

Welding Filler Metals for HY-80 Steel

Welding filler metals for HY-80 steel refer to specialized consumables designed for joining HY-80, a high-tensile, high-yield-strength, low-alloy (HSLA) steel developed for naval applications. HY-80, with a minimum yield strength of 80 ksi (550 MPa), is renowned for its combination of toughness, weldability, and resistance to brittle fracture under cryogenic conditions, making it ideal for submarine hulls, ship structures, and pressure vessels.

The selection of filler metals is critical to maintain these properties in the weld metal (WM), particularly to mitigate issues like hydrogen-induced cracking and ensure microstructural integrity through the formation of acicular ferrite. This article examines the primary filler metal, AWS ER100S-1, its composition, role in nucleating acicular ferrite, and welding procedures, drawing from military specifications (e.g., MIL-S-24371) and industry standards (e.g., AWS A5.28).

Background on HY-80 Steel

HY-80 was developed in the 1950s by the U.S. Navy's David Taylor Model Basin as part of the HY-series (High Yield) steels for submarine construction, succeeding HY-60 and preceding HY-100. Its designation reflects a yield strength of 80 ksi, achieved through controlled alloying with nickel (2-3%), chromium (1-1.5%), and molybdenum (0.3-0.6%), which enhance hardenability and toughness down to -60°C (-76°F). The steel's base composition includes low carbon ($\leq 0.18\%$) to improve weldability, but welding introduces challenges such as dilution (mixing of base metal and filler), heat-affected zone (HAZ) softening, and potential for martensite formation, which can reduce ductility.

Welding HY-80 requires filler metals that match or exceed the base metal's strength while promoting a fine-grained microstructure. The American Welding Society (AWS) classifies these as low-alloy filler

metals under A5.28, with ER100S-1 emerging as the standard choice for gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW). This filler produces welds with tensile strengths exceeding 100 ksi (690 MPa) and Charpy V-notch impact energies >50 ft-lb at -40° F, ensuring compliance with naval requirements like NAVSEA 250-1500-1.

Welding Challenges in HY-80

HY-80's high strength stems from quenched and tempered martensitic structure, but welding heat (typically 1200–1400° C) disrupts this, leading to:

- **Dilution Effect:** Base metal (high Ni/Cr) mixes with filler, altering chemistry and potentially increasing carbon equivalent ($CE = C + Mn/6 + (Cr+Mo+V)/5 + (Ni+Cu)/15$), raising cracking risk.
- **HAZ Softening:** Tempering in the HAZ reduces hardness from 25–30 HRC to 20–25 HRC, compromising local strength.
- **Microstructural Issues:** Coarse ferrite or bainite can form if cooling rates are too slow, reducing toughness. Hydrogen from moisture or shielding gas can cause cold cracking.

Filler metals address these by providing low CE (≤ 0.40), matching alloying, and promoting acicular ferrite—a fine, intragranular lath structure that nucleates on oxide inclusions, enhancing toughness without sacrificing strength. Studies show acicular ferrite can increase weld impact toughness by 20–50% compared to polygonal ferrite-dominated microstructures.

Recommended Filler Metal: AWS ER100S-1

The primary filler for HY-80 is **ER100S-1** (AWS A5.28 Class ER100S-1), a solid wire for GMAW and GTAW, developed in the 1970s for high-strength low-alloy (HSLA) steels like HY-80 and HY-100. It delivers weld metal with yield strength >88 ksi (607 MPa) and tensile strength >100 ksi (690 MPa), matching HY-80's properties while minimizing dilution effects through lower carbon (0.06–0.11%) and nickel (1.40–2.10%) content. The "S" denotes silicon deoxidized, improving arc stability and reducing porosity.

ER100S-1 is available in diameters 0.035–0.045 in (0.9–1.2 mm) for GMAW and 1/16 in (1.6 mm) for GTAW, with typical shielding gases like Ar-2%O₂ for short-circuit transfer or Ar-20%CO₂ for spray transfer.

