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An Approach to Best Welding Practice Part – XVIII.

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"AN APPROACH TO BEST WELDING PRACTICE. Part – XVIII." is the Eighteenth Detail Part of "AN APPROACH TO BEST WELDING PRACTICE" which was written as a General and Overall approach to the subject matter.

AN APPROACH TO BEST WELDING PRACTICE. Part – XVIII. is particularly focused on the WELD DEPOSITION / CALCULATION OF WELD VOLUME - Geometrical Configurations of weld Sections, Formula and Calculations and Weld Metal Deposition by Different Processes

This is a Working Guideline for Planning Engineers, Welding Co-ordinators, Quality Managers and Inspectors working in an Engineering Fabrication Plant using welding as the main manufacturing process.

In fact, this is a lengthy process to develop and as each and every step is connected with each other for cross references, none can be eliminated. I have divided it into four distinct Parts

I. WELDING PROCESS QUALITY / WELDING PROCESS EFFICIENCY

- Parameters,
- Basic Influencing Factors
- Data – Tables, Charts

II. CALCULATION OF WELD VOLUME/ WELD DEPOSITION

- Geometrical Configurations of weld Sections
- Formula and Calculations
- Weld Metal Deposition by Different Processes

III. COMPUTERIZED DATA PROCESSING

- Use of Excel Format for Data Storage
- Formulae and Calculations

IV. STATISTICAL PROCESS CONTROL

- Deciding Control Parameters
- Deciding Upper and Lower Control Limits
- Procedure to collect Process Data
- Calculations for Validation

This is a Working Guideline for Planning Engineers, Welding Co-ordinators, Quality Managers and Inspectors working in an Engineering Fabrication Plant using welding as the main manufacturing process.

In this Part, we will deal with the :

V. CALCULATION OF WELD VOLUME / WELD DEPOSITION

CALCULATION OF WELD VOLUME/ WELD DEPOSITION

- Geometrical Configurations of weld Sections
- Formula and Calculations
- Weld Metal Deposition by Different Processes

CALCULATION OF THE VOLUME OF WELD

Determining the volume of a weld requires some knowledge of basic geometrical calculations to determine the area of the weld and multiply this figure by its length. The first step then is to calculate the cross sectional area of the joint.

There are three factors that determine the volume of the weld in a single V butt weld. These are the angle of the bevel, b, the excess weld metal and the root gap, g, as illustrated in **Fig 6**. To calculate the area of this weld we need to be able to add together the areas of the four components illustrated in **Fig.1**.

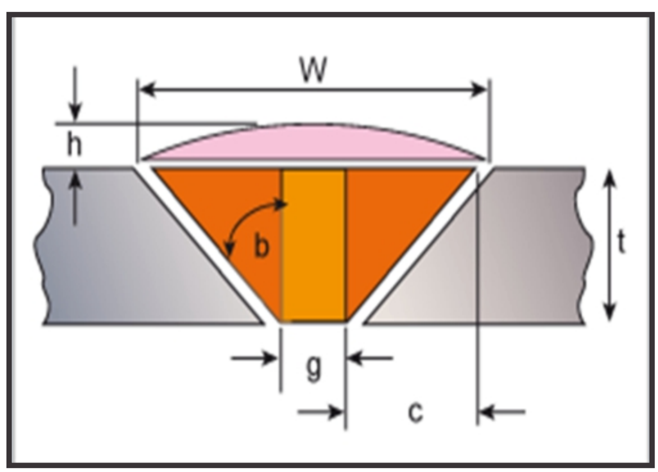


Fig.1 : The four areas of a single-V butt weld

The dimension 'c' is given by : (tan b x t);

The area of a single red triangle is therefore : t(tan b x t)/2.

The total area of the two red regions added together can be calculated using the formula : 2t(tan b x t)/2 or t(tan b x t).

The width of the weld cap, w, is given by : W=2(tan b x t)+g.

The area of the excess weld metal is approximated by the formula : (W x h)/2.

The area provided by the root gap by : g x t.

