Orbital Welding Reference Pack

Essential Charts, Tables & Quick References for Welding Professionals

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Tungsten Electrode Grinding Angle Chart

Grinding Angle by Application

Included Angle	Taper Length (3/32")	Arc Shape	Penetration Profile	Best Applications
14°	~0.375" (long)	Very wide, soft	Shallow, wide bead	Ultra-thin wall tube (0.020"–0.035"), foil welding, orbital fusion welds on thin sanitary tube
18–20°	~0.290"	Wide, stable	Moderate width, shallow	Thin-wall sanitary tube (0.035"–0.065"), orbital autogenous welds, semiconductor tube
30°	~0.180"	Moderate width	Balanced width & depth	General-purpose TIG on sheet/thin plate (16–11 ga), orbital welds on medium-wall tube
45°	~0.115"	Focused	Deeper, narrower	Pipe welding (Sch 10–40), plate joints, filler wire applications, root passes
60°	~0.080" (short)	Tight, concentrated	Deep, narrow	Heavy pipe (Sch 80+), thick plate, high-amperage applications (150 A+), deep groove welds

Recommended Angles by Material Thickness

Material Thickness	Recommended Angle	Electrode Diameter	Typical Amperage
0.020"–0.035" (foil/ultra-thin)	14°–18°	0.040" or 1/16"	5–20 A
0.035"–0.049" (thin-wall tube)	18°–20°	1/16" or 3/32"	15–35 A
0.049"–0.065" (sanitary tube)	18°–25°	3/32"	25–50 A
0.065"–0.109" (medium wall)	25°–35°	3/32" or 1/8"	40–90 A
0.120"–0.154" (Sch 10–40 pipe)	30°–45°	3/32" or 1/8"	60–130 A
0.218"+ (Sch 80+ pipe, plate)	45°–60°	1/8" or 5/32"	100–250 A

Electrode Types & Color Codes

Type	AWS Class	Color	Oxide	Best For
Pure Tungsten	EWP	Green	None	AC aluminum welding only
2% Thoriated	EWTh-2	Red	2% ThO2	DC, excellent arc stability. Mildly radioactive — being phased out
2% Ceriated	EWCe-2	Gray	2% CeO2	Low-amperage DC/AC, orbital welding. Non-radioactive
1.5% Lanthanated	EWLa-1.5	Gold	1.5% La2O3	Wide amperage range, direct thoriated replacement. Non-radioactive
2% Lanthanated	EWLa-2	Blue	2% La2O3	General-purpose, good arc starting. Non-radioactive
Rare Earth Blend	EWG	Various	Mixed	Proprietary blends, varies by manufacturer

Flat/Truncation by Electrode Diameter

Electrode Diameter	Recommended Flat	Notes
0.040"	0.005"–0.010"	Micro-flat — just break the point
1/16" (0.0625")	0.010"–0.015"	Standard for thin-wall orbital
3/32" (0.094")	0.010"–0.020"	Most common orbital electrode size
1/8" (0.125")	0.015"–0.030"	General TIG and orbital
5/32" (0.156")	0.020"–0.040"	Heavy-wall pipe and plate

Key rule: Always grind tungsten *longitudinally* (parallel to the electrode axis). Radial grind marks cause arc wander and inconsistent bead width.

Purge Plug Sizing Chart

Tube Purge Plug Sizing

Tube is specified by OD. ID = OD − (2 × wall thickness). Select plug by ID, not OD.

Tube OD	Wall: 0.035"	Wall: 0.049"	Wall: 0.065"	Plug Size
1/2" (0.500")	ID: 0.430"	ID: 0.402"	ID: 0.370"	3/8"–1/2"
3/4" (0.750")	ID: 0.680"	ID: 0.652"	ID: 0.620"	5/8"–3/4"
1" (1.000")	ID: 0.930"	ID: 0.902"	ID: 0.870"	7/8"–1"
1-1/2" (1.500")	ID: 1.430"	ID: 1.402"	ID: 1.370"	1-3/8"–1-1/2"
2" (2.000")	ID: 1.930"	ID: 1.902"	ID: 1.870"	1-7/8"–2"
2-1/2" (2.500")	—	ID: 2.402"	ID: 2.370"	2-3/8"–2-1/2"
3" (3.000")	—	ID: 2.902"	ID: 2.870"	2-7/8"–3"
4" (4.000")	—	ID: 3.902"	ID: 3.870" / 3.834"*	3-3/4"–4"

** 4" OD with 0.083" wall (extra heavy): ID = 3.834"*

Pipe Purge Plug Sizing

Pipe is specified by NPS. OD is standardized; ID varies by schedule (wall thickness).

