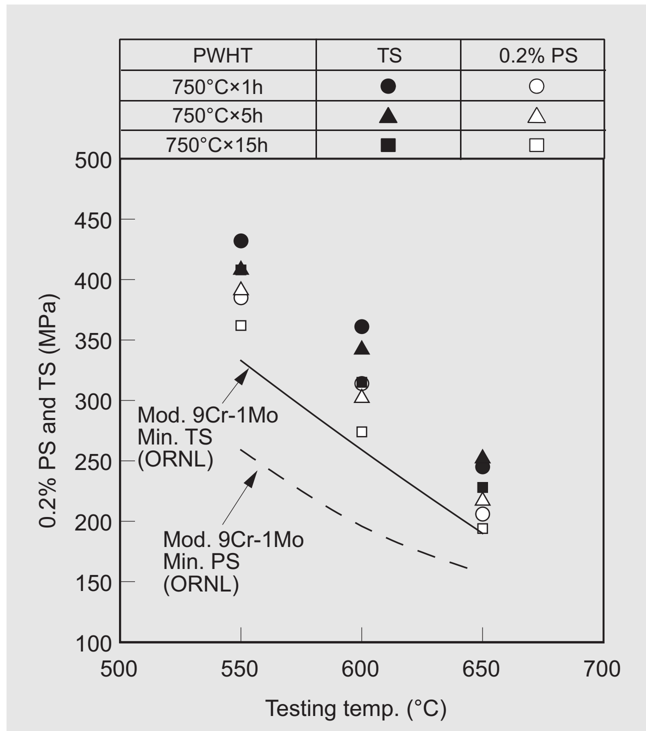
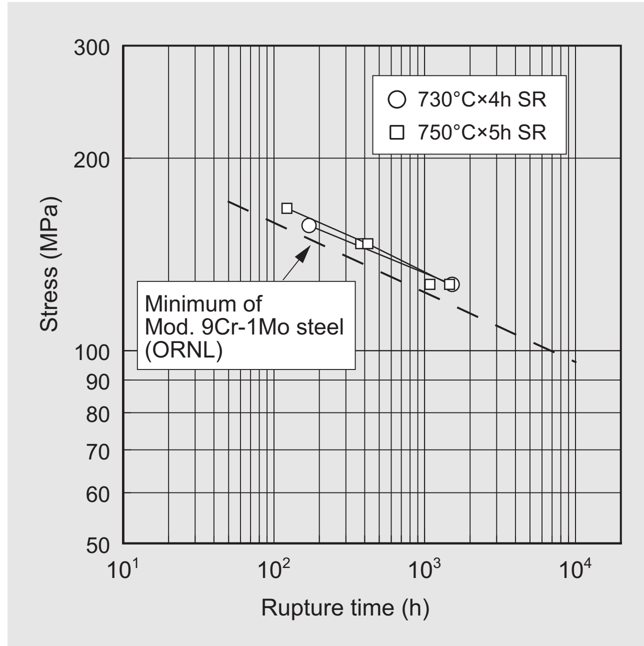


Figure 5: Creep rupture strength of CM-9Cb (4ϕ) weld metal, satisfying the minimum rupture strength of modified 9Cr-1Mo steel.



Typical applications for CM-9Cb and TG-S9Cb are girth welding of superheater tubes, reheater tubes and steam headers of USC boilers that are operated in the hard steam conditions (e.g. 593℃ × 31.4 MPa). Therefore, strength at elevated temperatures is the key property of this kind of filler metals. Figures 4 and 5 show high-temperature strength and creep rupture strength of CM-9Cb weld metal, respectively. These figures verify that CM-9Cb satisfies the minimum yield strength, tensile strength and rupture strength of modified 9Cr-1Mo steel.

CM-96B9, CM-95B9 and TG-S90B9: filler metals for international applications

These filler metals have been developed by modifying the chemical composition of CM-9Cb and TG-S9Cb to make it easier for international customers to select a suitable filler metal per the AWS chemical requirement designation (B9) for 9Cr-1Mo-V-Nb steel. The welding usability, mechanical properties and crack resistibility of these filler metals are comparable to the Kobelco original ones. Table 3 shows typical chemical compositions of SMAW filler metals (CM-96B9; CM-95B9) and the relevant AWS A5.5 requirements. A GTAW filler metal of TG-S90B9 features elaborate chemical composition in conformity with the AWS A 5.28 requirements, as shown in Table 4.

