

WELDING OF STEEL

The following information is for guidance in determining the weldability of various grades of steel which have been listed under the appropriate steel standard specification or proprietary trade names. For a comprehensive treatment of the "weldability of steels" please refer to the Welding Technology Institute of Australia (WTIA) Technical Note 1.

Factors influencing weldability:

1) The effect of Carbon on Steel:

Carbon is a major alloying element in the various grades of steel; increasing the carbon content of a particular steel results in a corresponding increase in hardenability when the material is subject to thermal treatment.

From a welding point of view, the best practice is to adopt a welding procedure which minimises the risk of high hardness in the Heat Affected Zone (HAZ) of the base metal and the weld deposit.

Determination of carbon equivalent and group number of the steel:

In determining the weldability of a particular grade of steel, consideration must be given to the combined effect of alloying elements, in particular carbon and manganese. The following formula for Carbon equivalent (CE) takes account of the important alloying elements in calculating a number which grades the steel in terms of its relative weldability. Refer to the Carbon Equivalent (CE) table and respective weldability reference numbers detailed in Table 1.

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

2) Determination of Combined Joint Thickness:

The concept of combined joint thickness (CJT) is required to address the expected cooling rate of adjoining sections - calculations for determining combined thickness are based on the following formula. Please refer to Diagram 1 for CJT's for a range of joint configurations.

$$T_{CJT} = t_1 + t_2 + t_3 + t_4$$

3) Welding Energy or Heat Input:

Welding energy or heat input calculations are dependent upon the practical welding variables used, in particular welding current, arc voltage and welding speed for the specific arc welding processes adopted including manual metal arc, semi-automatic and automatic welding.

Welding energy input is based on the following formula:

$$Q = \frac{I \times E \times 60}{V \times 1000}$$

where **Q** = Welding energy or heat input (Kilojoules per millimeter, KJ/mm)
E = Arc voltage (volts)
I = Welding current (Amperes)
V = Welding speed or travel rate (mm/min)

4) Hydrogen Controlled Consumables and Welding Process Selection:

When determining the weldability of steel, careful consideration must be given to welding consumable selection.

For the purpose of preheat determination, the welding consumable/process combination used can be broadly grouped into two major types. Those which are hydrogen controlled and those which are not hydrogen controlled:

▲ Non-hydrogen controlled welding consumables:

This group includes cellulose, mild steel and iron powder type electrodes to Australian Standard AS/NZS 1553.1 classifications EXX10, EXX11, EXX12, EXX13, EXX14 and EXX24. For these non-hydrogen controlled electrodes care should be taken to avoid moisture pick-up from exposure to adverse atmospheric conditions (ie excessive heat, humidity etc)

▲ Hydrogen controlled welding consumables:

Hydrogen controlled types are defined as those consumable/process combinations which produce less than 15 mls of diffusible hydrogen per 100 gms of deposited weld metal. These include hydrogen controlled manual arc electrodes of the EXX16, EXX18, EXX28 and EXX48 types to AS/NZS 1553 Parts 1 and 2. Many gas shielded metal-cored and flux-cored welding wires to AS 2203.1 and all steel gas metal-arc welding wires to AS/NZS 27171 satisfy the hydrogen controlled requirement provided they are used with the correct shielding gas.

For all hydrogen controlled welding consumables, precautions must be taken in storage and handling to ensure the hydrogen status is not compromised.

For further information on the correct storage and handling of CIGWELD welding consumables, please refer to this handbook or WTIA publication Tech Note 3 "Care and Conditioning of Welding Consumables".

General Procedure in Determining Weldability and Preheat Requirements.

1. Select the corresponding weldability reference number for the particular grade of steel.

Where a particular grade of steel is not listed, calculate the CE from the formulae given in section 1. Using Table 1 cross reference the CE calculation to determine the appropriate weldability reference number.

2. Using Diagram 1 as a guide, determine the combined joint thickness (CJT) for the specific joint being welded.
3. Using Figure 1, determine the joint weldability index from the intersection point of the two numbers from 1 & 2 above (ie the weldability reference number and the CJT number).
4. Cross reference the joint weldability index, with the expected welding energy input (in kJ/mm) on Figure 2* or 3* to calculate the appropriate preheat temperature.

*Note: if a **hydrogen controlled welding consumable** is to be used, refer to Figure 2; if a **non-hydrogen controlled welding consumable** is to be used, refer to Figure 3.

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The Need for Preheating of the Steel Joint:

The beneficial effects of preheating in improving the weldability of the steel joint are:

1. Preheating retards the cooling rate in the joint and is beneficial in preventing undesirable metallurgical microstructures from occurring in the heat affected zone (HAZ) of the base metal and in the weld metal of high alloy steel deposits.
2. Preheating is used to offset the thermal conductivity of the steel sections and is beneficial in reducing the level of residual stress in the joint after welding.
3. Preheat temperatures should be determined in accordance with the requirements of Figure 2 or 3 with the preheat temperature being maintained between subsequent weld passes.
4. Preheating assists in the removal of diffusible hydrogen from the weld zone ie. the weld bead and HAZ.

Tack Welding Procedure:

Best practice requires that the specified preheat is used prior to any tack welding operation regardless of the fact that tack welds will become part of the weldment.

Weldability Reference Numbers:

The Weldability Reference Numbers used in this guide relate to the carbon equivalent (CE) ranges shown in Table 1 below:

Carbon Equivalent (CE)	Weldability Reference Number	Carbon Equivalent (CE)	Weldability Reference Number
below 0.30	1	0.55 to below 0.60	7
≤ 0.30 to below 0.35	2	0.60 to below 0.65	8
0.35 to below 0.40	3	0.65 to below 0.70	9
0.40 to below 0.45	4	0.70 to below 0.75	10
0.45 to below 0.50	5	0.75 to below 0.80	11
0.50 to below 0.55	6	0.80 and above	12

Table 1

Note: Weldability Reference Numbers above 12 (ie. 12A, 12B, 12C & 13) are not related to CE.