NPS	Pipe OD	Sch 10S Wall	Sch 10S ID	Plug (10S)	Sch 40S Wall	Sch 40S ID	Plug (40S)
1/2"	0.840"	0.083"	0.674"	5/8"–3/4"	0.109"	0.622"	5/8"–3/4"
3/4"	1.050"	0.083"	0.884"	7/8"–1"	0.113"	0.824"	3/4"–7/8"
1"	1.315"	0.109"	1.097"	1"–1-1/8"	0.133"	1.049"	1"–1-1/8"
1-1/2"	1.900"	0.109"	1.682"	1-5/8"–1-3/4"	0.145"	1.610"	1-1/2"–1-5/8"
2"	2.375"	0.109"	2.157"	2-1/8"–2-1/4"	0.154"	2.067"	2"–2-1/8"
3"	3.500"	0.120"	3.260"	3-1/4"–3-3/8"	0.216"	3.068"	3"–3-1/8"
4"	4.500"	0.120"	4.260"	4-1/4"–4-3/8"	0.237"	4.026"	4"–4-1/8"
6"	6.625"	0.134"	6.357"	6-1/4"–6-3/8"	0.280"	6.065"	6"–6-1/8"

Purge Flow Rate Recommendations

Tube/Pipe ID Range	Flow Rate	Pre-Purge Time (min)
Under 1/2" ID	5–10 CFH (2.4–4.7 L/min)	30–60 sec
1/2" to 1" ID	10–20 CFH (4.7–9.4 L/min)	45–90 sec
1" to 2" ID	15–25 CFH (7.1–11.8 L/min)	60–120 sec
2" to 4" ID	20–35 CFH (9.4–16.5 L/min)	90–180 sec
4" to 8" ID	30–50 CFH (14.2–23.6 L/min)	120–300 sec

Critical: A "2-inch pipe" (OD 2.375") and a "2-inch tube" (OD 2.000") have completely different IDs. Never interchange plug sizes between tube and pipe systems.

Stainless Steel Tube Dimensions

Sanitary Tube — 316/316L SS (ASME BPE / 3-A Sizes)

OD (in)	Wall (in)	Wall Type	ID (in)	ID (mm)	Weight (lb/ft)	Weight (kg/m)
0.500	0.035	Light	0.430	10.92	0.174	0.259
0.500	0.049	Standard	0.402	10.21	0.237	0.353
0.500	0.065	Heavy	0.370	9.40	0.302	0.449
0.750	0.035	Light	0.680	17.27	0.268	0.399
0.750	0.049	Standard	0.652	16.56	0.367	0.546
0.750	0.065	Heavy	0.620	15.75	0.476	0.708
1.000	0.035	Light	0.930	23.62	0.362	0.539
1.000	0.049	Standard	0.902	22.91	0.498	0.741
1.000	0.065	Heavy	0.870	22.10	0.650	0.967
1.500	0.035	Light	1.430	36.32	0.549	0.817
1.500	0.049	Standard	1.402	35.61	0.760	1.131
1.500	0.065	Heavy	1.370	34.80	0.998	1.485
2.000	0.035	Light	1.930	49.02	0.736	1.095
2.000	0.049	Standard	1.902	48.31	1.023	1.522
2.000	0.065	Heavy	1.870	47.50	1.346	2.003
2.500	0.049	Standard	2.402	61.01	1.285	1.912
2.500	0.065	Heavy	2.370	60.20	1.694	2.521
3.000	0.049	Standard	2.902	73.71	1.547	2.302
3.000	0.065	Heavy	2.870	72.90	2.042	3.039
4.000	0.049	Standard	3.902	99.11	2.072	3.083
4.000	0.065	Heavy	3.870	98.30	2.738	4.074
4.000	0.083	Extra Heavy	3.834	97.38	3.478	5.175
6.000	0.065	Heavy	5.870	149.10	4.130	6.145
6.000	0.083	Extra Heavy	5.834	148.18	5.259	7.826
6.000	0.109	Sch 10S	5.782	146.86	6.872	10.225

Weight formula: lb/ft = 10.68 × (OD − Wall) × Wall. Dimensions per ASTM A270/A269.