The bevel angles, b, most often used are

10° = (tan 0.176),
15° = (tan 0.268),
22.5° = (tan 0.414)
32.5° = (tan 0.637) and
45° = (tan 1.00).

As will become obvious when the weight is calculated, it is easier to ensure that the decimal point is in the right place if centimetres are used in the calculations rather than millimetres.

Table 1

Sl No.	Nominal Thickness of mterial (in mm)	Maximum allowable reinforcement (in mm)	
		Categories B nd C Butt welds	Other welds
1.	Less than 2.4	2.5	0.8
2.	2.4 to 4.8, inclusive	3	1.5
3.	Over 4.8 to 13, inclusive	4	2.5
4.	Over 13 to 25, Inclusive	5	2.5
5.	Over 25 to 51, inclusive	6	3
6.	Over 51 to 76, Inclusive	6	4
7	Over 76 o 102, inclusive	6	5.5
8	Over 102 to 127, inclusive	6	6
9	Over 127	8	8

WORKED EXAMPLE

As a worked example,

if the weld is in a plate :

2.5cm thickness,
0.3cm root gap,
65° included angle

(b = 32.50°; tan 32.5° = 0.637)

and with a cap height of 0.2cm we have:-

1. c = tan32.5 x 2.5 = 0.637 x 2.5 = 1.59cm
2. w = 2(0.637x2.5) + 0.3 = 3.485cm so the area of the cap = (3.485x0.2)/2 = 0.348 sq. cm.
3. area of the orange area = 0.3 x 2.5 = 0.75 sq.cm.
4. area of the two red areas = 2 x (1.59 x 2.5)/2 = 3.97sq.cm.

This gives a total area of 5.07sq cm. The volume can then be calculated by multiplying the length of the weld by the area - ensuring that this length is also given in centimetres!

Conventionally, the volume is often expressed in cubic centimetres (cu.cm). per metre

So in this example the volume is 507 cu. cm/metre.

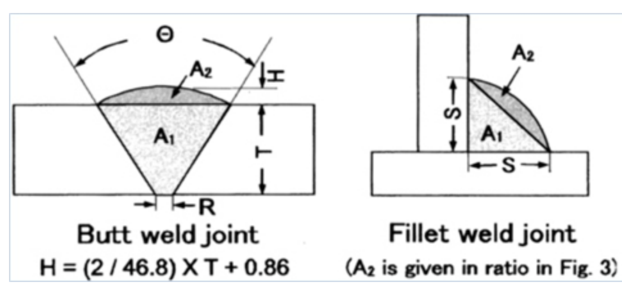


Fig. 2 : Weld Dimensions

Calculating Filler Metal Consumption

The number of pounds of welding electrodes or welding wire necessary to complete a given weld joint maybe calculated by the formula:

P = W x L x E

Where:

P = Pounds of electrode or wire required,

W = Weight per foot of weld metal

L = Length of weld (feet)

E = Deposition efficiency

Weight Per Foot of Weld Metal

Calculating the weight of weld metal required that we consider the following items.

1. Area of the cross-section of the weld.
2. Length of the weld.
3. Volume of the weld in cubic inches.
4. Weight of the weld metal per cubic inch.

It must be remembered that when deposition tests are performed in the laboratory, the deposition efficiency is calculated by the formula:

Deposition Efficiency= (Weight of metal deposited) / (Weight of electrode consumed)

The following equation for both groove and fillet welding joints under the prerequisites given below can be used for the calculation of Consumption of Electrodes.

$$C = [(A1 + A2) \times L \times G/E] \times 1/10$$

Where

C : Consumption of welding consumables (kg)
A1 : Area of Section A1 weld metal (mm^2)
A2 : Area of Section A2 reinforcement (mm^2)
Weld sizes (θ in deg., H, R, S and T in mm)
L : Weld length (m)
G : Specific gravity of weld metal (7.85 g/cm3)
E : Deposition Efficiency (%) —
SMAW covered electrodes: 55%
GMAW solid/metal-cored wires: 95%
FCAW flux-cored wires: 90%
SAW solid wires: 100%

Having calculated the weight of weld metal required to fill a weld preparation it is then possible to calculate the weight of filler metal required (these two figures are not necessarily the same) and to estimate the time required to deposit this weld metal; both essential in order to arrive at a cost of fabricating the weld.