Preheat (150–250° F) and interpass temperatures (<500° F) are recommended to control cooling rates (10–30° C/s) and prevent cracking.

Chemical Composition of ER100S-1

The composition is optimized for low CE (0.35–0.40) to counter HY-80's dilution, with manganese and silicon for deoxidation and molybdenum for hardenability.

Element	Composition (%)	Role in Weld Metal
Carbon (C)	0.06 - 0.11	Low to reduce CE and cracking susceptibility; promotes ferrite formation
Manganese (Mn)	1.40 - 2.10	Deoxidizer and strengthener; stabilizes austenite during welding
Silicon (Si)	0.20 - 0.65	Deoxidizer; improves fluidity and bead shape
Phosphorus (P)	≤ 0.010	Impurity; minimized to prevent brittleness
Sulfur (S)	≤ 0.010	Low for ductility; controlled to avoid hot cracking
Nickel (Ni)	1.40 - 2.10	Matches HY-80 for toughness; lower than base to offset dilution
Chromium (Cr)	0.60 - 1.40	Enhances corrosion resistance and hardenability
Molybdenum (Mo)	0.25 - 0.60	Improves strength and temper resistance in HAZ
Copper (Cu)	≤ 0.50	Optional for corrosion; limited to avoid cracking
Iron (Fe)	Balance	Base metal

This composition ensures the weld metal's CE remains below 0.45, reducing preheat needs compared to matching fillers like E11018-M.

Mechanical Properties of ER100S-1 Welds

ER100S-1 deposits yield weld metal with properties superior to HY-80 in some aspects, particularly impact toughness at low temperatures.

Property	Value (As-Welded)	Value (PWHT at 1150° F)	Test Standard	Notes
Yield Strength (Rp0.2)	≥ 88 ksi (607 MPa)	≥ 100 ksi (690 MPa)	AWS A5.28	Matches/exceeds HY-80; PWHT (post-weld heat treatment) for stress relief
Ultimate Tensile Strength (Rm)	≥ 100 ksi (690 MPa)	≥ 110 ksi (758 MPa)	AWS A5.28	High to compensate dilution
Elongation (A5)	≥ 16%	≥ 18%	AWS A5.28	Ductile; PWHT improves
Reduction of Area (Z)	≥ 50%	≥ 55%	AWS A5.28	Indicates toughness
Charpy V-Notch (CVN) at -60° F	≥ 50 ft-lb (68 J)	≥ 60 ft-lb (81 J)	MIL-S-24371	Critical for naval use; acicular ferrite enhances
Hardness (HRC)	25-30	22-28	Vickers	Balanced for machinability
Fatigue Strength (10 ⁷ cycles)	50-60 ksi (345-414 MPa)	55-65 ksi (379-448 MPa)	ASTM E466	Good in corrosive environments

PWHT at 1150° F (621° C) for 1 hour/inch thickness relieves residual stresses and tempers martensite, improving ductility without significant strength loss.

Role of Filler Metal in Acicular Ferrite Nucleation

A key function of ER100S-1 is to nucleate **acicular ferrite** (AF), a non-parallel lath structure that forms intragranularly on oxide inclusions during cooling (500-700° C). AF is preferred over Widmanstätten ferrite or bainite for its fine grain size (1-5 μm), which deflects cracks and boosts toughness (up to 100 J at -40° C).

Nucleation Mechanism

AF nucleates heterogeneously on non-metallic inclusions (e.g., MnO-SiO₂-Al₂O₃ oxides, 0.5-5 μm), facilitated by the filler's composition:

- **Low Carbon/Nickel:** Reduces austenite stability, promoting ferrite transformation; dilution with HY-80's high Ni is offset by ER100S-1's lower levels (1.4-2.1% vs. 2-3%).
- **Manganese and Silicon:** Form oxide inclusions during deoxidation, serving as nucleation sites. Mn depletion zones around inclusions lower local austenite transformation temperature, favoring AF over bainite.
- **Molybdenum:** Stabilizes ferrite, increasing AF volume fraction (40-70% in optimal welds).

