

# **Welding Procedure Specification (WPS) for ASTM A516 Grade 70 Pressure Vessel Steel Plates**

Note: This WPS is applicable for welding operations of ASTM A516 Grade 70 (A516 Gr70) carbon steel plates for medium and low temperature pressure vessels, covering conventional butt and fillet joints of medium and thick plates. It complies with ASME BPVC Sec.IX and relevant pressure vessel manufacturing specifications. The core controls include low hydrogen welding, preheating and interpass temperature, and post-weld stress relief to ensure joint strength and low temperature toughness, and eliminate defects such as cold cracks and embrittlement.

## **1. BASIC PROCESS INFORMATION**

### **1.1 Base Material Information**

- Material Grade: ASTM A516 Grade 70 (SA516 Gr70), supplied in normalized condition.
- Material Category: High-quality low carbon pressure vessel steel, carbon equivalent  $CE \leq 0.45\%$ , excellent weldability, low cold crack sensitivity.
- Applicable Plate Thickness: 6mm - 80mm (separate adjustment of preheating and heat treatment parameters required for extra thick plates).
- Application: Medium and low temperature pressure vessels, storage tanks, boilers, low temperature equipment.
- Design Operating Temperature:  $-45^{\circ}\text{C} \sim 350^{\circ}\text{C}$ .

### **1.2 Welding Methods and Applicable Scenarios**

Welding Method	Full Name	Applicable Scenarios	Common Joint Types	Characteristics
SMAW	Shielded Metal Arc Welding	Field installation, weld repair, small batch production, special-shaped joints	Butt V-groove, fillet joints	Flexible, low hydrogen electrodes recommended
GTAW	Gas Tungsten Arc Welding	Root pass welding for	Thin-walled butt joints,	Good forming, stable quality

	(TIG)	thin-walled components, high requirement joints, single-sided welding with double-sided forming	small diameter nozzles, groove root pass	
GMAW	Gas Metal Arc Welding (MIG)	Automatic welding of medium and thin plates, mass production	Butt and fillet joints of medium and thick plates	High efficiency, narrow heat-affected zone
SAW	Submerged Arc Welding	Mass welding of longitudinal and circumferential seams for thick plates, efficiency priority scenarios	X-groove/U-groove butt joints of thick plates	Deep penetration, high efficiency, stable quality

### 1.3 Joint Groove Forms

- Plate Thickness 6-20mm: Single V-groove, groove angle  $60^{\circ} \pm 5^{\circ}$ , root face 2-3mm, gap 2-3mm.
- Plate Thickness 20-40mm: Double V-groove, groove angle  $55^{\circ} \pm 5^{\circ}$ , root face 2-3mm, gap 2-3mm.
- Plate Thickness  $> 40$ mm: U-groove, reduce welding deposition, lower welding stress.
- All grooves must be machined or ground after carbon arc gouging before welding, remove oxide scale and burrs to ensure groove smoothness.

## 2. WELDING MATERIAL SELECTION

Requirement: Low hydrogen type welding materials must be selected, with strength matching the base material and qualified low temperature toughness. Ordinary acidic welding materials are strictly prohibited to avoid weld hydrogen-induced cracks. Welding

materials must have qualified quality certification documents and be compatible with the base material.

Welding Method	AWS Welding Material Grade	Welding Material Drying and Storage Requirements
SMAW	E7018 (preferred), E7015	Dry at 350-400°C for 1h, keep warm at 100-150°C, take as needed, re-dry if unused within 4h
GTAW	ER70S-2, ER70S-6	Welding wire sealed storage, remove surface oil and rust before welding, argon gas purity $\geq 99.99\%$
GMAW	ER70S-6	Shielding gas: Pure CO <sub>2</sub> or Ar+20%CO <sub>2</sub> mixed gas, no leakage in gas pipeline
SAW	H08MnA/H10Mn2 welding wire + SJ101/SJ301 flux	Flux dried at 300-350°C for 1h, remove oil and oxide scale from welding wire, sieving required for reused flux to remove impurities

### **3. PREHEATING AND INTERPASS TEMPERATURE CONTROL (KEY FOR CRACK PREVENTION)**

#### **3.1 Preheating Temperature Requirements**

- Plate Thickness <25mm: Weld at room temperature (preheating 50-80°C recommended for ambient temperature <0°C or high restraint joints).
- Plate Thickness 25-40mm: Preheating 100-150°C.
- Plate Thickness 40-80mm: Preheating 150-200°C.
- Special Working Conditions: Increase preheating temperature by 20-50°C for wet environment, high rigidity joints, and low temperature construction.