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Preheat Determination:

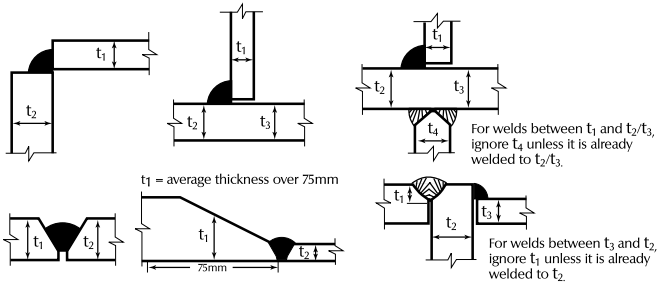


Diagram 1 - Combined Joint Thickness (CJT) calculations for welds shown in black.

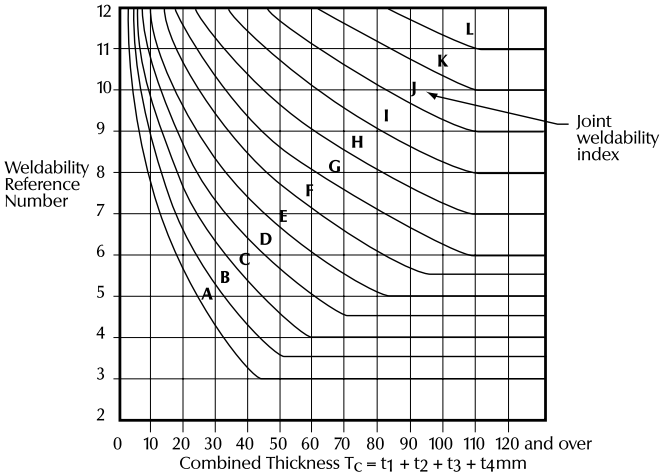


Figure 1 - Determination of joint weldability index using combined joint thickness and weldability reference number.

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Preheat Determination:

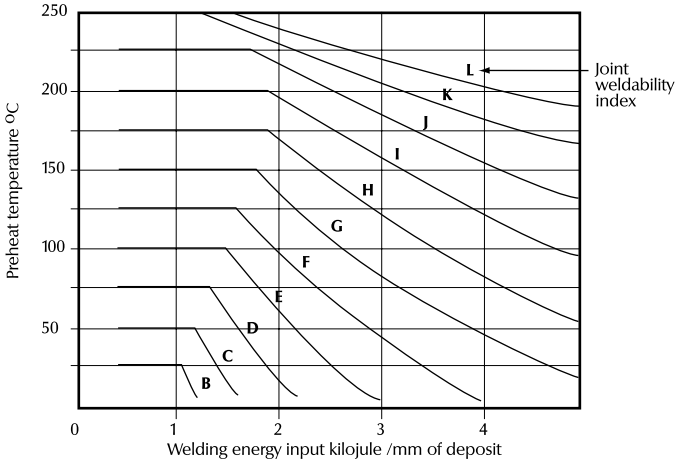


Figure 2 - Determination of preheat requirements for hydrogen controlled electrodes (EXX16, EXX18, EXX28 & EXX48) semi-automatic and automatic welding process.

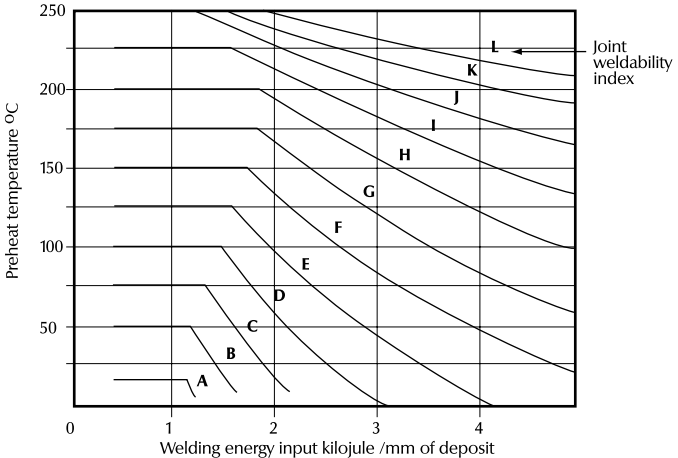


Figure 3 - Determination of preheat requirements for Manual metal-Arc Welding with other than hydrogen controlled consumables.

Steel Specifications:

AS 1442 (1992) Hot Rolled Bar and Semi Finished Product.
AS 1443 (1993) Cold Finished Bars Carbon Steel.

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
1006	0.08	0.25/0.50	0.10/0.35	1
1010	0.08/0.13	0.30/0.60	0.10/0.35	1
1020	0.18/0.23	0.30/0.60	0.10/0.35	2
1030	0.28/0.34	0.60/0.90	0.10/0.35	5
1040	0.37/0.44	0.60/0.90	0.10/0.35	8
1050	0.48/0.55	0.60/0.90	0.10/0.35	10
1060	0.55/0.65	0.60/0.90	0.10/0.35	11
1070	0.65/0.75	0.60/0.90	0.10/0.35	12

Free Machine Steels.

Steel Designation	Chemical Analysis %				Weldability Reference Number
	C	Mn	Si	Pb	
X1112	0.08/0.15	1.10/1.40	0.20-0.30		2A
1144	0.40/0.48	1.35/0.65	0.08-0.13		11A
X1147	0.40/0.47	0.60/1.90	0.10-0.35		11A
1214	0.15 Max	0.80/1.20	0.25-0.35		3A
12L14	0.15 Max	0.80/1.20	0.25-0.35	0.15-0.35	3A

AS 1447 (1991) Hot Rolled Spring Steels.

Steel Designation	Chemical Analysis %				Weldability Reference Number
	C	Mn	Si	Cr	
K1070S	0.65-0.75	0.60-0.90	0.10-0.35		12A
XK5155S	0.50-0.60	0.70-1.0	0.10-0.35	0.70-0.90	12A
XK5160S	0.55-0.65	0.70-1.0	0.10-0.35	0.70-0.90	12A
XK9261S	0.55-0.65	0.70-1.0	1.8-2.20		12A

AS 1663 (1991) Structural Steel Hollow Sections.

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
C250-C250LO*	0.12	0.50	0.05	1
C350-C350LO*	0.20	1.60	0.05	3
C450-C450LO*	0.20	1.60	0.35	3

* Nb + V + Ti = 0.15

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Steel Specifications:

Carbon Manganese Steels.