Table 3: Typical chemical compositions of all weld metals (mass%)

Elements	CM-96B9	CM-95B9	AWS A5.5 (2006 Edition) E9016-B9, E9015-B9
C	0.10	0.10	0.08-0.13
Mn	0.85	0.84	1.20 max
Si	0.19	0.22	0.30 max
P	0.007	0.007	0.01 max
S	0.004	0.002	0.01 max
Cu	0.03	0.02	0.25 max
Ni	0.52	0.51	1.0 max
Cr	9.01	8.94	8.0-10.5
Mo	1.05	1.02	0.85-1.20
V	0.24	0.23	0.15-0.30
Nb	0.04	0.04	0.02-0.07
Al	0.002	0.002	0.04 max
N	0.038	0.039	0.02-0.07
Mn+Ni	1.37	1.35	1.50 max
Polarity	DCEP	DCEP	E9016-B9: AC/DCEP E9015-B9: DCEP

Table 4: Typical chemical composition of TG-S90B9 filler wire (mass%)

Elements	TG-S90B9	AWS A5.28 ER90S-B9
C	0.11	0.07-0.13
Mn	0.69	1.20 max
Si	0.24	0.15-0.50
P	0.004	0.010 max
S	0.004	0.010 max
Cu	0.01	0.20 max
Ni	0.53	0.80 max
Cr	8.91	8.00-10.50
Mo	0.94	0.85-1.20
V	0.23	0.15-0.30
Nb	0.05	0.02-0.10
Al	0.003	0.04 max
N	0.042	0.03-0.07
Mn+Ni	1.22	1.50 max

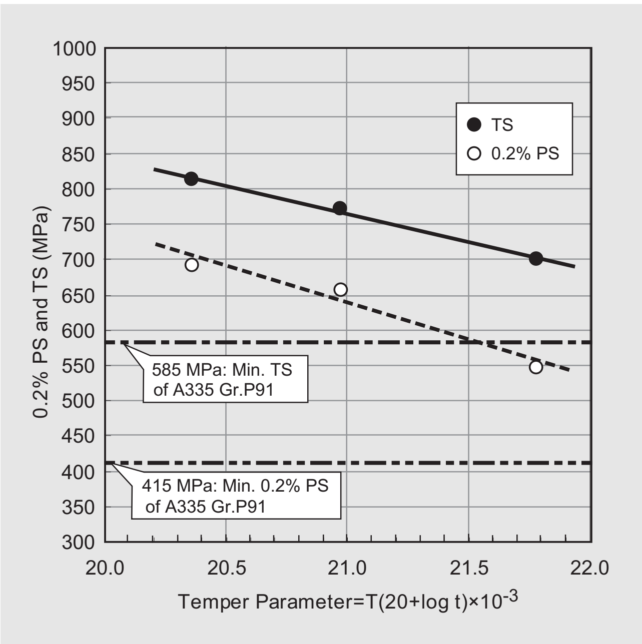
Table 5 shows the tensile properties of CM-96B9, CM-95B9 and TG-S90B9 weld metals, which satisfy the AWS requirements. In addition, Figures 6 and 7 verify that both SMAW and GTAW filler metals fulfill the ASTM requirements for A335 Gr. P91 even in the stricter condition of PWHT with a longer soaking time.

Table 5: Tensile test results of CM-96B9 and CM-95B (5ϕ, DCEP) as well as TG-S90B9 (1.2ϕ, DCEN) weld metals in comparison with the AWS requirements

Product names	PWHT (℃ × h)	Temper parameter [1]	0.2% PS (MPa)	TS (MPa)	El (%)
CM-96B9	745 × 1	20.36	695	814	20
	760 × 2	20.97	658	771	21
	775 × 6	21.78	550	701	29
CM-95B9	760 × 2	20.97	622	757	22
	780 × 2	21.38	581	724	24
TG-S90B9	745 × 1	20.36	756	852	21
	760 × 2	20.97	706	809	22
	775 × 6	21.78	631	744	26
AWS A5.5 E9016-B9 E9015-B9	760 × 2	20.97	530 min.	620 min.	17 min.
AWS A5.28 ER90S-B9	760 × 2	20.97	410 min.	620 min.	16 min.