ASTM A270 vs A269 — Quick Comparison

Feature	ASTM A270 (Sanitary)	ASTM A269 (General Service)
Primary Use	Dairy, food, pharma, bioprocessing	Chemical process, instrumentation, general industrial
ID Surface Finish	Specified (typically 20–32 Ra µin)	Not specified (mill finish unless ordered)
OD Surface Finish	Specified (typically 32 Ra µin or better)	Not specified
Inspection	100% eddy current or hydrostatic test	Hydrostatic or eddy current test
End Condition	Square-cut, deburred, orbital-weld ready	Cut ends, may need prep
BPE Compliance	Required for BPE product-contact	Not sufficient for BPE product-contact

Feature	ASTM A270 (Sanitary)	ASTM A269 (General Service)
Cost Premium	15–30% more than A269	Baseline

Welding Gas Flow Rates

Shielding Gas — Flow Rate by Cup Size

Cup Size	Opening Diameter	Recommended CFH	Application
#4	1/4" (6.4 mm)	8–12 CFH	Micro-welding, very thin material, tight access joints
#5	5/16" (7.9 mm)	10–15 CFH	Small-diameter tube, precision work
#6	3/8" (9.5 mm)	12–18 CFH	Thin-wall tube, orbital weld heads, light fabrication
#7	7/16" (11.1 mm)	15–20 CFH	General-purpose TIG, most common cup for shop work
#8	1/2" (12.7 mm)	18–22 CFH	Standard TIG welding, pipe root passes, structural
#10	5/8" (15.9 mm)	20–30 CFH	Larger joints, pipe welding, gas-lens setups
#12	3/4" (19.1 mm)	25–35 CFH	Large cup / gas-lens walking-the-cup technique

Note: Add 20% to shielding flow for pre-flow and post-flow gas coverage. In drafty conditions, increase flow rate or use a gas lens for better coverage.

Purge Gas — Flow Rate by Pipe/Tube Size

Pipe/Tube ID Range	Recommended Flow Rate	Pre-Purge Volume Exchanges	Typical Pre-Purge Time
Under 1/2" ID	5–10 CFH	5–7 exchanges	30–60 sec
1/2" to 1" ID	10–20 CFH	5–7 exchanges	45–90 sec
1" to 2" ID	15–25 CFH	5–7 exchanges	1–2 min
2" to 4" ID	20–35 CFH	5–7 exchanges	1.5–3 min
4" to 8" ID	30–50 CFH	5–7 exchanges	2–5 min
8"+ ID	40–60 CFH	5–10 exchanges	5–10 min

Purge Volume Calculation

$$\text{Purge Volume} = \pi \times r^2 \times L \times (\text{number of exchanges})$$

Where r = ID / 2 (inches), L = distance between purge dams (inches). Divide result by 1,728 to convert in^3 to ft^3.

Quick Purge Time Estimate

$$\text{Time (min)} = \text{Total Purge Volume } (ft^3) \div (\text{Flow Rate CFH} \div 60)$$

Target O2 levels: General stainless < 500 ppm • ASME BPE / pharma < 50 ppm • Semiconductor < 10 ppm. Always verify with an O2 analyzer before welding critical joints.

Argon Cylinder Reference

Cylinder Size	Capacity	Typical Use
R (20 CF)	20 CF	Small portable jobs, backup
Q (80 CF)	80 CF	Light shop use, small orbital jobs
S / K (250–330 CF)	250–330 CF	Standard shop cylinder, most common
T (330 CF)	330 CF	Full-size shop cylinder
Bulk / Dewar	2,000–6,000+ CF	High-volume production, multi-station

ASME BPE Quick Reference

Weld Acceptance Criteria (Autogenous GTAW Butt Welds, 316/316L SS)

Criteria	Acceptance Limit	Notes
ID Concavity	Max 10% of wall, not to exceed 0.015"	Must blend smoothly, no sharp transitions
ID Convexity (Penetration)	Max 10% of wall, not to exceed 0.015"	No ledge or crevice that could trap product
OD Concavity	Not permitted below parent metal	OD underfill is rejectable
OD Convexity (Reinforcement)	Max 20% of wall	Must blend smoothly into parent material
Lack of Penetration	Not permitted	100% circumference must show full penetration
ID Discoloration	Per owner spec (commonly light straw max)	Often limited to AWS D18.2 color #4 or lighter
Cracks	Not permitted	Any crack is rejectable, any size/orientation
Porosity (ID)	Not permitted	No pores of any size on process-contact surface
Undercut (ID)	Not permitted	Any undercut on ID is rejectable
Misalignment (Hi-Lo)	Max 20% of wall, not to exceed 0.020"	Offset between tube ID surfaces at the joint
Overlap / Cold Lap	Not permitted	No unfused material on either surface

Surface Finish Designations (BPE-2024)