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
X1315	0.12-0.18	1.40-1.70	5
X1320	0.18-0.23	1.40-1.70	5
X1325	0.23-0.28	1.40-1.70	6
X1340	0.38-0.43	1.40-1.70	10
X1345	0.43-0.48	1.40-1.70	11

AS 1444 (1986)

Fully Killed Alloy Steels.

AS 2506 (1990)

Wrought Alloy Steels.

Steel Designation	Chemical Analysis %						Weldability Reference Number
	C	Mn	Si	Ni	Cr	Mo	
XK3312(EN36A)	0.10-0.16	0.35-0.60	0.10-0.35	3.0-3.75	0.70-1.0		6
4130	0.28-0.33	0.40-0.60			0.80-1.10	0.15-0.25	9
4140	0.30-0.43	0.75-1.0			0.80-1.10	0.15-0.25	12
XK4150	0.47-0.55	1.0-1.40	0.10-0.40		0.40-0.80	0.10-0.20	12
XK4340	0.37-0.44	0.55-0.90	0.10-0.35	1.55-2.0	0.65-0.95	0.20-0.35	12
4620	0.17-0.23	0.45-0.65	0.10-0.35	1.65-2.0		0.20-0.30	6
5140	0.38-0.43	0.70-0.90			0.70-0.90		11
8620	0.18-0.23	0.70-0.90	0.10-0.35	0.40-0.70	0.40-0.60	0.15-0.25	6
9050	0.45-0.55	0.90-1.20	0.60-0.90				11
XK9315	0.12-0.18	0.25-0.50	1.10-0.35	3.90-4.30	1.0-1.40	0.15-0.30	10
XK9931	0.27-0.35	0.45-0.70	0.10-0.35	2.30-2.80	0.50-0.80	0.45-0.65	12
XK9940	0.36-0.44	0.45-0.70	0.10-0.35	2.3-2.80	0.50-0.80	0.45-0.65	12

Steel Specifications:

BS STEEL SPECIFICATION.

Steel Designation	Chemical Analysis %								Weldability Reference Number
	C	Mn	Si	Cr	Ni	Mo	S	P	
BS 1501 (1980) Steels for Fired and Unfired Pressure Vessels									
Grade 360	0.17	0.40 - 1.20							3
Grade 400	0.22	0.50 - 1.30							4
Grade 430	0.25	0.60 - 1.40							5
BS EN 10028-2 (1993) Steels for Pressure Purposes, Non-alloy and Alloy Steels with Elevated Temperature Properties									
Grade P235GH	0.16	0.40 - 1.20							3
Grade P265GH	0.20	0.50 - 1.40							4
Grade P295GH	0.08 - 0.20	0.90 - 1.50							5
Grade P355GH	0.10 - 0.22	1.00 - 1.70							5
BS EN 10025 (1980) Hot Rolled Products of Non Alloy Structural Steels									
Grade Fe 360									3
Grade Fe 430									4
Grade Fe 430		1.60							5
BS970 Specification Steels									
En 25	0.27-0.35	0.10-0.35	0.50-0.70	2.30-2.50	0.50-0.80	0.40-0.70	0.050	0.050	12
En 26	0.36-0.44	0.10-0.35	0.50-0.70	2.30-2.80	0.50-0.80	0.40-0.70	0.050	0.050	12
En 36A	0.15	0.10-0.35	0.30-0.60	3.00-3.75	0.60-1.10		0.050	0.050	6
En 39B	0.12-0.18	0.10-0.35	0.50	3.80-4.50	1.00-1.40	0.15-0.35	0.050	0.050	10
En 40A	0.10-0.20	0.10-0.35	0.40-0.65	0.40	2.90-3.50	0.40-0.70	0.050	0.050	10
En 40B	0.20-0.30	0.10-0.35	0.40-0.65	0.40	2.90-3.50	0.40-0.70	0.050	0.050	12

Ferritic Creep Resistant Steels

Steel Designation	Chemical Analysis %				Weldability Reference Number
	C	Mn	Si	Pb	
Mn-Mo	0.20	1.40	-	0.45	7B
1/2Cr-1/2Mo	0.15	0.50	0.50	0.50	7B
1Cr-1/2Mo	0.12	0.50	1.10	0.50	7B
2 1/4Cr-1Mo	0.12	0.50	2.30	1.00	12B
5Cr-1/2Mo	0.12	0.50	5.00	0.60	12B

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Steel Designation	Chemical Analysis %								Weldability Reference Number
	C	Mn	Si	Cr	Ni	Mo	S	Other	
Plastic Mould Steels									
ASSAB									
Calmax	0.6	0.8	0.35	4.5		0.5		V 02	12C
BOHLER STEEL									
M200	0.40	1.50	0.40	1.90		0.20	0.070		12C
M238	0.38	1.50	0.30	2.0	1.10	0.20			12C
M310	0.43			13.5					12C
COMMONWEALTH STEEL									
P20	0.30	0.75	0.60	1.70		0.40			12C
Maxel Holder Block	0.50	1.30	0.30	0.65		0.18			12C
STEELMARK EAGLE & GLOBE									
CSM20.30	0.80	0.50	1.65		0.40			12C	
Maxel HB	0.50	0.30	0.08	0.65		0.18			12C
420 MFQ	0.35	0.1	1.0	13.0					12C
Hot Work Tool Steel									
ASSAB									
8407	0.39	0.40	1.0	5.3		1.3		V0.9	12C
8407 Supreme	0.39	0.40	1.0	5.2		1.40		V0.9	12C
QRO 90 Supreme	0.38	0.75	1.0	.6		2.25		V0.9	12C
BOHLER STEEL									
W302	0.39	0.40	1.10	5.20		1.40		V0.95	12C
W321	0.39	0.35	0.30	2.90		2.8		V0.50 Co2.90	12C
W500	0.55	0.75	0.25	1.1	1.7	0.55		V0.10	12C
COMMONWEALTH STEEL									
R15	0.55	0.70	0.30	0.65	1.40	0.35			12C
H13	0.40	0.40	1.0	5.0		1.30		V1.10	12C
STEELMARK EAGLE & GLOBE									
ADIC	0.39		1.0	5.2		1.40		V0.35	12C
NCM5	0.55	0.85		1.2	1.65	0.35		V0.15	12C