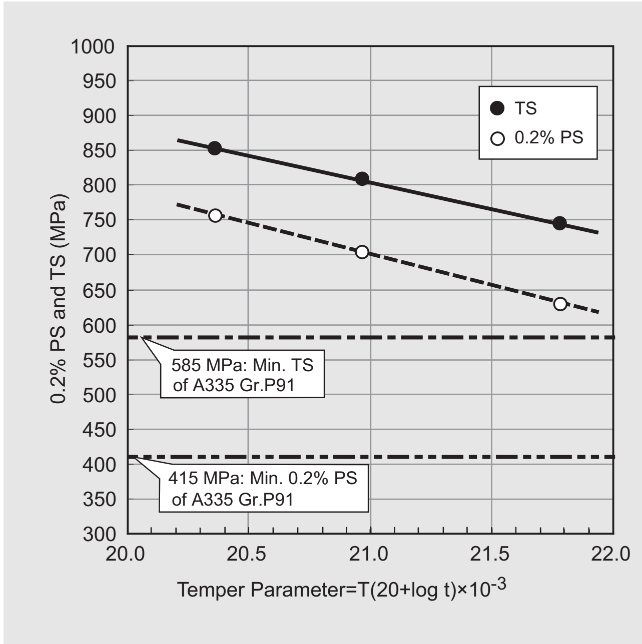
1. Temper parameter = T (20 + log t) × 10^{-3}.
T: K (=℃+273.15); t: hours

Figure 6: Tensile properties of CM-96B9 weld metal as a function of temper parameter.



T: K (=℃+273.15); t: hours

Figure 7: Tensile properties of TG-S90B9 weld metal as a function of temper parameter.



T: K (=℃+273.15); t: hours

Tips for successful welding of modified 9Cr steel

(1) Remedies to cold or delayed cracks:

9Cr-1Mo-V-Nb steel has higher self-hardenability relative to such Cr-Mo steels as 2.25Cr-1Mo, 1.25Cr-0.5Mo, and 0.5Mo. Therefore, preventive measures against cold cracking or delayed cracking must be stricter. The most effective measures are preheating the work by 250-350℃ and maintaining the work at this temperature during welding until starting PWHT. These measures can reduce the cooling rate of the weld to decrease the hardness of the weld and to promote hydrogen diffusion from the weld, thereby preventing cold cracking.

In cases where the postweld work has to be cooled to room temperature for nondestructive examination before PWHT, the work should first be heated at temperatures between 250-300℃ for 30-60 minutes immediately after welding to remove the diffusible hydrogen from the weld and prevent delayed cracking.

SMAW stick electrodes should be redried at 325-375 ℃ for 1 hour before use to remove absorbed moisture, the source of diffusible hydrogen.

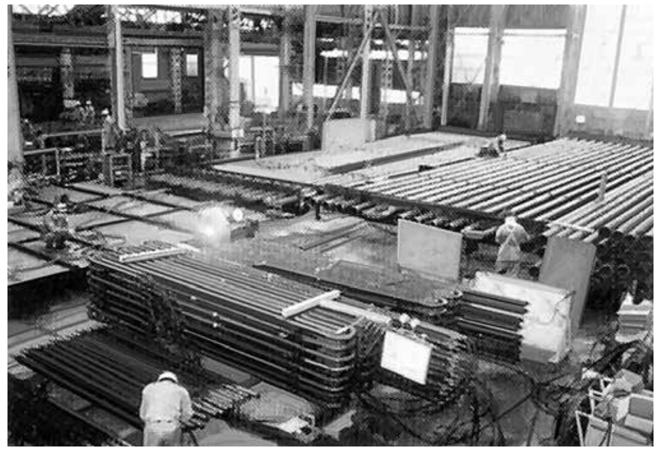
(2) Preventing hot or solidification cracks:

Kobelco 9Cr-1Mo-V-Nb filler metals contain phosphorous and sulfur at quite low levels and sufficient manganese to minimize the susceptibility to hot cracking or solidification cracking. However, 9Cr-1Mo-V-Nb weld metals are inherently susceptible to hot cracking. Small diameter tubes having thin sections also sometimes suffer from hot cracks in the weld. Therefore, excessively high welding currents should be avoided.