To obtain the weight of weld metal this figure is then multiplied by the density of the alloy. **Table 2** gives the density of some of the more common alloys in gm/cu.cm.

Note that with some alloys the alloying elements can change the density quite significantly.

The weight of weld metal to fill one metre length of the joint described above would therefore be;

- in carbon steel (507 x 7.86) = 3985gms or 3.98kgs/metre;
- in a 5XXX series aluminium alloy (507 x 2.65) = 1343gms, 1.34kgs/metr.

Deposition rate is measured as the amount of electrode per unit of time, that is fed into the molten puddle, measured in wire feed speed. Its value reflects the use of the factor for Electrode Efficiency

The melt-off rate for a particular electrode does not include the efficiency of the mode of metal transfer or the process as regards how much electrode is being melted. The factor for the particular mode of metal transfer employed depending upon the mode of metal transfer is applied to the melt-off rate.

To determine the deposition rate for a given diameter of solid carbon or low alloy steel wire electrode the following mathematical formula will be useful:

Table - 2 : Deposition Rate

Alloy	Density (gm/cm^3)
iron	7.87
0.25% carbon steel	7.86
12%Cr steel	7.70
304 stainless steel	7.92
nickel	8.90
80/20 Ni.Cr	8.40
625 type alloy	8.44
copper	8.94
70/30 brass	8.53
7% Al bronze	7.89
aluminium	2.70
Al 5052	2.65
Al 7075	2.8

Table 3 : Deposition Efficiency for Different Welding Processes

Process	Efficiency
Gas Metal Arc (98%A, 2%O_2)	98%
Gas Metal Arc (75%A, 25%CO_2	96%
Gas Metal Arc ($C0_2$).	93%
Metal Cored Wires	93%
Gas Shielded Flux Cored Wires	86%
Self Shielded Flux Cored Wires	78%*
Submerged Arc Welding	99%
*Shielded Metal Arc (Stick 12")	59%*
*Shielded Metal Arc (Stick 14")	62%
*50 mm stub loss is included here	

13.1 (D2)(WFS)(EE)

Where : D = electrode diameter
WFS = wire feed speed (inches per minute)
EE = electrode efficiency

13.1 = is a constant that is based upon the density of steel and its cross-sectional area.

Aluminum is approximately 33% the density of carbon steel, and its constant will be 13.1 x .33, or 4.32. Stainless steel, typically, is only slightly greater in density than carbon steel, 0.284 lbs/in.3 versus 0.283 lbs/in.3, and therefore the 13.1 constant is sufficient.

Table 4 : Arc Welding Electrodes GMAW – Deposition Rate

LA T-9 Plus, LA T-91, LA T-91 C40 LA T-91 C60 Ni1 LA T-91 K2, LA 91-T12M Wire		
Diameter mm	Amps.	Deposition Rate kg/h
1.2	160	1.8
	180	2.0
	200	2.4
	220	2.9
	240	3.2
	280	4.1
1.4	170	1.8
	190	2.0
	210	2.3
	240	2.8
	270	3.4
	300	4.1
1.6	180	1.8
	200	2.0
`	220	2.2
2.0	250	2.7
	275	3.1
	300	3.6
	350	4.8
	250	2.7
	350	5.0

LAHT – 75 GLAAS – 3 LAS – 6 Gas Shielded Type		
Diameter mm	Amps.	Deposition Rate kg/h
0.8	75	0.9
	100	1.2
	150	1.9
	200	3.2
0.9	80	1.4
	150	2.0
	200	2.8
	250	4.2
1.2	100	1.0
	125	1.3
	150	1.7
	200	3.3
	300	4.7
	350	6.1
1.6	250	3.0
	275	3.9
	300	4.2
	400	6.5

Fig.3 shows the calculated consumption of welding consumables as a function of plate thickness, welding process, groove angle, and root opening for butt joints.