Steel Specifications:

Steel Designation	Chemical Analysis %								Weldability Reference Number
	C	Mn	Si	Cr	Ni	Mo	S	Other	
Cold Work Tool Steel									
ASSAB									
XW10	1.0	0.60	0.30	5.3		1.1		V0.20	12C
XW5	2.05	0.80	0.30	12.5				W1.3	12C
XW41	1.55	0.4	0.3	11.8		0.8		V0.8	12C
DF2	0.95	1.1		0.6				W0.6 V0.1	12C
BOHLER STEEL									
K190	2.3	0.40	0.40	12.50		1.10		V4.0	12C
K600	0.45	0.40	0.25	1.30	4.0	0.25			12C
K660	0.70	2.0	0.30	1.0		1.35	0.15		12C
STEELMARK EAGLE & GLOBE									
SC23	2.0	0.20	0.30	12.0					12C
SC25	1.50	0.45	0.25	18.0		1.0		V0.35	12C
NSS6	0.70	1.90	0.30	1.0		1.35			12C
SRS	0.60	0.80	1.60	0.35		0.40		V0.15	12C

AS1302 (1991) Steel Reinforcing Bars For Concrete

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
Grade 250R Plain Bars*	0.25			4
Grade 250S Deformed Bars*	0.25			4
Grade 400Y Deformed Bars*	0.22			3

*Grain refining and micro alloying elements = 0.15%

AS1085.1 Rail Steels

Steel Designation	Chemical Analysis %			Weldability Reference Number
	C	Mn	Si	
Grade Grade 31kg or 41kg	0.53-0.69	0.60-0.95	0.15-0.35	12
Grade 50kg or 60kg	0.66-0.82	0.70-1.00	0.15-0.50	12

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Steel Specifications:

AS3678 (1990) Structural Steels Hot Rolled Plates, Floor Plates and Slabs

Steel Designation	Chemical Analysis %						Weldability Reference Number
	C	Mn	Si	Ni	Cr	Mo	
Grade 200	0.15	0.60	0.25	-	-	-	1
Grade 250-250L15	0.22	1.70	0.55	-	-	-	4
Grade 300-300L-15	0.22	1.70	0.55	-	-	-	4
Grade 350-350L15	0.22	1.70	0.55	-	-	-	5
Grade 400-400L15	0.22	1.70	0.55	-	-	-	5
Grade WR350/1, L0	0.14	1.70		0.55	0.35-1.05	0.15-0.50	5A

Steels to Shipping Classification Society Rules

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
Grade A	0.23	-	3A
Grade B	0.21	0.80 min.	3A
Grade D	0.21	0.60 min.	4A
Grade E	0.18	0.70 min.	4A
American Bureau of Shipping			
Class A	0.23	-	3A
Class B	0.21	0.80-1.10	4A
Class CS	0.16	1.00-1.35	3A
Class DS	0.16	1.00-1.35	3A
Class D	0.21	0.70-1.35	4A
Class E	0.18	0.70-1.35	4A
Det Norske Veritas			
Grade NVA	0.23	-	3A
Grade NVD	0.21	0.60 min.	4A
Grade NVE	0.18	0.70 min.	4A
Bureau Veritas			
Grade A	-	-	3A
Grade B	0.21	0.80-1.40	4A
Grade D	0.21	0.60-1.40	4A
Grade E	0.18	0.70-1.50	4A

Steel Specifications:

AS 1548 (1989) Steel Plates for Boilers and Pressure Vessels

Steel Designation	Chemical Analysis %							Weldability Reference Number
	C	Mn	Si	Ni	Cr	Mo	Cu	
7-430 R,N,A,T	0.20	0.50-1.60	.50	.30*	.25*	.10*	.20*	5
7-460 R,N,A,T	0.20	0.90-1.70	.60	.30*	.25*	.10*	.30*	5
5-490 N or A	0.24	0.90-1.70	.60	.30*	.25*	.10*	.20*	5
7-490 R,N,A,T	0.24	0.90-1.70	.60	.30*	.25*	.10*	.30*	6

*Total Ni + Cr + Mo + Cu = .70% max.

PIPE LINE STEELS

API 5L (1992) Specification for Seamless Line Pipe

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
Grade A25 Cl I, Cl II	0.21	0.30 - 0.60	2
Grade A	0.22	0.90	3
Grade B	0.27	1.15	5
Grade X42	0.29	1.25	5
Cold-expanded -Grades X46, X52	0.29	1.25	5
Non-expanded -Grades X46, X52	0.31	1.35	5
Grades X56, X60	0.26	1.35	5

API 5L (1992) Specification for Welded Line Pipe

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
Grade A25 Cl I, Cl II	0.21	0.30 - 0.60	2
Grade A	0.21	0.90	3
Grade B	0.26	1.15	4
Grade X42	0.28	1.25	5
Cold-expanded -Grades X46, X52	0.28	1.25	5
Non-expanded -Grades X46, X52	0.30	1.35	5
Grades X56, X60	0.26	1.35	5
Grade X65	0.26	1.40	5
Grade X70	0.23	1.60	5
Grade X80	0.18	1.80	5

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Steel Specifications:

ASTM SPECIFICATION STEELS

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
ASTM A36M (1991) Structural Steel Plates			
To 20mm including	0.25		4
Over 20 to 40mm including	0.25	0.80 - 1.20	4
Over 40 to 65mm including	0.26	0.80 - 1.20	4
Over 65 to 100mm including	0.27	0.85 - 1.20	5
Over 100mm	0.29	0.85 - 1.20	5
ASTM 242M (1991) High Strength Low Alloy Structural Steel			
Type 1	0.15	1.00	5
ASTM 283M (1992) Low and Intermediate Tensile Strength Carbon Steel Plates			
Grade A	0.14	0.90	2
Grade B	0.17	0.90	3
Grade C	0.24	0.90	4
Grade D	0.27	0.90	4
ASTM 284M (1990) Low and Intermediate Tensile Strength Carbon - Silicon Steel Plates			
Grade C:			
25mm and under	0.24	0.90	3
Over 25 to 50 mm, including	0.27	0.90	4
Over 50 to 100mm, including	0.29	0.90	4
Over 100 to 200mm, including	0.33	0.90	5
Over 200 to 300mm, including	0.36	0.90	6
Grade D:			
25mm and under	0.24	0.90	3
Over 25 to 50 mm, including	0.27	0.90	4
Over 50 to 100mm, including	0.29	0.90	4
Over 100 to 200mm, including	0.33	0.90	5
ASTM 285M (1990) Pressure Vessel Plates, Carbon Steel			
Grade A	0.17	0.90	2
Grade B	0.22	0.90	3
Grade C	0.28	0.90	4

Steel Specifications:

ASTM SPECIFICATION STEELS.