(3) Proper PWHT temperature:

PWHT temperature is a key factor to control the quality of welds. ASME Sec. Ⅷ Div. 1, for instance, specifies a minimum PWHT temperature of 704℃ for 9Cr-1Mo-V-Nb steel (e.g. A213 T91). However, for better quality in ductility and toughness of weld metal, the range 710-780℃ is recommended for filler metals discussed in this article.

9Cr-1Mo-V-Nb steel is often used for super heater tubes, reheater tubes and steam headers of coal-fired steam boilers in the trend of higher steam conditions (Photo courtesy: Nagasaki Kogyosho Co., Ltd., Japan).



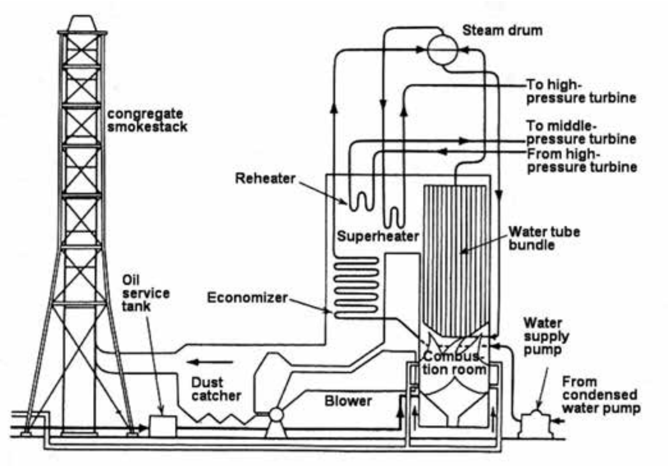
TRUSTARC™ TRUSTARC™

CM-2CW TG-S2CW

AWS A5.5 E9016-G AWS A5.28 ER90S-G

High-temperature high-pressure coal-fired power boilers require for the structural components such as super heater tubes and headers to be lower in fabrication costs and better in weldability as well as higher in creep rupture strength. CM-2CW and TG-S2CW are the right tools for such applications.

A tubing/piping diagram of a water tube boiler (Source: K. Nagumo, Basic Knowledge of Boilers, Ohmsha, 2002)



2.25Cr-1Mo steel, a typical type of heat-resistant low-alloy steel, has long been used for power boilers due to its superior high temperature strength and workability. However, in response to the demand for higher creep rupture strength materials for high-temperature high-pressure power boilers, low-C 2.25Cr-W-V-Nb steel has been developed by alloying with tungsten and optimizing the content of other alloying elements. In the ASTM standard, this steel is specified as A213 Grade T23 for tubes and A335 Grade P23 for pipes (Table 1).

This W-enhanced 2.25Cr steel offers superior creep rupture strength that is almost double that of conventional 2.25Cr-1Mo steel and comparable to that of 9Cr-1Mo-V-Nb steel. It also offers better weldability due to its low carbon content.

The piping and tubing of W-enhanced 2.25Cr steel for steam boilers, including supper heater tubes, can be welded by using Kobelco filler metals tailored for this steel. Table 2 shows the typical chemical and mechanical properties of the filler metals for individual welding processes. Such excellent properties are provided by the weld metal of fine bainitic microstructure as shown in Figure 1.

Table 1: Chemical and mechanical requirements for W-enhanced 2.25Cr steel tubes and pipes as per ASTM-2009

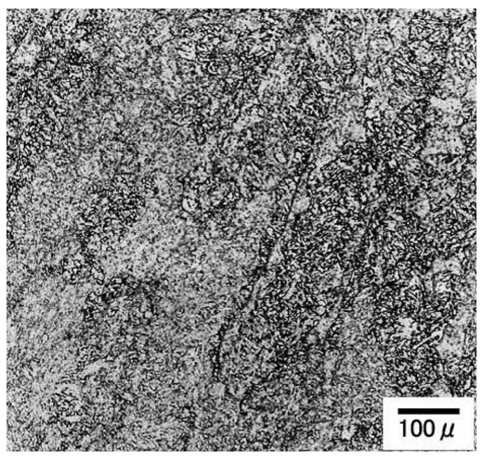
C	Si	Mn	P	S	Cr	Mo
0.04-0.10	0.50 max.	0.10-0.60	0.030 max.	0.010 max.	1.90-2.60	0.05-0.30
V	Nb	W	B	N	Al	
0.20-0.30	0.02-0.08	1.45-1.75	0.0005-0.006	0.03 max.	0.030 max.	
YS (MPa)		TS (MPa)		El (%)		
400 min.		510 min.		20 min.		