With respect to fillet joints, **Fig. 4** shows the calculated consumption of welding consumables as a function of fillet size, welding process, and reinforcement size These diagrams were developed using the calculations obtained by the following equation for both groove and fillet welding joints under the prerequisites given below:

C = [(A1 + A2) x L x G/E] x 1/10

Table - 5 : Welding Process - Duty Cycle - Filler Metal Yield

Welding Process	Duty Cycle %	Filler Metal Yield
MMA (SMAW)	15 -30	55 - 70 %
TIG (GTAW)	25 -40	80 - 90 %
Mechanized TIG	80 -90	90 - 96 %
MIG/MAG (GMAW)	30 -45	90 - 95 %
Mechanized MIG/MAG	80 -90	92 - 98%
Sub Arc (SAW)	80 -95	95 - 99 %

Filler Metal Consumption in GMAW

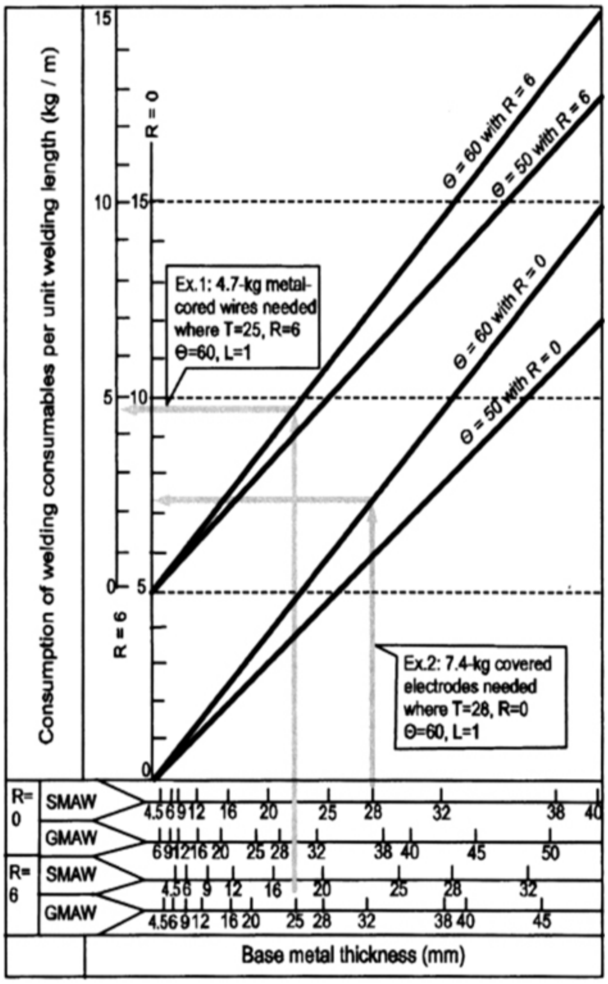


Fig. 3 : Consumption of covered electrodes in SMAW and solid/metal-cored wires in GMAW of butt joints