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
ASTM A516M (1990) Pressure Vessel Plates, Carbon Steel			
Grade 415			
12.5mm and under	0.21	0.60 - 0.90	3
Over 12.5 to 50mm including	0.23	0.85 - 1.20	4
Over 50 to 100mm including	0.25	0.85 - 1.20	5
Over 100 to 200mm including	0.27	0.85 - 1.20	5
Over 200	0.27	0.85 - 1.20	5
Grade 450			
12.5mm and under	0.24	0.85 - 1.20	4
Over 12.5 to 50mm including	0.26	0.85 - 1.20	5
Over 50 to 100mm including	0.28	0.85 - 1.20	5
Over 100 to 200mm including	0.29	0.85 - 1.20	5
Over 200	0.29	0.85 - 1.20	5
Grade 485			
12.5mm and under	0.27	0.85 - 1.20	5
Over 12.5 to 50mm including	0.28	0.85 - 1.20	5
Over 50 to 100mm including	0.30	0.85 - 1.20	6
Over 100 to 200mm including	0.31	0.85 - 1.20	6
Over 200mm	0.31	0.85 - 1.20	6
ASTM A537M (1991) Pressure Vessel Plates, Heat Treated, Carbon-Manganese-Silicon Steel			
40mm and under	0.24	0.70 - 1.35	5
Over 40mm	0.24	1.00 - 1.60	6
ASTM A569M (1991) Carbon Steel (0.15% max) Hot-Rolled Sheet and Strip			
Commercial quality	0.15	0.60	1
ASTM A572M (1992) High Strength Low Alloy Niobium Vanadium Steels			
Grade 290	0.21	1.35	5
Grade 345	0.23	1.35	5
Grade 415	0.26	1.35	6
Grade 450:			
13mm and under	0.26	1.35	6
over 13mm to 32mm	0.23	1.65	6

WELDING OF STEEL

Steel Specifications:

ASTM SPECIFICATION STEELS.

Steel Designation	Chemical Analysis %		Weldability Reference Number
	C	Mn	
ASTM A607 (1992) Steel Sheet and Strip, High Strength, Low Alloy, Hot Rolled and Cold Rolled			
Grade 415:			
Class 1, Grade 45	0.22	1.35	4
Class 1, Grade 50	0.23	1.35	5
Class 1, Grade 55	0.25	1.35	5
Class 1, Grade 60	0.26	1.50	6
Class 1, Grade 65	0.26	1.50	6
Class 1, Grade 70	0.26	1.65	6
Class 2, Grades 50,55	0.15	1.35	3
Class 2, Grades 60, 65	0.15	1.50	4
Class 2, Grade 70	0.15	1.65	4
ASTM A662M (1990) Pressure Vessel Plates, Carbon Manganese Steel for Moderate and Lower Temperature Service			
Grade A	0.14	0.90 - 1.35	3
Grade B	0.19	0.85 - 1.50	4
Grade C	0.20	1.00 - 1.60	5
ASTM A737M (1987) Pressure Vessel Plates, High Strength Low Alloy Steels			
Grade B	0.20	1.15 - 1.50	5
Grade C	0.22	1.15 - 1.50	5

Steel Specifications:

QUENCHED AND TEMPERED STEELS.

Structural and Abrasion Resistant Grades.

Properties	Steel Designation	Typical Chemical Analysis* (%)								Weldability Reference Number
		C	Mn	Si	Cr	Ni	Mo	S	Other	
BISALLOY Q & T STEELS (Australia).										
Yield Stress:										
500MPa	Bisplate 60	0.16-0.18	1.10-1.40	0.20	0.20-0.90	---	0.20	0.003	B: 0.001	13
600MPa	Bisplate 70								Ti: 0.02	
620-690MPa	Bisplate 80/80PV									
Hardness:										
320-360HB	Bisplate 320	0.18	1.15	0.40	0.85	---	0.20	---	B: 0.002	13
360-400HB	Bisplate 360								Ti: 0.03	
400-460HB	Bisplate 400	0.28	0.50	0.35	0.96	---	0.15	---	B: 0.002	13
									Ti: 0.04	
IMPORTED Q & T STEELS (JAPAN & USA).										
Yield Stress:										
550MPa	HY80	0.14	0.30	0.25	1.60	2.8	0.40			13
690MPa	HY100									
690MPa	USST1	0.16	0.85	0.30	0.57	0.90	0.50		B: 0.004	13
									V: 0.04	
									Cu: 0.30	
690MPa	USST1 Type A	0.18	0.90	0.30	0.55		0.20	---	B: 0.001	13
									V: 0.04	
450MPa	Welten 60	0.11	1.22	0.45	0.17				V: 0.04	13
690MPa	Welten 80C	0.10	0.85	0.22	0.80		0.45		B: 0.001	13
									V: 0.04	
									Cu: 0.28	
690MPa	Welten 80E	0.18	0.90	0.23	0.40				B: 0.001	13
									V: 0.03	
									Cu: 0.25	
Hardness:										
320HB min	Welten AR 320	0.18	1.10	0.25	0.70		0.35		B: 0.002	13
									V: 0.04	
									Cu: 0.35	
360HB min	Welten AR 360C	0.18	1.10	0.25	0.90		0.35		B: 0.002	13
									V: 0.04	
									Cu: 0.35	
477HB min	Welten AR 500	0.30	1.20	0.40	0.60		0.10		B: 0.003	13
									Cu: 0.28	

* Dependent on plate thickness.

WELDING OF STEEL

Quenched & Tempered Steels:

Preheat recommendations for Q & T Steels - Table 2.