Table 2: Typical chemical and mechanical properties

Elements	CM-2CW	TG-S2CW
	Weld metal (mass%)	
C	0.04	0.06
Si	0.27	0.43
Mn	0.84	0.41
P	0.009	0.007
S	0.006	0.008
Cu	0.02	0.14
Cr	2.39	2.39
Mo	0.07	0.48
V	0.21	0.31
Nb	0.02	0.03
W	1.70	1.24
0.2% PS (MPa)	473	494
TS (MPa)	582	627
El (%), 4D	28	31
vE0℃ (J)	158	289
Creep rupture time (h) [1]	11000 over [2]	11000 over [2]
PWHT (℃× h)	747 × 2	747 × 2
Polarity	DCEP	DCEN
Shielding gas	−	Ar

1. Testing temp. and stress: 550℃, 98 MPa.
2. Now testing (Apr '14)

Figure 1: Fine bainitic microstructure of CM-2CW weld metal after PWHT.



TRUSTARC™

CR-12S & TG-S12CRS

AWS A5.5 E9016-G & A5.28 ER90S-G

Increased efficiency in coal-fired power generation has reduced that industry's consumption of fuels, thereby decreasing carbon dioxide emissions associated with global warming. In a related trend, high performance steels have been developed to resist the increased temperatures and pressures of steam in the boilers. W-enhanced 9-12Cr steels (such as ASME P92 and P122) are now regarded as state-of-the-art high-Cr ferritic steels that are superior to 9Cr-1Mo-V-Nb steel (typically ASME P91) in creep rupture strength.

To accommodate this grade of steel, Kobe Steel has developed CR-12S for shielded metal arc welding and TG-S12CRS for gas tungsten arc welding. Tables 1 and 2 show the unique chemical compositions and excellent mechanical properties of these filler metals.

Table 1: Chemical compositions of weld metal and wire (mass%)

Elements	Product names		
	CR-12S		TG-S12CRS
C	0.08	0.08	0.07
Si	0.36	0.41	0.35
Mn	1.01	0.94	0.74
P	0.007	0.008	0.004
S	0.002	0.001	0.003
Ni	0.49	0.52	0.51
Co	1.58	1.57	1.01
Cr	9.83	9.62	9.92
Mo	0.24	0.23	0.35
Nb	0.032	0.030	0.04
V	0.35	0.37	0.21
W	1.63	1.63	1.45
Cu	0.02	0.02	0.01
Cr_{eq} [3]	7.55	7.85	8.40
Sampling	Weld metal		Wire
Polarity	AC [1]	DCEP [2]	DCEN

1. 4.0φ: 160A; Position: flat.
2. 4.0φ: 140A; Position: flat.
3. Cr_{eq} = Cr+6Si+4Mo+1.5W+11V+5Nb+1.2Sol.Al+8Ti-40C-2Mn-4Ni-2Co-30N-Cu (%)

Table 2: Typical mechanical properties of weld metal

Product names	CR-12S		TG-S12CRS
Polarity	AC	DCEP	DCEN
0.2% PS (MPa)	648	645	686
TS (MPa)	768	771	790
El (%)	26	22	23
RA (%)	64	68	68
IV (J) at 0℃	40	40	44
PWHT	740℃ × 8h		

note:
・CR-12S; 1.2 kJ/mm; Preheat & interpass temp.: 200-250℃.
・TG-S12CRS; 1.8 kJ/mm; Preheat & interpass temp.: 200-250℃.

The chemical compositions of CR-12S and TG-12CRS are designed with the proper chromium equivalent (Cr_{eq}) so as to minimize the precipitation of delta ferrite in the martensitic matrix, thereby assuring sufficient impact toughness and creep rupture strength.

Typical applications for these filler metals include headers and main steam pipes in supercritical pressure boilers and ultra-supercritical pressure boilers which operate at higher temperatures and pressures as compared with conventional boilers.

Figure 1: Main steam pipes and a header in position connected with a bundle of tubes. (Source: Mitsubishi Heavy Industries, Ltd. and National Institute of Materials Science, Japan)