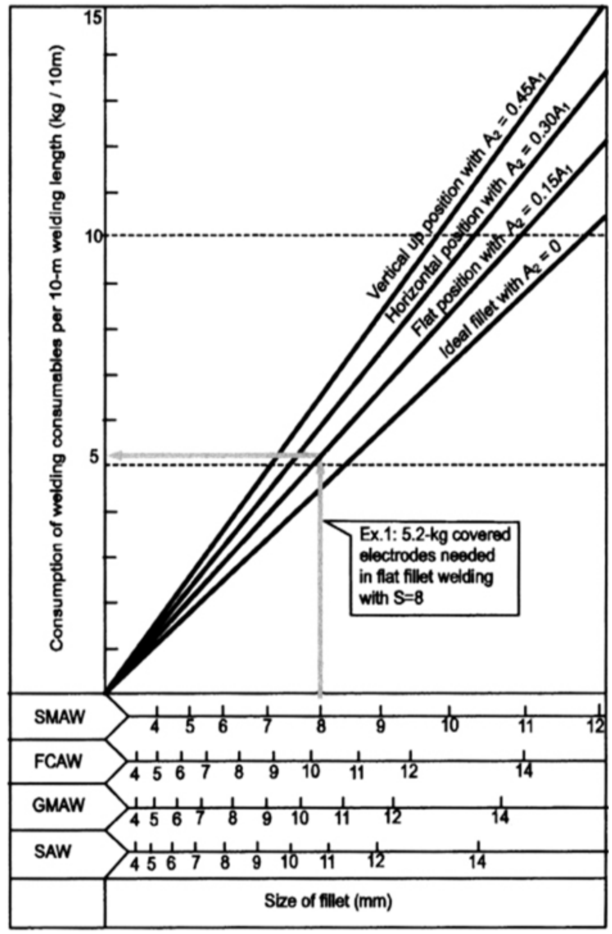


Fig. 4 shows the calculated consumption of welding consumables as a function of fillet size, welding process, and reinforcement size

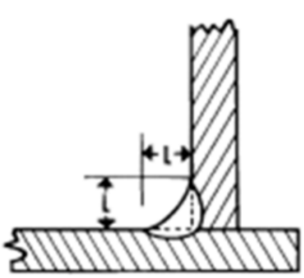
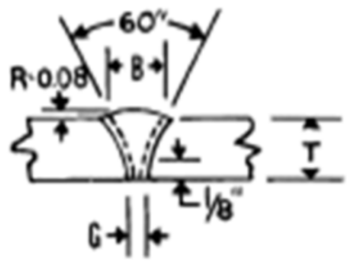
Table – 6 : Calculation of Electrode Consumption For Fillet Weld.			
Horizontal Fillet Weld	Size of Fillet L (in inches)	Pounds of Electrodes required per linear foot of weld* (approx.)	Steel Deposited per linear foot of weld (in pounds
	1/8	.048	.027
	3/16	.113	.063
	1/4	.189	.106
	5/16	.296	.166
	3/8	.427	.239
	1/2	.760	.425
	5/8	1.185	.663
	3/4	1.705	.955
	1	3.030	1.698

Table – 7. Calculation of Electrode Consumption For Butt Weld.

"V" Groove Butt Joint	Joint Dimensions		Pounds of Electrodes required per linear foot of weld* (approx.)			Steel deposited per linear foot of weld	
	MTL Thick L	Bead Width B	Root Open G	Without reinforce-ment	With reinforce-ment	Without reinforce-ment (lbs)	With reinforce-ment ** (lbs)
	1/4	.207	1/16	.15	.25	.085	.143
	5/16	.311	3/32	.31	.46	.173	.258
	3/8	.414	1/8	.50	.70	.282	.394
	1/2	.558	1/8	.87	1.15	.489	.641
	5/8	.702	1/8	1.35	1.68	.753	.942
	3/4	.847	1/8	1.94	2.35	1.088	1.320
	1	1.138	1/8	3.45	4.00	1.930	2.240

Flux Cored Arc Welding Electrodes GMAW

Table 8 : LA T-9 Plus, LA T-91, LA T 91 C40
LA T-91 C60 Ni1 LA T-91 K2, LA 91-T12M Wire

Diameter mm	Amps.	Deposition Rate kg/h
1.2	160	1.8
	180	2.0
	200	2.4
	220	2.9
	240	3.2
	280	4.1
1.4	170	1.8
	190	2.0
	210	2.3
	240	2.8
	270	3.4
	300	4.1
1.6	180	1.8
	200	2.0
	220	2.2
2.0	250	2.7
	275	3.1
	300	3.6
	350	4.8
	250	2.7
	350	5.0
2.4	450	7.0
	400	5.2
	450	6.5
	500	7.6

Table – 9. LAHT – 75 GLAAS – 3 LAS – 6
Gas Shielded Type

Diameter mm	Amps.	Deposition Rate kg/h
0.8	75	0.9
	100	1.2
	150	1.9
	200	3.2
0.9	80	1.4
	150	2.0
	200	2.8
	250	4.2
1.2	100	1.0
	125	1.3
	150	1.7
	200	3.3
	300	4.7
	350	6.1
1.6	250	3.0
	275	3.9
	300	4.2
	400	6.5