Q & T Steel Grade	< 13mm	> 13mm < 25mm	>25mm < 50mm	> 50mm
MINIMUM PREHEAT TEMPERATURE (°C) (assuming high joint restraint)				
High Strength Structural Grades.				
450 MPa minimum Yield Stress	10	25	75	100
620 MPa minimum Yield Stress	50	100	125	150
680 MPa minimum Yield Stress	50	100	125	150
Abrasion Resistant Grades.				
320 HB	50	100	125	100
360 HB	50	100	125	150
500 HB	100	150	150	---
MAXIMUM INTERPASS TEMPERATURE (°C)				
All Grades	150	175	200	220
MAXIMUM ARC HEAT INPUT (kj / mm)				
All Grades	2.5	3.5	4.5	5.0

Filler Metal Selection Guide for Bisalloy Q & T Steels - Table 3.

Steel Designation	Weld Strength Category*	Manual Metal Arc Welding (MMAW)	Gas Metal Arc Welding # (GMAW)	Flux Cored Arc Welding # (FCAW)
Bisalloy 60	MS LS	Alloycraft 90 Ferrocraft 61/ 7016	Autocraft Mn-Mo Autocraft LW1-6	Verti-Cor 91 K2 Supre-Cor 5 / Verti-Cor 80Ni 1
	MH	NR	NR	NR
Bisalloy 70	MS LS	Alloycraft 110 Ferrocraft 61/ 7016	Autocraft NiCrMo Autocraft Mn-Mo / Autocraft LW1-6	Tensi-Cor 110TXP Supre-Cor 5 / Verti-Cor 80Ni 1
	MH	NR	NR	NR
Bisalloy 80	MS	Alloycraft 110	Autocraft NiCrMo	Tensi-Cor 110TXP
	LS	Ferrocraft 61/ 7016	Autocraft LW1-6 / Autocraft Mn-Mo	Verti-Cor 111 K3 Supre-Cor 5 / Verti-Cor 80Ni 1
	MH	NR	NR	NR
Bisalloy 320, 360, 400, 500	MS	NR	NR	NR
	LS	Ferrocraft 61/ 7016	Autocraft LW1-6	Supre-Cor 5 / Verti-Cor 80Ni 1
	MH	Cobalarc 350, 650	Cobalarc 350, 650	Cobalarc 350, 650

* Weld Strength Category Definitions: MS - Matching Strength LS - Lower Strength
MH - Matching Hardness NR - Not Recommended

Use only recommended shielding gases, please refer to product data in this handbook.

Welding Recommendations:

Weldability Reference No:

- 1 & 2 Readily weldable with mild steel electrodes of the AS/NZS 1553.1: E41XX or E48XX, or AWS A5.1: E60XX or 70XX classifications (such as Satinarc 13, Ferrocraft 12XP, Ferrocraft 21 or Weldcraft). Gas Metal Arc (GMAW or MIG/MAG) welding or Flux Cored Arc welding (FAW) with an appropriate CIGWELD welding consumable such as Autocraft LW1-6 or Verti-Cor 'series' wires can be carried out with out any precautions. No preheat is normally required.
- 2A* The welding of these steels is normally not recommended because the high sulphur or lead content can often lead to hot shortness during welding. For non critical applications, best results are achieved using basic coated electrodes such as Ferrocraft 7016, Ferrocraft 61 or Ferrocraft 16TXP
- 3 & 4 Readily welded using mild steel electrodes as per recommendation 1 & 2. GMAW or FCAW processes can be used depending on specific welding details including equipment availability, welding location, material thickness and positional welding requirements etc. Refer to GMAW product data for Autocraft LW1-6 and FCAW product data for Verti-Cor XP / Ultra / Ultra 3 and 3XP in the front of this handbook.
For Combined Joint Thicknesses (CJT, refer Diagram 1) of ≥ 50 mm, the best practice is to select a hydrogen controlled welding process / consumable combination and a correspondingly lower preheat temperature.
- 3A* & 4A* Check specific Shipping Society approval requirements of the consumable.
This group of steels are readily welded using mild steel electrodes of the AS/NZS 1553.1: E41XX-2 or E48XX-2 classifications. Also readily weldable with the GMAW process and Autocraft LW1-6 welding wire or other "W503" GMAW welding wires. The FCAW process can also be used with Verti-Cor Ultra 3 / 3XP or other "W503" FCAW wires.
- 5 & 6 For intermediate strength and low alloy high strength steel, select a welding consumable producing near matching weld deposit analysis and/or mechanical properties. The best practice is to select a hydrogen controlled electrode or welding wire of a comparable strength grade to that of the steel being welded and use the recommended preheat.
- 5A* To achieve matching 'weathering' of the parent steel, a welding consumable containing Nickel and Copper alloy additions must be used. If colour match is not an issue refer to 5.
- 7, 8 & 9 Follow the recommendations prescribed in 5 & 6. The use a hydrogen controlled welding process / consumable combinations is considered more important as the carbon equivalent and hardenability of the steel increases. The weld deposit strength level should at least equal that of the grade of steel being welded. These steels are hardenable and the use of correct preheat and interpass temperatures and slow cooling after welding are important for success.
To avoid hydrogen cracking, the welding consumable should be used, stored and reconditioned in accordance with the manufacturer's recommendations. For CIGWELD welding consumables please refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.
- 7B* These Chromium-Molybdenum and Molybdenum type steels are usually welded with near matching welding consumables such as Alloycraft 80-B2 electrodes, Autocraft Mn-Mo / CrMo1 GMAW welding wires or Comweld CrMo1 GTAW rods etc. This is carried out to achieve comparable creep strength and corrosion resistance to the parent steel. Low hydrogen welding conditions are essential as are the correct preheat and interpass temperatures, retarded cooling and a post weld heat treatment.