Transmission electron microscopy (TEM) studies show AF laths (0.2-0.5 μm thick) intersecting prior austenite grains, with inclusion density >10⁴/mm² correlating to >60% AF. Cooling rate (20-50° C/s) is crucial; slower rates favor polygonal ferrite, reducing toughness by 30%.

Comparison with Other Fillers

Alternatives like ER110S-1 (higher strength) or E10018-M (SMAW electrode) exist, but ER100S-1 balances cost and performance.

Filler Metal	AWS Class	Ni (%)	Mo (%)	AF Volume (%)	Typical Use	Cost (per lb)
ER100S-1	A5.28 ER100S-1	1.4-2.1	0.25-0.6	50-70	GMAW/GTAW HY-80	\$5-7
ER110S-1	A5.28 ER110S-1	2.0-2.5	0.35-0.65	60-80	HY-100	\$6-8
E10018-M	A5.5 E10018-M	1.5-2.0	0.3-0.6	40-60	SMAW	\$4-6
ER80S-D2	A5.28 ER80S-D2	0.5-1.0	0.2-0.5	30-50	General HSLA	\$3-5

ER100S-1's inclusion-promoting oxides (from Si/Mn) yield higher AF than ER80S-D2.

Welding Procedures for HY-80 with ER100S-1

Welding HY-80 follows NAVSEA or AWS D1.1 guidelines, emphasizing controlled heat input (1-3 kJ/mm) to achieve AF-dominated microstructure.

Pre-Weld Preparation

- **Preheat:** 150-250° F (66-121° C) to reduce hydrogen and control cooling.
- **Cleaning:** Remove mill scale, oil; use acetone or grit blast.
- **Filler Storage:** Dry at 250° F to prevent moisture absorption.

Welding Processes

- **GMAW (Preferred):** Short-circuit or spray transfer, 75% Ar-25% CO₂ gas, current 200-300 A, voltage 24-28 V. Travel speed 10-15 ipm.
- **GTAW:** For root passes, 100% Ar gas, 120-180 A, filler addition 2-4 lb/h.
- **Multi-Pass:** 3-5 passes for 1-in plate, interpass <500° F.

Post-weld, PWHT at 1150° F for 1 h/inch relieves stresses, transforming retained austenite to tempered martensite/AF. Nondestructive testing (NDT) includes ultrasonic (UT) for defects and magnetic particle (MT) for surface cracks.

Applications and Case Studies

HY-80 with ER100S-1 fillers is integral to U.S. Navy vessels:

- **Submarine Hulls:** Virginia-class submarines use HY-80 plates welded with ER100S-1 for pressure hulls, enduring 1000+ ft depths with welds showing >100 J CVN at -60° F.
- **Surface Ships:** Arleigh Burke destroyers employ HY-80 for deck structures, where ER100S-1 ensures fatigue life >10⁷ cycles under cyclic loading.

- **Commercial Adaptations:** Offshore platforms adapt HY-80 equivalents with ER100S-1 for risers, reducing weight by 20% vs. carbon steels.

Case studies from the 1980s Los Angeles-class submarine welds demonstrated ER100S-1's role in AF nucleation, achieving 80% AF volume and 25% toughness improvement over earlier fillers.

Conclusion

Welding filler metals like ER100S-1 are essential for preserving HY-80's superior properties, with their low-alloy composition and oxide-promoting elements driving acicular ferrite nucleation for enhanced toughness. Ongoing research focuses on laser-hybrid welding to further optimize AF formation, reducing PWHT needs. Proper selection and procedure adherence ensure reliable performance in high-stakes applications.

References

This article adheres to neutral, verifiable principles, drawing from reliable sources. For further reading, consult AWS A5.28 and NAVSEA specifications.