Table – 10 : Weight of wire per 1000 mm (3.3 ft) Length
Solid wire Flux Cored and Metal Cored

Weight of wire per 1000 mm (3.3 ft) Length Solid wire Mild steel	
Diameter	Kg/1000 mm - lb/ft
0.8 mm - 0.030 in	0.004 - 0.0027
0.9 mm - 0.035 in	0.005 - 0.0034
1.2 mm - 0.045 in	0.008 - 0.0054
1.4 mm - 0.052 in	0.012 - 0.0081
1.6 mm- 1/16 in	0.018 - 0.0121
2.0 mm - 5/54 in	0.027 - 0.0181
2.4 mm - 3/32 in	0.04 - 0.027
3.2 mm - 1/8 in	0.06 - 0.04
4.0 mm - 5/32 in	0.09 - 0.06

Weight of wire per 1000 mm (3.3 ft) Length Flux Cored and Metal Cored Solid wire Mild Steel	
Diameter	Kg/1000 mm - lb/ft
1.2 mm - 0.045 in	0.007 - 0.0047
1.4 mm - 0.052 in	0.008 - 0.0054
1.6 mm - 1/16 in	0.0125 - 0.0084
2.0 mm - 5/64 in	0.0177 - 0.0119
2.8 mm - 7/64 in	0.0291 - 0.0195
2.4 mm - 3/32 in	0.0349 - 0.0234
3.2 mm - 1/8 in	0.0418 - 0.02

Electrode Filler Metal Yield

- Covered Electrode
  - SMAW 14" manual = 55-65% yield
  - SMAW 18" manual = 60-70% yield
  - SMAW 28" automatic = 65-75% yield
- Solid Bare Electrode For
  - Submerged arc = 95-100% yield
  - Electroslag = 95-100% yield
  - GMAW = 90-95% yield
  - Cold Wire = 100
- Tubular-flux Cored Electrodes For
  - Flux Cored Arc Welding = 80-85% yield
  - Cold Wire = 100%

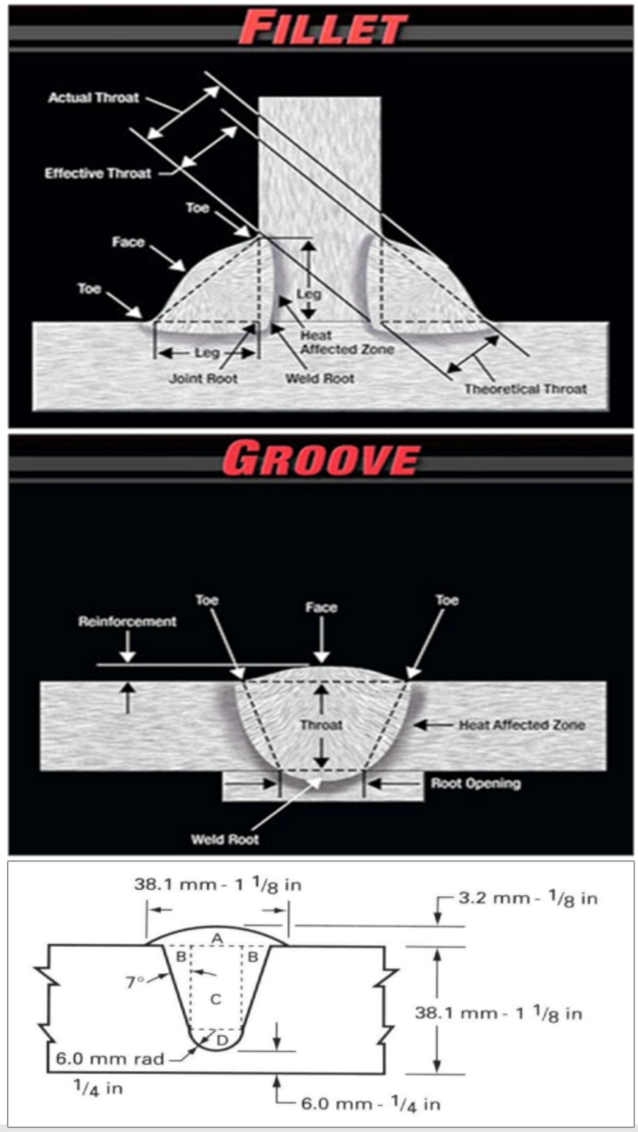


Fig 5. : Weld cross section used – procedure for calculating weight of weld metal

