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DEVELOPMENT AND EVALUATION OF ADVANCED WELDING TECHNIQUES FOR JOINING DISSIMILAR METALLIC MATERIALS

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Annotation. This study focuses on welding dissimilar metals, specifically ferritic alloy-steel and nickel alloys, using GTAW and SMAW with ERNiCr-3 filler. Due to differing material properties, joining is challenging. Mechanical tests showed that GTAW with ERNiCr-3 ensures high joint strength and corrosion resistance, enhancing reliability in critical industries.

Keywords: GTAW, ERNiCr-3, nickel-chromium-molybdenum-columbium alloy, dissimilar materials welding, filler materials, weld strength, corrosion resistance.

TURLI XIL METALL MATERIALLARNI BIRLASHTIRISH UCHUN ILGʻOR PAYVANDLASH USULLARINI ISHLAB CHIQISH VA BAHOLASH

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Annotatsiya. Turli xil metallarni, xususan ferritli qotishma poʻlat va nikel qotishmalarini ERNiCr-3 prutokidan foydalangan holda GTAW va SMAW usullari orqali payvandlashga qaratilgan. Materiallarning issiqlik kengayishi, eritish harorati va metallurgik xususiyatlari keskin farq qilgani sababli ularni birlashtirish murakkab jarayon hisoblanadi. Oʻtkazilgan mexanik sinovlar (choʻzilish mustahkamligi, zarba viskozligi va qattiqlik) GTAW usuli va ERNiCr-3 prutogi bilan bajarilgan payvand choklari yuqori mustahkamlik va korroziyaga chidamlilikni taʼminlashini koʻrsatdi. Bu natijalar muhim sohalarda ishlatiladigan konstruktsiyalarning ishonchliligini va xizmat muddatini oshirishda amaliy ahamiyatga ega.

Kalit soʼzlar: GTAW, ERNiCr-3, nikel-xrom-molibden-kolumbiy qotishmasi, turli xil materiallarni payvandlash, plomba materiallari, payvandlash kuchi, korroziyaga chidamlilik

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Introduction.

The demand for high-performance welded structures in industries such as petrochemical processing, thermal power plants, and nuclear systems has led to the increasing use of dissimilar metal welding (DMW). Ferritic alloy-steels are widely used for their low cost and weldability, whereas nickel-based alloys like inconel are preferred in areas requiring high corrosion resistance and strength at elevated temperatures. However, welding these materials together poses significant challenges, including hot cracking, dilution, and formation of brittle intermetallic phases. This paper investigates welding techniques to overcome these challenges by developing a reliable welding procedure specification (WPS) for joining ferritic alloy-steel and nickel alloy.

Technological equipment consists of complex structures such as pressure vessels, heat exchangers, pipes, reactors, etc. Most of these structures are assembled by welding. Therefore, the strength of each weld affects the reliability of the entire system.

Methods and materials.

A335-P11 is a ferritic alloy-steel, this specification covers nominal wall and minimum wall seamless ferritic alloy-steel pipe intended for hightemperature service. Selection will depend upon design, service conditions, mechanical properties, and high-temperature characteristics [1; P.511-512.]. Ferritic steels in this specification are defined as low- and intermediate-alloy steels containing up to and including 10 % chromium [1; P.516-517.].

Table 1

Chemical Requirements

№	Elements	Composition, %
1	Carbon	0.05-0.15
2	Marganese	0.30–0.60
3	Phosphorus, max	0.025
4	Sulfur, max	0.025
5	Silicon:	0.50-1.00
6	Chromium	1.00-1.50
7	Molybdenum	0.44-0.65

Table 2

Tensile Requirements

1	Tensile strength, ksi [MPa]	60 [415]
2	Yield strength, min, ksi [MPa]	30 [205]
3	Elongation in 8 in. [200 mm], min, %	22
4	Elongation in 2 in. [50 mm], min, %	30

B-619 (UNS N10276) - is a nickel-molybdenum-chromium alloy with an addition of iron and a trace amount of tungsten. It is highly resistant to a wide range of corrosive environments and is commonly used in chemical processing, pollution control, and marine applications [2; P.849-850.].

B-619 refers to the ASTM B619 specification, which covers welded nickel and nickel alloy pipes, including UNS N10276, intended for high-temperature and high-corrosion applications [2; P.851-855.].

Table 3

Chemical Requirements

№	Elements	Composition, %
1	Nickel	Note-1
2	Chromium	14.5-16.5
3	Molybdenum	15.0-17.0
4	Cobalt, max	2.5
5	Marganese, max	1.0
6	Phosphorus, max	0.010
7	Sulfur, max	0.08

Note-1: The composition of the remainder shall be determined arithmetically by difference.