#### **3.2 Interpass Temperature Control**

- Interpass Temperature Control Range: 150-250°C, strictly no more than 250°C to avoid toughness reduction caused by coarse grains in heat-affected zone.
- Temperature Measurement Requirement: Use temperature indicator pen or infrared thermometer, temperature measurement range is 3 times the plate thickness area on both sides of the groove, temperature must be measured before each pass in multi-layer and multi-pass welding.
- Prohibition: Excessively thick single pass welding, forced welding with too low interpass temperature.

### 3.3 Preheating Methods

Flame uniform heating and electric heating blanket heating are recommended to ensure uniform heating of the groove area, eliminate local overheating or uneven heating; local spot rapid heating is prohibited.

## 4. STANDARD WELDING PROCESS PARAMETERS (FOR REFERENCE)

### 4.1 Shielded Metal Arc Welding (SMAW, E7018, $\phi$ 3.2/4.0mm)

Parameter	3.2 mm Electrode	4.0 mm Electrode
Welding Current	90-130 A	140-180 A
Welding Voltage	26-30 V	24-28 V
Welding Speed	12-18 cm/min	15-20 cm/min
Polarity	DC Reverse Polarity (DC+)	DC Reverse Polarity (DC+)
Single Pass Thickness	3-4 mm	3-4 mm

### 4.2 Gas Tungsten Arc Welding (GTAW, ER70S-6, $\phi$ 2.0/2.4mm)

- Welding Wire Diameter: 2.0mm/2.4mm.
- Welding Current: 80-120A.
- Welding Voltage: 12-16V.
- Wire Feed Speed: 4-5m/min.
- Welding Speed: 25-35cm/min.
- Shielding Gas: Pure Argon.
- Shielding Gas Flow: 8-12L/min.

- Back Purge Argon Flow: 5-8L/min.

### **4.3 Gas Metal Arc Welding (GMAW, ER70S-6, $\phi$ 1.2mm)**

- Welding Wire Diameter: 1.2mm.
- Welding Current: 180-240A.
- Welding Voltage: 26-30V.
- Wire Feed Speed: 4-5m/min.
- Welding Speed: 25-35cm/min.
- Polarity: DC Reverse Polarity (DC+).
- Shielding Gas: Ar+CO<sub>2</sub> (CO<sub>2</sub>: 18–25%).
- Shielding Gas Flow: 15-20L/min.

### **4.4 Submerged Arc Welding (SAW, H08MnA, $\phi$ 4.0mm)**

- Welding Wire Diameter: 4.0mm.
- Welding Current: 450-600A.
- Welding Voltage: 32-38V.
- Welding Speed: 30-50cm/min.
- Heat Input Control: 15-30kJ/cm.
- Flux: SJ101, dried at 350°C×1h.
- Flux Coverage Thickness: 30-40mm.

## **5. KEY WELDING OPERATION NOTES**

- Pre-weld Cleaning: Thoroughly remove oil, rust, moisture and oxide scale within 20mm on both sides of the groove, grind to metallic luster to eliminate hydrogen source introduction.
- Multi-layer and Multi-pass Welding: Multi-layer and multi-pass welding must be adopted for thick plates, single pass thickness no more than 5mm, thoroughly clean slag and spatter after each pass to avoid interlayer slag inclusion.
- Back Gouging: For double-sided welding joints, perform carbon arc gouging for back gouging after front welding, grind to defect-free metal natural color before back welding to ensure full penetration.

- **Welding Heat Input Control:** Strictly prohibit welding with high current, wide swing and slow speed, control heat input to avoid overheating embrittlement of heat-affected zone and ensure low temperature toughness.
- **Environmental Control:** Welding operation environment humidity  $\leq 90\%$ , wind speed  $\leq 2\text{m/s}$  (gas shielded welding wind speed  $\leq 1\text{m/s}$ ), build protective shed for windy and rainy weather, outdoor welding in severe environment is prohibited.
- **Arc Striking and Termination:** Strictly prohibit arc striking on base metal surface outside the groove, fill the crater during termination to prevent crater cracks.