Table 11 : Calculation Of Weld Metal		
Segment	Given dimensions or included angle	Weight of each segment
A	T = 3.2 mm - 1/8" d = 28.6 mm - 1 1/8"	0.473 g
B	Included angle = 7° + 7° = 14° J = 38.1 - (6.0 + 6.0) = 26.1	0.621 * g
C	T = 6.0 + 6.0 = 12 mm - ½" d = 38.1 - (6.0 + 6.0) = 26.1	2.530 * g
D	r = 6.0 mm - ¼"	0.497 g
	Total value for the joint	4.12 g

Table - 12 : Deposition Efficiency of Welding Processes	
Welding Process	Deposition Efficiency %
GMAW	90-97%
FCAW (gas Shielded)	80-90%
MCWA	91-99%
FCWA (self Shielded)	74-82%
SAW	97-99%
SMAW	60 - 70 %

GAS METAL ARC WELDING

DEPOSITION RATES OF DIFFERENT MODES OF METALTRANSFER

Table 13 : Deposition Rates–Short Arc ($ER70S-X$ 75%Ar/25% CO_2)			
Wire Dia	Amps(WFS IPM)	Voltage	Deposition Rate lbs/hr
.030	75-140 (190-350)	14-16	1.8-4.0
.035	90-160 (180-300)	15-19	2.1-4.1
.045	130-250 (125-200)	17-19	2.8-5.5
.052	150-250 (135-240)	17-20	3.7-6.25

Table 14 : Deposition Spray–Short Arc (ER70S-X 98% Argon/2% CO_2)			
Wire Dia	Amps(WFS IPM)	Voltage	Deposition Rate lbs/hr
.030	140-200 (440-650)	24-26	4.0 - 6.7
.035	180-230 (400 - 550)	25-27	6.3.-8.0
.045	260-340 (300-500)	25-30	8.0-13.0
.052	275-400 (265-390)	26-33	8.3-13.5
1/16"	290-400 (180-280)	26-36	8.8-14.0

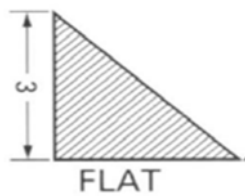
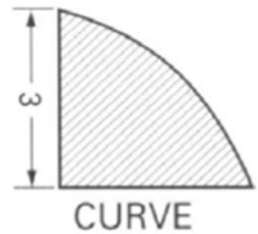
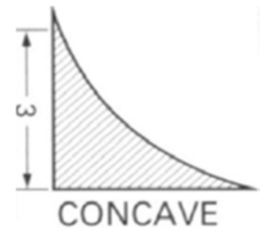
Table 15 : Flux Cored Arc Welding Process -ER70T-X 100% CO_2 FCAW (Flux Cored Arc Welding –Gas Shielded)			
Wire Dia	Amps(WFS IPM)	Voltage	Deposition Rate lbs/hr
.045	145-265 (200-500)	24-29	3.6-9.3
.052	215-370(280-600)	25-31	4.5-14.7
1/16"	195-445 (150-500)	24-32	4.5-16.7
5/64"	170-320 (125-300)	27-30	6.5-16.2
3/32"	220-475 (100-300)	27-32	8.4-25

Table 16 : Metal Cored Arc Welding Process E70C-X 90%AR/10%CO_2)			
Wire Dia	Amps(WFS IPM)	Voltage	Deposition Rate lbs/hr
0.45	170-360 (200-550)	24-33	5.2-13.9
.052	190-410(180-530)	26-36	5.5-15.7
1/16”	230-510 (150-480)	26-36	6.2-20.7