*Note A, B & C suffixes indicate constraints or conditions not adequately covered by the CE formula (eg high S, Pb etc)

WELDING OF STEEL

Welding Recommendations:

Weldability Reference No:

- 10 & 11 Use hydrogen controlled welding process / consumable combinations which best match the chemical composition and/or strength level of the parent steel. To avoid hydrogen cracking, the welding consumable should be used, stored and reconditioned in accordance with the manufacturer's recommendations. For CIGWELD welding consumables please refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**. Preheat temperature should be determined using the procedure described on page 69 of this guide. The use of 'dry' welding consumables is essential for the successful welding of these steels, as is slow cooling after welding. Post Weld Heat Treatment (PWHT) is also considered good welding practice.
- 11A Following on from recommendation 2A the welding of high carbon, sulphur bearing steel is not recommended except for non critical applications. Use hydrogen controlled process / consumable combinations. Welding consumables must be dry immediately prior to use, please refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.
- 12 Use hydrogen controlled welding process / consumable combinations, including such consumables as Ferrocrafter 61 and Ferrocrafter 7016 electrodes or Suprecor 5 flux cored wire for lower strength welding and Alloycraft 110 electrode or Tensi-Cor 110 TXP flux cored wire for higher strength joints. The choice of higher or lower consumable strength levels will depend on the specifics of the application. These steels are normally supplied in the hardened and tempered condition which requires strict control of preheat, interpass temperature, post weld cooling and PWHT. To achieve optimum results please refer to the steel supplier for specific technical information, in particular heat treatment recommendations.
- 12A* For the welding of high alloy spring steels in the hardened and tempered condition: Use hydrogen controlled process / consumable combinations including such consumables as Ferrocrafter 61, Ferrocrafter 7016 or Supre-Cor 5 in a thoroughly dry condition. Preheat steel sections to be joined to 250-300°C and maintain an interpass temperature of 250-300°C throughout welding. After welding slowly cool the joint in lime or wrap in a thermal blanket. Alternatively where preheat must be reduced to the minimum, use Weldall electrodes with approximately 100°C less preheat and interpass temperature (ie 150 - 200°C) and slowly cool as previously described.
- 12B* These Chromium-Molybdenum type steels are usually welded with near matching welding consumables such as Alloycraft 90-B3 electrodes, Autocrafter CrMo2 GMAW welding wire or Comweld CrMo2 GTAW rods etc. This is done to achieve comparable creep strength and corrosion resistance to the parent steel. Low hydrogen welding conditions are essential as are the correct preheat and interpass temperatures, retarded cooling and a post weld heat treatment.
- 12C* The welding of tool steels in the heat treated (hardened and tempered) condition should be avoided where possible. Comprehensive repair and maintenance applications using ferritic steel, low hydrogen consumables such as Ferrocrafter 18-Ni electrodes or Supre-Cor 5 flux cored wire should only be attempted on mould and tool steels in the annealed condition. Minor repair work on heat treated tool steels can be carried out using "reconditioned" Weldall electrodes and appropriate preheat and interpass temperatures, retarded cooling and a post weld heat treatment (PWHT) to reduce residual stresses. Please refer to the steel manufacturer for specific welding recommendations.

*Note A, B & C suffixes indicate constraints or conditions not adequately covered by the CE formula (eg high S, Pb etc)

Welding Recommendations:

Weldability Reference No:

13

Welding Quenched and Tempered (Q & T) steels:

1. Use only hydrogen controlled welding process / consumable combination, where the welding consumable has been used, stored and re-conditioned in accordance with the manufacturer's instructions. Refer to Recommended Storage, Care and Conditioning of CIGWELD Electrodes, Welding Wires and Rods **in this handbook**.
2. Welding consumable selection is dependant on the particular grade of steel being welded and the specific service requirements of the weldment.
3. For full strength weld joints select a welding consumable of matching (or near matching) weld metal mechanical properties. See Table 3 on Page 81 for CIGWELD welding consumable recommendations.
4. For lower strength welds select hydrogen controlled welding consumables having lower weld metal tensile properties and alloy content. See Table 3 on Page 81 for CIGWELD welding consumable recommendations.
5. Recommended preheat and interpass temperatures and maximum heat input data for structural and abrasion resistant Q & T steel grades are detailed in Table 2. If they are not adhered to closely the strength or integrity of the joint may be compromised.
6. Lower strength welding consumables are invariably used to join abrasion resistant Q & T steels because of their very high tensile properties. For butt welds subject to surface abrasion, a capping pass deposited with a welding consumable of matching hardness to the base steel is sometimes used.

WELDING OF STEEL

Consumables Prequalified to AS/NZS 1554.1: 1995

Manual Metal Arc Welding Consumables:	AS/NZS Standard	LRS/DNV Approval	Applicable Steel Types*
GP6012	E4112-0	2	1 & 2
Ferrocrafter 12XP	E4112-0	2Y	"
Satincraft 13	E4113-0	2	"
Ferrocrafter 11	E4111-2	3	3, 4, 5 & 6
PipeArc 6010P	E4110-2	3	"
Weldcraft	E4113-2	3	"
Ferrocrafter 21	E4814-2	3	3, 4, 5, 6, 7A & 7B
Ferrocrafter 22	E4824-0	2Y	"
Ferrocrafter 16TXP	E4816-2 H ₁₀	3YH	"
Ferrocrafter 55U	E4816-2 H ₁₀	3YH	"
Ferrocrafter 61	E4818-3 H ₁₀	3YH	"
Ferrocrafter 7016	E4816-3 H ₁₀	3YH	"
Gas Metal & Flux Cored ARC Welding Consumables:	AS/NZS Standard	LRS/DNV Approval	Applicable Steel Types*
Autocrafter LW1	ES4-GC/M-W503AH	3YMS	All Types
Autocrafter LWI-6	ES6-GC/M-W503AH	3YS	"
Verti-Cor Ultra	ETP-GCp-W502A. CM1 H ₁₀	2YSH	1, 2 & 4
Satin-Cor XP	ETD-GCp-W502A. CM1 H ₁₀	2YSH	"
Verti-Cor XP	ETD-GMp-W502A. CM1 H ₁₀	2YSH	"
Verti-Cor Ultra 3	ETP-GCp-W503A. CM1 H ₁₀	3YSH	All Types
Metal-Cor XP	ETD-GMn/p-W503A. CM1 H ₅	3YSH	"
Verti-Cor 3XP	ETP-GMp-W503A. CM1 H ₁₀	3YSH	"
Supre-Cor 5	ETP-GMn-W505A. CM1 H ₅	3YSH	"

* See applicable steel types on next page.