## **6. POST-WELD HEAT TREATMENT (PWHT) REQUIREMENTS**

**Purpose: Eliminate welding residual stress, stabilize joint microstructure, improve low temperature toughness, prevent delayed cracks, and ensure long-term operation safety of pressure vessels.**

### **6.1 Heat Treatment Applicable Conditions**

- Plate Thickness  $> 32\text{mm}$ : Mandatory post-weld stress relief heat treatment.
- Low temperature pressure vessels with design temperature below  $-30^\circ\text{C}$ .
- High restraint joints, hydrogen sulfide corrosion environment, thick-walled pressure components.

### **6.2 Heat Treatment Process Parameters**

- Heat Treatment Temperature:  $595\text{-}650^\circ\text{C}$ , commonly  $600\text{-}620^\circ\text{C}$ .
- Holding Time:  $1\text{-}3\text{min/mm}$ , for plate thickness  $\geq 50\text{mm}$ , holding time not less than 2h.
- Heating Rate:  $\leq 200^\circ\text{C/h}$ .
- Cooling Rate:  $\leq 150^\circ\text{C/h}$ , furnace cooling to below  $300^\circ\text{C}$  before air cooling.
- Hardness Requirement: Hardness of weld and heat-affected zone  $\leq 200\text{HB}$ , avoid brittle fracture caused by excessively high hardness.

### **6.3 Heat Treatment Methods**

Whole furnace heat treatment, local electric heating heat treatment. Local heat treatment must ensure uniform heating in the range of 3 times the plate thickness on both sides of the weld, temperature deviation  $\leq 50^\circ\text{C}$ .

## **7. WELD QUALITY INSPECTION STANDARDS**

### 7.1 Visual Inspection

- Uniform weld surface formation, no defects such as cracks, blowholes, slag inclusions, incomplete penetration, lack of fusion, spatter and excessive undercut.
- Undercut depth  $\leq 0.5\text{mm}$ , weld reinforcement 0-3mm, fillet weld leg size must meet design requirements.

### 7.2 Non-Destructive Testing

- Conventional Testing: UT (Ultrasonic Testing) or RT (Radiographic Testing) must be performed for pressure vessels, meeting ASME Level II acceptance standard.
- Surface Testing: MT (Magnetic Particle Testing) or PT (Penetrant Testing) to detect surface and near-surface cracks, mandatory for low temperature vessels.
- Testing Time: Perform 24h after welding to avoid missing delayed cracks; re-inspection can be conducted after post-weld heat treatment.

### 7.3 Mechanical Property Inspection (Procedure Qualification)

- Tensile Test: Tensile strength  $\geq 485\text{MPa}$ , matching the base material.
- Bend Test: Face bend and root bend  $180^\circ$ , no cracks.
- Impact Test: Impact energy  $\geq 27\text{J}$  at  $-30^\circ\text{C}$  or  $-45^\circ\text{C}$ , meeting low temperature toughness requirements.

## 8. COMMON DEFECTS AND PREVENTIVE MEASURES

Common Defects	Causes	Preventive Measures
Cold Cracks/Delayed Cracks	Excessively high hydrogen content, insufficient preheating, high restraint stress	Low hydrogen welding materials, strict preheating and drying, thorough hydrogen removal before welding, timely heat treatment after welding
Heat-Affected Zone Embrittlement	Excessively high heat input, excessively high interpass temperature, coarse grains	Control welding parameters, multi-layer and multi-pass welding, strictly control interpass temperature, PWHT, normalizing
Slag Inclusions/Incomplete Penetration	Inadequate interlayer cleaning, small groove	Thorough slag cleaning, standard groove

	angle, low current	processing, matching welding current
Insufficient Low Temperature Toughness	Poor welding material toughness, no heat treatment, uncontrolled heat input	Select high toughness welding materials, strict temperature control, PWHT, refined welding

## 9. SUPPLEMENTARY PROVISIONS

This WPS is a recommended reference process by engineers. Actual construction requires parameter fine-tuning according to product design requirements, plate thickness and on-site working conditions. Welding Procedure Qualification (PQR) must be completed before welding, welders must hold valid certificates and strictly implement this specification. Special welding schemes must be prepared separately for extra thick plates, special joints and extreme low temperature environments.

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**Applicable Specifications: ASME BPVC Sec.IX, ASTM A516, Relevant Standards for Pressure Vessel Welding**