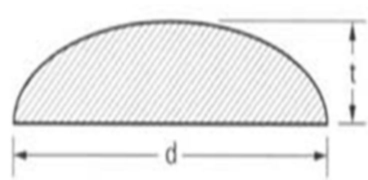
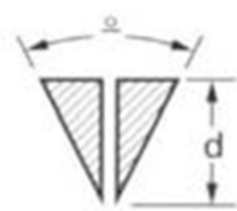
Table 17 : Flux Cored Arc Welding Process E7XTX –No Shielding Gas			
Wire Dia	Amps(WFS IPM)	Voltage	Deposition Rate lbs/hr
.035	80-200 (81-392)	15-17	.9-4.5
.045	95-225 (54-140)	15-18	.9-2.6
1/16	155-220 (150-275)	21-25	4.1-7.5
.072	184-355(100-300)	17-24	3.6-10.6
5/64	275-600(150-600)	22-31	6.4-25.8
3/32	265-615 (100-400)	22-29	6.1-25.8

SAW(Submerged Arc Welding)

Table 18 : SAW Process Carbon Steel 1.5-2lbs of Flux per lb. of Electrode			
Wire Dia	Amps(WFS IPM)	Voltage	Deposition Rate lbs/hr
3/32"	250-700 (55-180)	26-34	6.9-20
1/8"	300-900 (30-125)	28-36	8-28
5/32"	400-1000 (30-150)	28-38	9-48
3/16"	500-1300 (20-85)	32-40	10-42
1/4"	600-1600 (18-60)	34-42	15-55

Table - 19			
			
Size of fillet mm - in	Weight of metal	Weight of metal	Weight of metal
3.2 - 1/8	0.048	0.058	0.055
5.0 - 3/16	0.107	0.129	0.124
6.0 = 1/4	0.192	0.291	0.219
8.0 - 5/16	0.299	0.360	0.342
9.5 - 3/8	0.430	0.519	0.493
11.0 - 7/16	0.586	0.707	0.671

Note: Values are for leg size 10% oversize, consistent with normal shop practices.

Table - 20		
		
d (mm-in)	Dimension t (mm - in) 3.2 - 1/8	Included angle, 60°
11.0 - 7/16	0.185	0.560
13.0 - 1/2	0.211	0.731
14.3 - 9/16	0.237	0.924
15.9 - 5/8	0.263	1.140
17.5 - 11/16	0.290	1.380
18,9 - 3/4	0.315	1.652

The segments once identified and dimensioned can then be used with values found in to calculate the amount of weld deposit required to fill that particular joint.

Weight of wire per 1000 mm (3.3 ft) length Solid wire Mild steel (Approximate)		Weight of wire per 1000 mm (3.3 ft) length Flux cored & Metal cored Mild steel (Approx.)	
Diameter	Deposition Kg/1000 mm - lb/ft	Diameter	Deposition Kg/1000 mm - lb/ft
0.8 mm - 0.030 in	0.004 - 0.0027	1.2 mm - 0.045 in	0.007 - 0.0047
0.9 mm - 0.035 in	0.005 - 0.0034	1.4 mm - 0.052 in	0.008 - 0.0054
1.2 mm - 0.045 in	0.008 - 0.0054	1.6 mm - 1/16 in	0.0125 - 0.0084
1.4 mm - 0.052 in	0.012 - 0.0081	2.0 mm - 5/64 in	0.0177 - 0.0119
1.6 mm- 1/16 in	0.018 - 0.0121	2.8 mm - 7/64 in	0.0291 - 0.0195
2.0 mm - 5/54 in	0.027 - 0.0181	2.4 mm - 3/32 in	0.0349 - 0.0234
2.4 mm - 3/32 in	0.04 - 0.027	3.2 mm - 1/8 in	0.0418 - 0.02
3.2 mm - 1/8 in	0.06 - 0.04		
4.0 mm - 5/32 in	0.09 - 0.06		

CONCLUSION

In this Part, we have dealt with the :

CALCULATION OF WELD VOLUME/ WELD DEPOSITION

- Geometrical Configurations of weld Sections
- Formula and Calculations
- Weld Metal Deposition by Different Processes

Apart from calculating formulae for weld volume and deposition, several charts and tables are provided for ready references.