Designation	Finish Type	Ra (µin)	Ra (µm)	Typical Application
SF1	Mill finish	No req.	No req.	Non-product-contact utility services
SF2	Mechanical polish	30 max	0.76 max	Utility, WFI distribution (non-critical)
SF3	Mechanical polish	25 max	0.63 max	Purified water, WFI, clean steam
SF4	Mech polish + EP	25 → 20 max	0.63 → 0.51	Pharma process, biotech fermentation
SF5	Mech polish + EP	20 → 15 max	0.51 → 0.38	High-purity pharma, API manufacturing
SF6	Mech polish + EP	15 → 10 max	0.38 → 0.25	Ultra-high-purity, semiconductor UPW

EP = Electropolish. Must remove min 0.0001" (2.5 µm) of material. Ra measured per ASME B46.1.

Purge Requirements for BPE Welding

Parameter	Requirement
Purge Gas	Welding-grade argon, 99.996% min purity (Grade 4.6)
Pre-Weld O2 Level	< 50 ppm before arc initiation; many pharma specs require < 25 ppm or < 10 ppm
During Welding	Purge maintained throughout entire weld cycle
Post-Weld	Continue purge until weld cools below ~300°F (150°C)
Monitoring	Continuous O2 monitoring — calibrated inline analyzer
Flow Rate	5–20 CFH depending on tube size; avoid turbulence

BPE Material Requirements (316L)

Parameter	Requirement
Alloy	UNS S31603 (316L)
Carbon Content	0.035% max (some specs: 0.030% max)
Sulfur Content	0.005%–0.017% (weldable range)

Parameter	Requirement
Tubing Spec	ASTM A270 (sanitary) or A269 (general)
Delta Ferrite	Typically 3–10 FN per owner spec
Material Cert	EN 10204 3.1 or equivalent MTR required
Traceability	Full heat number traceability required

Orbital vs Manual Welding Cost Quick Reference

Typical Cost Per Joint Comparison (2" OD Sanitary Tube, 316L SS)

Cost Component	Manual TIG	Orbital	Notes
Labor	$42.50	$7.33	Manual: $85/hr × 30 min. Orbital: $55/hr × 8 min
Rework (failure rate)	$3.96	$0.09	Manual: 8% rework rate. Orbital: 1% rework rate
Consumables	$3.00	$2.00	Tungsten, filler wire (manual), collets, cups
Shielding/Purge Gas	$4.00	$2.00	Orbital uses less gas per joint (shorter arc time)
Subtotal (per joint)	**$53.46**	**$11.42**	Before equipment cost allocation
Equipment (rental)	—	$5.83	$350/day ÷ 60 joints/day (8-min cycle)
Equipment (purchased)	—	$2.25	$45,000 ÷ 20,000 joint expected life
Total (with rental)	**$53.46**	**$17.25**	68% savings per joint
Total (purchased)	**$53.46**	**$13.67**	74% savings per joint

Break-Even Analysis Guidance

Equipment Method	Typical Break-Even	Factors That Affect It
Rental ($300–$500/day)	5–15 joints/day	Rental rate, manual welder rate, joint complexity, rework rate
Purchase ($30K–$80K)	700–2,000 joints	Equipment cost, manual welder rate, rework rate, utilization

When Orbital Makes Sense

Orbital is the clear choice when:

- High joint count (50+ on a project)
- Regulatory requirements (ASME BPE, pharma, semiconductor)
- Repeatability and documentation are critical
- Tight access or confined spaces
- Thin-wall sanitary tube (0.035"–0.065")
- Rework costs are high (cleanroom, installed systems)
- Qualified manual welders are scarce or expensive

Manual may be better when:

- Very low joint count (<10 joints)
- Highly varied joint geometries and sizes
- Field repairs on existing systems
- Large-bore heavy-wall pipe (Sch 80+)
- Materials requiring filler wire additions
- One-off custom fabrication work
- No access to orbital equipment or training

Project Cost Quick Estimate (100 Joints on 2" Sanitary Tube)

	Manual	Orbital (Rental)	Orbital (Purchased)
Labor	$4,250	$733	$733
Rework	$396	$9	$9

	Manual	Orbital (Rental)	Orbital (Purchased)
Consumables	$300	$200	$200
Gas	$400	$200	$200
Equipment	—	$700 (2 days)	$225
Total	**$5,346**	**$1,842**	**$1,367**
Savings vs Manual	**—**	**$3,504 (66%)**	**$3,979 (74%)**

Use our interactive calculators for project-specific estimates: orbitalweldingguide.com/tools/cost-calculator and orbitalweldingguide.com/tools/purge-calculator

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