Table 4

Tensile Requirements

1	Tensile strength, ksi [MPa]	100 (690)
2	Elongation in 2 in. [50 mm], min, %	41(283)
3	Elongation in 8 in. [200 mm], min, %	40

Gas tungsten-arc welding (GTAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used [3; P.13-13.].

Advantages - it produces a very clean and high-quality weld, the welding site does not oxidize, so a strong and durable bond is formed, even hard and thin materials can be welded, it is easy to control the color and quality of the metal during welding, welding can be performed manually or automatically [4; P.231-236.].

Disadvantages - the method is relatively slower and more difficult, as it requires specific skills, requires welding equipment and inert gas, which increases costs, and is not widely used for heavy and thick metals [3; P.13-14.].

Shielded Metal-Arc Welding (SMAW) - an arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode [3; P.14-14.].

Advantages - a simple and inexpensive method, does not require special gas protection (the coating provides a protective gas), can be used in various places, especially outdoors and in outdoor conditions, is suitable for welding different metals, the equipment is simple and takes up little space [4; P.231-236.].

Disadvantages - the weld quality depends on the operator's skill, and slag formation may occur on the weld surface.

Results and discussions.

A Welding Procedure Specification (WPS) serves as a formal written document providing direction to the welder for making production welds in accordance with code requirements. Before developing a WPS, a Procedure Qualification Record (PQR) must be prepared based on experimental welds and validated through mechanical testing. This study presents a case where a PQR is developed for dissimilar welding between A335-P11 is a ferritic alloy-steel and B-619 (UNS N10276) - is a nickel-molybdenum-chromium alloy using GTAW. The objective is to demonstrate that the weld joint satisfies all mechanical and metallurgical standards to qualify the welding procedure for industrial use.

➢ **Procedure Qualification Record (PQR)**

Base Materials (QW-403).

- Alloy-steel: A335-P11, thickness: 6.02 mm;
- Nickel alloy: 619 (UNS N10276), thickness: 6.02 mm.

Filler Metals (QW-404).

- Type: ERNiCr-3 (equivalent to Alloy 625);
- Standard: AWS A5.14.

Welding Process and Parameters

- Process: GTAW;
- Type: Manual;
- Shielding gas: 99.99% argon;
- Preheat Temperature: 125 °C
- Interpass Temperature: < 250 °C

Post-weld, samples were tested for DPT, RT, tensile strength, hardness, and bend resistance. Microstructural analysis was conducted using optical and scanning electron microscopy.

➢ **Mechanical Testing for PQR**

All tests were carried out as per ASME Section IX standards.

Tensile Test

Two test samples were taken to pass the tension test according to the standard.

Table 5

Tensile tests results

Specimen №	THK (mm)	Width (mm)	Area (mm^2)	Ultimate load (N)	Ultimate unit stress (N/mm^2)	Breaking location
Tensile Test (T1)	5.3	19.0	100.7	55000.0	546.18	Base metal
Tensile Test (T1)	5.3	19.0	100.7	55000.0	546.18	Base metal

Tested on the MP-500 Tearing machine and the result is accepted (see Picture 1.). Requirement: ≥ 415 MPa (Passed)

Picture 1. During the tension test.

Bend Tests

Two test coupons for Root Bend and two test coupons for Face Bend were prepared.

Table 6

Bend tests results

Type of specimen №	Diameter and thickness	Bend	Result
Face bend (SB1)	19,0 x 5,3 mm.	180^0	No open defect
Face bend (SB2)	19,0 x 5,3 mm.	180^0	No open defect
Root bend (SB3)	19,0 x 5,3 mm.	180^0	No open defect
Root bend (SB4)	19,0 x 5,3 mm.	180^0	No open defect

Tested and the result is no cracks or discontinuities observed >3 mm (Passed) (see Picture 2.).

Picture 2. During the bend test.

The successful outcome of the mechanical tests confirms the viability of the selected welding parameters. The GTAW process, with controlled heat input and appropriate filler selection (ERNiCr-3), produced defect-free welds with balanced strength and ductility. The Charpy test results demonstrate sufficient toughness at low temperature, and the bend tests show excellent ductility with no surface cracking. These findings support the formal qualification of the PQR.

Conclusion.

This study confirms that GTAW welding using Alloy 625 filler metal is an effective method for joining ferritic alloy-steel and nickel alloy. The approach provides high mechanical strength and corrosion resistance, meeting industrial standards. Future work may involve the evaluation of other welding techniques (e.g., laser welding, friction stir welding) and long-term performance under cyclic thermal loads.

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