WELDING OF STEEL

APPLICABLE STEEL TYPES - PREQUALIFIED TO AS/NZS 1554.1: 1995

Steel type	AS 1163	AS 1397	AS 1450	AS 1548	AS 1594	AS 1595	AS 2074	AS 3678/ AS 3679.2	AS 3679.1	NZS 3415
1	C250	G250 G300	C200 H200 C250 H250	7-430 7-460	Hd1 Hd2 Hd3 Hd4 Hd200 Hd250 Hd300 Hd300/1 A1006 A1010 A1016	All grades	C2 C3 C7A-1	200 250 300 A1006 XK1016	250 300	Fe 430A
2	C250 L0			7-430L0 7-460L0					250 L0 300 L0	Fe 430C
3				7-430L20 7-430L40 7-430L50 7-460L20 7-460L40 7-460L50				250 L15 300 L15	250 L15 300 L15	Fe 430D
4	C350	G350	C350 H350	5-490 7-490	Hd350 Hd400 HW350		C1 C4-1 C4-2 C7A-2	350 WR350/1 400	WR350/1 WR350/2 350	Fe 510A Fe 510B
5	C350 L0			7-490L0	XF300 XF400			WR350/1 L0	WR350/1 L0 WR350/2 L0 350 L0	Fe 510C
6				5-490L20 5-490L40 5-490L50 7-490L20 7-490L40 7-490L50				350 L15 400 L15	WR350/2 L15 350 L15	Fe 510D
7A	C450	G450	C450							
7B	C450L0									

WELDING OF STEEL

Consumables for Welding Structural, Stainless and Engineering Steels:

Applicable Steel Grades	Manual Metal Arc	Gas Metal Arc	Gas Tungsten Arc	Flux Cored Arc
AS3678 (AS 1204) Grades 200, 250, 300 and LO & L15 Grades AS 1548 Grad 7-430R	Ferrocrafit 11 (P) Weldcrafit (P)	Autocraft LW1 (P) Autocraft LW1-6 (P)	Comweld High Test (P)	Verti-Cor XP (P) Satin-Cor XP (P) Metal-Cor XP (P) Verti-Cor Ultra (P) Satin-Cor HD70
AS3678 (AS 1204) Grades 350, 400 and LO & L 15 Grades AS 1548 Grades 7-460R, 5-490 and L20 Grades	Ferrocrafit 21 (P) Ferrocrafit 22 (P) Ferrocrafit 61 (P)	Autocraft LW1 (P) Autocraft LW1-6 (P)	Comweld Super steel	Verti-Cor 3 XP (P) Metal-Cor XP (P) Supre-Cor XP (P) Verti-Cor Ultra 3 (P)
AS2074 Grades C4, C5, C6, C7, L1A, L1B ASTM A106 All Grades	Ferrocrafit 61 Ferrocrafit 7016	Autocraft LW1 Autocraft LW1-6	 Comweld Super steel	Supre-Cor 5
AS1548 L40 ASTM A333 Grades 3 & 7				Supre-Cor 5 Verti-Cor 80Ni 1
AS1442 S5, K5, K9 AS2074 Grade L3A AS2056 EN33 ASTM Grades: A148 80-40, 80-50 A302B, C & D A420 WPL9 A437 Class 2	Alloycraft 80-C1	Autocraft Mn-Mo		Verti-Cor 80Ni 1
ASTM A2170-WC6 ASTM A335-P11 ASTM A387-G11, 12 AS2074 Grades L5B, L5D, L5F	Alloycraft 80-B2	Autocraft CrMo1	Comweld CrMo1	
ASTM A217-WC9 ASTM A335-P22 ASTM A387-G22 AS2074 Grades L5C, L5D, L5F	Alloycraft 90-B3		Comweld CrMo2	
AS3597 - 500 ASTM A537 C12 ASTM A572 Grades 60, 65 ASTM A852 eg. Bisalloy 60 AS2074 Grade L6	Alloycraft 90			Verti-Cor 91 K2

(P) These products are prequalified to AS/NZS 1554.1 for welding the steels listed.

WELDING OF STEEL

Consumables for Welding Structural, Stainless and Engineering Steels cont.

Applicable Steel Grades	Manual Metal Arc	Gas Metal Arc	Gas Tungsten Arc	Flux Cored Arc
AS 3597-600 & 700 ASTM A533 Type A ASTM A514 A517 eg. Bisalloy, Welten 70 & 80 AS2074 Grade L6A	Alloycraft 110	Autocraft NiCrMo		Tensi-Cor 110T XP Verti-Cor 111K-3
AS2074 Grades H1A, H1B (Hadfield Manganese) (Austenitic Manganese) ASTM A128 All Grades	Cobalarc Mangcraft (build up)	Autocraft 309LSi	Comweld 309L	Shieldcrome 309LT / LTD
AISI Grades 201, 202 301, 301, 304, 304L, 305 AS2074 Grade H5A	Satincrome 308L-17	Autocraft 308LSi	Comweld 308L	Shieldcrome 308LT
AISI Grades 316L, 316, 316TI AS2074 Grades H6B, H6C	Satincrome 316L-17 Satincrome 318-17	Autocraft 316LSi	Comweld 316L	Shieldcrome 316LT
AISI Grade 309 AS2074 Grades H8A, H8B	Satincrome 309Mo-17	Autocraft 309LSi	Comweld 309L	Shieldcrome 309LT / LTD
Joining 3CR12 & 5CR12. Joining dissimilar steels eg. stainless steel to structural steel	Satincrome 309Mo-17 Cobalarc Austex	Autocraft 309LSi	Comweld 309L	Shieldcrome 309LT / LTD
ASTM A288 Grade 5 ASTM A434 Grades BB, BC ASTM A513 Grades 4130, 8630 Hardened to 230-270 HB	Alloycraft 110	Autocraft NiCrMo		Tensi-Cor 110T XP Verti-Cor 111K-3
AS1444 Grade XK4140 ASTM A288 Grades 6, 7, 8 ASTM A434 Grades BB, BC, BD ASTM A513 Grades 4130, 8630 Hardened to 330-370HB AS2074 Grade L6C	Cobalarc 350			Cobalarc 350-G Cobalarc 350-0